EFFICACY AND LONGEVITY OF CONTROLLED-RELEASE CHLORPYRIFOS (DURSBAN® 10CR) FOR MOSQUITO CONTROL IN COASTAL DREDGED MATERIAL DISPOSAL SITES[1]

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ABSTRACT. Six diked dredged material disposal areas (7-yr-old) in coastal North Carolina were treated with controlled-release pellets of chlorpyrifos (Dursban® 10CR) at the recommended rate, and the water and underlying soil (dredged material) were analyzed by GLC (gas-liquid chromatography) to determine the chlorpyrifos residue levels at ca. monthly intervals pre- and posttreatment. Residue levels were usually much greater in the soil than in the water. The residue levels were extremely variable and the probable reasons are discussed. Overall, a minimum of 0.7 ppb of chlorpyrifos in the water of the field sites was needed for control of *Aedes taeniorhynchus*. Within 7 months after treatment, the chlorpyrifos residues were generally too low for practical mosquito control. In standardized laboratory bioassays using *Ae. taeniorhynchus* larvae, the LC_{50} and LC_{90} of chlorpyrifos residues in water from dredged material disposal areas were 0.69 and 15.4 ppb, respectively, while the LC_{50} and LC_{90} using technical chlorpyrifos and distilled water were much lower (0.09 and 0.21 ppb, respectively).

INTRODUCTION

The placement of dredged material from coastal waterways and harbors behind retaining dikes results in a cycle of drying and wetting (from rainfall) of the material which is conducive to the production of large numbers of *Aedes* mosquitoes (Ezell 1978, Scotton and Axtell 1979, Vorgetts et al. 1980). Treatment of these disposal sites with a controlled-release pellet formulation of chlorpyrifos (Dursban® 10CR, Dow Chemical Company, USA) is a method of mosquito control being adopted by some mosquito abatement programs.

Dursban® 10 CR has been evaluated as a mosquito larvicide in a variety of habitats. Evans et al. (1975) studied its effectiveness for control of *Aedes triseriatus* (Say) and *Ae. vexans* (Meigen) larvae in woodland pools, while Nelson et al. (1976) examined its ability to control *Psorophora columbiae* Dyar and Knab (= *Ps. confinnis* (Lynch-Arribálzaga)) in a rice culture habitat. Data are limited, however, on the use of Dursban® 10CR for mosquito control on coastal dredged spoil disposal sites. Keenan (1978) evaluated its use for control of several mosquito species in a variety of habitats in southern Maryland but included only one dredge fill pool. Axtell et al. (1979) tested the short-term efficacy of Dursban® 10CR for control of *Ae. taeniorhynchus* (Wiedemann) larvae on coastal dredged spoil sites. Our study was initiated to evaluate the effectiveness and longevity of Dursban® 10CR treatments under operational conditions on coastal dredged material disposal sites.

MATERIALS AND METHODS

TEST SITES. Tests were conducted in 1979 and 1980 on diked dredged material disposal areas Nos. 4 and 8 in Onslow County, and Nos. 18, 19, 20, and 23 in Brunswick County, North Carolina. The

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7-year-old disposal areas are located along the Atlantic Intracoastal Waterway, and periodically receive dredged material removed from the waterway to maintain appropriate water depth. Mosquito larvae, primarily *Ae. taeniorhynchus* and *Ae. sollicitans* (Walker), are produced in pools that form as rainwater accumulates in depressions of dredged material along the inside perimeter of the retaining dike of each disposal area (Scotton and Axtell 1979). Because of their history and potential to produce large mosquito populations, these disposal areas were selected for insecticide treatment.

