THE EFFECTS OF TWO DIFFERENT WATER MANAGEMENT REGIMES ON FLOODING AND MOSQUITO PRODUCTION IN A SALT MARSH IMPOUNDMENT[1]

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ABSTRACT. Over two years, the management regimes of: 1) opening a southeast Florida salt marsh impoundment to the adjacent estuary with culverts through the dike, then, 2) passively retaining water with flapgate risers was studied to determine the effects on marsh flooding and resultant mosquito production. Larval dipping demonstrated that all broods occurred at elevations of 0.25–0.90 ft (=0.08–0.27 m) NGVD. Mosquito production differed significantly between some sampling quadrats and 65 (out of 75) broods were produced in the spring and summer from rainfall. Without artificial pumping, trapping of rainfall with flapgate risers aided in eliminating oviposition sites but still allowed mosquito production in some marsh locations. Even though tidal flooding permitted larvivorous fish access to mosquito larvae, they were not able to provide adequate control to eliminate larviciding.

INTRODUCTION

Several studies have documented *Aedes* spp production in various coastal salt marsh habitats (Nielsen and Nielsen 1953, Chapman and Ferrigno 1956, Haeger 1960, Harrington and Harrington 1961, Zimmerman and Turner 1982, Balling and Resh 1983, Carlson 1983). In the 1950's and 1960's on the central east coast of Florida, the source reduction technique of impounding was implemented for the control of *Aedes sollicitans* (Walker) and *Ae. taeniorhynchus* (Wiedemann) (Clements and Rogers 1964).

Impoundments are high salt marshes that were diked and flooded to deny oviposition sites for salt marsh *Aedes* spp. Decisions to impound were made on a marsh by marsh basis. Local mosquito control agencies and the Florida Board of Health first verified that a marsh produced mosquitoes. Then the entire high marsh was diked and subsequently flooded during the mosquito producing season by pumping water from the estuary or with artesian wells.

In Indian River County, Florida, Clements and Rogers (1964) showed how larval *Aedes* densities varied greatly under different impoundment management regimes that did not use water control structures. Seasonally or permanently flooded impoundments produced very few mosquitoes whereas impoundments open to the estuary which were not flooded by pumping produced large mosquito numbers from rainfall.

Although impoundments are an effective and economical method of salt-marsh mosquito control (Provost 1977), they can interrupt the exchange of organisms and nutrients between the marsh and estuary and stress or kill vegetation by excessive or prolonged flooding (Gilmore et al. 1982). Formerly, impoundments were managed primarily for mosquito control. Now, impoundment management goals are becoming multipurpose; for mosquito control and the enhancement of fisheries resources, wildlife and water quality.

This study demonstrates the explosive mosquito production possible from rainfall and tidal flooding from non-artificially flooded impounded salt marshes. It also shows how the passive management regimes of: 1) opening the marsh to the adjacent estuary with culverts through the dike, then, 2) retaining water with flapgate risers provides some but not adequate source reduction benefits to eliminate larviciding. The ineffectiveness of fish predation in controlling mosquito populations in this situation is also discussed.

MATERIALS AND METHODS

STUDY SITE. The 20.2 ha impoundment studied, Indian River County Impoundment #12[2], is located on the barrier island at the Indian River—St. Lucie County border. A shallow cove, part of the Indian River lagoon, lies southwest of the impoundment. Part of the northern and the entire eastern side are an undiked upland hammock. This impoundment was constructed in March 1966. Until 1978, it

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[1] This research was one part of a cooperative project with R. G. Gilmore (Harbor Branch Foundation, Inc.) and J. R. Rey (Florida Medical Entomology Laboratory), partially funded by the Florida Department of Environmental Regulation and by the Coastal Zone Management Act of 1972, as amended, administered by the Office of Coastal Zone Management/National Oceanographic and Atmospheric Administration.

[2] W. L. Bidlingmayer and E. D. McCoy. 1978. An inventory of the salt-marsh mosquito control impoundments in Florida. Unpublished report to Fish and Wildlife Service, U. S. Dept. of Interior. 103 p.

was seasonally flooded from May to October by pumping water from the Indian River lagoon, when at a property owner's insistence, pumping was stopped. The marsh was then allowed to dry through evaporation and percolation.

