J. Field Ornithol., 55(2):160–180

THE EFFECT OF DITCHING FOR MOSQUITO CONTROL ON SALT MARSH USE BY BIRDS IN ROWLEY, MASSACHUSETTS

BY JO ANN CLARKE, BRIAN A. HARRINGTON, THOMAS HRUBY, AND FRED E. WASSERMAN

Historically, mosquito populations have been reduced by destroying their breeding habitat in salt marshes and freshwater wetlands through drainage or construction of impoundments. During the 1930's, 90% of the Atlantic coastal marshes were grid-ditched to drain surface water where mosquitos breed (Bourn and Cottam 1950). Ditches were dug at 50 to 100 m intervals throughout the marsh, connecting perpendicularly to common tidal channels. Additional ditches were often added to the system to drain specific pools and pans.

By increasing the area of marsh that is regularly flooded, ditches increase animal populations that exploit the intertidal habitat (Teal 1962, Ferrigno 1970, Kuenzler and Marshall 1973). Effects farther from the ditches, however, are not so well understood. Some authors report increased populations of invertebrates (Rockel 1969, Shisler and Jobbins 1975, Lesser et al. 1976), ducks, and muskrats (Corkran 1938) on ditched sites. Others (Bradbury 1938, Headlee 1939, Travis et al. 1954) have claimed little or no change in wildlife. Bourn and Cottam (1950) reported a significant decrease in invertebrate populations on Delaware marshes after drainage of marsh pools. Negative effects on marsh use by shorebirds, waterfowl, and wading birds have been reported in mid-Atlantic states (Urner 1935, Ferrigno et al. 1975), and in southern New England (Reinert et al. 1982).

The purpose of this study was to determine if grid-ditching alters bird use of Massachusetts salt marshes, and if so, whether the alteration in bird use corresponds to changes in invertebrate abundances. Data and conclusions presented here are based on quantitative observations made during the summer months of 1982 on 2 ditched and 3 unditched sites in the Rowley township, Essex County.

STUDY AREAS AND METHODS

Study areas.—The study areas selected represent: (1) salt marshes close to coastal bays and ocean inlets, with little fresh water input, and (2) backwater salt marshes with a less saline character (Fig. 1). Vegetation on the first marsh type was restricted to *Spartina alterniflora* (cord grass), *S. patens* (salt marsh hay), *Distichlis spicata* (spike grass), and *Limonium carolinianum* (sea lavender) on higher spots, and *Salicornia europea* (glass wort) around pools. The only encroaching upland vegetation was occasional *Iva frutescens* (marsh elder) on elevated ditch spoil or *Chenopodium album* (lambs quarter) on marsh edges. Vegetation on the backwater

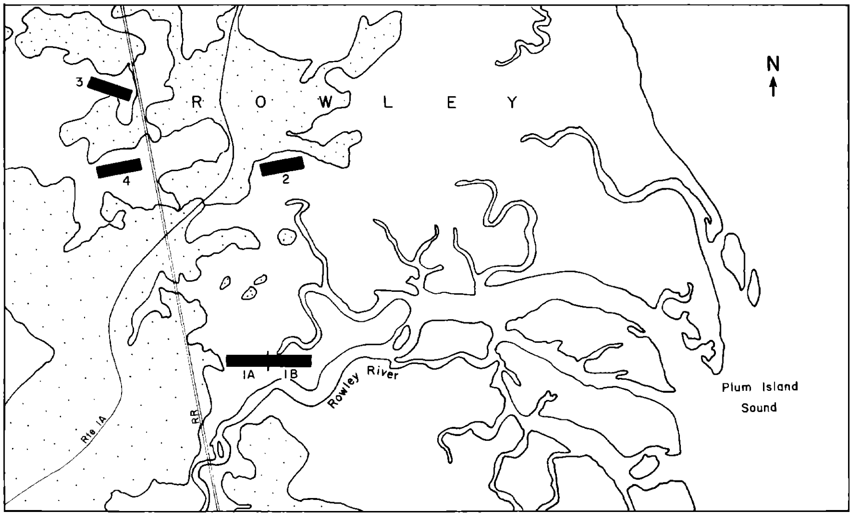

FIGURE 1. Upland (stippled) and marshland (open) habitat in Rowley, Massachusetts. Black rectangles indicate locations of five 3-ha plots studied during the summer, 1982. Plots 1A, 1B, and 2 (coastal marshes) are part of the Rowley River drainage system; Plots 3 and 4 (backwater marshes) drain at the head of the Mill River. For scale each plot is 100 × 300 m.

marshes was more varied. *S. alterniflora, S. patens,* and *D. spicata* were still characteristic, but many areas supported dense stands of *Potentilla egedei* (silverweed), *Juncus gerardi* (black grass), *Eleocharis parvula* (spike-rush), *Plantago oliganthos* (seaside plantain), and various grasses. Long rows of *I. frutescens* and the sedges *Scirpus americanus* and *Cyperus polystachyos* bordered creeks and ditches, and *Typhus angustifolia* (narrow-leaved cattails) encroached on the marsh edges.

Observations were carried out within 100 × 300 m plots during June–August, 1982; 3 plots were laid out on the coastal marsh (1A, 1B, and 2 in Fig. 1) and 2 on the backwater marsh (3 and 4 in Fig. 1). Plot 1A had been grid-ditched in the past, but not recently. In the center of the plot, ditches had clogged sufficiently for a small, shallow pool system to form. In Plot 1B, which was contiguous with 1A, we found evidence of old ditches, but most were completely filled and a system of deep pools stretched approximately ⅚ the length of the plot. Plot 2 was crossed about every 50 m by well-maintained ditches and contained only 2 small pools, although round sunken areas filled with *S. alterniflora* indicated, as suggested by Rockel (1969), that pools had existed prior to recent ditch maintenance. In our analyses, we considered the condition of Plot 1A as neglected ditches, Plot 1B as no ditches, and Plot 2 as recently maintained ditches.

The backwater marsh plots had more complex ditching histories. The ditches in Plot 3 were irregularly placed, often clogged, and failed to drain its 2 small pool systems. Ditching in Plot 4 was more regular. Although standing water was often found in the depressions between grass hillocks, there were no true pools. These sites were considered as unditched and ditched, respectively.

Bird censuses.—From 30 June to 10 July birds were censused once a week on each plot. From 11 July to 31 August, the major migration period for most shorebirds in the area, counts were increased to 5 times a week, then reduced to twice a week for the first 2 weeks of September. Counts were made at different times of the day and at varying stages of both daily and seasonal tidal cycles.

