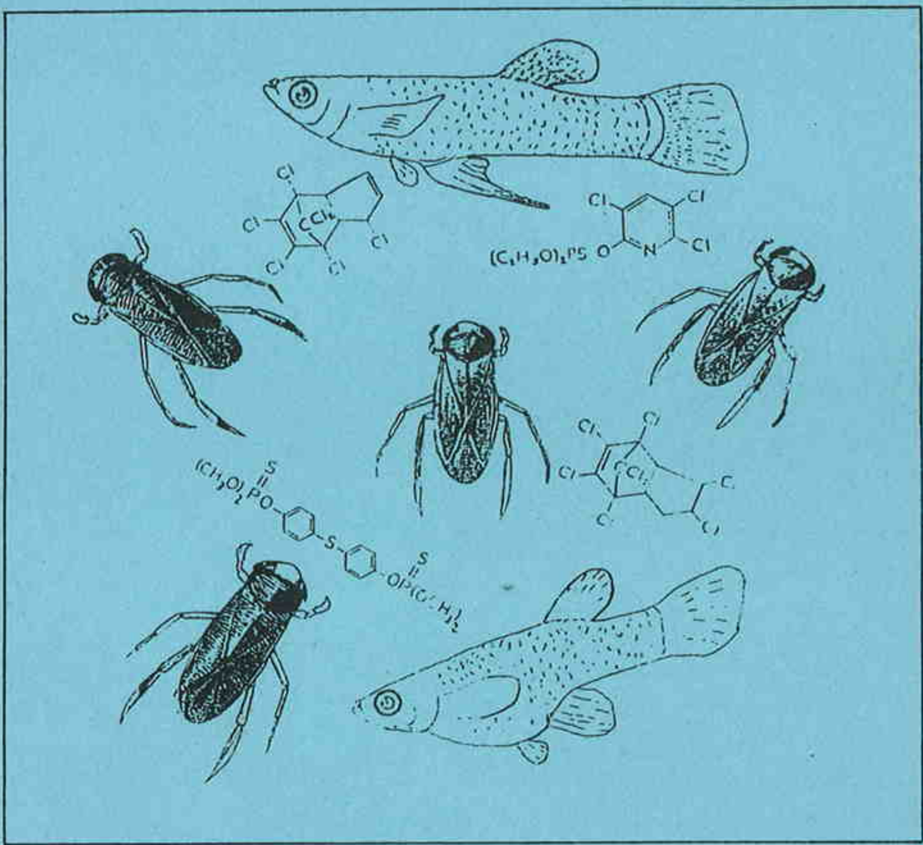
HERDSMAN LAKE PESTICIDE STUDY

- an investigation of the environmental effects of spraying to control the Argentine ant (***Iridomyrmex humilis***) at Herdsman Lake, Western Australia, in March/April 1986 .



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All pesticide analyses were carried out by the Government Chemical Laboratories. The study was coordinated by the Department of Conservation and Land Management and supported by funding from the State Planning Commission and the Department of Agriculture. Laboratory and computing facilities were provided by Murdoch University.

SUMMARY

1. The Department of Agriculture's programme to control Argentine ants in Western Australia commenced in 1954 with the extensive use of dieldrin. Dieldrin was replaced by heptachlor in 1970. The perimeter of Herdsman Lake has been sprayed for ant control every year since the mid-1950s except during 1984/85. Spraying was not carried out in 1984/85 due to the public concern expressed at the threat to wildlife posed by spraying at the lake. A spraying programme recommenced at the lake in 1986. A 40 ha area on the northeastern edge of the lake was sprayed with two organophosphates; temephos (Abate) and chlorpyrifos (Dursban), and the organochlorine, heptachlor (the 0.5% heptachlor solution contained approximately 9% chlordane), in the period 21 March to 11 April 1986.

   Temephos and chlorpyrifos are relatively non persistent compounds of low toxicity. Heptachlor and chlordane are highly toxic and persistent pesticides. The metabolism of heptachlor results in the formation of heptachlor epoxide, a toxic compound which can undergo bioaccumulation in animal tissues.

2. A sampling programme was carried out to establish the level of various organochlorines and organophosphates in the water, sediments of the lake bed and two members of the aquatic fauna; the mosquitofish, <u>Gambusia affinis</u> and the corixid <u>Micronecta robusta</u>. Samples were taken prior to spraying, one week after spraying and after the first heavy rains following spraying. Six sampling sites were selected in the shallow areas of the lake adjacent to the land to be sprayed and two control sites were selected in a separate waterbody (the Floreat Waters lagoon) on the southwestern edge of the lake. A semi-quantitative sampling method was used to assess changes in abundance of aquatic invertebrates following spraying.

3. All pesticide analyses were carried out by the Government Chemical Laboratories.

Four organochlorine pesticides were detected in the surface waters and sediments of the lake: dieldrin, DDT, heptachlor and chlordane. Two of the pesticides, DDT and dieldrin, were not applied during the March/April spraying programme, suggesting that the compounds have persisted from past spraying programmes carried out at the lake (prior to 1970), or from other sprayings, for example, termite control, carried out within the catchments of the drains that enter the lake.

4. Levels of DDT were very low but levels of dieldrin in the lake waters exceeded the recommended safe level (0.003 µg/L) at all sites and on all sampling occasions. Levels of dieldrin did not change significantly between the three sampling occasions, supporting the suggestion that the compound was a residue from previous sprayings.

5. DDT and dieldrin were present in the tissues of both the mosquitofish (Gambusia affinis) and the insects (Micronecta robusta) in nearly all samples analysed and may be attributed to previous spraying at the lake. The high levels of dieldrin recorded in some mosquitofish samples suggest that bioaccumulation of this pesticide is occurring in the lake's aquatic fauna.

6. Levels of chlordane and heptachlor in the water samples were low at all sites before spraying but increased significantly, and exceeded the recommended safe levels for aquatic life (0.004 µg/L and 0.001 µg/L, respectively), at the treatment sites after spraying (in both the post spray and post rain samples). In addition, levels of heptachlor were slightly above recommended levels at the two control sites after heavy rain. Whether this was due to circulation of water within the lake or additional

spraying (e.g. for termites by persons or agencies unknown) near the control sites is not known.

