SALT MARSH DIKING AND NUISANCE MOSQUITO PRODUCTION ON CAPE COD, MASSACHUSETTS

J. W. PORTNOY

Cape Cod National Seashore, South Wellfleet, MA 02663

ABSTRACT. Ecological surveys of mosquito breeding in diked and drained Cape Cod estuaries were conducted in 1982 and 1983. Production of the locally predominant nuisance species, *Aedes cantator*, was apparently enhanced in stagnant drainage ditches by acidification, caused by diking and drainage activities, which mediated the oxidation and dissolution of naturally-occurring pyrite to sulfate. High sulfate depressed pH and favored immatures of acid-tolerant mosquitoes by limiting fish and probably invertebrate predators. Breeding of *Ae. cantator* was restricted almost exclusively to acidified drainage ditches and occurred throughout the summer following rain events of at least 2.5 cm. Adults of this species comprised 72% (1982) and 56% (1983) of all nuisance mosquitoes caught in combination light/CO_2 traps set in or near the coastal flood plain throughout the summer. Current water quality and related mosquito problems associated with salt marsh diking and drainage strongly suggest that present water management methods are counterproductive for mosquito control and wetland preservation.

INTRODUCTION

Historic marsh management practices have often resulted in long term changes to wetland hydrology and ecology affecting both the production of nuisance insects and our ability to control their populations (Angerilli and Beirne 1980, Fleetwood et al. 1978, LaSalle and Knight 1974, Lesser et al. 1976, Vorgetts et al. 1980). Dikes and tide gates have been employed since at least the mid-nineteenth century to restrict tidal flow (from usually small estuaries) in an attempt to enhance agricultural use of highly organic flood plain soils. On Cape Cod, where the agricultural value of marshlands actually decreased after diking (Sterling 1976), dike maintenance has often been justified to reduce saline habitats for *Aedes sollicitans* (Walker) in wetlands that historically produced abundant mosquitoes. However, the identity of these historic pests is not recorded. Recent studies (Portnoy 1983) suggest that the combined effects of diking and subsequent ditch drainage may in fact increase the reproductive success of certain *Aedes* mosquitoes, especially *Ae. cantator* (Coq.).

This paper summarizes the results of mosquito surveys conducted in diked and drained outer Cape Cod estuaries during 1982 and 1983, relating larvae abundance and resultant adult nuisance levels to the quality of aquatic habitat.

STUDY AREAS

Most observations were made in the Herring River basin of Wellfleet (Fig. 1), an originally 445-ha salt marsh isolated by a dike from tidal flow (ca. 3.1 m tidal range) since 1908. Following the exclusion of seawater, salt marsh vegetation had been replaced by freshwater wetland species by the 1930's. With subsequent stream channelization and ditch drainage (begun about 1910, intensified in the 1930's and continued to the present for floodwater mosquito control), most of the basin's wetland habitat has been effectively drained, evidenced by the widespread invasion of upland shrubs and trees (Portnoy and Soukup 1982). Except during times of extremely heavy precipitation, surface water is restricted to the Herring River mainstream, tributary creeks and drainage ditches. Surface water quality varies seasonally with flow and biological activity, but is typically low in oxygen (20% saturation in ditches and 50% in main tributaries) and, especially in low-flow ditches, high in sulfate. Sulfate in solution, i.e.

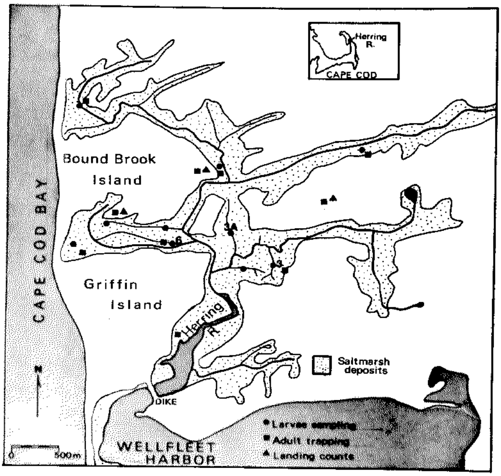

Fig. 1. The diked Herring River floodplain showing mosquito sampling stations.

sulfuric acid, severely depresses pH to ca. 3.0 in the poorly buffered water. Intensive drainage in the diked flood plain has allowed the aeration and oxidation of pyrites normally sequestered anaerobically in salt marsh sediments (M. A. Soukup and J. W. Portnoy, unpublished data) in a process that has been noted (Neely 1958, 1962; Edelman and Van Staveren 1958, Gosling and Baker 1980), but little appreciated. Ditches average 1–2 m wide, 1 m deep, and because they receive interstitial seepage through rather impermeable material, have a slow channel flow velocity which reaches a maximum of up to 5 $cm.s^{-1}$ in the central ditch channel following heavy rains.

