Abstract. Following the first recorded introduction of the Old World screwworm fly (OWS), Chrysomya bezziana Villeneuve (Diptera: Calliphoridae), into the Mesopotamia valley in Iraq in September 1996, cases of livestock myiasis caused by OWS developed a distinctly seasonal pattern. The annual cycle of clinical OWS cases is explained here on the basis of environmental variables that affect the different life-cycle stages of C. bezziana. This analysis suggests that low temperatures restricted pupal development during the winter, whereas the dispersal of adult flies was constrained by hot/dry summer conditions. A restricted number of OWS foci persisted throughout the year. In these foci, pupal development was fastest during the autumn months. In autumn, rapid multiplication, lasting several OWS generations, allowed subsequent adult fly dispersal across the valley floor during the winter. Hence, the monthly incidence of clinical OWS cases in livestock peaked during December–January and was lowest during July–August. In addition to temperature and humidity, vegetation cover played a role in OWS distribution. Hence the majority of OWS cases were clustered in the medium density type of vegetation [normalized difference vegetation index (NDVI) values of 0.2–0.4] along the main watercourses in the marshy Mesopotamia valley. Although sheep were the host most commonly infested by C. bezziana, local sheep density was not found to be a major factor in disease spread. Satellite imagery and the application of Geographical Information System (GIS) tools were found to be valuable in understanding the distribution of OWS in relation to vegetation and watercourses. The presence of screwworm in Iraq, at the perimeter of the intercontinental OWS distribution, may give rise to major seasonal flare-ups.

Key words. Chrysomya bezziana, geographical information system, myiasis, Old World screwworm, seasonality, sheep, Iraq.

Introduction

Although classified in different genera of the blowfly family, Calliphoridae, the Old World screwworm fly (OWS), Chrysomya bezziana Villeneuve, and the New World screwworm fly (NWS), Cochliomyia hominivorax Coquerel, have a very similar biology, ecology and behaviour (Spradbery, 1994) and both species are obligate parasites of vertebrates in their larval stages, causing traumatic myiasis. There is no overlap in their geographical distributions. NWS is confined to the Americas, but OWS is found across sub-Saharan Africa, the Indian subcontinent, South-east Asia, and the Gulf region of the Arabian Peninsula (Norris & Murray, 1964). Molecular analysis of OWS populations from sub-Saharan Africa, the Gulf region and Asia suggests that the geographical isolation of the sub-Saharan African
and Asian lineages of *C. bezziana* took place about one million years ago (Hall *et al*., 2001). This static distribution pattern is surprising given that domestic livestock have replaced wild ungulates as the most commonly infested host animals throughout most of the geographical range of OWS. Livestock numbers across the world are on the increase and so is the annual trade in live animals (FAO-STAT, 2001). It may be expected that further spread of livestock will occur and, with them, there is the potential for spread of parasites and pathogens.

The Middle East region is an area of particular interest, with extensive livestock movement. It has been suggested that the isolation of African and Asian OWS lineages is maintained by the zone of unfavourable arid environments between the Gulf and sub-Saharan Africa (Hall *et al*., 2001). Even so, it remains unclear why African lineage OWS have so far not been detected in the Arabian Peninsula given that millions of live ruminants are imported every year from the Greater Horn of Africa. Also difficult to explain is the fact that screwworm flies have not become established in Australia, despite the presence of OWS in Papua New Guinea and the occasional detection of dead *C. bezziana* flies in light fittings on livestock vessels returning from the Gulf area or on-board commercial aircraft arriving from OWS-infested India (Rajapaksa & Spradbery, 1989).

Although the global OWS and NWS picture has remained relatively unchanged, there has been considerable local spread, particularly at the perimeter of the continental OWS and NWS fly distributions. Outbreaks of NWS myiasis occurred in the United States during the 1930s, reaching Florida and then the south-eastern states in 1933 and extending up to the great lakes in 1935 (Readshaw, 1986). Mild winters and moist summers supported the widespread persistence of NWS, until its eradication by the Sterile Insect Technique (SIT) (Wyss, 2001). A shipment of NWS-affected livestock is believed to have brought *C. hominivorax* to northern Libya in 1988 (Gabaj *et al*., 1989; Lindquist *et al*., 1992). Here also, SIT was applied to eradicate the incursion (FAO, 1992).

