The results of monitoring the Department of Conservation and Land Management's programme of applying granulated herbicides by helicopter

A report to the Environmental Protection Authority

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This investigation originally began as an environmental assessment of a Department of Conservation and Land Management (CALM) proposal to apply herbicides by helicopter to new pine plantations. However, since there was almost no information available on the effects of these chemicals on the Western Australian environment, a monitoring programme was initiated to investigate the environmental impacts of this programme for the assessment of future programmes. The monitoring was carried out jointly by the Environmental Protection Authority (EPA) and CALM, and the chemical analyses were conducted by the Chemistry Centre of WA (CCWA).

There are, of course, many people who have contributed in some way to this investigation and the subsequent report. In particular the assistance of the following people is gratefully acknowledged: the staff from CALM who carried out most of the field sampling work and in particular Mr R Fremlin for his assistance at all levels of the investigation; Mr G Ebell of the CCWA for providing both analytical support and toxicological information; Mr I Growns for spending perhaps more time than he should on the aquatic invertebrate monitoring programme; Mr C Sanders and Dr R Humphries for their general support; Ms L Ferguson for word processing; Ms H Bradbury for editing and Ms M Butcher and Mr P Ion for production.

Summary

In 1989 an investigation of the environmental impacts of two herbicides proposed for helicopter application by the Department of Conservation and Land Management (CALM), was carried out by the Environmental Protection Authority (EPA). The available literature on the environmental toxicity, environmental impacts and environmental fate of these chemicals was reviewed. The environmental impacts of these chemicals on the aquatic environment was also monitored at five sites.The chemicals were leached into adjacent streams and intermittently detected at relatively low concentrations generally, but ranging from 0.8 to 38.0µg/L atrazine and 1.5 to 18µg/L hexazinone. There was no observed effect on aquatic algal growth in the Blackwood River, however, in the streams at two application sites there did appear to be some impact on the aquatic invertebrate fauna. The results indicate that helicopter application of granulated herbicides does not increase the risk of environmental contamination when compared to the more traditional methods of ground application. Off-site losses by misplacement of the herbicides and wind drift was measured and found to be negligible. There is a paucity of information relating to potential environmental impacts of all pesticides, including atrazine and hexazinone, in the Western Australian environment. Consequently further investigations are necessary before the environmental impacts of these chemicals can be adequately assessed.

1 Introduction

The Environmental Protection Authority (EPA) has investigated the environmental impact of two chemical herbicides used for the control of weeds in forestry areas in the south-west of Western Australia. The herbicides are used by the Department of Conservation and Land Management (CALM) to prevent weeds from successfully competing with tree seedlings in plantation forestry areas.

This investigation was conducted in response to the Acting Minister for the Environment referring a CALM herbicide application programme to the EPA under Section 38(2) of the Environmental Protection Act for formal assessment. The State Cabinet had also become involved after the Acting Minister for Transport and Environment halted the application programme. In the following Cabinet discussions it was decided that aerial applications should not be carried out in the vicinity of Nannup and that the EPA should assess the environmental impacts of the programme in conjunction with the CALM monitoring programme. The CALM programme included the application of herbicides by helicopter in some localities. The investigation was to provide information that could then be used to assess whether helicopter application increased the risk of environmental contamination and to assess the environmental impact caused by the use of such chemicals.

1.1 Background to the application programme

Residents in the Nannup area expressed concern regarding the aerial method of herbicide application and the adverse impacts on the environment and human health which might arise from the programme.

Previously in Western Australia the application of pesticides on CALM plantations has been from the ground by tractor-mounted boomsprays or hand-held sprays. Herbicide application by helicopter has been trialled in the eastern states of Australia since 1987 (principally Victoria). The Victorian trials showed that this means of applying agricultural chemicals is economic and efficient. To ensure that the materials are placed in the targeted areas application must only occur within a prescribed set of weather conditions. The CALM programme was proposed to obtain more detailed information, particularly on the economics of helicopter applications, in Western Australia.

The chemicals proposed for use are atrazine and hexazinone. Atrazine is a common herbicide used throughout the State. It has been used in Western Australian forestry situations for over 25 years and over this period there have been no reports of any major adverse environmental effects, but this may be a result of inadequate environmental monitoring. Hexazinone is a more recent chemical which has had only limited use in Western Australia.

Initially amitrole was also proposed for application at Nannup, however, its use in this programme was discontinued after Nannup staff refused to use it following statements in the press alleging that amitrole may present a health hazard. Amitrole has been cleared for use in Australia by the National Health and Medical Research Council. The public concerns expressed at the time mostly related to the use of amitrole and atrazine. Amitrole is only slightly toxic to most animals, but is known to cause cancers in some species of laboratory mammals (WHO, 1986). However, there is insufficient evidence to determine its effect on human health, particularly at the low concentrations expected during the proposed operations.

Toxicity tests conducted in the United States of America show atrazine to be moderately to highly toxic to aquatic invertebrates, moderately to slightly toxic to fish and only slightly toxic to most other animals. Hexazinone availability has been more recent than for atrazine, and in the light of current toxicity information it appears to be only slightly toxic to practically non-toxic and unlikely to adversely affect human health under normal practices.

1.2 The proposed application programme

Information from the Victorian Department of Conservation, Forests and Lands, showed that herbicide application by helicopter was economically and technically more efficient than ground-based methods. Earlier techniques used by CALM have included spraying herbicides from back-packs, and from tractor-mounted boomsprays.

On the basis of the Victorian information, and their own experience, CALM applied to the Health Department of Western Australia on 17 March 1989, seeking permission to apply the herbicides by helicopter. In support of this application, CALM provided a plan modified from material provided by their Victorian counterpart. This plan is included in Appendix 1, and gives some prescriptive details of the intended operation. It is clearly the intention of CALM, subject to their assessment of this trial, that wherever possible aerial application should replace the more labour intensive, slower hand or land-based systems of chemical application.

It was proposed to apply the granules by helicopter at all sites, except one in the Nannup region. This one exception was the Folly site where granules were applied by hand applicator around individual trees. However, as a result of public concern and advice from the EPA, CALM altered its proposed programme to exclude aerial applications on a second site in the Nannup region. This was in keeping with the State Cabinet's requirement that aerial applications not occur in sensitive locations within the vicinity of Nannup. Amitrole was not used, except for a small area in the Maidments site near Nannup where it had already been applied by a tractor-mounted boomspray. The atrazine application rate was reduced by one third and applied as a liquid called 'Gesaprim®' by a tractor-mounted and enshrouded boomspray. Amitrole was replaced with hexazinone and applied using the same method. Apart from two other sites not considered in this investigation, and which received liquid herbicide formulations, the remainder of the proposed sites received the herbicides in granulated form.

Weather conditions were closely monitored on site before and during helicopter applications to reduce the risk of losses outside the target areas.

1.3 The aims of the application programme

The main aim of the programme was to adequately control weed growth to reduce competition with tree seedlings for light, nutrients and water. The effective life of the herbicides varies from site to site and with climatic conditions, but generally ranges from about one month to over six months. This means that a repeat application may be required in the first year. Generally this only occurs in plantations along the south coast of Western Australia.

In this programme helicopters were being used on a trial basis to investigate the potential for increasing the efficiency, and reducing the overall costs associated with forestry management. Additional benefits of aerial application are reduced exposure to herbicides by staff, and improved targeting of optimum weather conditions for application. Application over the targeted area was expected to be much more accurate by helicopter than by other aerial methods.

In all situations the operation was designed to ensure nil effect on aquatic environments, non-target flora, and private property. This is the responsibility of the operator, requiring an approved monitoring programme to be conducted during and after the operation.

2 Discussion of potential environmental impacts

These chemicals have been used widely overseas both for management of forestry plantations and for weed control in agriculture. Atrazine has been used extensively in Australia, including Western Australia, but hexazinone has only been used very recently and rarely on a large scale in Western Australia. It has been used in Victoria, New South Wales, South Australia and the Australian Capital Territory for at least 10 years.

There are no data for Western Australia suggesting that properly formulated herbicides result in adverse environmental conditions. This is not to say that herbicides do not degrade the WA environment, but rather that there has been a lack of adequate monitoring. The data required to properly assess the impact of pesticides on the Western Australian environment can only be obtained by monitoring the toxicity to local biota and by measuring leaching losses from local soils. The limited amount of pesticide monitoring carried out in Western Australia has been in a very ad-hoc fashion dealing mainly with efficacy. In the few cases where environmental monitoring has occurred, organochlorines have generally been targeted (Atkins, 1982; Klemm, 1989; Rutherford, 1989).

There are data available from overseas studies on the toxicity and, to some extent, environmental impacts of a large number of pesticides including atrazine and hexazinone. This information, however, is based on species that do not occur naturally in Western Australia and in climates that may not be comparable. As a result the data may not be very applicable to the Western Australian situation, and therefore can only be used as a guide.

The aerial application of pesticides for forestry purposes is new to Western Australia, and if uncontrolled it may have a greater capacity to impact on adjacent lands, wetlands and streams, particularly since applications may occur over large areas at one time. Strict operating instructions will be required to ensure that environmental impacts from misplacement or wind drift are controlled.

In the United States, the aerial application of agricultural chemicals by fixed wing aircraft raised suspicions of surface water contamination from poor control of the spray pattern. To reduce this problem helicopters have been used because they enable a more directional application of the chemicals, and when flown in low wind conditions, wind drift is less of a problem.

Nevertheless, we are aware that in the Pacific North-West of the United States (Oregon and Washington States) an agreement signed in May 1989 limiting herbicide use on Forest Service lands, specifically prevents aerial application of atrazine.

In Sweden the aerial application of pesticides has been prohibited on health and environmental grounds. However, pesticide application to forestry areas is controlled by a permit system.

The leaching of pesticides through the soil profile has also been the subject of some studies overseas. Laboratory studies using leaching columns indicate that mobility of the triazine herbicides (eg. atrazine and hexazinone) in soils is attenuated by the organic, clay and silt components of the soil, but that mobility increases as soils become more sandy (Helling, 1970; Council for Agricultural Science and Technology, 1985). Western Australia's highly leached, sandy soils are well known for their poor absorbing characteristics, resulting in leached fertilizer nutrients entering the waterways and causing excessive algal growth. Mobility of some pesticides in these soils is also likely to be high, with the potential for significant quantities to leach into streams and rivers. The evidence also suggests that many pesticides, including those proposed for use in this operation, are degraded at a much slower rate once they have leached down the soil profile beyond the main zone of biological activity and entered the groundwater.

2.1 Atrazine

2.1.1 General

Atrazine is used as a selective pre- and post-emergent herbicide on many crops, including forestry applications where it is used for conifer release, site preparation, grass and noxious weed control.

The structure of atrazine is closely related to other triazine herbicides, including simazine and cyanazine. It has the empirical formula $C_8H_{14}ClN_5$ and molecular weight of 215.69.

Atrazine is absorbed primarily by plant roots, readily translocated to all above-ground parts of the plant and accumulates in the margins of leaves (US Department of Agriculture, Forest Service, 1984).

In an aquatic food chain atrazine was found to bioconcentrate in the phytoplankton, particularly at low biomass, but was not observed to continue up the food chain (Gunkel, 1984). It has a low tendency to biocumulate in animals and is rapidly metabolized to non-toxic metabolites, which are readily excreted by the kidneys.

Atrazine is moderately persistent in soil particularly when it has leached down beyond the zone of biological activity. In the soil it is lost primarily by means of chemical degradation, leaching and some limited microbial degradation. It is moderately mobile and adsorbs readily to soil particles, particularly in soils with a high organic content. Atrazine has a low solubility in water and this, coupled with a tendency to adsorb onto organic and clay particles, has resulted in relatively small amounts being leached into aquatic environments in some overseas studies. It degrades slowly in water and is lost by dilution, transport and metabolism by organisms. The rate of metabolic degradation of atrazine may depend on its concentration (Hamilton et al., 1989).

A study which measured atrazine distribution over one vegetation period in an aquatic pond treated with the herbicide, found that about 94% of the herbicide was in the water column and about 5% in the sediments. The remaining 1% was distributed in the biota or lost to the atmosphere (Gunkel, 1984).

2.1.2 Toxicology

Atrazine has been found to negatively affect algal production within lake periphyton communities at concentrations ranging from 80 to 1 560µg/L (Hamilton et al., 1987), (Hamilton et al., 1989). Gunkel (Gunkel, 1983) also found that atrazine inhibited algal biomass in aquatic systems and triggered a rapid succession of algal species with uncharacteristic species usually dominating. This potential to alter phytoplankton community structure and diversity was also observed by Hamilton (Hamilton et al., 1989), and has been shown to be a result of differing toxicity relationships between species under different light and temperature regimes (Mayasich et al., 1987 and 1988).

The impacts of atrazine on the microbial community may be even more acute. Studies on the impact of atrazine on the structure and function of aquatic microbial communities has shown that concentrations as low as 17.9 µg/L may have a negative impact (Pratt et al., 1988). The effect on soil microbial communities of normally recommended rates of atrazine is generally only temporary if the organic content of the soil is not also reduced. The effects can be both stimulatory and inhibitory to different organisms (Wardrop, 1986?).

Further up the food chain, atrazine concentrations in the water column as low as 20µg/L were shown to have a negative impact on aquatic insect species richness and emergence (Dewey, 1986). Non-predatory insect species were more sensitive to atrazine than were predatory species.

The toxicity of atrazine to a number of individual terrestrial and aquatic species has been studied in the laboratory and reported overseas (US Dept. of Agriculture, Forest Service, 1984; Mayer et al., 1986). Generally atrazine was found to be practically non-toxic to slightly toxic to mammals (LD_{50} of 500 to over 2000mg/kg), practically non-toxic to slightly toxic to birds (LD_{50} of 500 to over 2000mg/kg), although evidence suggests that juveniles may be more sensitive, practically non-toxic to slightly toxic (moderately toxic to some species) to soil organisms (inhibitory or toxic effects at 10 to over 100mg/kg), moderately toxic to highly toxic to aquatic invertebrates ((LC_{50} of 0.1 to 10mg/L), slightly to moderately toxic to adult fish ((LC_{50} of 1 to 100mg/L), and highly toxic to eggs and newly hatched fish (0.1 to 1.0mg/L). Concentrations of 0.28 and 0.16mg/L atrazine respectively, were found to cause hepatocyte necrosis and lipidic degeneration of liver in juvenile mullet. (Biagianta, 1985). Growth retardation for some algal species, including blue-green species, was reported at concentrations down to 0.01mg/L, whereas other species were able to tolerate atrazine at concentrations greater than 1mg/L.

2.1.3 Impacts

Because of its mobility, atrazine has been frequently detected in non-targeted parts of the environment. Investigations have shown that atrazine does leach when applied to catchments (Wu, 1981) and that the quantity detected in drainage increases with the proportion of the catchment to which it is applied. Wu also detected herbicide residues in the drainage from a catchment which received no direct applications of herbicide, indicating probable wind dispersal. In the United States an Environmental Protection Agency groundwater survey has detected atrazine contamination of groundwater by normal uses in thirteen States and contamination by point sources in seven States (Williams et al., 1988). In the majority of cases concentrations were low, the median level being below the health-advisory levels, but not in all cases.

Atrazine has also contaminated potable groundwater in West Germany and northern Italy. In Italy a regulation prohibiting the use of atrazine in six regions was approved in 1989 and reclamation programmes are to be implemented within two years to reverse the pollution of groundwater, wells and aqueducts. Some recent evidence indicates that a number of pesticides, including atrazine, has contaminated 200 km of the Po River in Italy.

In Australia information on both toxicology and environmental impacts of atrazine is very limited. In Tasmania the impact of atrazine on the stream invertebrate fauna is being investigated. The herbicide was sprayed in liquid form from a fixed wing aircraft at a rate of 6kg/ha active ingredient. No buffer strips were retained along the stream. Atrazine concentrations in the stream reached 50 to 100µg/L but no invertebrate kill was detected. However, a substantial increase in downstream drift was observed for a few invertebrate groups, particularly the Elmidae and Ostracoda (L Cook pers comm.).

A sampling survey to detect the presence of pesticides (including atrazine) in several rivers and estuaries in the south-west of Western Australia was conducted in 1987 by the EPA. Atrazine was not detected in either water or sediment samples. Atrazine was detected in farm dams, however, in an earlier study of herbicide use on roaded catchments to farm dams (Laing, 1983). Concentrations up to 90µg/L were detected but lower concentrations were found to persist throughout the year.

2.2 Hexazinone

2.2.1 General

This is a more recent herbicide than atrazine, and consequently there is less information regarding its environmental fate. Hexazinone is a triazine herbicide with moderate solubility in water and is applied as a selective herbicide for site preparation and weed elimination around conifers, and as a non-selective herbicide for weeds and woody plants.

The primary mechanism for uptake of hexazinone by plants is absorption from the soil solution by roots. It is readily metabolized into a variety of metabolites in plants and animals (US Dept of Agriculture, Forest Service, 1984). Hexazinone does not biocumulate in animals and both hexazinone and its metabolites are rapidly excreted by animals in urine and faeces.

In soil, hexazinone is either degraded by light and microbial activity or it is leached. Hexazinone is variably persistent in soil depending on field conditions, with a half-life of one month to more than six months. It is relatively mobile in soil and has been shown to be more mobile than atrazine (Bouchard et al., (1), 1985). In water, hexazinone is moderately to very persistent. When stream water containing hexazinone was incubated in the dark at 30^{0}C, several years were required for 50% disappearance (Bouchard et al., (2), 1985). Photodegradation, biodegradation and dilution are the prime mechanisms for loss of the chemical's activity in aquatic systems.

Investigations into the fate of hexazinone applied to catchments have shown that hexazinone and its residues can still be detected in stream run-off from nine months to over one year after application (Bouchard et al.,(2), 1985), (Neary et al., 1983), (Nutter et al., 1984). Bouchard found that hexazinone concentration within the surface 10cm of soil decreased to approximately 10% of the 2kg/ha applied within 42 days. This loss rate was more rapid than could be accounted for by degradation and may indicate leaching to the deeper profile. Neary also found that hexazinone was largely lost from the surface 10cm within one month, but that it was being leached through the profile and transported downslope via subsurface groundwater movements, showing up in drainage base flow three to four months after application. This highlights the potential for hexazinone to be transported off site and affect vegetation outside the target area, particularly in sandy soils with strong groundwater flows.

Maximum hexazinone concentrations in stream flow appear to occur soon after the time of application, particularly during periods of runoff after rainfall. The maximum concentrations reported in drainage from the above investigations was 14µg/L by Bouchard and 514µg/L by Neary. Concentrations associated with rainfall runoff rapidly decreased with time from application. The maximum stream base flow concentration recorded by Neary from subsurface flow was 23µg/L. The proportion of applied hexazinone lost to drainage is dependent on many factors including rainfall intensity and timing, soil type topography and drainage proximity and density. Accordingly loss rates reported by Bouchard and Neary varied greatly at 2.0 - 3.0% and 0.53% respectively.

Application of hexazinone to a catchment can also indirectly affect the water quality of the draining streams (Neary et al., 1986). Neary found that suspended solids and total sediment yields in drainage were increased on treated catchments as a result of loss of vegetation and increased runoff. However, these increases were less than those expected from alternative mechanical revegetation disturbances.

A very large increase in the quantity of nitrate leached from the treated catchments was also observed and persisted for two years. The evidence indicates that hexazinone may have stimulated nitrifying bacteria in the soil, and this coupled with the reduced nitrate uptake by vegetation could have produced the high nitrate loss rates (up to 5mg/L NO_3-N). The leaching rates of other nutrients were also observed to have substantially increased with hexazinone treatment because of the increased runoff. However, apart from nitrate, the only nutrients that increased in drainage concentration were chloride, magnesium and potassium.

Hexazinone has also been observed to indirectly cause the death of fish in pond systems (Anderson, 1982). Hexazinone at a concentration of 1mg/L killed the aquatic vegetation. Subsequent decomposition of the organic matter stripped the oxygen from the water column in five days resulting in fish mortality.