A typical census consisted of walking a rectangular path 30 m inside each plot edge at approximately 21 m/min average walking rate (25 min per census). All birds spotted or heard singing within the plot during the census were identified by species and classified as (1) foraging or non-foraging, and (2) in-pools or not-in-pools. Birds flying over the plot were not recorded unless foraging on the wing.

Invertebrate censuses.—Invertebrates moving around on the surface of marshes were trapped in plastic pitfall traps (10 cm wide at the mouth, 7 cm wide at the base, and 15 cm tall) with 3 cm of water in the bottom. The traps were buried flush with the soil surface at approximately 25 m intervals along transects on the 50, 150, and 250 m lines of each plot. This resulted in 9 pitfall samples per plot. When a trap site located by this method ended in a permanent pool, it was moved to the nearest pool edge. Traps were placed for 48 h during neap tides from 14 to 16 July and 15 to 18 August. In spite of the lower tides, some August traps were flooded, resulting in fewer than 9 pitfall samples per plot at that time.

Soil dwelling invertebrates were collected from substrate cores using a section of 10 cm diameter polyvinyl chloride (PVC) pipe with a sharpened lower edge. The pipe was driven 4 cm into the marsh. Inasmuch as the majority of infaunal marsh invertebrates live in the top 1 to 4 cm (Wieser and Kanwisher 1961, Bell et al. 1978, Coull and Bell 1979), this depth was considered sufficient. Half of the sod plug was placed in a Berlese funnel for 48 to 82 h where heat and light drove the invertebrates out of the soil into a collecting jar containing formalin. The other half of the sod plug was discarded. Core sites were located alternately 10 m to the left and right of the pitfall sites in each plot. Samples were collected from 24 June to 12 July, and again from 2 August to 17 August. This resulted in 18 core samples per plot.

Pool dwelling invertebrates were captured using a 10-cm diameter PVC pipe with a sliding bottom panel. The pipe was submerged in a pool and allowed to settle through about 2 cm of bottom flocculus. The sliding door was then pulled shut by an attached line and the sample of bottom flocculus and standing water lifted out and poured through a 0.5 mm mesh. Invertebrates caught in the sieve were collected and preserved. The size of the mesh precluded quantitative samples of nematodes, minute copepods, and small mite species. Pool samples were col-

TABLE 1. Species and abundance of birds sighted on the 5 Rowley plots during 38 censuses, July–September 1982. Common names follow the American Ornithologists' Union (1983).

Species	Plot 1A	Plot 1B	Plot 2	Plot 3	Plot 4	Total # sighted
Great Blue Heron	—	7	—	4	1	12
Great Egret	—	4	—	—	—	4
Snowy Egret	34	67	—	18	1	120
Little Blue Heron	1	26	—	—	—	27
Green-backed Heron	10	24	—	1	3	38
Black-crowned Night Heron	—	4	—	—	—	4
Glossy Ibis	6	10	—	13	—	29
American Black Duck	1	6	—	3	—	10
Red-tailed Hawk	4	—	2	11	12	29
American Kestrel	—	—	—	13	2	15
Merlin	—	—	—	—	1	1
Black-bellied Plover	—	14	—	—	—	14
Semipalmated Plover	—	51	—	7	—	58
Killdeer	—	—	—	41	—	41
Greater Yellowlegs	22	39	—	51	—	112
Lesser Yellowlegs	46	55	—	139	1	241
Spotted Sandpiper	12	25	1	4	1	43
Semipalmated Sandpiper	3	125	—	173	—	301
Least Sandpiper	95	336	6	178	1	616
Reeve	—	—	—	2	—	2
Ring-billed Gull	3	4	1	1	3	12
Herring Gull	—	8	1	3	—	12
Common Tern	3	131	—	—	—	134
Least Tern	—	20	—	—	—	20
Mourning Dove	—	—	—	2	3	5
Chimney Swift	3	1	—	—	—	4
Belted Kingfisher	—	—	—	4	—	4
Northern Flicker	—	—	—	1	—	1
Eastern Kingbird	11	—	4	30	9	54
Tree Swallow	140	142	117	119	60	578
Bank Swallow	90	89	58	35	12	284
Barn Swallow	31	17	33	14	21	116
Blue Jay	—	—	—	1	—	1
American Crow	6	47	—	7	—	60
Marsh Wren	—	—	—	—	14	14
Brown Thrasher	—	—	—	1	—	1
European Starling	16	20	51	235	—	322
Sharp-tailed Sparrow	30	16	13	50	94	203
Song Sparrow	3	—	1	31	11	46
Common Yellowthroat	—	—	—	2	1	3
Bobolink	—	—	50	11	53	114
Red-winged Blackbird	27	6	33	76	73	215
Common Grackle	1	—	1	52	29	83
American Goldfinch	—	—	—	3	1	4

	1A	1B	2	3	4
1A	28.3 (20.7)				
1B	23.9 (17.8) ***	36.8 (18.6)			
2	22.6 (37.3)	10.8 (10.4) ***	24.8 (24.2)		
3	18.6 (13.5) ***	17.0 (11.4) ***		22.6 (14.5)	
4			20.3 (18.6) ***	31.7 (14.5) ***	31.7 (24.7)

Birds

FIGURE 2. The mean similarity (Jaccard coefficient) of bird censuses paired within and between plots. Numbers indicate mean values and standard deviations are in parentheses. Asterisks indicate between group similarities that were statistically different ($P < .001$) from within group similarities. Comparisons were made between similar marsh types with different ditching histories or between different marsh types with similar ditching histories. Comparisons between ditched and unditched sites on dissimilar marsh types were not made, as indicated by the blank squares.

lected from 8 to 26 July; 16 samples were collected from pools in Plot 1A, 13 from Plot 1B, and 13 in Plot 3. Random measurements of temperature, salinity, and pH of the pool systems were made throughout the period of invertebrate collection using a Yellow Springs Instruments meter (33 set).

