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FIELD GUIDE TO INVASIVE ALIEN INVERTEBRATES IN THE SOUTH ATLANTIC UK OVERSEAS TERRITORIES

PART 3 – INSECTS (termites, beetles, earwigs, flies)

Chris Malumphy, Sharon Reid, Rachel Down, Jackie Dunn,
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First Edition

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https://fera.co.uk/

Published digitally: May 2019

Suggested citation: Malumphy, C., Reid, S., Down, R., Dunn., J. Collins, D. & Matthews, J. 2019. Field Guide to Invasive Alien Invertebrate Pests in the South Atlantic UK Overseas Territories. Part 3 – Insects (termites, beetles, earwigs, flies). Defra/Fera. 51 pp.

Frontispiece
Top row: Asian Tiger Mosquito *Aedes albopictus* adult © Susan Ellis, Bugwood.org; Fall armyworm *Spodoptera frugiperda* adult © Fera; Pumpkin fly *Dacus bivittatus* adult female © Fera. Second row: Sheep tick *Ixodes Ricinus* adult © Fera; South American tomato moth *Tuta absoluta* larvae © Fera; European earwig, *Forficula auricularia* adult male © Pudding4brains. Third row: Big-Headed Ant *Pheidole megacephala* worker © Alexander L. Wild; Brown soft scale *Coccus hesperidum* adult female © C. Malumphy; Fall armyworm *Spodoptera frugiperda* larva © Fera. Bottom row: Oriental Fruit Fly *Bactrocera dorsalis* adult © Fera; Harlequin ladybird *Harmonia axyridis* adults © Bugwood.org; Red Imported Fire Ant *Solenopsis invicta* worker © April Noble, Bugwood.org.

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PART 4 – INSECTS (bugs, ants, wasps, moths)

PART 5 – INVERTEBRATES (except insects) & REFERENCES

6. Invasive alien invertebrate species

Illustrated datasheets are provided for 32 species of invasive alien invertebrate species that pose a potential economic, biodiversity or human health risk to some or all of the UKOTs in the South Atlantic Ocean. The species were selected from a list of major invasive threats identified for each UKOT during Horizon Scanning workshops held in Saint Helena and Cambridge (UK) during 2018 (see Section 2.5). Species that posed a threat to more than one territory were given priority. The pests were also selected to cover the wide range of groups of potential invertebrate pests that may be encountered. Some of the pests are already established in parts of the South Atlantic but have not been recorded from all the UKOTs, whereas others have never been recorded from anywhere in the region. Some are polyphagous whereas others are host specific. Each datasheet provides information on the geographical distribution, host plants (where relevant), biology, dispersal and potential impact. Photographs, descriptions and information on detection are provided to assist with biosecurity inspections.

In the top right-hand corner of each datasheet is a table showing the presence or absence of the pest in each of the territories. It also indicates the type of major threat is presents to each territory. The table below indicates that the species discussed in the datasheet does not occur in any of the UKOTs in the South Atlantic and it has been identified as a priority threat to the British Antarctic Territory. It may also have an impact on the biodiversity of the other territories, but it is not identified as a priotity species.

	Present l / Absent ¡	Threat		
		Bio	Hlth	Econ
SH	¡			
Asc	¡			
Tris	¡			
FI	¡			
SG	¡			
BAT	¡	ü		

Abbreviations

SH = Saint Helena; Asc = Ascension Island; Tris = Tristan da Cunha; FI = Falkland Islands; SG = South Georgia and the South Sandwich Islands; BAT = British Antarctic Territory

Bio = Biodiversity (Environmental) Threat; Hlth = Human Health Threat; Econ = Economic (Agricultural/ horticultural) Threat

6.1 Formosan Subterranean Termite

	Present l / Absent ¡	Threat		
		Bio	Hlth	Econ
SH	¡			ü
Asc	¡			ü
Tris	¡			
FI	¡			
SG	¡			
BAT	¡			

Order: Blattodea
Family: Rhinotermitidae
Species: *Coptotermes formosanus* (Shiraki)

Figure 6.1.1 Formosan Subterranean Termite worker (top), soldier (bottom) © Gerald J. Lenhard, Louisiana State University, Bugwood.org

Background

Formosan subterranean termites, *Coptotermes formosanus*, live in nests underground and, like other subterranean termites, feed on dead trees and wooden debris on the soil surface of natural habitats. Their nests are made up of soil, chewed wood or plant material, the termite's own saliva and their faecal matter – this substance is known as carton (Fig. 6.1.3). When in final form the nest can appear as a typical rocky structure due to the appearance of carton. Their nests can also be very large, housing hundreds and thousands of termites in a single colony. However, the termites require a moist environment and if moisture levels are not right underground they may build nests above ground e.g. on boats, porches, flat rooftops, trunks of trees both dead and alive, as well as walls of homes and buildings.

Coptotermes formosanus can cause structural damage to buildings (Fig. 6.1.5) and infrastructure, resulting in substantial economic losses. For this reason, along with its widespread global distribution, it is a threat to all the UKOTs in humid subtropical and temperate regions.

Geographical Distribution

Coptotermes formosanus is native to China in the Palearctic region and has since been introduced to many other regions of the world. *Coptotermes formosanus* was first reported to have been transported to Japan in the 1600s and later recorded to have infested Hawaii in the late 1800s, by the 1950s it was recorded in Africa. In 1960 it began to appear in the United States and by 2010 it had spread throughout the south-east region of this continent; it is also present in the U.S. Virgin Islands within the Caribbean (CABI, 2019).

Figure 6.1.2 Tree damage caused by *Coptotermes formosanus* © Wood Product Insect Lab USFS Gulfport, MS, Bugwood.org

Figure 6.1.3 *Coptotermes formosanus* carton nest © Wood Product Insect Lab USFS, Gulfport, MS, Bugwood.org

Figure 6.1.4 Damage to a nest of Formosan subterranean termites brings large numbers of workers and soldiers with dark, oval shaped heads scrambling to repair the hole © Scott Bauer, USDA Agricultural Research Service, Bugwood.org

Figure 6.1.5 Termite damage to a windowsill. The nest was located two floors below in the soil. Much of the wood had been consumed before they were detected. © Scott Bauer, USDA Agricultural Research Service, Bugwood.org

Host Plants

Coptoformes formosanus is an opportunistic feeder of any material containing cellulose. A large number of living plants are known to be attacked by *C. formosanus*, but it usually does not kill the plants unless the root system is significantly damaged (Lai *et al.*, 1983; La Fage, 1987). Records show that living citrus (*Citrus* spp.), eucalyptus (*Eucalyptus* spp.) and sugar canes (*Saccharum* spp.) may be killed by *C. formosanus*, but in most cases damage occurs in the heartwood of a tree (Fig. 6.1.2). The infested trees may be more easily blown over by high winds due to the loss of structural strength. The pest status of *C. formosanus* is most significant when it attacks wood products in a house such as structural lumbers, cabinets, etc. *Coptoformes formosanus* is also known to damage non-cellulose materials in search of food, including plastic, concrete and soft metal (Suszkiw, 1998). Occasionally underground high-voltage power lines may be penetrated by *C. formosanus*, resulting in an area-wide power cut (CABI, 2019).

Description

The colonies of *C. formosanus* contain three primary castes: the reproductives, soldiers, and workers. The majority of the nestmates are workers that are responsible for the acquisition of nutrients, i.e. cellulose in the wood. The white soft-bodied workers are 4-5 mm long (Fig. 6.1.1). They are difficult to distinguish from other termite species. The alates (winged reproductive termites) and soldiers are most useful for identification. The alates are yellowish-brown and 12-15 mm long and are attracted to lights, so are usually found near windows, light fixtures and in spider webs around well-lit areas. The soldiers are approximately the same size as the workers and have an orange-brown oval-shaped head, curved mandibles and a whitish body (Fig. 6.1.1). When disturbed, the soldiers readily attack any approaching objects, and may secrete a white gluey defensive secretion from the frontal gland; they will also scramble to repair their nest (Fig. 6.1.4). Approximately 10-15% of a *C. formosanus* colony consists of soldiers (CABI, 2019).

Biology

A single colony of *C. formosanus* may produce over 70,000 alates. Swarming occurs at dusk on a humid and windless night. After a brief flight, alates shed their wings. Females immediately search for nesting sites with males following closely behind. When the pair finds a moist crevice with wooden materials, they form the royal chamber and the female lays approximately 15 to 30 eggs (depending on temperature). Within two to four weeks, young termites hatch from the eggs. The reproductives nurse the first group of young termites until they reach third instar. One to two months later, the queen lays the second batch of eggs which will eventually be nursed by termites from the first egg batch. It may take three to five years before a colony reaches a substantial number to cause severe damage and produce alates (Suszkiw, 1998).