2.2.2 Toxicology

The impact of hexazinone on aquatic macrophytes and aquatic and terrestrial invertebrates was investigated after it was applied to less than 5% of a second order forested catchment (Mayack et al., 1982). Concentrations of the herbicide and its residues were generally below 1mg/L, but intermittently during storm runoff, reached between 6 and 44mg/L. Detection of hexazinone in stream vegetation and aquatic macro-invertebrates was very sporadic and at very low concentrations. There appeared to be no biocumulation of hexazinone. No discernible changes within the aquatic macro-invertebrate community were observed. In the terrestrial macro-invertebrates hexazinone and its metabolites did accumulate to one or two orders of magnitude above that of the forest litter. However, the macro-invertebrate samples were too small to conduct meaningful community diversity and similarity studies. Sampling eight months after application of the herbicide suggested that there were no major changes in the terrestrial micro-arthropod communities.

The data on the toxicity of hexazinone are fairly limited. Results from laboratory toxicity studies on some individual species have been reported (Mayer et al.,1986; U.S. Dept of Agriculture, Forest Service, 1984; Wan et al., 1988). Generally hexazinone is reported to be practically non-toxic to slightly toxic to mammals (LD50 of 500 to over 2000mg/kg), practically non-toxic to birds (LD50 over 2000mg/kg), practically non-toxic to soil micro-organisms (LD50 of 500 to over 100mg/kg) although data are scarce, slightly toxic to practically non-toxic to aquatic invertebrates (LC50 of 10 to over 100mg/L) and practically non-toxic to fish (LC50 of over 100mg/L). The inhibition of some aquatic algal species has been recorded at concentrations of 0.5 to 1.0mg/L hexazinone. Results from laboratory tests indicate that hexazinone is neither mutagenic nor carcinogenic to mammals.

2.2.3 Impacts

Apart from experimental trials there appears to be very little information regarding hexazinone contamination of the environment as a result of normal uses. A survey of pesticides in groundwater conducted by the United States Environmental Protection Agency has detected hexazinone contamination in at least one State as a result of field uses but the concentrations were well below known toxicity levels or the maximum recommended levels for human health.

2.3 Summary

Both of the herbicides used have been tested or monitored for effects on a range of organisms and the toxicology has been largely established. The toxicological data suggest that these chemicals should not be applied directly onto open water bodies because of potentially lethal or inhibitory effects on some of the more sensitive aquatic organisms. In particular, the effects of atrazine on the aquatic invertebrates, aquatic microbes and fish, particularly at the egg and juvenile stages, is of concern. The evidence suggests that the aquatic animals most likely to dominate the stream fauna in the Nannup/Collie region, are those that are also most likely to be sensitive to atrazine contamination.

Both herbicides do not appear to bioaccumulate in the food chain, but bioconcentration of atrazine in phytoplankton and hexazinone in terrestrial invertebrates was reported.

Hexazinone appears to be very mobile in soil and can be transported by groundwater flow. It therefore has the potential to damage vegetation outside the targeted area, particularly on sandy soils.

The mobility of these herbicides indicates that with regular use there is a potential for accumulation in groundwater, as has been observed in the United States.

There is a lack of information for both toxicity and potential impacts of these herbicides on Australian species and environment. In the face of this lack of knowledge, priority should be given to monitoring the fate of pesticides (including these two herbicides) in our environment, particularly since many of the soils in Western Australia are highly leached sandy soils with high water tables.

In terms of human health there should be no adverse health risks from the use of these herbicides as long as they are used according to the registered label.

3 The investigation programme

After discussions between staff from CALM, the EPA and the Chemistry Centre of WA, a monitoring programme was developed to enable the environmental impacts of the proposed herbicide application programme to be assessed.

The programme involved monitoring herbicide loss outside the target areas during application, sampling stream water before and after herbicide application and monitoring the aquatic invertebrate density and species diversity both before and after application.

Monitoring of wind drift and misplacement outside the target boundaries was done jointly by CALM and the EPA. Water sample collection was the responsibility of local CALM officers. The EPA initiated monitoring of the stream fauna by contracting Mr Ivor Growns, a PhD student from Murdoch University, to conduct the study. The report is included as Appendix 2. All pesticide analyses were carried out by the Chemistry Centre of WA..

3.1 The objectives of the investigation programme

The main objective of the programme was to assess the environmental impacts of applying the proposed herbicides by helicopter. The investigation programme was also to assess the environmental impacts of these herbicides applied in the traditional manner.

Stream water quality and stream fauna were monitored at four of the proposed application sites to assess the impacts of the programme on the aquatic environment. At a fifth site, only stream water quality was monitored.

The potential for off-site loss of herbicides to affect algal growth in the Blackwood River was also assessed. Algal biomass in the smaller, often fast flowing and temporary streams draining the proposed herbicide application areas is negligible. The food chain is instead based on detrital inputs from vegetation in the surrounding catchment. Algae are likely to be a more important part of the food chain in the larger, slower flowing and permanent waterways such as the Blackwood River.

Losses of the herbicides outside the target areas during application was monitored to estimate the amount lost and the distance that the chemicals drifted. Several herbicide application methods are being monitored so that their environmental impacts can be compared. Recommendations can be made for future herbicide application programmes if any adverse environmental impacts are observed.

3.2 Site selection and description

The sites selected for herbicide treatment were all to have pine seedlings planted concurrently. Five of the sites were located adjacent to, or near natural waterways. There was a concern that these streams may receive deleterious concentrations of herbicides from either direct surface dusting by helicopters or surface and subsurface runoff. Consequently water samples were to be taken from all such streams and analysed for herbicide concentration.

To assess fully any potential impacts on the aquatic environment it was necessary to monitor both water quality and the invertebrate fauna. Four sites were selected for this assessment based on proximity to waterway, size of adjacent waterway, soil type, application method and proposed herbicide. The sites are known as Folly, Maidments, Grimwade and Bussell. Because of budgetary constraints a fifth site called Darrell was monitored only for water quality. The water course adjacent to this site was a major river, and therefore any herbicide leached off-site was considered, at that time, to be sufficiently diluted to have a negligible impact on the invertebrate fauna.

The Folly site (Figure 2) is located approximately 3km south of the Nannup townsite (Figure 1), in the upper catchment of a tributary to the Blackwood River. It has a steep topography with a loamy soil over granite rock. The underlying granite regularly outcrops on-site, particularly on the steeper valley sides. The target area covers 160ha and is situated on both sides of a stream flowing down the centre of the valley. The pine plantation previously covering this site had recently been burnt so the area was largely devoid of any vegetative cover. The herbicide proposed for this site was hexazinone, as Velpar 20G, applied in granule form at approximately 0.53kg/ha active ingredient. Because of the steep nature of the site herbicides had to be applied by hand. The method of application was by hand applicator delivering 0.4gm hexazinone around each individual seedling.

The Maidments site (Figure 3) covers 180ha of pastured loams which includes steep valleys to gently undulating flats. It is situated approximately 10km north-east of Nannup within the catchment of a small tributary which flows directly into the Blackwood River. On this site a small amount of Vorox AA (atrazine and amitrole) had been applied before the programme was referred to the EPA. The area receiving this application was small and remote from the stream. The majority of the catchment was sprayed with atrazine and hexazinone at 2.0kg/ha active ingredient and 1.5kg/ha active ingredient respectively. The method of application was by tractor-mounted boomspray which was curtained on all four sides and on the top to prevent loss by wind drift. The spray was applied as a strip along the rows of planted seedlings.

The stream draining this site flows directly into the Blackwood River and therefore also provided a good site to measure the effects of leached herbicides on algal growth.

The site at Grimwade (Figure 4) is approximately 15km east of Kirup townsite (Figure 1). It covers 136ha which includes the head waters of a small temporary tributary to Balingup Brook. The soils are sandy loams on an undulating topography and had been previously used to grow pines. The entire area was deep ripped on the contour.prior to herbicide application. Hexazinone was applied by helicopter to this site in a granulated form. Application was conducted at a height of 33 metres. The herbicide was applied at two slightly different rates averaging approximately 1.7kg/ha active ingredient as Velpar ULW over the whole site.

The fourth site, Bussell (Figure 5), is located approximately 19km south-west of Collie (Figure 1) near the south-eastern corner of the Wellington dam. The topography was undulating with loamy soils. The area to be treated was about 100m at its closest point from a nearby stream which ultimately entered Wellington Dam. The site was heavily vegetated with annual and perennial plants. The applied herbicide was hexazinone in a granulated form called Velpar ULW, and spread by helicopter at a height of approximately 33 metres above ground level. The application rate was approximately 1.6kg/ha active ingredient.

The fifth site, Darrell (Figure 6), is located 4km due north of Collie on the banks of the Collie River. The site covers 100ha of pastured land on an undulating topography. The soils are alluvial loams near the river to lateritic on the ridges. There is also a small intermittent stream leaving this site and entering the Collie River. A 200 metre buffer zone was placed between the Collie River and the treated area. Both atrazine and hexazinone were applied to this site by helicopter at active ingredient rates of 5.2kg/ha atrazine and 1.5kg/ha hexazinone. The herbicides were in a granulated form called Forest Mix.

Monitoring of these five sites enabled any detrimental environmental effects to be detected and also allowed some comparison between application methods in regard to herbicide loss to the aquatic environment.

3.3 Methods

To monitor any wind drift or mis-targeting of the helicopter applied herbicide granules, bucket traps were placed at discrete intervals along transects perpendicular to target boundaries and streams on the Bussell and Grimwade sites (Figures 4 and 5). The buckets were placed at five metre intervals across both boundaries and streams and gradually increased to twenty metre intervals with distance. Any granules found in the buckets were then collected, weighed and mapped to ascertain the distribution of any drift.

Water samples were collected in decontaminated and sealed glass bottles received from the analytical laboratories of the Chemistry Centre of WA to ensure that no contamination of water samples occurred. Samples were stored in the dark, kept cool and then sent to the Chemistry Centre laboratories for analysis as soon as was possible.

Water samples were analysed for the herbicides atrazine and hexazinone, using the same method. Analysis required two litres of the sample to be extracted with dichloromethane after the addition of 20 grams of Na_2SO_4. The solvent was then changed into hexane and evaporated to 4mL. The resultant solution was then put through two capillary columns (DB1 and DB1701) in a gas chromatograph and monitored on two channels to measure the herbicide concentrations. Further details on the method of analysis can be obtained from the Chemistry Centre.

Streams adjacent to target areas were to be sampled prior to application and for the first four storms after application as outlined in Appendix 1.

The invertebrate fauna in the adjacent streams were sampled prior to application and also approximately two weeks after the first major rainfall following completion of the application programme at each site. At all sites except Grimwade the stream fauna was sampled upstream from the target area, to function as a control, and also downstream. At Grimwade the fauna were only sampled downstream of the application area. At Maidments two downstream sites were sampled, site 1 was a small stream that had herbicide applied to most of the catchment and site 2 was in the main stream, downstream of the target area.

Ten replicate samples were taken randomly within the riffle zone of each sampling site at each sampling occasion and species number and diversity were recorded. An analysis of variance was used to test the statistical significance of any differences before and after application and between the control and treated areas. Further details on the invertebrate sampling and analytical methods used in the interpretation of the results have been supplied in the report in Appendix 2.

The potential for herbicide loss from the Maidments site to affect algal growth in the Blackwood River was ascertained using diatometers (glass algal growth plates). Growth plates were placed on the west bank of the river about 100 metres above and below the mouth of the Maidments tributary. Six plates were sampled from each position at approximately fortnightly intervals, oven dried and weighed to determine algal biomass. Sampling began during the application programme and continued until well after the programme was completed.

3.4 Results

Herbicide drift outside the target area was monitored jointly by the EPA and CALM at the Grimwade and Bussell sites. The results are presented in tables 1 and 2. There were no significant quantities of herbicide caught in the traps outside the target areas or within the 20 metre stream buffers, indicating that wind drift and/or mis-targeting by the helicopter was minimal. The trace amounts recovered from some of the buckets may have been the remnants of the initial calibration exercise. However, observations at other sites indicated that the Forest Mix granules (hexazinone and atrazine) had a tendency to crumble,. and as a result some dust which probably contained herbicide was lost to wind drift.

Hexazinone was detected at relatively low concentrations in stream runoff from all sites. Atrazine was detected in runoff from all sites where it had been applied and also at some sites which had not recently received atrazine. However, since the only detection at the Bussell site of both hexazinone and atrazine (which was not applied) was upstream of the treatment area, and on the day of application, the possibility of a contaminated sample from this site can not be ruled out.

	A	B	C	D	E
	(g)	(g)	(g)	(g)	(g)
1	0	0.019	T	0.396	T
2	0	T	T	0.267	0.110
3	0	T	0	0.119	0.205
4	0	T	0.003	0.085	0.327
5	0	T	0.068	0.154	0.091
6	0	T	0.166	0.172	0.185
7	0	0	0.101	0.132	0.120
8	0.001	T		0.179	0.195
9	T	T		0.211	
10	T	0.001		0.431	
11	T	T		0.339	
12	0.012	T		0.304	
13				0.291	
14				0.342	
15				0.446	

Table 1: Weight of herbicide granules caught in traps within each transect (A-E) at the Grimwade site (Figure 4)

	A	B
	(g)	(g)
1	0.027	0.172
2	0.011	0.185
3	0.010	0.180
4	T	0.110
5	0.004	0.150
6	0	0.084
7	T	0.153
8	T	0.327
9	0	0.158
10	0	0.355
11	0	0.223
12		0.176
13		0.204
14		0.375
15		0.254

Table 2: Weight of herbicide granules caught in traps within each transect (A and B) at the Bussell site (Figure 5)