This impounded marsh contains a 1 to 8 m wide perimeter ditch which abuts approximately 65% of the impoundment perimeter (Fig. 1). There are well defined drainage patterns from the marsh interior to this interior perimeter ditch. Several large depressions occur over the marsh surface, some of which retain water even during dry periods.

Marsh elevations (excluding all depressions which range up to 2 m deep with mud) were determined in summer 1982, and ranged from −0.35 to 1.80 ft (−0.11 to 0.55 m) NGVD (National Geodetic Vertical Datum).[3] Most elevations are between 0.40 – 0.90 ft (0.12–0.27 m) NGVD (Fig. 1).

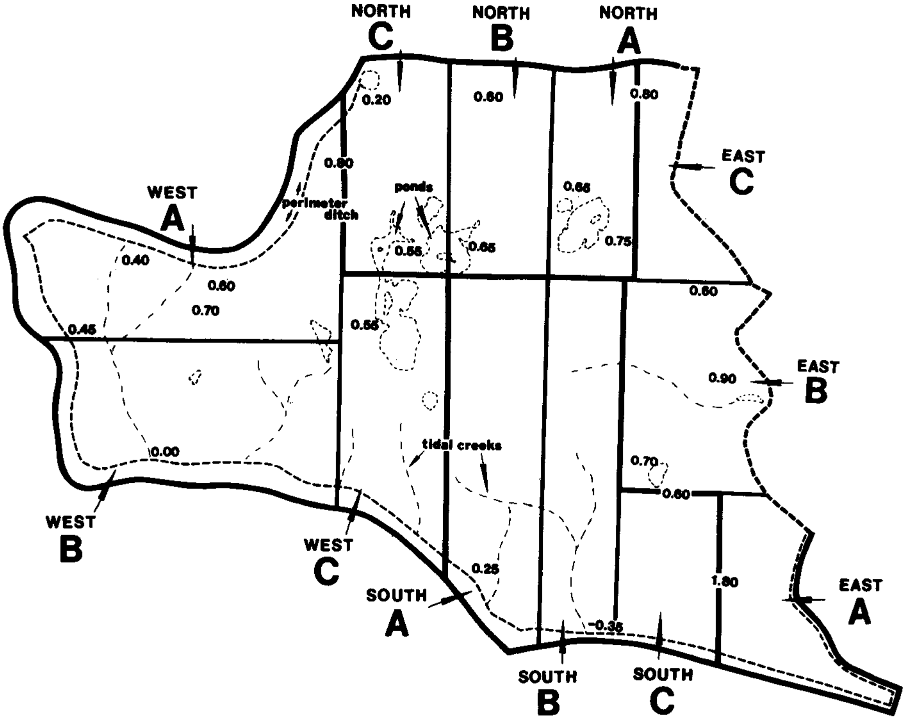

Fig. 1. Representative marsh elevations in ft NGVD (summer 1983).

WATER MANAGEMENT TIMETABLE DURING STUDY. The study commenced in February 1982 when a 45.7 cm (18 in) culvert (Culvert A) was opened to the adjacent cove, allowing unobstructed flow of water between the Indian River lagoon and the impoundment. This was continued until July 1983 when a flapgate riser was attached to the culvert. The riser top was set at 1 ft (=0.3 m) NGVD to trap rainfall and tidal intrusion to this elevation. When impoundment water levels exceeded 1 ft, spillage into the estuary occurred. In September 1983, an additional 45.7 cm culvert with flapgate riser was installed at the northwest corner of the impoundment (Culvert B) to allow increased water exchange with the marsh. The riser height was set so that no water could exit over it. On January 19, 1984, the flapgate riser was removed from the original culvert (Culvert A) to reestablish free water flow to the lagoon. On January 30, Culvert B was sealed.

The study area was kept free of insecticides during the first year, allowing mosquitoes produced between February 1982 and May 1983 to emerge as adults. From June 1983 to March 1984, larvae were treated either from the ground with a diesel oil surfactant mix or, when broad scale applications were necessary, from the air with Altosid (methoprene) adsorbed to sand.