Dispersal and Detection

Natural spread of *C. formosanus* occurs by the dispersal flights of the reproductives originating from mature colonies. However, *C. formosanus* is better known for its tendency to establish populations in new geographic areas via maritime vessels, cars, and by importation of infested materials such as in wood packaging, containers and the plant trade. It can take new colonies several years to reach a size that creates detectable damage, and they can often be mistaken for other subterranean termites, e.g. of the *Reticulitermes* genus.

Economic and other Impacts

Coptotermes formosanus can cause substantial economic losses. Of the 80 serious pest termite species currently recognized, *C. formosanus* stands out as one of the most dangerous of all subterranean termites because of its widespread global distribution. In New Orleans (USA) the control and repair cost due to *C. formosanus* is estimated at US$ 300 million annually (Suszkiw, 1998; 2000). In 1998, the USDA initiated an eradication program in the French Quarter of New Orleans (Henderson, 2001; Ring *et al.*, 2002). Over the next 13 years over $70 million dollars was spent on studies to control this termite and although termite numbers were reduced, eradication was not achieved. *Coptotermes formosanus* is considered to be the single most economically important insect pest in Hawaii.

Coptotermes formosanus has been known to cause damage to underground electrical and phone lines by eating through PVC pipes and shorting-out electrical systems. It is one of the few termite species that will regularly infest creosoted rail road ties, wooden trestles and telephone poles.

6.2 Harlequin Ladybird

Order: Coleoptera
Family: Coccinellidae
Species: *Harmonia axyridis* (Pallas)

	Present l / Absent ¡	Threat Bio	Threat Hlth	Threat Econ
SH	¡	ü		
Asc	¡	ü		
Tris	¡	ü		
FI	¡	ü		
SG	¡			
BAT	¡			

Figure 6.2.1 *Harmonia axyridis* adult © Fera

Background

Harlequin ladybird (*Harmonia axyridis*) is a brightly coloured aphidophagous ladybird with a highly variable appearance with over 100 different colour forms reported worldwide. It is an invasive species which has spread rapidly outside of its native range due mainly to its use as a biological control agent of pest insects such as aphids and scale insects (Koch, 2003; Roy, *et al.*, 2006). The first releases were made in North America in 1916 but it was not until 1988 that the first individuals were found in the wild. Since then it has rapidly invaded most of North America and Europe, and it is now spreading in other regions such as South America and South Africa. In most invaded regions, numbers have increased exponentially and *H. axyridis* has quickly become the most abundant ladybird in a wide range of habitats (Brown *et al.*, 2008).

Geographical Distribution

Harmonia axyridis is native to central and eastern Asia, with a range extending from the Altai Mountains in the west to the Pacific Coast in the east, and from southern Siberia in the north to Japan in the south (Dobzhansky, 1933; Chapin, 1965; Koch, 2003). It is known to have been introduced (both intentionally and unintentionally) to Europe, North America, South America, the Middle East and South Africa (Stals & Prinsloo, 2007; Brown *et al.*, 2008).

Host

Harmonia axyridis is widely reported as a semi-aboreal species however it also thrives and breeds in agricultural habitats, coniferous woodlands, heathland, meadows and reedbeds (Brown *et al.*, 2008). It is a polyphagous species although mainly feeds on aphids it will also consume coccids (scale insects), psyllids (plant lice) and adelgids (aphid-like Hemiptera). Alternative foods include many other invertebrates, nectar, pollen, honeydew, plant sap and the juice of ripe fruit.

Harmonia axyridis distribution map © CABI

Figure 6.2.2 *Harmonia axyridis* eggs © Bugwood

Figure 6.2.3 *Harmonia axyridis* larvae © Fera

Figure 6.2.4 Examples of the many variant colour forms of adult *Harmonia axyridis* © Bugwood

Description

The adults (Figs. 6.2.1) are 5-8 mm long and 4-6.5 mm wide (Kuznetsov, 1997). The colour and maculation are highly variable (Fig. 6.2.4), the body is oval, slightly convex, and 4/5 wide as long (Kuznetsov, 1997). The head can be black, yellow or black with yellow markings. The pronotum is creamish yellow with black markings. These black markings can form four black spots, two lines, a black M-shaped mark or a solid black trapezoid (Chapin and Brou, 1991). The elytra range from yellow-orange to red with 0 to 21 spots. The black melanic form commonly has two or four orange or red spots (Roy *et al.*, 2006). The eggs are 1.2 mm long, oval shaped, pale yellow in colour when first laid (Fig. 6.2.2) but turn progressively darker yellow and turn grey-black prior to hatching. The first instar larvae are 2 mm long and reach 7.5-10.5 mm by the fourth and final instar. The larvae are covered with branched setae (Fig. 6.2.3). The pupae are exposed and the fourth instar exuvium remains attached to the posterior end of the pupa, where the pupa is attached to the substrate (Koch, 2003).

Biology

Female *H. axyridis* overwinter in protected sites unmated with most of the population mating in spring. They have a complete metamorphosis with a life-cycle consisting of egg, four larval instars, pre-pupa, pupa and adult. A female adult produces 20-50 eggs per day and eggs generally hatch in 3-5 days. The larval stage lasts 12-14 days and the pupal stage, which takes place on leaves, lasts 5-6 days. In cool spring weather, development from egg to adult can take 36 days or longer. After emergence, adults can live as long as two to three years under optimal conditions but typically live for only one year. Temperature and diet have shown to significantly affect the rate of development (Hukusima & Ohwaki, 1972). *Harmonia axyridis* can reproduce without a dormancy period and so they typically have two generations a year in much of Asia, North America and Europe (Koch, 2003), however in regions with an extended warm season they may have up to five generations (Wang, 1986).

Dispersal and Detection

The rapid spread of *H. axyridis* has been a consequence of both natural dispersal by flight and anthropogenic processes (Roy & Brown, 2015). This species flies readily between host plants during breeding periods seeking high density aphid populations and can migrate over long distances to and from dormancy sites, and in spring they take dispersal flights to seek food and suitable host plants. *Harmonia axyridus* can travel 18 km in a "typical" high-altitude flight, but up to 120 km if flying at higher altitudes, indicating a high capacity for long distance dispersal (Jeffries *et al.*, 2013). Such dispersal may result in a considerable increase in their distribution.

Anthropogenic processes include accidental and intentional introductions. Accidental introductions include transportation in or on vehicles or with people and goods, e.g. transportation with vegetables into mainland Britain (Roy & Brown, 2015) and South Africa (Stals & Prinsloo, 2007). There is a long history of intentional introductions of this species as a biological control agent of aphids. The first release was in North America in 1916 with repeated releases in the USA. This species was favoured because of its size, diverse dietary range, efficiency as a predator and wide colonisation ability (Majerus *et al.*, 2006). These traits now contribute to the invasive nature of this beetle. The species has spread across much of the USA and Canada. It was intentionally introduced in Argentina and has now spread though South America with known establishment in Brazil (Koch *et al.*, 2006). It has also been intentionally introduced into at least 12 European countries since 1982 (Brown, 2008). Poutsma *et al.* (2008) predict that *H. axyridis* may establish in most of Europe as well as in many temperate and subtropical regions worldwide.

Economic and other Impacts

Harmonia axyridis has the ability to spread very rapidly across new environments, including the UKOTs, as it can colonise a wide range of habitats and phenotypically adapt to local conditions. It is a voracious, generalist predator that dominates over other aphidiphages and coccidophages (Majerus et al., 2006). It has been designated as a pest of fruit production and processing (Koch, 2003) as the ladybirds feed on fruits such as apples (*Malus*), pears (*Pyrus*) and grapes (*Vitis*) in the autumn when insect prey becomes scarce, blemishing the fruit and tainting wine. As such the potential adverse impacts of *H. axyridis* outweigh its benefits as a biological control agent to farmers and gardeners. In addition, as their numbers increase, they are becoming an increasing urban nuisance as houses, sheds and garages have become the preferred overwintering sites for swarms of these ladybirds during autumn and winter.