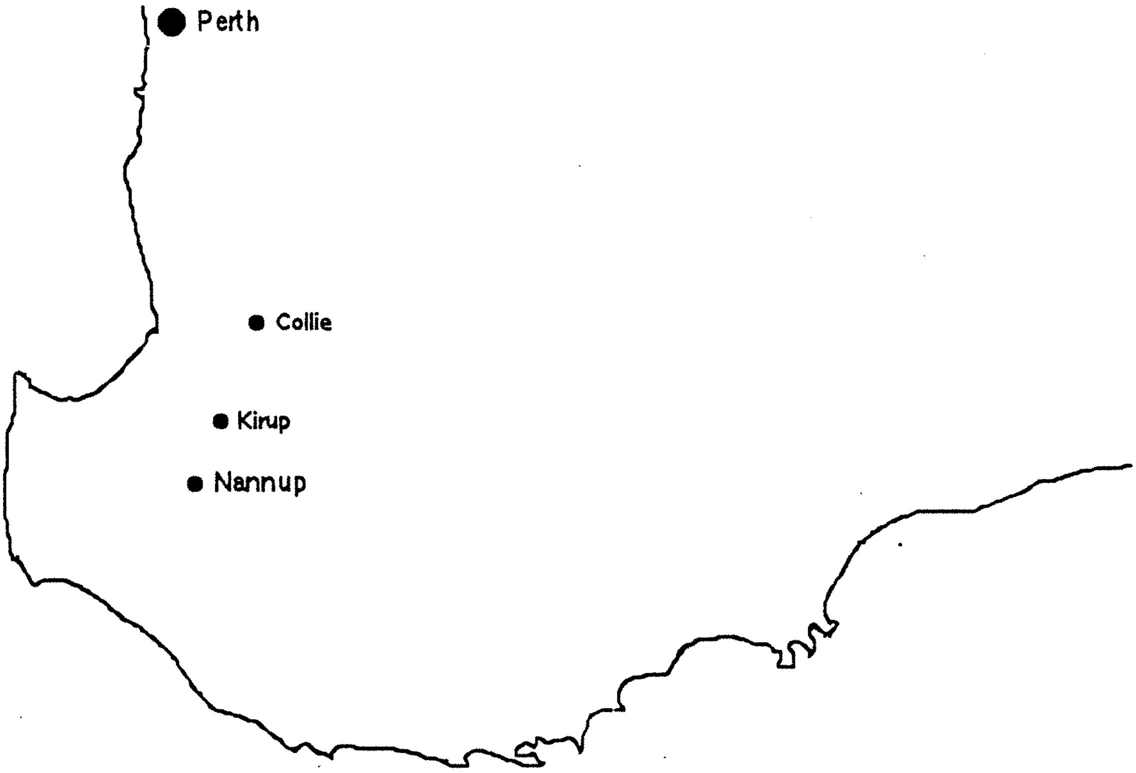


Figure 1: Location map

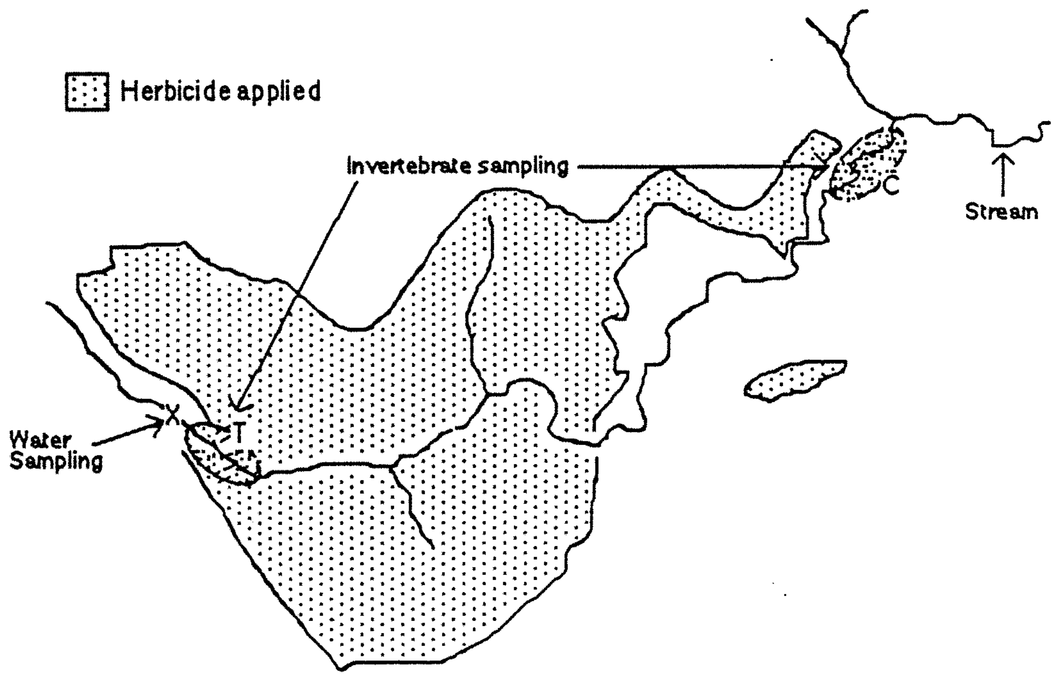


Figure 2: Folly site

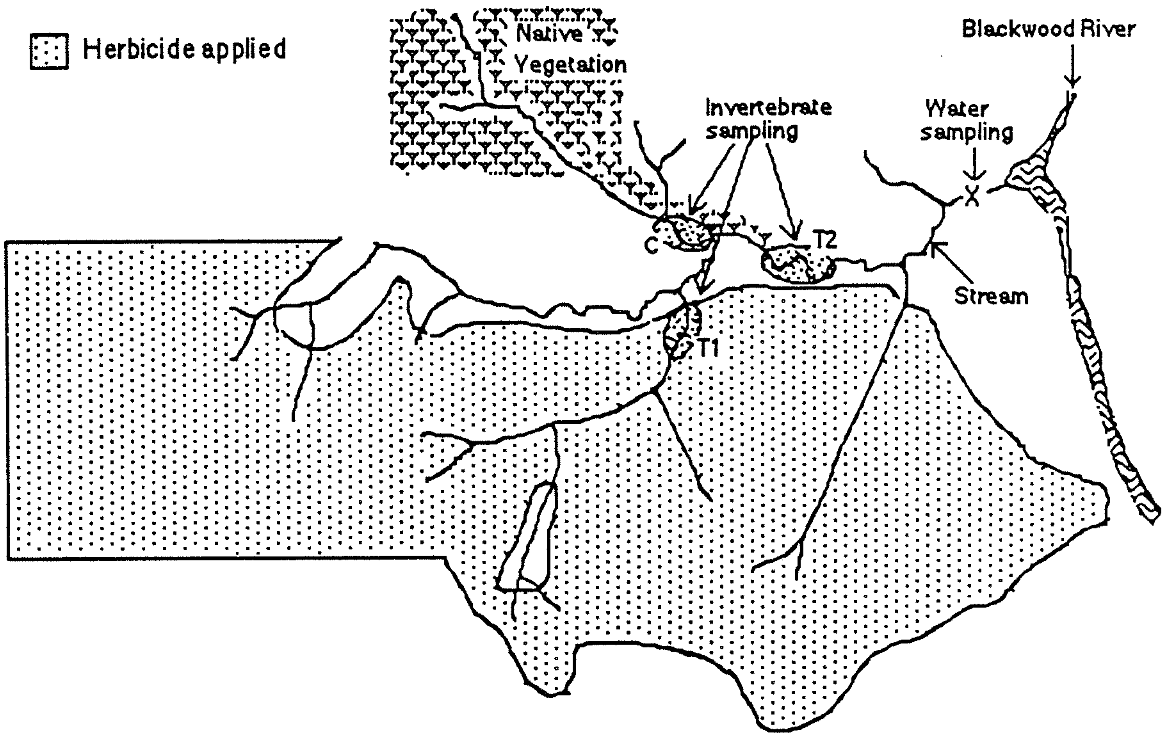


Figure 3: Maidments site

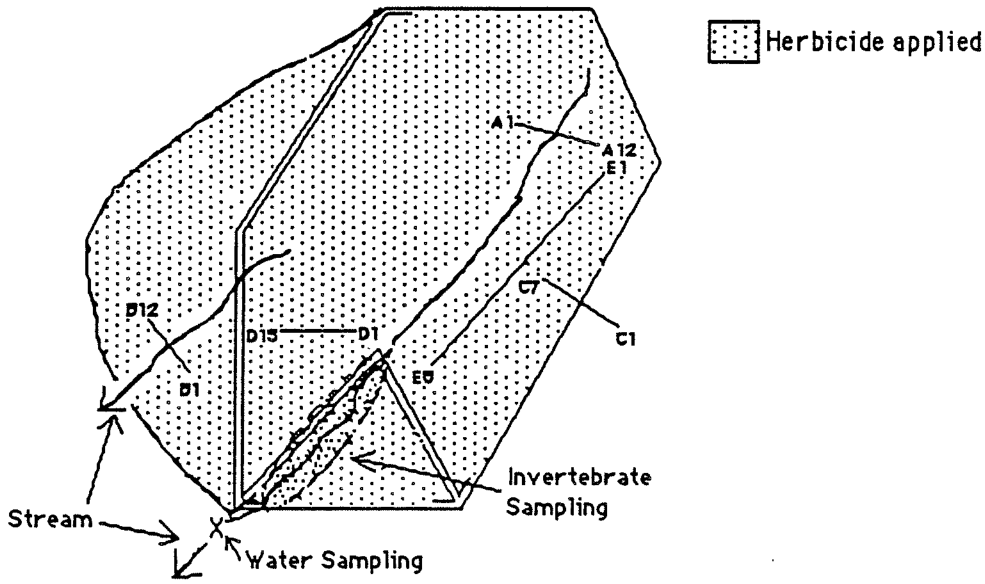


Figure 4: Grimwade site

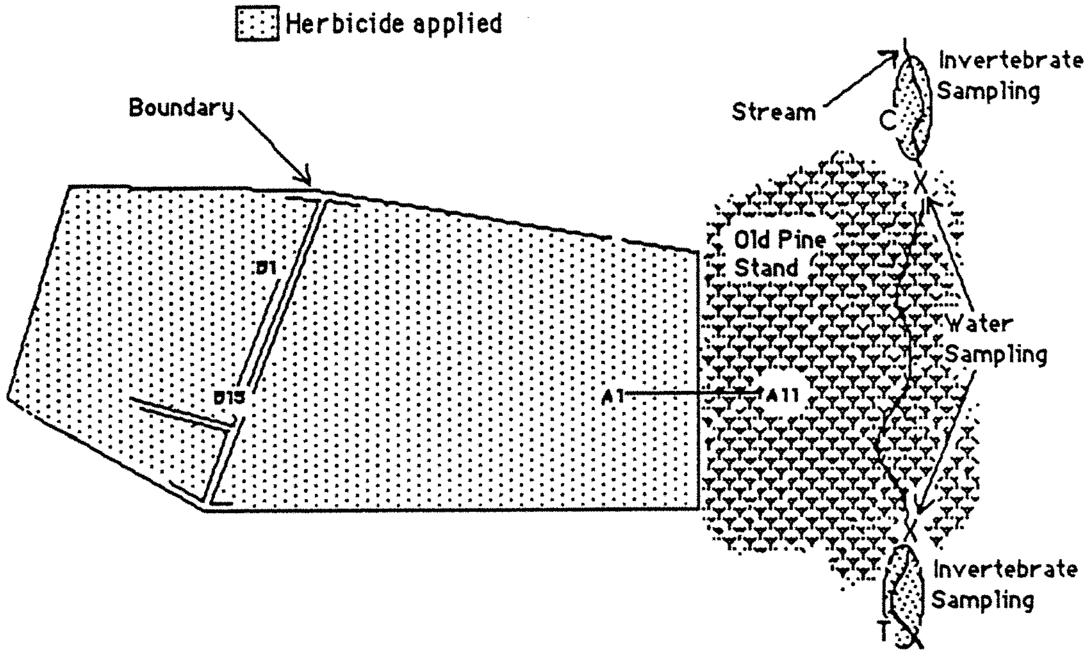


Figure 5: Bussell site

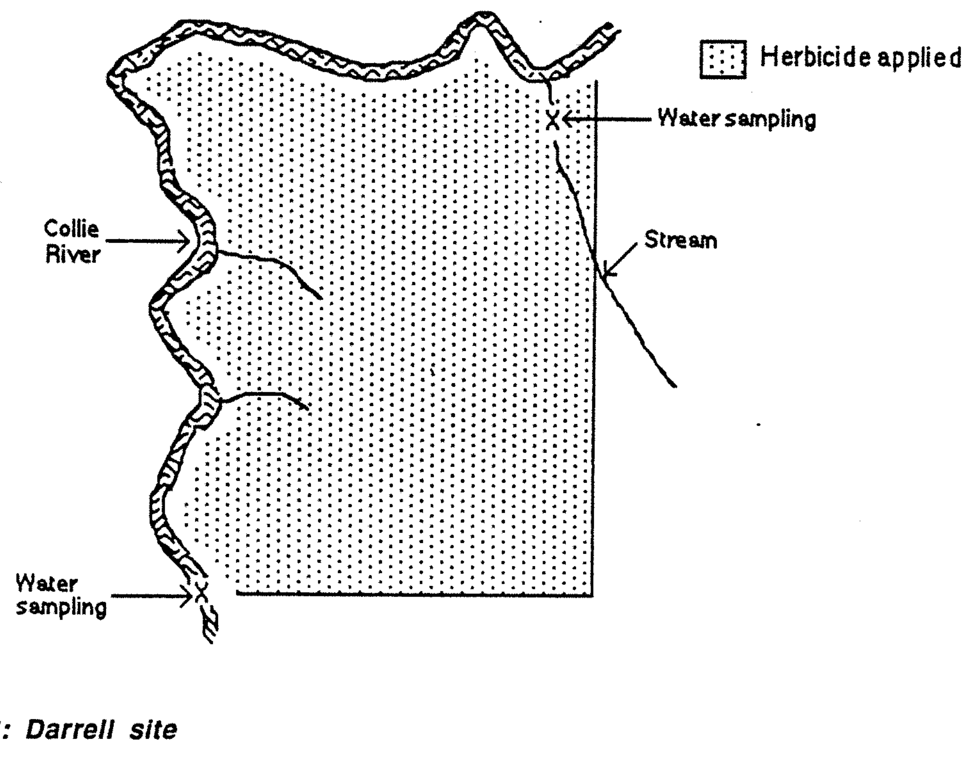


Figure 6: Darrell site

3.4.1 Folly site

At the Folly site herbicide was applied over approximately three weeks from about 27 July 1989. Stream sampling at this site was unfortunately very sporadic, but hexazinone was detected at low concentration on one sampling occasion (Figure 7).

The observed concentrations are unlikely to have had any significant impact on the stream fauna. However, the invertebrate monitoring has shown a marked decline in both abundance and diversity downstream of the site compared to the upstream control (Figures 8 and 9).

This change in the stream invertebrate population cannot be explained by the observed concentration data, but since there is a wide time span where no samples were collected it is not possible to exclude hexazinone as the cause. As seen in Figure 20 there were significant falls of rain between the period of herbicide application and time of sampling. Given the steep slopes of this site it is possible that runoff during these events could have flushed hexazinone granules into the stream, temporarily elevating concentrations sufficiently to kill the invertebrates or increase drift. Another more plausible explanation is that the heavy rainfall in mid August, which was observed to have eroded the bare slopes, carried a heavy sediment load to the stream, and as a consequence invertebrates may have drifted downstream as an avoidance mechanism. This would not explain the disappearance of at least one of the species (*Tasmanocoenis tillyardi*) which is tolerant of high sediment habitats.

3.4.2 Maidments site

At the Maidments site both hexazinone and atrazine were detected downstream of the target area (Figure 10). Again concentrations were not very high, however, there is some evidence suggesting that the small intermittent runnels at the head of the catchment may have contained significantly higher levels of herbicides for short periods during heavy rainfall. These runnels only contain runoff during rainfall events. An independent sample from one of these intermittent runnels on 26 July contained 22mg/L atrazine and 5.8mg/L hexazinone. Some dilution can be expected downstream, particularly since only part of the stream catchment was sprayed. A sample taken downstream during the same event but the day before measured 1.3 and 2.3mg/L atrazine and hexazinone respectively. Likewise a downstream sample two days after measured 1.4 and 3.5mg/L atrazine and hexazinone respectively.

The invertebrate study showed no significant reduction in abundance between the control and treatment sites but species diversity was significantly affected at both sampling sites downstream of sprayed areas (Figures 11 and 12). Sediment load is unlikely to have contributed to this decline indicating that it may be a result of the presence of herbicides.

Several samples were collected from the Blackwood River downstream from the Maidments site. In these samples atrazine and hexazinone were not found at detectable concentrations by the Chemistry Centre of WA.

The algal growth data from the diatometers placed in the Blackwood River upstream and downstream from the Maidments site have been listed in Table 3. Statistical analysis of the data for the entire sampling period shows that there is no significant difference in algal growth between the two sites at the 95% confidence level (Table 4), or at each sampling date. The results do not give any indication that algal production within the river system was affected by herbicides leached from this site.

Date	Upstream (g)	Downstream (g)
07/07/89	0.0087	0.00783
2107/89	0.0105	0.01066
28/07/89	0.011	0.01183
11/08/89	0.0133	0.013
25/08/89	0.0136	0.01366
06/08/89		0.014
Average	0.01142	0.01183

Table 3: Average algal biomass recorded from the diatometer growth plates in the Blackwood River

Source of variation	Sum of squares	Degrees of freedom	Mean square	F value	Probability
Up vs. Down	0.0000	1	0.0000	0.72	0.405
Residual	0.0004	70	0.0000		
Total	0.0004	71			

Table 4: Analysis of variance for algal growth in the Blackwood River upstream and downstream of the Maidments site

3.4.3 Grimwade site

At Grimwade there was no control sampling site because the entire catchment of the small tributary was to have herbicide applied. The observed herbicide concentrations (Figure 13) were relatively low during and after application and therefore an adverse impact on the stream fauna was not expected.

Detection of atrazine at low concentrations was unexpected since it was not applied as part of the programme. Its presence indicates that there may be a residual component of this herbicide remaining in the soil from previous applications in the catchment two years ago or it may be a result of spraying firebreaks on 5 July 1989. The herbicides used on the firebreaks were 2kg/ha atrazine and 1.5kg/ha hexazinone.

The data on the stream fauna in Figures 14 and 15 show a significant increase in abundance and a smaller increase in diversity post-treatment. This is considered to be a result of the temporary nature of the stream. Because the stream only exists for a short period after the onset of winter, colonisation can only occur at this time, and hence the dramatic increase in abundance between sampling occasions.

3.4.4 Bussell site

None of the herbicides were detected at the Bussell site (Figure 16) after application occurred on 4 July, however, the invertebrate data from the adjacent stream does indicate a small effect downstream of the treated site. There was a significant increase with time in both abundance and diversity of the invertebrate fauna upstream of the site, whereas abundance and diversity downstream showed no significant increase with time (Figures 17 and 18).

This may be a function of the large forested buffer between the target area and the stream. The samples that did contain herbicide are an anomaly. Since atrazine was not applied to this site, contamination by aerial means seems unlikely. Instead, contamination of the sample must be considered as a possibility. The samples were collected before herbicide application began by an officer who had no contact with preparations for the programme. The catchment upstream of the site apparently has not received herbicides for at least 20 years, if at all.

3.4.5 Darrell site

Water samples were also collected from the southern branch of the Collie River and from a stream at a site called Darrell. The samples were analysed for both atrazine and hexazinone as shown in Figure 19a and 19b. The treatment area drained directly into the Collie River. The catchment of the sampled stream included a small portion of the treated area.

The concentrations of atrazine observed in the river on 24 July were very high and exceeded what would normally be considered as a safe limit for the maintenance and preservation of aquatic ecosystems (Department of Conservation Environment, 1981), but were unlikely to be sufficiently high to kill the aquatic fauna. The samples were taken in a wet period during a sudden heavy fall of rain (18mm) (Figure 20a) from the side of the river and directly downstream of the application area. Given the volume of water flowing down the river and the relatively small area that received herbicide, it seems unlikely that the entire river flow could become so contaminated. Considering the position of the sample site it is likely that the sample was taken from an unmixed plume of surface runoff from the application area.

The frequency of water sampling in the streams at all five of the above locations was not very high, but nevertheless when peaks in concentration are compared with the rainfall record (Figures 20a and 20b) they coincide with periods of significant rainfall. This is consistent with other studies which have shown that herbicide export to drainage channels is greatest during the first major runoff after application (Neary et al., 1983). After the first major runoff Neary found that concentration of herbicide residues in subsequent runoff declined as a power curve function.

4 Environmental assessment of the herbicide application programme

4.1 Drawbacks of the assessment

The monitoring was designed to assess, with the limited resources available, the impact of the herbicide application programme on the surrounding environment. Although the results are adequate to assess the programme, a more intensive monitoring programme would be required to fully assess the impacts and fate of these herbicides in the natural environment. For example, stream water sampling is required at regular intervals, particularly during runoff events, for the entire wet season to detect pulses in herbicide concentration and to understand the nature of herbicide loss to streams. Information on invertebrate drift in the streams associated with herbicide pulses would have been useful. A longer term sampling programme would have provided information on the rate of recovery of any herbicide affected environments. Information on the toxicity of these herbicides to local biota is essential. Data on herbicide movement through, and persistence in, local soil profiles is essential in determining the long-term impacts of herbicides. The impacts of these chemicals on local soil microbial communities and hence soil bio-chemistry, may indirectly impact on downstream water quality.

The application sites in this programme had all been highly disturbed and were no longer in their natural state and hence had little conservation value. However, the downstream river environments are considered to be of high conservation value and require protection. These environments act as 'garbage collectors' for much of what is applied to the catchments up-stream. Consequently they are at the mercy of catchment land uses and become polluted and unhealthy when their capacity to assimilate pollutant material is exceeded. Often low levels of pollutants can be either tolerated or assimilated by the system. It is vital that all land uses within the catchments are managed so that these levels are never exceeded and that is why further investigations in regard to pesticides in the environment are required.

4.2 Terrestrial environment

The use of helicopters to apply granulated herbicides to large areas appears to be an economic alternative. From the results of the bucket traps placed in transects across some boundaries and streams it appears that granulated herbicide application by helicopter can be acceptably precise if the conditions of application are tightly controlled within the constraints used in the current programme. For example: the boundaries of the target areas, including any buffer zones must be clearly marked for aerial view; buffer zones must be of an adequate size to prevent herbicide from drifting outside the target area; meteorological conditions must be constantly monitored during operations; and operations halted if conditions become likely to transport herbicide off-site (eg. winds, including gusts, exceeding 15km/hr at target level). A detailed list of control conditions have been listed in CALM's internal report AIRWEED 89 and included in Appendix 1.

The rates of herbicide application used in this programme are within the range that have been reported to induce both inhibitory and stimulatory effects on soil micro-organisms. In the experimental trials conducted by Neary a hexazinone application of 1.68kg/ha affected soil denitrification such that stream nitrate concentrations were increased four fold. Nitrate export rates were increased by two orders of magnitude, which was one order of magnitude more than the increase in export rates of all the other nutrients.

The impact of these herbicides on soil micro-organisms and subsequent nitrate concentrations in stream runoff was not monitored in this investigation. Certainly any increase in nutrient loss rates (particularly of phosphorus) within catchments to waterbodies is cause for concern, particularly for the shallow water bodies of WA.

This same application rate was reported to have resulted in terrestrial macro-invertebrates bioconcentrating hexazinone to two orders of magnitude above the concentration in the surrounding litter material. However, the terrestrial micro-arthropod community remained essentially unaltered. There is very little toxicity data on these herbicides available for terrestrial invertebrates and none for Australian species. For this reason, and because all sites were highly altered from their natural condition, the terrestrial invertebrate fauna were not monitored during and after herbicide application.

Exposure of native mammals and birds to the chemicals is most likely to be by consumption in either vegetation or invertebrates. The likely dose rates are below the rates that have been reported as causing chronic effects in laboratory animals. There are no data on chronic and acute toxicity to native mammals.

4.3 Aquatic environment

The results from the bucket traps placed in transects across the streams showed at most trace quantities of herbicides being top-dressed directly over the waterways by helicopter application. This would have led to a negligible increase in hexazinone concentration in stream water. Instead, as Neary observed and as experienced with nutrient leaching, the highest herbicide concentrations were associated with runoff from the treated catchments entering the streams. In larger streams where only a portion of the catchment had received herbicide, Neary found that concentrations were diluted and occurred in unpredictable pulses.

Unfortunately the instream sampling record for herbicide concentrations was rather sporadic and incomplete. Generally the concentrations of both herbicides measured in the streams were below the concentrations reported in the literature to adversely effect the aquatic environment.

Atrazine concentrations were 2µg/L or less, except for one pulse at the Darrell site which almost reached 40µg/L and an independent sample taken during heavy rainfall at the Maidments site. These concentrations did exceed the Western Australian water quality criteria for the maintenance and preservation of aquatic ecosystems (Depart. Cons. and Environ., 1981). These criteria stipulate that pesticide concentrations should not exceed 0.01 of the 96 hr LC_{50} of the test organism. In this case, since there are no toxicity data for the local fauna, the LC_{50} for the most sensitive species in the literature was used. This test species was the larvae of a chironomid midge (*Chironomus tentans*) with a 48 hr LC_{50} of 720µg/L

The literature indicates that a concentration of about 20µg/L may negatively affect aquatic microbial communities and aquatic insect communities. Concentrations as low as 10µg/L were also found to inhibit some algal species. However, these effects were observed under conditions of constant exposure to atrazine and not occasional pulses such as in stream environments. There is no information on the effects of atrazine under these conditions, particularly in the Australian environment. It is likely that given the pulse-like nature of these events and the limited area over which they occurred, any effects on the aquatic communities would be temporary.

Concentrations of hexazinone were generally slightly higher than atrazine, reaching approximately 5μg/L but with a pulse at the Darrell site reaching almost 20μg/L. This was below the recommended water quality criteria for Western Australian, calculated to be about 500μg/L. In the study by Mayack (Mayack et al, 1982) it was reported that hexazinone pulses of 6 - 44μg/L had no effect on the aquatic floral and faunal communities. Hexazinone was only detected sporadically by Mayack and at very low concentrations in samples of the flora and fauna.

The results of the invertebrate monitoring programme (Appendix 2) showed a statistically significant reduction in average species richness at the Maidments site and a decrease in both species richness and invertebrate abundance at the Folly site, downstream from the herbicide applied areas. The sampling intervals were not sufficient to determine whether this effect was long-term, or whether the invertebrate communities would quickly recover. The observed impact at these two sites was not expected given the findings of the cited literature. In Tasmania Cook found that reduction of invertebrate stream fauna from atrazine affected streams was the result of drift downstream to more tolerable environments rather than death. This may also explain the apparent changes in the aquatic invertebrate communities observed in this study.

It is possible that this change in community structure is the result of some other event affecting the downstream site and not the control site. The most likely alternative disturbance to herbicide concentration is increased sediment load from the target area. This was not observed at the Maidments site and there were no such observations for the Folly site. The catchment at Maidments was covered with pasture and some scrub both before and after treatment so that a significant increase in silt load to the stream was unlikely. At Folly the potential for siltation was much greater since the topography was steep and the vegetation cover was less dense. However, at this site *Tasmanocoenis tillyardi,* which is a silt tolerant species (Edward et al., 1986), was lost from the treatment site after herbicide application.

