TRENDS IN URBAN REFUSE DISPOSAL: A PEST'S PERSPECTIVE

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Abstract - The effective disposal of solid refuse from the urban environment is a fundamental requirement for a healthy city. Waste materials may be classified according to their origin and disposal technique. Municipal solid waste (MSW) is waste produced by the home, retail sector, offices, hotels, and similar activities, and will constitutes a large proportion of the waste produced internationally. MSW contains10 to 50% of putrescible organic material. As a result of this putrescible content, MSW may support infestation under appropriate conditions. At the point of generation, waste deposition has evolved from simply depositing the MSW in a heap to await collection, to use of refuse chutes, individual household refuse bins with or without sacks to contain the refuse, and community collection points. Many recycling and composting schemes require separation-at-source for MSW. All these approaches influence the pests associated with the curb-side refuse, and the level of infestation. As MSW is increasingly disposed of on a regional as opposed to a local basis, transfer stations increase in number, bringing their own special pest profile to the urban environment. Final disposal of refuse may take a number of routes. Recycling/re-use is a growth sector, and the international spread of tyre-inhabiting vector mosquitoes has resulted from this trade. Composting of organic waste is a fast-growing route in many countries, and in some situations may develop significant infestation. The proportions of MSW being incinerated or going to landfill are declining slowly, although the latter is still very important in terms of infestation and the impact of the infestation on the surrounding area, which may extend over many square kilometres.

Greater environmental awareness coupled with economic pressures, are changing the way that MSW is processed around the world. Actively reducing the potential for infestation needs to be an integral part of the development of these new technologies, in order to avoid adverse repercussions on the urban environment.

Key words - Putrescible refuse, solid waste, vectors, insects, rodents

INTRODUCTION

The urban environment may be considered as a dynamic ecosystem, and therefore subject to the same general type of rules and processes as any more conventional ecosystem.

The urban ecosystem consists of a substantial abiotic element, together with it's associated factors such as temperature, available water, and other parameters. The biotic elements of the urban ecosystem are driven by a range of external inputs, including energy (as fossil fuels or electricity), and both raw and processed materials.

Although of course the human community dominates the urban environment, there are nonetheless a range of other communities that have critical part to play. The pest communities that inhabit and take advantage of human housing and accommodation, are recognised in terms of their threat to human well-being, and are reasonably well understood (eg. Murphy, 1993; Building Research Establishment, 1992; Rivault, 1993). Similarly, the pest communities that are found within the food industry have also received extensive attention as a result of their economic importance (eg Gorham, 1991). These various communities interact to various degrees, and co-evolve over time in response to changes in the abiotic environment, and in relation to each other. Together, these communities process the various urban inputs, through a wide variety of processes within the city.

These processes in turn produce a range of outputs from the urban environment, including waste solids. Their composition varies over time in response to the evolution of urban processes. The way that these waste materials are in turn managed as they leave the urban environment, is subject to the changing technical and political demands of the urban community. The infestation communities associated with these waste outputs are influenced by the nature of the refuse produced and the techniques used for its disposal. In some cases the potential for infestation will directly influence the refuse disposal techniques used.

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Wm H. Robinson, F. Rettich and G.W. Rambo (editors). 1999.

There have already been reviews of some of the infestation processes associated with various stages in waste disposal (eg Busvine, 1980; Darlington, 1969). The importance to the health of the human community of effective disposal of urban refuse, is well recognised (WHO, 1980). However, waste processing and disposal are evolving rapidly in response to waste generation patterns, and in response to environmental legislation and related pressures. The end of the 20th century therefore provides a useful standpoint from which to re-appraise the current processes and trends in waste disposal, together with their significance in terms of infestation.

Waste classification

Many countries operate a waste classification system, in order to be able to regulate its disposal. The classification is typically based around the origin of the waste, together with any special problems likely to be presented during its collection and disposal. National or regional waste classification schemes will often include the following categories

Table 1. Typical waste classification. (adapted from Williams, 1998)

Household waste. Waste from private domestic accommodation, but may also include educational establishments, moored vessels, and prisons.
Commercial waste. Waste from premises used for the purposes for trade or business, such as offices, hotels and shops.
Industrial waste. Waste from registered factory premises.
Sewage solids. The solid waste remaining after filtration and separation of sewage.
Clinical waste. Waste arising from healthcare and veterinary establishments, which includes human or animal tissue and waste, dressings, instruments and other potentially infective waste and its packaging.
Hazardous waste. A range of waste products that are likely to present special hazards to human health and the environment, and consequently require special precautions and techniques for their disposal.
Inert waste. Uncontaminated earth or demolition wastes, such as concrete, gravel, masonry etc.

For convenience, that waste which is collected routinely by or on behalf of the municipality or local authority, is known as Municipal Solid Waste (MSW). This will typically include Household, Commercial and some Industrial wastes, and often includes waste deposited by the public at community waste disposal sites. MSW by definition originates primarily within urban areas, and typically contains enough organic waste to support infestation. It is primarily MSW that is addressed in the rest of this review.

Trends in waste composition

The quantify and nature of MSW generated nationally is greatly influenced by regional, socio-economic and temporal factors. In terms of quantity, Fig. 1 (adapted from Williams, 1998) demonstrates the extent of national variation in the quantity of MSW produced.

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The per capita quantity of MSW produced is loosely correlated with economic development. Although MSW includes many forms of refuse, it is only the putrescible organic fraction which is capable of sustaining infestation, that is of particular importance here. This fraction is generally known as putrescible waste, and typically includes food and garden waste, but may also include faecal matter. The putrescible content of MSW is critical in determining the extent of the infestation that develops upon it (Imai, 1989), and will vary widely over time and place. For example Fig. 2 (Open University, 1993) shows the content of putrescible waste in MSW in the UK, over the period 1879 to 1990.