6.3 European Earwig

Order: Dermaptera
Family: Forficulidae
Species: *Forficula auricularia* (Linnaeus)

	Present l Absent ¡	Threat		
		Bio	Hlth	Econ
SH	¡			ü
Asc	¡			ü
Tris	¡			
FI	¡			
SG	¡			ü
BAT	¡			

Figure 6.3.1. *Forficula auricularia* adult female © Bugwood

Background

The European earwig (*Forficula auricularia*) is a common omnivorous predatory insect feeding on detritus, fungi, plants and insects but can cause damage to buds, leaves, flowers and fruits of a broad range of plants including those of economic importance (Crumb *et al.*, 1941). The earwigs are nocturnal and seek protection during the day and can be a nuisance by entering buildings. However, they can be beneficial due to their predatory feeding habits, but it is a careful balance between protecting plants from injury while reaping the benefits from biological control and organic matter decomposition (Blommers, 1994; Maher & Logan, 2007; Gobin *et al.*, 2008).

Geographical Distribution

The European earwig is native to Europe, Western Asia and Northern Africa but has been introduced to North America, Australia and New Zealand (Pavon-Gozalo *et al.*, 2011). This species can be found on all continents except Antarctica and is currently present in Mexico, Chile, the Falkland Islands and the island of Guadaloupe (Maczey *et al.*, 2016).

Figure 6.3.2 Adult female *Forficula auricularia* with eggs and young © Bugguide

Figure 6.3.3 Immature (first instar) *Forficula auricularia* © Bugguide

Figure 6.3.4. *Forficula auricularia* feeding on lettuce at night © WA State University

Figure 6.3.5 *Forficula auricularia* feeding damage on ornamental flower © RHS.org.

Host Plants

Forficula auricularia is omnivorous, feeding on a wide variety of plant and animal matter. It has been reported to cause damage to a wide variety of crops, vegetables, flowers and stone fruits (CABI, 2019). Plant damage is mainly caused by external feeding of late instars and adults but sometimes by penetrating the inside of crops such as cabbages (*Brassica oleracea* var. *capitata*) and cauliflowers (*Brassica oleracea* var. botrytis) (CABI, 2019). They also cause contamination with their faecal matter, bean (Fabaceae), beet (*Beta*), cabbage, celery (*Apium graveolens*), chard (*Beta*), cauliflower, cucumber (*Cucumis sativus*), lettuce (*Lactuca sativa*), pea (*Pisum sativum*), potato (*Solanum tuberosum*), rhubarb (*Rheum rhabarbarum*) and tomato (*Solanum lycopersicum*) are among the vegetable crops sometimes injured (Fig. 6.3.4; CABI, 2019). The most injured flowers are dahlia (*Asteraceae)*, carnation (*Dianthus caryophyllus*), sweet william (*Dianthus barbatus*) and zinnia (*Zinnia elegans*) (Fig. 6.3.5; Capinera, 2016) and fruits include apple (*Malus*), apricot (*Prunus armeniaca*), peach (*Prunus persica*), plum (*Prunus subg. Prunus*), pear (*Pyrus*), hops (*Humulus lupulus*) and sometimes strawberry (Fragaria × ananassa) (Capinera, 2016). Its negative phytophagous behaviour can sometimes be offset by its predatory habits on aphids, spiders, caterpillar pupae, leaf beetle eggs, scale insects, springtails, etc. (Buxton, 1976; Capinera, 2016). Earwigs also consume algae and fungi and often consume vegetable and animal matter in equal proportions (Buxton, 1976).

Description

Adult *F. auricularia* are 13-16mm long but can be shorter if they have developed under adverse conditions. Their bodies are dark reddish brown in colour but paler ventrally with a brighter reddish coloured head and pale yellow-brown legs (Figs. 6.3.1-2; Crumb *et al.*, 1941; Capinera, 2016). There are 14 segments in the adult antennae (Crumb *et al.*, 1941; Capinera, 2016). Despite the appearance of being wingless, adults have long hind wings folded beneath the forewings. *Forficula auricularia* exhibit gender polymorphism with the shape and size of the cerci (pincers at the rear of the body) differing between males and females. The cerci of females are straight and parallel with only a slight curvature. In males the cerci are strongly curved and have a prominent tooth in the middle (Crumb *et al.*, 1941; Capinera, 2016).

The eggs are pearly white in colour and oval to elliptical in shape (Fig. 6.3.2). They measure 1.13 mm in length and 0.85 mm wide when first deposited, but they absorb water, swell and are nearly double the volume before hatching (Crumb *et al.*, 1941; Capinera, 2016). Clusters of up to 60 eggs are deposited inside a nest structure built by the parents just below the soil surface (CABI, 2019).

There are five nymphal stages all of which resemble the adult earwig in shape (Fig. 6.3.3), but they have reduced wings and cerci that increase in size with maturity (CABI, 2019). Wing pads are only developed in the fourth instar (Crumb *et al.*, 1941; Capinera, 2016). The body colour darkens, gradually changing from a pale greyish brown colour as a first instar to a dark brown in the last whereas the legs are pale throughout (Crumb *et al.*, 1941). Young nymphs are guarded by the mother earwig, which remains in or near the cell where the eggs are deposited until they become second instars (Capinera, 2016).

Biology

Forficula auricularia are nocturnal although their night-time activity is influenced by the weather, stable temperatures encourage activity and activity is favoured by higher minimum temperatures but discouraged by higher maximum temperatures (Chant & McLeod, 1952). During the day they hide under leaf debris, in cracks and crevices, or other dark locations. They produce an aggregation pheromone in their faeces that is attractive to both sexes and to nymphs, and release quinones from their abdominal glands as a chemical defence mechanism (Walker *et al.*, 1993).

There is a weakly developed social behaviour with the European earwig; males and females' mate in late summer or autumn and then construct a subterranean tunnel (nest) in which they overwinter. The female then drives the male from the nest at the time of oviposition. She cleans and cares for the eggs and then as the time for hatching approaches she spreads the eggs into a single layer. The female continues to guard the nymphs and provide them with food until they reach second instar. Food is provided by females carrying objects into the nest and by regurgitation. Thus, there is parental care but no cooperative brood care (Lamb, 1976; Capinera, 2016; CABI, 2019).

Dispersal and Detection

Forficula auricularia are not likely to disperse over long distances naturally as although they can fly, they rarely do, and they do not move far by crawling either (Crumb *et al.*, 1941). However, they can be easily transported passively along river systems and floods as they are resistant to drowning in cold waters (Crumb, 1941).

Accidental introduction within building material, bulk goods, flowers, vegetables and hitchhiking on vehicles etc. is the most likely means of dispersal (Capinera, 2016; CABI, 2019). Earwigs are nocturnal and tend to hide in small crevices and can withstand a wide range of temperatures/humidity levels and long periods without food (Crumb *et al.*, 1941), so long-distance transport via ship, trucks, containers can easily facilitate their spread. In addition, females can deposit fertile eggs several months after mating (Crumb *et al.*, 1941) and it is therefore feasible that new colonies can be founded by single females. *Forficula auricularia* is sometimes used as a biological control agent in fruit production (He *et al.*, 2008; Logan *et al.*, 2011). However, there are no records of deliberate introductions for this purpose.

Detection is relatively straightforward in the field as they can be easily seen on crop edges etc. whilst feeding at night, and during the day they tend to aggregate in dark places such as under loose bark, stones, pots etc. Corrugated cardboard rolls or bands on trunks of trees is therefore an easy way to detect earwigs in orchards and vines. However, detection within shipments is more difficult due to their cryptic nature. Samples need to be cut open to reveal any hidden earwigs however external damage to the commodity and the presence of frass can be an indication of their presence.

Economic and other Impacts

The European earwig is widely regarded as a beneficial predator of insect pests in fruit orchards within its native range, however outside this range there are reports that this species can cause significant agricultural problems and a public nuisance (Maczey, *et al.*, 2016; CABI, 2019). *Forficula auricularia* was first discovered in the Falkland Islands in 1997/1998 and is now a significant pest on the island causing damage to garden and green house crops and leading to the halt in the production of several commercial crops. Attempts at chemical control created considerable annual costs which has led to the use of biocontrol agents (Maczey *et al.*, 2016). This species can easily spread to other UKOT islands in the South Atlantic if measures are not taken to control its pathways of introduction.

6.4 Yellow Fever Mosquito

Order: Diptera
Family: Culicidae
Species: *Aedes aegypti* (Linnaeus)

	Present l / Absent ¡	Threat		
		Bio	Hlth	Econ
SH	¡		ü	ü
Asc	¡		ü	ü
Tris	¡		ü	ü
FI	¡			
SG	¡			
BAT	¡			

Figure 6.4.1 Adult female *Aedes aegypti* acquiring a blood meal from a human host © James Gathany & Prof. Frank Hadley Collins

Background

Yellow fever mosquito (*Aedes aegypti*) is the primary vector for several important diseases including yellow fever virus, dengue virus, chikungunya virus and Zika virus and therefore has a significant impact on public health (ECDC, 2016a). This mosquito originated in Africa, but is now found in tropical, subtropical and temperate regions throughout the world. The yellow fever mosquito's distribution has increased in the past two to three decades worldwide, and is among the most widespread of all mosquito species (ECDC, 2016a). The adults can be recognized by white markings on its legs and a marking in the form of a lyre on the upper surface of its thorax.

