MOSQUITO PRODUCTION IN A ROTATIONALLY MANAGED IMPOUNDMENT COMPARED TO OTHER MANAGEMENT TECHNIQUES[1]

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ABSTRACT. Mosquito production was monitored by larval dipping for 12 months in a 20.2 ha central east coast Florida salt marsh impoundment which was being managed under a rotational impoundment management (RIM) regime. This regime, implemented to provide mosquito control while retaining natural resource benefits, virtually eliminated salt-marsh *Aedes* mosquito production from late May through September when the marsh was closed to the estuary and flooded to approximately 1.0 ft NGVD. *Anopheles* spp. were collected only along the upland marsh edges in relatively low densities. Compared with the management methods of: 1) open to the estuary with culverts and, 2) passive retention of water with flapgate risers, RIM proved to be significantly more effective in reducing mosquito production.

INTRODUCTION

Along the central east coast of Florida, impoundments were constructed in the 1950s and 1960s by isolating high salt marshes from the estuary with earthen dikes. The marsh surface is flooded by pumping water from the adjacent estuary during the mosquito producing season (approximately May to October), to deny ovipositional opportunities for the salt-marsh mosquitoes *Aedes taeniorhynchus* (Wiedemann) and *Ae. sollicitans* (Walker) (Provost 1977).

While this source reduction method is both effective and economical for salt-marsh mosquito control (Clements and Rogers 1964), it interrupts the historic exchange of organisms and detritus between the marsh and estuary. Excessive flooding may also stress or kill existing high marsh vegetation (Gilmore et al. 1982). In the early 1980s this conflict of marsh management objectives was addressed by the formation of the Subcommittee on Managed Marshes, a subcommitte of the Florida Coordinating Council on Mosquito Control, to serve as a forum to mediate the differing management interests in impoundments (Carlson and Carroll 1985). Currently several impoundment management methods are in use along the Indian River Lagoon. They include year-round flooding by pumping, seasonal flooding, no flooding, open with breached dikes and utilization for wastewater retention (Carlson 1983).

The Subcommittee has stressed management decisions based on local research findings. The impoundment management technique most favorably viewed by the Subcommittee for the objectives of natural resource enhancement while maintaining source reduction benefits is a rotational impoundment management (RIM) technique. Culverts with flapgate risers are installed through the impoundment dike to seasonally reconnect the marsh with the estuary. The culverts are closed in the late spring and the marsh is kept flooded by periodic pumping of estuarine water until the early fall. At this time the culverts are opened and the high autumnal tides cause daily water level fluctuations while still maintaining marsh inundation (Carlson and Carroll 1985).

The quantitative verification of mosquito production from impoundments using different management techniques is of interest to all marsh managers. Clements and Rogers (1964) demonstrated how larval *Aedes* densities varied under different techniques for impoundments not connected to the estuary. However, with the current trend to reconnect impoundments to the estuary, mosquito production information on impoundments reintegrated in differing ways is important. Carlson and Vigliano (1985) demonstrated the explosive salt-marsh mosquito production possible from an impoundment; 1) open to the estuary with first one, 2) then two culverts,[2] and 3) the failure of passive water retention with flapgate risers to provide adequate control. The study reported here compared mosquito production in those previously published studies with RIM, currently the impoundment management method most favored

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[2] D. B. Carlson, P. D. O'Bryan and R. R. Vigliano. 1986. Impoundment management, mosquito sampling section. Final report to the Florida Department of Environmental Regulation/Office of Coastal Zone Management (CM 93). 19 p.

by salt marsh managers in this area when trying to balance salt marsh resource interests and mosquito control, while minimizing the use of pesticides.

MATERIALS AND METHODS

Study site selection. Indian River Impoundment No. 12,[3] constructed in 1966 and located on the barrier island at the Indian River—St. Lucie County border, served as the study site. This 20.2 ha (50 acre) impoundment contains an interior perimeter ditch along two and one-half of the four impoundment sides. The eastern edge is not ditched and gently slopes to upland. The Indian River Lagoon, an estuarine lagoon, borders the western impoundment side (Fig. 1). Two 18 in (45.7 cm) diameter culverts had been placed through the dike permitting management flexibility in connecting the impounded marsh with the estuary.

