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RECRUITMENT FAILURE IN AMERICAN AVOCETS AND BLACK-NECKED STILTS NESTING AT KESTERSON RESERVOIR, CALIFORNIA, 1984–1985[1]

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Abstract. We evaluated recruitment by American Avocets (*Recurvirostra americana*) and Black-necked Stilts (*Himantopus mexicanus*) in 1984 and 1985 at the selenium-contaminated Kesterson Reservoir and at a nearby reference site, the Volta Wildlife Area, both in western Merced County, California. Nests were monitored to determine their outcomes, including hatching success, and broods were censused three times per week during the breeding season. Chicks were counted and broods classified according to age. Although large numbers of chicks were presumed to have hatched at Kesterson, only one chick older than about 2 weeks of age was observed there during the 2-year study. It is unlikely that chicks of either species survived to fledging at Kesterson during the study period, whereas one-month-old or older avocet and stilt broods were seen both years at Volta. Selenium occurred at high concentrations in food-chain organisms only at Kesterson and was the most likely cause of the recruitment failure of stilts and avocets at Kesterson Reservoir.

Key words: Agricultural drain water; American Avocet; Black-necked Stilt; California; Himantopus mexicanus; *Kesterson Reservoir; recruitment;* Recurvirostra americana; *selenium.*

INTRODUCTION

Subsurface agricultural drain water containing high concentrations of selenium was used for marsh management at Kesterson Reservoir beginning in 1978 (U.S. Bureau of Reclamation 1986). Although selenium is an essential dietary trace element, excess amounts in the diets of Mallards (*Anas platyrhynchos*) and domestic poultry have decreased egg hatchability (Arnold et al. 1973, Ort and Latshaw 1978), caused embryonic abnormalities (Poley et al. 1937; Heinz et al. 1987, 1989), and reduced growth and survival of young (Hill 1974; Jensen 1975; Heinz et al. 1987, 1988, 1989).

Selenium is known to bioaccumulate (Wilber 1980, Ohlendorf 1989), and concentrations in mosquitofish (*Gambusia affinis*) sampled at Kesterson Reservoir in 1982 (120–140 μg/g, dry weight) were more than 70 times those in mosquitofish from the Volta reference area (Saiki 1986). By comparison, dietary selenium concentrations of 7–10 μg/g were known to impair reproduction of poultry (NAS-NRC 1976, Ort and Latshaw 1978). These results raised concerns that consumption of selenium-contaminated foods by birds at Kesterson could adversely impact their reproduction. In 1983, Ohlendorf et al. (1986a, 1986b) confirmed that high concentrations of selenium in food-chain organisms severely impaired reproduction in several species, including Eared Grebe (*Podiceps nigricollis*), Mallard, Gadwall (*Anas strepera*), American Coot (*Fulica americana*), and Black-necked Stilt (*Himantopus mexicanus*). The overall findings related to nest success, cause-specific nest failure, and egg hatchability for aquatic birds at Kesterson Reservoir and the Volta reference site during 1983–1985 are described by Ohlendorf et al. (1989).

In the present study, we monitored fledging success at Kesterson Reservoir during 1984 and 1985 to evaluate the impact of high selenium concentrations on survival by American Avocet (*Recurvirostra americana*) and Black-necked Stilt

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chicks from hatching to about 5 weeks posthatching.

STUDY AREAS AND METHODS

The primary study site was Kesterson Reservoir, located on Kesterson National Wildlife Refuge in Merced County, California (see figure 1 in Ohlendorf et al. 1989). The 12 ponds that comprised Kesterson Reservoir (hereafter referred to as Kesterson) covered about 500 ha. During 1978–1985, the primary source of water was subsurface agricultural drainage that contained elevated concentrations of selenium (e.g., 300 μg/l in 1983; Saiki and Lowe 1987). The 1,130-ha Volta Wildlife Area (hereafter referred to as Volta), located about 10 km southwest of Kesterson, served as the reference site for this study (see figure 1 in Ohlendorf et al. 1989). The 36 ponds at Volta are managed by the California Department of Fish and Game primarily for wintering waterfowl and public hunting. In 1984 and 1985, only four Volta ponds (about 150 ha) had water and habitat suitable for nesting stilts and avocets. Historically, Volta has not received agricultural drain water, and selenium occurred in the water at <1 μg/l in 1983 (Saiki and Lowe 1987).

