WATER LEVELS AND THE EMERGENCE OF *CULICOIDES FURENS* (DIPTERA:CERATOPOGONIDAE) FROM MANGROVE SWAMPS IN GRAND CAYMAN

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ABSTRACT. The effect of water levels on *Culicoides furens* (Poey) emergence in non-tidal mangrove was studied by daily emergence trapping and water level measurements in various mangrove habitats. A multiple emergence trap forming a complete transect across a canal through mangrove was used to show the relationship of emergence zones to moving and stationary water levels. This and conventional emergence trapping indicated that (a) slowly rising water levels stimulate pupation and emergence and could lead to increases in adult abundance; (b) rapidly rising water levels stimulate pupation and emergence but no increase in adult abundance is likely due to great pupal mortality; (c) most flooded larvae do not seek new water lines but continue their larval life for several months until water levels fall to re-expose mud; (d) some emergence can take place in flooded conditions particularly where pneumatophores are present to give a solid substrate and (e) exposure of swamp mud by falling water levels leads to bursts of emergence especially in the second week after exposure.

INTRODUCTION

Both light and emergence trapping results in Grand Cayman (a small island lying between Cuba and Jamaica) indicated that the main peaks of *Culicoides furens* (Poey) abundance occurred at periods of low swamp water levels (Davies and Giglioli 1977). The larvae of this important nuisance species is known to favor a damp mud habitat an inch or so above water level (Myers 1932, Rogers 1962, Davies 1964 and Linley 1966) and it seemed very likely that in the flat low-lying mangrove breeding sites, subject to rapid flooding and drying, water level would have an important effect and might be one of the main factors regulating abundance of the adult. Two factors have been discovered which indicate how important water levels are likely to be. The first is the inability of the larva to pupate when flooded and the second the inability of the pupa to emerge unless attached to a solid substrate (Bidlingmayer 1961 and Linley 1966).

In Grand Cayman most of the mangrove swamp is not affected by daily tidal movements. Water levels are usually below ground during the dry season, except for scattered pools and lakes. Occasional high sea levels cause a slow rise and even flooding but slow fall is the rule, aided by evapotranspiration, till by the end of the dry season even the bottoms of pools begin to dry out. During the wet season the rainfall pattern is the dominant factor affecting swamp water levels, sometimes flooding the mangrove for long periods and at other times allowing it to dry out at intervals.

To examine more closely the effects of water level on sand fly emergence a program of emergence trapping and multiple emergence trapping was carried out on a daily basis in the mangrove swamps of Grand Cayman.

TRAPPING METHODS AND SITES

MULTIPLE EMERGENCE TRAPPING. The multiple emergence trap was a continuous transect of wooden emergence traps 2 ft wide divided into 1 ft compartments. Each compartment collected separately into a 3

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× 1 in. glass tube. The tubes were greased internally with motor vehicle lubricating grease, and the catch was removed with kerosene. Fig. 1 shows a diagram and photographs of the trap *in situ* across a shallow canal running through mangrove in the South Sound area. The trap formed a complete transect across the canal in 18 one-foot sections. Compartment 1 was close against red mangrove stilt roots at general swamp mud level. From there the trap sloped at 5° to compartment 6 which occupied the center of the canal. Compartments 7 and 8 were slightly higher while 9 to 14 climbed the bank of the canal at a 15° angle and 15 to 18 reached towards the top of a marl dyke at a gradually decreasing angle.

Sampling was carried out daily on the productive parts of the transect. During periods of static or slow moving water level the unproductive parts were sampled at longer intervals but one negative compartment on each side of a positive section was sampled daily so that the beginning of shifts in the productive zone were continuously monitored. Thus a figure for the daily emergence rate in each of the 18 compartments was gained for most of the 17½ month collecting period (December 1970 to June 1972).