Predation by birds in salt marsh pools.—One pool from Plot 1A and one from Plot 1B were used for exclosure studies to examine the effect of bird predation upon fish and invertebrate populations of the pools. The 1A pool was shallow (<25 cm deep) with gradually sloping sides and a surface area of approximately 12 m^2. The pool on Plot 1B was over 50 cm deep with steep sides and a surface area of 10 m^2. Both pools were divided into approximately equal sections by extending 1 mm mesh fiberglass screening across the pool from the pool bottom to 5 cm above the water's surface; this prevented movement of minnows and macroinvertebrates between halves. Dupont VEXAR 2 cm plastic utility netting was placed approximately 50 cm above the water surface to exclude birds from one half of each pool. The closed halves served as controls for the open experiments.

TABLE 2. Use of salt marsh with pools (unditched) and without pools (ditched) in Rowley, Massachusetts by birds of seven foraging guilds, June–September 1982.

Guild	Total # per ha in plots with pools[a]	Total # per ha in plots without pools[b]	Total expected # in each plot[c]	Chi-square value
Herons and ibises	25	1	13	23.1***
Shorebirds	158	7	80	152.5***
Gulls	2	1	2	0.6 ns
Terns	17	0	9	17.1***
Swallows and kingbirds	80	52	66	5.7*
Blackbirds	49	48	49	0.01 ns
Other songbirds	22	23	22	0.01 ns

[a] Plots 1A, 1B, and 3; a total of 9 hectares.
[b] Plots 2 and 4; a total of 6 hectares.
[c] Calculated according to the assumption, Ho: pools(unditched)= no pools(ditched).
*** Difference at significance level of $P < .001$.
* Difference at significance level of $P < .05$.
ns Difference not statistically significant.

To measure initial invertebrate abundance, water column samples were collected from each experimental and control area. The numbers of minnows present in each area were estimated by placing an 11 × 15 cm piece of light gray plexiglass on the pool bottom and counting all minnows swimming across it during 10 min. Minnows were counted in each pool half. Netting was left over the pools for 18 days (25 July to 13 August). At the end of this time, we again counted minnows and sampled control and experimental halves for invertebrates.

Similarity and statistical analysis.—The invertebrate and bird populations from the study plots were compared using similarity analysis. This procedure calculates a similarity coefficient for each pair of samples yielding a final matrix of coefficients that compares each sample with every other sample in the analysis (Field and McFarlane 1968). To compare invertebrate samples, the similarity coefficient described by Bray and Curtis (1957) was calculated after logarithmic transformation of the abundance data. The very wide abundance range of some species made log transformation necessary. To compare bird populations from plot to plot, the Jaccard coefficient was used (Jaccard 1902) which considers only species presence as the criterion of similarity.

The mean similarities between replicate samples within each plot and between samples from different plots were calculated from the matrix of coefficients. The Student's *t*-test was used to determine if the mean similarity of samples from 2 different plots was significantly less than either within-plot mean. If this were true, then the two sites were considered ecologically distinct.

Differences in total invertebrate abundances in each plot were tested using a one-way analysis of variance. Pair comparisons were made with

TABLE 3. Mean abundance, x̄ (SD), and percentage of invertebrate taxa in pitfall trap samples from 5 study plots in Rowley, Massachusetts, summer 1982.

	Plot 1A (n = 13) x̄	Plot 1A %	Plot 1B (n = 14) x̄	Plot 1B %	Plot 2 (n = 9) x̄	Plot 2 %	Plot 3 (n = 15) x̄	Plot 3 %	Plot 4 (n = 14) x̄	Plot 4 %
Adult insects:										
Collembola	1.8 (4.7)	4.6	19.0 (52.2)	10.4	—	—	0.6 (2.3)	1.0	—	—
Coleoptera	1.7 (3.3)	4.3	2.5 (2.1)	1.3	4.7 (6.4)	11.2	0.9 (1.1)	1.6	0.8 (1.3)	1.3
Diptera	—	—	0.3 (0.6)	0.2	—	—	0.1 (0.3)	0.2	0.4 (1.1)	0.7
Hemiptera	2.8 (4.9)	7.2	1.7 (2.0)	0.9	0.4 (0.7)	1.0	1.5 (3.1)	2.6	2.4 (3.1)	4.1
Homoptera	0.2 (0.4)	0.5	—	—	0.1 (0.3)	0.1	0.1 (0.3)	0.2	—	—
Hymenoptera	0.3 (0.6)	0.8	—	—	0.6 (0.7)	1.4	0.5 (0.9)	0.9	0.1 (0.3)	0.2
Lepidoptera	—	—	0.1 (0.3)	0.1	0.1 (0.3)	0.2	0.1 (0.3)	0.2	0.1 (0.3)	0.2
Orthoptera	—	—	—	—	—	—	1.9 (2.8)	3.3	0.3 (0.6)	0.5
Larvae/nymphs:										
Diptera	0.4 (0.8)	1.0	0.9 (1.3)	0.5	—	—	0.4 (0.6)	0.7	0.4 (0.6)	0.7
Neuroptera/Coleoptera	0.2 (0.6)	0.5	0.7 (0.9)	0.4	—	—	—	—	0.1 (0.3)	0.2

TABLE 3. Continued.

	Plot									
	1A (n = 13)		1B (n = 14)		2 (n = 9)		3 (n = 15)		4 (n = 14)	
	x̄	%	x̄	%	x̄	%	x̄	%	x̄	%
Odonata	—	—	—	—	—	—	—	—	0.1 (0.3)	0.2
Arachnids:										
Acarina	12.9 (20.3)	33.0	88.6 (80.1)	48.5	10.3 (5.8)	24.6	10.3 (11.7)	18.0	6.1 (5.2)	10.5
Araneae	2.3 (2.7)	5.9	8.9 (7.9)	4.8	3.4 (2.1)	8.2	14.3 (26.5)	25.0	10.9 (19.0)	18.8
Crustaceans:										
Amphipoda	4.7 (3.5)	12.0	59.9 (57.5)	32.7	21.0 (14.6)	50.1	26.1 (21.7)	45.6	34.6 (34.6)	59.6
Isopoda	—	—	0.1 (0.4)	0.1	—	—	—	—	0.1 (0.3)	0.2
Gastropods:										
Hydrobia minuta	11.7 (25.7)	29.9	0.1 (0.4)	0.1	1.3 (3.6)	3.1	0.3 (1.3)	0.5	0.9 (3.2)	1.6
Melampus bidentatus	—	—	—	—	—	—	0.1 (0.5)	0.2	—	—
Littorina littorea	—	—	—	—	—	—	—	—	0.6 (1.3)	1.0
Worms:										
Opheliids	0.1 (0.3)	0.3	—	—	—	—	—	—	0.1 (0.3)	0.2
Mean no. of invertebrates per sample	39.1 (24.8)	100	182.8 (143.6)	100	41.9 (19.8)	100	57.2 (36.2)	100	58.0 (38.0)	100

a Student Newman-Keuls test (SNK) (Zar 1974). Total seasonal abundances of birds on the plots were compared directly, and apparent preferences of different avian guilds for the ditched or unditched condition were tested using chi-square analysis. In the pool exclosure studies and associated controls, the mean population of invertebrate and fish taxa before exclosure was compared to that after 18 days of exclosure. The Student's t-test was used to determine if an observed difference was significant. The significance level applied in all tests was $P < .05$ unless otherwise indicated.