The evidence appears to indicate a negative effect of the herbicide on the invertebrates, but it is not conclusive since there is no toxicity data on the local species and the stream sampling for herbicide concentration was not sufficiently regular. In addition there was no sampling to determine whether the observed changes were temporary or long-term effects.

It is very unlikely that these herbicide application operations conducted by the Department of Conservation and Land Management had any significant and long lasting effect on the fauna and flora of the major rivers downstream because of the massive dilution factor. Certainly there was no effect on algal growth in the Blackwood River below the confluence with the Maidments catchment. Concentrations of both hexazinone and atrazine were below Chemistry Centre of WA detection limits in the Blackwood River both downstream of the Maidments site and at the river mouth. The high herbicide concentrations detected in the south branch of the Collie River, however, indicate a potential for some impact to occur where an unmixed plume may exist downstream from the confluence with a tributary. Under normal circumstances these events are likely to be short in duration and will affect a relatively small area

The areas receiving herbicide under the above operations were relatively small. Consideration needs to be given to the potential impacts of large-scale applications.

4.4 Human health

Chemicals that may affect human health and that are to be used publicly must first be approved at the national level by the National Health and Medical Research Council, and also by the associated State agency. In this context the Department of Health approved CALM's application to use the herbicides discussed here. The National Health and Medical Research Council also publish guidelines for drinking water quality in Australia that include maximum recommended levels for contaminants such as pesticides.

Of the two chemicals used in this programme, only atrazine has been the subject of particular human health concerns, but conclusive evidence is lacking. However, the information available to the EPA suggests that human contact with this chemical (and logically with any others) should be minimised.

These chemicals are commonly used in Australia and it would seem that there is no reason to prevent the use of these herbicides provided they are used with care, formulated correctly, and applied to the target plants. To ensure that no adverse off-site effects occur, a monitoring programme should be prepared and adhered to.

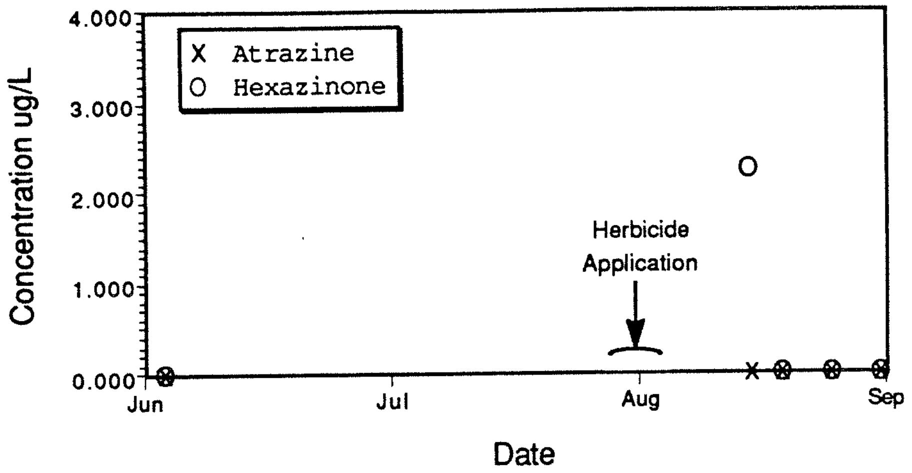


Figure 7: Downstream herbicide concentrations at the Folly site

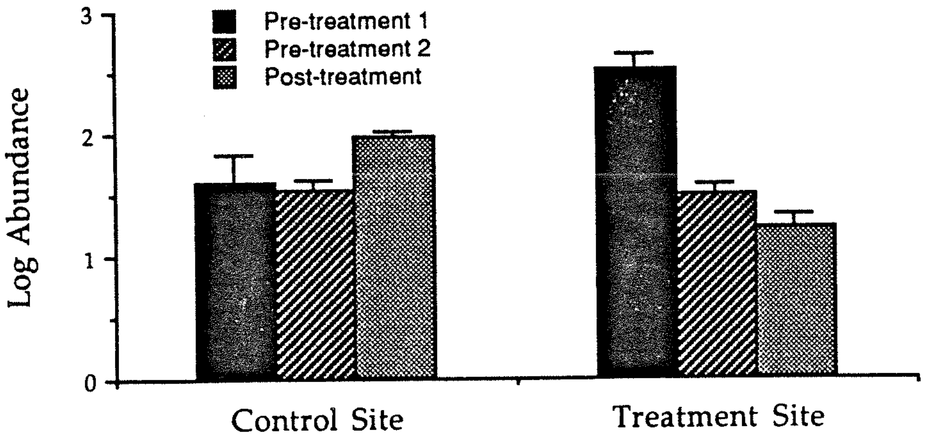


Figure 8: Change in abundance of the invertebrate fauna at the Folly site with standard errors shown

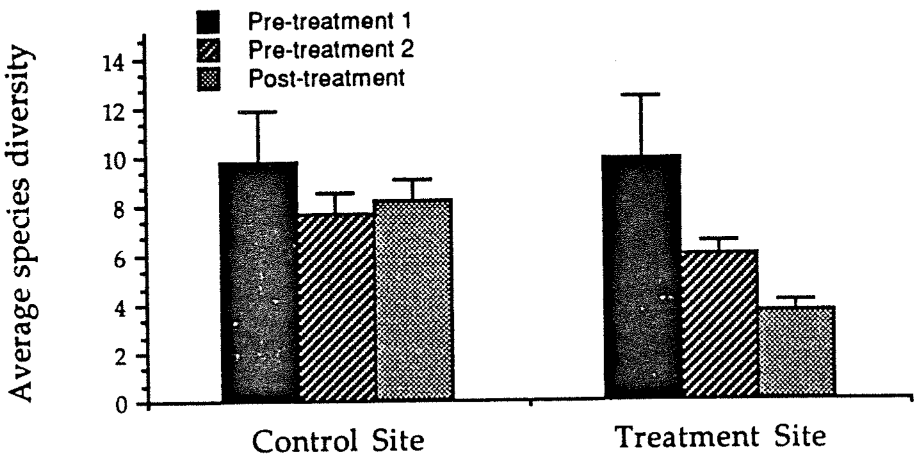


Figure 9: Change in diversity of the invertebrate fauna at the Folly site with standard errors shown

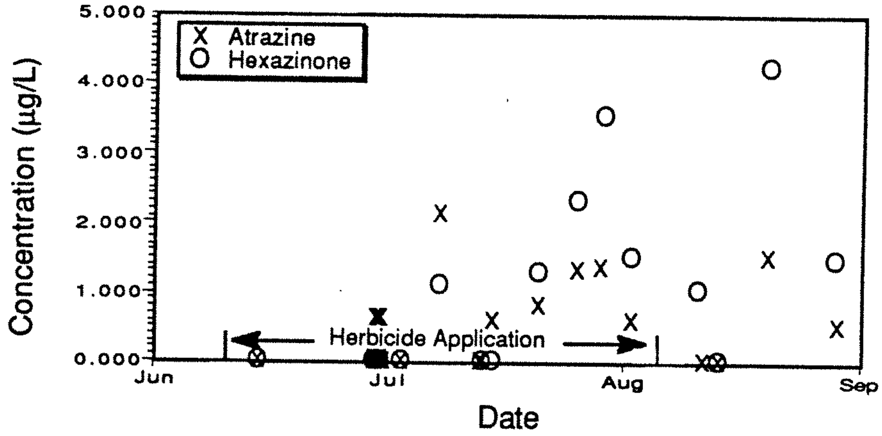


Figure 10: Downstream herbicide concentrations at the Maidments site

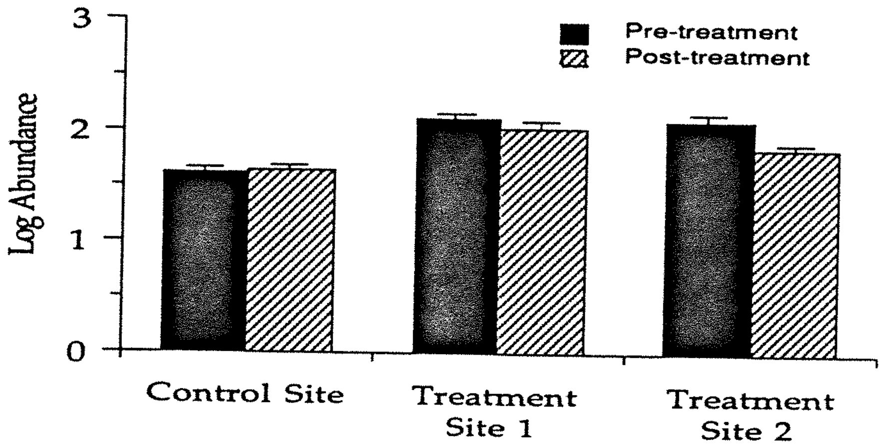


Figure 11: Change in abundance of the invertebrate fauna at the Maidments site with standard errors shown

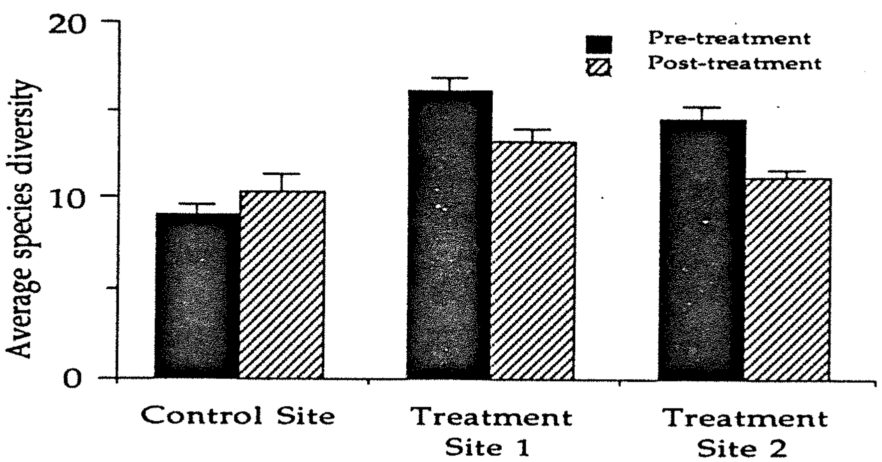


Figure 12: Change in diversity of the invertebrate fauna at the Maidments site with standard errors shown

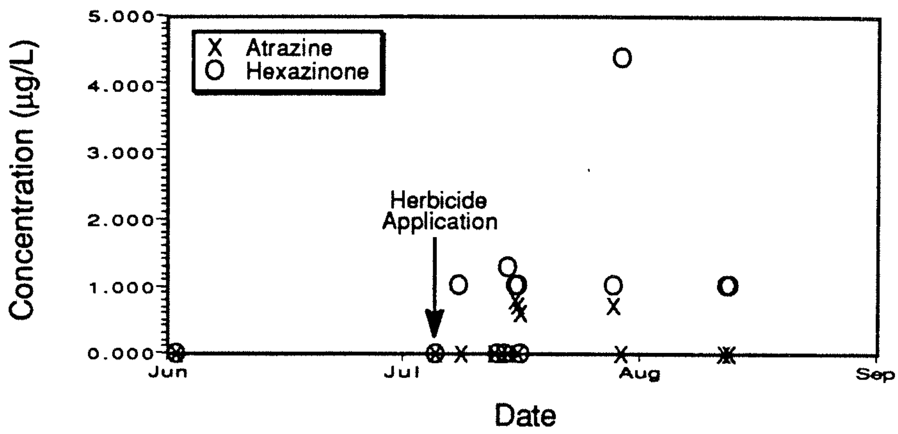


Figure 13: Downstream herbicide concentrations at the Grimwade site

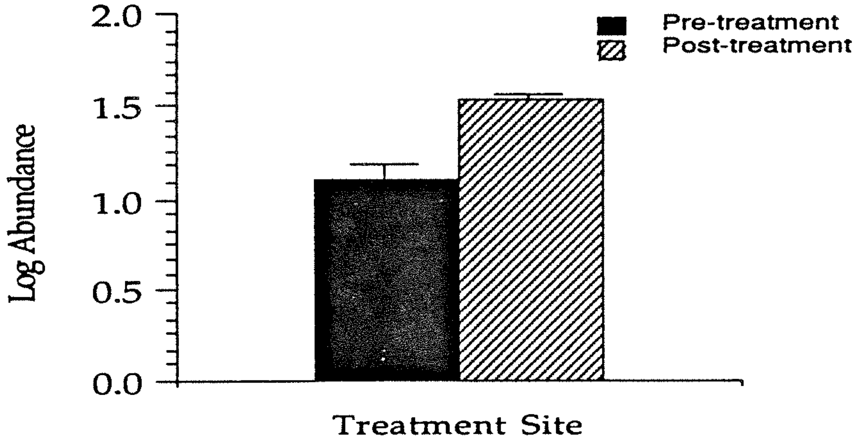


Figure 14: Change in abundance of the invertebrate fauna at the Grimwade site with standard errors shown

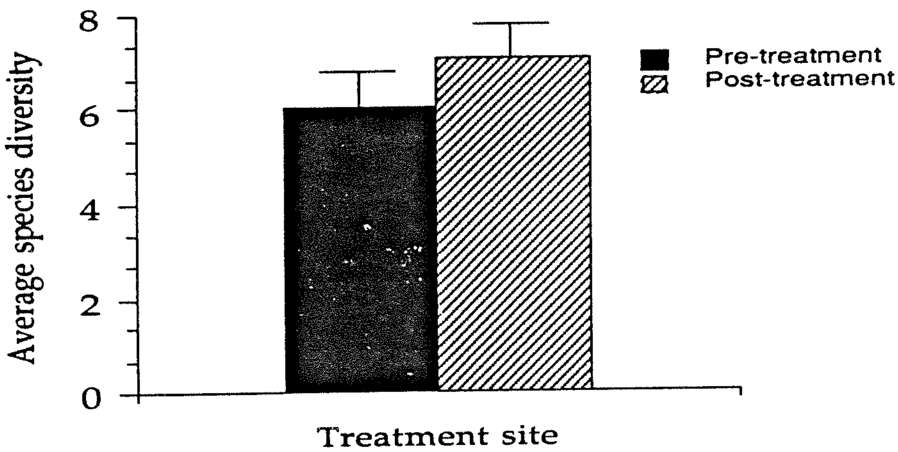


Figure 15: Change in diversity of the invertebrate fauna at the Grimwade site with standard errors shown

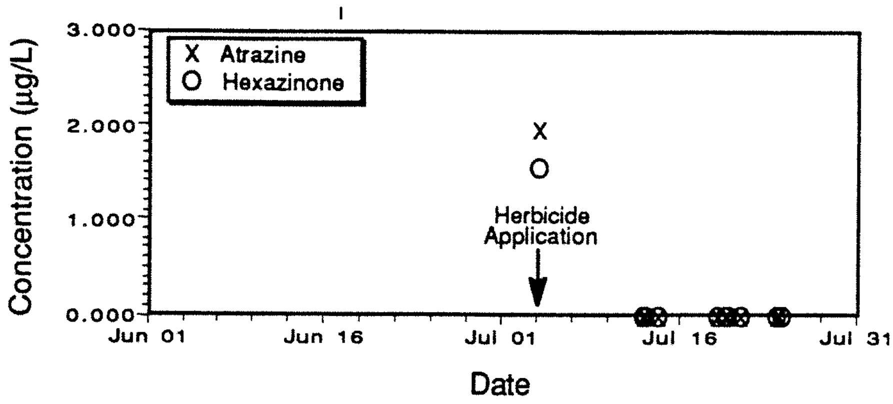


Figure 16: Upstream herbicide concentrations at the Bussell site

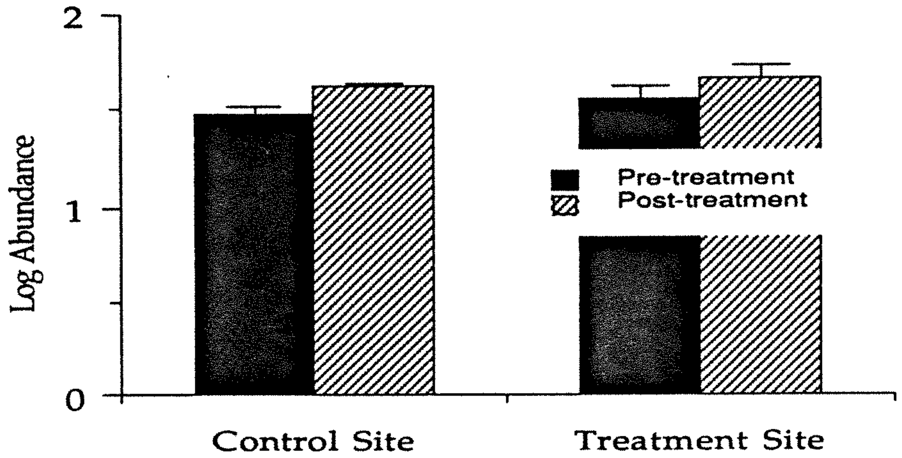


Figure 17: Change in abundance on the invertebrate fauna at the Bussell site with standard errors shown

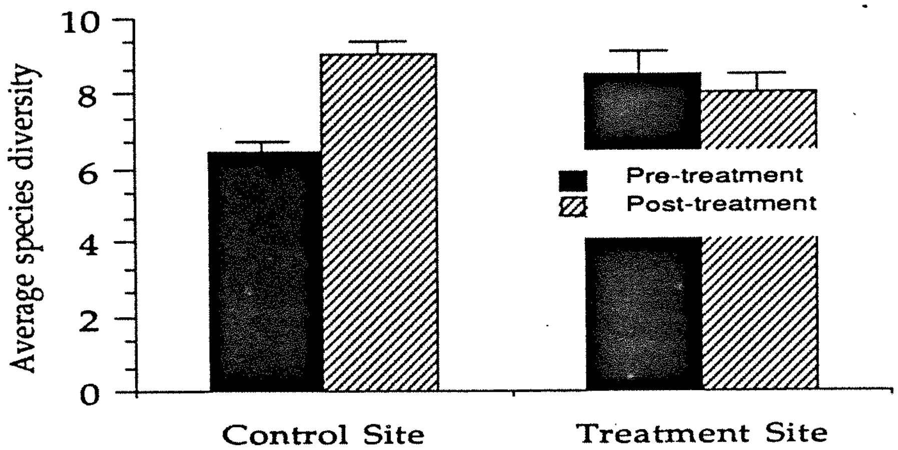


Figure 18: Change in diversity of the invertebrate fauna at the Bussell site with standard errors shown

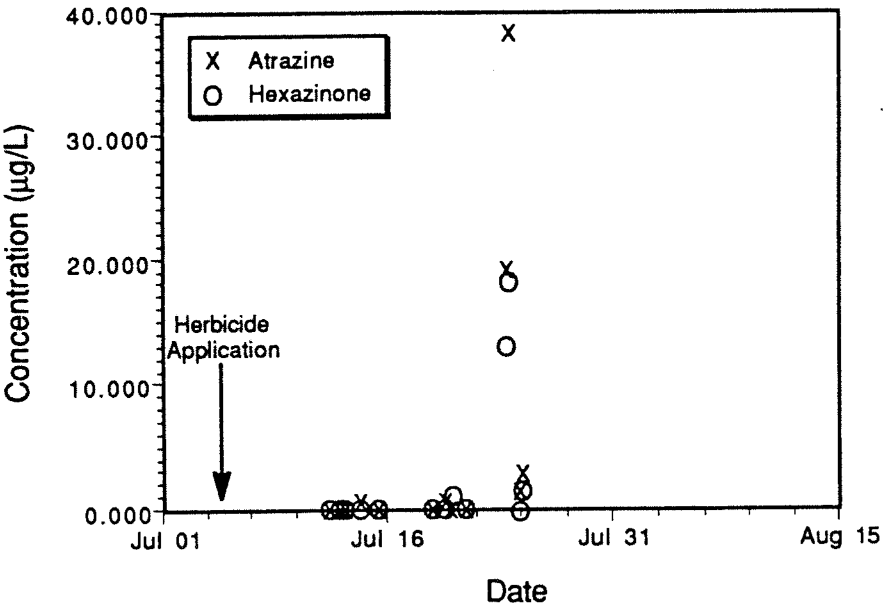


Figure 19a: Herbicide concentrations in the Collie River downstream of the Darrell site