MOSQUITO SAMPLING. Because of ovipositional habits, the aggregation of later instar lar-

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[3] National Geodetic Vertical Datum, Vertical Control Data by the National Geodetic Survey, Sea-level Datum of 1929, U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

vae, and the contracting and expanding water surface area of the preadult habitat, preadult (larvae or pupae) salt-marsh mosquitoes are non-randomly distributed (Nielsen and Nielsen 1953). Complete random sampling for salt marsh mosquitoes can greatly misrepresent brood occurrence and size. Therefore, this study used stratified sampling (Southwood 1978) similar to Zimmerman and Turner (1982). For this study, a brood is defined as a group of preadult mosquitoes in a sampling area which hatch and mature concurrently.

For mosquito sampling purposes, the entire marsh surface was divided into 12 quadrats. The quadrats, which were not of equal size, were designated North A,B,C, West A,B,C, South A,B,C, and East A,B,C (Fig. 1). On each twice weekly sampling visit, mosquitoes were sought out in all quadrats. No areas were neglected but through experience those vegetated areas shown to produce mosquitoes were most thoroughly examined. When larvae were found, random sampling of five 350 ml dips were taken per quadrat. Brood size is expressed as mean number per dip in a quadrat. When larvae were encountered, an aliquot representative of the brood size was returned to the lab and identified to species. Aliquots ranged in size from 1 to 1,444 mosquitoes.

WATER LEVEL AND VEGETATION INFORMATION. Impoundment water elevations were measured biweekly from June 1982 to November 1983 with a greased elevation pole which recorded maximum and minimum flooding levels. Maps showing the extent of marsh flooding at sequential elevations were compiled during the second year of the study. Rainfall was collected at each visit using a tube rain gauge located at the northeast marsh corner. A vegetation survey was conducted by inspection in January 1984 to determine approximate percent coverage of marsh surface components.

RESULTS

The majority of mosquito broods (65 out of 75) were produced by rainfall in the spring and summer. However, tidal flooding as opposed to rainfall played the largest role in sustained marsh inundation. During the study, the number of broods ranged from a high of 17 in East C to 0 in the three South quadrats. The mean brood size also fluctuated greatly from 65.9 per dip in East C to 0.2 in West C (Table 1).

With equal sample sizes ($n = 30$ per quadrat), the Kruskal-Wallis multiple comparison technique showed significantly greater mosquito production in East C and West A over other quadrats ($n = 360$). Specifically, East C was significantly greater than East A, South A, South B, South C, West C (all at $P < 0.001$) and North A ($P < 0.1$). West A was significantly greater than South A, South B, and South C (all at $P < 0.1$). Although a probability level of 0.1 is generally considered of questionable significance, the conservative nature of this non-parametric technique and the large sample size, makes us confident we are not making a Type I error.

Numerically, *Ae. taeniorhynchus* was the most common mosquito species collected (82%). However, on occasion, *Ae. sollicitans* dominated the collection, totaling 16% of the larvae identified. Other mosquitoes collected in trace numbers were the salt marsh species *Anopheles atropos* Dyar and Knab and *An. bradleyi* King, and the typically fresh water species *An. walkeri* Theobald, *Culex nigripalpus* Theobald and *Cx. salinarius* Coquillett (Table 1).

In this impoundment, water levels below 0.45 ft (0.14 m) NGVD generally flood only the perimeter ditch. Water levels of 0.6 ft (0.18) NGVD flood the West quadrats whereas water levels of 0.9 ft or greater flood the marsh to the eastern edge. In early September during both years, the fall tidal increase reached and exceeded this 0.9 ft level. It should be noted that rainfall in all quadrats can cause pockets of water isolated from the perimeter ditch that are not reflected by the water level recorders.

MARSH FLOODING SEQUENCE AND ASSOCIATED MOSQUITO PRODUCTION

A. WATER MANAGEMENT REGIME: UNOBSTRUCTED CONNECTION OF IMPOUNDMENT TO ESTUARY THROUGH ONE CULVERT. MARCH 8, 1982–JANUARY 1, 1983. During this 10-month period, water flowed freely between the impounded marsh and the Indian River lagoon through the existing 45.7 cm diam culvert (Culvert A). Mosquito broods triggered by both rainfall and tidal flooding varied greatly in size and occurred in seven quadrats: North A, B and C, East B and C, and West A and B (Table 1).