Geographical Distribution

Aedes aegypti is thought to originate from sub-Saharan Africa (Farajollahi & Price, 2013) but is now very widespread in tropical and subtropical regions across Asia, Africa, North America, Central America and Caribbean, South America, Oceania and some countries in Europe making it one of the most globally widespread species of mosquito (ECDC, 2016a). This species has a broad distribution potential across tropical and subtropical regions (Kamal, 2018) but its range is limited by its inability to survive cold winter months (Farajollahi & Price, 2013; ECDC, 2016a)

Figure 6.4.2 *Aedes aegypti* egg © Centers for Disease Control and Prevention

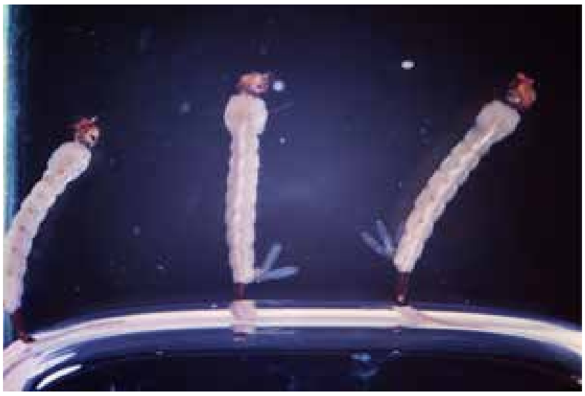

Figure 6.4.3 Fourth instar *Aedes aegypti* larvae© D. Pratt. Centres for Disease Control and Prevention

Figure 6.4.4 *Aedes aegypti* pupae suspended from the water surface by their respiratory trumpets © D. Pratt. Centres for Disease Control and Prevention

Figure 6.4.5 Discarded tyres collect rainwater and act as prime breeding sites for species of mosquitoes such as *Aedes aegypti* © D. Pratt & G Heid, Centres for Disease Control and Prevention

Hosts

Adult male *A. aegypti* feed on plant nectar/juices to obtain energy but the females must feed on blood to produce eggs (GISD, 2013). Blood is mainly obtained from mammalian sources e.g. *Homo sapiens* (humans; Fig. 5.7.3), *Bos taurus* (cattle), *Canis familiaris* (dogs), *Felis* (cats), and *Rattus* spp. (rats), but they will also take blood from birds (Stenn *et al*. 2019). *Aedes aegypti* is a common domestic vector mosquito, which lives in close association with and shows a preference for feeding on humans, even when other hosts are available.

Description

Aedes aegypti has four distinct life stages: egg, larva, pupa and adult.

Eggs: Long, smooth, ovoid shaped, and approximately one millimetre long (Fig. 6.4.2). They are white when first laid but within minutes turn a shiny black. Eggs may develop in as little as two days in the tropics, whereas in cooler temperate climates, development can take up to a week. *Aedes aegypti* eggs can survive desiccation for months and hatch once submerged in water, making the control of *A. aegypti* difficult (see references in Zettel & Kaufman, 2008).

Larvae: There are four larvae instars, newly hatched first instar larvae are approximately 1 mm in length (Fig. 6.4.3). Larvae can be distinguished from other species of *Aedes* (with the exception of *A.*

albopictus) by the presence of a single straight row of comb scales on the eighth abdominal segment. First to third instar larvae have a black head.

Pupae: Mosquito pupae are different from many other insects in that the pupae are mobile and respond to stimuli (Fig. 6.4.4). Pupae, also called "tumblers," do not feed and take approximately two days to develop. Adults emerge by ingesting air to expand the abdomen thus splitting open the pupal case and emerge head first.

Adults: *Aedes aegypti* adults (Fig. 6.4.1) are relatively small and has a black body with distinctive white/silver stripes on the legs and other parts of the body (it is easily confused with *A. albopictus*). One diagnostic character is the presence of a white/silver lyre-shaped patch on the scutum (dorsal part of the thorax). The domestic form is paler than its ancestor and has white scales on the first abdominal tergite (ECDC, 2016a).

Biology

Aedes aegypti is primarily an anthropophilic species, primarily feeding on humans, preferring lower body parts, but it will sometimes feed on domestic animals (Farajollahi & Price, 2013). Larvae are usually found in domestic water-containers close to humans (Farajollahi & Price, 2013). Temperatures between 21 – 29°C are ideal for development and between 22 -30°C for adult fecundity and longevity (reported in Honório *et al*., 2009). Historically, *A. aegypti* was found in forested areas, using tree holes as habitats but has adaptated to urban domestic habitats. They are often found in puddles, tyres (Fig. 6.4.5), or within any object holding water. *Aedes aegypti* eggs can survive desiccation for months and hatch once submerged in water, making the control of *A. aegypti* difficult (Nelson, 1984). Larvae feed on organic particulate matter in the water, such as algae and other microscopic organisms. Most of the larval stage of *A. aegypti* is spent at the water's surface, although they will swim to the bottom of the container if disturbed or when feeding (Nelson, 1984). The larvae pass through four instars, spending a short amount of time in the first three, and up to three days in the fourth instar. Males develop faster than females, so males generally pupate earlier. If temperatures are cool, *A. aegypti* can remain in the larval stage for months so long as the water supply is sufficient (Foster & Walker 2002).

Dispersal and Detection

Natural dispersal of *A. aegypti* occurs only over a short-range. A wide variety of maximum dispersal distances between 27 m and 1,150 m have been estimated from mark-release-recapture studies. However, most studies show that the majority of *A. aegypti* travel less than 80 m.

Aedes aegypti has historically been transported between continents by sea traffic, but accidental movement of water harbouring eggs and larvae via road and air transport are also means of medium to long-range dispersal (ECDC, 2016a). Human assisted dispersal has occurred with shipments of tyres as evidenced by the discovery of *A. aegypti* in tyre yards in the Netherlands (ECDC, 2016a). Rainwater collects and remains in tyres that are stored outside and contributes to the spread of the insect eggs and larvae when these tyres are transported either by road or internationally (ECDC, 2016a).

Aedes albopictus females can be caught in BG-Sentinel™ traps used with lures containing ammonia, fatty acids and lactic acids to emulate the smell of a human body, especially when carbon dioxide is also added. Miniature CDC traps (without light) and mosquito magnets, both utilising a carbon dioxide lure (and also an octenol lure in the mosquito magnets), can also be used but the former is not very effective at detecting invasive mosquito species. Gravid and sticky infusion traps can be used to trap females seeking oviposition sites, but neither are particularly efficient, and the standard gravid trap does not attract invasive mosquito species (ECDC, 2012).

The most likely means of detection in the horticultural and nursery trades is through inspection by quarantine officers at the destination port.

Economic and other Impacts

Aedes aegypti is a nuisance insect, feeding in the daytime and preferring shady areas. They are easily disturbed when feeding and will fly away only to return a little later, this behaviour is thought to increase its capacity to vector disease because it increases host probing (Farajollahi & Price, 2013). *Aedes aegypti* has a significant impact on public health because it is the primary vector for several important diseases including yellow fever virus, dengue virus, chikungunya virus and Zika virus (ECDC, 2016a). However, this species is not considered to be an important bridging vector for West Nile virus because of its preference for feeding on humans, although the virus has been detected in field specimens of *A. aegypti* (CDC, 2013 in Farajollahi & Price).

6.5 Asian tiger mosquito

Order: Diptera
Family: Culicidae
Species: *Aedes albopictus* (Skuse)

	Present l Absent ¡	Threat Bio	 Hlth	 Econ
SH	¡		ü	ü
Asc	¡		ü	ü
Tris	¡		ü	ü
FI	¡			
SG	¡			
BAT	¡			

Figure 6.5.1 Adult *Aedes albopictus* © Susan Ellis, Bugwood.org

Background

Aedes albopictus is known as the Asian tiger mosquito but other international common names include forest day mosquito and tiger mosquito. Its global range has expanded tremendously, principally from the movement of used tyres and 'Lucky Bamboo' plants (*Dracaena sanderiana*). The adult is known to transmit the viruses responsible for Dengue and Chikungunya and the filarial nematodes that cause dirofilariasis, a zoonotic infection that is on the increase (ECDC, 2016b; CABI, 2019). *Aedes albopictus* is also considered a potential vector of the Zika virus (ECDC, 2016b) as well as several other human and animal viral diseases (ECDC, 2016b; CABI, 2019). The predicted spread, confirmed involvement in disease transmission cycles, and potential for zoonotic disease transmission, means this species is considered to be the most invasive mosquito species (Farajollahi & Price, 2013) and one of the top "100 of the World's worst invasive alien species" (GISD, 2019), and as such surveillance and control are important (ECDC, 2016b).