The success of the SIT campaign was probably enhanced by low winter temperatures in both the Southern United States (Readshaw, 1986) and Libya (Krafsur & Lindquist, 1996).

In 1983, an accidental introduction of *C. bezziana* from a ship reportedly took place in the coastal Salalah area of the Sultanate of Oman (Spradbery *et al*., 1992). A total of 10 500 animals became affected until the situation was finally brought in check by insecticide treatments. Similarly, *C. bezziana* spread out from the Gulf port of Booshehr, Iran, in April 1995 (Navidpour *et al*., 1996; Haddadzadeh *et al*., 1997), prompting a major insecticidal campaign. Minor incursions have also occurred in other Gulf States, including an introduction of *C. bezziana* into Bahrain in 1977 (Kloft *et al*., 1981) and into the United Arab Emirates in 1988 (Spradbery & Kirk, 1992). Sporadic cases of OWS myiasis also occur in Saudi Arabia, in humans (Ansari & Oertley, 1982) and livestock (Alahmed, 2002; El-Azazy & El-Metenawy, 2004).

More permanent infestations appear to have occurred in the Sultanate of Oman and in Iraq. A 10-month survey carried out in the Sultanate of Oman during 1989–1990 found 82 OWS cases in the northern part of the country during the cooler months of the year (Spradbery *et al*., 1992). The first introduction of OWS into Iraq reportedly took place in June 1996 (Abdul Rassoul *et al*., 1996). Traumatic myiasis assumed epidemic proportions during the winter months of late 1996 and early 1997 (Hopkins & Khattat, 1997), ultimately giving rise to 9306 and 45 398 cases in 1996 and 1997, respectively (Al-Adhadh, 2001). Scarcity of insecticide limited effective disease control and a second epidemic wave developed during the second winter, with a monthly incidence amounting to 23 000 OWS clinical cases in December 1997 (Al-Izzi *et al*., 1999a). During 1998, significant quantities of insecticide became available to the veterinary clinics and the incidence was eventually reduced. The objective of the present study was to examine the interaction of environmental factors and fly biology that gave rise to the observed seasonality of OWS myiasis cases.

**Materials and methods**

**Collection of case data**

In September 1996, the presence of OWS in Iraq was confirmed by the FAO Collaborating Centre on Myiasis Causing Insects and their Identification at the Natural History Museum in London, U.K. (Hall, 1997). Subsequently, strict guidelines were issued to field veterinary services and clinics on how to record any clinical cases of traumatic myiasis in livestock, detailing host species, breed, age and locality for each case encountered. Medical centres received instructions for the recording of human cases.

Field data were collated bimonthly and the findings reported to relevant national, regional and international organizations. Clinical cases of traumatic myiasis caused by *C. bezziana* were identified and recorded by veterinarians in a network of 111 government veterinary clinics (Al-Ani, 1997; Al-Taweel *et al*., 2000), which were geo-referenced for the production of digital maps. Identifications were based on the descriptions given by Zumpt (1965) and Spradbery (1991) and sub-samples were confirmed by the Natural History Museum in Baghdad. They are believed to present an accurate record of OWS cases because this species was the only one in the region responsible for the deeply penetrating wounds characteristic of screwworm species. *Wohlfahrtia magnifica* (Diptera: Sarcophagidae), which produces similar wounds, is also found in Iraq, but only in the northern regions and not in cases reported here. The monthly incidences of OWS in livestock considered here were just those recorded for the first 2 years following OWS introduction. Subsequently the use of insecticides increased, distorting natural population levels.
Collection of Old World screwworm fly biological data

An OWS fly-rearing unit was established in the Entomology Department of the Iraqi Atomic Energy Commission in 1996, in the Tuwaitha region of south Baghdad. To obtain data on pupal survival of laboratory-reared *C. bezziana*, a wooden box (35 × 27 × 10 cm) was divided into 15 cells (7 × 9 cm) and a fine metal mesh closed the base. Each cell was filled with moist sand. Thirty mature larvae, taken from the colony just before pupariation, were introduced into the box at a density of two larvae per cell. Shortly after pupariation, the box was placed outside to expose the pupae to field conditions. The box was left on the soil surface under the shade of a tree. A glass vial covered each pupa in order to confine the adult when it emerged. Monthly experiments were run, from September 1998 to August 1999. Protocols for larval rearing and handling were obtained from Spradbery (1992) and Al-Izzi et al. (1999b).