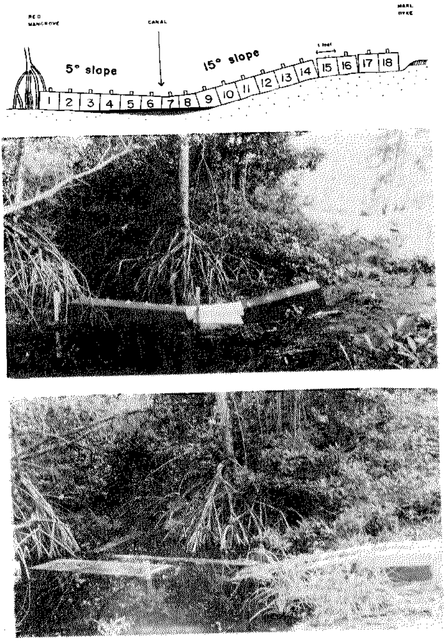

Fig. 1 A. Diagram of multiple emergence trap. B. Compartments 1 to 14 in position at a time of low water level. C. Complete multiple emergence trap at a time of high water level.

The trap was too cumbersome to be moved regularly and was left in one place for the whole survey. Any change in the environment of the area it covered was not likely to affect the reaction of the larvae to water level changes. Also, the buildup of numbers that occurs under stationary traps (Davies 1966a) was an advantage in this case, giving larger numbers for analysis.

EMERGENCE TRAPPING. Since the multiple emergence trap was sited in a man-made environment, further trapping using a more standard type of emergence trap was carried out in natural mangrove sites. The sites were the bed of a large pool in the northwest corner of the South Sound mangrove swamp, and a section of swamp across the West Bay Peninsula from the beach ridge to the edge of a large mangrove pool. These sites are shown diagrammatically in Fig. 5. The emergence traps used were wooden boxes covering 4 ft.^{2} collecting into 3 × 1 inch glass tubes greased internally as described above.

WATER LEVEL MEASUREMENTS. Vertical movements of ground water were measured at all trapping sites both above and, where necessary, below the mud surface. In addition, horizontal movements of the water line were measured along the edges of the multiple emergence trap.

RESULTS AND DISCUSSION

WATER LEVELS. During the 536 day multiple emergence trapping program, water level was stationary for 5 periods totalling 79 days. Mostly (9 periods totalling 336 days) it was falling slowly at the rate of 0.1 to 0.5 in. per day, or rising at a similar rate (6 periods totalling 91 days). Rapid rises were of short duration (7 periods totalling 30 days) and rapid decreases did not occur.

Typical water level movements in relation to general mangrove mud level can be seen in Fig. 5.

EMERGENCE IN RELATION TO WATER LINE AND SOIL WATER LEVELS. In the section of the multiple emergence trap which sloped at a 15° angle the bulk of emergence occurred within 2 to 3 feet of the water's edge with a peak in the compartment next to the one straddling the water line. Water level in this band was not more than 8 in. below ground. Only 0.9% of emergence occurred from compartments where water level was over 11 in. below ground and only 2.4% occurred in totally flooded compartments.

On the 5° slope most emergence was similarly above the water line but instead of a well defined peak the emergence rate showed signs of levelling off as a plateau covering a wider area than the trap sampled.

The emergence zones remained much the same during stationary and slowly moving water levels but were completely disrupted by rapid rises. Most emergence from flooded compartments occurred immediately following rapid rises which drowned productive compartments. Emergence here died out after a few days, and new emergence zones established on high stationary water lines after flooding were much nearer the water line than usual.

EFFECT OF SLOW WATER LINE MOVEMENTS. Williams (1962), Rogers (1962) and Linley (1966) all noted that the emergence zone must migrate following slow movements of the water line and this movement could be seen to occur in the daily results from the multiple emergence trap. However, daily changes were very small and the movement is best demonstrated by showing the extent of the zone for each water level. Fig. 2 is thus arranged as a single period of water line retreat followed by an advance, but it is computed from the series of smaller scale oscillations which occurred during the survey.

No emergence occurred during those days when the trap was completely flooded or when the water line was in compartment 18 (Fig. 2 rows A and B). As soon as the water line fell into compartment 17 emergence began in 18 (row C) and further drops into 16, 15 and 14 (rows D, E and F) increased the width of the emergence zone above the water line. Rows G to J show emergence ceasing in the higher drier compartments and following the water line down the 15° slope. In K the water level is low enough for the top of the 5° slope to become exposed so the canal now has two water lines with two emergence zones moving down towards the center of the canal.