Suitable nesting and feeding habitat for stilts and avocets was available at both sites in 1984 and 1985. At Kesterson, diked roads surrounded all ponds and afforded good visibility of birds in these habitats. Ponds at Volta were also surrounded by diked roads, and visibility of most nesting and feeding areas was good. In 1984, however, early flooding of nests at Volta may have forced some of the birds to renest in ponds that were not searched for nests and where bird visibility was restricted by heavy vegetative cover.

As part of continuing studies of avian reproduction at Kesterson and Volta in 1984 and 1985 (Ohlendorf et al. 1989) nesting habitat at each site was systematically searched to locate active nests of avocets and stilts (see Ohlendorf et al. 1986b for details). Nests were monitored to determine their fate and hatching success, and the results were used to estimate the numbers of stilt and avocet chicks and broods produced each year.

We considered that a brood was produced if at least one egg was observed or was presumed to have hatched, including nests that had chicks in them when they were found. By contrast, for their Mayfield estimates of nesting success, Ohlendorf et al. (1989) included as successful those eggs that were collected if they contained live, late-stage, normal embryos, and they excluded all nests that had already hatched when found (as required for the Mayfield analysis). Therefore, the numbers of chicks in these two studies are not directly comparable.

Fledging success of avocet and stilt chicks was estimated by censusing broods (i.e., one or more chicks accompanied by one or two adults) in nesting habitat and nearby areas. Censuses were conducted three times per week by observing with 7 × 35 binoculars and a 6–30× spotting scope from a car parked on dike roads. Broods were classified according to age of the chicks (Gibson 1971a, 1971b; Hamilton 1975; Burger 1980) (Fig. 1), and the number of chicks per brood was recorded. Within age classes, broods may have been counted more than once per week; therefore, only the highest of each week's counts were used in the analyses.

Juvenile stilts younger than 45 days of age could be differentiated from adults based on size and coloration. Successful fledging of juvenile stilts could, therefore, be confirmed by estimating the percentage of juvenile birds in postbreeding, foraging flocks (see Gibson 1971b, Burger 1980). Juvenile avocets up to about 38 days of age were distinguishable from adults based on size, behavior, and presence in a family unit; thereafter, juveniles and adults, especially in flocks, were not readily distinguishable.

Chi-square analyses were used to compare brood survival at Kesterson with that at Volta. The probability level used to determine statistical significance of all tests was $P \leq 0.05$.

RESULTS

Overall, about 2.6 times more broods hatched at Kesterson than at Volta during 1984–1985. In 1984, we estimated that about 141 chicks hatched from 48 stilt nests at Kesterson, compared with 14 chicks from 5 nests at Volta (Fig. 1). That same year, 46 avocet chicks hatched from 17 nests at Kesterson, while 25 nests produced 67 chicks at Volta. The U.S. Fish and Wildlife Service conducted a hazing program at Kesterson in 1985 designed to prevent birds from using the ponds. However, nesting success was not reduced (Ohlendorf et al. 1989). In 1985, the 47 successful stilt nests at Kesterson produced 109 chicks, while the 11 successful nests at Volta produced 32. Also in 1985, 20 successful avocet nests at Kesterson produced 44 chicks, whereas