SAMPLING PROCEDURES. To quantify the chlorpyrifos residues on the disposal sites, one composite water sample and one composite soil (dredged material) sample were taken from each of 4 pools on each dredged material disposal area in Onslow County and from a minimum of 2 pools on each of the 4 disposal areas in Brunswick County. Water and soil samples were taken at random locations within a 10 m radius of a reference stake placed in each pool. Each 3.8 liter water sample was a composite from 10–12 locations using a standard 0.47 liter white enameled dipper, and transferred via funnel to a dark glass jug which was sealed and labelled according to date, pool, and disposal area. A soil sample consisted of 5 sub-samples, each ca. 7×7×2 cm, which were placed into a heavy plastic bag, mixed, and labelled. Samples were returned to the laboratory and placed in cold storage (water 4°C, soil 0°C) until analyzed for chlorpyrifos residues. In Onslow County, water samples were taken once per month from April 11 to November 30, 1979, and monthly soil samples were taken from July 11 to November 30, 1979. In Brunswick County, water samples were taken at least once per month from May 1 to November 11, 1979, and monthly soil samples were taken from July 5 to November 11, 1979. Two water samples and soil samples were taken from each pool on November 11 and November 30 in Brunswick and Onslow Counties, respectively. In 1980, water and soil samples were collected on March 14 in Brunswick County and on March 28 in Onslow County.

Estimations of mosquito production were based on the average of 10 dips taken with a standard white enameled dipper at random locations, equidistant around the edge of each pool.

INSECTICIDE APPLICATION. Test sites in Onslow County and Brunswick County were treated with a controlled release formulation of chlorpyrifos (Dursban® 10CR, Dow Chemical Company: 0,0-diethyl 0-(3,5,6-trichloro-2-pyridyl phosphorothioate), chlorinated polyethylene pellets containing 10.6% active ingredient).

In Onslow County, test pools were treated on July 12, 1979, by personnel from the Department of Entomology, North Carolina State University (NCSU) and the Onslow County Department of Public Works, Division of Mosquito Control. The treated pools and breeding sites had surface areas of ca. 10-1600 m^2 with most ca. 240-670 m^2. After determining the surface areas of the pools and potential breeding sites, the insecticide pellets were applied with a hand-operated cyclone spreader at the rate of 4 lb/acre (9.69 kg/ha). It was not practical to calculate application rates by water volume because some areas had only shallow, temporary accumulations of water, while other areas were dry at the time of treatment.

Dredged material disposal areas in Brunswick County were treated by personnel from the Brunswick County Department of Public Works, Division of Mosquito Control. These personnel were familiar with the history of flooding and mosquito production in these areas and were able to make crude estimates of the size of the mosquito breeding areas and the potential water depths. Label recommendations for application rates of Dursban 10CR were followed to the extent possible. Since most insecticide applications were made while the areas were dry, it was not possible to calculate the actual rates of application by water volume. Application rates by surface area were at least 4 lb pellets/acre (9.69 kg/ha) Higher rates were used in those areas where water depths of greater than 2.5 cm were anticipated. All of the disposal areas were treated on May 8, 1979. Sites that had dried on disposal areas Nos. 18 and 23 were treated a second time on August 24, while dry sites on disposal areas Nos. 19 and 20 were treated again on August 23.

RESIDUE ANALYSIS. Chlorpyrifos residues in water samples and soil samples were analyzed at the Pesticide Residue Research Laboratory, N.C.S.U., Raleigh, N.C. Water samples were removed from cold storage, a 500 ml aliquot from each sample tared into a 950 ml glass jar and 2 ml concentrated HC1 and 200 ml hexane added to each jar. The jars were sealed with teflon, capped, and shaken for 30 minutes. The hexane layer was pulled off, filtered through anhydrous sodium sulfate, and flash evaporated under vacuum at 30°C to 1 to 2 ml volume. Ethyl acetate was used as a diluent for GLC analysis. Percent recovery of chlorpyrifos was determined by adding known amounts of the chemical to 500 ml aliquots of distilled water containing 0.5% NaC1 and analyzing by the same procedures as the field water samples.