In rows N to R the same process is shown in reverse with emergence being pushed gradually back up the canal sides as the water rises. The 5° side soon floods completely (row Q) to leave a single emergence band climbing the steeper slope.

The movement can be explained in terms of migration of the larvae (Linley 1966). Average daily horizontal water line movements were 0.9″ on the 15° slope and 2.75″ on the 5° slope and observations of larval movement in the laboratory indicate they are well able to cope with such movements.

The figures for catch and number of days for each water level (Fig. 2) show that a very definite increase in the rate of emergence occurred as water levels dropped. On the 5° slope this could be attributed at least partly to the increasing size of the emergence zone, but on the 15° slope the emergence zone remained roughly the same size at different water levels showing that a definite increase in productivity per unit area of mud was involved. This agreed with results using conventional emergence traps and the possible causes of it are discussed elsewhere (Davies and Giglioli 1977). The multiple emergence trap results, however, suggested further factors which may be involved.

Firstly, periods of low water tended to

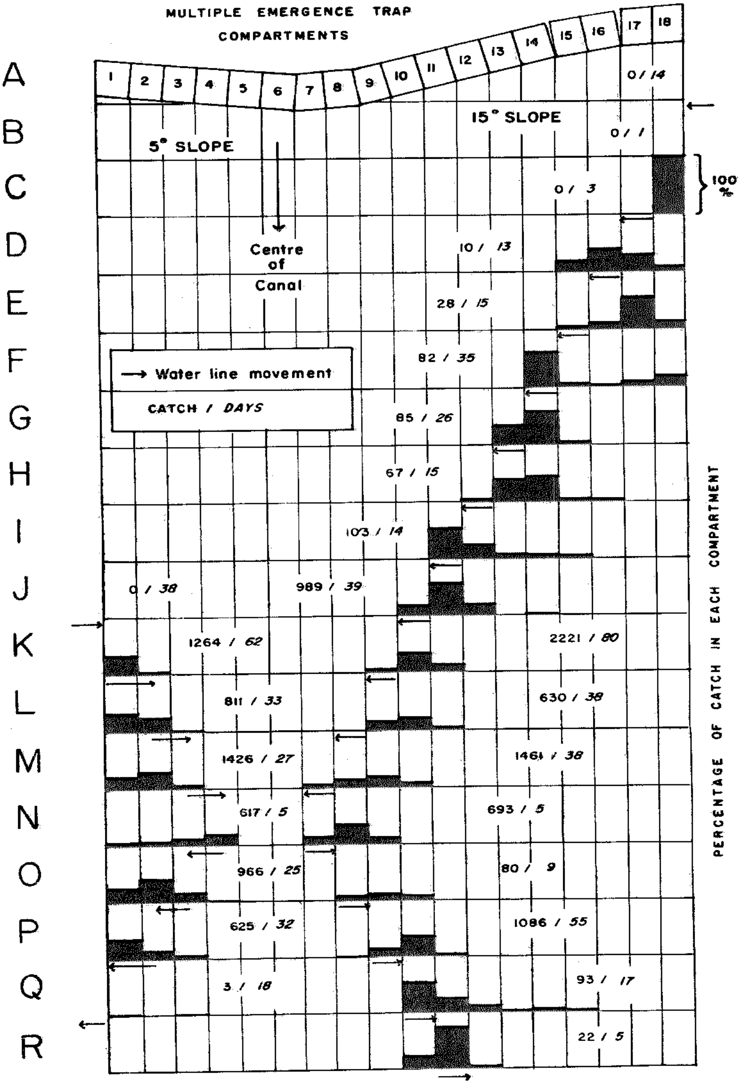

Fig. 2 Movement of emergence zones with slowly falling (A–N) and rising (O–R) water lines.