From March through August 1982 flooding in the North and East quadrats was primarily induced by rainfall. The six North and East quadrats are distant from the perimeter ditch, thus commonly inundated by rainfall but irregularly by tides unless marsh water elevations exceed 0.75 ft (0.23 m) NGVD (Fig. 3).

Tidal flooding in the West quadrats occurred during the spring due to lower marsh elevations and close proximity to the perimeter ditch. Quadrats West A and B are lower in elevation and closer to the perimeter ditch than the North and East quadrats. Therefore they are

Table 1. Mosquito production in Indian River Impoundment #12 (March 1982–March 1984).[1]

	North			West			South			East			
Date	A	B	C	A	B	C	A	B	C	A	B	C	Hatching stimulus[2]
February 1982—Water management regime: unobstructed connection of impoundment to estuary through one 45.7 cm diam culvert.													
1982: March 7											3.8		R
March 24				0.3	0.5								R
March 28	1.2	14.6	6.3							3.0	1.7	3.4	B
B													
April 9											1.0		R
April 11				0.4									R
April 24				9.5									R
April 25			7.6									81.3	R
April 29											2.6		R
May 1				150.2									T
May 3	0.7	2.4	0.7										R
May 25		1.6	4.6	36.7	1.6						19.1	34.5	R
June 1		1.3	3.3	5.4							14.5	10.0	R
June 5				6.1									R
June 6											6.6		R
June 15	1.4	3.5	5.5										B
June 16											19.9	89.0	B
June 17				32.3	3.6	0.2							B
June 21												132.6	R
June 22		0.6											R
June 23			1.0										R
June 24				23.4	5.4	0.2							R
August 11				73.4	2.6								B
August 17				122.9	5.7								B
August 20											5.4		B
August 21		2.0											B
September 4				28.6									T
September 14												116.5	T
September 17		15.5	138.6										T
1983: April 1												5.6	R
April 10												24.1	R
April 12				11.6									R
April 21				3.2									R
April 22												43.6	R
May 4												30.6	R
June 5				7.3								46.5	R
June 17	139.8	90.6	71.8									349.0	T
June 22												4.2	R
July 13, 1983—Water management regime: water retention with a flapgate riser in the existing culvert.													
July 30		36.8	1.8										R
August 10		1.6										39.0	R
August 14												109.4	R
September 12												2.1	T
September 27, 1983—Water management regime: installation of additional 45.7 cm diam culvert and water retention with flapgate risers in both culverts.													
January 19, 1984—Water management regime: unobstructed connection of impoundment to estuary through both culverts.													
# of broods	4	11	10	15	6	2	0	0	0	1	9	17	
X brood size	35.8	15.5	24.1	34.1	3.2	0.2	0.0	0.0	0.0	3.0	8.3	65.9	
# of dips	550	730	735	850	880	870	890	625	290	160	745	690	
(% positive)	(6.2)	(8.8)	(8.3)	(13.5)	(3.0)	(0.3)	(0.0)	(0.0)	(0.0	(3.1)	(12.1)	(32.0)	

	North	West	South	East
Aliquot composition[3] *A.t.*/*A.s.*/other	1039/105/10	2508/609/9	10/0/0	2656/583/93

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[1] Broods are dated on day of hatching and expressed in mean number per dip.

[2] R = rainfall; T = tides; B = both.

[3] *A.t.* = *Aedes taeniorhynchus; A.s.* = *Ae. sollicitans.*

more frequently flooded by tides in addition to rainfall. Flooding to an elevation of 0.6 ft NGVD is sufficient to inundate large portions of the West quadrats and did occur during every month of this 10-month period. After the first thorough tidal flooding of this area since our study had commenced, on May 6, 1,444 preadult mosquitoes were collected there in one dip.

Preadult mosquitoes were never found in the three South quadrats and rarely in East A and West C. South A and B directly abut the perimeter ditch, thus were inundated frequently throughout this study period. Much of South C and East A extends into the adjacent upland hammock and was dry throughout the study with elevations as high as 1.8 ft NGVD (Fig. 1).