Aedes albopictus is currently absent from the Atlantic UKOTS, however, the territories of St Helena, the Ascension Islands and Tristan da Cuhna have identified this species as a priority invasive threat.

Figure 6.5.2 *Aedes albopictus* distribution map © CABI

Figure 6.5.3 *Aedes albopictus* resting on flower (unknown species) © Ary Farajollahi, Bugwood.org

Figure 6.5.4 *Aedes albopictus* female feeding on *Homo sapiens* © Susan Ellis, Bugwood.org

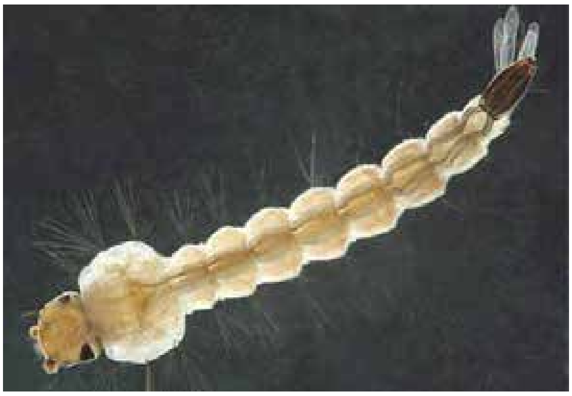

Figure 6.5.5 *Aedes albopictus* larva © Michele M. Cutwa, University of Florida

Figure 6.5.6 *Aedes albopictus* adult abdomen with distinctive white stripes © Pest and Diseases Image Library, Bugwood.org

Geographical Distribution

Aedes albopictus is native to the Oriental region stretching from the tropics of Southeast Asia, the islands of the Pacific and Indian oceans, west to Madagascar, and north through China and Japan (CABI, 2019) (Fig. 6.5.3). It is considered a temperate species (Farajollahi & Price, 2013). It has spread rapidly in recent decades and is now present in at least 28 countries outside of its native range across both North and South America, Africa, Oceania and several countries in Europe (CABI, 2019). A further increase in range is expected with climate change (CABI, 2019) but its inability to survive extreme cold temperatures will limit distribution in colder regions (Farajollahi & Price, 2013). A mean winter temperature greater than 0°C is required for overwintering of eggs and a mean annual temperature of more than 11°C is required for adult survival and activity (ECDC, 2012). Areas with at least 500 mm of rainfall per year, with a warm month mean temperature of 20°C and a mean winter temperature above 0°C are at risk (ECDC, 2016b; CABI, 2019). Establishment of *A. albopictus* is unlikely in areas with an annual rainfall of less than 300 mm (CABI, 2019) although there are reports of establishment in areas with lower rainfall (290 mm per year) (Benedict *et al.*, 2007).

Hosts

Adult *A. albopictus* feed on plant nectar/juices (Fig. 6.5.3) to obtain energy but the females must feed on blood to produce eggs (GISD, 2013; CABI, 2019). Blood is mainly obtained from mammalian sources e.g. *Homo sapiens* (humans; Fig. 6.5.4), *Bos taurus* (cattle), *Canis familiaris* (dogs), *Felis* (cat), *Mus musculus* (house mouse) and others, but females will also take blood from birds, reptiles and amphibians (Eritja *et al.*, 2005). Females feed during the day and are opportunistic feeders in shaded urban areas such as gardens and landscaped areas (Farajollahi & Price, 2013).

Description

Aedes albopictus has four distinct life stages: egg, larva, pupa and adult.

Eggs: Shiny black in colour. Oblong, measuring approximately 524 µm in length, with a slight dorso-ventral curvature (Suman *et al.*, 2011). They are similar in appearance to the eggs of *A. aegypti* but eggs of the two species can be distinguished by size (*A. aegypti* eggs are larger; 625 µm in length).

Larva: Elongate with a whitish segmented abdomen, and pale brown coloured head (Fig. 6.5.5). Approximately 2 mm in size on hatching and attain a size of approximately 10 mm in the final larval instar (ECDC, 2012). Larvae can be distinguished from other container-dwelling species of *Aedes* (with the exception of *A. aegypti*) by the presence of a single straight row of comb scales on the eighth abdominal segment, however, *A. albopictus* has a double preantennal head hair, and the lateral sides of the thorax have small or absent hooks, whereas *A. aegypti* has a single preantennal head hair and prominent black hooks on the lateral sides of the thorax (Farajollahi & Price, 2013).

Pupa: Paddle attachment (at the terminal end of the abdomen) characteristics can be used to distinguish *A. albopictus* from other species; the *A. albopictus* paddle is ovate, with a pointed apex, a fringe of elongate hairs along the margin; and a long single terminal paddle seta (Ogawa, 2011).

Adult: Small and slender (body length approximately 4.8 mm; Figs 6.5.1 and 3-4). Black body with conspicuous silver/white stripes on the abdomen (Fig. 6.5.6) and a very distinctive white stripe along the length of the scutum (Fig. 6.5.4; ECDC, 2016b; CABI, 2019). They have one pair of narrow wings and their legs are long and slender, also with white stripes (Figs. 6.5.1 and 6.5.4; ECDC, 2016b). Males can be distinguished from females by their dense feathery antennae (Sánchez *et al.*, 2017).

Biology

Aedes albopictus is a tree hole mosquito, its natural breeding places are restricted to small shaded bodies of water that are surrounded by vegetation such as tree holes. However, the species is adaptable and as such has successfully colonised many man-made sites and urban areas, breeding in items such as abandoned containers and drinks cans, receptacles for collecting water, flower pots in cemeteries, bird baths and particularly used tyres because they collect and retain water and often stored outside (Eritja *et al.*, 2005; CABI, 2019). Eggs, which are resistant to desiccation, are laid individually just above the surface of the water (Eritja *et al.*, 2005; ECDC, 2012). On hatching, the first instar larvae drop straight into the water where they develop, passing through four instars (ECDC, 2012). The pupa is formed at the fourth moult and floats near the surface of the water; adults emerge and rest a short while on the water before flying off (ECDC, 2012). Larval and pupal development takes three to eight weeks and adult females can survive for up to three weeks (Gatt *et al.*, 2009; ECDC, 2016b).

In tropical and subtropical zones this species is active all year round with continuous egg and larval development throughout the year hence 5-17 generations may occur per year depending on temperature and rainfall (Gatt *et al.*, 2009). Populations in temperate regions (north of the +10 °C January isotherm) overwinter as diapausing eggs (Eritja *et al.*, 2005; Gatt *et al.*, 2009). Females are stimulated into laying eggs that enter diapause with shortening daylight hours, generally when daylight gets below 13-14 hours (ECDC, 2012); eggs do not hatch until daylight reaches 11 to 11.5 hours per day and the mean temperature is 10 to 11 °C (Gatt *et al.*, 2009). In less temperate regions *A. albopictus* will overwinter as an adult (Gatt *et al.*, 2009).

Dispersal and Detection

Natural dispersal of *A. albopictus* occurs only over a short range (CABI, 2019) because the adult flight range is less than 1 km with most dispersing less than 180 m during their lifetime (references cited in Gatt *et al.*, 2009).

Most medium and long-range dispersal is via anthropogenic activities. Such activities may include transport linked to the horticultural and nursery trade. In 2001, *A. albopictus*, was discovered in a containerised shipment of *Dracaena sanderiana* (Lucky Bamboo), shipped in standing water to allow the plants to survive the longer low-cost shipping route from China to Los Angeles (USA) (CABI, 2019). These plants are of cultural relevance in Asian communities, and have also become a popular gift worldwide, consignments destined for the USA and elsewhere are therefore on the increase (CABI, 2019). *Aedes albopictus* has been found at destination wholesale nurseries in California (CABI, 2019).

A further important recognised means of anthropogenic dispersal is via the international tyre trade. Rainwater collects and remains in tyres that are stored outside and contributes to the spread of the insect eggs and larvae when these tyres are transported either by road or internationally (ECDC, 2016b; CABI, 2019). Human assisted local dispersal is by similar means: road transportation of used tyres, water containers and moist vegetation that can hold the eggs and larvae (CABI, 2019).