Vegetation of the marsh surface is primarily *Batis maritima* Linn. (saltwort), *Salicornia virginica* Linn. (perennial glasswort), and *S. bigelovii* Torr. (annual glasswort) with scattered *Avicennia germinans* (Linn.) (black mangrove), *Rhizophora mangle* Linn. (red mangrove) and *Laquncularia racemosa* Gaertn. (white mangrove). There are many open areas and ponds, some of which retain water all year. Marsh surface elevations (excluding ponds and the perimeter ditch) range from −0.35 to 1.80 ft. (−0.11 to 0.55 m) NGVD[4] with the majority of the elevations between 0.40–0.90 ft. (0.12–0.27 m) NGVD (Carlson and Vigliano 1985). Prior to culvert closure and estuarine pumping, the mosquito larvicides Altosid® (methoprene) or a diesel fuel—spreader mix were applied when needed.

Sampling methodology. The immature (larvae and pupae) mosquito sampling technique used by Carlson and Vigliano (1985) was employed during this continuation of Florida DER/CZM funded impoundment research. Because preadult salt-marsh mosquitoes are non-randomly distributed (Nielsen and Nielsen 1953), random sampling can greatly misrepresent brood occurrence and size. Therefore, stratified sampling (Southwood 1978) similar to Zimmerman and Turner (1982) was used. A brood is defined as immature mosquitoes in a quadrat which hatch and mature concurrently. Since under local summer conditions salt-marsh mosquito larval development progresses at a rate of an instar per day, the date of brood hatch can be accurately determined.

For sampling purposes, the entire marsh surface was divided into 12 quadrats (Fig. 2). These unequally sized sampling areas were designated North A,B,C, West A,B,C, South A,B,C and East A,B,C. On each twice weekly sampling visit from October 1, 1985 through September 30, 1986, immature mosquitoes were sought out in all quadrats. No areas were neglected but through experience those vegetated areas known to produce mosquitoes were most thoroughly examined. When immature mosquitoes were found, five 350 ml dips per quadrat were taken and the individuals were counted in the field. Rainfall was collected at each site visit using a tube rain gauge located at the northeast marsh corner. Water level measurements were determined using a staff gauge.

The following water management timetable was used:

1. October 1, 1985: Both culverts open to free flow of water between the impoundment and estuary.
2. May 16–19, 1986: Flapgates and riser boards placed in both culverts established the flooding elevation at 1.0 ft. NGVD which trapped tidal water that entered the impoundment during the previous week.
3. May 28, 29 and June 4, 1986: Water pumped into the impoundment with a 6,000 gallons per minute (gpm) portable diesel pump for a total of approximately 16 hours to establish and maintain the desired flooding elevation.
4. September 16, 1986: Flapgate risers from both culverts removed to allow free ebb and flow of water between the impounded marsh and estuary.

RESULTS

A summary of mosquito production during the 12 month period of RIM management follows. For descriptive purposes, the study was broken into convenient periods for considering management and/or climatological effects. Table 1 provides a detailed account of mosquito production throughout the year.

First period: October 1–December 15, 1985. During the first month and a half of this 2.5 month period when the impoundment was open to the estuary through both culverts, the marsh remained almost continuously flooded due to the annual high fall tides and heavy rainfall. During this period, low numbers of *Anopheles* mosqui-

[3] 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.

[4] 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.