In early September, the annual seasonal high tides began after most of the marsh had been dry for the previous 2 months. After this tidal surge the entire impoundment, except most of South C and East A, remained flooded until early December. The initial flooding hatched large broods of mosquitoes in 4 quadrats (North B and C, West A, East C) (Table 1). During the next 3 months of tidal flooding, water level measurements on the high marsh and in the Indian River lagoon showed that daily water level fluctuations outside the impoundment were greater than those within it. On December 6, the tides began to recede, temporarily drying the marsh.

JANUARY 1–MARCH 31, 1983. From January through March 1983, the study site received heavy rainfall (55.9 cm) reflooding approx 80% of the marsh surface but not producing mosquitoes. Apparently the marsh surface had not become attractive for ovipositing mosquitoes during the dry down period or eggs had not completed development before inundation.

APRIL 1–JULY 12, 1983. In April–May 1983, rainfall (11.9 cm) produced six broods over two quadrats (East C and West A) which were chemically treated (Table 1). The Mann-Whitney U statistic shows mosquito production at the study site during this 2-month period was significantly greater in 1982 than in 1983 (U = 66, P = 0.05). In April–May 1982, rainfall (23.4 cm) produced 15 broods occurring over seven quadrats.

In June 1983, rainfall (10.4 cm) produced three broods in two quadrats. Four large broods in four quadrats were produced from tidal flooding. The Mann-Whitney U statistic shows significantly greater mosquito production in June 1982 compared to June 1983 (U = 123, P = 0.004) when both tides and rainfall (26.7 cm) resulted in 21 broods over eight quadrats.

B. WATER MANAGEMENT REGIME: WATER RETENTION WITH A FLAPGATE RISER IN THE ONE EXISTING CULVERT. JULY 13–SEPTEMBER 27, 1983. On July 13 a flapgate riser was attached to Culvert A and set at 1 ft NGVD to trap rainfall and tidal intrusion. The elevation of 1 ft was chosen because flooding to this level covers marsh locations shown to produce mosquitoes without excessive penetration of water into upland areas. Small amounts of rainfall in July of both years (1982 = 4.8 cm, 1983 = 2.5 cm) resulted in no mosquito production in 1982 and only two broods in the North quadrats in 1983.

Rainfall in August and early September of 1983 (12.9 cm) and 1982 (10.9 cm) was not significantly different (Mann-Whitney U = 25.5, P = 0.4). In August and early September of 1983, with similar rainfall to this 1982 period, but with the flapgate riser in place, the West quadrats remained flooded with trapped rainwater. This eliminated ovipositional opportunities which resulted in no mosquito production from rainfall or the early September seasonal high tides (Table 1). This is in contrast to 1982, when four broods were produced in West A and B from intermittent rainfall which caused the marsh surface to dry and reflood. One brood was also produced in West A by the fall tidal surge.

C. WATER MANAGEMENT REGIME: INSTALLATION OF ADDITIONAL CULVERT (B) AND WATER RETENTION WITH FLAPGATE RISERS IN BOTH CULVERTS. SEPTEMBER 28, 1983–JANUARY 18, 1984. Mosquito production in September, October and November of 1982 and 1983 were similar in that in both years mosquitoes were produced only by the fall tidal surge which covered the entire marsh at flooding elevations from 1.0 to 1.7 ft (0.52 m) NGVD. In early September 1983, high fall tides penetrated the marsh through Culvert A and the marsh remained flooded until early December 1983.

The installation of an additional 45.7 cm diam culvert (Culvert B) with flapgate riser on September 28 enhanced tidal access into the marsh. During both years tides kept the marsh flooded during October and November. Whereas in 1982 water levels began to recede in early December, with the flapgate risers in place to retain high water in 1983, the marsh remained flooded longer. Flooding persisted until January 19, 1984 when the flapgates were removed to allow free water exchange. Both years during this period, constant marsh inundation eliminated ovipositional sites and mosquito production.