7. High levels of chlordane in the lake sediments at all sites before and after spraying indicate that chlordane is persisting from previous spraying programmes (prior to 1984). Levels of heptachlor in the sediments were generally low at all sites except the samples taken from the treatment sites after heavy rain. The presence of chlordane residues, but not heptachlor residues, prior to spraying, may be explained by the findings of previous studies, which suggest that chlordane has a persistence of five years, whilst that of heptachlor is two years.

8. The presence of chlordane and heptachlor in post-spray fish samples must be attributed to the 1986 spraying programme. The compounds were below the limits of detection in pre spray samples, but significant increases were recorded in post spray samples taken from treatment sites. The high levels recorded in the mosquitofish suggest some bioaccumulation and the possible development of a physiological resistance to these organochlorines.

9. A statistically significant increase in levels of chlorpyrifos occurred in samples of water and sediments taken from the treatment sites after spraying. Levels did not exceed the recommended permissible level for the organophosphates (10 µg/L, McEwen and Stephenson (1979)) but they may have exceeded the EPA criterion (EPA 1981) for invertebrates of 0.01 of the LC_{50} (96 hour).

Chlorpyrifos was not detected in the tissues of the fish (Gambusia affinis) which supports the view that it does not undergo bioaccumulation in the food chain.

10. Levels of temephos were below the limits of detection in all samples.

11. Difficulties in collecting sufficient insect material for analysis after spraying meant that levels of pesticides in insect tissue could not be adequately measured. However, ANOVA results indicate that a significant reduction occurred in corixid numbers, at treatment sites, after spraying, whilst the abundance of corixids at the control sites did not change. Levels of chlordane, heptachlor and chlorpyrifos accounted for a large percentage of the variation in corixid abundance (significant at the 0.05 level). Heptachlor and chlordane accounted for most of the variation. Chlorpyrifos alone did not adequately account for the decrease in abundance. However, chlorpyrifos has been shown to cause little or no mortality in corixids at concentrations sufficient to control mosquito larvae.

12. Increases in the levels of chlordane, heptachlor and chlorpyrifos in the water samples collected after heavy rain suggest that surface runoff or leaching through the adjoining sandy soils, plays an important part in the transport of pesticides into the lake. High levels of chlordane and heptachlor in the post spray and post rain samples of water and fish collected at Site I, compared to those recorded at other sites, may be explained by the fact that this site was located at the entrance of a major drain. The extensive drainage system which delivers stormwater to the lake appears to facilitate pesticide transport into the lake.

13. Because Herdsman Lake is valued as an area for wildlife conservation, the presence of organochlorines in the surface waters and sediments of the lake should be regarded as a source of concern.

Alternative means of Argentine ant control should be considered. Sources of pesticides, in additon to the Argentine ant control programme, need to be identified and an ongoing monitoring programme established for the measurement of pesticide levels both within the lake and in the adjoining drains.

High levels of organochlorines in fish may also pose a problem to the waterfowl which feed upon them. The occurrence and extent of bioaccumulation of organochlorines within the lake's fish and bird populations should also be determined.

Introduction

Herdsman Lake is a large, shallow wetland located 6 km northwest of the central business district of Perth. The wetland area includes approximately 300 ha of public open space zoned for use as parks and for recreation. Light industrial developments and residential areas adjoin the wetland area and the lake has had a long history of human disturbance.

The clearing of sections of the lake vegetation for agriculture in the 1930s, together with frequent summer fires and changes in the water regime, appear to have promoted the growth of the bulrush, *Typha orientalis* at the expense of other wetland species (ESRI, 1983) and large areas of the lake now comprise dense stands of *Typha*. Recent dredging has produced two regions of deeper water; the Floreat Waters lagoon and the Herdsman Industrial Park lake.

Despite many and varied human influences the lake still supports a diverse bird community. Over 100 species have been observed at the lake, of which 39 species breed there intermittently (ESRI, 1983). The lake is important both for wildlife conservation and as an area of open space within the urban environment. It is to be declared a regional park for the protection of flora and fauna, and compatible recreation, early in 1988. The lake also forms an important component of the urban drainage system and now receives much of its water through regional and local drains.

The Western Australian Department of Agriculture has conducted a spraying programme for the control of the Argentine ant (*Iridomyrmex humilus*) at Herdsman Lake every year since 1955 except during 1984/85. Dieldrin was the major pesticide used in the years 1955 to 1969 but was replaced by heptachlor in 1970. Spraying was not carried out at the lake in 1984/85 due to the public concern expressed at the threat the pesticides posed to wildlife.

The occurrence of ant infestations in houses adjoining the lake during 1985 prompted recommencement of the spraying programme in 1986. A 40 ha area on the northeastern edge of the lake was sprayed with two organophosphates; temephos (Abate) and chlorpyrifos; and the organochlorine, heptachlor (the 0.05% solution of heptachlor contained approximately 9% chlordane) between the period 21 March to 11 April 1986. Temephos and chlorpyrifos are relatively non-persistent compounds of low toxicity, although they have been shown to affect non-target invertebrates (McEwen and Stephenson, 1979).

Heptachlor, however, is a highly toxic and persistent pesticide. Considerable concern has been expressed over the use of heptachlor and its active constituent, chlordane. The Advisory Committee on Pesticides in Great Britain recommended in 1969 that the use of heptachlor should be kept to a minimum because of the hazards to wildlife associated with its use. The use of heptachlor was banned in Canada in 1968 due to concern over the occurrence of heptachlor epoxide residues in milk and the possible effects on birds (McEwen and Stephenson, 1979). The U.S. Environmental Protection Agency has cancelled all agricultural uses of heptachlor and chlordane and restricted their use mainly to termite control (PAN, 1985).

The major objective of this study was to assess the environmental effects of the 1986 Argentine ant spraying programme at Herdsman Lake. The specific aims of the study were:

1. To establish the level of various organochlorines and organophosphates in the water. sediments of the lake bed, and in two groups of aquatic organisms of different trophic levels, in the shallow areas of the lake adjacent to the land to be sprayed.

