

ARTICLES

WETLAND MANAGEMENT STRATEGIES THAT ENHANCE WATERFOWL HABITATS CAN ALSO CONTROL MOSQUITOES

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ABSTRACT. Two studies in California wetlands and a third in Minnesota wetlands indicate that management practices designed to enhance habitat quality for waterfowl can concurrently reduce mosquito problems. In a seasonally flooded pickleweed wetland in Suisun Marsh, Solano Co., CA, we demonstrated that reducing plant-cover by 50% increased benthic densities of chironomid midge and dytiscid beetle larvae; these insects can be important in waterfowl diets. This manipulation also concentrated *Aedes melanimon* and *Culiseta inornata* mosquito larvae along wetland perimeters; thus, the need for control measures was greatly restricted spatially. A study in 9 experimental ponds in Suisun Marsh demonstrated that higher water levels could enhance populations of the macroinvertebrates important in waterfowl diets; general macroinvertebrate densities were higher at 60 cm depths than 20 cm or 40 cm depths. In contrast, *Cs. inornata* densities were lowest at 60 cm depths and highest at 20 cm depths. A study conducted in a perennial-water cattail wetland in Minneapolis-St. Paul, MN, demonstrated that a temporary water-level drawdown, designed to enhance waterfowl habitat quality of perennial-water wetlands, also reduced densities of *Coquillettidia perturbans* mosquito larvae. These mosquitoes disappeared immediately after the drawdown, but even after water depths were restored to pre-drawdown levels, significant numbers did not reappear until 4 years post-drawdown. Studies in 202 other Minnesota wetlands also demonstrated the susceptibility of *Cq. perturbans* populations to drawdown, but the impact of drawdown was greater in stands of emergent cattail than in floating cattail.

INTRODUCTION

Mosquito control and waterfowl management agencies are both concerned with wetland habitats, yet the management goals of these groups often appear to conflict. For example, mosquito control agencies are concerned that management activities designed to enhance wetlands for waterfowl use (e.g., artificial flooding) may also produce large numbers of mosquitoes (Fleetwood et al. 1978). On the other hand, waterfowl management agencies are concerned that mosquito control activities (e.g., pesticide use) may harm waterfowl or the invertebrates consumed by them (Meyer and Swanson 1982).

Although management plans for wetlands seldom incorporate both mosquito and waterfowl management goals, our past research suggests that these goals can be compatible. For example, in a California wetland, we compared macroinvertebrate responses in areas that had 50% of the vegetative cover removed to areas that were unmanipulated (Batzer and Resh 1991, 1992). Densities of *Culex tarsalis* Coq. mosquito larvae were lower, but densities of the macroinvertebrates that are important in waterfowl diets were higher in the 50% plant-cover habitats than in unmanipulated habitats. Thus, the goals of mosquito reduction and waterfowl habitat enhancement were achieved concurrently. In this paper, we describe how populations of 3 additional mosquitoes, *Aedes melanimon* Dyar,

Culiseta inornata (Williston) and *Coquillettidia perturbans* (Walker), can also be reduced using wetland management strategies that enhance quality of waterfowl habitats.

MATERIALS AND METHODS

Mosquito species and wetland management strategies used. *Aedes melanimon*: When seasonal wetlands in California are artificially flooded in autumn to provide habitats for migratory waterfowl, *Ae. melanimon* mosquito larvae can create control problems (Garcia and Des Rochers 1984). In some wetlands, these larvae tend to accumulate mainly along upland edges. In such cases, edge habitats would be the only areas requiring mosquito control, and potential negative impacts of this control could thereby be confined to these areas (Garcia and Des Rochers 1984). However, in heavily vegetated areas, *Ae. melanimon* larvae may remain dispersed throughout large areas, and do not concentrate along upland edges of wetlands.

A study was designed to examine how heavily vegetated areas of wetlands could be managed to induce *Ae. melanimon* larvae to concentrate along upland edges. Vegetation mowing was chosen because this technique can also improve waterfowl habitat in heavily vegetated areas by increasing the amount of open-water available for waterfowl use (Rollins 1981) and increasing

densities of the macroinvertebrates consumed by ducks (Murkin et al. 1982; Batzer and Resh 1991, 1992).

Culiseta inornata: California seasonal wetlands also support large numbers of *Cs. inornata* mosquito larvae (Bohart and Washino 1978). Because these mosquitoes can occur with *Ae. melanimon*, response of *Cs. inornata* to the vegetation mowing described above was also examined.

