Impact of Management Practices on Mosquito Abundance in Wetlands Managed for Wildlife

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ABSTRACT The management of seasonal wetlands for waterfowl and other wetland-dependent wildlife has the potential to produce mosquito abundance that surpasses abatement thresholds of local mosquito control districts. To help minimize the impact of wetland management activities on public health and safety, best management practices (BMPs) were developed by the Central Valley Joint Venture in coordination with the California Department of Public Health and the Mosquito and Vector Control Association of California. In the current study, we evaluated the effect of two BMPs (discing and establishment of predator reservoirs) on the presence of mosquito larvae in wetlands managed by the California Department of Fish and Wildlife (CDFW) at two wildlife areas (Gray Lodge and Los Banos). Larval mosquito abundance during early summer in disced treatments at both study sites (1.6 and 0.15 larvae per dip at Gray Lodge and Los Banos, respectively) was much lower compared to two other management strategies – traditional (6.02 and 3.23 larvae per dip) and optimal seed production (10.85 larvae per dip at Los Banos) and were lower than in wetlands with reservoirs for mosquito predators (2.58 and 1.65 larvae per dip). Immature mosquito abundance was similar in areas treated by both BMPs during July at Gray Lodge Wildlife Area, and the lack of irrigation in the traditional control wetlands meant that no mosquitoes were collected. When financially feasible, discing has the potential to both enhance wetland quality for waterfowl and decrease mosquito production in units managed for wintering waterfowl, but there may be occasions when wetland units utilizing these BMPs require insecticide treatment because mosquito abundance has surpassed abatement thresholds. Further evaluation is needed to determine the overall cost-effectiveness and long-term applicability of these control strategies.

INTRODUCTION

The Central Valley of California is one of the most important areas for migrating birds in North America (Heitmeyer et al. 1989), exhibiting some of the highest concentrations of waterfowl anywhere in the world. Since the Gold Rush Era, approximately 90% of the wetlands in this region have been lost to agriculture, water diversions, and flood control (Gilmer et al. 1982). This loss places an ever-increasing importance on the few remaining wetlands in this region.

Irrigating seasonal wetlands during the summer months is one of the most effective tools for increasing the carrying capacity of a seasonal wetland for waterfowl. On average, irrigating seasonal wetlands during the summer months doubles the carrying capacity for wintering waterfowl as compared to Central Valley wetlands without summer irrigation (Naylor 2002, Olson 2010). Irrigating wetlands during this time period also has been shown to produce larval mosquito abundances that surpass abatement thresholds of local mosquito and vector control districts (Washburn 2012). There is no universal abatement threshold for mosquitoes, but discussion among members of the AB 896 working group found that thresholds for treatment of *Aedes* mosquitoes were between 1 and 3 larvae per dip while 1 *Culex* mosquito found in 10 dips indicated that treatment was needed (unpublished discussion December 2017).

To minimize the impact of wetland management strategies on public health and safety, the Central Valley Joint Venture, in coordination with the California Department of Public Health and the Mosquito and Vector Control Association of California, developed guidelines for best management practices (BMPs) for mosquito control in managed wetlands (Kwasny et al. 2004). This guide is readily used by wetland managers, but the effect of these BMPs on larval mosquito numbers and whether these strategies can reduce adult mosquito abundance below current abatement thresholds rarely has been investigated. The current study evaluated the efficacy of different BMPs in wetlands at wildlife areas of the Central

Valley that are managed primarily for wintering waterfowl.

In this initial study, we evaluated the impact of two BMPs for limiting mosquito abundance and enhancing wildlife values. Discing has been shown both to reduce mosquito production in managed wetlands (Lawler et al. 2007, Washburn 2012) and to increase the carrying capacity of seasonal wetlands for waterfowl (Gray et al. 1999, Naylor 2002). This is done largely by reducing the presence of perennial emergent plant species and promoting more productive annual species of moist-soil vegetation. The presence of semi-permanent water within the swales and potholes of wetland units offers a habitat that is generally lacking in the Central Valley of California, but has been suggested to reduce mosquito production in irrigated seasonal wetland units (Washburn 2012).

MATERIALS AND METHODS

Our evaluation was conducted on Gray Lodge Wildlife Area (Butte County) in the Sacramento Valley, and Los Banos Wildlife Area (Merced County) in the San Joaquin Valley. Both of these properties are owned and operated by the California Department of Fish and Wildlife and are actively managed to promote plant communities beneficial to wintering waterfowl. Wetland units that were evaluated were chosen in coordination with area managers, and ranged between 6.9 and 29.1 ha (mean=13.8 ha).