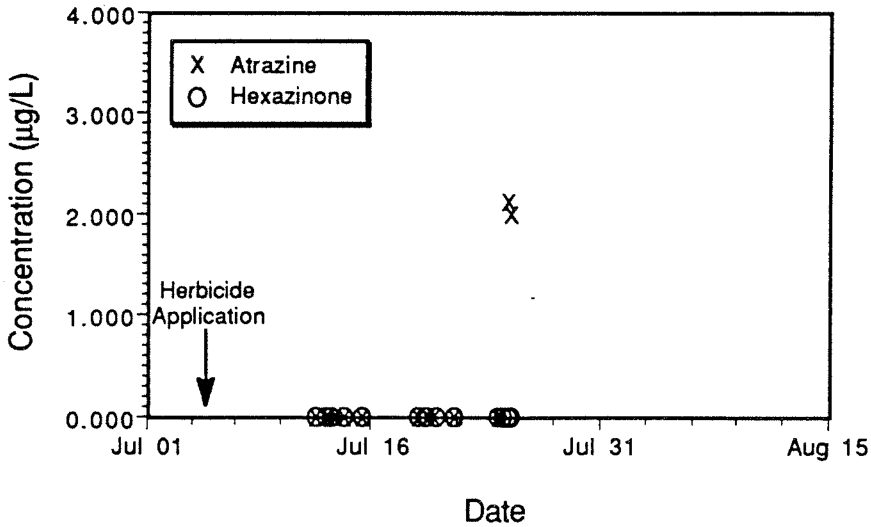
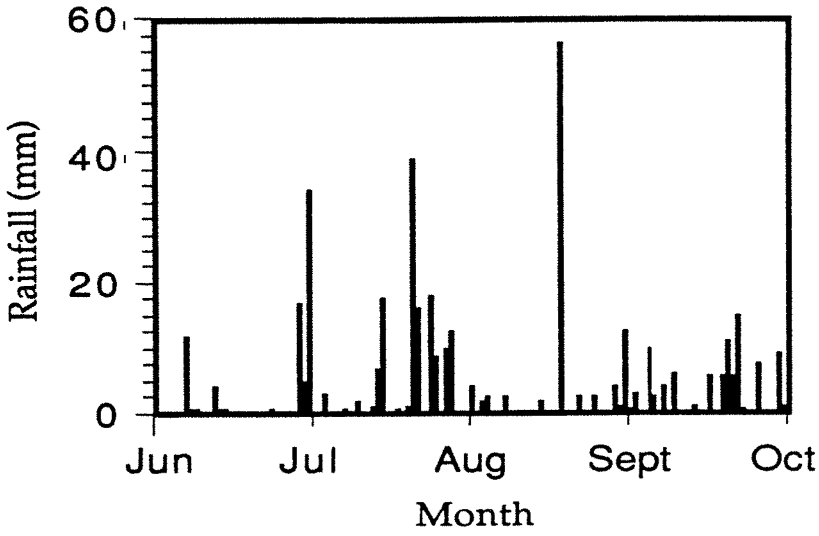
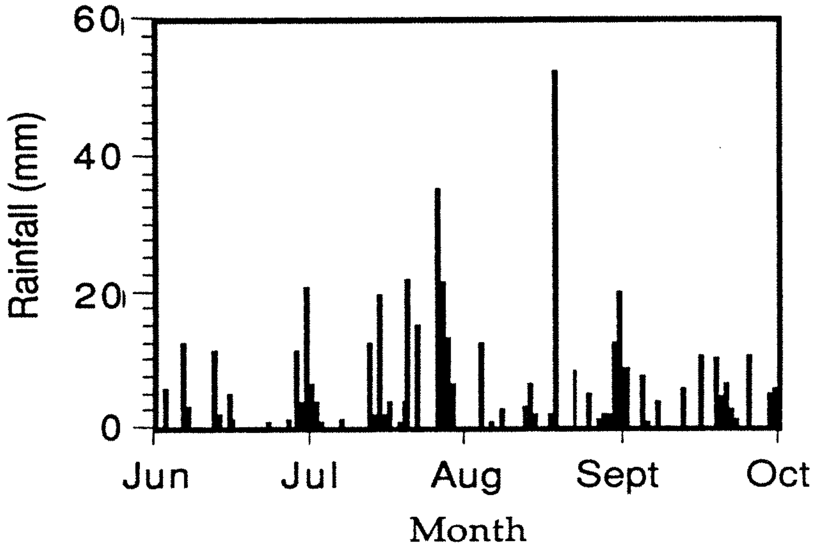


Figure 19b: Herbicide concentrations from a stream adjacent to the Darrell site



(a)



(b)

Figure 20: Daily rainfall data for (a) Collie and (b) Nannup (1989)

5 Conclusions

The results of this investigation indicate that after herbicide application significant off-site losses into the aquatic environment occurred no matter what the application method. These losses are considered to be a result of leaching processes rather than problems associated with application. Factors such as rainfall intensity and frequency, water saturation of the soil, soil type, topography, vegetation cover and buffer size are therefore implicated as the prime influencing parameters controlling export of the herbicides to the aquatic environment.

The results indicate that where herbicide is to be used, helicopter application of granulated formulations does not increase the risk of environmental contamination. Targeting of the application area by helicopter was reasonably accurate and therefore did not contribute significantly to any losses off-site. However, it is essential that the conditions for helicopter applications continue to be tightly controlled to ensure that off-site losses remain negligible. In addition granulated formulations that crumble into fine particles should be avoided. The observed problem of the Forest Mix formulation crumbling is now being rectified by the manufacturer. It should be stressed that the results and conclusions of this study, in respect to application by helicopter, apply only to application of granulated formulations of the chemicals and not liquid formulations.

The leached herbicides subsequently appear to have affected the aquatic invertebrates in the streams adjacent to some of the application areas. This is in spite of the fact that herbicide concentrations measured in these streams were lower than those quoted in the available literature as having an effect on aquatic invertebrates. Nevertheless, a decrease in invertebrate abundance was observed in the adjacent stream at one site, and a decrease in invertebrate diversity was observed in the adjacent streams of at least two sites. This disparity with the literature needs further investigation, but may be a result of the infrequent stream sampling missing the concentrated pulses of the herbicides, or the local species of aquatic invertebrates being particularly sensitive to these herbicides. To gain a more confident result on the impact of these herbicides in the surrounding environment, a greater resource input would be required in order to monitor more intensively over a longer period and to monitor a range of biological and physical environmental parameters.

It is not possible to fully assess the environmental impacts of these two herbicides in Western Australia from the information in this report alone. A great deal more information is required, not only of the environmental impacts, but on the efficacy, toxicity and the environmental fate of these chemicals in Western Australia. In regard to CALM's future herbicide application programmes, monitoring of the environmental impact and fate of the chemicals should be an integral part of the programmes with resources allocated accordingly. The results should be made available to the public. It is essential that the monitoring programme should cover the following issues:

- the long-term and short-term environmental impacts of the chemicals, particularly in the aquatic environment, outside the target areas;
- the environmental fate of the chemicals in both the long-term and short-term ie. in the soil, groundwater and surface runoff; and
- (in the case of granulated formulations applied by helicopter) wind drift or misplacement of the chemicals outside the target boundaries to ensure the continued accuracy of helicopter application and also to assess the cause of any off-site effects that may occur.

Since herbicide losses off-site mainly appear to be a result of leaching processes, any methods that reduce the amount of runoff into the adjacent drainage channels may also reduce the quantity of chemical lost to the aquatic environment. Hence practices such as deep ripping along the contour, leaving as much of the previous vegetation as possible (either alive or as debris) and leaving substantial buffers between the target areas and all drainage channels should also be investigated and carried out by CALM, provided the likely environmental impacts of these practices are not significant.

The impacts of this programme on the wider environment are unlikely to be significant considering the relatively small areas over which herbicide was applied. There is a potential for significantly large impacts to occur when entire catchments to larger streams and rivers have herbicides applied at the same time. This may already occur in some agricultural districts and is now possible in plantation forestry with the improved economics of helicopter application. It should be acknowledged, however, that CALM uses only a minor portion of the total quantity of pesticides used in Western Australia each year.

This investigation was very specific in that it has only addressed the direct impacts of two herbicides on the aquatic environment. Hence this report has not addressed the much wider issue of pesticides in the environment, although it does highlight the lack of local information on the effects of commonly used pesticides in Western Australia. In a recent report to the WA Environmental Protection Authority (Rutherford, 1989) pesticide monitoring in the State was reviewed. The report discussed a number of deficiencies in pesticide monitoring in the State and made recommendations accordingly. Two of the more important problems highlighted were:

- a lack of investigation into potential environmental impacts and the environmental fate of pesticides in WA; and
- no coordination of pesticide investigations conducted in the State.

These problems are not confined to WA. In New Zealand a recent discussion document on pesticide issues and options outlined a large number of problems over a wide range of issues including environmental and consumer safety monitoring (MacIntyre, 1989).

Since many pesticides, including the two herbicides in this investigation, are commonly used or recommended by a number of government bodies in Western Australia, the Government needs to give some consideration to the environmental implications of their use, and the coordination of the collection, interpretation and dissemination of information relating to environmental effects in WA.

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Appendix 1

Reproduced (with permission) from the
Department of Conservation and Land Management
internal report Airweed 89.

AIRWEED 89

A REPORT OF THE PROGRAMME

INTRODUCTION

In many parts of the world the use of helicopters to apply herbicides and fertilizers has become an integral part of silviculture. Helicopters have been used in New Zealand and the United States for over two decades to apply herbicides to control unwanted vegetation in commercial plantations. Helicopters offer the most effective means of applying herbicides to sites inaccessible to ground machinery. Confidence in the ability to apply herbicides accurately has come with advances in technology. With production rates expected to be between 4 and 10 times greater than tractor mounted equipment, helicopters have the potential to provide a safer method of applying herbicides (in terms of human exposure and environmental impact of herbicides). Traditionally, ground operations continue throughout the planting season, often under sub-optimun weather conditions, with the consequential increased probability of exposure of operators to herbicides and increased likelihood of off target movement.

Many of the soil active herbicides are now available in granulated form. These have distinct advantages over liquid formulations in that they are lighter, require no mixing, do not drift (provided there is no dust), easy to recover after spillage and there is no difficulty in disposing of containers. At present the only equipment specifically designed to apply granulated herbicides is fitted to aircraft or is operated by hand.
The Airweed 89 programme was designed to evaluate aerial application (by helicopter) of liquid and granulated formulations of herbicides. Specifically the system was to be evaluated as an alternative to the labour-intensive means currently used to control competing vegetation when establishing pines on steep land. However other flatter areas were included in the programme to evaluate the technique over a wider range of topographic, soil and weed conditions.

PREPARATORY PROCEDURES

Control specifications

The conditions of the contract were a modification of those in use by the Department of Conservation, Forests and Lands, Victoria for aerial spraying of competing vegetation in pine plantations. The contract document [appendix 1] specifies the extent of the programme, condition of supply, control of the operation, charges, specifications for equipment, responsibility for insurance, compliance to relevant Acts and Regulations, and safety procedures.

Sites

As the main objective of the exercise was to evaluate aerial application of herbicides on areas that were inaccessible to ground machinery,priority was given to second rotation sites and steep first rotation sites in the Blackwood valley. Other areas were included to cover a diverse range of conditions and provide a programme that was viable for the helicopter operator (Table I). All sites were in the rainfall zone between 800 and 1000 mm. However, the adverse response to the aerial programme generated by the community living in the Blackwood Valley, and the subsequent backdown by the government in response to community pressure, resulted in a severe reduction in the size of the programme. (Attachment 1 details the circumstances relating to the controversy surrounding the application of herbicides by air in the Blackwood Valley].

Table I Description of sites selected for Airweed '89

Plantation	Area (ha)	Topography	Soil Description	History	Site Preparation
Maidment *	180	steep, 78	loam (igneous)	farmland	none, shade trees removed
Folly *	120	steep. 78	loam (igneous)	1 rotation pine	windrowed, burned (1988-89)
Milward *	100	moderate to steep	loam (igneous)	1 rotation pine	windrowed, burned (1988-89)
Ferndale *	180	moderate to steep	clay loam (igneous)	eroded farmland	deep ripped, shade trees removed
Grimwade	115	undulating	sandy, loam loam (igneous and lateritic	1 rotation pine	windrowed, burned (1986) deep ripped on lateritic soil
Darrell	140	undulating	loamy sand - loam (lateritic)	farmland	deep ripped
Bussell	56	moderate to steep	loam (igneous)	1 rotation pine	windrowed, burned (1987)
McLarty	70	moderate to flat	sand (sedimentary)	1 rotation pine	windrowed, burned (1986), ploughed, furrowlined
Myalup	79	flat	sand (Sedimentary)	1 rotation pine	windrowed, burned (1988-89) furrowlined
Total anticipated	1040				
Total(actual)	460				

* Areas deleted from the aerial programme after government backdown following community protests. Milward was not replanted pending the outcome of a submission by an adjacent landholder to purchase the property.

Herbicide prescriptions

Herbicides and the formulations (Table II) were selected to provide broad spectrum weed control and sufficient residual activity at each site to maintain weed free conditions for 12 months. Four herbicide prescriptions were selected for the programme (Table IIIA). The allocation of treatments was based on the weed composition of each site. (Table IIIB) However, after the cancellation of much of the programme, granular formulations were given greater prominence in order to fully utilize the applicating equipment while it was in Western Australia, and acquire realistic cost data for granule application.

Table II Description of herbicides

Trade name	Formulation	Operation rate
Velpar ULW	750gm/kg of hexazinone as a disbursable granule	2kg/ha (1.5kg/ha ai), 3kg/ha (2.25 kg/ha, ai)
Velpar L	250gm/kg of hexazinone as a water miscible liquid	6 l/ha (1.5kg/ha , ai)
Gesaprim	500gm/kg of atrazine as a flowable liquid	10 l/ha (5.0kg/ha, ai)
Vorox AA	320gm/kg of amitrole, 320gm/kg atrazine as a flowable liquid	4 l/ha (1.28kg/ha, 1.28kg/ha, ai)
Forest Mix	75gm/ha hexazinone, 250gm/kg atrazine as a coated clay granule	20 kg/ha (1.5kg/ha + 5kg/ha, ai)

An anti-evaporant (DC Trate) was added to liquid formulations at 4% VV.

Equipment specifications

Helicopter - Hiller UH 12E Soloy
Turbine - Allison 250 C20
Spray equipment - see attachment I p27, 28 [plate 1]
Granule applicator - DuPont ULW applicator manufactured by Simplex USA. Pneumatic material conveyance, independent rate adjustment at each side of helicopter.[plate 2]
Additional specified features - onboard fogging system
- spray valve suck-back device

Table IIIA Herbicide prescriptions applying to Airweed 89 before cancellation of part of the programme

Plantation	Prescription (preplant broadscale application unless noted otherwise)	Area (ha)
Maidment	Velpar ULW at 3 kg/ha	45
"	Strip spray Velpar L at 6 l/ha plus Gesaprim at 10 l/ha	45
"	Strip spray Vorox AA at 4 l/ha plus Gesaprim at 10 l/ha	45
"	Forest Mix at 20 kg/ha	45
Folly	Velpar ULW at 3 kg/ha	40
"	Velpar L at 6 l/ha plus Gesaprim at 10 l/ha	40
"	Vorox AA at 4 l/ha plus Gesaprim at 10 l/ha	40
"	Forest Mix at 20 kg/ha	40
Milward	Velpar ULW at 3 kg/ha	25
"	Velpar L at 6 l/ha plus Gesaprim at 10 l/ha	25
"	Vorox AA at 4 l/ha plus Gesaprim at 10 l/ha	25
"	Forest Mix at 20 kg/ha	25
Ferndale	Strip spray Velpar L at 6 l/ha plus Gesaprim at 10 l/ha	130
"	Overspray Velpar L at 6 l/ha plus Gesaprim at 10 l/ha	50
Grimwade	Velpar L at 6 l/ha plus Gesaprim at 10 l/ha	115
Darrell	Vorox AA at 4 l/ha plus Gesaprim at 10 l/ha	140
Bussell	Velpar L at 6 l/ha plus Gesaprim at 10 l/ha	36
"	Velpar ULW at 3 kg/ha	20
McLarty	Velpar L at 6 l/ha plus Gesaprim at 10 l/ha	70
Myalup	Velpar L at 6 l/ha plus Gesaprim at 10 l/ha	16
"	Forest Mix at 20 kg/ha	42
"	Vorox AA at 4 l/ha plus Gesaprim at 10 l/ha	21

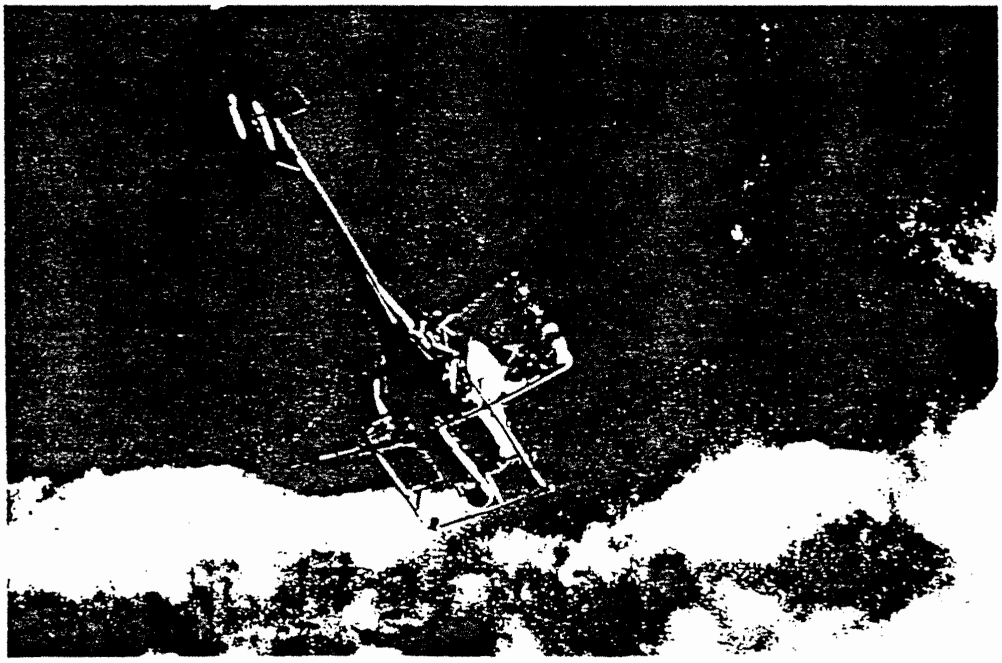
Table IIIB Description of sites where treatment occured

Plantation	Prescription (broadscale appl.)	Predominant weeds occurring on site	Area (ha)
Grimwade	Velpar ULW at 2kg/ha	Trifolium subterraneum, Acacia pulchella	34
"	Velpar ULW at 3kg/ha		81
Darrell	Forest Mix at 20kg/ha	Trifolium subterraneum, Lolium ridigium, Hordium vulgare, Avena sativa (fatua) Arctotheca calendula, Erodium spp., Bromus mollis, Bromus diandrus	140
Bussell	Velpar ULW at 2 kg/ha		41
	Velpar ULW at 3 kg/ha	Bossiaea aquafolium ,Acacia spp,phytolacca octandra, Lolium rigidum, Bromus mollis	15
Myalup	Velpar L at 6 l/ha, Gesaprim 500 FW at 10 l/ha		16
"	Vorox AA at 4 l/ha, Gesaprim 500 FW at 10 l/ha		21
	Forest Mix at 20 kg/ha		
McLarty	Velpar L at 6 l/ha, Gesaprim at	Acacia pulchella, Bromus mollis Trifolium hirtum, Trifolium cherleri, Medicago Tornata	70

Plate 1

Hiller UH 12E Soloy with Spraying equipment attached

Plate 2



Hiller UH 12E Soloy fitted with Simplex granule applicator

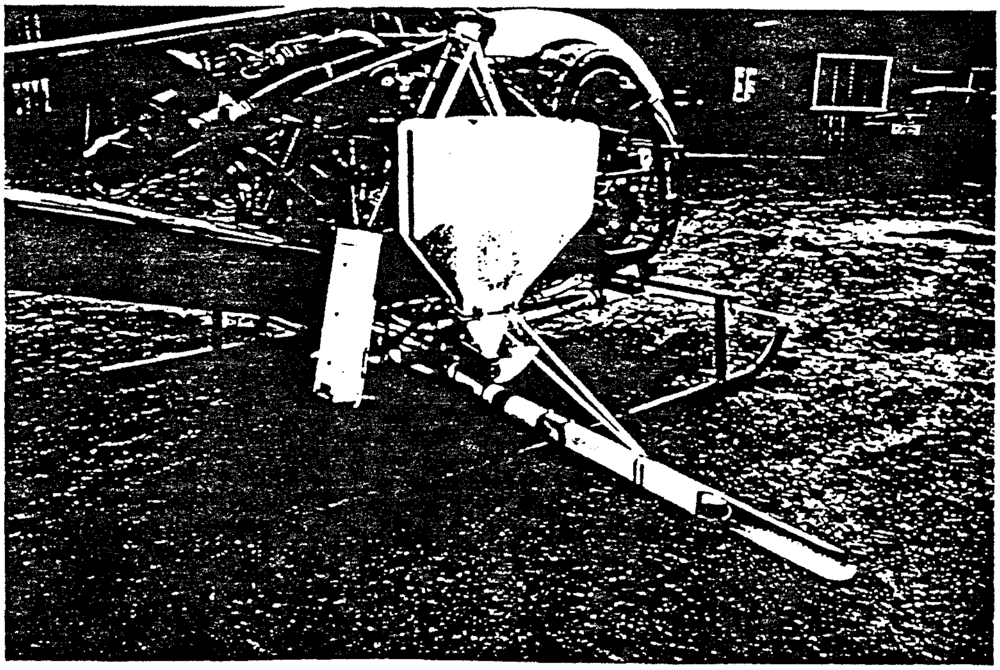
Calibration

For liquid formulations the helicopter was calibrated to deliver 60 l/ha of spray mixture. Twenty Spraying Systems 6515 nozzles were used. Foward indicated speed was 84 kph. An onboard flowmeter enabled the pilot to monitor output at all times during flight. Swathe width was 9 m and marking was achieved by the pilot dropping a "flag" at the end of each run and positioning the aircraft directly over the flag to execute the next run. Release height was stipulated at 1-2 metres above target with a maximum acceptable height of 3 metres. Full details of equipment specifications appear in Appendix I.