These data show that there has been a steady decline in the proportion of ashes in MSW over this period, arising from a switch from coal to oil and gas for heating. As a result, the proportion of

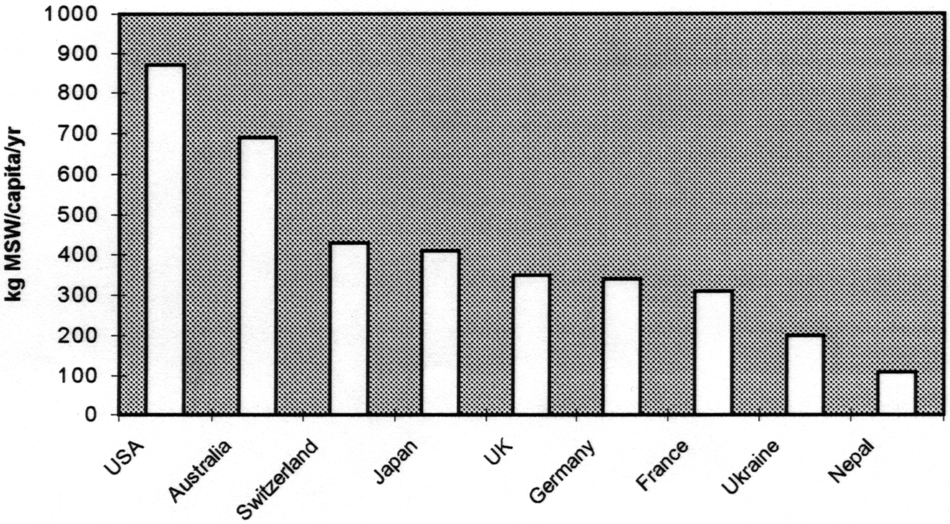

Figure 1. National municipal solid waste per capita.

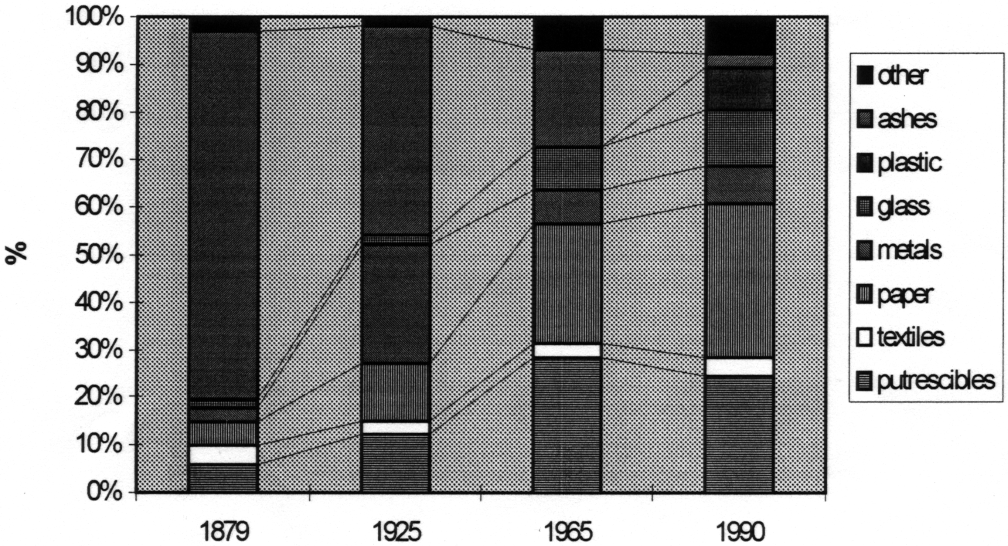

Figure 2. Composition of domestic waste in the United Kingdom.

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Wm H. Robinson, F. Rettich and G.W. Rambo (editors). 1999.

putrescible material has risen over this period from <10%, to c.25% at the present day. Over the course of the year there will also be a cycle of change in the proportion of putrescible material. Data from the USA for example (Williams, 1998) shows a peak in the putrescible content of MSW of 37% in the summer, just at the time when MSW is at its most vulnerable to infestation owing to higher temperatures. Certainly, looking at different countries, even in Europe as shown in Fig. 4 (Williams, 1998), there are differences in the proportion of putrescible material in MSW. MSW from Greece for example has approximately twice the putrescible content of say, the United Kingdom.

The underlying reasons for changes in the putrescible content are seldom clear. Sometimes these appear to be related to differences in the consumption of pre-prepared food, which tends to generate less food waste. However the recent development of products such as disposable diapers for babies, has also led to a significant change in the organic content of refuse. For example, in the UK the Department of the Environment (1994) showed that nappies then constituted 7.1% of household waste, while in Tur-

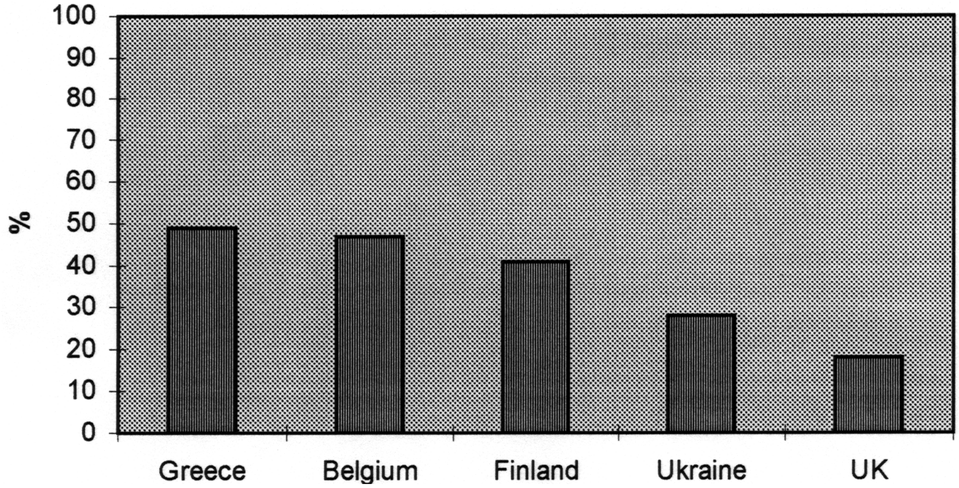

Figure 3. Putrescible content of municipal solid waste (1995).