A second study examined how altering water depths of seasonal wetlands influences *Cs. inornata* larval populations. Manipulation of water depths can improve waterfowl habitats by producing a 50:50 ratio of open-water to emergent plant-cover, which is the mixture preferred by most ducks (Weller 1981) and increasing densities of the macroinvertebrates consumed by ducks (Murkin and Kadlec 1986).

Coquillettidia perturbans: The third mosquito species examined, *Cq. perturbans*, occurs most commonly in perennial-water wetlands in eastern North America (Carpenter and LaCasse 1955), rather than the seasonally flooded wetlands described above. *Coquillettidia perturbans* larval habitats tend to have low levels of dissolved oxygen (Batzer and Sjogren 1986), which may also indicate that the wetlands are stagnant and have low productivity for waterfowl (Kadlec 1962, Danell and Sjoberg 1982).

For *Cq. perturbans*, we examined mosquito response to the wetland management technique of a temporary water-level drawdown. This technique can improve perennial-water wetlands as waterfowl habitats by stimulating growth of plants that are beneficial to ducks (Kadlec 1962) and maintaining wetlands in the earlier stages of habitat succession that are preferred by ducks (Danell and Sjoberg 1982).

Study I — Aedes melanimon and Culiseta inornata response to vegetation mowing: A 70-ha seasonal wetland (Pond 11B) located at Grizzly Island Wildlife Area, Suisun Marsh, Solano County, CA, was selected for study. This brackish wetland contained dense stands of pickleweed, *Salicornia virginica* Linn., which is a perennial, woody emergent plant common in wetlands of Suisun Marsh (Rollins 1981).

A 300-m stretch along the eastern edge of this wetland was divided into a row of six 50 × 50 m plots, which were blocked into 3 pairs (i.e., plot 1 with 2; 3 with 4; and 5 with 6). One plot per pair was then randomly selected to have its plant-cover reduced by 50%, whereas the other half of each pair remained unmanipulated (i.e., 100% plant-cover). Each of the 3 plots selected for mowing was first divided into seven 7.1 × 50 m strips that extended perpendicularly from the upland edge of the wetland. During September

1989, the vegetation found in strips 1, 3, 5 and half of 7 was mowed using a tractor-pulled mower. This reduced the original pickleweed canopy height of 30–50 cm to 0–10 cm; slash was not removed. After mowing was completed, an intact strip of vegetation at least 1-m wide still remained along the entire upland edge of the wetland in each 50% plant-cover plot. The wetland was flooded on October 30, and median water depths of plots ranged from 35 to 45 cm.

On November 10, mosquito larvae in each of the 6 plots were sampled using a mosquito dipper. Sampling was conducted along 2 transects: 1) 0.5 m from and parallel to the upland edge of the wetland (within the 1-m strip of intact vegetation along this edge), and 2) 25 m from and parallel to the upland edge of the wetland (through the center of the plot). In the latter transects in 50% plant-cover plots, separate sample units were collected in open-water strips and in unmowed plant strips. For each transect, 15 dips were collected at randomly selected locations; similar samples were also collected on January 12 and March 5, 1990. Mosquito densities between edge and interior transects within plots and between 50% and 100% plots were compared using paired *t*-tests.

In addition to mosquitoes, general macroinvertebrate populations were sampled on November 21 and again on March 5. Samples were collected in 3 areas of each plot-pair: 1) the vegetated portions of 50% plant-cover plots, 2) the open water portions of 50% plant-cover plots, and 3) the 100% plant-cover plots. Macroinvertebrates from the water column and on plants were sampled using D-frame sweep-nets (30 cm width, 1-mm mesh); 1-m sweeps were taken through the upper 20 cm of the water and plants. Macroinvertebrates from benthic substrates were sampled using a modified bilge-pump sampler (Walker and Crans 1986); the pump intake was placed on the wetland bottom, and the substrate and water from 4 pumping repetitions was passed through a 0.3-mm sieve. Because macroinvertebrates can be influenced by differences in water depth, both sweep-net and benthic samples were collected at randomly selected locations ($n=3$ for each sampler) along the 40 cm depth contour, which was the median depth in the plots. Paired *t*-tests were used to contrast macroinvertebrate densities between open-water and unmowed plant strips within 50% plant-cover plots and between 50 and 100% plant-cover plots.

Study II — Culiseta inornata response to different water depths: Nine experimental ponds also located at Grizzly Island Wildlife Area were used to analyze macroinvertebrate response to water depth. Each pond was 11 × 22 m, and all

were dominated by dense stands of pickleweed (for descriptions of the ponds see Batzer and Resh 1988).