Granulated formulations were applied by a DuPont ULW applicator manufactured by Simplex, USA. This equipment was specifically developed for the purpose of applying granulated herbicides from helicopters in forest operations. The device features positive rate adjustment and pneumatic material conveyance to 3 release points on each side of the helicopter[plate 3]. Monitors and controls in the cockpit allow the pilot to accurately adjust air velocity and herbicide feed rates. Pilot-controlled positive shut-off gates allow an instant on/off control to prevent inadvertent dispersal of herbicide. Forward indicated apeed was 84 kph.

This applicator had not previously been used in Australia and it was necessary to assemble the machine at Ludlow. A technologist specialising in the use of the equipment travelled from the USA to assemble, calibrate [plate 4], and develop an acceptable distribution pattern (figs 1A, 1B ,1C) for each formulation. This procedure took 15 days.Swathe widths of 30m (Velpar ULW at 2kg/ha),20m(Velpar ULW at 3kg/ha) and 15m (Forest Mix at 20kg/ha) were adopted.

Plate 3



Simplex granule applicator

CALIBRATED DISTRIBUTION PATTERNS

FIG. 1A

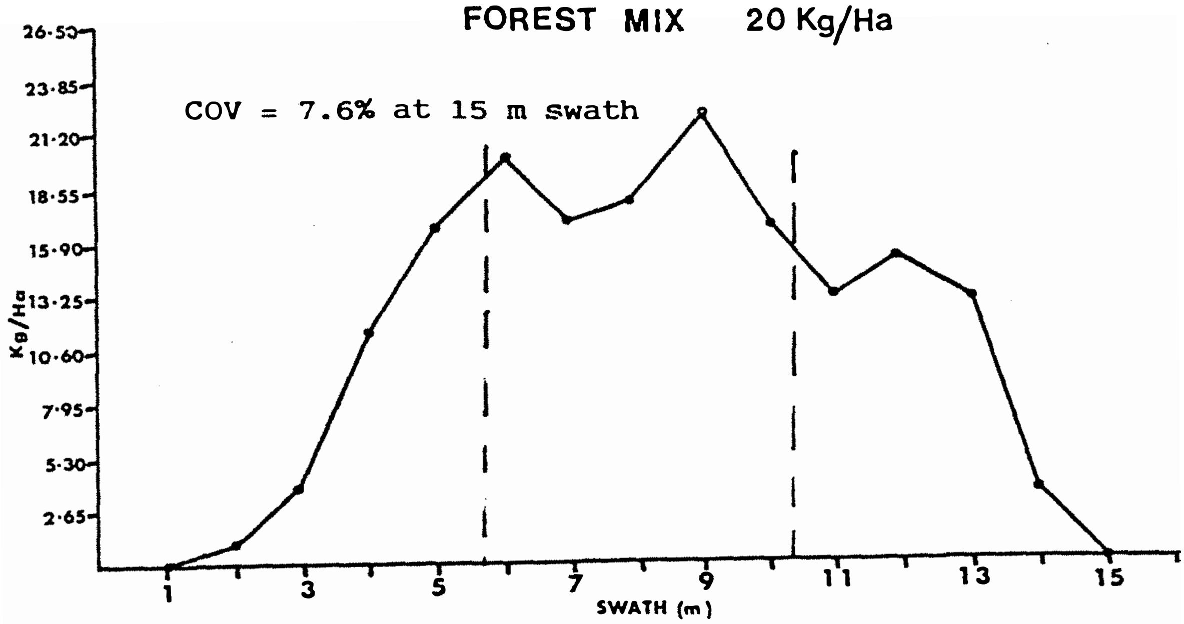


FIG. 1B

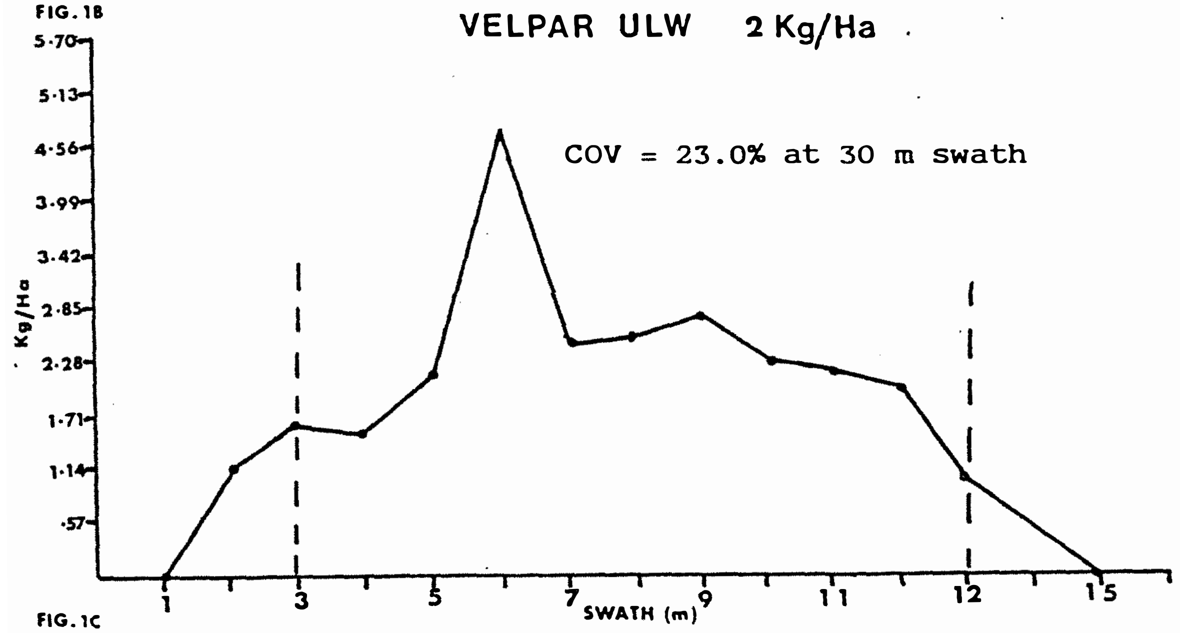


FIG. 1C

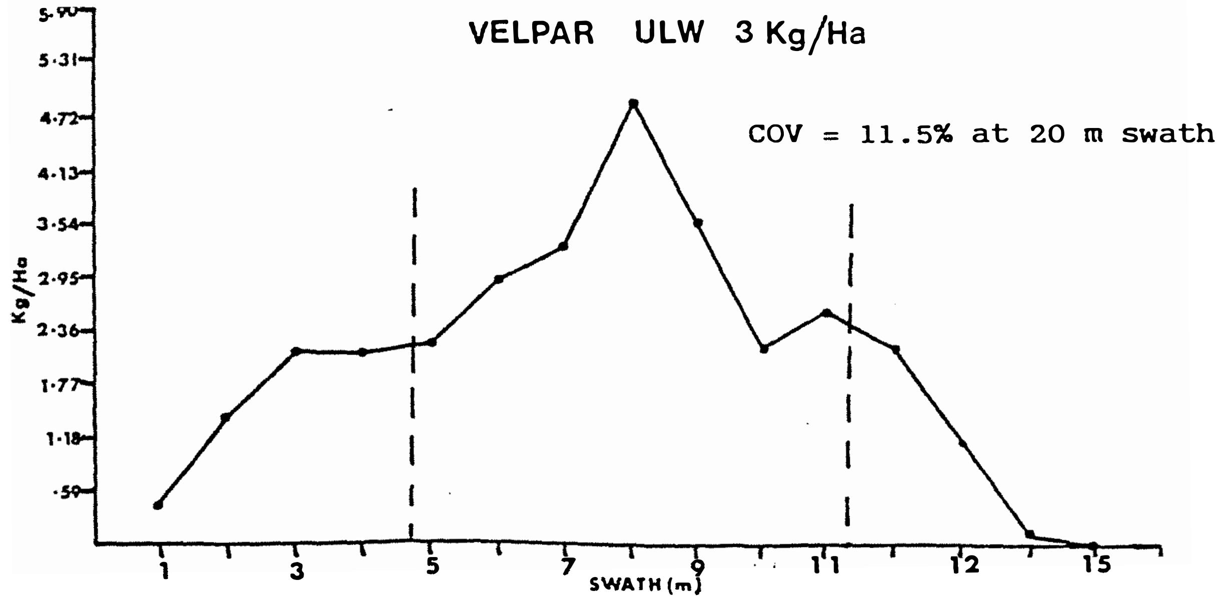


Plate 4

Traps used to calibrate the Simplex granule applicator

Meteorological constraints

Strict compliance to weather constrains were necessary to prevent off-target movement of herbicide. A weather forecast was requested each day in order to plan the daily programme. For Airweed 89, maximum wind speed was set at 10 kph with gusts of 5 kph above main wind speed allowable. Spraying was not to occur in calm conditions, when a temperature inversion was identified, or cadiabatic conditions prevailed. A maximum air temperature for spraying was set at 25°c. Two weather monitoring teams were allocated to each target area and readings were taken prior to and at 15 minute intervals during the operation. Weather monitoring sites were chosen in or adjacent to the target area such that extremes of weather conditions were recorded. Weather teams measured dry bulb temperature, relative humidity, wind speed and wind direction. Each team was in continuous radio contact with Operation Control (appendix 11, pl).

Environmental constraints

It was recognised that aerial application of herbicides would generate emotional debate in the community. Consequently more stringent precautions were taken to avoid off-target movement, either directly (drift) or by storm run-off, then was normal for ground operations. Buffer strips of no less than 20 metres were provided either side of any water course and at least 40 metres adjacent to major rivers.

Where liquids were applied, water sensitive cards were placed at the edges of the target areas adjoining private property or stream buffers. The minimum distance between water sensitive cards was 100 metres. However, the frequency was negotiable on the request of adjoining land holders. For granular formulations traps were placed in a line at right angles to a boundary adjoining private property, streams or native forest (see Appendix II, p3).

Environmental Monitoring

There were 3 aspects of environmental monitoring:

I. Water sensitive paper was placed on the edges of the target area. Granule traps were positioned on target boundaries, particularly where edges were adjacent to private property or rivers. This was to monitor if off-target applications occurred.

II. Water samples from streams draining the target areas and from nearby rivers or streams were collected in bottles supplied by the chemistry centre. Samples were taken before herbicide application and at intervals thereafter corresponding to significant rainfall events (appendix II, p2,3). The proposal was to monitor run-off water from 4 rainfall events after application. An EPA officer undertook high intensity during the first rainfall event. Sampling were sent by courier to the Chemistry Centre for analysis.

III. A study of the effects of herbicide application on aquatic invertebrates was undertaken by an EPA officer.

The EPA will prepare a report detailing the results and implications of the environmental monitoring programme.

Control

The organisational structure for the aerial programme involved the appointment of 4 key personnel.

1. Controller - John Skillen
Overall responsibility for the operation with specific responsibility for media , public liaison and information distribution to other CALM staff.

2. Heliboss - Max Rutherford
Responsible for field operations. Co-ordinated monitoring, preparation of maps, safety contingency plan and field logistics.

3. Helipad Manager - Scott Wood
Responsible for loading aircraft, recording, aircraft safety and training of helipad crew.

4. Programme Advisor - Ray Fremlin
Specific responsibility for prescriptions, training arrangements, supply logistics and co-ordination of information.

In addition to the Heliboss and Helipad Manager who were on site during each operation, two crews were responsible for weather monitoring and two wages employees were located at the helipad performing duties related to the helipad.

Appendix II

PROGRAMME FOR MONITORING HERBICIDE APPLICATION AND CONTINGENCY PLANNING FOR CONTAMINATION IN THE DEPARTMENT OF CONSERVATION AND LAND MANAGEMENT'S AERIAL (HELICOPTER) APPLICATION OF HERBICIDE (AIRWEED)

CONTENTS

INTRODUCTION

Monitoring of the Airweed Programme is carried out during the application of herbicide, and for a period afterwards whilst it is considered there is any chance of herbicides entering the water supplies adjacent to the target area.

The contingency plan for a herbicide spill involves:
(a) training of ground crews
(b) implementation of emergency procedures in the event of a herbicide spill

WEATHER MONITORING

The heliboss will obtain spot forecasts for likely target areas, on the afternoon of the day prior to the spraying operation commencing.

Two weather monitoring teams will be allocated to each target area. They will take reading prior to the operation commencing, and at 15 minute intervals during the operation. The weather monitoring sites will be determined by the heliboss, who will choose sites in or adjacent to the target area which are likely to record the extremes in weather conditions - eg: near ridgetops.

Weather teams will measure dry bulb temperature, relative humidity, wind speed and direction (including variations).

Spraying shall not occur if:

1. Wind gusts exceed 5km/h above the mean wind speed.

2. Winds, including wind gusts, exceed 15km/h at target level.

3. There is a possibility of still air containing suspended droplets draining to a non-target area.

4. Air temperature exceeds 25 degrees C.

5. Rain is falling or likely to fall within six hours of conclusion of a days operation.

6. Meteorological conditions indicate predisposition to formation of a temperature inversion lower than 3000 feet agl.

7. Conditions are such that cold air drainage in evenings may transport suspended droplets downhill to non-target areas.

8. The heliboss considers there is any risk of contamination of non-target areas.

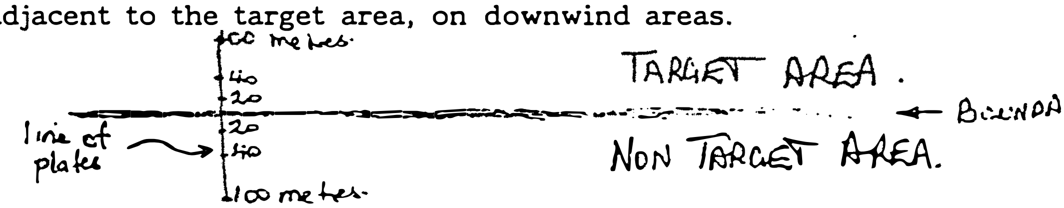
MONITORING SPRAY OPERATIONS

1. Water Sensitive Paper

Prior to spraying commencing the weather teams will put out spray sensitive paper on the edges of the target area. High priority will be given to placing the strips on edges of the target area which adjoin private property and stream buffer. The minimum distance between spray strips will be 100 metres or at greater frequencies at the request of adjoining landholders. The weather monitoring teams will observe these strips for signs of contamination while the spray operation is in progress.

2. Chromatographic Plates

Arrangements are in hand for an officer of the E.P.A. to lay out the plates within each target area. These plates will be located within the target area, and immediately outside the target area. The location of these plates will be determined in order to ensure a high priority is given to buffer areas and private property immediately adjacent to the target area, on downwind areas.



If contamination of the water sensitive paper is observed by the weather monitoring team or the E.P.A. officer then the operation will be immediately cancelled.

The plates which have been exposed to the spraying operation will be forwarded by the E.P.A. officer to the Government Chemical Laboratories for analysis. The plates will allow quantative measurement of active herbicide applied during the spraying operation.

3. Water Sampling

Instructions:

Sampling will be done by a CALM officer using bottles provided by Government Chemical Laboratories.

Dip sample prior to spraying then at first rainfall event greater than 5mm as close as possible to start of rainfall event then at 2 hour intervals and up to 6 hours after rainfall event. (During daylight hours).

The same procedure should be followed for 4 rainfall events following spraying. Samples will be taken in 500ml amber glass bottles with tim caps and should have sampling location, time and date recorded on a label on each bottle.

An E.P.A. officer will undertake a high intensity sampling during the initial stages of the first heavy rainfall event (greater than 5mm) following spraying. He will also place diatometer slides upstream and downstream in major water courses - eg: the Blackwood River to monitor any changes in stream flora.

The sample bottles will be forwarded to the Government Chemical Laboratories by courier immediately after the samples have been taken.

On being provided with the results of the sampling the Department will immediately advise the Public Health Department if the levels of herbicide exceed 10ug/litre (see Water Quality Criteria for Marine and Estuarine Waters of Western Australia - EPA Bulletin 76 April, 1980).

Locations:

Hills - Site 1 (FX5123)
Grimwade - Site 1 (FM6378)
Long - Site 1 (GC6654)
Folly - Site 1 (GK5052)
Webb - Site 1 (EL6954)
 - Site 2 (EJ7021)
Milward - Site 1 (GD4993)
 - Site 2 (GD4961)
 - Site 3 (GE4989)
Gilchrist - Site 1 (FY5389)

MONITORING GRANULE OPERATIONS

Granule Traps

Arrangements are in hand for an E.P.A. officer to lay out the traps within each target area and immediately outside the target area. The location of these traps will be in accordance with the same criteria for the use of chromatographic plates.

If granules are observed to fall in traps located outside the target area the operation will be immediately cancelled.

note - Stream sampling will be carried out in areas where granules have applied

CONTINGENCY PLAN FOR CONTAMINATION

See attached extract from the Airweed Manual.

CONTINGENCY AND SAFETY PLAN

1. General

1.1 Common sense and adherence to Departmental safety procedures will ensure the minimum risk of accidents occuring during aerial spraying operations. This plan provides the necessary information to deal with the anticipated emergencies that could occur.

1.2 The Heliboss is in charge of the operation at all times. However ALL PERSONNEL involved in the operation are RESPONSIBLE for the safe conduct of the operation. ANY PERSON observing potentially dangerous situations is required to take appropriate action to avoid an accident. This may mean taking immediate action and then informing the Heliboss.

1.3 ALL PERSONNEL are required to be fully familiar with the information presented in this plan BEFORE the operation commences.

1.4 Incident management is co-ordinated by Heliboss and in his absence the Helipad Manager.

2. Helicopter Operations

Details are provided in publication 'Helicopter Safety' FPS Jan 1987 (Victoria) Salient points to remember are:

- Helipad is noisy, windy and events happen QUICKLY.
- Movements towards helicopter ONLY if pilot can make eye contact with you.
- Clothing, headgear and other objects must be secure as rotor wash is phenomenal (i.e. wear chinstraps).

3. Herbicide Spill Containment/Decontamination

3.1 Concentrate spills.

- Contain spill within a moat or a trench.
- Spray concentrate with KOH Solution, and spread slaked lime over area.
- Cover decontaminated area with 50mm fresh earth.

3.2 Operational Spills (Dumping)

- Identify dumpsite.
- Contain spill with trench or moat.
- Spray dump area with KOH solution, and spread with slaked lime.
- Record dumpsite on map.