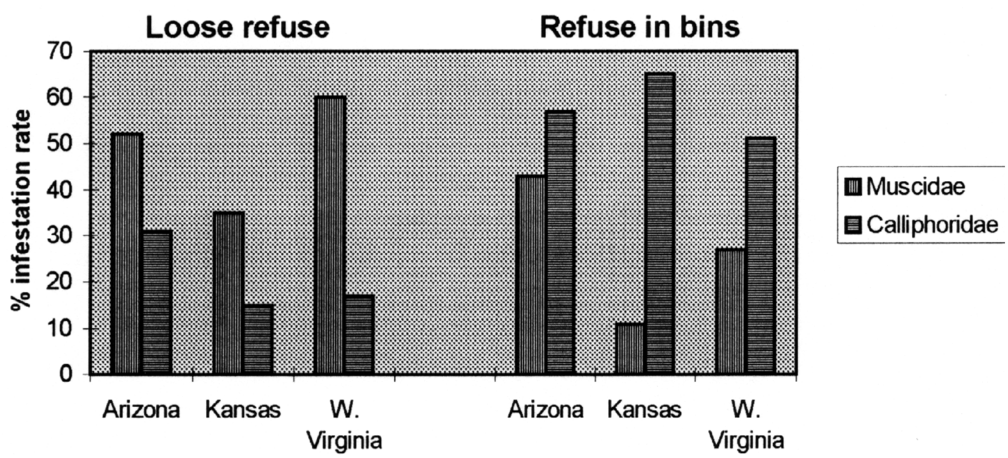

Figure 4. Relative occurrence of fly species in the United States (1950-1952).

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key, Arykan *et al.* (1997) found that nappies constituted 3.2% of MSW. As well as adding to the putrescible content, soiled diapers are also likely to increase the pathogenic content of MSW.

MUNICIPAL SOLID WASTE COLLECTION SYSTEMS

A number of alternatives exist for the deposition and collection of MSW in the urban environment, in buildings and at the curbside.

Refuse handling within buildings

In most low-rise housing, the individual householder carries their own refuse out of the building to the designated deposition point. However in high-rise housing, because of the logistical difficulties in doing this for residents on the upper floors, most buildings have internal refuse chutes. These chutes will typically run up through the entire building, with access points on each floor. The chute typically terminates in a large open-topped wheeled bin at ground level. In some countries the design of the chute and waste reception area is controlled by national standards (Building Research Establishment, 1992) that are intended to prevent pest access to refuse, and to prevent pests using the chute as a route for movement through the block. Elsewhere, partially blocked chutes and poorly designed chute closures enable the refuse chute system to be extensively accessed by insects such as cockroaches, and by mice (Shenker, 1973). Inappropriate routing of hot water and steam pipes though refuse reception rooms can also create conditions conducive to the development of serious infestations, particularly of cockroaches.

In many countries it is now becoming increasingly common for commercial food waste, eg from restaurants, hotels, or hospitals, to be kept within a designated refrigerated store at the premises, prior to collection and removal. This clearly will prevent the refuse being accessed by insects and birds, and makes it unlikely that it will suffer significant attack by rodents. Once removed from the refrigerated holding room, refuse may take some to reach ambient temperatures again, and so will have extended protection from insect infestation.

Loose refuse

One of the simplest approaches to refuse disposal is the designation of certain areas within the town as 'public dustbins', at which refuse may be simply deposited in a heap on the ground, prior to collection by the municipality. Public dustbins are typically located on street corners, small areas of waste-land, or other locations close to the point of generation of the refuse. Although such an approach leaves the refuse highly vulnerable to infestation, by concentrating the refuse in designated locations, it does enable it to be collected and removed, and is an improvement on no system at all.

Depending on the climate, the nature of the MSW, and the frequency of collection, open public dustbins will often result in the development of serious infestations of flies and rodents, as well as attracting birds, dogs, cats, cattle, goats and other animals. Where public dustbins are located on loose substrates, fly larvae will leave the refuse to pupate and so avoid collection, and remain to re-infest the site.

Although exposed putrescible refuse is initially attractive to pests, the level of attractiveness will change not only with time but also in response to weather. Hot and dry conditions may reduce the attractiveness of the refuse to flies within days, while by contrast hot and wet conditions may prolong the attractiveness (Toyama, 1988). As a result fly infestations in exposed refuse will vary considerably between wet and dry seasons in tropical areas. In temperate areas, refuse will still lose attractiveness over time. Imai (1984) in Japan found that fresh MSW left exposed in the open was no longer able to support a fly infestation after about 20-30 days from deposition.

Refuse bins

In more developed countries, portable community or household refuse containers with lids, and typically made of galvanised steel or plastic, may be provided. At simplest, the loose refuse is placed directly in the

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bin, and then emptied from there into a collection vehicle at regular intervals. Although appearing to provide a much higher level of protection for refuse, and ease of emptying, such bins are still very vulnerable to infestation.

Even when new, the lids on bins may not provide a sufficiently good seal to prevent the entrance of blowflies (Calliphoridae). Siverley and Schoof (1955) showed that adult blowflies are capable of entering through apertures only 3.2 mm wide. Larger scavenging mammals such as foxes, may still be able to dislodge the lids in order to gain access, and in doing do subsequently allow access for smaller pests.

Over time metal bins quickly become deformed, so that lids fail to fit tightly. Rusting, either as a result of exposure to the weather, or through corrosive refuse, also soon leads to holes in the base of the bin. Such holes allow easy ingress of flies and other pests, and allows late instar fly larvae to leave the bin in search of pupation sites. Late stage blowfly larvae are also capable of climbing the internal surface of intact metal 112 litre domestic refuse containers, in order to migrate away from the container and find suitable pupation sites (Campbell and Black, 1960). Although resistant to corrosion, plastic bins may sometimes be perforated by rodent attack. Even when bins themselves remain in good condition, many bins will have the lids left off during the filling process, or will be over-filled with refuse so that the lid rests on top of the refuse, providing no seal at all.

As a result of such processes, studies in the United Kingdom (Green, 1963) and in the United States of America (Quarterman *et al.*, 1949) both showed that when loose refuse was placed directly in the bin, around 60% of refuse bins were infested with fly larvae prior to collection, and so represented one of the main sources of fly breeding in urban areas. Campbell (1960) found an average of >1000 flies emerging per bin per week in California. Many of the immature flies were associated with the sludge in the bottom of the can, as well as with the loose refuse itself.