To obtain data on adult survival of laboratory-reared *C. bezziana*, for matching against the monthly humidity and temperature conditions, 50–100 pairs of newly emerged adults were placed inside cages (either 0.5 × 0.5 × 0.5 m or 1.5 × 1.5 × 2.0 m) made from black or white cloth netting, suspended inside a metal frame (either 0.51 × 0.51 × 0.51 m or 1.52 × 1.52 × 2.01 m). Four to six cages were used at any one time, their size depending on the number of adults that emerged, i.e. small cages for 50 pairs of adults and bigger cages for greater numbers (cage size did not affect adult longevity at the fly densities used). To provide natural ventilation in field conditions, the cages were kept outdoors in the shade of a tree. The flies were provided with water and food in a dish containing cotton wool saturated with water, granulated sugar, honey and ground beef. An additional protein source was provided, formulated by mixing 50 g of spray-dried cow blood and 50 g of dry chicken eggs and then transferring 10 g of this mixture to the feeding container in 100 mL of water. Dead adults were collected daily and adult life span was calculated as the period from the first day of emergence until death. New adult cages were prepared weekly or biweekly and left outside in the same site, always under shade, from September 1998 to August 1999 (Al-Izzi et al., 1999a,b; Al-Jowary, 2000). Although it is appreciated that adult survival outside in cages might not be a realistic reflection of the mortality of wild flies, we were interested in this study in comparative rather than absolute values and our protocol enabled monthly comparisons of longevity to be made where the only variable was the local climate.

Climate data were collected from a thermohygrograph located at the experimental site and also from the Baghdad meteorology station, located 5 km from the site.

**Digital mapping**

Digitized maps showing monthly OWS distribution, as co-ordinates of the veterinary clinics and their OWS case data, were taken for further analysis into an ArcView Geographical Information System (GIS) environment and related to climate data, to information on livestock distribution and to satellite imagery, which indicated vegetation cover, landscape, topography and watercourse distribution. Vegetation index information were taken from the monthly (average of the monthly maximum for years 1998–2001) normalized difference vegetation index (NDVI) values produced and made available by FAO ARTEMIS at a 1 km² resolution (http://metart.fao.org). These values were derived from data from the VEGETATION instruments on board the SPOT-4 polar orbiting satellite, after processing the output using the following equation, \[ \text{NDVI} = \frac{(IR - R)}{(IR + R)} \], where IR stands for the infrared band and R stands for the visible red band. The NDVI values were categorized into the following zones of

![Figure 1](image-url)
vegetation cover: high vegetation (> 0.4), medium vegetation (0.2–0.4), light vegetation (0.1–0.2), and bare soil (< 0.1). These arbitrary NDVI categories give a measure of vegetation amount and condition and are representative of plant assimilation condition and of its photosynthetic apparatus capacity and biomass concentration (Loveland et al., 1991; Groten, 1993). They were not equated here to particular plant taxa. The display and integration of satellite imagery, digital maps and associated databases were facilitated by FAO Windisp4 software (http://metart.fao.org).

Results

Seasonality of Old World screwworm fly case numbers and distribution

In both years of the study, the monthly OWS case incidence peaked in the period of late autumn to early winter and declined sharply in springtime, reaching a low during the long, hot and dry summer (Fig. 1).

OWS appeared to disperse along the main rivers and major tributaries of the lower lying areas of the Mesopotamia valley during the first full year of establishment of OWS in Iraq (Fig. 2). The original foci of OWS cases observed during the autumn outbreak, September 1996, were in an approximately linear distribution around the Tigris river system (Fig. 2a), with few cases along the Euphrates system. During the following winter and spring months, there was not only a spread of these foci along the Tigris, but also a more significant expansion of the range along the Euphrates river system (Fig. 2b). The number of cases of OWS declined during the first summer months, with populations retreating mainly into Euphrates refugia (Fig. 2c). However, these same refugia provided the base for a more pronounced expansion in the second winter, indicated by the increase in number and concentration of OWS cases along the Euphrates starting in September–October 1997 (Fig. 2d).