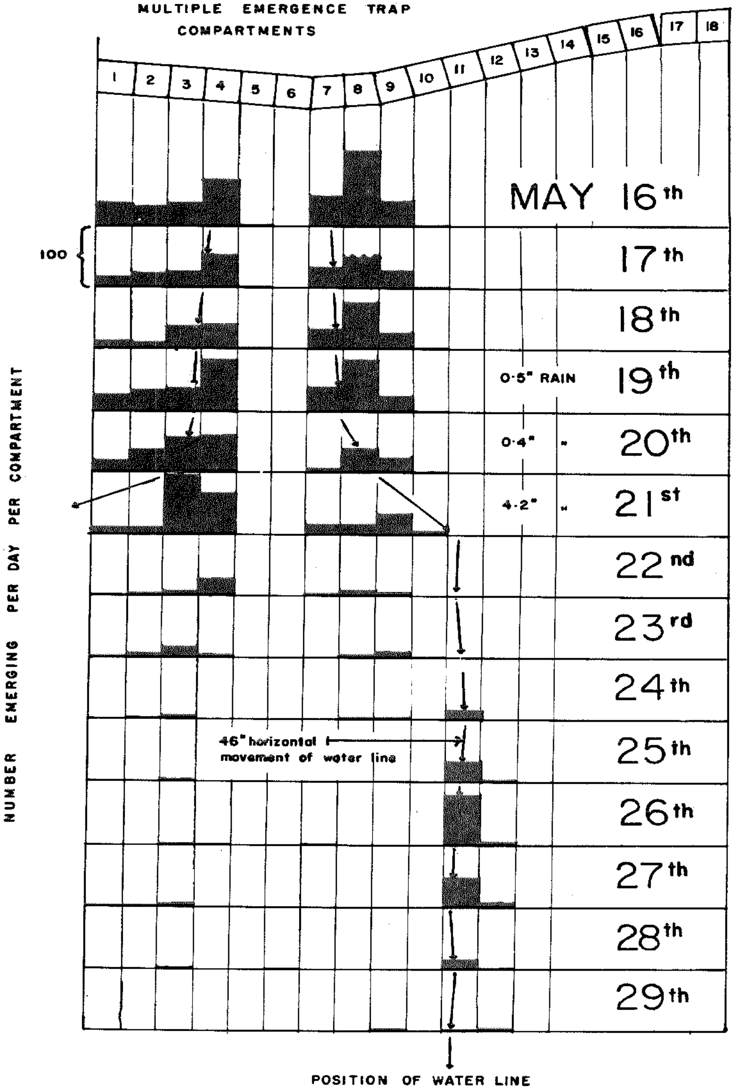

Fig. 3 Movement of emergence zones during a period of rapidly rising water lines.

last longer than periods of high water and this element of increased stability may have played a part in inducing pupation. Certainly long periods at a given water level showed consistently higher average emergence rates per day than short periods at the same level. Secondly, if larvae tended to move down the slope more readily than up this would lead to greater concentrations at lower levels. Evidence for this was given by results on the 5° slope. When water levels were falling the mud of compartment 1 became exposed at the same time as the general mud level of the adjacent mangrove. Thus there was no question of larvae migrating down into this compartment. But emergence began immediately mud was exposed (Fig. 2, row K) so larvae must have been present there in large numbers during the period of flooding. This indicates that larvae survive well in flooded habitats and therefore do not need to follow a water line upwards except when ready to pupate. However the dry conditions which threaten when a water line is falling make it necessary for the whole larval population to move downwards. Thus it is possible that only mature larvae move upwards but all stages move downwards leading to more dense population at lower levels.

By far the highest emergence rates occurred when water levels were rising from their lowest levels (Fig. 2, row N). The rate was several times that when water levels were at the same level but falling (Fig. 2, row M). This indicates that slowly rising water levels may stimulate emergence and possibly pupation.

EFFECT OF RAPID FLOODING. Most rapid increases in water level occurred in the rainy season when water levels were already high and emergence rates too low to give a good idea of larval reaction. Fig. 3 shows the most extensive water movement to occur at initially low levels with high emergence rates from the multiple emergence trap. The water line moved 46 inches up the 15° slope and completely flooded the 5° slope in the course of a few days. The result was a sudden drop in emergence in the flooded areas (compartments 1 to 10) followed by the reestablishment of emergence on the new water line (in compartment 11). This new emergence zone was narrower and closer to the water line than normal.