Aedes albopictus females can be caught in BG-Sentinel™ traps used with lures containing ammonia, fatty acids and lactic acids to emulate the smell of a human body, especially when carbon dioxide is also added (CABI, 2019). Miniature CDC traps (without light) and mosquito magnets, both utilising a carbon dioxide lure (and also an octenol lure in the mosquito magnets), can also be used but the former is not very effective at detecting invasive mosquito species and the latter is not very efficient at catching *A. albopictus* (ECDC, 2012). Gravid and sticky infusion traps can be used to trap females seeking oviposition sites, but neither are particularly efficient, and the standard gravid trap does not attract invasive mosquito species (ECDC, 2012).

The most likely means of detection in the horticultural and nursery trades is through inspection by quarantine officers at the destination port, and also by keeping the large nurseries where these consignments originate from, in regions of China with suitable climatic conditions for this insect, under observation (CABI, 2019).

Economic and other Impacts

Aedes albopictus has significant negative impacts on the economy, and human and animal health (CABI, 2019). Aside from its ability to vector disease, it is a public nuisance in areas where it is abundant (Farajollahi & Price, 2013). It is an aggressive biter in the outdoors during the daytime attacking a broad range of hosts; 30-48 bites per hour have been recorded (CABI, 2019). The presence of this mosquito has been linked to a reduction in outdoor physical activity for children which in turn contributes to childhood obesity (ECDC, 2016b).

Transmission of disease by *A. albopictus* is dependent on the numbers present, whether it bites and takes a blood meal from multiple humans, and how effectively the virus passes from the insect gut to the salivary glands (CABI, 2019). Asian tiger mosquito is a confirmed vector of the Dengue and Chikungunya viruses however, it will not transmit Dengue virus if it feeds on a lizard or bird after a human. Under field conditions receptivity to the West Nile, Japanese encephalitis, Jamestown Canyon, Keystone, LaCrosse, Potosi, Cache Valley, Tensaw, eastern equine encephalitis and yellow fever has been confirmed (CABI, 2019; Farajollahi & Price, 2013). There is concern over its ability to act as a bridge vector for West Nile virus (and potentially other animal viruses) because of its presence in rural areas and broad animal host range, allowing for the passing of enzootic cycles to humans (CABI, 2019). In addition, laboratory tests have indicated receptivity to the virus that causes Sindbis, and those which cause Rift Valley fever, African horse sickness, bluetongue, western encephalitis and vesicular stomatitis in animals, some of which can also infect humans (Moore, 1999; CABI, 2019).

As discussed within CABI (2019), some sources suggest that the spread of *A. albopictus* may result in a net gain on public health because it has a competitive advantage over *A. aegypti* (an even more important vector of diseases because it feeds almost exclusively on humans) and is displacing *A. aegypti* in some areas. *Aedes albopictus* is also displacing the *Ochlerotatus triseriatus* mosquito, which transmits LaCrosse virus. However, other sources disagree with this hypothesis because a mutation in the Chikungunya virus that enabled it to be more effectively transmitted by *A. albopictus*, resulted in devasting impacts during recent outbreaks on the Indian Ocean Islands, and there is concern that similar such mutations could also occur with the Dengue virus and other viruses for which *A. albopictus* has demonstrated receptivity.

6.6 African Malaria Mosquito

Order: Diptera
Family: Culicidae
Species: *Anopheles gambiae* complex

	Present l Absent ¡	Threat Bio	 Hlth	 Econ
SH	¡		ü	ü
Asc	¡		ü	
Tris	¡			
FI	¡			
SG	¡			
BAT	¡			

Figure 6.6.1 *Anopheles gambiae* adult feeding © James Gathany

Background

Anopheles gambiae senso stricto is the primary mosquito vector responsible for the transmission of malaria in most of sub-Saharan Africa and is one of the most efficient vectors of malaria in the world. It is part of a species complex that currently consists of eight sibling species: *A. arabiensis*; *A. bwambae*; *A. melas*; *A. merus*; *A. quadriannulatus*; *A. gambiae* sensu stricto; *A. coluzzii*; and *A. amharicus*. The individual species of the complex are morphologically difficult to distinguish from each other, and molecular identification may be necessary (Scott *et al.*, 1993). Correct identification is important as the species exhibit different behavioural traits. For example, *A. quadriannulatus* is both a saltwater and mineral-water species. *Anoheles melas* and *A. merus* are saltwater species, while the remainder are freshwater species. *Anopheles quadriannulatus* generally takes its blood meal from animals, whereas *A. gambiae* sensu stricto generally feeds on humans.

Anopheles gambiae complex is currently absent from the Atlantic UKOTs and the territories of St Helena and the Ascension Islands have identified this species as a priority invasive threat.

Geographical Distribution

The *Anopheles gambiae* complex is widely distributed throughout tropical sub-Saharan Africa (Roberts & Janovy, 2000), so long as water is readily available to allow them to breed (Blackwell & Johnson, 2000; Evans, 1938).

Hosts

All *A. gambiae* complex females are temporary ectoparasites, living in the environment and coming to the host to feed. The females require blood meals to mature their eggs. Males, however, are non-parasitic and feed on plant fluids. Females do not display a tremendous amount of host specificity, but *A. gambiae* sensu stricto preferentially feeds on humans. Females locate their hosts using a variety of sensory receptors, but respond to movement, carbon dioxide gradients, and sweat (World Health Organization, 2004; Konate, *et al*., 1999; Meijerink, *et al*., 2000; Roberts & Janovy, 2000).

Description

Figure 6.6.2 *Anopheles gambiae* larva © Ray Wilson, Bird and Wildlife Photography

Adult female *Anopheles* can be distinguished from other mosquito genera because the palps (appendages found near the mouth) are as long as their proboscis. Adult *Anopheles* also have a distinctive resting position where their abdomen is raised into the air (Fig. 6.6.1) (Foster & Walker 2009). *Anopheles gambiae* have a variable body colour, but it typically ranges from light brown to grey with pale spots of yellow, white or cream scales, and dark areas on their wings. Adults are small to medium-sized mosquitoes with average wing length varying from 2.8-4.4 mm (Gillies & de Meillon 1968). Eggs are about 0.5 mm long, convex below and concave above, and the surface is covered with a polygonal pattern (Gillies & de Meillon 1968). *Anopheles gambiae* lay their eggs singly and directly on the water, with each egg having floats on either side (Foster & Walker 2009). All *Anopheles* larvae (Fig. 6.6.2) lack the respiratory siphons used as breathing tubes found in most other mosquito genera, and therefore the larvae lie parallel to the water surface to breathe. *Anopheles* mosquitoes develop though four larval instars before pupating (Foster & Walker 2009). Fourth instar larvae reach 5-6 mm (Gillies & de Meillon 1968). They feed on organic matter and algae (Garros et al. 2008). The pupae are comma-shaped and highly mobile; they use the paddle at the end of their abdomen to quickly move through the water (Foster & Walker 2009).

Biology

Anopheles gambiae has four life stages: egg, larva, pupa, and adult. Both male and female adult mosquitoes feed on nectar from plants, but only the female blood-feeds on vertebrates, where she obtains nutrients for her eggs (Foster & Walker 2009). Although adults can survive for up to one month in captivity, they usually survive around one to two weeks in the wild (CDC 2010). Adults are nocturnal, with peak hours of activity from after midnight to 4:00 am, with activity continuing until just before dawn (Gillies & de Meillon 1968).

Adult females lay their eggs on the surface of water in a variety of aquatic habitats, but prefer shallow sunlit pools of standing water (Gillies & de Meillon 1968). Larvae hatch from eggs and develop within the aquatic habitat. Studies have shown that *A. gambiae* larvae can develop in permanent man-made structures such as concrete tanks and drainage canals, and natural pools such as swamps, hoof prints, and marshes (Kweka *et al*., 2012; Mala *et al*., 2011). The larvae of *A. gambiae* pupate after the fourth instar once they acquire an appropriate amount of nourishment (Foster & Walker 2009). *Anopheles* *gambiae* can develop from egg to adult in 10-11 days, but development is temperature dependent and can take as long as three weeks under colder conditions (Gillies & de Meillon 1968).

Seasonal abundance of *A. gambiae* varies depending on location, but generally the population decreases during the dry season and peaks during the wet season (Gillies & de Meillon, 1968; Yaro *et al*., 2012). Populations begin to increase as the rainy season commences, peak in mid-season, and decline as water levels stabilize and aquatic predators establish themselves (Gillies & de Meillon, 1968).

