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CONTROL OF NUISANCE MIDGES, CHIRONOMIDAE AND PSYCHODIDAE (DIPTERA), IN SEWAGE WASTEWATER FILTER BEDS WITH *BACILLUS THURINGIENSIS* SUBSP. *ISRAELENSIS*

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ABSTRACT

Highly specific larvicides are required to control Chironomidae and Psychodidae larvae in wastewater filter beds. The filter beds provide a habitat for bacteria and a variety of nontarget invertebrates necessary for the breakdown of the organic matter in sewage. A dense population of midge larvae, often emerging in enormous numbers, can cause a major nuisance when resting or swarming over neighbouring properties. Early application of high concentrations of *Bacillus thuringiensis* subsp. *israelensis (Bti)* can reduce the larval population. Frequent applications of *Bti* in the confined area of a filter bed has resulted in resistance. Alternation with other methods, such as an insect growth regulator or some physical means, will delay the onset of resistance.

KEY WORDS: Chironomidae, Psychodidae, sewage wastewater filter beds, *Bacillus thuringiensis* subsp. *israelensis,* IGR, control, resistance.

INTRODUCTION

Fly nuisance is principally confined to treatment plants employing percolating filter systems for wastewater treatment and drying beds for sludge treatment. The latter is an increasingly rare process in the northern hemisphere due to climatic considerations and restrictions. However, percolating filter works are still in extensive use, and more are being built and upgraded. Within Europe, the UK has probably the largest number of filter works when measured against sewage per head of population treated. Fly nuisance and attempts to find remedies in the UK are well documented and reports date from the beginning of the 20th century.

Normally, sewage works are sited well away from towns but expanding building programmes have resulted in houses and industrial estates moving closer to the sewage works, with inevitable complaints from local residents and employees. Birkbeck College were asked to study control of the fly problem.

The filterbeds support a dense population of Chironomidae and Psychodidae and possibly other, closely related groups, interest being concentrated on the flies which swarm. The enormous number of emerging adults can cause major problems when resting or swarming over neighbouring properties. They deface buildings and other surfaces, collect on lighting fixtures and generally cause a nuisance to local occupants. Ultimately the spider population will increase, producing an enormous number of cobwebs over doors and windows (Mulla et al., 1990). The smaller fly species can pass through standard screens on windows and infest indoors.

Adult midges are not vectors of any known disease organism, but are possible mechanical carriers of some microorganisms when emerging from polluted waters (Ali, 1991). The Psychodidae are hairy flies and large numbers in close human contact can cause skin irritation and development of asthma.

Ceratopogonidae or biting midges are possible opportunistic residents of either the wastewater treatment works or local streams. *Culicoides vexans* and *Forcimopyia bipunctata* have been found in insect traps (Learner, 1975). These species are possible vectors for parasitic worms. Their potential association with wastewater treatment works and their potential of acting as a vector for disease contamination does not appear to have been researched in any detail.

Our first studies were made on 16 trickling filters in a biological sewage treatment farm. Initially, the wastewater is allowed to settle for about 8–10 hours in order to remove the coarser solid material and is then pumped to the revolving sprinklers. Wastewater is continously or intermittently distributed on the beds. The filterbeds are rectangular or circular, generally 14 m in diameter and up to a maximum of 45 m, the size governed by the mechanism which controls the four arms of the sprinklers. The water gradually filters through clinker from blast furnaces or a similar media such as coke, usually about 2 m deep. The clinker is full of cavities creating a large surface area, providing a habitat for bacteria, blue-green algae, protozoa, worms, fungi, snails and fly larvae. Fly larvae have few or no predators in this habitat and survive well in the holes in the clinker. In natural habitats, they often seek a protective covering, such as a tube of debris in the mud.

Bacteria and protozoa play an important part in the purification process by breaking down the organic matter in the sewage wastewater. They can form a gelatinous film with the algae which could seal the surface, but the growth is checked by plentiful molluscs, which live off the algae — assisted by the worms and fly larvae, which feed on the film.

One factor likely to affect the kind of insect community inhabiting the filter depends on the proportion of industrial waste to organic waste of the sewage. The amount of film usually increases with increased organic waste (Learner, 1975). The competition for food between the species determines the density of particular larvae, and the success of the organic breakdown in the water filtration process. Seasonal fluctuations influence the nuisance of the fly emergence.