Emergence on the new water line began 3 days after the water stopped rising, building to a peak on the 5th day and then rapidly declining. Assuming a 3-day pupal period (Linley 1969), pupation must have begun as soon as the water line ceased to move, but it did not reach a peak till 2 days later. Thus, either most mature larvae waited for several days on the new water line before pupating, or it took several days for the bulk of them to find it. If larvae from the drowned 5° slope reached the single new water line on the 15° slope a delay would be expected since the distance is 7 to 8 ft. at least. The definite burst of emergence on the new water line indicates that rising water levels may stimulate mature larvae to pupate, but absence of emergence in compartment 10 shows they do not do this until conditions stabilise.

In the 2nd week after flooding, emergence dropped to 4% of its preflooding level. This was surprising since there was plenty of damp mud still available above the single new water line which could have received immigrants from 2 heavily populated drowned emergence zones. These results suggest that most of the larvae did not seek the new water line.

The pattern of emergence in suddenly flooded compartments is shown in Fig. 4. This shows daily emergence rates before and after flooding averaged for 9 different compartments during 3 separate periods of flooding. The compartments were chosen for their high rate of emergence prior to flooding.

On the 1st day following inundation the emergence rate was in the same range as before flooding (Fig. 4), but on the 2nd and 3rd days there was a reduction of about 77%. On the 4th day a slight increase occurred, but then emergence dropped to very low levels. However, it did not cease altogether as these low levels were observed even in the 4th week of flooding.

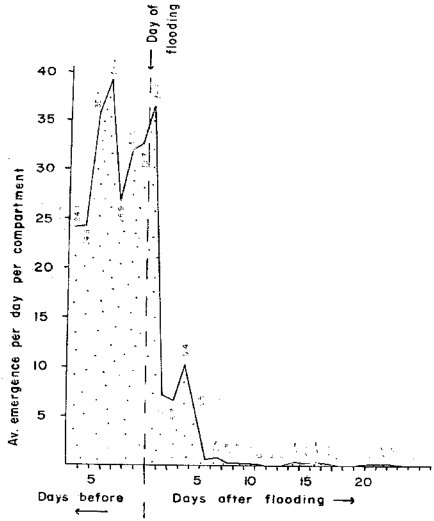

Fig. 4 Emergence rates before and after rapid flooding (average of nine multiple emergence trap compartments).

Since flooded larvae cannot easily pupate (see introduction), most of the post flood emergence must be from pupae already present on the mud. With a pupal period of 3 days emergence could therefore be expected at high levels for 3 days after flooding. The fact that this does not occur must be due to a proportion of pupae being unable to free themselves from the mud, and probably a larger proportion of floating pupae failing to find solid substrates from which to emerge (many empty pupal cases were found attached to the inside of flooded emergence boxes, just above the water line). The results indicate a pupal mortality of 77% on the second and third days. The lack of such mortality on the 1st day could be due to rising water stimulating mature pupae to emerge while a solid substrate was still available.

Adults emerging on the 4th day after flooding are likely to be from larvae which pupated as the flooding occurred and the increase in numbers compared with days 2 and 3 indicate that more pupated than normal.

Thus flooding may stimulate mature larvae to pupate as well as mature pupae to emerge but a burst in adult densities is not likely since the former suffer considerable mortality and the latter are present only in the same densities as before flooding.

Larvae of all ages would be left inside flooded emergence trap compartments and from time to time some may manage to pupate against irregularities in the wooden walls of the trap. This would account for the low levels of emergence continuing for weeks after flooding.

EMERGENCE IN FLAT HABITATS. The slope of the area sampled by the multiple emergence trap was not characteristic of the main *C. furens* breeding sites. These were either flat or at low angles so that very little vertical water level movement was necessary to cause widespread flooding or the sudden exposure of large tracts of mud. The substrate in these areas was either bare mud or mud studded with the pneumatophores of mangrove trees (*Avicennia germinans* (L)L.).

Fig. 5 A shows the daily water levels and emergence from bare mud at the edge of a mangrove pool. No emergence occurred while the pool was flooded but started a few days after the mud became exposed and built up to a peak on the 13th day. It then declined although the water level remained 1½ to 2½ in. below mud level but by the 22nd day of mud exposure new peaks of emergence had built up. These were cut short by an upward movement of the water causing re-flooding of the mud surface.