The 9 ponds were flooded in late-September 1987, which coincided with the flooding schedule of the managed wetlands surrounding the ponds. Water used for flooding came from a canal parallel to the row of ponds, but it was first filtered through a 1-mm mesh to reduce introductions of the macroinvertebrates and fish present in the canal.

Using a randomized block design, three of the 9 ponds were filled to each of 3 depths: 20, 40 and 60 cm. The 20-m depth resulted in <25% open-water; the 40-cm depth resulted in approximately 50% open-water; and the 60-cm depth entirely covered much of the pickleweed, resulting in >75% open-water. If ponds deviated more than 5 cm from their prescribed depth as a result of seepage or rains, initial depths were restored using a portable water pump. Ponds were maintained at their prescribed depths until early March 1988, and then were drained (this coincided with drawdown in surrounding wetlands).

Macroinvertebrates (including mosquitoes) were sampled every 2 wk from October 1987 through March 1988 within each pond. Epiphytic and nektonic macroinvertebrates were collected using 1-m sweeps of a D-frame net through the upper 20 cm of the water column and plants. Benthic macroinvertebrates were collected by imbedding a corer (5 cm diam) into the substrate, stirring the contents for 10 sec, and then passing the slurry through a 0.3-mm mesh. Three sweep-net and benthic samples were collected at randomly selected locations in each of the 9 ponds on each sampling date. Mosquito densities were additionally measured around the perimeters of each pond using dip sampling ($n = 20$ per pond). Water temperatures, pH and conductivity were measured monthly, and dissolved oxygen levels were measured once in February 1988, using the Winkler technique.

Macroinvertebrate and mosquito population responses to the 3 water-depth treatments were first contrasted using least-square linear regression techniques; if data could not meet the assumption of linearity, then ANOVA techniques followed by range tests were used.

Study III — Coquillettia perturbans response to water-level drawdown: Populations of *Cq. perturbans* larvae were monitored in perennially flooded wetlands throughout the Minneapolis-St. Paul area of Minnesota. However, two of these wetlands were selected for more detailed examination: one in Baker Park Reserve, Hennepin County; and the second in North Oaks Township, Ramsey County. Cattail (*Typha*

spp.), which dominated both of these wetlands, is the most abundant plant in Minnesota wetlands that are habitats for *Cq. perturbans* (Batzer and Sjogren 1986).

In 1981 and 1982, both the Baker Park Reserve and North Oaks wetlands supported similarly high densities of *Cq. perturbans* larvae. However in June 1983, the Baker Park Reserve wetland was subjected to a partial water-level drawdown that was designed to improve habitat conditions for waterfowl (Kadlec 1962). Although some water remained in the deeper pools, the portions of this wetland with emergent vegetation remained unflooded from June 1983, until the wetland was reflooded the following November 1983. Thereafter until autumn 1987, water depths there were maintained at levels similar to those occurring in 1981 and 1982. Water depths in the North Oaks wetland were kept at similar levels from 1981 through 1987.

The 1983 drawdown in the Baker Park Reserve wetland was a planned event. However, a drought in 1987 and 1988 resulted in a natural, temporary drawdown in most wetlands in the Minneapolis-St. Paul region. The drought was ended by the subsequent wetter years of 1989 and 1990 when water depths in most wetlands returned to pre-drought levels. This weather pattern permitted an examination of *Cq. perturbans* response to drawdown in 202 wetlands that had been found to support larvae prior to the drought. Because larvae attached to roots of either emergent cattail (plants anchored into the substrate) or floating cattail (plants forming mats with roots hanging down into a water layer) (Batzer and Sjogren 1986), the presence of either of these cattail morphs in individual wetlands was recorded.

Populations of *Cq. perturbans* larvae in the Baker Park Reserve and North Oaks wetlands were monitored from 1981 through 1987. Personnel of the Metropolitan Mosquito Control District (MMCD) monitored larval populations in 202 breeding sites in the Minneapolis-St. Paul region from 1986 through 1990. All sampling was conducted during autumn, because in Minnesota these univoltine mosquitoes hatch in late summer but do not emerge until the following June, thus high densities of third and fourth instar *Cq. perturbans* larvae are available for sampling in autumn. In the Baker Park Reserve and North Oaks wetlands, densities of *Cq. perturbans* were measured by scraping larvae from roots of randomly selected plants ($n = 20$) using a screened-bottomed dipper (Batzer and Sjogren 1986). The same sampler was used in the 202 wetlands sampled by MMCD personnel.