Soil samples were removed from cold storage, 50 g moist soil from each sample tared into a 950 ml glass jar and 200 ml distilled water containing 0.5% NaC1 added to the soil. The water and soil were stirred to form a slurry. Two ml concentrated HC1 and 200 ml hexane were added to each jar. The jars were sealed with teflon, capped, and shaken for 30 minutes. The hexane layer was pulled off, filtered through anhydrous sodium sulfate, and flash evaporated at 30°C under vacuum to 1 to 2 ml volume. Ethyl acetate was used as a diluent for GLC analysis. Dry weights and moisture content were determined for each sample by weighing, drying, and reweighing aliquots of soil. Percent recovery of chlorpyrifos was determined by adding known amounts of the chemical to 50 g aliquots of untreated soil from dredged material disposal area No. 12, Brunswick Co., and analyzing by the same procedures as the other samples.

Gas-liquid chromatographic (GLC) analysis was used to identify and quantitate the residual levels of chlorpyrifos in the water and soil samples. The analyses were performed using a flame photometric detector operated in the P mode. A 183 by 0.64 cm i.d. U-shaped glass column packed with 4% SE-30+ 6% QF1 on Gas Chrom Q (80/100). Temperature (°C): column, 190; detector, 220; inlet, 205. Flow rates: carrier; N_2, 120 ml/min; detector; H_2,50 ml/min; Air, 80 ml/min. Chlorpyrifos residue levels in soil and water samples were determined against standards of known concentrations using the peak height method. The percent recovery of chlorpyrifos residues in both water and soil samples averaged greater than 90%.

BIOASSAY AND LC_{50} DETERMINATION. The toxicities of the chlorpyrifos residues in the water samples were determined by bioassays using 1-day-old mosquito larvae from a laboratory culture of *Ae. taeniorhynchus*. The culture was established from pupae collected on May 29, 1979 from pools on disposal sites Nos. 4 and 8 in Onslow Co., N.C. Bioassays were conducted within 24 hr after GLC analysis of chlorpyrifos residues in water collected from 9 pools on March 14, 1980 in Brunswick Co., and 8 pools on March 28, 1980 in Onslow Co. Twenty-five mosquito larvae and 40 mg ground dog chow were added to a 200 ml aliquot of water (in a 250 ml glass beaker) from each pool. There were 3 replicates per test pool and for distilled water controls. Percent mortality was determined after 72 hr at 25°C. Mortalities in the test pool samples were corrected for mortalities in the controls by Abbott's formula.

A dosage-response test was conducted using 1-day-old *Ae. taeniorhynchus* larvae from the laboratory culture. The following ppb concentrations of chlorpyrifos were prepared in distilled water using technical grade chlorpyrifos (Chem Service, West Chester, Pa., PS-674, 98.6% purity): 0.35, 0.2, 0.1, 0.08, and 0.05. Twenty-five mosquito larvae and 40 mg ground dog chow were added to 200 ml distilled water (in 250 ml glass beakers) at each treatment level and untreated control. There were 3 replicates per treatment and control. Percent mortality was determined after 72 hr at 25°C. Mortalities in the treated samples were corrected for mortalities in the untreated controls by Abbott's formula. The data from the bioassay and dosage-response test were plotted using probit transformations of the mortalities and $\log_{10}$ transformation of the concentrations. The LC_{50} and LC_{90} values for chlorpyrifos residues and technical grade chlorpyrifos were determined according to the methods of Litchfield and Wilcoxon (1949).

RESULTS

The mean levels of chlorpyrifos in water and soil samples and observations of mosquito production from dredged material disposal areas Nos. 4 and 8 in Onslow County, N.C. are shown in Table 1. Since both disposal areas were treated with chlorpyrifos in mid-July of 1978 by the U.S. Army Corps of Engineers, presumably at the recommended rate, the mean chlorpyrifos residues in the April 11 and May 29, 1979, water samples were the amounts at ca. 9 months after treat-

Table 1. Mean levels of chlorpyrifos in water and soil samples, and observations of mosquito production (*Aedes taeniorhynchus*) from dredged material disposal areas 4 and 8, Onslow County, N.C., 1979–80 after treatment with Dursban 10CR, N/S indicates that samples were not taken.