2. To assess whether any changes in the levels of pesticides occur one week after the spraying, or subsequently following heavy rain.

3. To provide a qualitative assessment of any changes in total abundance of aquatic invertebrates following spraying.

<u>Methods</u>

Description of sampling sites

The locations of the eight sites at which water, sediment and faunal samples were collected are given in Fig. 1. Sites 1-6, on the northeastern edge of the lake, were situated adjacent to the area treated with pesticide, whilst the two control sites (7 and 8) were situated adjacent to non-treated areas on the western and southern edges of the lake. The treated and control sites were on different waterbodies; Herdsman Industrial Park Lake and the Floreat Waters Lagoon. respectively. At the time of the pesticide treatment (March and April 1986), water levels were low and it is unlikely that the two water bodies were directly connected. They may, however, represent a continuous body of water when water levels rise during winter. Sites 2-5 and 8 were classified as "bare littoral" sites being in areas of open wetland with little fringing vegetation. Sites 1, 6 and 7 were adjacent to dense stands of the bulrush. *Typha orientalis*, and classified as "Typha" sites.

The Department of Agriculture employed different spraying methods within the two areas. A grid method was used within the bare littoral regions, whilst more intensive spraying was undertaken within the stands of *Typha*. The locations of the areas treated with pesticide are given in Fig. 1. Specific details relating to the volumes of pesticides used and areas treated are given below (P. Davis, pers. comm.).

Chemical	Total volume(L)	Area treated (ha)	Rate (L/ha)	Kgai/ha
0.5% heptachlor	38,880	35.5	1095.2	5.5
1.0% chlorpyrifos	3,240	3	1080.0	10.8
5% temephos (granules)	40 kg			

The corixid, *Micronecta robusta* and the mosquitofish, *Gambusia affinis* were the two species chosen for pesticide analysis primarily because preliminary sampling had revealed that they were the most common and abundant members of the invertebrate and fish fauna, respectively, at the lake. Analyses of the gut contents of a small sample of each species revealed that the corixids could be classed as detritivores (feeding primarily on decomposing organic matter), whilst the mosquitofish were predators. Chironomid larvae (nonbiting midges) appeared to be the major prey item of the mosquitofish.

Initially only four treatment sites were selected for sampling; however, difficulties experienced with the collection of sufficient corixid material at two sites (3 and 4) resulted in the addition of a further two sites (5 and 6) to the sampling programme.

Sampling frequency

The sites were sampled on three separate occasions: before the start of the spraying programme (pre-spraying), one week after the completion of spraying (post-spray), and approximately one week after the first heavy rains (six weeks after spraying (post-rain). The spraying programme undertaken by the Department of Agriculture took place during the period 21 March to 11 April 1986. The pre-spray sampling was carried out on 17 and 18 March 1986, and the post-spray sampling on 14 and 15 April 1986. The final sampling session was undertaken on 29 May 1986 approximately one week after the onset of the winter rains.

Sampling methods

One two-litre water sample was collected at approximately mid-depth at each site and stored in glass containers prior to analysis. Samples of lake sediments were collected using a 10 cm diameter stainless steel corer. One core sample, 10 cm in diameter and 4 cm deep, was collected at each site. Samples were stored in glass containers prior to analysis.

Faunal samples were collected with a longhandled sweep net. The net was swept vigorously through the water for a known period of time, usually 60 seconds. Samples were sorted in the field, individuals of *Micronecta robusta* and *Gambusia affinis* were removed and stored in separate containers. Samples were transported alive to the laboratory and then preserved by freezing.

Estimates of species abundance were obtained by recording the number of individuals collected per minute of sampling effort on each sampling occasion. A representative sample of the taxa present at each site was collected and preserved in 70% ethanol. Additional samples of *M. robusta* and *G. affinis* were collected and preserved in 70% ethanol for gut content analysis.

Pesticide analysis

All pesticide analyses were performed at the Government Chemical Laboratories under the supervision of Dr G. Ebell. Analyses for commonly used organochlorines (DDT, dieldrin, aldrin, heptachlor and chlordane) and organophosphates (temephos and chlorpyrifos) were conducted on all samples; water, sediments and fauna. Post-spray water samples from control sites were lost during analysis.

Data analysis

The pesticide data were analysed statistically using the SPSS-X statistical package. Analyses of variance and non-parametric tests were used to test for significant differences and interactions in the levels of chlordane, heptachlor and chlorpyrifos, in the samples of water, sediments and fish collected from treatment and control sites on the three sampling occasions.

In all cases comparisons were made between treatments (sprayed versus non-sprayed (control) rather than between individual sites. Pesticide levels at the six treated sites (1-6) were combined to form the treated (spray) data set and levels at the two control sites (7 and 8) were combined to form the control (non-spray) data set. Ideally the number of treated sites and control sites should have been equal. Although this was not the case, the lower number of control sites (two) compared to treated sites (six) would tend to favour acceptance of the null hypothesis, that is, that there was no difference between the treated and control samples. As a consequence, all differences found to be statistically significant must be considered to be fairly robust.

Analysis of variance and one-way tests were used to determine significant differences in corixid abundance between the three sampling occasions and the treatment and control sites. As above, comparisons were made between treatments (spray and control) rather than between individual sites.

Regression analysis was performed to determine how much variation in corixid abundance could be attributed to differences in the levels of pesticides. All three pesticide levels, heptachlor and chlordane levels together and chlorpyrifos levels alone were considered.

Results

Pesticide levels in samples of water, sediments, fish and insects (where analysed) collected from Herdsman Lake on three sampling occasions are given in Table 1. The maximum recommended levels of pesticides in water, for aquatic life, are given in Table 2. The primary source of recommended levels was the water quality criteria established by the United States Environmental Protection Agency for the maintenance of freshwater and marine aquatic life (Government Chemical Laboratory, unpublished report, EPA (1981)).