Within each of the Baker Park Reserve and North Oaks wetlands, differences in *Cq. pertur-*

bans larval densities among the sampling years were determined by ANOVA techniques, followed by range tests and least-square regression techniques. In the 202 wetlands sampled by the MMCD, yearly patterns of larval presence or absence from 1986 (which was prior to the drought) until 1990 (which was 2 years after the drought ended) were analyzed with contingency tests.

RESULTS AND DISCUSSION

Study I — *Aedes melanimon* and *Culiseta inornata* response to vegetation mowing: In the November dip samples (10 days post-flooding), 52% of the mosquito larvae collected were *Ae. melanimon* and 48% were *Cs. inornata*. In 50% plant-cover plots, densities of mosquito larvae (both species combined) were significantly higher along the upland edge of the wetland than in the wetland interior ($P < 0.05$, paired t -test, Fig. 1). In 100% plant-cover plots, however, densities of mosquito larvae did not significantly differ between edge and interior transects ($P > 0.05$, paired t -test, Fig. 1). Although fewer larvae were collected in the interior transects of 50% plant-cover plots than 100% plant-cover plots, densities did not differ statistically. January and March sampling indicated that densities of mosquito larvae in all plots were low (< 1.0 larvae/transect, *Cs. inornata* was the only mosquito collected), and the November mosquito patterns were not evident.

Soon after the wetland was flooded, mosquito larvae in 50% plant-cover plots concentrated along the upland edges of the wetland, whereas larvae in 100% plant-cover plots remained dispersed throughout the plot. A study by Garcia and Des Rochers (1984) in seasonal wetlands with low, grassy vegetation suggested that winds moved *Ae. melanimon* larvae to wetland edges; our plant-cover reductions may have increased the influence of winds on mosquito larvae in the dense cover provided by emergent pickleweed.

Two macroinvertebrate groups were numerically dominant in the benthic fauna of the 6 plots: larvae of the midge *Chironomus stigma-terus* Say (Diptera: Chironomidae); and predaceous water beetle larvae, primarily *Agabus dis-integratus* (Crotch) with $< 5\%$ of the total being *Rhantus* sp. (Coleoptera: Dytiscidae). In the March benthic sample, densities of both chironomid larvae and dytiscid larvae were significantly higher in 50% plant-cover plots than in paired 100% plant-cover plots (Fig. 2, $P < 0.05$). In benthic samples from November or the sweep-net samples from November or March, macroinvertebrate densities did not differ significantly between 50% and 100% plant-cover plots ($P > 0.05$).

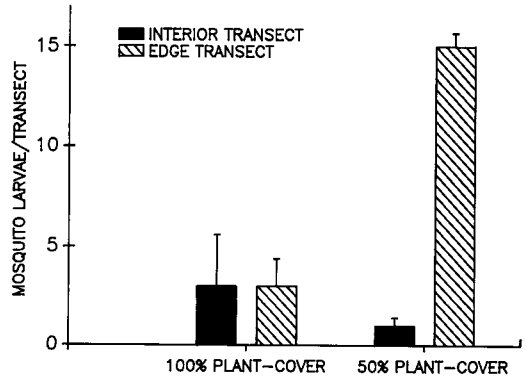


Fig. 1. Numbers of *Aedes melanimon* and *Culiseta inornata* mosquito larvae collected per transect (both species pooled, 15 dip samples/transect) from 3 plots with 100% plant-cover and 3 plots with 50% plant-cover in a wetland located at Grizzly Island Wildlife Area, CA (error bars = 1 SE). Sampling was conducted in early November 1989, which was 10 days after the wetland was flooded.

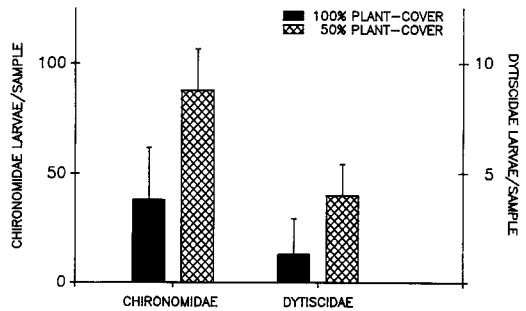


Fig. 2. Mean densities of benthic chironomid midge larvae and dytiscid beetle larvae collected in 50% plant-cover and 100% plant-cover plots of a California wetland in March 1990 (3 plots for each treatment, and error bars = 1 SE).