Occasional observations of mosquito larval abundance, larval species composition and water quality were also made in Salt Meadow, Truro, another diked estuary about 11 km north of the Herring River. Salt Meadow, comprising about 150 ha of original salt marsh within its total 300-ha flood plain, was isolated from tidal flow about 1860 and thereafter has had a drainage history similar to that of the Herring River basin—with similar effects on plant succession and, from preliminary observations, water quality. Again, surface water is largely restricted to channelized streams and mosquito control drainage ditches.

METHODS

Semiweekly (1982) and weekly (1983) larval surveys were conducted from April through August at 10 stations throughout the Herring River flood plain. Specific sampling locations were chosen as typical of available larval habitat (surface water with little or no flow) for each physiographic sub-area of the coastal flood plain after initial surveys in 1981 (Fig. 1). I also sampled breeding habitat outside the flood plain on a weekly basis in both 1982 and 1983. Immatures were collected with a standard 1-pint (500-ml) dipper using a protocol intended to maximize dip counts by concentrating on highest larval/pupal densities within 15 m of each specific station. Water quality routinely included pH and conductivity, measured electrometrically at each station and date. Larval surveys in Salt Meadow were conducted irregularly in 1982 and weekly in 1983 using the same procedures.

Light traps (BioQuip EVS)[1] baited with 100 g dry ice were set one night (1800 hr to 0800 hr) weekly from early June through August to document emergence and to sample relative densities and species composition of adult mosquitoes at seven stations in the Herring River flood plain and at three nearby upland residences. Landing counts, conducted by exposing an observer's naked forearm for 10 min. at dusk, accompanied light trapping at the three residential sites which were located within 500 m of the flood plain. I did not sample adult mosquitoes in the vicinity of Salt Meadow in either year.

[1] BioQuip Products, Santa Monica, CA 90406.

SURVEY RESULTS AND DISCUSSION

In both 1982 and 1983, *Ae. cantator* was the predominant nuisance mosquito breeding in the Herring River and Salt Meadow diked flood plains. Figure 2 describes larval densities at three representative Herring River stations regularly sampled in 1982 and 1983.

As suggested by Weaver and Fashing (1981), breeding appeared less affected by season than by changes in wetland water levels. In 1982, larvae were very abundant and widespread following record precipitation in May and June that inundated much of the diked flood plain; breeding continued throughout the 1982 summer with consecutive broods following rain

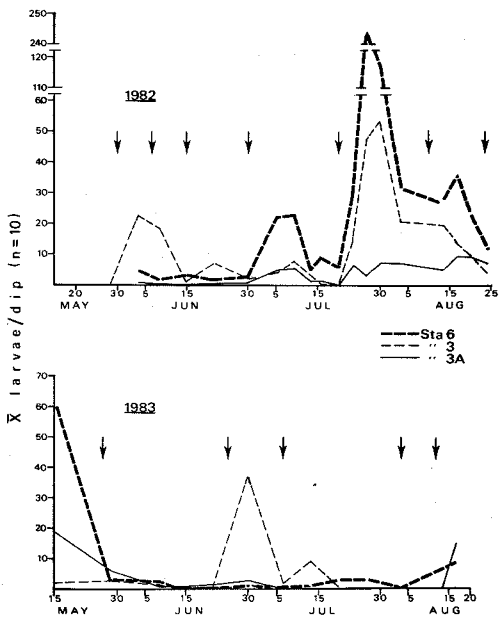

Fig. 2. Mosquito larvae densities at three typical acidified breeding sites in the Herring River basin during 1982 and 1983. Arrows (↓) indicate rain events of 2.5 cm or more.

events of 2.5 cm or more. Low rainfall in spring 1983 resulted in no coastal marsh flooding and correspondingly low larval densities. Breeding was probably also suppressed in 1983 at specific sampling stations by periodic (but unreported) larvicide applications by the local mosquito control agency. Most breeding occurred in slow-flowing or stagnant drainage ditches. *Aedes cantator* immatures also predominated in ditches draining the Salt Meadow flood plain in 1982 and 1983.