Within these wetland cells, we evaluated the effect of two BMPs that have been suggested to reduce mosquito larval densities within managed wetlands and provide benefits to wildlife using those wetlands. These treatments included: 1) discing wetland units prior to irrigating, and 2) maintaining water in swales between irrigations to serve as a reservoir for maintaining native invertebrate predators. Larval mosquito abundance in the wetlands managed using BMPs was the compared to traditional and optimal management methods, described below.

The discing treatment entailed drying seasonal wetland units in March, and discing all undesirable or residual vegetation using two passes with a stubble disc, and then one pass with a finish disk approximately 4-6 weeks after drawdown. Operators used stubble disks with 71.12-91.44 cm (28-36 in.) blades that cut a minimum of 15.24-20.32 cm (6-8 in.) below ground level. Following discing, units were flash irrigated (for not more than 5 days) to germinate moist-soil seeds, and irrigated 1 or 2 more times (4-7 days for each irrigation) to bring plants to maturity. Wetlands were monitored for mosquito larvae during each irrigation period, using the sampling method described below. Wetlands with predator reservoirs were drawn down in April. About 4 weeks after drawdown, managers conducted any pre-irrigation treatments they felt were necessary other than discing (e.g. mowing of cocklebur, spraying of jointgrass, etc). Following this, swales and potholes were flooded within the unit to establish the desired predator base. Units were then irrigated 2-3 times to get moist-soil plants to maturity. Water levels in swales and potholes were maintained between irrigations to maintain predator populations. The predator populations were not sampled, but were expected to be similar in nature to Washburn's study (2012). Wetlands were monitored for mosquito larvae during each irrigation period, using the sampling method described below.

Traditional wetland management (= control treatments) entailed drawing down the water in wetlands in April. About 4 weeks after drawdown, managers conducted any pre-irrigation treatments they felt were necessary other than discing as described above. Units were then irrigated once, approximately 6 weeks after drawdown for 14-21 days. This is the method of moist-soil management that has historically been used by wetland managers to achieve their target plant species composition and productivity. This is by far the simplest (and cheapest) to employ without considering costs associated with mosquito abatement.

The optimal management treatment entailed drawing down water in wetland units in April. Approximately 4 weeks after drawdown, managers conducted any pre-irrigation treatments they felt were necessary other that discing as described above. Units were then irrigated 2-3 times (initial irrigation approximately 6 weeks after drawdown), with the last irrigation being approximately 2 weeks in duration. This method typically results in the highest carrying capacity for wintering waterfowl.

Wetlands were monitored weekly during irrigation periods, starting 2 days after wetland units were filled. Mosquito larvae were sampled within three 200-meter sections along the perimeter of each wetland that were identified as being representative of vegetation occurring throughout the unit. We took 20 dips per section (10 meters between each dip), for 60 total dips per wetland unit. At each location we sampled the best available habitat within reach, and collected larvae with a standard, white, 400-ml dipper. Sampling was conducted by technicians of Butte County Mosquito and Vector Control District or CDFW staff trained by Fresno Westside Mosquito Abatement District. When able, laboratory technicians from Fresno Westside MAD aided in verifying the genera of captured mosquitoes.

The abundance of mosquito (*Culex* and *Aedes*) larvae per dipper sample was compared among three treatments at a particular wildlife area using a Kruskal-Wallis one-way analysis of variance for each sampling date. Pairwise comparisons of mosquito abundance between treatments were made using the Mann-Whitney test. Dipper counts from the three sampling areas in each wetland were treated as independent estimates of mosquito abundance: 60 samples per wetland per date were ranked regardless of sampling area. The three sampling dates at each wildlife area were mid-June, mid-July and late July at Gray Lodge WA and late June, late July and mid-August at Los Banos WA.