The higher numbers of benthic midge larvae and dytiscid beetle larvae in 50% plant-cover plots than 100% plant-cover plots may result from adult oviposition rates being higher in the 50% plant-cover plots. Alternatively, other studies in Grizzly Island wetlands indicate that oxygen levels in some areas may be insufficient for benthic midges, and perhaps the 50% plant-cover reductions allowed winds to keep dissolved oxygen levels higher, which would benefit benthic midge populations.

This first study indicates that mowing vegetation (creating sparser cover) can concentrate mosquito larvae along upland edges of wetlands, so mosquito management, and any accompanying negative impacts, could thereby be limited to edge habitats. Concurrently, mowing prob-

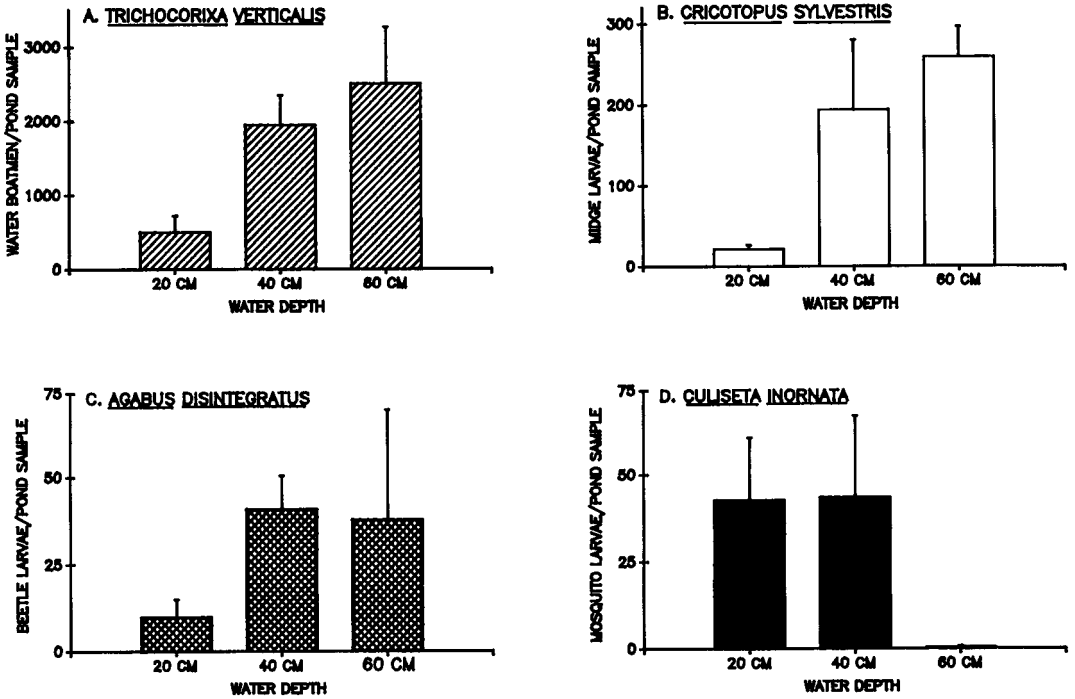


Fig. 3. Densities of macroinvertebrates found in ponds flooded to each of 3 depths (3 ponds for each treatment, and error bars = 1 SE). Separate graphs indicate densities of the 4 most common taxa collected in the ponds from January 1988 through March 1988.

ably improved the habitats for waterfowl use by enhancing densities of benthic chironomid and dytiscid larvae, which are both important food resources for ducks (Connelly and Chesemore 1980, Euliss and Grodhaus 1987, Euliss and Harris 1987, Miller 1987).

Study II — Culiseta inornata responses to different water depths: In late-winter, *Cs. inornata* mosquito larvae are abundant in the experimental ponds. During this same period, ducks are preparing for migration and reproduction, and thus require the abundant proteins and other nutrients present in macroinvertebrates (Heitmeyer and Fredrickson 1981, Krapu 1981). Therefore, the data collected from January through March were used to evaluate the influence of different water depths on populations of mosquitoes and the macroinvertebrates important in duck diets.