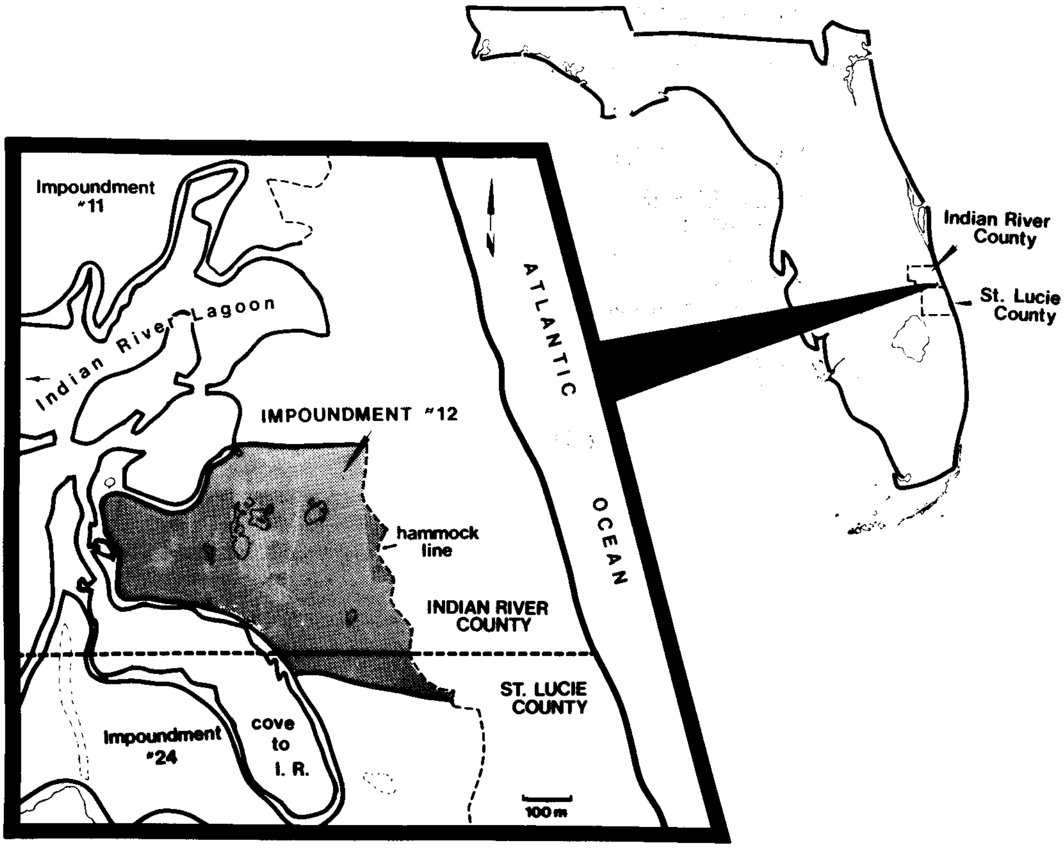

Fig. 1. Location of Indian River Impoundment #12.

toes ($\bar{X}$/dip = 0.6) in the North and East quadrats were common. In mid-November, flooding elevations dropped below 1.0 ft. NVGD exposing portions of the marsh surface. Subsequent rain in December hatched large *Aedes* broods in North A and East C. Rainfall for the period was 39.9 cm.

Second period: December 16, 1985—March 15, 1986. Rainfall hatched several *Aedes* broods in East C during the second period but the sites usually dried too rapidly to permit adult emergence. Observed water levels fluctuated greatly with especially low levels during the first two weeks of February (approx. 0.0–0.1 ft. NGVD). Rainfall was 11.7 cm.

Third period: March 16–June 15, 1986. Tidal inundation of the marsh contributed to mosquito broods produced during this period. In mid-May, the two culverts were closed with flapgate risers, trapping water which had entered the marsh on the May spring tide. Pumping of Indian River Lagoon water into the impoundment with a portable diesel-driven 6,000 gpm pump was necessary for only 16 pumping hours and resulted in just one brood from the initial pumping. This raised the flooding level to the desired elevation of slightly over 1.0 ft. NGVD. Rainfall during this period was 21.8 cm.

Fourth period: June 16—September 30, 1986. Because frequent rainfall during this 3.5 month period kept the impoundment flooded to the 1.0 ft. NGVD level, it was not necessary to pump water. When the expected high fall tides reached this level in early September, both flapgate risers were removed on September 16 restoring the interchange of water between marsh and estuary. As expected, because of the continuous flooding, no *Aedes* production occurred. Low numbers of anopheline mosquitoes ($\bar{X}$/dip = 1.0) were frequently collected along the East and North quadrats. Rainfall during this final period measured 49.5 cm.

DISCUSSION

Meteorological and tidal considerations. Along the central east coast of Florida, salt-marsh mosquito production can occur year-round, but typically is greatest from May through September. During the summer months, lagoonal water levels are usually low and inadequate to flood the marsh surface except for a brief rise nor-