RESULTS

Bird censuses.—The bird species recorded in each plot are listed in Table 1. The similarity analysis (Fig. 2) indicates that species spotted on Plot 1B were different from those on Plots 1A and 2; likewise, the birds on Plot 3 were distinct as a group from those on Plot 4. Thus, bird use of actively ditched sites (no pools) differed from use of sites with no ditches or neglected ditches (pools). Similarity analysis also revealed differences between species of birds spotted on coastal and backwater marshes. Bird populations on Plots 1A and 1B were different from those on Plot 3, and Plot 2 was different from Plot 4.

When species abundance is included in the analysis, the differences between bird populations of ditched and unditched sites are even more apparent. The greatest number of individuals, regardless of guild, was seen on the unditched plot with pools. When a species was also observed on Plot 1A (neglected ditches) the numbers were always less than on 1B. Most species were absent from Plot 2, the actively ditched site with no pools. The exceptions were Least and Spotted sandpipers and Ring-billed Gulls. In these 3 species, however, the number of birds seen on Plot 2 was small compared to the number foraging on Plots 1A and 1B. A comparison of shorebird, heron, tern, and gull abundances on the backwater marsh indicates that, as on the coastal marsh, these birds foraged almost exclusively on Plot 3, the unditched plot with pools. Exceptions were the Green-backed Heron, which frequented the tall *S. alterniflora* along the ditches of Plot 4, and the Ring-billed Gull.

A chi-square analysis (Table 2) also indicates that shorebirds, herons, and other marine-oriented birds were attracted by marsh pools. Aerial insectivores such as swallows and kingbirds also preferred the unditched plots for foraging. The pattern of occurrence of hawks, songbirds, and other species on the plots, however, did not appear correlated with the ditched or unditched condition. The only exceptions were the American Crow, which was observed only in plots with pools, and the Belted Kingfisher.

Pitfall traps.—The invertebrate animals collected from pitfall traps on the 5 plots are listed in Table 3. Significantly more invertebrates were collected per sample on Plot 1B than on any of the other plots (ANOVA, $F = 9.46$, df $= 4,60$, $P < .001$; SNK, $P < .05$). On Plots 1A and 1B (coastal marshes with pools), large numbers of the minute snail,

Cores

	1A	1B	2	3	4
1A	42.5 (17.5)				
1B	45.5 (19.4)	51.0 (21.1)			
2	44.8 (15.7)	46.4 (18.2) *	51.7 (13.4)		
3	44.3 (16.8)	48.6 (18.3)	44.3 (16.5) *	49.7 (14.9)	
4	45.2 (15.4)	49.1 (16.7)	48.4 (14.2) *	50.5 (15.0)	57.0 (11.7)

Pitfalls

	1A	1B	2	3	4
1A	42.7 (20.1)				
1B	45.6 (15.5)	66.5 (13.4)			
2	51.4 (16.9)	60.0 (11.8) *	68.9 (11.6)		
3	42.3 (17.9)	53.4 (17.4)	57.5 (16.1)	51.6 (18.4)	
4	40.3 (18.8)	50.9 (20.8)	53.1 (20.1)	50.3 (32.6)	46.5 (22.9)

Pools

	1A	1B	3
1A	55.8 (15.1)		
1B	55.7 (13.0)	66.8 (12.2)	
3	20.1 (14.5) *	23.4 (14.8) *	30.5 (24.3)

FIGURE 3. The mean similarity (Bray-Curtis coefficient), after logarithmic transformation of invertebrate abundance data, between and within plots for all samples taken by core, pitfall, and pool sampling methods. Numbers indicate mean values and standard deviations are in parentheses. Asterisks mark the between group means that were significantly different ($P < .05$) from the within group means.

Hydrobia minuta, were collected in the traps, while spiders were common on Plots 3 and 4 (backwater marshes). Amphipods and mites were abundant in samples from all marsh types.

Similarity analysis of the pitfall samples (Fig. 3) revealed that the type and number of invertebrates in Plot 1B were different from those in Plot 2. There were no other significant differences between plots.

Substrate cores.—Invertebrates collected from the core samples on the plots are listed in Table 4. The mean number of invertebrates collected per core did not differ significantly from plot to plot, regardless of the ditched or unditched condition (ANOVA, $P > .20$). Mites and springtails were the most commonly collected invertebrates at all sites. Dipterans, both larval and adult stages, and amphipods were also abundant.

Comparison of the mean similarities of core samples paired within and between plots (Fig. 3) revealed that invertebrate taxa collected on

TABLE 4. Mean abundance, x̄ (SD), and percentage of invertebrate taxa in core samples from 5 study plots in Rowley, Massachusetts, summer 1982.

	Plot									
	1A		1B		2		3		4	
	x̄	%	x̄	%	x̄	%	x̄	%	x̄	%
Adult insects:										
Collembola	23.5 (72.5)	54.4	25.4 (52.1)	46.1	30.1 (114.7)	48.2	10.5 (20.1)	19.1	1.9 (4.5)	5.3
Coleoptera	1.2 (2.7)	2.8	0.1 (0.2)	0.2	0.3 (0.5)	0.5	0.2 (0.5)	0.4	0.2 (0.4)	0.6
Diptera	1.2 (0.9)	2.8	2.3 (3.1)	4.2	2.1 (2.4)	3.4	2.1 (1.8)	3.8	0.4 (0.6)	1.1
Hemiptera	—	—	0.1 (0.2)	0.2	0.1 (0.2)	0.2	0.1 (0.3)	0.2	0.1 (0.5)	0.2
Homoptera	0.1 (0.5)	0.2	—	—	—	—	0.1 (0.3)	0.2	0.2 (0.4)	0.6
Hymenoptera	0.7 (1.7)	1.6	—	—	0.2 (0.4)	0.3	0.1 (0.3)	0.2	—	—
Lepidoptera	0.1 (0.3)	0.2	0.1 (0.2)	0.2	0.1 (0.2)	0.2	0.3 (0.5)	0.5	0.2 (0.5)	0.6
Larvae/nymphs:										
Diptera	2.6 (5.5)	6.0	4.2 (3.6)	7.6	3.9 (4.8)	6.3	11.7 (13.8)	21.2	8.9 (7.8)	24.8
Neuroptera/Coleoptera	1.8 (2.8)	4.2	1.1 (1.3)	2.0	1.4 (2.1)	2.2	1.9 (3.3)	3.4	0.8 (1.2)	2.2
Odonata	—	—	—	—	—	—	0.1 (0.2)	0.2	0.1 (0.2)	0.3

TABLE 4. Continued.