Only one of the three pesticides used in the 1986 spraying programme, temephos (Abate), was not detected in any of the pre-spray, post-spray or post-rain samples. Heptachlor, chlordane (the 0.5% heptachlor solution used in the 1986 spraying programme contained approximately 9% chlordane) and chlorpyrifos were present in post-spray and post-rain samples of water and sediments, and chlordane alone was present in some pre-spray water and sediment samples.

Chlordane was present in levels above the maximum recommended level (0.01 µg/L) in water samples taken from two sites (Site 1: 0.012 µg/L and Site 4: 0.017 µg/L) prior to spraying and in all water samples taken from treatment sites after spraying and after rain. The highest concentration of chlordane recorded was 0.19 µg/L at Site 1 after rain.

Levels of heptachlor were very low at all sites before spraying but increased to levels exceeding the maximum recommended level for aquatic life

(0.001 μg/L) in all post-spray and post-rain water samples. The highest level of heptachlor recorded was 0.17 μg/L at Site 1 after rain.

Levels of heptachlor were slightly above recommended levels at the two control sites after heavy rain. Whether this was due to circulation of water within the lake or additional spraying (e.g. for termites by persons or agencies unknown) near the control sites is not known.

High levels of chlordane in the lake sediments at all sites (including controls) before and after spraying indicate that chlordane is persisting from previous spraying programmes. Levels of heptachlor in the sediments were generally low at all sites except the samples taken from the treatment sites after heavy rain.

Chlordane but not heptachlor was detected in tissue samples of the mosquitofish Gambusia affinis prior to spraying and both compounds were detected in tissue samples after spraying. The highest levels (0.35 mg/kg of chlordane and 1.1 mg/kg of heptachlor) were recorded in tissues of fish collected from Site 1 after spraying. Site 1 was situated at the entrance of a major drain bringing water into the lake from the light industrial area and beyond.

Two organochlorines used previously at the lake (prior to 1970) but not in the 1986 spraying programme. dieldrin and DDT, were detected in samples collected in this study. Levels of DDT were very low but levels of dieldrin in the lake waters **exceeded** the recommended safe level (0.003 μg/L) at all sites (including controls) and on all sampling occasions. Levels of dieldrin did not change significantly between the three sampling occasions. The highest level of dieldrin in water, 0.029 μg/L, was recorded in a pre-spray sample taken from

Site 4. The highest level of dieldrin in the sediments, 0.42 mg/kg, was recorded in a post-rain sample taken from Site 5.

Both dieldrin and DDT were detected in samples of the mosquitofish, G. affinis, and the corixid, M. robusta. The highest level of dieldrin, 0.46 mg/kg, was recorded in a sample of fish collected at Site 7 (a control site) prior to spraying.

Chlorpyrifos was not detected in pre-spray samples but was present in samples of both water and sediments taken from treatment sites after spraying and after rain. Levels did not exceed the recommended permissible level for the organophosphates (10 μg/L, McEwen and Stephenson (1979)) but they may have exceeded the EPA criterion (EPA, 1981) for invertebrates of 0.01 of the LC_{50} (96 hour).

Chlorpyrifos was not detected in any samples of the mosquitofish G. affinis.

Statistical analysis of pesticide data

The results of the ANOVA's and Mann Whitney tests (F values and Z statistic respectively, and associated levels of significance) conducted on pesticide levels in water, sediments and fish at control and treatment sites and on all sampling occasions, are given in Table 3. Changes in the levels of chlordane, heptachlor and chlorpyrifos only were treated statistically, levels of dieldrin remained virtually unchanged throughout the study.

(i) Pesticide levels in water

A two-way ANOVA indicated signficant differences between the treatment and control sites and before and after spraying for levels of chlordane, heptachlor and chlorpyrifos in the surface waters of the lake. A significant treatment x time interaction for levels of chlordane and chlorpyrifos indicated that levels at the treatment (spray) sites increased after spraying, whilst those at control sites remained unchanged. Levels of heptachlor showed a tendency to increase at treatment sites after spraying. However, the treatment x time interaction was not significant, probably because levels rose at both the control and treatment sites after rain. The fact that no data was available for the control sites after spraying, but before the rain made differences harder to distinguish. A significant Mann Whitney Z statistic suggests that heptachlor levels at the spray sites were significantly higher than those at the control sites after rain.

(ii) Pesticide levels in sediments

Chlordane levels in the sediments were not significantly different between sites or sampling occasions. However, this result may have been largely attributable to the high levels of chlordane present in both pre- and post-spray samples taken from one control site (Site 8). A significant treatment x time interaction suggested that levels at the treatment sites increased after spraying while those at the control sites did not.

Levels of heptachlor in the lake sediments increased significantly after spraying but differences between control and treatment sites were not significant.

Levels of chlorpyrifos in the sediments increased significantly after spraying and between sites but the treatment x time interaction was not significant. A significant Mann Whitney Z statistic indicates that levels of chlorpyrifos in the sediments increased significantly at treatment sites in comparison to control sites after heavy rain.

(iii) Pesticide levels in the Mosquitofish, *G. affinis*

Levels of chlordane in the mosquitofish increased significantly after spraying and levels of heptachlor displayed a tendency to increase. However, differences between sites (treatment) and the treatment x time interaction were not significant. *G. affinis* is a very mobile member of the aquatic fauna and the fact that individuals may well have moved away from or between sites during the study could account for the similar levels of pesticide in fish taken from both control and treatment sites.

Faunal abundance

Changes in the abundance (total numbers collected) and density (number collected per minute of sampling effort) of the mosquitofish, *G. affinis* and the corixid. *M. robusta*, on each sampling occasion, are given in Table 4.

Results of the ANOVA and multiple regression analysis for corixid abundance at different levels of pesticides are given in Tables 5 and 6 respectively. A highly signficant treatment term in the ANOVA indicates that corixid numbers were considerably lower at the treatment (spray) sites than at the control sites and a significant treatment x time interaction indicates that numbers at the treatment sites decreased considerably after spraying in comparison to numbers at the control sites.

Low numbers of corixids at the treatment sites in the post-rain samples suggested that the population had not recovered from the effects of the spraying six weeks after the completion of the spraying programme.