D. WATER MANAGEMENT REGIME: UNOBSTRUCTED CONNECTION OF THE IMPOUNDMENT TO THE ESTUARY, JANUARY 19, 1984–MARCH 8, 1984. After opening the culverts, the marsh dewatered quickly reaching the condition where 50% of the marsh surface was flooded. On January 31 Culvert B was closed from the estuary. From January 19 to March 8, 1984, water elevations on the marsh ranged from less than 0.3 to 0.5 ft (0.09–0.15 m) NGVD. Marsh water elevations lower than 0.4 ft NGVD usually dried the marsh flats.

DISCUSSION

As illustrated by past and current research at the study site, different water management regimes have changed the high marsh ecology.

Preimpounding (up to 1966). Prior to impounding, this marsh was densely vegetated with *Batis maritima* L. (saltwort), *Salicornia virginica* L. (perennial glasswort), *S. bigelovii* Torr. (annual glasswort) and *Avicennia germinans* (L.) (black mangrove). Harrington and Harrington (1961) showed 16 fish species were present feeding on a variety of organisms. Haeger (1960) and the Harringtons described the huge mosquito production capability of this marsh.

Impounded with seasonal flooding (1966–78). Thirty months after the marsh was isolated from the estuary by impounding with seasonal pumping, excessive flooding had killed all vegetation leaving only dead mangrove trunks (Harrington and Harrington 1982). Fish use decreased to 5 species feeding primarily on detritus and vegetation. During this period in another Indian River County impoundment (#25)[2], Clements and Rogers (1964) demonstrated that diking and flooding a high marsh, the water management scheme used in the study site from 1966 to 1978, effectively controlled salt-marsh mosquito production.

Impounded without seasonal flooding (1978–82). Gilmore et al. (1982) showed that when the marsh was no longer pumped, yet still unconnected to the Indian River lagoon, isolated red and black mangroves, saltwort and glasswort were reestablishing over much of the marsh. Twelve fish species were found under stressed environmental conditions.

Current study-impounded with connection to estuary by culverts (1982–present). Currently, this salt marsh impoundment is similar to many impoundments on Florida's east central coast. The majority of elevations range between 0.4–0.9 ft NGVD. Elevations of locations where mosquitoes were collected varied between 0.25 (0.08 m) and 0.9 ft NGVD. The large mosquito collections in East C, North A,B,C and West A were between elevations of 0.5 (0.15 m) and 0.9 ft NGVD.

The current study simulated flooding levels used by the Brevard Mosquito Control District on a mangrove island in Brevard County, Florida. That is, flooding levels were established to eliminate mosquito oviposition sites but not inundate black mangrove pneumatophores or other high marsh vegetation thus allowing their survival. In our study site, a flooding elevation of 1 ft NGVD adequately met these management criteria.

In their impoundment study without water control structures, Clements and Rogers (1964) demonstrated that natural marsh flooding was inadequate for mosquito control. Table 1 quantifies the extent of explosive mosquito production possible from rainfall or tidal flooding in revegetated impoundments. The water management alternative of passive retention of rainfall and tidal intrusion by two 45.7 cm diam culverts with flapgate risers provided some source reduction benefits. However, these benefits were not adequate to eliminate larviciding. Both their study and ours have shown that during the spring and summer artificial flooding in these marsh situations would have been necessary for mosquito control benefits sufficient to eliminate larviciding.

A concurrent vegetation study by the Florida Medical Entomology Laboratory reports considerable revegetation with *B. maritima, S. virginica* and *S. bigelovii* occurring after the marsh was opened to the Indian River lagoon. Revegetation by *Avicennia germinans, Rhizophora mangle* L. (red mangrove) and *Laguncularia racemosa* Gaertn. (white mangrove) is heaviest along the perimeter ditch and much less evident in the impoundment interior. During our study after the water management scheme was changed to trap water, signs of stress to *Salicornia* plants was reported.[4]