The process of containing refuse in bins alters the relative abundance of blowflies and houseflies (*Musca domestica* L.) breeding in the refuse, even when access to both species is physically possible. Studies by Schoof (1954) summarised in Fig. 4 showed that loose refuse was infested predominately by Muscidae, while in the same area refuse contained in bins was predominately infested by Calliphoridae. The reasons for this difference are not clear, although may be related to the oviposition habits of the flies.

Wrapped refuse

Awareness of the infestation and hygiene problems caused by the accumulation of sludge in the bottom of refuse containers, led to the use of paper or plastic bags to wrap refuse in prior to placement in the bin. Such containment is believed to reduce the opportunity for flies (and other pests) to infest the refuse (ADAS, 1985), and such a view is upheld by studies by Campbell and Black (1960) who showed that refuse wrapped in newspaper prior to deposition in the refuse container tended to very substantially reduce the numbers of flies breeding within the rubbish and within the bin.

However, use of standard plastic sacks is now increasingly under scrutiny. Containment of refuse in plastic sacks slows the decomposition of the refuse in landfill sites, and will actively interfere with recycling and composting processes. Putrescible refuse in plastic sacks tends to follow an anaerobic decomposition route resulting in production of unpleasant odours. As a result toughened paper sacks are once again becoming increasingly popular with refuse collection and disposal organisations. They may be shredded together with the refuse itself when fed into the composting processes, and being permeable to air, allow odourless, aerobic decomposition of the refuse to commence prior to collection. Nonetheless in practice, sacks are often not fastened properly at the neck by the householder, so allowing pests to gain entry. When used independently or in addition to a refuse container, they are vulnerable to tearing, either accidentally or by larger pests such as birds, rodents, cats, dogs or foxes.

Timing of refuse collection

Refuse deposited at the curbside awaits collection by the refuse disposal authority. Collection frequency is partly a function of climate, of the size of refuse container, and of the access to refuse deposition points. In southern Europe, for example, refuse collection is often carried out daily to minimise nuisance from odours and fly breeding, while in many temperate areas, collection of household waste containing putrescible material is on a weekly basis (Pescod, 1991-3).

Nonetheless, even well-planned refuse collection schemes can nonetheless result in delays in refuse collection. A survey in the United Kingdom (Grimston, 1999) indicates that the proportion of refuse containers that are missed by the refuse collection personnel on each weekly visit, ranges from 4.3% in Liverpool and 2.1% in Slough, down to c.0.01% in other areas. In addition to this uncollected refuse, there will be partially full refuse containers that have not been put out for collection at all, perhaps because the residents were away from home on the day scheduled for refuse collection. Given that holidays are often taken during the warmer time of year, there is therefore an increased tendency for missed refuse to occur just when conditions for infestation development are most favourable. Missing a weekly collection will result in refuse remain in the container 1- 2 weeks; ample time during the warmer months for flies to go through one generation and start on the 2nd, before the refuse even reaches the disposal site. Given that refuse is more likely to miss collection during warmer weather, refuse received at transfer stations and disposal sites during warmer weather will often carry a heavier fly burden than at other times.

Where composting schemes operate, separation at source of compostable and non-compostable waste entails storing undiluted organic waste at the point of generation, prior to collection. Such putrescible waste stored in bags or bins is vulnerable to infestation and the organisation responsible for collection of the waste will need to establish a collection frequency that minimises infestation problems, but yet maintains economic viability.

Transfer stations

As refuse disposal become more tightly regulated, many disposal sites close to urban centres are closed, and the final disposal point of the MSW therefore moves further away from the point of refuse generation. It therefore becomes uneconomic and impractical to transport the refuse in the street collection vehicle direct to the disposal site. Instead the refuse will be taken to a waste transfer station, where it will be emptied from the collection vehicle, and then typically loaded into a compactor to reduce the volume, or into a baling plant where it is highly compressed. It is then loaded onto a larger vehicle in loads of up to 30 tonnes, for transportation over longer distances to the final disposal point. In recent years there has been a steady growth in the numbers of transfer stations in some countries, as MSW disposal moves from being local to regional.

Operating licences for transfer stations typically require that a rapid turn-around of refuse, and regular cleaning, takes place. Nonetheless from time to time, due to mechanical breakdown of the compaction equipment, or difficulties with onward transport, or other logistical or managerial problems, refuse does sometimes remain on site for longer periods. If such problems coincide with warm weather, and the arrival of particularly putrescent and pest-laden refuse, then pest problems, particularly with flies but occasionally with rodents, can occur. Where gulls are common, some individuals may learn to frequent the refuse reception area and snatch refuse from incoming vehicles, particularly in bad weather. The siting of transfer stations close to urban centres, mean that when such problems do occur, the infestation can cause problems in the vicinity.

MUNICIPAL SOLID WASTE DISPOSAL OPTIONS

There are a wide range of disposal options potentially available for MSW. The actual availability of each of those options in any once country will depend on a range of historical factors. Countries with a strong demand for compost are likely to have a well developed MSW composting industry, countries with low pressure on land may tend to predominately use landfill, countries with limited fossil fuel resources may favour incineration, while countries with a strong environmental lobby are likely to move in the direction of re-use/recycle and compost. Over time the balance of these and other factors is likely to alter and be

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Wm H. Robinson, F. Rettich and G.W. Rambo (editors). 1999.

reflected in the type of disposal facilities available. Fig 5 shows the balance of the main disposal routes for a number of countries (adapted from Williams (1998).

In terms of trends over time, Fig 6 (Glenn, 1998) shows the current direction of refuse disposal routes in the United States of America, but is also likely to be broadly indicative of trends in several other developed countries.