KOH IS A POTASSIUM HYDROXIDE SOLUTION, VERY CAUSTIC AND CORROSIVE. PROTECTIVE CLOTHING MUST BE WORN WHILE USING THIS DECONTAMINATING AGENT.

Heliboss is to notify Controller of any spills in excess of 10 litres. Further action will depend on size and location of spill.

3.3 Helicopter Decontamination

- Contractor is responsible for daily cleaning of machine.
- KOH is used to purge spray gear. This is to be contained by trenches into the sump at the helipad.
- Personnel on pad are to ensure that vehicles, equipment and personnel are upwind of find droplets during flushing.
- Contractor will also wash helicopter body with solution, to be contained and directed into sump.

3.4 Personal Contamination

- Personnel are to avoid being contaminated by wearing appropriate safety equipment (see Section 9).
- If contaminated
  * Remove affected clothing.
  * Wash affected skin surfaces with soap and water, (tanker water can be used at helipad).
  * If eyes are contaminated flush with water for 20 minutes.
  * If herbicide is ingested refer to appropriate Calm 729 for first aid treatment and evacuate to nearest hospital.

4. Evacuation

In the event of further medical treatment being required, evacuation to be arranged by radio through the District Office to nearest hospital.
- Casualty condition will dictate need for ambulance assistance.
- First Aid treatment to stabilize patient is to be undertaken until evacuation is undertaken.

5. Communications

RADIO

The Heliboss will have radio contact with the helicopter on "simplex" VHF.

Each group in the operation, reporting to the Heliboss will have radio contact with him using the standard VHF frequency for the District.

TELEPHONE

District Offices to have telephone numbers for emergency services available for immediate use.

Appendix 2

The effect of herbicides (Atrazine and Hexazinone), entering streams through runoff, on the macroinvertebrate communities of four catchments in south-west Western Australia.

The effect of herbicides (atrazine and hexazinone), entering streams through runoff, on the macroinvertebrate communities of four catchments in south west Western Australia.

A report prepared for the Environmental Protection Authority

by

Ivor Growns, Consultant.

Introduction

Although the use of hexazinone and atrazine as herbicides is widespread in Australia and other countries, their effects on non-target aquatic flora and fauna in Australia are largely unknown.

Atrazine is known to have toxic effects on fish, where it can cause hepatocyte necrosis at concentrations small as 280 µg/l, and lower concentrations (160µg/l) cause degeneration of the liver (Biagianti, 1985). The carp *Cyprinus carpio* shows marked physiological changes in response to sublethal concentrations of atrazine, affecting plasma cortisone levels and gill ATPase activity (Assem, 1984).

Several studies have shown that aquatic macroinvertebrates can tolerate a wide range of herbicide concentrations . For example, *Daphnia magna* has an 18 hour LC50 of 0.6 mg/l for atrazine, while *Culex restuans* has an LC50 of 200 mg/l for the same time period (USDA handbook, 1984). There are fewer studies describing the toxicity of hexazinone, although it appears to be less toxic than atrazine, e.g. an LC50 of 151.6 mg/l for 48hrs was shown for *Daphnia magna* (USDA handbook, 1984). One study reported no major changes in species composition and diversity in a macroinvertebrate benthic community that experienced intermittent concentrations of hexazinone from 6 to 44 mg/l (Mayack, 1982).

The community structure of aquatic invertebrates can be affected by low concentrations of herbicide. Dewey (1986) showed that the numbers of emerging *Labrundinia pilosella* (Chironomidae) were significantly reduced with concentrations of atrazine in the water as low as 20 μg/l. Other fauna were similarly affected and the emergence of all species declined significantly with atrazine addition. The abundance of nonpredatory insects and the total benthic species richness were also greatly reduced. However, predatory insects showed no response to herbicide treatment.

Herbicide addition to streams may indirectly affect invertebrate communities by affecting algal and periphyton communities, which are known food sources for some groups of aquatic invertebrates. Atrazine is known to reduce the biomass of some algal species (Gunkel, 1983) and cyanobacteria (Stratton, 1984). Mayasich et al. (1987) noted that the presence of atrazine in streams had the potential to affect both the diversity and structure of natural phytoplankton populations.

The aim of this study was to determine the direct, short term effect of atrazine and hexazinone application on the structure of the macroinvertebrate communities in the streams of four sub catchments in south west Western Australia. Herbicide was applied to part of each catchment, and was leached to the stream through direct runoff or groundwater flow.

Methods

To allow comparisons with other studies conducted in W.A. samples were collected in riffle zones (stretches of turbulent, fast flowing water) wherever possible. The sites used in this study are described in Table 1. For three of the catchments (Bussells, Grimwade and Maidments) pre-treatment samples were taken immediately before application of herbicide on the 21/6/89. The post-treatment samples were taken on the 4/8/89, two weeks after the first major rainfall event after completion of the herbicide treatment. Two pre-treatment samples for the Folly catchment were taken on the 21/6/89 and 4/8/89. Post-treatment samples were collected on the 6/9/89 due to late application of the herbicide, and again they were collected approximately two weeks after a major rainfall.

Ten replicate benthic samples were taken randomly at each site using a modified Boulton (1986) sampler. A PVC pipe (24 cm bore, 40 cm height, bottom area 450 cm2) with a rubber foam skirt was placed onto the substrate. The inlet pipe to a bilge pump was held free through the top of the PVC standpipe and a 250 µm net was placed over the outlet of the pump to collect disturbed material. Sediments were disturbed for one minute to a depth of 8 cm with a trowel. Samples were stored in ethanol until sorting, when material was sieved into 2 mm, 1 mm and 500 µm fractions. Collected animals were stored in 70% ethanol until identified.

Total number of each species, total abundance of invertebrates and species richness were recorded for each sample. A two-way Analysis of Variance (ANOVA) was carried out on average total abundance and average species richness using site (control, impact area) and time (before, after herbicide treatment) as parameters for each catchment. A Cochran's C test for homogeneity of variance was also calculated to test if the underlying assumptions of the ANOVA were valid for each analysis.

When using an ANOVA, a significant interaction between site and time would probably indicate an effect of herbicide treatment on species abundance or richness. For each catchment where an effect of herbicide treatment was evident two-way ANOVAs and Cochrans' C test were carried out on the abundance of each species that were present at greater than 10% of the total abundance in any one replicate sample.

Water samples were taken after major storms at all the catchments by members of the Environmental Protection Authority (E.P.A.) and the Department of Conservation and Land Management (C.A.L.M.) and were analysed for herbicide content by the Chemistry Centre of Western Australia.

Results

A total of 74 taxa were recorded in this study. The most species-rich catchment was Maidments with 53 taxa recorded. Only 28 taxa were found in samples taken from both Bussells and Grimwade catchments (Appendix 1).

The mean abundance of invertebrates significantly increased over time at all sites in the Bussells and Grimwade catchments (Table 2, Figure 1). A highly significant difference in abundance was found between sites at Folly and Maidments, the control sites having a higher density than the treatment sites at Folly, but lower at Maidments (Figure 1). The significant interaction (site x time) found at Folly is due to the increase in the invertebrate density at the control site over time and a large decrease in densities at the treatment site.

Average species richness differed both between sites and over time at the Maidments catchment (Table 2, Figure 2). The significant interaction indicated by the ANOVA can be explained by the decrease in species richness at both treatment sites, compared with the control which had a slight increase in species richness. At the Folly catchment changes in species richness show the same pattern as the changes in invertebrate density (Figure 1), the significant interaction being explained by the decrease in richness at the treatment site. The increase in species richness at the control site at the Bussells catchment probably explains the significant interaction indicated by the ANOVA. The treatment site slightly decreased in species richness over the same time period.

Thus only the Folly and Maidments catchments show any possible statistically significant effect of herbicide application. The average species richness decreased at Maidments but both invertebrate abundance and species richness were affected at Folly.

At the Folly catchment, average macroinvertebrate abundance and species richness, decreased at the treatment site between the first and second sampling occasions (21/6/89 and 4/8/89), when no herbicide had been applied (Figure 3). The decrease in average abundance was due mainly to the loss of large numbers of *Newmanoperla* which comprised 80% of all the invertebrates (Figure 4). Between these two dates several major rainfall events (> 20mm) were recorded at Nannup. One major rainfall event (>50mm) and several smaller ones were also recorded between the second and third sampling occasions, when herbicide had been applied to the catchment.

Of the species that accounted for more than 10% of the total abundance in any replicate sample at Folly or Maidments, only *Newmanoperla* and *Austrosimulium furiosum* showed any significant decline with herbicide application (Tables 3 & 4, Figure 4). The amphipod *Austrochiltonia* sp. increased at Maidments and simulid *Simulium ornatipes* showed a significant increase in abundance at the Folly catchment (Table 4). All the other species have significant Cochrans' C test indicating that the variances of the samples taken both before, and after from the control and treatment sites are unequal. The precondition of equality of variances for the use of an ANOVA is not true for these species, thus invalidating the use of a two-way ANOVA in these instances.

The chironomid *Polypedilum nubifer* was the only invertebrate species that was lost at the treatment sites of both Folly and Maidments (Appendix 2). The following invertebrates were also not present in post-impact samples taken from the treatment site at Folly; *Tasmanocoenis tillyardi*, *Simulium ornatipes*, Tabanidae sp. 1, Tipulidae spp. and Tanypodinae sp. 3. At the Maidments catchment Tanypodinae sp.1 and *Chironomus alternans/australis* did not reappear at any of the treatment sites (Appendix 2).

The maximum herbicide concentrations measured in each stream are shown in Table 5.

Discussion

Previous studies of the community structure of benthic macroinvertebrates in the streams of Western Australia have indicated that both species numbers and total abundance increase or remain static through time, from winter to summer (Bunn, 1986). The invertebrate communities examined at both the control and treatment sites in the Bussells and Grimwade catchments emulate this trend, as do the control sites at Folly and Maidments. The significant decrease in invertebrate species richness and abundance at the treatment sites of Folly and Maidments is against this trend, providing possible evidence for the negative effect of the herbicide treatment.

One would expect Maidments to show the greatest impact because it was the only catchment where atrazine was applied (although small concentrations were measured at both Grimwade and Bussells) (Table 1) and atrazine is more toxic than hexazinone (USDA handbook, 1984). However, it appears that though Folly was affected to the greatest extent as both species richness and invertebrate density decreased.

The decline of total invertebrate abundance and the numbers of *Newmanoperla* between the first two sampling occasions (when no herbicide had been applied) at the treatment site of the Folly catchment may have been due to the major rainfall events, recorded at Nannup. These would have greatly increased flow rates and may have caused large amounts of sediment to be washed into the stream. The control site however, did not suffer from either decreased abundance or species richness. The reason for the differential impact between the control and treatment sites is unknown but it might be explained by factors such as differences in local topography between sites.

Between the second and third sampling occasions at the Folly catchment (4/8/89 and 6/9/89) another decrease was noted in total invertebrate abundance, average invertebrate richness and the numbers of *Newmanoperla* at the treatment site. Approximately 60mm of rain was recorded at Folly in a 24hr period, two weeks before the last sampling occasion. The significant decrease in invertebrate abundance and richness could again be explained by the differential impact of rainfall on the treatment site caused by local factors (other than herbicide treatment).

Another possibility is that due to the steepness of the Folly catchment, that more herbicide was washed into the stream than any of the other catchments, causing the decline in invertebrate richness and abundance at the treatment site. However, no large concentrations of herbicide were recorded from Folly, but it is possible that any herbicide washed into the stream would have been removed quickly from the area by increased flow rates due to the large amount of rainfall.

From the maximum herbicide concentrations recorded at each catchment (Table 5) it appears as though a concentration of 4.4 µg/l of hexazinone did not adversely affect community structure at Grimwade. However, the combined concentration of atrazine (2.1 µg/l) and hexazinone (3.5 µg/l) measured at Maidments appears to have reduced average species richness.

It is hard to judge which species were actually affected by the herbicide addition. The list of species that were present in the pre-treatment but not post-treatment samples (Appendix 2) may give some indication of sensitive species. However, most of the species documented show rare occurrences and are only represented by a single specimen in a single sample. If other, slightly more common, invertebrates were not recorded after treatment there is a chance that they were present after herbicide treatment but did not occur in the post-impact samples. Two species (*Newmanoperla exigua* and *Austrosimulium furiosum*) did show a statistically significant interaction in an ANOVA, suggesting that they were adversely affected. Since these analyses are based upon the absence of species from post treatment samples there could be other reasons for their decline. For example some species may have emerged as adults in large numbers though this would be expected to affect both control and treatment sites. Extensive laboratory toxicity studies would be required to identify sensitive species.

Evidence for the effect of an environmental perturbation can be inferred from changes in species abundance and richness that occur in the biological community of an impacted area, provided that the changes do not also occur at a control site (Green,1979). An Analysis of Variance (ANOVA) used with samples taken from control and impact areas both before and after a perturbation, represent an excellent approach to the analysis of an areas (treatment, control) by times (before and after impact) factorial sampling design (Green, 1979).

However, Hurlbert (1984) and Eberhardt (1976) raise objections to this approach citing problems with 'pseudoreplication'. By taking replicate samples from control and treatment areas within the same stream and not replicating the entire experiment in another stream comparable to the first, it is difficult, if not impossible, to extrapolate the effects of a perturbation to other stream systems. Also, it is possible that an event other than the herbicide treatment may affect the impact area, but not the control, making it difficult to conclude whether the impact itself was responsible.

Thus a more extensive study involving more streams (preferably replicate streams within the same catchment) is needed to determine unequivocally the effects of these herbicides on stream macroinvertebrate fauna. This study investigated the short term, direct influence of herbicides present in the runoff from catchments. However, a study involving the long term and indirect effects of herbicide application on stream fauna, with data collected a year before and after the application, would be desirable to fully elucidate any ecological damage to the environment.

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Table 1. Environmental data for catchments and streams

	Catchment			
	Bussels	Folly	Grimwade	Maidments
Soil type	loam	loam/granite	loam/sand	loam
Topography	undulating	steep	undulating	steep,undulating
Buffer zone	yes	part	no	no
Stream width (m)	3	4	1.5-2.5	1
Stream depth (cm)	15-25	15-40	13-24	15-30
Permanent or temporary	permanent	permanent	temporary	temporary
Number of control sites	1	1	0	1
Number of treatment sites	1	1	1	2
Herbicides applied	hexazinone	hexazinone	hexazinone	atrazine & hexazinone
Area applied (ha)	56	160	136	180
Part or whole catchment	part	part	whole	part

Table 2. F values and associated probability levels for two-way ANOVA's for community parameters at each catchment.

Catchment	Variable	Source of Variation			Cochran's C
		Site	Time	Interaction Site x Time	
Bussel	Log Abundance	0.96 n.s.	5.48*	0.09 ns	0.24 n.s.
	Richness	1.42 n.s.	5.16 *	11.25**	0.45 n.s.
Folly	Log Abundance	20.29***	1.02 n.s.	15.77**	0.35 n.s.
	Richness	23.09***	1.95 n.s.	4.71*	0.37 n.s.
Grimwade	Total Abundance	-	45.48***	-	0.57 n.s.
	Richness	-	1.10 n.s.	-	0.54 n.s.
Maidments	Log Abundance	25.34***	0.98 n.s.	1.40 n.s.	0.24 n.s.
	Richness	22.87***	7.90**	6.18**	0.27 n.s.

ns - not significant ($p>0.05$)
* - $0.01 < p < 0.05$
** - $0.001 < p < 0.01$
*** - $p < 0.001$

Table 3. F values and associated probabilities for two-way ANOVA's on log abundance of species at Maidments

Species	Source of Variation			Cochran's C
	Site	Time	Interaction (Site x Time)	
Candonocypris novazealandiae	32.54 ***	1.68 ns	2.58 ns	0.28 ns
Odonata spp. juv.	20.30 ***	1.83 ns	0.70 ns	0.53 ***
Austrochiltonia sp.	7.81***	0.01 ns	4.51 **	0.21 ns
Oxytheria retracta/brevis	42.49 ***	36.42 ***	6.29 **	0.36 *
Newmanoperla exigua	3.44*	27.19 ***	0.59 ns	0.29 ns
Tipulidae spp.	3.86 *	0.01 ns	0.85 ns	0.22 ns
Austrosimulium furiosum	24.35 ***	16.30 ***	3.54 *	0.32 ns
Orthocladiinae sp 4	53.91 ***	11.79 ***	6.38 **	0.55 ***
Ceratopogonidae spp.	0.49 ns	1.88 ns	1.15 ns	0.48 ***
Tasmanocoenis tillyardi	71.02 ***	0.53 ns	1.63 ns	0.77 ***
Dytiscid spp.	30.81 ***	9.97 **	0.42 ns	0.30 ns

ns - not significant ($p>0.05$)
* - $0.01 < p < 0.05$
** - $0.001 < p < 0.01$
*** - $p < 0.001$

Table 4. F values and associated probabilities for two-way ANOVA's on log abundance of species at Folly.

Species	Source of Variation			Cochran's C
	Site	Time	Interaction (Site x Time)	
Newmanoperla exigua	5.27 *	0.58 ns	8.13 **	0.31 ns
Simulium ornatipes	13.34 ***	8.83 **	12.59 ***	0.31 ns
Oxytheria retracta/brevis	0.98 ns	3.09 ns	0.98 ns	0.85 ***
Tasmanocoenis tillyardi	0.15 ns	3.04 ns	1.36 ns	0.71 ***
Cheumatopsyche modica	6.07 *	3.96 ns	6.07 *	0.88 ***
Oligochatea	1.70 ns	0.30 ns	2.17 ns	0.53 *
Leptophlebiidae spp.	31.08 ***	10.12 **	7.95 **	0.57 **
Tipulidae spp.	2.43 ns	5.23 *	0.70 ns	0.54 *
Orthocladiinae spp.	17.28 ***	0.80 ns	1.78 ns	0.59 **
Candonocypris novazealandiae	6.08 *	0.28 ns	0.28 ns	0.59 **

ns - not significant ($p>0.05$)
* - $0.01 < p < 0.05$
** - $0.001 < p < 0.01$
*** - $p < 0.001$

Table 5. Maximum concentrations of the herbicides atrazine and hexasinone measured at each catchment. Dates the water samples were taken are indicated in paretheses.