Target fly species

The fly larvae most commonly associated with the filterbeds are the moth fly *Psychoda alternata*, dominant during the summer, and *P. severini*, dominant in the winter and spring; and the chironomids *Metriocnemus hygropetricus, Chaetocladius perennis* and *Limnophyes minimus* as described by Lloyd et al. (1940) and Lloyd (1947). The male adults of all these species are of particular interest because of the highly developed habit of swarming.

The chironomids lay transparent eggs in ribbons with a glutinous protective covering. There are 4 larval instars and the time taken for development depends on temperature and available food.The filterbeds are a rich source of insect food. The larvae are mainly scavengers of algae, particles in suspension and detritus. Some larvae are predacious, devouring eggs, pupae and larvae of smaller species. A tracheal system is absent in the larvae, their oxygen being obtained through a thin permeable cuticle. Oxygen is stored in the haemoglobin giving the larvae a red colour. This enables the larvae to survive in deep water where there is little or no oxygen.

Larvae nearer the surface are paler in colour or even white and up to 20 mm in length. *C. perennis* migrate downwards into the filter during their development, which normally results in most of the larvae being found at the base of the filters. In contrast, *M. hygropetricus* larvae move upwards and pupate near the surface, greatest numbers being found in the upper section.

Psychoda larvae are frequently encountered in large numbers near the surface. They show a preference for living in clumps and survive a thick film, due to their possession of a respiratory siphon at the posterior end. The larvae are white and and up to 9 mm in length. The amount of film affects the occurrence and density of the various insect species at different levels within the filterbed. However, it is the ability of the chironomids to out-compete other flies including *Psychoda* for available food, which may influence the *Psychoda* population density at the surface of the filter.

The temperature of the water feeding the filters is stable at 15°C for most of the year, although the dark colour of the clinker may cause the temperature to rise in hot weather. The day length also has an influence on the time of emergence. Adult fly populations remain low during the winter, with the maximum emergence during June and July. Seasonal variations occur, of which the parameter temperature appears to have the greatest influence (Ali and Fowler, 1983).

Adult chironomid males, up to 5 mm in length, are generally differentiated from females by the possession of plumed antennae. Females lay up to 250 eggs; 66% laid their eggs from where they had emerged, causing frequent reinfestation. The Psychodidae are minute flies about 1.5 mm in length with hairs on the body, legs and wings.

Methods of fly control

The rise of resistance in the 1980's to toxic chemicals, such as the organophosphates, has resulted in the search for alternative and safer methods of control (Ali and Lord, 1980).

The advantage of treating a number of filterbeds for research purposes is that it gives an ideal comparison between the success of different methods of fly control compared with one bed left untreated. Results can be evaluated by placing exit traps on the clinker surface.

Control measures must not upset the water purification process. The advantage of using biological, target specific, methods is obvious. *Bacillus thuringiensis* subsp. *israelensis* (*Bti*), well known for its activity against mosquito larvae (WHO, 1982; Margalit and Dean, 1985), has produced high mortality after 3 days against Psychodidae in natural field environments. Much higher dosages, however, are needed in the filter beds to achieve a 100% control — from 1 ppm to 100 ppm (WHO, 1982; Houston et al., 1989a,b; Coombs et al., 1991; Becker and Margalit, 1993.) Probably this is due to the high density of the fly larvae as well as the high level of organic polluted matter in filters compared to natural habitats, rather than to the relatively low susceptibility of fly larvae described below. All non-target organisms in the filter beds remain unharmed.

Chironimidae are less sensitive than Psychodidae; a dosage rate 10 times that for mosquito larvae is needed to control larvae of both types of fly, in the range of 5–10 kg/ha (Ali, 1981). Teknar TC wettable powder (Sandoz) is more effective than the liquid concentrate (Mulla et al., 1990). At these dosage rates *Bti* has the potential to reduce the number of emerging adults of sewage flies, though a complete kill is neither likely nor desirable. Some flies are needed to continue a level of fly larvae required for the health and performance of the beds. *Bti* does not affect the late fourth instar larvae or the pupae, both non-feeding stages. It is advisable to have an initial high dose at the optimum time to combat the high density of larvae. This will also assist in avoiding resistance, which is likely to increase with repeated dosages at lower concentrations.