	Plot									
	1A		1B		2		3		4	
	x̄	%	x̄	%	x̄	%	x̄	%	x̄	%
Arachnids:										
Acarina	6.9 (9.6)	16.0	19.9 (19.1)	36.1	17.6 (16.7)	28.2	26.3 (28.0)	47.7	20.1 (19.7)	56.0
Araneae	0.3 (0.6)	0.7	0.3 (0.5)	0.5	0.3 (0.5)	0.5	0.2 (0.5)	0.4	0.8 (0.8)	2.2
Pseudoscorpionida	0.1 (0.2)	0.2	—	—	0.1 (0.2)	0.2	—	—	—	—
Crustaceans:										
Amphipoda	2.7 (3.5)	6.3	0.8 (0.9)	1.5	4.7 (3.4)	7.5	0.7 (1.2)	1.3	1.9 (4.9)	5.3
Isopoda	0.4 (1.0)	0.9	0.2 (0.4)	0.4	1.4 (2.7)	2.2	0.4 (1.0)	0.7	0.1 (0.5)	0.3
Gastropods:										
Hydrobia minuta	0.2 (0.4)	0.5	0.6 (1.2)	1.1	0.1 (0.3)	0.2	0.2 (0.6)	0.4	—	—
Melampus bidentatus	0.4 (1.2)	0.9	—	—	—	—	—	—	—	—
Littorina littorea	—	—	—	—	—	—	0.2 (0.7)	0.4	0.2 (0.4)	0.6
Worms:										
Polychaetes	0.1 (0.2)	0.2	—	—	—	—	—	—	—	—
Mean no. of invertebrates per sample	43.2 (83.3)	100	55.1 (61.4)	100	62.4 (112.6)	100	55.1 (44.0)	100	35.9 (25.2)	100

TABLE 5. Mean abundance, x̄ (SD), and percentage of invertebrate taxa in pool samples from Plots 1A, 1B, and 3 in Rowley, Massachusetts, summer 1982.

	Plot					
	1A (n = 16)		1B (n = 13)		3 (n = 13)	
	x̄	%	x̄	%	x̄	%
Adult insects:						
Collembola	—		0.2 (0.6)	0.3	—	
Coleoptera	0.1 (0.3)	0.1	—		—	
Diptera	0.1 (0.3)	0.1	0.2 (0.8)	0.3	0.2 (0.4)	1.9
Hemiptera	0.1 (0.3)	0.1	—		—	
Homoptera	0.1 (0.3)	0.1	—		0.1 (0.3)	0.9
Notonectidae	33.9 (115.3)	24.1	6.4 (4.9)	8.8	0.8 (0.9)	7.5
Hymenoptera	—		—		0.1 (0.3)	0.9
Larvae:						
Diptera	3.4 (5.3)	2.4	4.5 (6.4)	6.2	3.2 (4.9)	30.2
Neuroptera/Coleoptera	0.1 (0.3)	0.1	—		0.2 (0.4)	1.9
Arachnids:						
Acarina	0.6 (1.1)	0.4	7.4 (6.2)	10.1	0.1 (0.3)	0.9
Araneae	—		—		0.1 (0.3)	0.9
Crustaceans:						
Amphipoda	5.1 (17.3)	3.6	0.1 (0.3)	0.1	—	
Isopoda	—		0.1 (0.3)	0.1	—	
Ostracoda	0.1 (0.3)	0.1	2.9 (5.0)	4.0	2.9 (5.1)	27.4
Gastropods:						
Hydrobia minuta	96.7 (103.7)	68.8	50.7 (34.5)	69.5	0.9 (1.8)	8.5
Worms:						
Polychaetes	—		0.2 (0.4)	0.3	—	

TABLE 5. Continued.

	Plot					
	1A (n = 16)		1B (n = 13)		3 (n = 13)	
	x̄	%	x̄	%	x̄	%
Capitellids	0.1 (0.3)	0.1	—		2.0 (2.3)	18.9
Opheliids	0.1 (0.3)	0.1	—		—	
Ascidians	—		0.3 (0.6)	0.4	—	
Mean no. of invertebrates per sample	140.5 (166.0)	100	73.0 (47.0)	100	10.6 (8.3)	100

Plot 2 were significantly different from those collected from Plots 1B, 3, and 4. No other differences were significant.

Pool sampling.—The invertebrates collected from water column and bottom flocculus of the pool systems on Plots 1A, 1B, and 3 are listed in Table 5. Temperature, salinity, and pH of these pools are presented in Table 6. The pools on Plot 3 were warmer (ANOVA, $F = 59.27$, df = 2,39, $P < .001$; SNK, $P < .01$) and less saline (ANOVA, $F = 130.14$, df = 2,39, $P < .001$; SNK, $P < .01$) than those on Plots 1A and 1B. The pH on plot 3 was also higher than that on Plot 1B (ANOVA, $F = 9.10$, df = 2,39, $P < .001$; SNK, $P < .05$). Fewer invertebrates were collected per sample from pools on plot 3 than from other pools (ANOVA, $F = 5.42$, df = 2,39, $P < .01$; SNK, $P < .01$ for 1A to 3, $P < .001$ for 1B to 3). *Hydrobia minuta* was by far the most abundant invertebrate collected on Plots 1A and 1B (approximately 70% of sample), while Plot 3 had 3 equally abundant taxa: dipteran larvae, ostracods, and capitellid worms. Homopterans of the Family Notonectidae (backswimmers), *Hydrobia minuta,* and dipteran larvae were common on all plots, but the first 2 animals predominated in the more saline pools of Plots 1A and 1B. Dipteran larvae were equally distributed in all pools. In addition to the invertebrates listed, numerous grass shrimp (*Palaemonetes pugio*) were seen in Plot 1A and 1B pools. The only vertebrate identified, the common mummichog (*Fundulus heteroclitus*), was present in large numbers in all pool systems.