Seasonality of meteorological conditions and their effect on Old World screwworm fly development

To explain variability in monthly OWS case incidence, in both time and space, the observed seasonal pattern was related to relevant environmental variables. In the Baghdad area there was a considerable contrast between the cool/wet...
winter (November–February) and the hot/dry summer (June–August) (Fig. 3).

For the laboratory-reared larvae, a positive and significant ($R^2 = 0.988$) linear relationship was observed between the monthly values of average mean daily temperature and rate of pupal development (reciprocal of the duration [days] of the pupal stage) (Fig. 4). Spradbery (1992) established a similar relationship in the laboratory using climate-controlled cabinets (Fig. 4, dashed line). No flies emerged during July and August 1999 when ambient temperatures exceeded 35°C and pupae died. Pupal development was also low during the low temperatures of November to March. Adult flies did emerge, but only after an extended pupal development of up to 3–4 weeks and only 21–44% of adults emerged. Emergence rates during the months of autumn (September–October) and spring (April–June) contrasted strongly with rates observed during winter and summer. Hence, pupal development during this period ranged from 5 to 9 days and 54–77% of flies emerged.

**Relationship between major water sources and Old World screwworm fly distribution**

The impact of major water sources on OWS distribution was considered by plotting the average distance from large watercourses of all veterinary clinics reporting cases of OWS each month during 1996–1997 and the observed longevity of the laboratory-reared flies each month during 1998–1999, together with the average monthly air temperatures during those two periods. Longevity and distance data could not be collected for the same periods; however, these periods were very similar in relation to temperature (Fig. 5). Large watercourses were defined as the main rivers, their tributaries and canals. Distances of clinics from watercourses were measured using Arc View. No new foci became established during the hot/dry August of 1997, when flies suffered from adverse weather conditions. In the same period of 1998, adult longevity was only 5–8 days (Fig. 5). Inverse relationships were apparent between adult longevity and temperature and between average distance from watercourses and temperature. The effect of these relationships on fly longevity and distribution was such that during the winter period when adult flies lived longest the average distance from the major water sources was greatest. Hence, the geographical distribution of OWS cases was greatest in the period when adult fly survival was also greatest and vice versa.
Relationship between the distributions of vegetation and of Old World screwworm fly cases

The first records of OWS cases at veterinary clinics that were previously free of OWS were largely reported from September to January, during both 1996–1997 and 1997–1998. Although individual flies are naturally capable of covering large distances (Spradbery, 1994; Spradbery et al., 1995), OWS cases remained mainly confined to the medium category vegetation coverage at all times, during both high and low periods of OWS case incidence (Fig. 6). This suggests that the extent of colonization of the Mesopotamia valley floor under optimal conditions was primarily dictated by the vegetation pattern.

Relationship between the distributions of sheep and of Old World screwworm fly cases

The relationship between the distribution of sheep and the numbers of OWS cases was explored at different levels of resolution. At the national level and just using areas covered by vegetation bands 0.2–0.4, there was no statistically significant correlation between major sheep-keeping areas and OWS presence \((y = 5353.4x + 0.1, R^2 = -0.03, \text{d.f.} = 16, P < 0.49)\). In addition, at the resolution of village level, the number of sheep per clinic and corresponding OWS incidence per clinic were analysed, but no significant correlation was found between them \((y = -54.15x + 64815, R^2 = 0.007, \text{d.f.} = 109, P = 0.37)\).

Discussion

During the last two decades of the 20th century, major ecological changes occurred in the southern marshlands of the Mesopotamia valley due to drainage (Partow, 2001). However, these marshlands remained uninfested by OWS during the study period and it was concluded that there was no discernible causal relationship between drainage of the marshlands and OWS outbreaks.