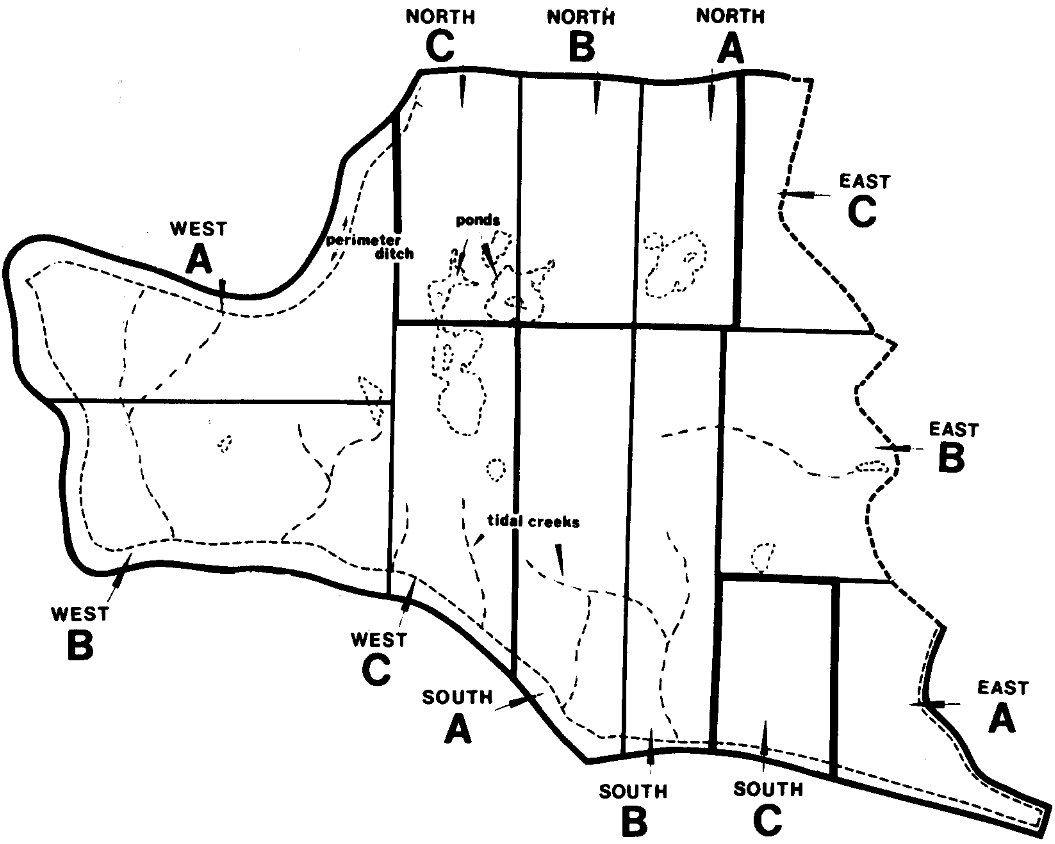

Fig. 2. Mosquito sampling quadrats in Impoundment #12.

Table 1. Mosquito production in Impoundment #12 (October 1, 1985–September 30, 1986). Broods are dated on day of hatching and expressed as mean/dip.

Date	North			West			South			East			Hatching stimulus
	A	B	C	A	B	C	A	B	C	A	B	C	
FIRST PERIOD													
1985: October 1—Water management regime: impoundment open to estuary through both culverts.													
December 7	66.6											351.4	R
SECOND PERIOD													
1986: January 1												78.0	R
January 17												124.2	R
February 9												15.6	R
March 1												3.4	R
THIRD PERIOD													
March 27	4.3	2.3	7.5	25.7		20.8					1.9	117.4	B
May 10												39.0	B
May 16—Water management regime: flapgates installed both culverts.													
May 19—Water management regime: riser boards installed both culverts.													
May 23											1.2	635.8	T
May 28, 29—Water management regime: estuarine pumping (9 hours).													
May 29											9.0		P
June 4—Water management regime: estuarine pumping (7 hours).													
FOURTH PERIOD													
Sept. 16—Water management regime: flapgates removed both culverts.													

R = rainfall; T = tides; B = both; P = pumping.

mally occurring in June. The high fall water levels, those capable of sustained flooding of the high marsh usually do not begin until mid-September. Therefore, the artificial flooding of impoundments to prevent salt-marsh mosquito oviposition is primarily targeted for the months when tides are low and most broods are produced by rainfall (Carlson et al. 1985).

The Kolmogorov-Smirnov two sample test was used to compare rainfall amounts and frequency during the spring through summer period of the four study years. This statistical analysis demonstrated that there were no significant distributional differences in rainfall between the RIM study year and each of the three other management technique years.

Because in mid-May we were able to trap high tides of approximately 0.8 ft. NGVD with the flapgate risers, little pumping was necessary to reach the desired flooding elevation of 1.0 ft. NGVD necessary on the initial pumping (May 28–29, 1986) to inundate all mosquito producing areas. During the remainder of the study, rainfall and tides maintained the desired level limiting the need for additional pumping to only June 4.