Similarity analysis of invertebrates in the pool samples is summarized in Fig. 3. The invertebrates from pools in both Plot 1A and Plot 1B were significantly different from those of Plot 3's pool system.

Predation by birds in salt marsh pools.—Invertebrate abundances in the netted and open sides of the 2 test pools before and after exclosure of

TABLE 6. Mean temperature, pH, and salinity of pools on Plots 1A, 1B, and 3 as monitored with YSI instruments, Rowley, Massachusetts, summer 1982.

Plot	Temperature (C)	pH	Salinity (ppt)
	x̄ (SD)	x̄ (SD)	x̄ (SD)
1A (n = 16)	25.1 (3.0)	6.8 (0.4)	21.6 (2.1)
1B (n = 13)	23.6 (1.3)	6.5 (0.5)	23.9 (2.0)
3 (n = 13)	32.9 (2.3)**	7.5 (1.0)*	10.6 (2.6)**

* Indicates pH of Plot 3 was significantly different from that of Plot 1B ($P < .05$).
** Indicates temperature and salinity of Plot 3 were significantly different from those of Plots 1A and 1B ($P < .01$).

birds are compared in Table 7. Although almost all the invertebrate populations fluctuated, only the one change marked with an asterisk is statistically significant ($P < .05$). Fluctuations in the netted half of a pool generally corresponded with fluctuations in the open side. The relative minnow abundances in pools 1A and 1B before and after the exclosure period are shown in Fig. 4. While minnow numbers were stable in the exclosed areas, numbers decreased in the areas exposed to bird predation. The decrease was significant, however, only in the shallow pool in Plot 1A.

During the exclosure period, birds were seen frequently in and around the open halves of both test pools. Snowy Egrets and Greater and Lesser yellowlegs were repeatedly observed foraging in pool 1A, while terns and yellowlegs were seen fishing in the deeper pool on Plot 1B. Semipalmated and Least sandpipers, and Semipalmated Plovers were observed foraging and probing along the edges of both pools 1A and 1B.

DISCUSSION

Ditching for mosquito control does not appear to have had a marked effect on the invertebrate fauna of the Rowley study sites. On all plots, whether coastal or backwater, similar numbers and types of invertebrates were collected from core samples and pitfall traps. The invertebrates collected from pool samples, however, were different on the coastal and backwater marshes. The warmer, less saline, and higher pH environment in the pools of Plot 3 predictably would support different species than would the pools of coastal plots 1A and 1B. Both the ditched and unditched backwater marsh sites had similar numbers and orders of invertebrates. The invertebrate populations of the coastal plots with active and neglected ditches, although different from those on the unditched plot with pools, seemed roughly comparable to each other in terms of the quantity of potential prey for birds. Epifaunal invertebrates taken in pitfall traps were more abundant on unditched Plot 1B than on ditched Plot 2, but, except for the rarer taxa, no order was found exclusively on a ditched or unditched site. With the exception of backswimmers (Family Notonectidae), invertebrates found in pools on

TABLE 7. Mean abundance, x̄ (SD), of invertebrate taxa in samples from experimental (netted) and control (open) salt marsh pools before (1) and after (2) an 18-day bird exclosure period, Rowley, Massachusetts, summer 1982.

	Pool 1A				Pool 1B			
	Netted		Open		Netted		Open	
Taxa	1	2	1	2	1	2	1	2
Insects:								
Hemiptera								
Notonectidae	2.0 (2.6)	4.0 (6.9)	0.7 (1.2)	1.0 (1.0)	5.8 (4.3)	4.0 (3.6)	9.7 (5.7)	1.7 (1.5)
Diptera								
Adults	0.3 (0.6)	0.3 (0.6)	0.3 (0.6)	0.3 (0.6)	—	1.7 (2.1)	—	—
Larvae	13.3 (4.2)	11.3 (11.7)	1.3 (0.6)	4.7 (2.5)	1.5 (1.3)	3.7 (4.7)	10.0 (12.2)	6.3 (10.1)
Arachnids:								
Acarina	0.3 (0.6)	2.7 (4.6)	0.3 (0.6)	—	5.3 (4.6)	—	10.7 (6.1)	1.0 (1.7)
Crustaceans:								
Amphipoda	1.0 (1.7)	0.3 (0.6)	—	0.3 (0.6)	—	—	—	0.7 (1.2)
Isopoda	—	—	—	0.3 (0.6)	0.3 (0.5)	—	—	—
Ostracoda	—	0.7 (1.2)	—	0.7 (1.2)	0.3* (0.5)	21.3* (13.3)	—	6.7 (6.4)
Gastropods:								
Hydrobia minuta	37.7 (7.2)	79.0 (136.8)	10.7 (9.3)	31.3 (30.5)	51.5 (31.0)	57.0 (25.6)	46.3 (34.6)	53.0 (41.0)
Total increases	4+		6+		4+		4+	
Total decreases	2−		1−		3−		3−	
Unchanged	2		1		1		1	

* Indicates these two values are significantly different, $P < .05$.

Plots 1A, 1B, and 3 were found under moist thatch or in wet sunken areas of the ditched marshes. The minnows abundant in pools were also abundant in ditches at the sites without pools.

We conclude that while grid-ditching for mosquito control may have some effect on marsh invertebrate populations, it does not significantly reduce invertebrate abundances in Massachusetts. The effect of ditching on invertebrates has been poorly researched in the New England area, so we have no local comparison for this conclusion. Invertebrate research on ditched and unditched sites in mid-Atlantic and southern states has produced contradictory results, although most recently published reports (Rockel 1969, Shisler and Jobbins 1975, Lesser et al. 1976, Chick