A climate matching model (CLIMEX) indicates that OWS is most successful under hot and wet conditions and is sensitive to prolonged cold or dryness (Sutherst et al., 1989). Hot and wet conditions are not encountered in Iraq and therefore the climate is marginal for OWS development. The initial focus of OWS within the Mesopotamia valley was in the Tigris river system, but the distribution...
expanded during the first winter period, when conditions for adult fly survival were seasonally ideal, following an autumn period optimal for pupal development. Although the population declined in the summer of 1997, it had by then become established in the previously OWS-free Euphrates river system. Hence the second season of expansion was even more pronounced than the first (Fig. 1), with the number and distribution of the OWS refugia that enabled summer survival being indicative of the magnitude of the following autumn and winter outbreaks. The seasonal picture became one of expansion of OWS populations as marginal habitats became tolerable, followed by contraction of populations as habitat suitability again declined. The initial spread of OWS within Iraq was probably enhanced by a shortage of insecticide and by an inadequate means to distribute it.

No relationship was found between sheep populations and numbers of OWS cases in our study. However, the data on national sheep distribution was not very detailed, and the OWS distribution, determined here by distribution of cases at veterinary clinics, may not have represented the ecological limit of OWS spread. Since 1997, OWS has become gradually more widespread in Iraq, albeit within the Mesopotamia valley. Compared to sheep density, the vegetation index class appeared far more important as a determinant of the distribution of OWS cases. The OWS distribution pattern broadly agreed with the amount of medium-dense type of vegetation along the Tigris and Euphrates rivers and major tributaries. Although it is difficult to accurately depict all areas of potential spread, it appears that most areas with medium-dense vegetation have now become invaded: few OWS cases have been found in open areas of either low vegetation, despite the presence of veterinary clinics in those areas, or dense swamp vegetation. Adult flies avoid the high temperatures and high solar radiation encountered in open areas of bare soil without any vegetation. The fact that there were few OWS cases recorded along the greenest, riverine vegetation might be explained by the scarcity of livestock on, and consequent placement of veterinary clinics away from, this irrigated arable land.

As vegetation type appears to be a critical factor in OWS epidemiology, it is relevant to recall the widespread ecological change brought about by the construction of river dams upstream of the Tigris and Euphrates rivers in Turkey, Syria and Iraq. As a result of these dams, some 20 000 km² of lake areas within the Mesopotamia valley dried out. OWS may one day appear in this new environment as it becomes vegetated. OWS could also potentially

Fig. 2. Continued.
spread further along the Euphrates river system, into Syria.

It is notable that the veterinary inspection at the Iraq/Syria border was intensified following the detection of an OWS-infected animal there in June 1997, just 12 km from the border with Syria (Spradbery & El-Dessouky, 1998). The Mesopotamia valley type of ecology is also found in adjacent regions of Iran, where Iran has reported OWS problems to occur (Navidpour et al., 1996; Haddadzadeh et al., 1997). OWS was reported from Kuwait in 1997 and 1998 (source: routine reports of OWS Coordinator to FAO), but has since been eradicated by chemical means. Infestations in Bahrain were only supported when feedlots were established in irrigated areas with tree cover. These OWS foci disappeared when the feedlots were moved to dry locations (Kloft et al., 1981).

Although the seasonal expansion and contraction of OWS populations could be influenced by a range of factors, such as the extent of OWS spread during the previous month, local vegetation, host abundance and movements of infested animals, the data suggest (Fig. 5) that the hot/dry summer conditions (June–August) are least favourable for adult fly survival and population spread.

Although the areas affected by OWS within the Arabian Peninsula may remain restricted, OWS is capable of increasing

---

**Fig. 3.** Monthly average mean temperature and relative humidity for the Baghdad area (Source: Baghdad Climate Station, Meteorological Office of Iraq via Arab Organization for Agriculture Development).

**Fig. 4.** The relationship between temperature and duration of Old World screwworm fly (OWS) pupal development (1/no. of days), from Spradbery (1992; shown as a dashed line) and that observed under field conditions in Iraq from September 1998 to June 1999 (shown as monthly squares, regression line not fitted, $y = 0.0079x - 0.0679$, $R^2 = 0.977$).
at an exponential rate in seasonally favourable conditions to give rise to major outbreaks of traumatic myiasis (Fig. 1). Such epidemics could arise when a number of critical conditions are met for population multiplication and dispersal because screwworm fits the pattern of a ‘boom and bust’ r-strategist (Southwood et al., 1974). Given the high mobility of the fly and the extensive movement of livestock across the Middle East, occasional major flare-ups are likely to continue in the absence of a sustained international control effort. Remote sensing and GIS tools may be applied by veterinary and medical services to assist early detection and early response to OWS incursions and flare-ups, as shown by Rogers (1998) and Hay et al. (1996).