LANDFILL SITES

Disposal by landfill has been a very common MSW disposal route, probably for centuries. Using refuse to fill old quarries or reclaim low-lying land, has until relatively recently seemed a worthwhile and inex-

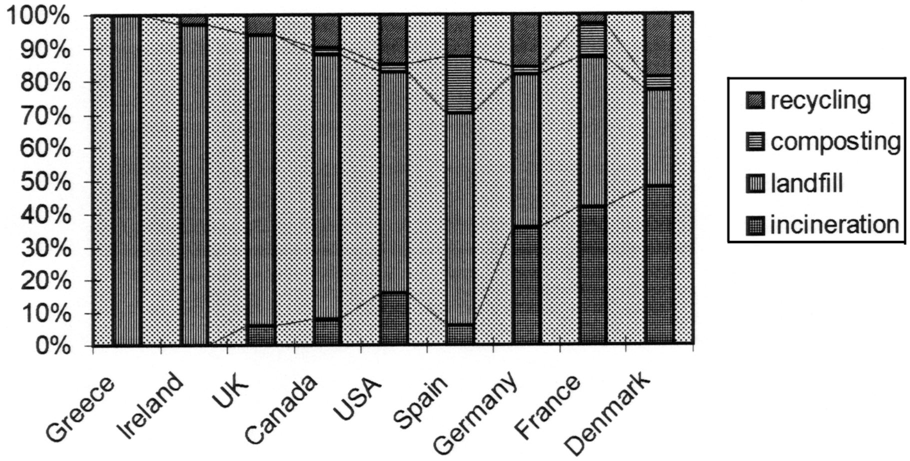

Figure 5. Comparison of municipal solid waste disposal routes (1995).

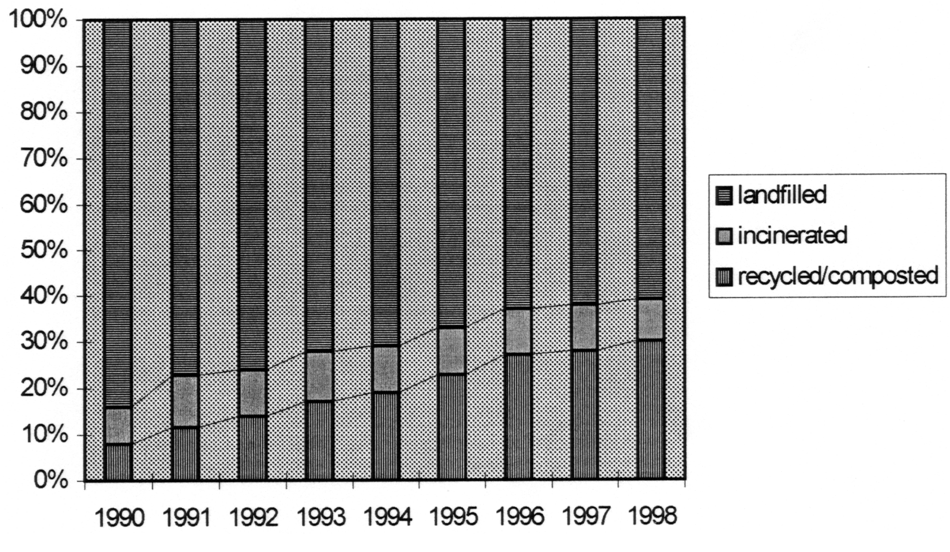

Figure 6. Disposal routes for municipal solid waste in the United States (1990-1998).

pensive disposal route. However in recent years, imposition of tighter regulations on landfill site management in many countries has increased the running costs, and has resulted in the closure of numbers of small sites. As a result the sites that remain are fewer in number, but better managed than they were 20 or even 10 years ago (Glenn, 1998). The proportion of refuse going to landfill has fallen in some regions as a result of the growth in other disposal routes, such as incineration, or more recently composting.

Waste tipping and compaction

Having arrived and been tipped at the landfill site, MSW is generally compacted using bulldozers, or steel-wheeled compaction vehicles. Compaction is carried out to reduce the volume occupied by the refuse and to provide a safer surface for vehicles. However compacting by itself will tend to reduce the numbers of flies infesting the refuse, perhaps by reducing the opportunity for flies to access and emerge from the refuse. Studies by Toyama (1988) in Hawaii showed that the worst fly infestations occurred on sites where refuse was left uncompacted.

On larger landfill sites, tipping will typically be carried out on a particular face for some days or weeks, and then switched to another location at the same site. This will allow the refuse at the first face to undergo further natural settlement for some period before tipping is resumed there. As the refuse at the first tipping face ages, it will become less attractive to pests. Fly oviposition will decrease, and adult flies will then disperse away from the aging refuse. Imai (1984) showed increases in fly emigration rates as MSW increased in age.

Daily cover

Good practice for the management of refuse on landfill sites, includes regularly covering the fresh compacted refuse on the working face and flanks of the site, with a compacted layer of soil to a depth of 150 mm (WHO, 1971). Ideally this is carried out at the end of each working day using a bulldozer, but longer intervals between covering may elapse. Daily cover is intended to prevent pests such as flies, birds, rodents and other vertebrates accessing the refuse, to prevent emergence of pests (typically flies) already contained within the refuse at arrival, to prevent odours, and to prevent wind dispersing the refuse. Again Toyama (1988) in Hawaii showed that where refuse was covered on a daily basis, fly infestations were less severe than where refuse was covered once or twice a week.

However several studies have shown that 150 mm of soil is insufficient to completely prevent emergence of flies from buried infested refuse. Toyama (1988) found that houseflies could emerge from MSW buried under 250 mm of bulldozer compacted soil, and Quarterman (1949) working in the USA found that flies (including Muscidae, Sarcophagidae and Calliphoridae) could emerge from infested dog faeces buried under 460 mm of compacted soil. Observations indicated that to some extent, buried larvae forced their way up through the soil prior to pupation, thus reducing the depth of soil through which the adult subsequently had to emerge. However in many areas, loose soil is not available in sufficient quantities or at the right price to bury in landfill sites. As a result less suitable soils, such as those with a high clay content, may be used. However such material cannot be spread uniformly over the surface of the refuse, leaving a proportion of the refuse exposed, resulting in the potential for development of pest problems.