Date		Water[a] (ppb)	Soil[a] (ppb)	Soil:Water residue ratio	Mean no. mosquito larvae per dip[b]
		Dredge Disposal Area No. 4			
Apr	11	0.05	N/S	—	0
May	29	0.25	N/S	—	2.0 (all 4 pools)
June	19	Dry	N/S	—	Dry
Jul	11	Dry	50.0	—	Dry
Jul	12	—Area treated with Dursban 10CR			
Aug	07	0.90	80.0	89	0
Sept	10	0.19	57.5	305	4.0 (1 of 4 pools)
Oct	08	0.57	32.5	57	0
Nov	30	0.38	77.5	204	0.1 (1 of 4 pools)
March	28	<0.17	4.3	25	1.0 (all pools)
		Dredge Disposal Area No. 8			
Apr	11	0.08	N/S	—	0
May	29	0.43	N/S	—	2.0 (1 of 2 pools)
Jun	19	Dry	N/S	—	Dry
Jul	11	Dry	212.5	—	Dry
Jul	12	—Area treated with Dursban 10CR			
Aug	07	Dry	167.5	—	Dry
Sept	10	0.26	727.5	2798	4.5 (2 of 4 pools)
Oct	08	0.80	180.0	225	0
Nov	30	0.96	341.4	356	0
Mar	28	0.77	29.2	38	4.0 (1 of 4 pools)

[a] Mean based on samples from 4 pools on each disposal area.
[b] Mean based on 10 dips per pool when water present.

ment. The May 29 residues were greater than those of April 11, because much of the water in the pools had evaporated by the end of May, thus apparently concentrating the chlorpyrifos.

On disposal area No. 4, the greatest chlorpyrifos level detected was 0.90 ppb (August), ca. 4 weeks after insecticide application. Two months after treatment, the mean level of chlorpyrifos in water samples decreased significantly due, in part, to flooding caused by Hurricane David, which occurred the first week of September. Three months after treatment, the levels of chlorpyrifos were higher (0.57 ppb) but declined in the fourth month post-treatment and were only <0.17 ppb in March (7 months post-treatment).

Mean levels of chlorpyrifos in soil samples from disposal area No. 4 were ca. 25 to 305 times higher than those in the water samples. The mean level of chlorpyrifos in soil samples increased after treatment but decreased the following 2 months. Interestingly, during this period the levels of chlorpyrifos in water samples increased. The level of chlorpyrifos in the November 30 soil sample increased, however, to nearly that in the first posttreatment soil sample. Eight months after treatment with chlorpyrifos, the mean residue in soil samples was only 4.3 ppb. There were only 2 broods of mosquitoes (*Ae. taeniorhynchus*) during the 1979 season on disposal area No. 4. The first brood was small and occurred on May 29 before chlorpyrifos was applied. The second brood occurred on September 10 after the flooding by Hurricane David, when the levels of chlorpyrifos in water samples were apparently diluted. *Aedes taeniorhynchus* larvae and pupae were observed the following spring in all pools.

On disposal area No. 8, the mean levels of chlorpyrifos in pretreatment water samples were generally lower than the levels in the posttreatment samples, with the exception of the September 10 water sample. Mean chlorpyrifos residues in the November 30 and March 28 water samples remained high, in contrast to a decreasing level of chlorpyrifos residues in respective water samples from disposal area No. 4.

The mean levels of chlorpyrifos in soil samples from disposal area No. 8 fluctuated throughout the 1979–80 season. As on area No. 4, the chlorpyrifos residues decreased in October, one month after flooding by Hurricane David, increased in November and decreased to their lowest amount 4 months later in March. The chlorpyrifos residues in the soil samples from disposal area No. 8 were ca. 2-12× greater than those from disposal area No. 4. Also, while the highest chlorpyrifos residues on area No. 4 were detected on August 7, the highest residues on No. 8 were found ca. one month later on September 10.