At the perimeter of the intercontinental OWS distribution, seasonality becomes a natural feature of OWS epidemiology, as it was for NWS in North America. Screwworm population expansion and regression, in time and space, would appear an innate characteristic of screwworm ecology and behaviour. For screwworm flies to survive, it is critically important that a sufficient number of oviposition sites are encountered (Krafsur & Hightower, 1979; Atzeni et al., 1994). Yet suitable wounds to serve as oviposition sites may be a relatively rare resource, favouring widespread dispersal (Spradbery et al., 1995). Given that screwworm existed long before the domestication of farm animals, it follows that its ecological features and behaviour go back to the time that wild ungulate hosts prevailed as the main source of wounds for oviposition (Hall et al., 2001). At that time, and in the absence of today’s ruminant livestock biomass, screwworm flies depended on their ability to cover large areas and be present in fresh wounds, navel of the newborn and also other undamaged body orifices in wildlife. Spradbery et al. (1995), in a study carried out during the south-east Asian (dry) season when conditions were likely to be hostile for OWS, found a typical dispersal range of 10.8 km for female screwworm flies before depositing an egg mass. In North America, over several generations C. hominivorax populations were found to disperse northwards up to 2400 km each year, from over-wintering areas in the southern states of the United States and from Mexico, with an average weekly dispersal of 50–60 km (Barrett, 1937). As indicated by the results of the present study, adult OWS survival and distribution become severely curtailed in the field by hot/dry conditions. Seasonality becomes a prominent feature at the perimeter of a species distribution, simply because marginal conditions imply reduced and more variable survival rates. Screwworm

---

**Fig. 5.** Mean distance (km) from the main watercourses of veterinary clinics reporting Old World screwworm fly (OWS) cases in 1996–1997 (left-hand axis, solid squares) and adult OWS longevity in 1998–1999 (number of days, left-hand axis, solid circles), plotted with average monthly air temperatures for Central Iraq for 1996–1997 (right-hand axis, triangles) and for 1998–1999 (right hand axis, inverted triangles).

**Fig. 6.** The frequency distribution of Old World screwworm fly (OWS) cases according to a satellite-derived vegetation index class; shown for the period of population expansion, September 1996 to January 1997 (grey columns), and for the summer refugia, as indicated by the July to August 1997 foci (black columns).

---

© 2005 The Royal Entomological Society, *Medical and Veterinary Entomology, 19*, 140–150
spread requires that the right conditions be met in the right place, at the right moment and in the right sequence. Multiplication and subsequent fly-dispersal phases become synchronized with seasonal cycles in the environment. In situations where there is a wet/cool season followed by a hot/dry one there is bound to be a period, even short, during which pupal development conditions are favourable. For population expansion, it is critical that this phase be followed by a period during which conditions are conducive to fly survival and population spread. In Iraq, pupal development conditions are optimal during the spring, but any adults that emerge are subjected to the harsh summer conditions (hot and dry) that follow, when adult fly longevity is drastically reduced. Hence, conditions for successful OWS introduction are met only during late summer and early autumn.

Acknowledgements

We are grateful to the International Atomic Energy Agency (IAEA) for provision of supplies towards construction of the OWS rearing facility at Tuwaitha. We are also grateful to Dr Rod Mahon for his many helpful comments. Professor Krafsur, for his kind attention and for providing the satellite imageries of the Mesopotamia valley marshland. The technical support from the SDNR staff at FAO is highly appreciated. A very special thanks goes to Professor Krafsur, for his kind attention and for providing us with all his publications on NWS. We are also very grateful to Dr Rod Mahon for his many helpful comments on an early draft of this manuscript.

References


Krafsur, E.S. & Hightower, B.G. (1979) Field tests of sterile screwworm flies, Cochliomyia hominivorax (Diptera: Calliphoridae), against natural populations in three coastal areas of Mexico. Journal of Medical Entomology, 16, 33–42.

Krafsur, E.S. & Lindquist, D.A. (1996) Did the sterile insect technique or weather eradicate screwworms (Diptera:
Calliphoridae) from Libya? Journal of Medical Entomology, 33, 877–887.


Accepted 23 December 2004