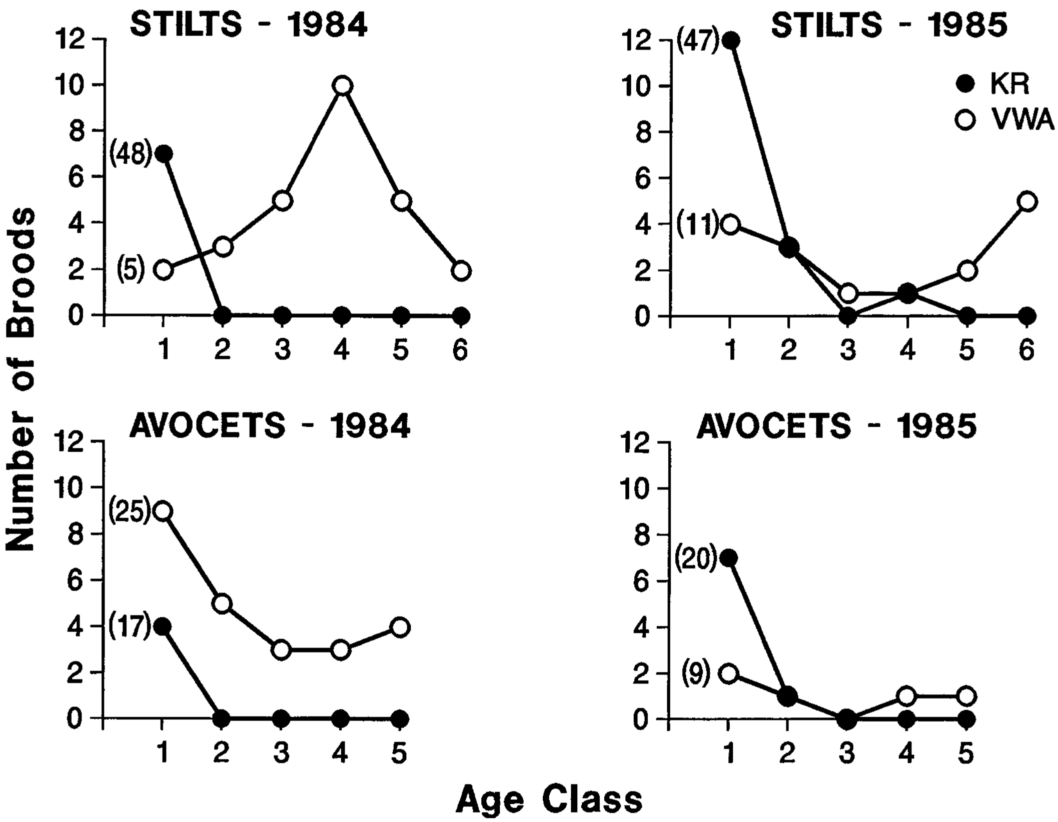

FIGURE 1. Numbers of Black-necked Stilt and American Avocet broods observed, by age class, during 1984–1985 at Kesterson Reservoir (closed circles) and Volta Wildlife Area (open circles). The numbers of nests presumed to have hatched are in parentheses. The estimated ages of chicks in the various age classes are: 1: 1–10 days, 2: 11–17 days, 3: 18–24 days, 4: 25–31 days, 5: 32–38 days, and 6: 39–45 days. (Based on work of Gibson 1971a, 1971b; Hamilton 1975; and Burger 1980).

9 nests at Volta produced 23 chicks. The impact of hazing on chick survival was not assessed.

With the exception of one 4-week-old stilt chick (class 4) observed early in the season in 1985, none of the 90 avocet or 250 stilt chicks presumed to have hatched at Kesterson during the 2-year study was observed beyond age class 2 (Fig. 1). At Volta, broods of both species were observed both years through age class 5; nine age-class-5 broods (26 chicks) were seen in 1984, and three (8 chicks) were seen in 1985.

Brood census data for stilts at Volta in 1984 contained an anomaly; more stilt broods were observed in age class 4 than were presumed to have hatched from marked nests (Fig. 1). Apparently, some nests were not found, and the resulting broods went undetected until they reached older age classes.

Overall, brood survival was better at Volta than at Kesterson. In 1984, 15% of the stilt broods presumed to have hatched—and thus available for observation—were observed as age-class-1 chicks at Kesterson, compared with 40% at Volta (not significantly different; $\chi^2 = 3.19$, $P > 0.05$). No brood older than age class 1 was seen at Kesterson in 1984. A significantly higher percentage of stilt broods survived to age class 5 at Volta than at Kesterson ($\chi^2 = 26.5$, $P < 0.05$). In 1985, 26% of the potential class-1 stilt broods were observed at Kesterson, while 36% were seen at Volta (no significant difference; $\chi^2 = 3.47$, $P > 0.05$), but, by age class 5, significantly more broods were observed at Volta (18%) than at Kesterson (0%) ($\chi^2 = 5.64$, $P < 0.025$). Further, 45% of the potential broods were observed at Volta as age-class-6 chicks.

In 1984, 24% of the avocet nests presumed to have hatched at Kesterson were observed as age-class-1 broods, while 36% were observed at Volta. As with the stilts in 1984, no brood older than class 1 was observed at Kesterson, but 16% of the potential class-5 broods were observed at Volta. In 1985, 35% of the avocet broods that were presumed to have hatched were observed as class-1 broods at Kesterson, while 22% were observed at Volta. Only one class-2 brood was observed at Kesterson in 1985, and older broods were not observed. At Volta, 11% of the potential class-5 broods were observed. Although no avocet brood older than class 2 was observed at Kesterson, there were no statistically significant differences in brood survival between sites either year.

No chick mortality was observed at Volta during our nest searches and revisits. At Kesterson we found five dead stilt chicks in 1984 and three in 1985; we found two dead avocet chicks there in 1985. One of the stilt chicks was killed by a Northern Harrier (*Circus cyaneus*), but the causes of death of the others could not be determined. Chicks were too decomposed when found to permit detailed necropsy or chemical analysis, but no obvious external deformities were noted.