There were 2 broods of mosquitoes (*Ae. taeniorhynchus*) on disposal area No. 8 during the 1979 season. The first was observed on May 29 in one of 2 pools, and the second was observed in 2 of 4 test pools on September 10. The following spring, *Ae. taeniorhynchus* populations averaged ca. 4.0 pupae and fourth-instar larvae per dip in one of 4 pools.

The mean levels of chlorpyrifos in water and soil samples, and observations of mosquito production from disposal areas in Brunswick County are shown in Table 2. These areas received at least one chlorpyrifos treatment at the recommended rate in June or July of 1978 by personnel from the Division of Mosquito Control, Brunswick County Department of Public Works. Thus, the chlorpyrifos residues in the water samples collected on May 1, 1979, from areas Nos. 19, 20 and 23 were the amounts remaining ca. 9 months after treatments.

On disposal area No. 18, the mean level of chlorpyrifos in water samples was high following the initial insecticide treatment on May 8, 1979, and decreased the next month. The mean level of chlorpyrifos in the September 12 water samples following the second insecticide treatment was further reduced, possibly due to exten-

Table 2. Mean levels of chlorpyrifos in water and soil samples, and observations of mosquito production from dredged material disposal areas Nos. 18, 19, 20 and 23, Brunswick County, NC, 1979–80 after treatments with Dursban 10CR. N/S indicates that samples were not taken.

Date		Water[a] (ppb)	Soil[a] (ppb)	Soil:Water residue ratio	Mean no. mosquito larvae per dip[b]
		Dredge Disposal Area No. 18			
May	01	Dry	N/S	—	Dry
May	08	—Area treated with Dursban 10CR			
May	23	4.92	N/S	—	0
Jun	05	1.91	N/S	—	0
Jul	05	Dry	130.0	—	Dry
Aug	24	—Area treated with Dursban 10CR			
Sept	12	0.59	20.0	34	0
Oct	10	Dry	75.0	—	Dry
Nov	11	Dry	25.0	—	Dry
Mar	14	<0.23	2.7	12	1.0
		Dredge Disposal Area No. 19			
May	01	0.50	N/S	—	0
May	08	—Area treated with Dursban 10CR			
May	23	7.22	N/S	—	Many
June	05	0.24	N/S	—	0
Jul	05	Dry	25.0	—	Dry
Aug	23	—Area treated with Dursban 10CR			
Sept	12	0.78	65.0	83	21.0
Oct	10	0.48	90.0	187	0
Nov	11	Dry	30.0	—	Dry
Mar	14	<0.11	16.8	153	1.0
		Dredge Disposal Area No. 20			
May	01	0.07	N/S	—	2.0
May	08	—Area treated with Dursban 10CR			
May	23	9.78	N/S	—	0
Jun	05	0.30	N/S	—	0
Jul	05	0.19	10.0	53	0
Aug	23	—Area treated with Dursban 10CR			
Sept	12	0.70	80.0	114	3.0
Oct	10	1.12	30.0	27	0
Nov	11	1.05	60.0	57	0
Mar	14	1.30	1.7	1	3.3
		Dredge Disposal Area No. 23			
May	01	0.07	N/S	—	2.0
May	08	—Area treated with Dursban 10CR			
May	23	8.80	N/S	—	0
Jun	05	0.50	N/S	—	0
Jul	05	0.20	20.0	1	0
Aug	24	—Area treated with Dursban 10CR			
Sept	12	0.57	50.0	88	0
Oct	10	0.64	50.0	78	0
Nov	11	0.67	102.5	153	0
Mar	14	0.22	27.6	125	0

[a] Mean based on samples from 2 or 3 pools on each disposal area.
[b] Mean based on local mosquito abatement personnel records of dipping counts.

sive flooding, while the lowest mean chlorpyrifos level was detected in water samples taken the following spring. Chlorpyrifos residues in soil samples fluctuated, but generally decreased with time. They were highest on July 5, 1979, and lowest in the soil samples taken on March 14, 1980. There was no mosquito production observed on disposal area No. 18 during 1979, but on March 14, 1980, mosquito production was observed.