Ditch water pH and conductivity for periods of high larvae counts (greater than 10 larvae/dip) are given in Table 1, demonstrating the extremely acidic conditions. High conductivity (total dissolved solids) is largely due to strongly acidifying sulfate ions, together with chloride; pH values of 3.2 correspond with sulfate concentrations of 200—700 ppm. The low pH in turn mobilizes toxic metals like aluminum, reaching as high as 49 ppm in pH 3.2 ditch water (M. A. Soukup and J. W. Portnoy, unpublished data). This combination of extremely low pH and high aluminum, toxic to fish at 0.3 ppm (Driscoll et al. 1980), severely limits larvivorous fish. Minnow traps placed in mosquito control drainage ditches throughout summer and fall never caught fish despite the frequent occurrence of *Lepomis gibbosus* and *Fundulus* spp. in the adjacent and confluent mainstream having better water quality. From casual observations, macro-invertebrates, including important mosquito predators (see Mathazan 1976) such as Dytiscidae, Hemiptera, and Odonata, are also scarce in acidic ditch water. The depression of invertebrate diversity and density in similarly high sulfate strip mine drainage is well documented (Roback and Richardson 1969, Bell 1971, Dills and Rogers 1974, Scullian and Edwards 1980). Correlations of invertebrate densities with water quality and *Ae. cantator* larval densities will be undertaken in the future.

Extensive surveys of outer Cape Cod wetland habitats in both 1982 and 1983 (unpublished data) revealed little *Ae. cantator* breeding outside the diked acidified flood plains.

The reproductive success of *Ae. cantator* was indicated by 1981 and 1982 observations of successful emergence (hatched puparia) and by adult densities in 1982 and 1983 trapping (Table 2 and Fig. 3) and landing count data (Fig. 3). This species comprised 52% (1982) and 49% (1983) of all females trapped, and 72% (1982) and 56% (1983) of all pest mosquitoes trapped. (Pest mosquitoes are defined here as those that commonly bite man in this area.) Casual observations since the summer of 1981 indicate that *Ae. cantator* is the predominant nuisance biter throughout the outer Cape Cod area.

The almost exclusive occurrence and observed success of *Ae. cantator* breeding in acidic ditches of diked flood plains, together with the absence of vertebrate and the rarity of invertebrate predators, suggest the primary source of the *Ae. cantator* nuisance. It is likely that *Ae. cantator* immatures, adapted to high conductivity and tolerant of low pH (MacGregor 1929), are selectively favored over pH-sensitive predators. In unaltered coastal marshes, *Ae. cantator* larvae are typically found in brackish (Magnarelli 1978) and high-ionic-strength freshwater at the salt marsh/upland ecotone (P. Slavin, personal communication). A genetically fixed preference for brackish habitats could be manifested in site selection by ovipositing adult fe-

Table 1. pH and conductivity at typical Herring River larvae sampling stations during periods of high larvae density (greater than 10 larvae per dip).

Date	pH	Conductivity (µmhos/cm) @ 25°C.	Date	pH	Conductivity
1982	Sta 3			Sta 6	
6–3	3.13	860	7–6	3.04	1470
6–8	3.59	480	7–9	3.06	1530
7–23	3.47	1495	7–23	3.24	1515
7–27	3.30	1836	7–27	3.30	1310
7–30	3.00	1628	7–30	3.20	1131
8–5	3.92	524	8–5	3.64	1305
8–13	3.30	1101	8–13	3.05	1363
8–17	3.27	1669	8–17	3.30	1434
1983	Sta 3A			Sta 6	
3–31	3.52	749	3–31	3.49	714
4–14	3.60	720	4–12	3.37	598
5–5	3.81	1122	4–20	3.48	696
5–13	3.85	768	5–5	3.48	1135
8–16	3.36	1200	5–13	3.96	738

Table 2. Summary and comparison of 1982 and 1983 mosquito trapping results in the Herring River Basin. Pest species included all *Aedes* spp. and *Coquillettidia perturbans*.