Spearman's coefficient of rank correlation was used to compare percent vegetative cover (Table 2) with number of mosquito broods (Table 1). On a quadrat basis, it appears that while *Batis maritima* is significantly associated ($r = 0.89$, $P = 0.002$, $n = 12$) with number of mosquito broods, *Salicornia* spp ($r = 0.05$, $n = 12$) and combined vegetative cover ($r = 0.17$, $n = 12$) were not. However, our observations within quadrats that produced mosquitoes show that preadult mosquitoes were generally, but not exclusively, found in or near dense vegetation. They were rarely found on open unvegetated flats. A concurrent research project conducted by the Harbor Branch Foundation, Inc. studied this impoundment's ichthyofauna. A variety of sampling techniques which included

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[4] D. B. Carlson, R. G. Gilmore and J. Rey. 1984. Impoundment management. Unpublished report to the Florida Department of Environmental Regulation/Office of Coastal Zone Management (CM 47 & CM 73). 259 p.

Table 2. Percent cover of marsh surface components at Indian River Impoundment #12 (January 1984).

Component (expressed in %)	North			West			South			East		
	A	B	C	A	B	C	A	B	C	A	B	C
Batis maritima	10	13	16	17	16	11	8	6	8	7	15	39
Salicornia spp.	17	25	36	64	45	42	44	43	79	50	54	54
Mangroves	<1	<1	<1	3	3	7	12	3	4	7	2	1
Open flats	62	58	32	15	35	30	34	48	9	36	25	5
Mud-filled depressions	10	3	15	1	1	10	2	—	—	—	4	<1
Combined vegetative cover	27	38	52	84	64	60	64	52	91	64	71	94