In response, a range of alternative daily cover materials are being increasingly tested and used. Alternative daily cover materials that may be spread on the surface of the refuse, include paper pulp, fragmented plastic waste, foundry sand, and quarry waste (Landfill Cover Task and Finish Group, 1997). Foams that may be sprayed over the surface of the refuse, such as urea formaldehyde foam, have also been used and appear to be effective, although they tend to be relatively expensive. In addition, the total amount of refuse that can be deposited at many landfill sites is constrained by natural limits, eg as in the size of the quarry being used, or by limits set by regulatory authorities. As a result landfill operators are reluctant to partially fill their available void with material such as soil that they have to buy in, as opposed to refuse for which they can charge.

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Wm H. Robinson, F. Rettich and G.W. Rambo (editors). 1999.

Where void limits are critical, a number of alternative daily cover materials that occupy minimal volume, are being used. Materials include hessian, plastic sheets, and woven geotextiles. Large strips of these materials, often jointed at the edges to form single large sheets, are spread over the fresh compacted refuse. They are either removed prior to the next day's tipping, or buried together with the refuse. To be effective at preventing pest escape from, or access to, the refuse, the cover needs to be continuous. At one site in the UK where textile cover was poorly fitted, fly development could still continue, and as the protection offered to the flies by the remaining textile cover reduced the effectiveness of insecticide treatments, severe problems were created. Plastic sheets are believed to create a micro-climate beneath the sheet in which the temperature in direct sunlight rises to a level where it may inhibit fly development. However buried plastic sheets can create problems later in the development of the site as they interfere with the percolation of rainwater through the site, and will trap landfill gases. Birds such as gulls and crows, may be seen attempting to feed through the textiles and sheets, but are usually discouraged. The overall implications for infestation of these various novel materials are still under consideration.

Infestation on landfill sites, and its impact on the surrounding area

The steady arrival of organic refuse, together with low numbers of established predators, makes landfill sites an attractive habitat for a limited numbers of species. Although numbers of individual species may reach very high levels, diversity remains relatively low when compared with other habitats.

Landfill sites are also biologically unstable environments. The MSW may vary considerably in terms of its ability to support infestation, particularly when it contains variable quantities of commercial food waste. It will then be subjected to various processes, as described above, intended to rapidly reduce its attractiveness to infestation. On each landfill, the tipping face will switch from place to place, forcing those organisms dependant on fresh MSW to move in order to stay in their ideal environment. Even away from each tipping face, there is often little stable habitat, which together with regular disturbance by vehicles and workers, forces some pests, such as larger vertebrates, to live away from the landfill site, and yet commute in regularly in search of food. This continual movement of large populations of pests in response to the changing environment, often results in a dispersion of a proportion of the pest population off the site and into the surrounding area. This can result in a nuisance to nearby residents. Fig. 7 illustrates the extent of nuisance reported by residents near 5 landfill sites in Finland (Nuorteva, 1980).

Insects

A large and diverse insect community may be found on landfill sites. Dirlbeck (1986) identified in total 67 species of Diptera associated with landfill sites in Czechoslovakia, and defined a succession of Diptera as the refuse aged. In Turkey, Calisir (1993) studied 5 landfill sites and found 17 dipteran species from the Muscidae, Calliphoridae, Sarcophagidae, Otitidae and Syrphidae. Globally, most publications on the insect fauna of landfill sites will describe the common housefly as the most abundant dipteran species on fresh MSW at landfill sites, closely followed by various Calliphoridae. In warm climates, such infestations will occur throughout the year, as long as fresh refuse is available, although fly infestations tend to be worse in wet weather (Toyama, 1988). In temperate climates, flies are less obvious during the winter months, although they may survive and breed by restricting their activity to the warmer sub-surface layers (ADAS, 1985).

Although most adult houseflies will remain close to the larval breeding sites, a proportion will nonetheless disperse over much greater distances. This dispersion is most marked when refuse loses its attractiveness to flies, perhaps as a result of drying or decomposition. Studies in urban areas in the U. S. (Ogata, 1960; Parker, 1916; Quarterman, 1949; Schoof, 1952) have shown that although most flies stay close to their release point, nonetheless houseflies and blowflies can travel distances of up to c. 1.5 km within 8 hours and marked flies have been recovered 3 km or more from the release point. Measurements of nuisance caused by flies in Finland (Nuorteva, 1980), Fig. 7 show that even at 1km from the landfill site there may still be measurable nuisance levels. In addition to causing nuisance, flies from the vicinity of landfill sites have been shown to carry a number of pathogenic bacteria and parasites (Oo, 1989; Sulaiman, 1988), and so have the potential for disease transmission. Fly larvae have also been recorded as migrating from landfill sites and causing a nuisance to nearby residents (Rentokil, 1989).

In Egypt, Beier (1986) investigated the breeding sites of the sandflies *Phlebotomus papatasi* (Scopoli) and *P. langeroni* (Nitzulesu) during an outbreak of visceral leishmaniasis, and found that rodent burrows on refuse disposal sites were among the preferred breeding sites. The high organic content of the landfill substrate appears to particularly associated with breeding sites of this species (El-Sawaf, 1991). After complete filling of a landfill site, the waste is normally capped with an engineered barrier of clay, soil, or other materials to seal in the waste. At hazardous waste disposal sites, it is critical that this barrier provides a good seal for very long periods. At disposal sites in the Hanford 300 area in the U. S., capped with 1.2 m of soil, harvester ant (*Pogonomyrmex* spp.) nests were found with tunnel depths ranging up to 2.7 m underground. The ants were estimated to be bringing 151 kg of material to the surface annually. At another U. S. radioactive disposal site, harvester ants had penetrated a gravel covering, and had incorporated particles of U^{235} and Cs^{137} into their surface mounds (Blom, 1991).