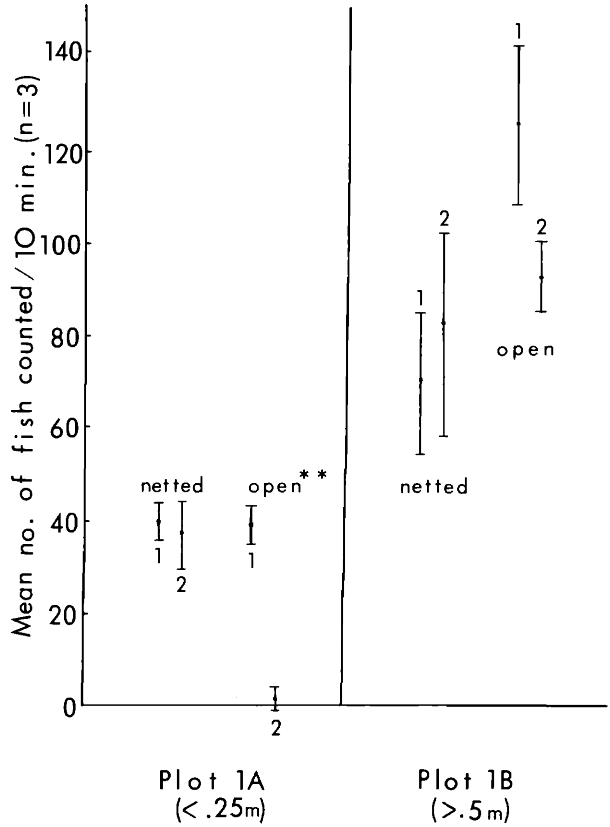

FIGURE 4. Changes in minnow abundance in shallow (1A) and deep (1B) salt marsh pools at control sites closed to prevent bird predation for 18 days and at experimental sites open to predation. Bars represent 1 standard deviation from the mean value of 3 counts; those labelled 1 represent initial counts, those labelled 2, final counts.

1979) agree that ditching does not have the marked effect on invertebrate populations reported by earlier researchers (Bourn and Cottam 1950). It is important to note that the distinction between ditched and unditched plots in our study depended only on the current condition of each study site. All areas had at one time been ditched, and this may have affected aspects of the plots' current invertebrate fauna.

Ditching of the salt marsh for mosquito control appears to affect bird use of the Rowley sites. The unditched plots of both coastal and backwater marsh types had a greater variety and and number of birds than did the corresponding ditched sites. Shorebirds, herons, terns, and swallows exhibited a preference for foraging on the unditched plots with pools.

Analysis also indicated that the composition of bird species seen on the Rowley plots was different for backwater and coastal marshes. Many songbirds nesting in the large wooded area surrounding the backwater sites used the nearby marsh for foraging. The many stands of marsh elder, sedge, and cattails on the backwater marshes also provided a habitat for Red-winged Blackbirds and Sharp-tailed Sparrows. The difference between coastal and backwater marsh types, therefore, is more likely attributable to the greater variety of passerine species frequenting the backwater plots than to differences in the presence of shorebirds, herons, terns, and swallows.

The pool exclosure experiments suggested heavy fish predation by yellowlegs and Snowy Egrets. Great and Little Blue herons, Glossy Ibises, and terns were also seen foraging in pools during the summer. The smaller sandpipers and plovers foraged heavily around pool edges. The exclosure studies seemed to indicate that bird predation had little effect on marsh pool invertebrate populations during an 18-day period, but the edges of the pools were not well sampled, and it is possible that these smaller birds had an effect there that we did not detect. In addition to these species, kingbirds and swallows foraged for insects in the air above the pool systems. All of these birds focused their foraging in and around salt marsh pools.

Decreases in invertebrate populations did not consistently correspond to decreases in bird use. While ditching may have some effect on the invertebrate fauna of a marsh, it does not strongly limit the abundance of potential prey for birds that might forage there. Therefore, the effect of ditching on bird use appears to be controlled by factors other than prey abundance.

Ditching may not significantly decrease invertebrate populations of the marsh, but it does drain pools. Pool drainage was a primary goal of the original grid-ditching systems (Smith 1975), and the effect has been documented in New England marshes (Reinert et al. 1982). In the present study, shorebirds, wading species, terns, swallows, and crows were strongly attracted to the salt marsh pools. Given this strong attraction, we conclude that ditching adversely affects avian populations by draining their foraging areas.

We speculate that the effect of ditching on birds does not result from a reduction in the abundance of potential prey, but rather from the reduction in accessibility of prey as a result of pool drainage. Although invertebrates and fish may still be plentiful on the marsh, without pools and pool edges, they may be more difficult to spot and capture. The foraging area available in ditches is limited by their narrow width, steep sides, and constantly fluctuating water levels (Reinert et al. 1982). In addition, pools often support algal mats which, when cast to the marsh surface on flood tides, smother and kill small patches of marsh vegetation, opening up new spots for foraging. Without pools, fewer surrounding bare spaces are created. These mats also carry trapped invertebrates out of the water making them available to small sandpipers and plovers.

Our hypothesis concerning limited accessibility of prey is consistent with the results of Reinert et al. (1982) in southern New England. That study indicated that birds were more abundant on marshes with pools, but the reasons for this preference were unclear. No other studies have been published that address the effect of ditching on avian populations in New England. Research elsewhere (Urner 1935, Ferrigno 1970, Burger and Shisler 1978, Shisler and Jobbins 1975) is limited, and has generally concentrated on bird species that breed on the marsh, not on migratory or transient flocks.

The marsh management currently practiced by Massachusetts mosquito control associations consists almost entirely of maintaining the old grid-ditching systems that drain pools (McGlathery 1982). We are unable to directly judge the effectiveness of this practice in limiting area mosquito breeding, because mosquito populations were not censused on the Rowley plots. Open marsh water management (OMWM), however, which treats only selected areas of the marsh and often retains or creates pools, is the technique strongly recommended in the mid-Atlantic states for both effective mosquito control and minimum impact on salt marsh fauna (Ferrigno and Jobbins 1968, Ferrigno 1970, Ferrigno et al. 1975, McGlathery 1982). Total implementation of modern OMWM systems is presently cost-prohibitive in Massachusetts, and may not be entirely applicable to northern marshes because of the tidal regimen, problems from winter icing, and differences in species diversity (N. Dobson, pers. comm.). It is probable, however, that existing grid ditches can be modified to allow some pool formation on salt marshes without increasing mosquito levels (N. Dobson and W. Montgomery, pers. comm.), thereby enhancing the value of the marsh to shorebirds, herons, and terns.