The sudden start of the first peak shows that pupation began as soon as the mud became exposed. This means that mature larvae had either migrated down from the pneumatophore zone which surrounded the pool (see diagram in Fig. 5A) or had been already present in the flooded pool. Trapping in the pneumatophore zone for 123 days before emergence started from the pool produced only one *C. furens* even though water levels were mostly favorable. Thus it seems most likely that larvae were

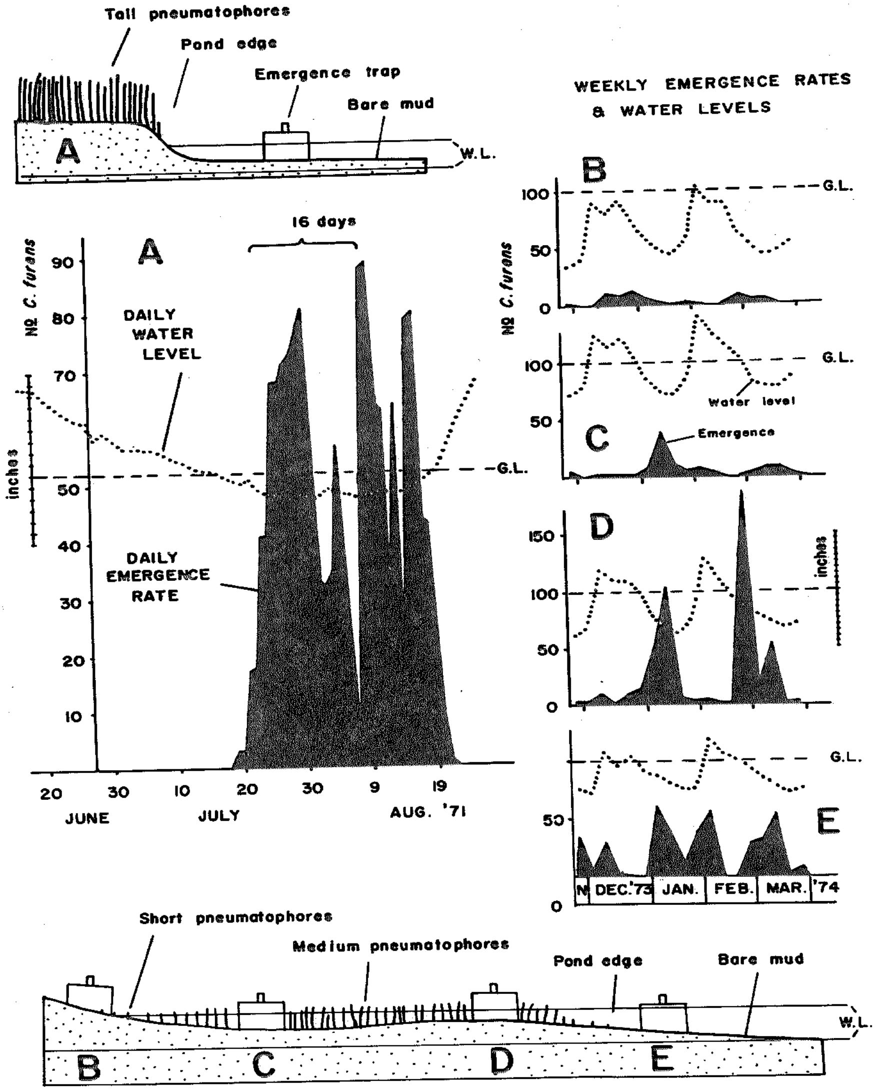

Fig. 5 Emergence rates and water levels in flat habitats A. Daily rates from bare mud in a natural mangrove pool. B.–E. Weekly rates on a transect across pneumatophore zones from beach ridge to the edge of a mangrove pool. (G.L. = Ground level, W.L. = Water Level).

not present in the pneumatophores (which were tall and close packed) but were present in the pool during the period it was flooded.

The peak of emergence on the 13th day shows that most larvae waited 7 to 10 days after mud exposure before pupating. The second peak starting about 16 days after the first could represent the offspring of individuals in the first as the temperature was warm enough for generations of short duration (averaging over 27°C).