On disposal area No. 19, mean levels of chlorpyrifos in water samples increased following the initial insecticide treatment on May 8, 1979. Within 2 weeks the level of chlorpyrifos in the water decreased significantly. Following a second application of Dursban 10CR on August 23, the mean level of chlorpyrifos increased slightly on September 12, and then declined on October 10. Approximately 7 months after the second chlorpyrifos application, the mean chlorpyrifos residue was very low. Mean chlorpyrifos residues in soil samples were much higher than those in the water samples and fluctuated throughout the season.

Two broods of mosquito were produced during the 1979 season on disposal area No. 19. On May 23, a large population of adult mosquitoes had recently emerged and were resting in the vegetation (*Spartina patens* (Ait.) Muhl.) at the edges of the pools. Many pupal exuviae were observed in the water. A second brood was observed on September 12, and was composed of *Ae. sollicitans* and *Ae. taeniorhynchus* larvae. This brood was within 3 weeks of insecticide treatment, but the mean level of chlorpyrifos in the water samples was much lower than that in the May 23 water samples following the first treatment of the season.

The mean chlorpyrifos residues in the water samples from disposal area No. 20 increased following the initial insecticide application on May 8. Mean levels of chlorpyrifos in water samples successively decreased the next 2 months, but following the second chlorpyrifos application on August 23, 1979, mean chlorpyrifos levels increased and remained relatively high on all sampling dates through March 14, 1980. In contrast to the consistently high mean chlorpyrifos residues in water samples, the mean chlorpyrifos residue in soil samples taken March 14, 1980, was much lower than those of the preceding posttreatment sampling dates. Mosquito larvae were observed on May 1 prior to insecticide treatment, and *Ae. sollicitans* and *Ae. taeniorhynchus* larvae were observed on September 12 following the second insecticide treatment on August 23 and extensive flooding the first week of September. Mosquito production was also observed the following spring.

The mean levels of chlorpyrifos in water and soil samples from disposal area No. 23 followed a trend similar to those from disposal area No. 20. Mean chlorpyrifos residues increased following the first application of Dursban 10CR, and subsequently declined the next 2 months. After the second insecticide treatment mean chlorpyrifos residues increased and remained high for 3 months, although not as high as the May 23 levels. Mean levels of chlorpyrifos in soil samples were highest on November 11, 3 months after the second insecticide treatment and lowest 4 months later. The only observation of mosquito production on disposal area No. 23 was recorded prior to insecticide treatment on May 1, 1979, when the mean level of chlorpyrifos in the water samples was very low.

The mortalities of *Aedes taeniorhynchus* larvae vs. the concentration of chlorpyrifos residues in water samples from the treated diked dredged material disposal areas are shown in Figure 1. The chlorpyrifos LC_{50} and LC_{90} values for *Ae. taeniorhynchus* were 0.69 ppb (95% confidence limits = 0.39 to 1.20) and 15.4 ppb, respectively. There was too much variation in data to calculate meaningful 95% confidence limits for the LC_{90} value. Only 4 of the 17 water samples tested contained levels of chlorpyrifos yielding greater than 50% mortality of *Ae. taeniorhynchus* test larvae, and only one