The decrease in corixid abundance could be attributed to the levels of all three pesticides. 55.6% of the variance in corixid numbers was explained by the combined levels of chlordane. heptachlor and chlorpyrifos (Table 6). Levels of chlordane and heptachlor together, however, accounted for 51.5% of the variance, which suggested that the decrease in corixid numbers was largely attributable to these two pesticides. Only 23% of the observed variance in corixid numbers could be attributed to the levels of chlorpyrifos alone. Difficulties experienced with the collection of G. affinis at the post-rain sampling session (as a result of strong winds the fish were sheltering in areas away from the study sites) resulted in low numbers and made statistical analysis of the data unrealistic.

Discussion

The pesticide analyses conducted in this study revealed that the surface waters and sediments of the bed of Herdsman Lake contained detectable levels of four organochlorine pesticides: dieldrin, DDT, chlordane and heptachlor. Two of the pesticides, DDT and dieldrin, were not applied during the 1986 spraying programme, suggesting that the compounds detected are residues from previous spraying programmes at the lake (prior to 1970), or from other spraying events (for example, household termite control) carried out within the catchments of the drains that enter the lake.

Although the levels of DDT were very low, the fact that the levels of dieldrin in the lake waters **exceeded** the recommended maximum level for aquatic life (0.003 µg/L) at all sites and on all sampling occasions must be viewed with some concern. Levels of dieldrin did not change significantly between the three sampling occasions, supporting the suggestion that this compound was a residue from previous sprayings.

The last recorded use of dieldrin for Argentine ant control at the lake was in 1969. This suggests that dieldrin residues have persisted in the lake for at least 17 years. Alternatively, or in addition, dieldrin may have entered the lake from more recent commercially undertaken termite control programmes in nearby suburbs or from agricultural uses in market gardens that lie within the

Herdsman Lake catchment. Unpublished data on levels of dieldrin in drains entering Herdsman Lake provided by the Government Chemical Laboratories (T. Webb, pers. comm.) support this view. Dieldrin levels ranging from 0.013 to 0.04 µg/L were recorded in water samples taken from drains entering the lake in 1982 and levels ranging from 0.011 to 0.045 µg/L were recorded in inflow drains in October 1985. The highest level of dieldrin recorded in water samples collected in this study was 0.029 µg/L. This value is almost ten times greater than the recommended maximum level for aquatic life (0.003 µg/L) and considerably higher than the levels listed by Shewchuk (1981) for drains and rivers in southwestern Western Australia. However, none of the Herdsman Lake samples exceeded the Australian and American drinking water criterion for dieldrin of 0.1 µg/L.

Levels of chlordane and heptachlor in the water samples were low at all sites before spraying but increased significantly, and exceeded the recommended safe levels for aquatic life (0.01 µg/L and 0.001 µg/L, respectively), at the treatment sites after spraying (in both the post spray and post rain samples). These results suggest that heptachlor and chlordane (which was present as an active constituent in the heptachlor solution used in the 1986 spraying programme) entered the lake very quickly after spraying and were present at levels which pose a threat to the aquatic fauna. A knowledge of pesticide levels in water is important because the major route for absorption of pesticides in much of the aquatic fauna is by direct uptake from water (Khan, 1977). Higher levels in predators may also be attributed to additional uptake via the food chain.

Levels of heptachlor were slightly above recommended levels at the two control sites after heavy rain. This may have been due to horizontal movement of water within the lake (from treatment to control sites) or from additional spraying (for example, household termite control) conducted near the control sites or within the catchments of drains that enter the lake near the control sites. The latter suggestion is also supported by unpublished data provided by the Government Chemical Laboratories. Heptachlor levels ranging from 0.005 to 0.063 µg/L were recorded from inflow drains in 1982 and levels ranging from <0.001 (below detectable limits) to 0.006 were recorded from inflow drains in October 1985 (T. Webb, pers.comm.).

High levels of chlordane in the lake sediments at all sites before and after spraying indicate that chlordane is persisting from previous Argentine ant spraying programmes (prior to 1984) or from other spraying programmes conducted near the lake. Levels of heptachlor in the sediments were generally low at all sites except the samples taken from the treatment sites after heavy rain. The presence of chlordane residues, but not heptachlor residues in sediments, prior to spraying, may be explained by the findings of previous studies, which suggest that chlordane has a persistence of five years, whilst that of heptachlor is two years (Guenzi, 1974).

DDT and dieldrin were present in the tissues of both the mosquitofish (*Gambusia affinis*) and corixids (*Micronecta robusta*) in nearly all samples analysed and may be attributed to previous sprayings at or near the lake. The high levels of dieldrin recorded in some samples suggest that bioaccumulation of this pesticide is occurring in the aquatic fauna.

The 1986 spraying programme must be regarded as the source of chlordane and heptachlor in the post-spray fish samples. These compounds were below the limits of detection in pre-spray samples, but significant increases were recorded in post spray samples taken from treatment sites. The high levels recorded in the mosquitofish suggest some bioaccumulation and the possible development of a physiological resistance to these organochlorines. Several studies have documented the ability of *G. affinis* to form a resistance to organochlorines, including chlordane, heptachlor, DDT and dieldrin (Mowbray, 1979; Pimental, 1971). High levels of organochlorines in fish may also pose a problem to the waterfowl which feed upon them and further studies are required to determine the extent of bioaccumulation of organochlorines in the food chains associated with Herdsman Lake.

Levels of both chlorpyrifos and temephos were below the limits of detection in all samples prior to spraying. However, levels of chlorpyrifos increased significantly in both water and sediment samples at treatment sites, compared to control sites, after spraying. Levels did not exceed the recommended permissible level for the organophosphates (10 µg/L, McEwen and Stephenson (1979)) but they may have exceeded the EPA criterion (EPA, 1981) for invertebrates of 0.01 of the LC_{50} (96 hour) for many species.

Chlorpyrifos was not detected in the tissues of the fish (Gambusia affinis) which supports the view that organophosphates do not undergo bioaccumulation in the food chain (McEwen and Stephenson, 1979).

Levels of temephos were below the limits of detection in all samples and this result supports the findings of the studies documented by Blair (1979) in which Abate was found to have virtually no detectable residues, except within the first few hours after application, and significant bioaccumulation within the aquatic environment did not occur.