SUMMARY

Observations of bird populations on salt marshes with and without well-maintained grid ditches showed that this form of mosquito control decreases habitat use by shorebirds, herons, ibises, terns, and aerial insectivores. These birds normally forage in or around salt marsh pools that are absent on well-drained, ditched marshes. Foraging by passerines and other species seemed unaffected by the ditched or unditched condition of the marshes. A concurrent study of invertebrate populations suggests that ditching does not cause a reduction in the abundance of invertebrate prey. It may reduce the accessibility of that prey to certain avian predators, however, by eliminating the pools where these birds forage. If shorebird, heron, and tern populations using the salt marsh are to be encouraged, marsh pools should be maintained. Experimental modification of existing Massachusetts ditching systems is recommended.

ACKNOWLEDGMENTS

Funding for this study was provided under a contract to Manomet Bird Observatory from the Town of Rowley, Massachusetts, via a Community Assistance grant from the Massachusetts Coastal Zone Management Program. Cooperative services were provided by the Essex County Mosquito Control Commission and the Massachusetts Audubon Society, Resources for Cape Ann Program. Technical advice and assistance were provided by a number of individuals. In particular, we wish to thank Norman Dobson and Walter Montgomery of the Essex County Mosquito Control Commission, Dr. Ernest Ruber, and Dr. Gary Benson. We are also grateful to the citizens of Rowley, especially John Ewell and Donald and Ruth Alexander for their encouragement of our work.

LITERATURE CITED

AMERICAN ORNITHOLOGISTS' UNION. 1983. Check-list of North American birds, 6th Edition.

BELL, S. S., M. C. WATZIIN, AND B. C. COULL. 1978. Biogenic structure and its effect on the spacial heterogeneity of the merofauna in a salt marsh. J. Exp. Mar. Biol. 35:99–107.

BOURN, W. S., AND C. COTTAM. 1950. Some biological effects of ditching tidewater marshes. U.S. Dep. Int. Fish and Wildl. Serv. Res. Rep. 19.

BRADBURY, H. M. 1938. Mosquito control operations on the tide marshes in Massachusetts and their effect on shorebirds and waterfowl. J. Wildl. Manage. 2:49–52.

BRAY, J. R., AND J. T. CURTIS. 1957. An ordination of the upland forest communities of southern Wisconsin. Ecol. Monogr. 27:325–349.

BURGER, J., AND J. K. SHISLER. 1978. The immediate effects of ditching a salt marsh on nesting Herring Gulls, *Larus argentatus.* Biol. Conserv. 15:85–105.

CHICK, B. E. 1979. A report detailing the Rye salt marsh management pilot study for mosquito prevention and marsh rejuvenation. Rye Mosquito Control District Comm. Rep.

CORKRAN, W. S. 1938. New developments in mosquito control in Delaware. Proc. N.J. Mosquito Exterm. Assoc. 25:130–137.

COULL, B. C., AND S. S. BELL. 1979. Perspectives of marine merofaunal ecology. Pp. 189–216, *in* Ecological processes in coastal and marine systems, Livingston, R. J., ed., Mar. Sci. Vol. 10. Plenum Press, N.Y.

FERRIGNO, F. 1970. Preliminary effects of open marsh water management on the vegetation and organisms of the salt marsh. Proc. N.J. Mosquito Exterm. Assoc. 57: 79–94.

———, AND D. M. JOBBINS. 1968. Open marsh water management. Proc. N.J. Mosquito Exterm. Assoc. 55:104–115.

———, P. SLAVIN, and D. M. JOBBINS. 1975. Salt marsh water management for mosquito control. Proc. N.J. Mosquito Exterm. Assoc. 62:30–38.

FIELD, J. G., AND G. MCFARLANE. 1968. A quantitative "similarity" analysis of rocky shore samples in False Bay, South Africa. Zool. Afr. 3:119–137.

HEADLEE, T. J. 1939. Relation of mosquito control to wildlife. Proc. N.J. Mosquito Exterm. Assoc. 26:5–12.

JACCARD, P. 1902. L'ois de distribution florale dans la zone alpine. Bull. Soc. Vaudoise Sci. Nat. 38:6–130.

KUENZLER, E. J., AND H. L. MARSHALL. 1973. Effects of mosquito control ditching on estuarine ecosystems. N.C. Water Resources Res. Inst. Rep. 81.

LESSER, C. R., F. J. MURPHY, AND R. W. LAKE. 1976. Some effects of grid system mosquito control ditching on salt marsh biota in Delaware. Mosq. News 36:69–77.

MCGLATHERY, K. J. 1982. A literary review of the effects of mosquito control ditching on the salt marsh ecosystem, and its implication on the management policies for TNC preserves. Nature Conservancy Eastern Regional Office Rep.

REINERT, S. E., F. C. GOLET, AND W. R. DERAGON. 1982. Avian use of ditched and unditched salt marshes in southeastern New England: a preliminary report. URI Res. Rep.

ROCKEL, E. G. 1969. Marsh physiography: influence on distribution of intertidal organisms. Proc. N.J. Mosquito Exterm. Assoc. 56:102–116.

SHISLER, J. K., AND D. M. JOBBINS. 1975. Aspects of biological productivity in mosquito ditched salt marshes. Proc. N.J. Mosquito Exterm. Assoc. 62:48–49.

SMITH, L. W., JR. 1975. Training manual for the Northeastern Mosquito Control Association.

TEAL, J. M. 1962. Energy flow in a salt marsh ecosystem of Georgia. Ecology 43:614–624.

TRAVIS, B. V., G. H. BRADLEY, AND W. C. MCDUFFIE. 1954. The effect of ditching on salt marsh vegetation in Florida. Proc. N.J. Mosquito Exterm. Assoc. 41:235–244.

URNER, C. A. 1935. Relation of mosquito control in New Jersey to bird life of the salt marshes. Proc. N.J. Mosquito Exterm. Assoc. 22:130–136.

WIESER, W., AND J. KANWISHER. 1961. Ecological and physiological studies on marine nematodes from a small salt marsh near Woods Hole, Massachusetts. Limnol. Oceanogr. 6:262–270.

ZAR, J. H. 1974. Biostatistical analysis. Prentice-Hall, Englewood Cliffs, N.J.

Manomet Bird Observatory, Box 936, Manomet, Massachusetts 02345, and Boston University, Department of Biology, Boston, Massachusetts, 02215 (JAC); *Manomet Bird Observatory* (BAH); *Resources for Cape Ann, Massachusetts Audubon Society, 159 Main Street, Gloucester, Massachusetts 01930* (TH) (M.A.S. Contribution 83-7); *Biology Department, Boston University* (FEW).
Received 9 Aug. 1983; accepted 20 Jan. 1984.