Dispersal and Detection

Natural dispersal of Anopheline mosquitoes occurs only over a short range, as the adults are weak fliers and generally cannot fly in windy conditions. Mark-release-recapture (MRR) experiments conducted in Kenya with emerging *A. gambiae* complex and *Anopheles funestus* Giles showed a maximum flight distance of 661 m (Midega *et al*., 2007).

As with other mosquitoes, most medium and long-range dispersal is likely to be due to anthropogenic activities. Such activities may include transport linked to international tyre trade and the horticultural and nursery trade.

Adult detection is achieved by surveillance. There are several types of adult mosquito traps available for this. Resting boxes are the best trap method for an unbiased collection of the adult population (Weathersbee & Meisch 1990) but there are others such as the New Jersey Light trap and the CDC Light trap (VDCI).

Monitoring the immature stages of *Anopheles* is traditionally done by sampling for eggs, larvae, or pupae in water bodies. Recent studies have demonstrated the potential use of eDNA analysis for detection and quantification of *A. gambiae* s.s. larvae in aquatic habitats (Odero *et al*., 2018).

Economic and other Impacts

A. gambiae is one of the most efficient vectors of malaria in the world. It is responsible for the transmission of malaria and other serious diseases throughout Africa. *Anopheles gambiae* transmits Plasmodium falciparum, which is the most severe of the four malarial agents. Although this disease was wiped out in the United States, it remains a world health hazard. There are an estimated 300 to 500 million cases of malaria each year and as a result, 1.5 to 2.7 million deaths worldwide. Continental sub-Sahara Africa, however, accounts for roughly 90% of all malarial cases worldwide (Nchinda, 1998).

6.7 Common Malaria Mosquito

Order: Diptera
Family: Culicidae
Species: *Anopheles quadrimaculatus* (Say)

	Present l Absent ¡	Threat		
		Bio	Hlth	Econ
SH	¡		ü	ü
Asc	¡		ü	ü
Tris	¡			
FI	¡			
SG	¡			
BAT	¡			

Figure 6.7.1 Female *Anopheles quadrimaculatus* © 2006 Sean McCann, BugGuide

Background

Anopheles quadrimaculatus is a medium sized, dark brown mosquito and the chief vector of malaria in the U.S. due to its susceptibility to infection with the malaria causing *Plasmodium* parasites. *A. quadrimaculatus* prefers habitats with well-developed beds of submergent, floating leaf or emergent aquatic vegetation e.g. irrigation ditches, freshwater marshes and vegetated margins of lakes, ponds and reservoirs (Carpenter & LaCasse, 1955).

Geographical Distribution

A. quadrimaculatus is a mosquito that is commonly found in the United States, primarily in the eastern part of the country, from the East Coast to the Texas panhandle. The highest densities are found in the southeast of United States. They have also been found in Mexico and southern Canada, including Ontario and Quebec (Carpenter and LaCasse, 1955).

Hosts

A. quadrimaculatus larvae feed on organic matter (e.g. plant and animal matter) that is suspended on the surface of the water in which the larvae float. The larvae feed on many different aquatic organisms with no feeding preference (Carpenter and LaCasse, 1955).

Adult *A. quadrimaculatus* feeding patterns differ according to their sex. To produce eggs females must feed on blood from animals such as humans, cows, horses, pigs, sheep, dogs, cats and birds (Carpenter and LaCasse, 1955). Blood feeding begins in the spring and declines in the fall, ceasing by November

(Robertson et al., 1993). Males and females also feed on sugars and nectar from many different plant species. The adults typically feed from dusk until sunrise but will feed during the day if hosts are readily available (Carpenter and LaCasse, 1955).

Description

Figure 6.7.2 *Anopheles quadrimaculatus* eggs © C. Roxanne Connelly, University of Florida

Figure 6.7.3 *Anopheles quadrimaculatus* larva (left) and pupa (right) © James M. Newman, University of Florida

Figure 6.7.4 Adult female *Anopheles quadrimaculatus* feeding © Sean McCann, University of Florida

Adult *A. quadrimaculatus* rest with their abdomens positioned at a discrete angle to the surface whereas other species keep their bodies parallel to the surface which helps in identification when sitting on skin (Rios and Connelly, 2015) (Figure 6.7.4). The abdomen and wings are dark brown in colour with the wings having dark scales and patches of scales forming four darker spots (Carpenter and LaCasse, 1955) (Figures 6.7.1 and 6.7.4). Females have a body and wing length of about 5mm. The males have a body length of about 5.5 mm and a wing length of 4.5mm (Carpenter and LaCasse, 1955). Species in the genus Anopheles have long palps approximately equal in length to the proboscis (Carpenter and LaCasse, 1955).

Eggs are deposited by the females on the surface of the water such as in freshwater streams, ponds and lakes with aquatic vegetation (Carpenter and LaCasse, 1955). The eggs are unique in having floats on either side (Figure 6.7.2) and will hatch after 2-3 days after oviposition (Carpenter and LaCasse, 1955).

The larvae (Figure 6.7.3) lie horizontally at the surface of the water where they filter feed on organic material (O'Malley 1992). They do not possess the breathing siphon present in other mosquito genera. They obtain oxygen through palmate hairs along the abdomen. The food sources include a variety of plant and animal matter suspended at the surface of the water and small enough to eat (O'Malley 1992).

The pupae of all mosquitoes are active and when disturbed will “tumble” from the water surface where they obtain oxygen, to the bottom of their aquatic habitat. Even though they are active, the pupae do not feed as there are no functional mouthparts during this stage.

Biology

Adult mosquitoes can mate within a few days after emerging from the pupal stage with the entire life cycle – from egg to larva to pupa to adult – taking as little as five days when the temperature is warm mid-season, but usually taking one to two weeks (CDC, 2012).

The males live for about a week feeding on nectar and other sources of sugar. Females will also feed on sugar sources for energy but require a blood meal for the development of eggs (Carpenter and LaCasse, 1955). After obtaining a full blood meal the female will rest for a few days while the blood meal is digested, and eggs are developed. Feeding occurs at night, During the days, the adults rest inside dark buildings and shelters in dark corners. Flight activity peaks a short period after dark, with limited flight for blood for the remainder of the night and at dusk they search for resting sites (Carpenter and LaCasse, 1955). Once the eggs are developed the female will oviposit and then seek blood to sustain another batch of eggs. Adult females can lay 50-200 eggs per oviposition (CDC, 2012). The cycle repeats itself until the female dies. Females can survive up to a month (or longer in captivity) but most do not live longer than 1-2 weeks in nature (CDC, 2012). Their chances of survival depend on temperature and humidity, their ability to successfully obtain a blood meal while avoiding host defences, and the availability of larval habitats. Seasonal changes of lake water levels and the availability of larval habitats are directly correlated with population size (Robertson et al., 1993).

A. quadrimaculatus are more active in the summer months and exhibit slower development in the winter (Weidhass et al., 1965). Adult *A. quadrimaculatus* overwinter as fertilized adults in colder climates. The overwintering adults stay in protected shelters such as barns, tree holes and other dark protected areas (Magnarelli, 1975). Blood feeding begins in the spring and declines in the fall, ceasing by November (Robertson et al., 1993)

Dispersal and Detection

Anopheline mosquitoes are weak fliers that in general cannot fly in windy conditions. Flight range is usually regarded as less than one mile under normal conditions (Carpenter and LaCasse 1955) but this species is capable of longer flights (about 2 miles) as demonstrated by mark and recapture studies (Weathersbee and Meisch, 1990).

Adult detection is achieved by weekly surveillance. There are several types of adult mosquito traps available for this. Resting boxes are the best trap method for an unbiased collection of the adult population (Weathersbee & Meisch 1990) but there are others such as the New Jersey Light trap and the CDC Light trap (VDCI).

Economic and other Impacts

A. quadrimaculatus is the most important species in the eastern United States regarding malaria transmission. Although malaria has been considered eradicated from the United States since 1954, the CDC continues to report around 1,500 cases annually in the United States, the majority of which were acquired outside of the country (Rios and Connelly, 2015). *A. quadrimaculatus* can also transmit Cache Valley virus (Blackmore et al.; Rios and Connelly, 2015), West Nile Virus (CDC, 2007) and is an excellent host for dog heartworm (*Dirofilaria immitis*) (Nayar and Sauerman, 1975; Rios and Connelly, 2015). There are no records in the literature of this species occurring outside the United States.