Herbicide	Catchment: Bussels		Folly		Grimwade		Maidments	
Atrazine (µg/l)	1.9	(4/7/89)	O.O	(2/6-31/8/89)	0.8	(28/7/89)	2.1	(7/7/89)
Hexasinone (µg/l)	1.5	(4/7/89)	2.3	(14/8/89	4.4	(28/7/89)	4.2	(20/8/89)

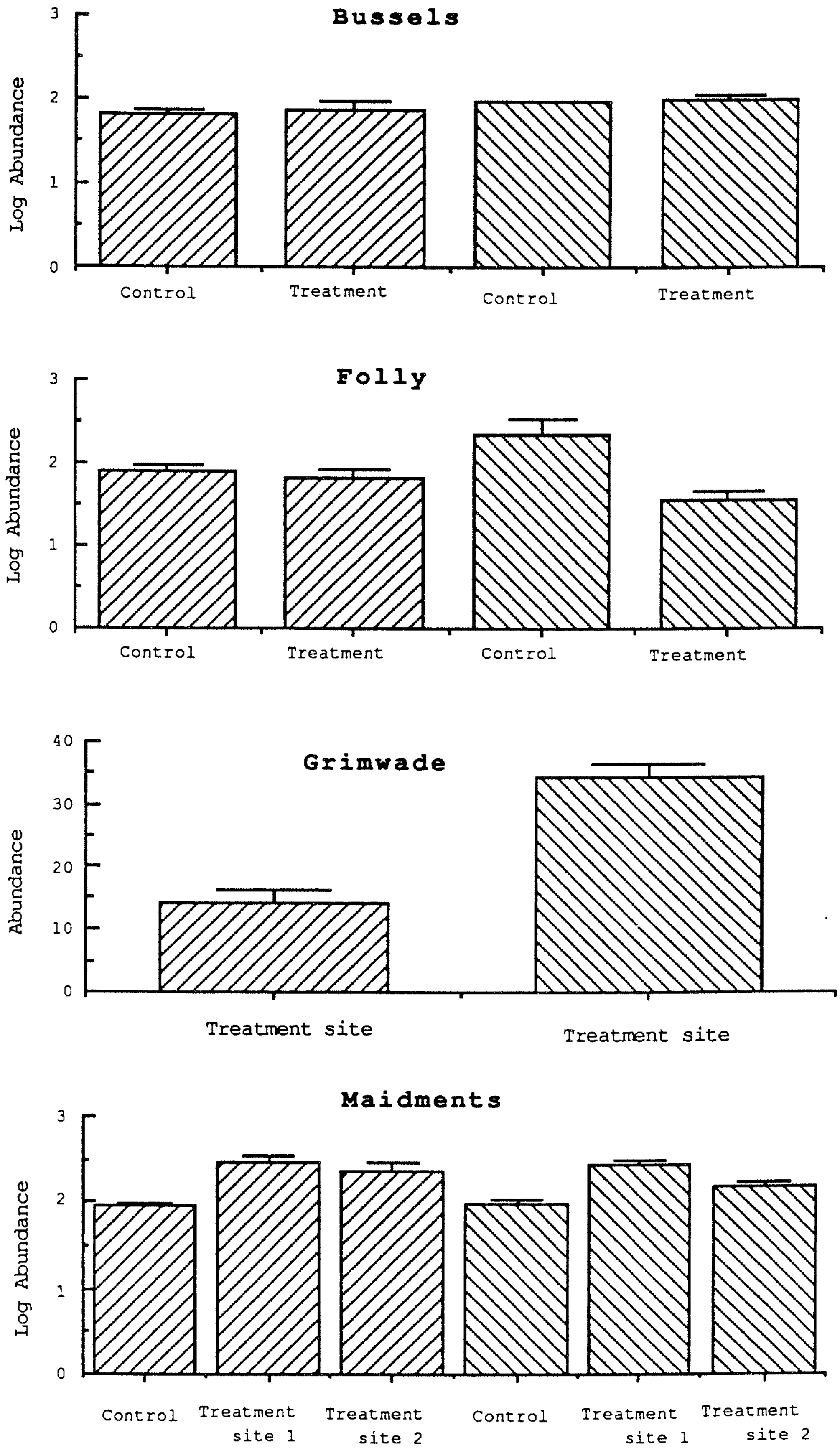

Figure 1.Changes in abundance of macoinvertebrates (μ±S.E) between pre- and post-treatment of herbicide

pre-treatment   post-treatment

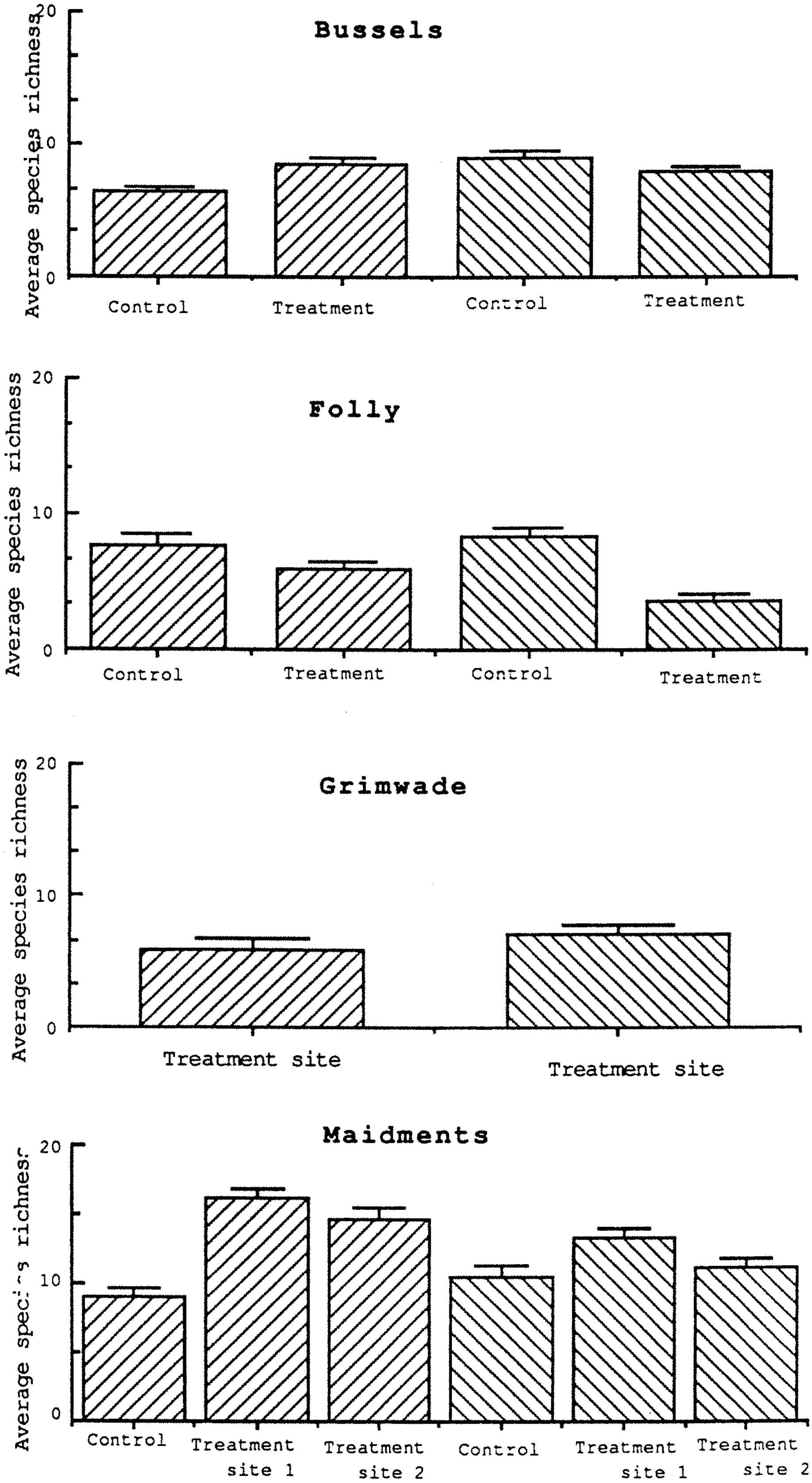

Figure 2. Changes in average macroinvertebrate species richness (μ±S.E.) between pre- and post-treatment of herbicide

pre-treatment   post-treatment

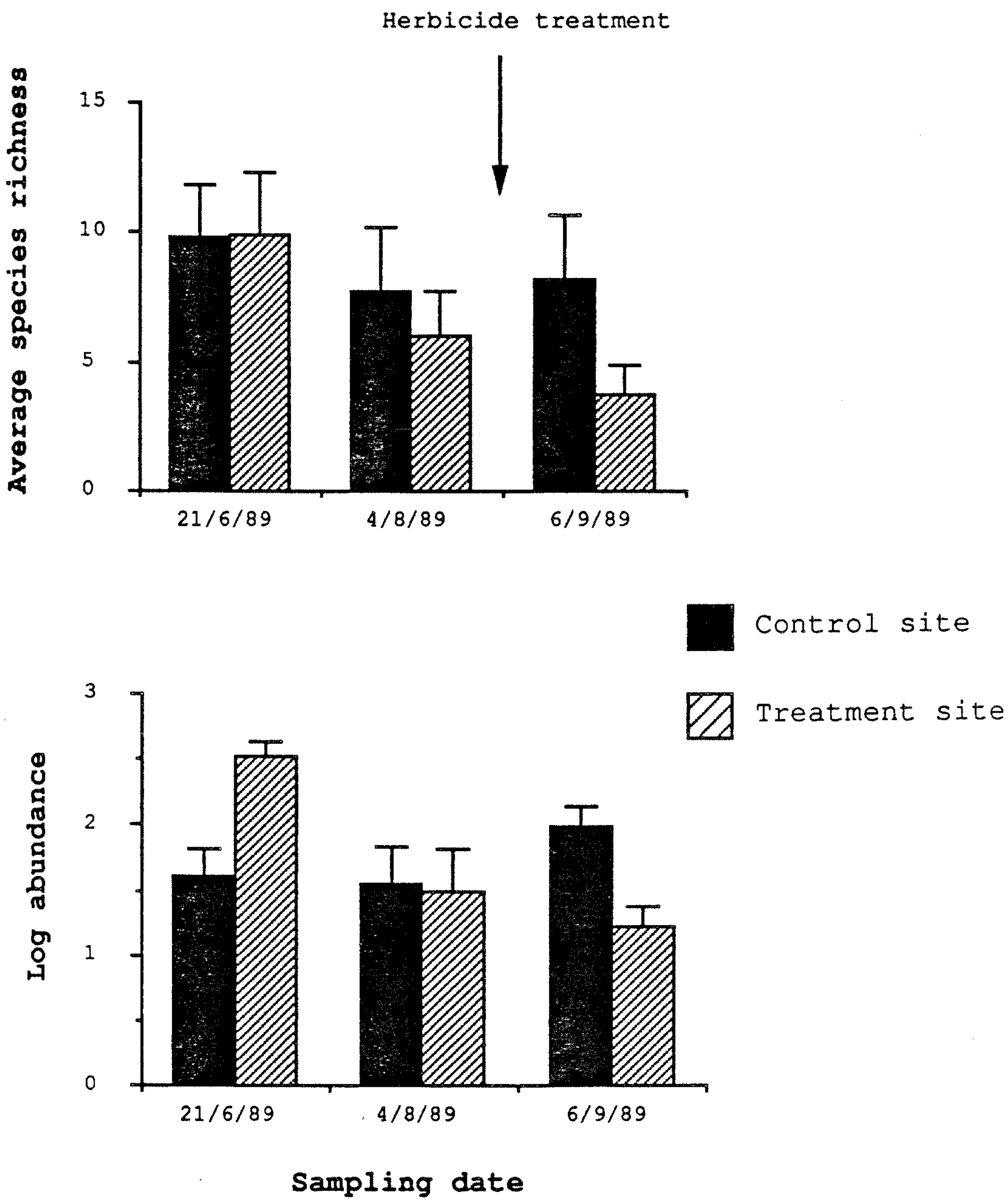

Figure 3. Changes in abundance of macroinvertebrates and species richness on three sampling occasions at control and treatment sites of the Folly catchment

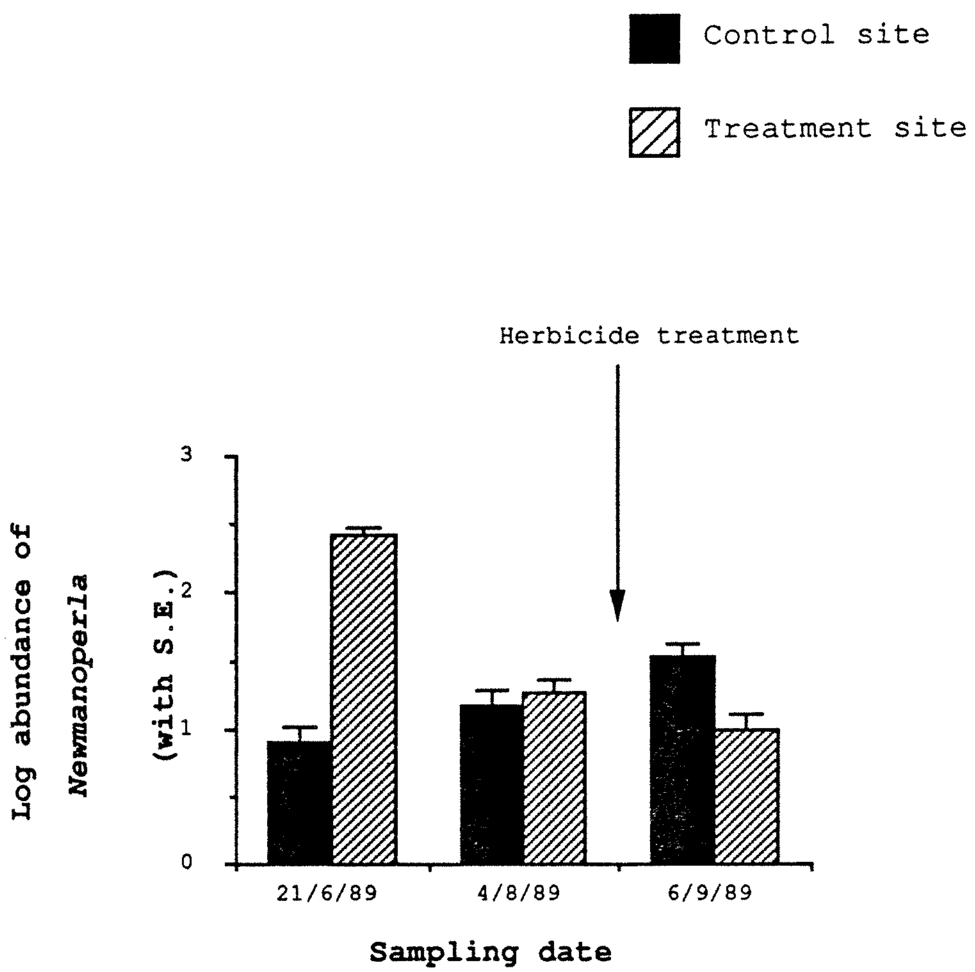

Figure 4. Changes in abundance of *Newmanoperla* on three sampling occasions at control and treatments sites of the Folly catchment

Appendix 1. Macroinvertebrate species present at each catchment

TAXON	CATCHMENT Bussel	Folly	Grimwade	Maidments
GASTROPODA				
Planorbidae				
Physastra georgiana				+
Physidae				
Physa acuta				+
Ancylidae				
Ferrissia petterdi				+
OLIGOCHAETA	+			+
ACARINA				
Hydracarina			+	+
Oribatidae				+
OSTRACODA				
?Alboa wooroa	+			
Candonocypris novaezealandiae	+	+	+	+
COPEPODA				
Cyclopoida	+			
AMPHIPODA				
Gammaridae				
Perthia acutitelson			+	
Austrochiltonia sp.			+	+
DECAPODA				
Parastacidae				
Cherax tenuimanus	+		+	
Cherax quinquecarinatus		+		+
PLECOPTERA				
Gripopterygidae				
Leptoperla australica			+	
Newmanoperla exigua		+		+
Gripopterygidae spp. juv.	+	+	+	+
EPHEMEROPTERA				
Leptophlebiidae				
Bibulemena kadjina		+	+	
Nebiossophlebia occidentalis		+		
Nyungara bunni		+		
Unidentifiable Leptophlebiidae	+	+	+	
Baetidae				
Baetis soror		+		+
Caenidae				
Tasmanocoenis tillyardi		+		
ODONATA				
Anisoptera				

Odonata spp. juv.	+		+	+
Libelluidae				
Orthetrum caledonicum			+	+
Synthemidae				
Synthemis macrostigma	+			+
Aeshnidae				
Acanthaeschna anacantha		+	+	
Corduliidae				
Hemicordulia tau				+
Lathrocordulia metallica		+		
Zygoptera				
Coenagrioidea				
?Pseudagrin coeruleum				+
MEGALOPTERA				
Chaulioidae				
Archichauliodes cervulus		+		
DIPTERA				
Simulidae				
Austrosimulium furiosum		+	+	+
Cnephia sp.		+		
Simulium ornatipes	+		+	+
Simulidae spp. juv.	+	+	+	
Chironomidae				
Aphroteniinae				
Aphroteniini				
Aphroteniella ?filicornis		+		+
Tanypodinae				
Tanypodinae sp. 1	+			+
Tanypodinae sp. 2	+			+
Tanypodinae sp. 3	+	+	+	+
Orthocladiinae				
nr. Cordites sp. A	+	+		+
Orthocladiinae spp. juv.				
Orthocladiinae sp. 4	+	+	+	+
Orthocladiinae sp. 3/8 group		+	+	
Thienemanniella sp. A	+	+		+
Chironominae				
Chironomini				
Chironomus australis/alternans	+	+	+	+
Chironomini sp. 5	+			
Polypedilum nubifer	+	+	+	+
Chironomini spp. juv.	+	+		
Tanytarsini				
Rheotanytarsus sp. 1	+			+
Tanytarsus sp. 1				+
Tanytarsini spp. juv.	+			
Ceratopogonidae				
Ceratopogonidae spp.	+	+	+	+
Tipulidae				

Tipulidae spp.	+	+	+	+
Empididae				
Empididae sp.1		+	+	+
Psychodidae				
Psychodidae sp. 1			+	+
Thaumaleidae				
Thaumalidae sp. 1				+
Tabanidae				
?Tabanus sp.		+	+	+
Athericidae				
Athericidae sp. 1		+		
?Muscidae				
?Muscidae sp. 1		+		
LEPIDOPTERA				
Lepidoptera spp.				+
TRICHOPTERA				
Ecnomidae				
Ecnomidae sentosa group				+
Leptoceridae				
Triplectides australis	+			
Triplectides sp. 1				+
?Oecetis sp. 1				+
?Notalina fulva				+
Hydrobiosidae				
Apsilochorema urdalum		+		
Taschorema pallescens		+		
Hydroptilidae				
Hellytheria sp. 1				+
Oxythira retracta/brevis	+		+	+
Hydropsychidae				
Cheumatopsyche modica		+		+
Smicrophylax australis		+		
Philopotamidae				
Hydrobiosella sp. 1			+	
Philorheithridae				
Kosrheithrus boorarus?				+
COLEOPTERA				
Curculionidae				
Curculionidae spp.				+
Dytiscidae				
Cybister sp. 1 (adult)				+
Dytiscidae larvae sp. 1	+	+		+
Dytiscidae larvae sp. 2				+
Dytiscidae adult sp. 1				+
Dytiscidae adult sp. 3				+
Dytiscidae adult sp. 4				+
Helminthidae				
Helminthidae spp.			+	+

Appendix 2 . Macroinvertebrate species not present in (lost) or only present in (gained) post-treatment samples.

Site	Species lost	Species gained
Folly		
- Control site	Oligochaeta	*Lathrocordulia metallica*
	Austrochiltonia sp.	*Archichauloides cervulus*
	Cherax quinquecarinatus	*Aphroteniella ?filicornis*
	Leptoperla australica	*Thienemanniella so.*
	Acanthaeschna anacantha	*Polypedilum nubifer*
	?Muscidae sp. 1	*Cnephia sp.*
	Empidid sp. 1	Athericidae sp. 1
	Oxytheria retracta/brevis	*Cheumatopsyche modica*
	Dytiscid larvae sp.1	
	Total = 9	Total = 8
- Treatment site	*Austrochltonia sp.*	Oligochaeta
	Tasmanocoenis tillyardi	Leptophlebidae
	Simulium ornatipes	*Cnephia sp.*
	Polypedilum nubifer	
	Empididae sp. 1	
	Tabanidae sp. 1	
	Tipulidae sp. 1	
	Tanypodinae sp. 3	
	Oxytheria retracta/brevis	
	Dytiscid larvae sp.1	
	Total = 10	Total = 3
Maidments		
- Control site	Orabatidae spp.	Ferrissia petterdi
	Acanthaeschna anacantha	Hydracarina spp.
	Tanypodinae sp. 2	Tanypodinae sp. 3
	Leptoceridae spp. juv.	Thaumaleidae sp. 1
	Oxytheria retracta/brevis	Tabanidae sp.
	Curculionidae spp.	Psychodidae
		Tanytarsus sp. 1
		Heliminthidae spp
		?Lepidoptera spp.
		Ecnomidae spp.juv.
	Total = 6	Total = 10
- Treatment site 1	*Physa acuta*	*Baetis soror*
	Hydracarina spp.	*Rheotanytarsus sp. 1*
	Orthetrum caledonicum	*?Pseudagrian coeruleum*
	Austrosimulium furiosum	
	Tanypodinae sp. 1	

	Tanypodinae sp. 2	
	nr. Cordites sp. A	
	Polypedilum nubifer	
	Chironomus alternans/australis	
	Aphroteniella ?filicornis	
	?Oecetis sp. 1	
	Hellytheria sp.1	
	Cheumatopsyche modica	
	Dyticid adult sp. 1	
	Dyticid adult sp. 2	
	Dyticid adult sp. 4	
	Total = 16	Total = 3
- Treatment site 2	*Physastra georgiana*	*Austrosimulium furiosum*
	Hemicordulia tau	Tanypodinae sp. 2
	Polypedilum nubifer	Tabanidae spp.
	Chironomus alternans/australis	Thaumaleidae spp
	Tanytarsus sp. 1	*Thienemanniella sp. A*
	Tanypodinae sp. 1	
	Notalina fulva	
	Kosrheithrus boorarus?	
	Ecnomidae sentosa group	
	Total = 9	Total = 5