The numerically dominant macroinvertebrates found in the 9 ponds from January through March were: *Trichocorixa verticalis* Fieber water boatmen nymphs and adults (Hemiptera: Corixidae); *Cricotopus sylvestris* (Fabr.) midge larvae (Diptera: Chironomidae); *A. disintegratus* beetle larvae; and *Cs. inornata* mosquito larvae. With the exception of the mosquitoes, these or similar macroinvertebrate species

have been reported to occur in diets of California ducks (Connelly and Chesemore 1980, Euliss and Grodhaus 1987, Euliss and Harris 1987, Miller 1987).

Sweep-net sampling indicated that densities of *T. verticalis* water boatmen increased significantly with increased water depth (Fig. 3A; linear regression of log transformed data, $P < 0.05$). Densities of *C. sylvestris* midge larvae also responded to differences in water depth (however, because this response was non-linear, ANOVA tests rather than regression tests were used); midge densities at 40 and 60 cm water depths were similar, but midge densities were significantly lower at 20 cm depths (Fig. 3B; $P < 0.05$, two-way ANOVA followed by a range test). Although *A. disintegratus* beetle larvae were also least common at 20 cm depths, these densities did not significantly differ among water depths (Fig. 3C; two-way ANOVA, $P > 0.05$).

In contrast to the patterns observed with the macroinvertebrates that are important in waterfowl diets, mosquito dip-sampling along pond perimeters indicated that densities of *Cs. inornata* larvae were similar at 20 and 40 cm water depths, but were significantly lower at 60 cm depths (Fig. 3D; $P < 0.05$, two-way ANOVA of $\log(x+1)$ data followed by a range test). Like the

results from dipping along pond perimeters, sweep-net sampling in pond interiors also indicated that mosquito densities were lowest in 60 cm ponds.

In the above analyses, block (location) or interaction effects were not significant ($P \geq 0.05$). Although benthic macroinvertebrate densities and water chemistries (pH, conductivity and dissolved oxygen level) did not differ significantly among water depths in this study ($P > 0.05$), these factors have been influenced by water depth in other studies (Murkin and Kadlec 1986).

The significant differences in densities of *Cs. inornata* mosquito larvae, *T. verticalis* water boatmen and *C. sylvestris* midge larvae in the experimental ponds were probably caused by oviposition or colonization patterns of their adults. The lack of significant differences in *A. disintegratus* beetle densities was not unexpected because adult beetles aestivate in dry wetland habitats during the summer (Garcia et al. 1990), and thus these beetles had likely colonized the experimental ponds prior to flooding in October.

This second study also indicates that wetlands can be managed to achieve waterfowl and mosquito management goals concurrently. Flooding wetlands to 60 cm depths was optimum in achieving both goals. Densities of macroinvertebrates important in waterfowl diets were enhanced, and a mixture of open-water and emergent plant-cover considered beneficial to ducks (Weller 1981) was provided. Densities of *Cs. inornata* mosquitoes were reduced. During the season-ending drawdown of water in the spring, macroinvertebrate densities would be further concentrated and benthic invertebrates would become more accessible to ducks.

In contrast to the patterns observed at 60 cm depths, the 20 cm depth treatments were least desirable in terms of either goal. Densities of macroinvertebrates important in waterfowl diets were low, and the thick pickleweed canopy, combined with the lack of open-water, would have inhibited duck use of those habitats. Likewise, densities of mosquitoes were high. Possibly the ponds with 20 cm depths would be more desirable as waterfowl habitats if the thick plant-cover could be reduced (see Study I). This question should be pursued, because in California seasonal wetlands that have plant compositions other than pickleweed, 20 cm depths do provide high quality waterfowl habitat (Euliss and Harris 1987).

Study III — *Coquillettidia perturbans* response to water-level drawdown: Following the planned drawdown of the Baker Park Reserve wetland during the summer of 1983, densities of

Cq. perturbans larvae were significantly lower in the subsequent autumns of 1983, 1984 and 1985 than in the previous autumns of 1981 and 1982 (Fig. 4; $P < 0.05$, one-way ANOVA followed by a range test). However, after the initial decline in 1983, numbers of larvae increased significantly from 1983 until 1987 (Fig. 4; $r = 0.91$, $P < 0.05$, $\log(x+1)$ transformed data). A drought-induced drawdown in 1988 again eliminated larvae from this wetland. In contrast to the Baker Park Reserve wetland, larval populations in the North Oaks wetland, which was not subjected to drawdown, decreased somewhat but did not differ significantly from 1981 through 1987 (Fig. 4, one-way ANOVA or linear regression, $P > 0.05$).