Difficulties in collecting sufficient insect material for analysis after spraying meant that levels of pesticides in insect tissue could not be adequately measured. However, ANOVA results indicate that a significant reduction occurred in corixid numbers, at treatment sites, after spraying, whilst the abundance of corixids at the control sites did not change. Levels of chlordane, heptachlor and chlorpyrifos accounted for a large percentage of the variation in corixid abundance (significant at the 0.05 level). Heptachlor and chlordane accounted for most of the variation. Chlorpyrifos alone did not adequately account for the decrease in abundance. However, chlorpyrifos has been shown to cause little or no mortality in corixids at concentrations sufficient to control mosquito larvae (Pimental, 1971; Muirhead and Thomson, 1971).

The effect of chlorpyrifos on corixids, however, cannot be extrapolated to the effect that chlorpyrifos may have had on more susceptible invertebrate groups, for example, chironomids, amphipods and cladocerans.

The relationship between pesticide levels and the abundance of G. affinis was not as clear as that for the corixids. This may be partially attributed to the fact that adverse weather conditions (strong winds) at the time of the post-rain sampling session made collection of G. affinis difficult and may have been the cause of low numbers at one of the control sites. There is some indication, however, (Table 6) of a decrease in the abundance of G. affinis at the treatment sites after spraying.

Increases in the levels of chlordane, heptachlor and chlorpyrifos in the water samples collected after heavy rain suggest that surface runoff plays an important part in the transport of pesticides into the lake. The fact that the highest levels of chlordane and heptachlor were recorded in post-rain samples supports this view. High levels of chlordane and heptachlor in the post spray and post rain samples of water and fish collected at Site 1, compared to those recorded at other sites, may be explained by the fact that this site was located at the inflow of a major drain.

Conclusions

Both the 1986 Argentine ant spraying programme and past Argentine ant control programmes conducted at Herdsman Lake appear to be responsible, at least in part, for the persistence of organochlorines within the surface waters and sediments of the lake and for the presence of dieldrin, chlordane and heptachlor in the water at levels which are considered detrimental to the maintenance of aquatic ecosystems. Evidence of bioaccumulation of these organochlorines withn the tissues of a common and abundant member of the lake's aquatic fauna, the mosquitofish, Gambusia affinis, suggests that organochlorine levels may be elevated in members of higher trophic levels, in particular, the predatory species of waterfowl that feed upon the fish.

Lethal effects of organochlorines on waterfowl at Herdsman Lake do not appear to have been recorded. However, sublethal effects may be present and could include decreases in reproductive capacity and increases in susceptibility to disease. Connell's (1986) recent statement that the lack of documentation of adverse ecological effects of high levels of organochlorines in the aquatic environment may merely reflect the lack of long-term quantitative ecological investigations appears to be relevant to the Herdsman Lake situation.

The extensive series of drains entering Herdsman Lake probably serves to increase the efficiency of transport of terrestrially applied pesticides into the lake. In addition, the drains provide a means by which pesticides applied at some distance from the lake will eventually enter the lake's waters.

Because Herdsman Lake is valued as an area for wildlife conservation within the metropolitan region and is to become a regional park for the protection of flora and fauna, the continued input of organochlorines and organophosphates into the lake, as a consequence of the Argentine ant control programme and other spraying programmes, must be a cause for concern. Sources of pesticides in addition to the Argentine ant control programme need to be identified and an ongoing monitoring programme established both for the measurement of pesticide levels within the lake proper and in inflowing drains.

The occurrence and extent of bioaccumulation of organochlorines within higher trophic levels at the lake should also be determined and some investigation of the possible effects of organochlorine residues on the lake's birdlife should be be made.

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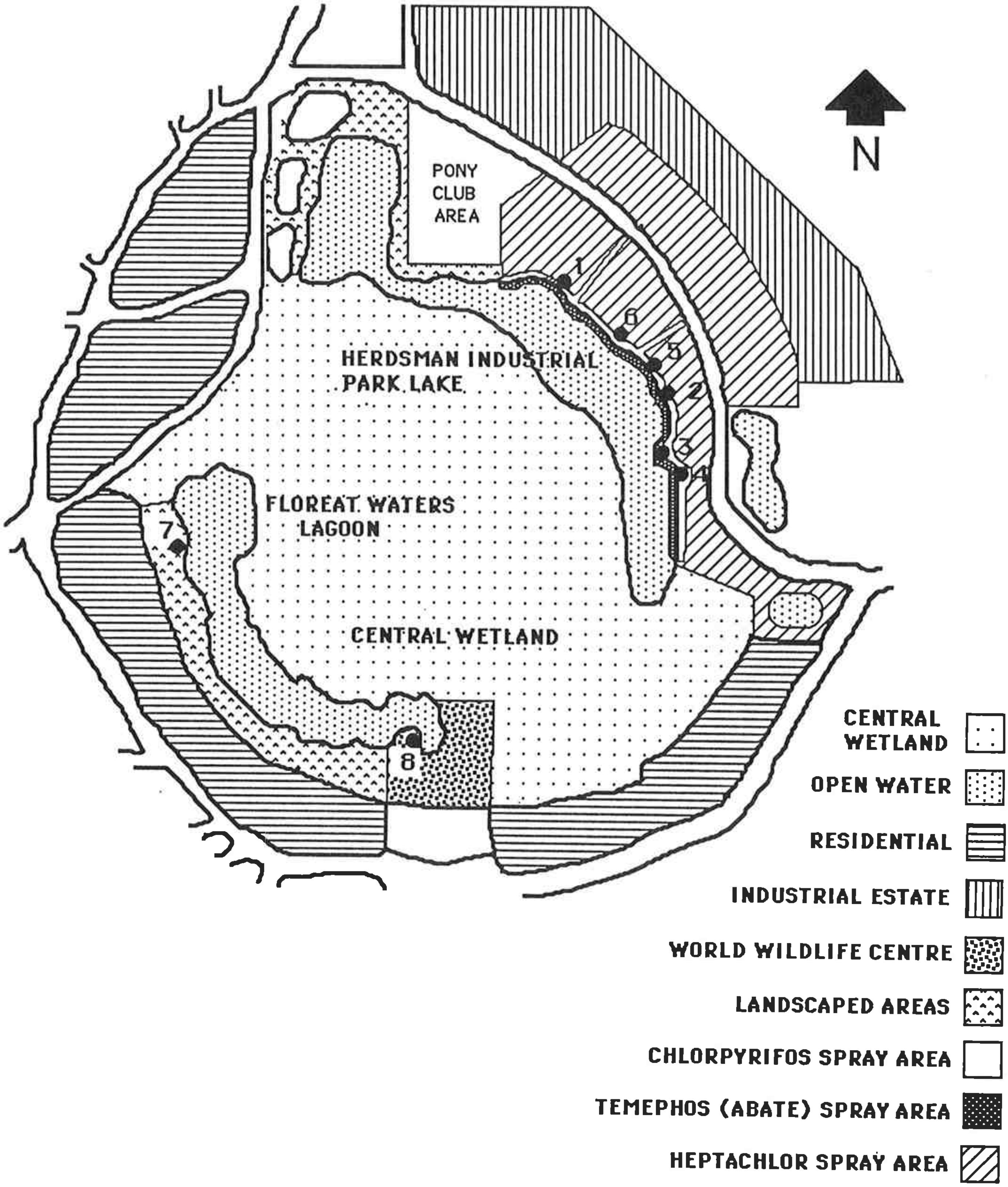