Insects such as crickets *Acheta domesticus* L. (ADAS, 1985; Rentokil, 1989; and Stein, 1994), American cockroaches *Periplaneta americana* L. (Rentokil, 1989), German cockroaches *Blattella germanica* L. (Stein, 1994) and Oriental cockroaches *Blatta orientalis* L. (ADAS, 1985; Gould, 1941) can become established within refuse. Even in temperate climates, the warmth of decomposing refuse enables them to survive and breed through the winter. Infestations have often been linked to pockets of building waste, which have created voids in which the insects could live, despite compaction of the MSW around. Both crickets and cockroaches are known to disperse off landfill sites to cause a nuisance to nearby residents, with migration in Germany occurring predominately during the warmer summer weather, and in a southerly direction (Stein, 1994). Crickets have caused a nuisance to nearby residents by their stridulation (ADAS, 1985). In former Czechoslovakia, the tick *Ixodes ricinus* L., the vector of Lyme disease, was found to occur on the wood mouse *Apodemus sylvaticus* L. living on landfill sites (Kohn, 1991).

Birds

A very wide range of birds visit landfill sites to fed on the MSW. Gulls (Laridae), crows (Corvidae), starlings (Sturnidae), kites (Accipitridae) are all abundant on landfill sites in different regions. Few if any of these birds nest on the site but will include the site within their normal foraging area. In temperate areas, numbers of birds on landfill sites often increase substantially outside the breeding season as a result of winter visitors.

Their impact on neighbouring areas may arise from gulls carrying and dropping litter, which can be a nuisance to residents (Nuorteva, 1980) and a potential threat to the health of livestock (ADAS, 1985). The large-scale movement of gulls between the landfill site and other feeding and roosting areas may be a threat in terms of bird-strikes to civil and military aviation. Faeces of gulls that have been feeding on landfill sites have been shown to contain human pathogenic bacteria such as *Escherichia. coli* 0157. Transport of such bacteria by gulls from landfill sites to cattle pasture, has been proposed as one route for infection of cattle herds with this pathogen (Wallace, 1997).

Rodents

The brown rat *Rattus norvegicus* L. is very commonly associated with landfill sites (ADAS, 1985; Rentokil, 1989). Municipal solid waste provides ample food for large populations to develop (Schein, 1953). Lore (1978) showed that 90% of all nest burrows examined on landfill sites were within 100 m of the fresh MSW and also close to water, yet were typically located in loose soil on sloping terrain. Some nests and feeding stations were also found inside discarded vehicle tyres. Burrowing rodents may be able to penetrate surface capping at waste disposal sites. At radioactive disposal sites in the U. S.

Proceedings of the 3rd International Conference on Urban Pests.
Wm H. Robinson, F. Rettich and G.W. Rambo (editors). 1999.

covered with up to 2.4 m of soil, burrowing deer mice (*Peromyscus manicualtus*) were found to have up to 384 times the radioactive levels of mice living in control areas, providing strong indirect evidence for penetration of the surface barriers (Bowerman, 1988). For those people scavenging on landfill sites, primarily in developing countries, the risk of bites from rodents is significant. (Cointreau-Levine, 1997). Infestations of *R. norvegicus* are known to disperse off landfill sites and cause a nuisance to residents (ADAS, 1985; Nuorteva, 1980).

Larger vertebrates occur regularly on landfill sites, including foxes, feral dogs and goats. These visit the landfill site in order to feed directly on the refuse, or to prey on other animals living there (Lore, 1978). Bites from feral dogs are recognised as a common complaint among those working on landfill sites in developing countries (Cointreau-Levine, 1997).

Incineration

Incineration was originally conceived simply as technique to dispose of refuse. Even up to the 1960s and 1970s in the U. K., the majority of refuse incinerators were still built as waste disposal systems, with no attempt to harness the energy produced. Despite the fact that the first MSW incinerator for energy production was established in London in 1870, it was not until the 1980s that energy-from-waste became a strong component of incineration, with incinerators producing power for district heating systems, or producing electricity for supply to the national grid. The 1970s in particular saw a growth in refuse incineration world-wide, in response to a growth in MSW volumes, and to an increase in the combustible proportion of MSW resulting from a rise in packaging. (Public Services Privatisation Unit; European Federation of Public Service Unions, 1998).

At present, it is now probably true to say that at least in developed countries, the incineration option is now less attractive than it was in the 1970s, owing to concerns about air pollution, the cost of limiting pollution, and the need for re-cycling of waste. In the U. S. the quantity of refuse being incinerated has declined very slowly over the 9 years from 1989 to 1998, while other techniques such as composting have increased substantially over the same period, as shown in Fig. 6 (Glenn, 1998).

At modern MSW incinerators, refuse is typically tipped from the collection vehicles into reception chambers. Rogue non-combustible objects are then removed from the refuse before it is transferred into a holding bay. A stock of refuse is typically held for a few days in the holding bay, to ensure that there is always enough fuel to keep the furnace fed, even on days when there is no new refuse arriving at the facility. Refuse is then fed from the holding bay into the furnaces. The ash produced is essentially inert in terms of infestation.

In terms of pest problems, refuse incinerators are typical of sites involved in short-term MSW handling and storage, such as transfer stations, baling and sorting plants. Flies may be a problem inside the refuse holding pit during warm weather, particularly if some time has elapsed between generating the refuse and it's arrival at the site. However in some plants the feed air for the incinerator is drawn in over the refuse, so reducing the numbers of flies that fly against the airflow and out of the plant. Rodents and birds may be attracted to spilt refuse on arrival or departure roads if these are not swept regularly. In a well-managed incinerator site, significant pest problems are only likely to be experienced when the site experiences unforeseen operational problems such as mechanical breakdowns, that may result in refuse being held on site for longer than normal.

Re-using and recycling

From an environmental angle, re-using and recycling of waste are attractive options. As a result, there has been a substantial growth in recycling in recent years (Figure 7 and Table 2) although absolute quantities recycled in many countries are still relatively small compared with landfill or incineration. In many countries, separation of recyclable items is carried out by the householder who will deposit the items such as glass, aluminium, newsprint etc in dedicated holding containers situated throughout the community. In general the low quantities of putrescible material associated with such waste, together with the design of the dedicated holding containers, minimises infestation problems. However some

Proceedings of the 3rd International Conference on Urban Pests.
Wm H. Robinson, F. Rettich and G.W. Rambo (editors). 1999.

sites do have minor problems with flies, particularly Drosophilidae and Faniidae associated with recycling points.