RESULTS

Gray Lodge In mid-June, significantly more mosquito larvae (*Culex* and *Aedes*) were collected in control and predator reservoir treatments than in wetlands that had been disced (χ^2 = 13.14, df = 2, P < 0.001) (Figure 1A); the majority of the mosquitoes collected were *Aedes*. Discing reduced total immature mosquito

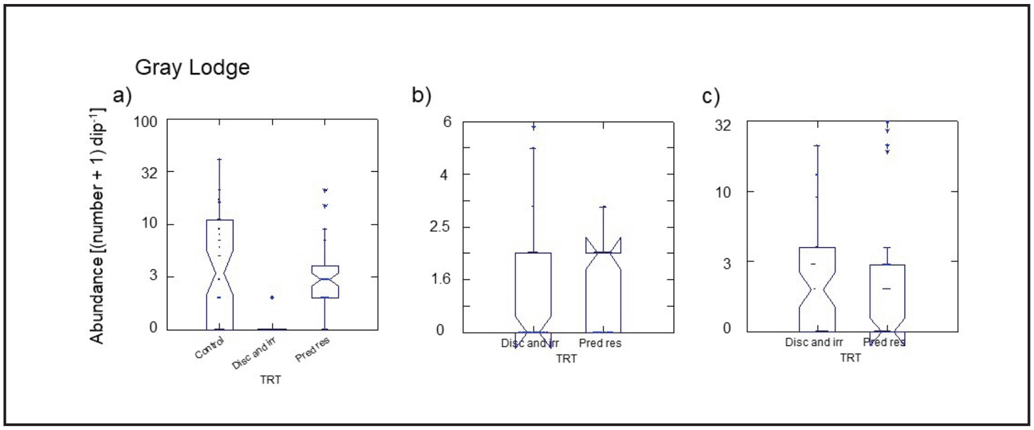

Figure 1 Larval mosquito abundance in wetland management treatment areas at Gray Lodge Wildlife Area. a) mid-June, b) mid-July, c) late July

abundance by 3.8- and 1.6-fold as compared to traditional management practices (control) and to a wetland with predator reservoirs, respectively (Table 1). In mid- and late July, larval mosquito abundance did not differ significantly between wetlands that had been disced or had predator reservoirs ($P > 0.06$) (Figures 1B and 1C). The wetlands with traditional (control) management practices had been irrigated in June but were not irrigated in July. No standing water was found, and so no samples were taken.

Los Banos The sites were more variable in Los Banos, in that not every treatment was present at each of the sampling points. In late June, larval mosquito abundance differed significantly among three treatments ($\chi^2 = 40.53$, df = 2, $P < 0.0005$) (Figure 2A). The optimal management sites did not have water and were not sampled in late June. Dip samples from the traditionally managed wetland and the wetland with predator reservoirs harbored 16- and 9-fold more immature mosquitoes per dip sample, respectively, than did the disced wetland (Table 1). However, the sampling stations in areas A and B in the disced wetland contained very little water.

In late July, approximately 5-times more mosquito larvae were collected from a wetland under optimal management than from the control wetland treatment ($\chi^2 = 64.14$, df = 2, $P < 0.0005$) (Figure 2B). There was not enough water in the wetlands under the disced treatement to be sampled. The number of mosquito larvae per dip sample from a wetland with predator reservoirs was intermediate to the wetland under optimal management and the disced wetland (Table 1).

In mid-August, only the wetland under optimal management and the wetland with predator reservoirs contained enough water for sampling. The wetland under optimal management produced 7 times more larvae per dip sample than did the wetland with predator reservoirs ($\chi^2 = 32.39$, df = 1, $P < 0.0005$) (Figure 2C). The optimal management wetland contained *Aedes* larvae, whereas the wetland with predator reservoirs contained a mixture of *Culex* and *Aedes*.

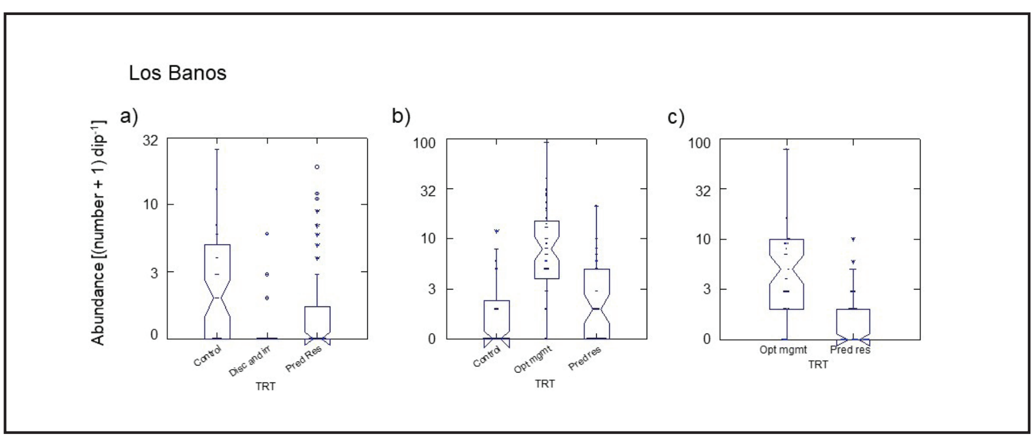

Figure 2 Larval mosquito abundance in wetland management treatment areas at Los Banos Wildlife Area. a) late June, b) late July, c) mid-August