FIGURE 1: Map of Herdsman Lake showing location of sampling sites 1 to 8, and areas of pesticide spraying.

Table 1. Levels of pesticides in samples taken from the water sediment and fauna (fish and insects) of Herdsman Lake before and after spraying (and following heavy rain), for the control of Argentine ants in March/April 1986. All analyses were conducted by the Government Chemical Laboratories. All levels which exceed recommended maximum levels for aquatic life are underlined.

Pre-spray samples (17/3/86 - 21/3/86)

		Pesticides (μg/L)		
Site	Chlordane	DDT	Dieldrin	Heptachlor
Water				
1 17/3/86	0.012	-	0.004	<0.001
2	0.001	-	0.005	<0.001
3	0.003	-	0.011	<0.001
4	0.017	-	0.029	<0.001
5 18/3/86	0.002	-	0.016	<0.001
6	0.001	-	0.008	<0.001
7(c) 21/3/86	0.002	<0.001	0.007	<0.001
8(c) 21/3/86	0.001	<0.001	0.009	<0.001

		Pesticides (mg/kg)		
Site	Chlordane	DDT	Dieldrin	Heptachlor
Sediments				
1	0.01	-	0.15	<0.01
2	<0.01	-	<0.01	<0.01
3	0.03	-	0.14	<0.01
4	0.02	-	0.10	<0.01
5	0.01	-	0.13	<0.01
6	<0.01	-	0.09	<0.01
7(c)	0.05	-	0.04	<0.01
8(c)	0.1	-	0.02	<0.01

Pre spray samples contd

Site	Chlordane	Pesticides (mg/kg) DDT	Dieldrin	Heptachlor
Fish				
Gambusia affinis				
1 (72)	<0.01	<0.01	0.01	-
2 (35)	<0.01	0.01	0.01	-
3 (49)	0.01	<0.01	0.04	-
4 (55)	<0.01	<0.01	0.02	-
7(c) (25)	0.01	0.01	0.46	-
8(c) (50)	0.01	0.01	0.12	-

Site	Chlordane	Pesticides (mg/kg) DDT	Dieldrin	Heptachlor
Insects				
Micronecta robusta				
1 (30)	-	-	-	-
2 (100)	<0.01	0.02	0.02	-
4 (14)	-	-	-	-
5 (150)	<0.01	0.02	0.02	-
6 (130)	<0.01	0.01	0.02	-

Numbers of G. affinis and M. robusta in samples tested are given in brackets following site number.

No other organochlorine or organosphosphate pesticides were detected in the water samples. The limit for detection of chlorpyrifos in water is 0.02 µg/L and 0.02 mg/kg in sediments, and for temephos is 0.02 µg/L in water and 0.4 mg/kg in sediments.

No other common organochlorine pesticides were detected in the fish samples.

Insect samples from sites 1 and 4 were not analysed because of insufficient material, the insect sample from site 7 was not analysed in view of the low results in the water samples.

Table 1 contd

Post spray samples (14/4/86)

Site	Chlordane	DDT	Dieldrin	Heptachlor	Chlorpyrifos
			Pesticides (µg/L)		
Water					
1	0.033	-	0.005	0.028	0.18
2	0.032	-	0.015	0.028	1.3
3	0.014	-	0.012	0.001	0.14
4	0.013	-	0.007	0.003	0.17
5	0.016	-	0.007	0.01	0.32
6	0.033	-	0.007	0.022	0.41

7 and 8 not analysed

Site	Chlordane	DDT (and metabolites)	Dieldrin	Heptachlor and its epoxide	Chlorpyrifos
			(mg/kg)		
Sediments					
1	<0.01	0.01	0.01	<0.01	<0.02
2	0.01	<0.01	0.14	<0.01	<0.02
3	0.04	<0.01	0.10	<0.01	0.18
4	0.23	<0.01	0.13	<0.01	4.4
5	0.02	<0.01	0.18	<0.01	0.76
6	<0.01	<0.01	0.02	<0.01	0.09
7(c)	0.04	<0.01	0.14	<0.01	<0.02
8(c)	0.08	<0.01	0.08	0.01	<0.02

Site	Chlordane	DDT (and metabolites)	Dieldrin	Heptachlor and its epoxide
Fish				
Gambusia affinis				
1 (4)	0.35	0.01	0.08	1.1
2 (*Pseudogobius olorum* - goby) (14)	0.03	0.01	0.01	0.03
2 (18)	0.10	0.01	0.02	0.17
3 (35)	0.05	0.01	0.04	0.04
4 (45)	0.01	0.01	0.13	0.01
7(c)	0.01	<0.01	0.02	0.01
8(c) (35)	0.07	0.01	0.1	0.10

Numbers of fish comprising each sample are given in brackets next to site number.
No temephos was detected, the limit of detection in water being 0.2 µg/L and in sediments 0.4 mg/kg.
No other common organochlorine or organophosphate pesticides were detected.
Four insect samples have not yet been analysed.