The slow decline in larval populations in the non-drawdown North Oaks wetland may have resulted from a regional *Cq. perturbans* control program initiated by the MMCD in 1984, which reduced the numbers of adults available to colonize wetlands. The slow recovery of larval densities in the Baker Park Reserve wetland may have also been influenced in part by reductions in numbers of ovipositing adults. However, larval numbers in the Baker Park Reserve wetland still increased from 1985 onward, after control measures were begun in the region. Mosquito control was not used in the Baker Park Reserve wetland during the 1981–87 study period.

Coquillettidia perturbans larvae usually occur in near-anaerobic waters and are found attached with modified air siphons to specialized roots of cattail (Batzer and Sjogren 1986). These "water roots" occur in the water column and are a response by cattail to low-oxygen conditions (Dean 1933). Drawdown exposes wetland sediments to air, which enhances aerobic decay of

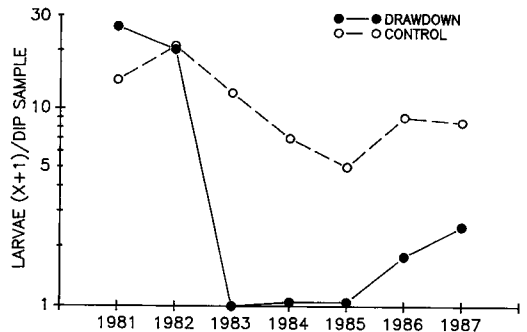


Fig. 4. Autumn densities of *Coquillettidia perturbans* mosquito larvae from 1981 through 1987 in 2 wetlands in Minnesota; in Baker Park Reserve (solid line) and North Oaks Township (dashed line). The Baker Park Reserve wetland was subject to a summer-long water-level drawdown in 1983, and then allowed to refill that autumn. The North Oaks wetland had similar water levels from 1981 through 1987.

accumulated detritus, and also causes cattail water roots to dry and fall off the plants. The multi-year effect of drawdown on *Cq. perturbans* populations may have occurred because several years are required for wetlands to again become stagnant, and for emergent cattail plants to grow the water roots that are needed for attachment by these mosquito larvae.

We also experimentally examined the influence that drawdown conducted only during the autumn months can have on larvae. However, some *Cq. perturbans* larvae were able to survive this drawdown schedule; the inability to dry wetlands completely likely reduced the influence of autumn only drawdown. Despite this negative result, mosquito response to drawdown during periods other than summer should continue to be examined, because summer drawdown can stimulate growth of many plants (Kadlec 1962) including the undesirable exotic plant, purple loosestrife (*Lythrum salicaria* Linn.) (Purple Loosestrife Control Project, Minnesota Department of Natural Resources; unpublished data).

The patterns for *Cq. perturbans* observed in the Baker Park Reserve wetland, which was subjected to an artificial drawdown, were also observed in the 202 wetlands in the Minneapolis-St. Paul region that were subjected to a drought induced drawdown. However, the impact of the drought on mosquitoes differed between wetlands containing only emergent stands of cattail and wetlands containing floating mats of cattail.

In 1986 (prior to the drought), 88 of the 202 wetlands that contained larvae only had emergent cattail. Of these wetlands, only 26% still supported larvae in autumn 1987 (after 1 year of drought) and only 1% still supported larvae in autumn 1988 (Fig. 5A; χ^2 , $P < 0.01$). Despite the abundant rainfall in 1989 and 1990, *Cq. perturbans* was only re-established in 24% of those wetlands by autumn 1990 (Fig. 5A).

In 1986, 114 of the 202 wetlands that contained larvae had floating cattail; these wetlands, however, often also contained some emergent cattail along their perimeters. Of these wetlands, 71% still supported larvae in autumn 1987 and 21% still supported larvae in autumn 1988 (Fig. 5B; χ^2 , $P < 0.01$). Although the drought significantly impacted mosquito populations in wetlands with floating cattail, the degree of impact was less than in wetlands with emergent cattail only (see data from 1987 and 1988 in Fig. 5A-B; $P < 0.01$). In addition, a higher percentage of the wetlands with floating cattail again supported larvae in autumn 1989 and 1990 than of the wetlands with emergent cattail only (Fig. 5A-B). Wetlands with floating cattail may be more resistant to drought because