An initial bioassay was carried out on the *Metriocnemus* larvae obtained from a works that had used *Bti* for a number of years and reported that it was no longer successful. The larvae were first raised to adults and a new generation of larvae obtained, uncontaminated by bacteria or other fauna in the sewage works, which might contribute to cause of death. A similar bioassay was carried out from a works that had never been treated with *Bti*.

The group unexposed to *Bti* showed almost complete mortality whereas those previously treated with *Bti* showed a 30% survival. This preliminary bioassay was too small for a statistical analysis but it suggests that resistance may have developed in only a proportion of the larvae treated with *Bti*. This may be inconsistent with reports of no effect following treatment.

One problem may be that of uneven distribution of the *Bti* and the formulation used; problems of this nature have been described before (Coombs et al., 1991). The *Bti*, Teknar liquid, was added to the distribution chamber before being applied to the filter beds by the rotating sprinklers. A *Bti* wettable powder applied directly on the filter medium may give a longer-lasting and more even distribution of the *Bti*. Unfortunately, the wettable powder is not as yet licensed for this purpose in the UK.

Alternating *Bti* with an insect growth regulator (IGR) provides another safe method of control. There are two main types of IGR's: one prevents chitin synthesis, and the other has high juvenile hormone growth-retarding properties — a juvenoid (WHO, 1983). Both are considered to be environmentally safe and to give long-lasting control (Mulla, 1995). IGR's have been used in the USA for some time to control fly larvae in lakes and on clean and polluted waters. The chitin synthesis inhibitor Dimilin (diflubenzuron) affects all instars at the time of moulting (Lacey and Mulla, 1977). In Japan diflubenzuron was found to be superior to the juvenoid Altosid (methoprene) when treating discharge from sewage plants (Tabaru et al., 1987; Ali, 1991).

The most effective juvenoid is pyriproxyfen (Sumitomo). IGR's have not as yet been passed by the Health and Safety Executive for use in the UK other than for crop control. Altosid was cleared in 1997, and will thus be available for future use.

Physical methods of control are being considered and will be evaluated. A finer filter media on the top 250 mm of the filter reduces emergence of *Psychoda* species but has no effect on chironomids. Plastic netting and plant screens along the perimeter also can give some measure of protection.

DISCUSSION

The high dosage of the first application is recommended to give maximum mortality before the larvae become resistant to *Bti*. Frequent applications of *Bti* in the confined area of the filterbeds can hasten the onset of resistance. It therefore becomes desirable to alternate *Bti* with other safe methods of control. Various methods and different formulations are to be evaluated in the future.

As the fly larvae contribute to the water purification process by consuming some of the gelatinous film, both *Bti*, which will only cause a reduction in numbers, and the IGR's, which are slow-acting and prevent emergence, have a considerable advantage over more lethal pesticides.

The greatest emergence occurs during the summer months. Swarming Chironomids have been described by Ali (1991) as an emerging global problem. If swarms can be confined to the purification plants by erecting high screens to protect them from the wind and prevent them from moving into the surrounding area, this would be a great asset. These swarms are attracted to a topical feature such as bushes, trees or buildings; they form dense elliptical clouds which move from site to site. As a general rule they are not likely to travel beyond 1.5 km.

Observations have shown that, where a suitable surface is available, the *Psychoda* will gather, preferably as close to the emergence site as possible. They tend to swarm near the ground and then find a resting site. This phenomenon can frequently be observed on filters of rough concrete wall construction, where vast numbers will accumulate in available holes, cracks and crevices on the down-wind side of the filter walls. They tend not to travel far but pressure of numbers and lack of suitable resting sites may cause substantial distances to be covered. As there is evidence that a high percentage of female flies lay their eggs in the place from which they emerged, it is desirable to keep the flies within the area and prevent them causing a nuisance elsewhere.

CONCLUSIONS

The filterbeds provide an interesting ecosystem and the specialised populations are dense, with high multiplication rates and unlimited food. The existence of this community is of critical importance for maintaining the treatment capability of the percolating filters. Target specific methods of fly larval control, such as *Bti*, need high dosage rates because alternative food is available to the larvae and *Bti* will be consumed also by unaffected non-target organisms. Teknar liquid formulation received approval for use on sewage filterbeds in 1991 and has become the standard method of fly control for this purpose in the UK. The method of application and the timing is important in order to reduce fly emergence. Care must be taken to avoid resistance, but if it develops it is likely to be location-dependent and will not spread outside the treatment works. General resistance is not, as yet, a problem in the UK.

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