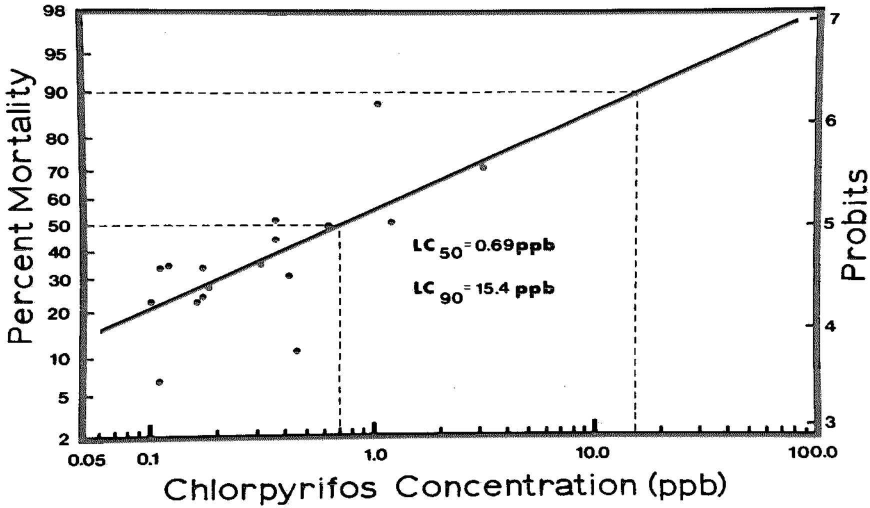

Fig. 1. Mortalities of *Aedes taeniorhynchus* larvae in water samples taken from diked dredged material disposal areas in Brunswick (March 14, 1980) and Onslow (March 28, 1980) counties, N.C. and containing various concentrations of chlorpyrifos residues as a result of previous treatment with Dursban 10CR.

sample gave near 90% mortality (Area 8, Pool C, Onslow Co., 1.04 ppb chlorpyrifos). These mortality data of *Ae. taeniorhynchus* in water samples taken at least 7 months following Dursban 10CR application and observations of mosquito production at the corresponding sample date (Tables 1 and 2) indicate that the chlorpyrifos residues were not adequate for mosquito control at these sites.

The LC_{50} and LC_{90} values for *Ae. taeniorhynchus* obtained using technical chlorpyrifos in distilled water were 0.09 ppb (95% confidence limits = 0.06 to 0.12) and 0.21 ppb (95% confidence limits = 0.11 to 0.40), respectively. These values were much lower than those of the bioassay using chlorpyrifos-containing water from the field sites treated with Dursban 10CR.

It appears that chlorpyrifos concentrations greater than ca. 0.7 ppb were required for control of mosquito larvae under the 1979–80 field conditions as indicated by the chlorpyrifos residue LC_{50} value (0.69 ppb) and a mean level of chlorpyrifos residues of 0.39 ppb (S.E. = 0.12, N = 26) in water samples from pools where positive observations of mosquito production were made.

DISCUSSION

The treatment of dredged material disposal areas with Dursban® 10CR for mosquito management resulted in tremendous variation in chlorpyrifos concentrations in water samples from different pools on a single area as well as from different areas. This was true of both the applications made by us and the applications made routinely by the local mosquito abatement personnel following label recommendations. Rawn et al. (1978) suggested that after the release of chlorpyrifos, the amount of active ingredient remaining in the water was dependent on the type of substrate. They found that sand-lined pools maintained higher chlorpyrifos concentrations in the water than either clay or sod-lined pools when treated at the same rate. Chapman and Harris (1980) found that chlorpyrifos residues were more persistent in muck (organic) soils than in sandy (mineral) soils. Dredged material can be highly variable in its texture. Ezell (1978) reported that sand ranged from 2.2 to 81.4%, silt ranged from 7.0 to 52.1%, and clay ranged from 11.6 to 55.6% in comprising the surface material of several disposal areas in coastal South Carolina. The greater chlorpyrifos residues detected in soil samples from disposal area No. 8 than on area No. 4 (Table 1) may be due to the higher clay content of the dredged spoil material on area No. 8 absorbing more chlorpyrifos than the more sandy, dredged spoil material on area No. 4. Thus from an operational standpoint, the differential adsorbtive capacities of various soils for chlorpyrifos may affect the efficacy of Dursban® 10CR and, as a consequence, may require the application rates to be altered.