However there are some more conspicuous examples of the effect of the recycling trade on pest status. Used vehicle tyres are a universal component of urban waste. However national differences in the national levels of permissible wear, or in regulations regarding re-capping of used tyres, often result in the waste tyres from one country being a marketable commodity in another. As a result a global trade has developed in used tyres (Reiter and Sprenger, 1987). Used tyres stacked in the open awaiting shipment will trap rainwater, and so become suitable breeding sites for container breeding mosquitoes. In S.E. Asia, such used tyre dumps will often contain numbers of larvae of the mosquito *Aedes albopictus*

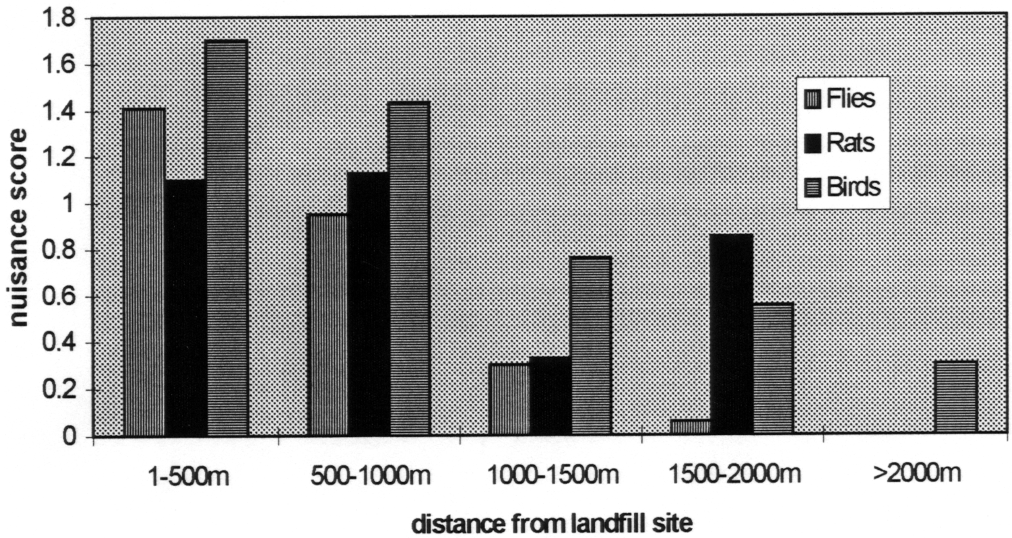

Figure 7. Pest nuisance around landfill sites in Finland (1980).

(Skuse), a common container-breeding urban mosquito, and vector of dengue fever. Shipment of such infested tyres is believed to have been responsible for the introduction and establishment of this species into the U. S. in the early 1980s, and since then imported used tyres containing this species have been detected in other countries such as S. Africa (Cornel and Hunt, 1991). Introduction of exotic vector mosquitoes via the re-use/recycling trade has created problems for vector control and health management in affected counties.

Composting

Composting in a traditional form has been carried out by householders and farmers for centuries. However in recent decades it has been increasingly viewed as a way to dispose of the organic waste in MSW, and at the same time to produce a useful soil fertility enhancer. Although anaerobic digestion of organic waste has been used, this is not now preferred, and aerobic composting is much more widespread. Raw MSW will be separated into compostable and non-compostable waste prior to composting. This may be done at source, as in Germany, U. K. and the Netherlands for example, while other countries such as Italy, Spain and the Middle East will separate the 2 streams at a central processing facility. The organic waste will be macerated and then typically stacked in long ridges or 'windrows' across a concrete base in the open air. The windrows of refuse are watered in dry weather to maintain moisture levels, and are turned mechanically at intervals to ensure an even biodegradation. They may be covered

Proceedings of the 3rd International Conference on Urban Pests.
Wm H. Robinson, F. Rettich and G.W. Rambo (editors). 1999.

by plastic sheets or tunnels, or by removable covers to prevent desiccation and to keep the waste warm. In a well-managed process, biological degradation will raise the internal temperature inside the windrows to c.60 ºC. After an interval of 4 to 6 weeks, the refuse becomes a dark, friable material, suitable for incorporating into soil to improve fertility. Typical end users are agriculture, horticulture, private gardening, or landscaping and reclamation projects. Table 2 shows the trends in composting facilities in several European counties. (Walker, 1997).

Table 2. Growth in numbers of European composting facilities

Country	1990	1996
France	45	167
Germany	16	340
Austria	116	153
The Netherlands	10	24
UK	4	44

However, the use of composting as a disposal technique for the organic fraction of MSW does raise infestation issues.

Separation at source of compostable and non-compostable waste entails storing undiluted organic waste at the point of generation, prior to collection. As discussed earlier, such putrescible waste is vulnerable to infestation. McEvey (1988) identified 21 species of Drosophilidae associated with vegetable waste in housing areas in S. Africa, while Powell (1998) also reported drosophilid flies as a pest of composting vegetable waste. Where separation of putrescible and non-putrescible waste is carried out at a processing plant, then like other similar plants such as transfer stations or baling plants, there are risks of infestation, particularly with flies in warmer weather.

Once macerated putrescible refuse is stacked in windrows, it is again particularly vulnerable to the development of infestation, particularly if it already contains infestation acquired prior to collection. Block (1998) describes a range of infestation problems occurring in the U. S. on composting sites, including flies in the composting material, mosquitoes and other insects breeding in the leachate pools running out of windrows, gulls and crows feeding on fresh waste, rodents feeding on the waste particularly where the refuse was composting under covers, and even larger vertebrates including bears. The windrows of fresh, uncomposted refuse were most attractive, but once the waste had heated up, and turned so that the surface consisted of partially composted waste, it became very much less suitable for the development of infestation. Turning the refuse at intervals substantially shorter than the generation time of the flies, was critical in preventing the development of infestations. Strazdine (1996) working in Lithuania examined the insects developing in MSW, and in mixtures of MSW with manure, that were allowed to compost for periods of up to 3 years. Although the precise composting regime was not completely clear, 43 insect species were found, with a clear succession over the composting period. Covering the composting MSW with a 3-5 cm layer of soil was found to eliminate most of the synanthropic fly species.

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