At Kesterson, five postbreeding foraging flocks of stilts, averaging 18 birds per flock, were observed during 1984; two flocks, averaging 44 birds per flock, were observed in 1985. Juveniles were not observed in any of these flocks. Postbreeding flocks of stilts were observed at Volta both years. In 1984, four flocks contained an average of 47 birds each, with juveniles comprising about 8% of the total in three of those flocks. In 1985, 17 flocks averaged 50 birds per flock; juveniles comprised about 3% of the birds in eight of those flocks.

It was not possible to determine the age composition of postbreeding foraging flocks of avocets. However, at Volta, five such flocks, averaging 25 birds each, were observed in 1984, and 11 flocks, averaging 43 birds, were seen in 1985. Flocks were not observed at Kesterson in 1984, and only two flocks of about 15 birds each were observed in 1985.

DISCUSSION

We estimated that prefledging brood mortality at Kesterson approached 100% for both stilts and avocets in 1984 and 1985. The virtual absence of chicks beyond age class 2 has not been reported in previous studies of stilts or avocets, even in areas with substantial nest predation (Grover and Knopf 1982, Sidle and Arnold 1982). Predation would probably not explain the complete recruitment failure at Kesterson during both years, because about one-fourth of the broods survived to at least age class 5 at Volta, despite heavy nest losses to predation both years (Ohlendorf et al. 1989). Furthermore, significantly more stilt nests were lost to predation at Volta than at Kesterson in 1985, further decreasing the likelihood that predation caused the complete failure at Kesterson.

An alternative explanation for disappearance of shorebird chicks at Kesterson is that broods left the reservoir shortly after hatching. However, this is unlikely because chicks are not normally very mobile until they are able to fly (Gibson 1971b, Hamilton 1975, Sordahl 1982), and the presence of deep-water channels on all sides of the nesting areas probably prevented adults and their broods from leaving by swimming. In 1985, it was even less likely that broods left Kesterson because surrounding areas were dry and would not have provided favorable feeding habitat for the broods.

A high percentage of the stilt nests monitored during 1984 (22%) and 1985 (44%) at Kesterson contained dead or deformed embryos (Ohlendorf et al. 1986b, Ohlendorf 1989). These high rates of embryotoxicosis were attributed to the elevated concentrations of selenium found in the eggs. Despite these high failure rates, at least one chick was presumed to have hatched in many of these same nests. Dead or deformed embryos were not found in avocet nests in 1984, but 23% of the nests in 1985 had at least one dead or deformed embryo (Ohlendorf 1989). Three dead embryos, but no abnormal ones, were found at Volta during the 2-year study. This occurrence of dead embryos is not unusual, and bird livers and eggs from Volta contained selenium at mean concentrations that were similar to those found at other uncontaminated sites (Ohlendorf 1989; Ohlendorf and Skorupa, in press).

In a series of laboratory studies, Heinz et al. (1987, 1988, 1989) fed selenium as selenomethionine to Mallards. Adult Mallards that were fed diets containing 8 or 10 μg selenium/g produced embryo deformities that were similar to those seen at Kesterson (Heinz et al. 1987, 1989). In addition, duckling survival to 21 days was significantly reduced when adults were fed a diet containing 10 μg selenium/g (Heinz et al. 1987). Adult Mallards fed diets containing 8 μg selenium/g produced significantly fewer 6-day-old ducklings than the controls, and those fed a diet with 16 μg selenium/g did not produce any ducklings that survived to 6 days (Heinz et al. 1989). In another study, about 20% of the Mallard ducklings that received a diet supplemented with 40 μg selenium/g for 6 weeks died, and all those on an 80-μg/g diet died within that 6-week period (Heinz et al. 1988).

During 1983–1985, the mean total selenium concentrations in aquatic invertebrates typical of those eaten by stilts and avocets ranged from 45 to 215 μg/g at Kesterson (Saiki and Lowe 1987; Schuler 1987; Hothem and Ohlendorf, in press). Similar invertebrates at Volta contained <2 μg selenium/g. Selenium concentrations at Kesterson were equal to or greater than those that caused duckling mortality in the Mallard studies mentioned above, leading us to conclude that selenium contamination was most likely the primary reason no stilt or avocet chicks survived to fledging at Kesterson Reservoir in 1984 and 1985.

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