The type and amount of vegetation on a disposal area may also have an effect on the persistence and efficacy of Dursban® 10CR treatment. As dredge spoil areas mature, various plant species colonize the area and form distinct vegetative zones (Scotton and Axtell 1979). Relatively large, mosquito-breeding indicator plant species such as *Spartina cynosuroides* (L.) Roth, *S. alterniflora* Loisel., and *Phragmites communis* Trin. (see Ezell 1978), while their size may make the application of the insecticide at a uniform rate difficult, may increase the longevity and effectiveness of chlorpyrifos by shading the water and inhibiting photodecomposition of the chlorpyrifos. Miller et al. (1973) reported that pools shaded from sunlight had higher chlorpyrifos residues than those pools exposed directly to the sun. Vegetation may, however, act as soil particles do and play a role in adsorbing chlorpyrifos from the water. Smith et al. (1966) reported that ca. 70% of the chlorpyrifos in his tests was adsorbed by both plants and soil within 8 hr after application.

The LC_{50} for *Ae. taeniorhynchus* (0.69 ppb) of chlorpyrifos residues in our water samples from the dredged material treated with Dursban 10CR is close to that reported by Nelson et al. (1976). They reported an average mortality of 58% for *Ps. columbiae* when the average chlorpyrifos residues recovered from test plot water was 0.6 ppb. However, the LC_{50} of technical chlorpyrifos in distilled water for *Ae. taeniorhynchus* in our tests was much lower (0.09 ppb) and close to the LD_{50} of less than 0.1 ppb for field-collected *Aedes* larvae reported by Tawfik and Gooding (1970). The difference between the LC_{50} for chlorpyrifos residues in the water from the field sites and the LC_{50} for technical chlorpyrifos in our study was probably due to the adsorption of chlorpyrifos to suspended particulate matter in the water samples from the disposal areas, and thus not being biologically active. This hypothesis is supported by the results of Hurlbert et al. (1970) who found that unfiltered water had chlorpyrifos residues twice as great as those in water which was filtered through sharkskin filter paper.

From an operational standpoint, an important factor influencing the efficacy of Dursban® 10CR for mosquito control on coastal dredge spoil disposal areas is the degree and frequency of flooding. For example, the unexpected flooding caused by Hurricane David in early September, 1979 undoubtedly lowered the chlorpyrifos concentrations in many pools on the disposal areas. Furthermore, miscalculation and underestimation of the total water volume when treating an area can result in low, ineffective chlorpyrifos concentrations as pointed out by Evans et al. (1975). It should be noted though, that while Dursban® 10CR was applied at the recommended rate, concentrations equal to 1.5 ppm as stated on the label were not attained in any of the water samples. Nelson et al. (1976) also detected lower chlorpyrifos residues than those one would theoretically expect from the application rates.

SUMMARY AND CONCLUSIONS

Residue levels of chlorpyrifos in water samples, observations of mosquito production, and bioassays of *Ae. taeniorhynchus* indicate that a minimum chlorpyrifos concentration of 0.7 ppb was needed for mosquito control on diked dredged material disposal areas. Dursban® 10CR treatment of these areas following label recommendations resulted in tremendous variation in chlorpyrifos concentrations in water and soil samples from different pools on the same disposal area and different disposal areas. When operationally treated at the recommended rate, soil samples usually contained much more chlorpyrifos than did the water samples. In general, the chlorpyrifos residues (based on soil and water samples) decreased to relatively small amounts within 7 months following its application. Observations of mosquito production, levels of chlorpyrifos residues in water samples, and bioassays indicated that chlorpyrifos residues in the water 7 months following application were not adequate for mosquito control at these sites. These data indicate that the variation in the levels of chlorpyrifos detected in water and soil samples from different sample sites following an operational application of Dursban® 10CR may be due to the degree and frequency of flooding, soil and water conditions (especially the nature and amount of suspended particulate material), and operational conditions that make it difficult or impractical to apply the insecticide uniformly at the recommended rate.

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