Table 1 contd

Post rain samples (29/5/86)

Site	Chlordane	DDT	Pesticides (µg/L) Dieldrin	Heptachlor and its epoxide	Chlorpyrifos
Water					
1	0.19	-	0.023	0.17	6.5
2	0.082	-	0.011	0.068	1.5
3	0.021	-	0.01	0.006	6.8
4	0.016	-	0.011	0.009	6.6
5	0.062	-	0.011	0.051	1.7
6	0.036	-	0.007	0.034	1.5
7(c)	0.001	-	0.005	0.003	<0.02
8(c)	0.001	-	0.01	0.002	<0.02

Site	Chlordane	DDT	Dieldrin	Heptachlor	Chlorpyrifos
Sediments mg/kg (dry basis)					
1	0.01	-	<0.01	0.01	0.84
2	0.03	-	0.06	0.03	0.15
3	0.18	-	0.27	<0.01	3.0
4	0.03	-	0.09	0.01	3.5
5	0.04	-	0.42	0.02	0.03
6	0.06	-	0.02	0.06	0.77
7(c)	<0.01	-	<0.01	<0.01	<0.02
8(c)	<0.01	-	0.10	<0.01	<0.02

No other common organochlorine or organosphosphate pesticides were detected.

Fish and insect samples have not yet been analysed.

Table 2. Recommended maximum levels of selected pesticides in surface waters. Compiled from the Government Chemical Laboratories criteria (unpublished data), USA-EPA, EPA (1981), and McEwen and Stephenson (1979).

Chlordane and metabolites	DDT and metabolites	Dieldrin	Heptachlor and its epoxide	Organo-phosphates
0.01	0.001	0.003	0.001	10*

All levels are expressed as µg/L

*Permissible level only, recommended maximum level not given.

Table 3. ANOVA results (F value and significance) and non-parametric test results (Mann-Whitney Z statistic and significance) for pesticide levels in water, sediment and fish.
(n.s. = not significant, $^{+}$ = tendency ($0.1 < P < 0.05$), * = $P < 0.05$, ** = $P < 0.01$, *** = $P < 0.001$.)
Treat = spray/control sites. Time = sampling sessions.

Pesticide	ANOVA		Mann-Whitney	
	Source of variation	F value	Source of variation	Z statistic
WATER				
Chlordane	Treat	31.769***		
	Time	8.865**		
	Treat by time	3.910*		
Heptachlor	Treat	10.407**		
	Time	13.499***	Post spray	-1.72^{+}
	Treat by time	2.769^{+}	Post rain	-2.0*
Chlorpyrifos	Treat	81.557***		
	Time	78.557***		
	Treat by time	26.186***		

Pesticide	ANOVA		Mann-Whitney	
	Source of variation	F value	Source of variation	Z statistic
SEDIMENT				
Chlordane	Treat	$0.839^{n.s.}$		
	Time	$0.422^{n.s.}$		
	Treat by time	4.735*	Post rain	-1.719^{+}
Heptachlor	Treat	$1.151^{n.s.}$		
	Time	3.454*		$-1.421^{n.s.}$
	Treat by time	$1.141^{n.s.}$	Post rain	$-1.146^{n.s.}$
Chlorpyrifos	Treat	6.768*		
	Time	5.829*	Post spray	
	Treat by time	$1.943^{n.s.}$	Post rain	-2.012*

Table 3 contd

Pesticide	ANOVA		Mann-Whitney	
	Source of variation	F value	Source of variation	Z statistic
FISH				
Chlordane	Treat	$0.506^{n.s.}$		
	Time	6.876^{*}	Post spray	$-0.704^{n.s.}$
	Treat by time	$0.506^{n.s.}$		
Heptachlor	Treat	$2.139^{n.s.}$		
	Time	4.278^{+}		
	Treat by time	$2.139^{n.s.}$	Post spray	$-1.476^{n.s.}$

Table 4. Density (number of individuals collected per minute of sampling effort) and abundance (total numbers) of mosquitofish, Gambusia affinis and corixids, Micronecta robusta, at Herdsman Lake sites on pre-spray, post-spray and post-spray/post-rain sampling occasions.

Site	Pre-spray		Post-spray		Post-spray/Post-rain	
	G. affinis	M. robusta	G. affinis	M. robusta	G. affinis	M. robusta
1	14.4(72)	6(30)	0.2(4)	0.6	0.6(3)	0(0)
2	5.8(35)	20(100)	1.8(18)	5.6	0.4(2)	0(0)
3	9.8(49)	0(0))	0(0)	0(0)	4.4(22)	0(0)
4	11(55)	2.8(14)	3.5(35)	0(0)	*0(0)	1(5)
5	0(0)	30(150)	0(0)	2.6(13)	*0(0)	0(0)
6	0(0)	32.5(130)	0(0)	2.8(14)	0(0)	0(0)
7	5(25)	53.3(130)	6(30)	50(150)	0(0)	15(150)
8	16.6(50)	5(20)	15(30)	6(30)	7(28)	10(40)

*Large numbers of the Goby Pseudogobius olorum were present at these sites Site 4 = 25, Site 5 = 35.

Table 5. ANOVA results for corixid abundance (F value and significance, + = tendency (0.1<P<0.05, ** = P<0.01, *** = P<0.001).
Treat = spray/control sites. Time = sampling sessions.

Source of variation	F value
Treat	82.917***
Time	3.052+
Treat by time	9.565**

Table 6. Regression for corixid abundance (F value, R^2, and significance. $^{+}$ = tendency (0.1<)<0.05), * = P<0.05).

Variables	F value	R^2
Chlordane/Heptachlor/Chlorpyrifos	4.592*	0.556
Chlordane/Heptachlor	6.381*	0.515
Chlorpyrifos	3.903^{+}	0.231