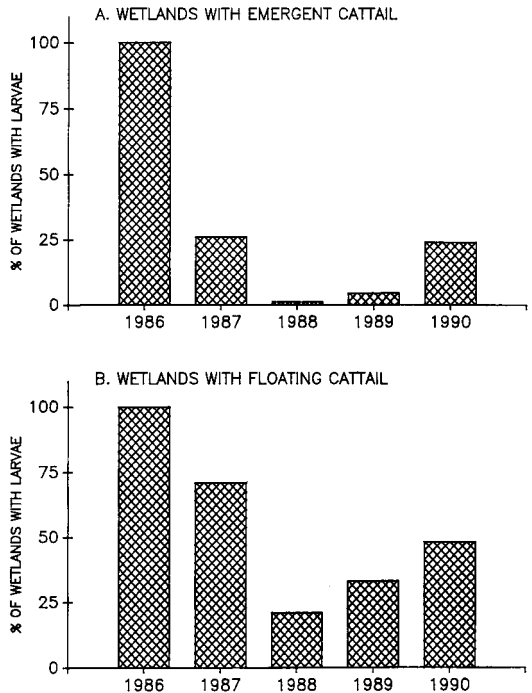


Fig. 5. Percentages of the 202 wetlands in the Minneapolis-St. Paul area in which *Coquillettidia perturbans* larvae were found in autumn 1986 that still supported larvae in autumn 1987, 1988, 1989 or 1990. A. Wetlands (88) with only emergent cattail; B. wetlands (114) with floating cattail.

they are deeper or because floating cattail mats reduce evaporation rates. In addition, *Cq. perturbans* larvae may recolonize floating cattail soon after wetlands are refilled because floating plants immediately provide roots in the water column for larval attachment (unlike emergent cattail), and dissolved oxygen levels quickly become low beneath mats of vegetation.

The drawdowns induced by the 1987-88 drought resulted in only 76 of the 202 wetlands that supported larvae in 1986 to again support larvae in 1990. In addition, larval densities in these wetlands during 1990 were only 32% of the 1986 levels (in 1990, $\bar{x} = 0.81 \pm 0.11$ larvae/dip sample, $n = 76$ vs. in 1986, $\bar{x} = 2.55 \pm 0.14$ larvae/dip sample, $n = 202$); these densities, however, were not compared statistically because samples within wetlands were not consistently collected in a random fashion. This slow recovery of larval densities after the drought was likely caused in part by habitat conditions in the wetlands being unsuitable for larvae, as discussed above for the Baker Park Reserve wetland, and also because ovipositing adults were relatively rare after 2 years of drought.

Although the 1987-88 drought negatively influenced regional waterfowl, the increased productivity of the wetlands after reflooding in 1989 and 1990 should have assisted their recovery. This third study indicates that a summer-long artificial drawdown once every 4-5 years may provide effective multi-year control of *Cq. perturbans* mosquitoes; however, this technique will be more effective in wetlands with emergent cattail than in wetlands with floating plants. Drawdown on this same schedule has already been recommended for use by wildlife officials from the Minnesota Department of Natural Resources and U.S. Fish and Wildlife Service to enhance waterfowl habitat in perennial-water wetlands of Minnesota. However, reflooding of drawdown wetlands could result in problems with *Aedes* mosquitoes that oviposit in damp areas. The MMCD suggests that reflooding of wetlands should be done in autumn when cold temperatures would naturally reduce *Aedes* populations.

CONCLUSIONS

Results from these experiments involving *Ae. melanimon*, *Cs. inornata* and *Cq. perturbans*, in addition to our studies of *Cx. tarsalis* (Batzer and Resh 1992), indicate that certain wetland management strategies currently used to enhance wetlands as waterfowl habitats, may also be useful for mosquito control. Studies in salt marsh habitats of California, Delaware, Florida and Australia have also indicated that management practices designed to control mosquitoes can preserve or even enhance habitat quality for fish and wildlife (Resh and Balling 1983, Collins and Resh 1985, Meredith et al. 1985, Carlson and O'Bryan 1988, Hulsman et al. 1989). These practices have been well received by wildlife agencies (Carlson et al. 1991).

The approach used in our work differs somewhat from these other studies. Rather than demonstrating that mosquito management practices are not harmful to fish or wildlife, our studies demonstrate that some of the management practices already in use for wetland enhancement can also be used to help control mosquitoes. We believe this latter value and approach will be appreciated and accepted by managers of wildlife habitats, because they already are aware of the other benefits of the management techniques involved.

Wetland management plans must be tailored to individual settings, and the manipulations presented here may not necessarily be universally applicable. However, our results are encouraging because they indicate that careful examination of mosquito and waterfowl manage-

ment goals in other wetland settings may suggest mutually compatible strategies to achieve the goals.

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