DISCUSSION

Implementing established BMPs has significant potential to reduce mosquito production in managed wetlands and improve habitat for waterfowl. At both of our study sites, disced wetlands were shown to have substantially fewer mosquitoes than traditionally managed and optimally managed wetlands early in the year. Most of the mosquitoes collected at both areas were *Aedes* mosquitoes (2,699 *Aedes* and 109 *Culex*). At Gray Lodge, as the season progressed, there was not a significant difference between the two BMP strategies implemented – both had low larval mosquito counts in the middle of June and numbers that exceeded the threshold for treatment in late June. At Los Banos, disced units typically had fewer mosquito larvae per dip than other treatments, with units with predator reservoirs having fewer larvae than traditional or optimal vegetation management strategies. The benefit to using one of the two BMPs to reduce numbers of mosquito larvae was seen over practices for traditional or optimal vegetation management in this single study year. This was due in part to the amount of time that water was permitted to stand within the treatments. The traditional wetland management (control treatments) was kept to a two irrigation events, where the second event was a long flooding of 14-21 days. The number of irrigation events was more similar between the management to produce the optimal vegetation and the two BMPs (2-4 total irrigation events), but the optimal management included a long flooding of 14 days.

There are potential drawbacks to the BMPs. Discing is expensive (approximately $50/acre), and not all wildlife areas have the capacity to implement discing at a large scale. Most wildlife areas

Table 1 Comparisons of immature mosquito abundance among best management practices treatments in wetlands at two wildlife areas. 20 dips were taken in 3 separate areas of each wetland for a total of 60 dips per sampling date per wetland.

Refuge	Date	Treatments	Larval mosquitoes [median (lower, upper quartile) dip^{-1}]
Gray Lodge	mid-June	control = predator reservoirs > discing	2.5 (0, 10) = 2 (1, 3) > 0 (0, 2.5)
	mid-July	predator reservoirs = discing	1 (0, 1) = 0 (0, 1)
	late July	predator reservoirs = discing	0 (0, 2) = 1 (0, 3)
Los Banos	late June	control > predator reservoirs > discing	1 (0, 4) > 0 (0,1) > 0 (0, 0)
	late July	optimal mngmt > pred reservoirs > discing	7 (3, 14) > 1 (0, 4) > 0 (0, 2)
	mid-Aug	optimal mngmt > predator reservoirs	4 (1, 9) > 0 (0, 1)

also lack the water conveyance capabilities to get water on and off in 5-7 days, and it is unrealistic for many properties to achieve this. Although not as effective as discing, adding swales and potholes to act as mosquito predator reservoirs, supporting Coleoptera (Dytiscidae and Hydrophilidae), Hemiptera (Notonectidae and Belostomatidae), and Odonata (Coenagrionidae), may be beneficial in some areas (Washburn 2012). This technique is less cumbersome to wildlife area managers than discing, and provides additional semi-permanent wetlands within the boundary of a seasonal wetland. Quantifying the impact of these smaller semi-permanent wetlands on the recruitment of locally breeding waterfowl and other wetland dependent wildlife would be of benefit to wetland managers.

Implementation of these BMPs resulted in an approximate 25% decrease in seed yield in target plan species compared with optimal management strategies. However, most of the negative impacts of these BMPs on wildlife are indirect, in that implementing the BMPs takes time away from other wildlife management activities. Staffing and funding levels at many wildlife areas are approximately ¼ to ½ what is required to optimally manage these lands. Wetland managers in California have more to do than time available to accomplish in a given year, and any additional effort (or reduction in scale of activities) requires more time per acre for management activities. Additional funding and staffing on these wildlife areas would directly increase their ability to implement BMPs that reduce mosquito production and enhance wildlife values.

A limitation to this work is that it focused on a single year. A second trial of the BMPs is planned in similar locations to examine if the trends seen in this study are repeated in 2018.

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