Species	Total females trapped (%)		Females/trap-night+		Percent of pest species	
	1982	1983	1982 (n = 145)	1983 (n = 96)	1982	1983
Aedes cantator	10279 (52)	3547 (49)	70.9	37.0	72	56
Aedes canadensis	3437 (18)	2427 (34)	23.7	25.3	24	38
Aedes vexans	181 (1)	3 (T)	1.2	T	1	T
Aedes cinereus	128 (T)	63 (1)	0.9	0.7	1	1
Aedes excrucians	35 (T)	1 (T)	0.2	T	T	T
Aedes sollicitans	14 (T)	4 (T)	0.1	T	T	T
Aedes provocans	9 (T)	0 (0)	T	0	T	—
Aedes triseriatus	3 (T)	1 (T)	T	T	T	T
Culex spp.	4100 (21)	697 (10)	28.3	7.3	0	0
Culiseta minnesotae	1168 (6)	55 (1)	8.1	0.6	0	0
Culiseta melanura	46 (T)	73 (1)	0.3	0.8	0	0
Culiseta morsitans	1 (T)	2 (T)	T	T	0	0
Coquillettidia perturbans	228 (1)	307 (4)	1.6	3.2	2	5
Orthopodomyia signifera	1 (T)	0 (0)	T	0	0	—

+ Significant change (decrease) for *Aedes cantator* only (t-test, $P < .05$).

males as well as in (and because of) enhanced survival of immatures.

Studies of two other salt marsh *Aedes, Ae. sollicitans* (Dixon 1947) and *Ae. taeniorhynchus* (Wied.) (McGaughey 1968), implicate sulfate as a powerful oviposition attractant. Abundant sulfate in both natural-brackish and altered acidic *Ae. cantator* habitats may be an important attractant for this species as well. Interestingly, immatures of more typically freshwater species, eg., *Ae. canadensis* (Theobald), *Ae. cinereus* (Meigen), and several *Culex* spp., occurred only in isolated and limited flood plain locations where sulfate, conductivity and acidity were low.

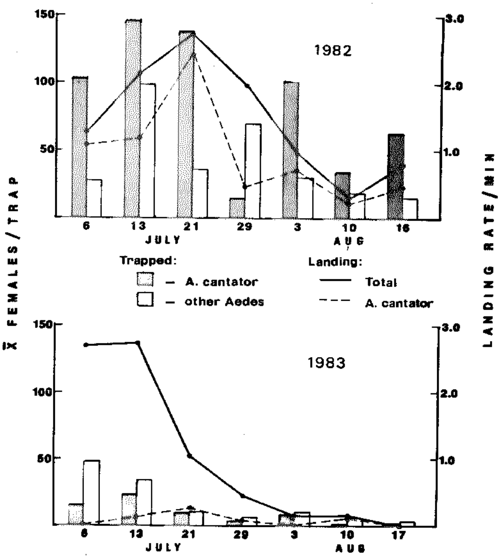

Fig. 3. Mean trap (n = 10) and landing (n = 3) counts of *Ae. cantator* vs. other biting mosquitoes in the Herring River area in 1982 and 1983.

CONCLUSIONS

Although the development of extremely acidic conditions following salt marsh diking and drainage has been observed elsewhere (Edelman and Van Staveren 1958, Neely 1958, Gosling and Baker 1980), the overall significance to wetland functions (M. A. Soukup and J. W. Portnoy, unpublished data) and, in particular, to biting insect production is not well recognized. In view of recent observations, continued drainage in these diked salt marshes may be an inappropriate method of "source reduction" control. The consequent oxidation of pyrite acidifies and degrades water quality for larvivorous predators and selectively favors acid-tolerant *Ae. cantator* immatures.

More appropriate management of diked systems (Ferrigno and Jobbins 1968, J. Shisler, personal communication) would include the restoration of seawater flow to increase tidal flushing and to neutralize acidity in presently stagnant and acidic freshwater habitats. The re-creation of *Ae. sollicitans* breeding habitat is probably less of a concern to pest management because: 1) water quality problems that presently limit natural controls would be eliminated, and, 2) *Aedes sollicitans* production from adjacent outer Cape Cod salt marshes that are open to tidal flow is presently insignificant (Table 2 and unpublished data). Either little suitable *Ae. sollicitans* habitat remains here or, more likely, local control agents experience greater success using source reduction methods more appropriately applied in undiked coastal marshes. Salt marsh diking on outer Cape Cod thus seems to be unjustified for the control of nuisance mosquitoes. In fact, diking probably generates a much less manageable pest control situation, and eliminates well-recognized (Nixon and Oviatt 1973) estuarine resources.

ACKNOWLEDGMENTS

I wish to thank D. Crary, L. Harrison and B. Samora for field assistance and M. A. Soukup for critical review.

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