Fig. 5, E shows another example of trapping on bare mud at the edge of a pool. A similar picture of emergence closely regulated by water level is apparent. Fig. 5, C and D show the results from two traps sited in fairly flat pneumatophore zones and the picture is again similar except that periods of flooding did not eliminate emergence quite so thoroughly as in bare mud areas. This may be due to a small percentage of larvae successfully pupating against pneumatophores. The pneumatophores here were of medium size and not so closely packed as to obscure the mud surface.

Fig. 5, B shows the results from a trap on a more sloping substrate at the junction of mangrove swamp and beach ridge. A water line was often present near this trap. When other areas were flooded the water level here was a few inches below ground and sand fly production at a peak. When the mud of other areas was exposed giving peaks of emergence, this site became too dry, emergence becoming reduced or absent when the water level dropped more than 8 in. below mud level. In other words emergence in this trap was out of phase with that in all the others. Larvae probably migrated horizontally towards and away from it following water line movements but emergence was never as high as in the other traps indicating a lack of mass movement away from these at times of flooding.

CONCLUSIONS

In mangrove swamp unaffected by daily tidal inundation, most emergence occurs when water level is between ground level and 8 in. below the ground. On a sloping substrate this gives a band of emergence just above the water line. The width of the band varies with angle of slope, being about 3 ft wide at 15°. Water level movements cause the band to move maintaining its position in relation to the water line even when the latter moves over 40 in. in the course of 2 days. However, although the emergence band covers the same area at different water levels, the amount of emergence increases as water levels drop and decreases as they rise. The reasons for this are not clear but the tendency towards more stable conditions at low water levels and the possibility of larvae migrating more readily downwards than upwards may have an influence.

In flat habitats water level is the primary factor affecting the start and end of emergence. A slow rise in water level may stimulate pupation and emergence and could lead to a burst in adult numbers. Sudden flooding, however, even though it may also stimulate pupation and emergence, causes much pupal mortality, and emergence diminishes rapidly with no final burst. Lack of intense emergence on high water lines near previously productive areas indicates that little migration takes place and most larvae must remain submerged and lead an extended larval life until water levels again drop to expose the mud. (The emergence shown in Fig. 5A started after 3 months of continuous flooding.) This, together with the low level of emergence that continues from flooded pneumatophore zones, is important when considering the control of *C. furens* by impoundment (Rogers 1962, Davies 1966b).

When mud becomes exposed, especially after long periods of flooding, there is likely to be a burst of emergence reaching a peak in the second week. Short periods of mud exposure followed by re-flooding are not likely to result in much emergence since most larvae seem to wait 7 to 10 days before pupating. This could be a way of ensuring stable low water level conditions before the bulk of the larval population commits itself to pupation.

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RESPONSE OF *CULEX* SPP. LARVAE AND THEIR NATURAL INSECT PREDATORS TO TWO INOCULATION RATES WITH *DUGESIA DOROTOCEPHALA* (WOODWORTH) IN SHALLOW PONDS

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ABSTRACT. Population densities of mature *Culex* spp. larvae were reduced proportional to numbers of the planarian, *Dugesia dorotocephala* (Woodworth) inoculated in experimental earthen pond ecosystems; whereas the abundance of natural insect predators in these ponds was unaffected. Planaria densities also increased proportional to initial inoculation numbers. A single inoculation at the highest rate, 25 planaria/m^2 of water surface, on July 15, 1975, resulted in a sustained suppression of *Culex* spp. below 0.25 mature larvae/400 ml-dipper sample for 51 days.

The ability of the planarian, *Dugesia dorotocephala*, to suppress natural populations of *Culex* spp. mosquitoes has been demonstrated (Legner and Yu 1975, Legner et al. 1975, Medved and Legner 1974, Yu and Legner 1975). However, the response of mosquito populations to different planaria inoculation rates and the effects such inoculations have on non-target beneficial insect predators was not determined. This study investigated these effects.

Materials and Methods. Studies were performed in 12, 4 x 7-m, 0.36-m deep, earthen ponds at the University of California, Riverside. Ponds were filled on June 23, 1975, to a center depth of ca. 0.36 m, which was maintained during the study.