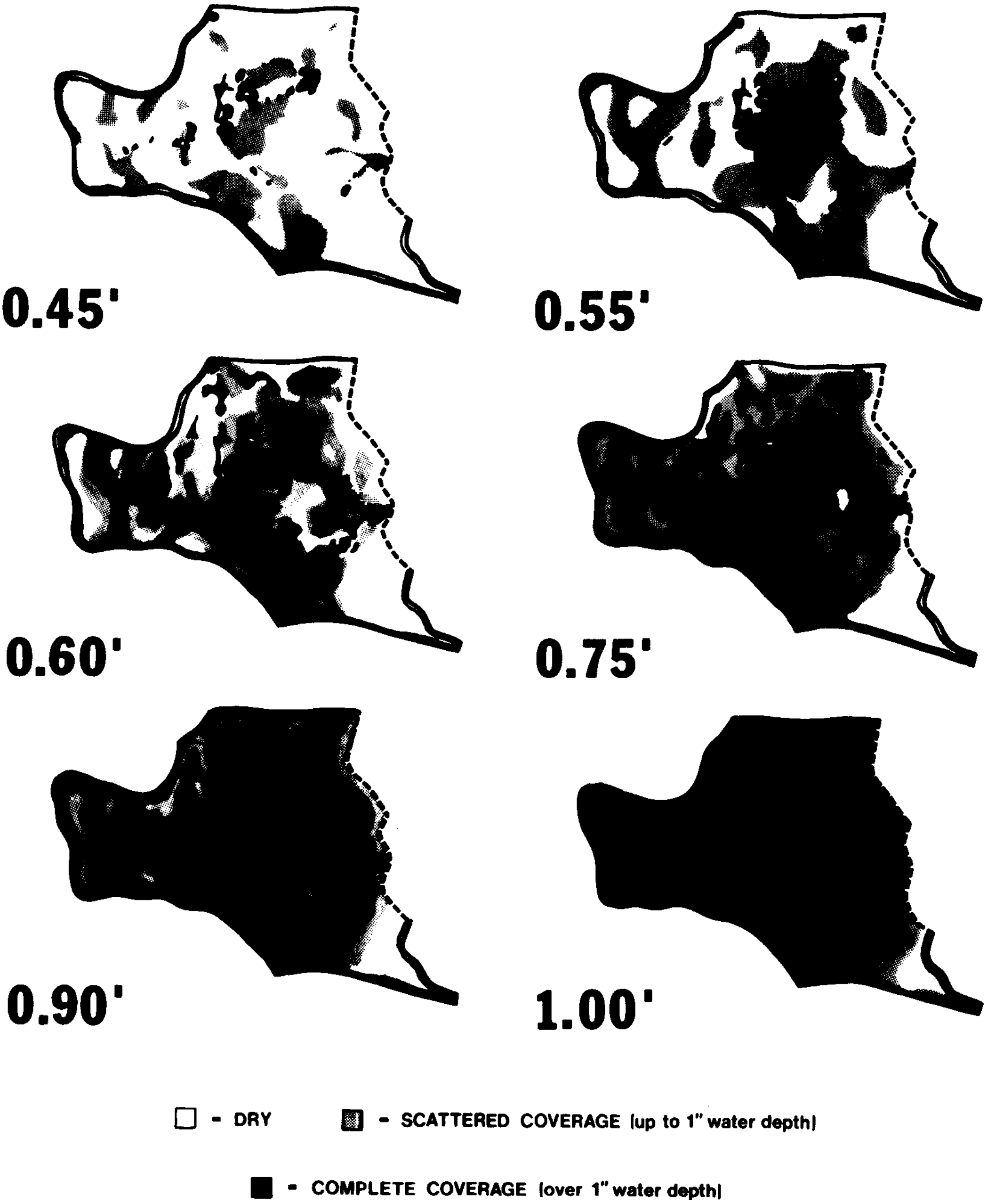

Fig. 2. Marsh flooding profile at sequential flooding elevations.

throw traps, seines and heart traps showed that larvivorous resident marsh fish were present on the upper marsh year-round with captures as high as 44.7 individuals per m.^{2}

Figure 2 illustrates that flooding elevations of 0.9 ft or greater inundate all mosquito producing areas. Figure 3 shows that these flooding elevations were reached numerous times during the year and maintained by fall tidal surges. Harbor Branch Foundation's collections of upper marsh fish in June and September 1982, when large mosquito broods were produced by tidal flooding, reached maximums of 24.7 and 8.7 individuals per m^2, respectively.[4] Thus, although sizeable densities of larvivorous fish were present and had access to large mosquito broods, they were unable to eliminate the need for larviciding.

The total absence of mosquito production in South A, B and C cannot be explained merely by fish predation. The perimeter ditch, which fish use as a harborage, abuts West A, just like South A, B and C. However, mosquito production in West A, which also allows fish access during much of the year, was significantly greater than South A, South B and South C.

Our findings on the ineffectiveness of fish predation in controlling synchronous mosquito broods parallel those of Todd and Giglioli (1983) who also showed that larvivorous marsh fish were not capable of adequately controlling large hatches of salt marsh mosquitoes on Grand Cayman, W. I. They attributed this phenomenon to the immediate hatching of large numbers of mosquito eggs, the dilution of predatory fish densities and delayed increase of fish numbers. All of these factors apparent in Grand Cayman marshes were probably occurring in South Florida as well. In addition, the dense *B. maritima* and *Salicornia* spp. beds where larvae were frequently found were an impediment to fish movement.

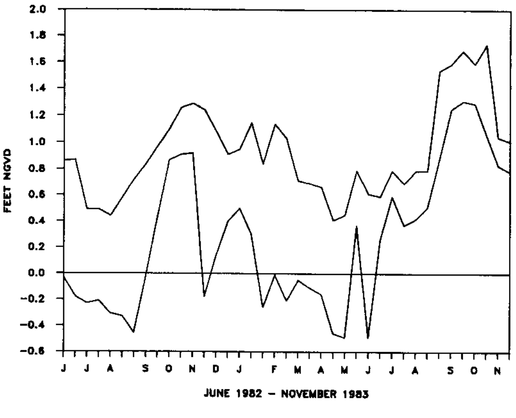

Fig. 3. Water levels in impoundment.

In conclusion, this study demonstrates that rainfall and tidal intrusion can cause prolific mosquito production in revegetating impoundments. It also demonstrates that there can be significant differences in mosquito production capability between marsh surface locations. In this impoundment situation, flapgate risers and fish predation were unable to provide adequate mosquito control benefits to eliminate larviciding.

ACKNOWLEDGMENTS

We wish to thank Dr. J. Rey for sharing his water level measurements and Mr. A. Curtis for review comments and advice with statistical analysis of the data. We also want to thank Mr. G. Dodd, Mr. E. J. Beidler, Mr. R. G. Gilmore, and Dr. J. Rey for reviewing the manuscript.

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