Mosquito production comparisons. From October through April of all four study years, Impoundment No. 12 remained open to the estuary. The important May through September period was when management technique differences occurred and thus is the period chosen for mosquito production comparisons.

Although Clements and Rogers (1964) demonstrated that flooded impoundments without a connection to the estuary effectively controlled salt-marsh mosquitoes, Impoundment No. 12 differed from theirs in possessing culverts and in that the eastern side of the impoundment lacks a dike or perimeter ditch. Because of the gentle slope, we anticipated that even small water level fluctuations might produce salt-marsh mosquitoes along the upland edge.

A 2 × 2 contingency table analysis demonstrated that during May through September, significantly less mosquito production occurred during RIM as compared to the impoundment management techniques of: A) open to the estuary with one culvert (Chi square = 34.75, $P < 0.001$), B) 2 culverts (Chi square = 33.86, $P < 0.001$) or C) passive retention of water with flapgate risers (Chi square = 7.23, $P < 0.01$). We have demonstrated earlier in the paper that no significant rainfall differences occurred between years. Therefore, the lack of mosquito production during RIM can be attributed to this management technique (Table 2).

Seventeen mosquito broods occurred during the study prior to impoundment closure as a result of rainfall and/or tidal flooding. Most were found in the same locations reported by Carlson and Vigliano (1985) when the dominance of *Ae. taeniorhynchus* (82.7%) over *Ae. sollicitans* (17.3%) was demonstrated. One small brood was produced in East A by pumping (Table 1). Interestingly, water level fluctuations were minimal during the closure period and *Aedes* production was not observed in the impoundment. Prior to the study, we anticipated water level fluctuations along the sloping upland edge might produce mosquitoes there.

No two marshes are completely alike making the use of a true "control" in a study such as this impossible. However, Impoundment No. 11[3] (a non-pumped impoundment adjacent to Impoundment No. 12) served as a good comparison marsh in that historically it has usually required larviciding whenever Impoundment No. 12 did. From late May through September of this study when Impoundment No. 12 was flooded, field inspection verified the need for five aerial larviciding applications of Impoundment No. 11. This provides further indication of the effectiveness of RIM in preventing mosquito production and limiting the need for chemical treatment. Another cost benefit of a fully flooded impoundment is that larval inspection time is greatly reduced there.

Table 2. Salt-marsh mosquito production in Indian River Impoundment #12 under different management regimes (May 1–September 30).

Management regime	Rainfall (cm.)	Number of mosquito broods	Brood size	
			Range of means	Overall mean
Open with 1 culvert[a] (1982)	66.8	41	0.2–150.2	27.6
Passive retention[a] (1983)	61.47	14	1.6–349.0	66.5
Open with 2 culverts[b] (1985)	69.34	43	0.2–1290.0	115.0
RIM (1986)	58.17	4	1.2–635.8	171.3

[a] Data from Carlson, D.B. and R.R. Vigliano. 1985. The effects of two different water management regimes of flooding and mosquito production in a salt marsh impoundment. J. Am. Mosq. Control Assoc. 1:203–211.

[b] Data from D.B. Carlson, P.D. O'Bryan and R.R. Vigliano. 1986. Impoundment Management, Mosquito Sampling Section. Final report to the Florida Department of Environmental Regulation/Office of Coastal Zone Management (CM 93). 19 p.

Carlson and Vigliano (1985) demonstrated an *Anopheles* ratio of *An. bradleyi* King (55.8%), *An. atropos* Dyar and Knab (40.4%) and *An. walkerii* Theobald (3.8%) occurred in Impoundment No. 12. Even though *Aedes* production was virtually eliminated during the closed-pumped period of the current study, anopheline production along the North and East quadrats averaged 1.1/dip. The observed low level of *Anopheles* production at Impoundment No. 12 is not considered sufficient to require treatment.

SUMMARY

Year to year variability in mosquito production from salt marshes can be great and the ability to maintain an adequate flooding level varies from one impoundment to the next depending on pumping capabilities, weather patterns, and soil conditions. Carlson and Vigliano (1985) demonstrated that passive retention of water was superior to an open culvert situation in controlling salt-marsh mosquitoes in Impoundment No. 12 but still allowed considerable mosquito production along the upland edge. This study shows that during the closed-pumped period of RIM, *Aedes* spp. production was virtually eliminated from the entire study site verifying the superior effectiveness of this management technique if adequate water levels can be maintained. However, additional fine-tuning of this method is still necessary to better evaluate the numerous natural resource implications of impoundment management.

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