6.8 Oriental Fruit Fly

Order: Diptera
Family: Tephritidae
Species: *Bactrocera dorsalis* (Hendel)

	Present l Absent i	Threat		
		Bio	Hlth	Econ
SH	i			ü
Asc	i			ü
Tris	i			ü
FI	i			
SG	i			
BAT	i			

Figure 6.8.1 Adult male *Bactrocera dorsalis* reared from guava exported from Sri Lanka © Fera

Background

Bactrocera dorsalis, commonly called the Oriental Fruit Fly (OFF), is the most important pest Tephritid in its native Asia. As it is a highly invasive species with a high dispersal potential and an extensive host range, it presents a potentially serious plant health threat to all the UK Overseas Territories with tropical climates, particularly to those located in the Caribbean where the fly has the potential to establish. It is a member of the *Bactrocera dorsalis* species complex (OFF species complex), a group of 85 morphologically similar species, many with overlapping host preferences. The most similar major pest species include *B. carambolae*, *B. caryeae*, *B. kandiensis*, *B. occipitalis* and *B. pyrifoliae*.

Geographical Distribution

Native to parts of the Indian subcontinent, China and southeast Asia, *B. dorsalis* is now found in at least 65 countries, including parts of America and Oceania, and Africa (CABI, 2019). It is well established in Hawaii and French Polynesia, and most countries of sub-Saharan Africa since the first appearance in Kenya in 2003 (as *Bactrocera invadens,* now considered a subjective synonym of *B. dorsalis* sensu latu). It has also been introduced to Madagascar, the Comoros and Cape Verde Islands, and has successfully been eradicated from Mauritius. There are frequent detections of OFF in North America (California and Florida) and an ongoing eradication programme in California since August 2017. In 2018, adults in the OFF species complex were trapped for the first time in Europe, in the Campania Region of Italy (Nugnes *et al.*, 2018). The distributions of other notable pest species in the OFF complex are mapped with their pest status and invasion history by Vargas *et al.* (2015).

Figure 6.8.2 *Bactrocera dorsalis* adult female ovipositing in a papaya fruit ©Scott Bauer

Figure 6.8.3 *Bactrocera dorsalis* larva and emergence hole in guava (*Psidium guajava*) fruit © Fera

Figure 6.8.4 Oriental fruit fly, *Bactrocera dorsalis*, larvae tunnelling in a mango (*Mangifera indica*) © Fera

Figure 6.8.5 Rotting mango (*Mangifera indica*) fruit imported from the Philippines heavily infested with *Bactrocera dorsalis* larvae © Fera

Host Plants

Bactrocera dorsalis is a highly polyphagous species whose larvae develop in a very wide range of wild and cultivated host fruits. It attacks over 270 host species in 50 plant families; host relationships vary from region to region and are dependent largely on what fruits are available.

Important hosts for some islands in the Atlantic region include apple (*Malus spp.*), banana (*Musa* spp.), coffee (*Coffea* spp.), fig (*Ficus carica*), guava (*Psidium guajava*), mango (*Mangifera indica*), orange (*Citrus* spp.), peach (*Prunus persica*), peppers (*Capsicum* spp.), plum (*Prunus domestica*), pear (*Pyrus* spp.), and tomato (*Solanum lycopersicum*) (White & Elson-Harris, 1992).

Due to confusion between *B. dorsalis* and related species in South East Asia, some published host data may concern other species within the *B. dorsalis* species complex.

Description

The adults of the OFF complex have a body length of about 8 mm and the body colour has variable dark markings (Fig. 6.8.1). The thorax has dark-brown to black markings and lateral yellow markings and a yellow scutellum. The abdomen has two horizontal black stripes and a longitudinal median stripe extending from the base of the third segment to the apex of the abdomen, which may form a T-shaped pattern. The ovipositor is very slender and sharply pointed. Oriental fruit flies have wings with clear membranes, except for a narrow costal band.

Identification to species level requires morphological examination of adult flies and is incredibly difficult. Species in the OFF complex are morphologically very similar, and some species exhibit great variability, therefore it is essential that they are examined by an experienced entomologist. Rapid and *accurate* diagnostics are critical to prevent the establishment and limit the spread of invasive fruit flies.

The larva of the Oriental fruit fly is quite like that of the Mediterranean fruit fly (*Ceratitis capitata*). Third instar larvae are creamy-white to pale yellow in colour, around 10 mm long, sub-cylindrical, with the front-end pointed and the rear-end broad (Fig. 6.8.4). The small tapering head has two heavily sclerotised mouth hooks, 9-11 oral ridges with accessory plates, and paired anterior spiracles with 9-12 tubules. The posterior spiracles are positioned at the rear of the body and are a very useful taxonomic character at family level. The spiracles have three sub-parallel slits and are not present on raised lobes. Tephritidae pupae are cylindrical, approximately 4.9 mm long and yellow-reddish brown.

It is not possible to morphologically identify eggs, larvae or pupae to species level or to the *Bactrocera dorsalis* complex.

Biology

All fruit flies have six developmental stages: egg, three larval instars, pupa and adult. Each adult female Oriental fruit fly usually lays around 1200-1500 eggs over their lifespan of one to three months. Up to 20 eggs are laid under the skins of fruit that is just beginning to ripen, sometimes where the skin is already broken. The eggs hatch within one to three days (although this can be delayed up to 20 days in cool conditions), and the larvae develop inside the fruit. Larvae tunnel and feed in the fruit for 6 to 35 days (usually depending on temperature and food availability). The larvae exit the fruit by making a small hole (Fig. 6.8.3) and fall to the ground and pupate in soil. Depending on temperature, adult emergence occurs after 10-12 days under ideal conditions, but up to 90 days in cool conditions (CABI, 2019).

Dispersal and Detection

Oriental fruit fly is a highly invasive pest introduced to new areas in fruit trade and illegally in passenger baggage. After introduction, it can easily establish and disperse because it has a high reproductive potential and high biotic potential (short life cycle, up to ten generations of offspring per year depending on temperature). There is limited reliable data on the flight and passive wind-assisted dispersal of this species (CABI, 2019).

An extensive host range and a tolerance of both natural and cultivated habitats over a comparatively wide temperature range has facilitated its success. The pest has spread rapidly across Africa since it was detected in 2003 in Kenya and is now reported from 36 other countries in the sub-Saharan region.

Fruit flies can be detected as eggs or larvae in fruits or as adults caught in traps. Attacked fruit will often have puncture marks made by the female fly's ovipositor. Fruit with a high sugar content may exude globules of sugar. A depression and discolouration may occur at the puncture site. Eggs or larvae may be found by carefully cutting into the fruit. It is necessary to rear them to adult for species identification. Pupae may also be found beneath the soil at the base of the host plant or in any packaging associated with imported fruit. A variety of specialist traps are available for trapping adult fruit flies. Male Oriental fruit fly are attracted to the chemical pheromone methyl eugenol, and both sexes can be monitored using sticky traps. Many countries that are free of *Bactrocera* spp., e.g. the

USA (California and Florida) and New Zealand, maintain a grid of methyl eugenol and cue lure traps, at least in high-risk areas (ports and airports) if not around the entire climatically suitable area. The trap used will usually be modelled on the Steiner trap or Jackson trap.

Economic and other Impacts

Bactrocera dorsalis is an economically important pest in its native range and other parts of the world where it has accidentally spread. Increasing international tourism and trade, and changes in climate and land use, facilitate the introduction of the pest. It is considered one of the most destructive fruit fly pests and remains at the top of quarantine lists. The highly polyphagous nature of the species enables it to attack a wide range of fruits, and damage to fruit crops is frequently high (Fig. 6.8.5) and may reach 100% loss of unprotected fruits. Economic impacts include reduced production, the cost of eradication and surveillance, and significantly, lost export markets through quarantine restrictions. In Mauritius, the total cost of the eradication operation was approximately US$1 million (Seewooruthun *et al.*, 2000). In California it has been estimated that the cost of not eradicating Oriental fruit fly would range from US$ 44 to 176 million in crop losses, additional pesticide use, and quarantine requirements. (CABI, 2019)

Invasive *B. dorsalis* is highly competitive with native fruit flies wherever it has established. In many African countries it has displaced the indigenous *Ceratitis cosyra* (see Fact Sheet 6.10) as the dominant mango pest and has proven to be more aggressive (Ekesi *et al.*, 2009). There is also potentially a significant environmental impact following the initiation of chemical control, which could harm native insects and species of conservation significance.

6.9 Mediterranean Fruit Fly

Order: Diptera
Family: Tephritidae
Species: *Ceratitis capitata* (Wiedemann)

	Present l / Absent ¡	Threat		
		Bio	Hlth	Econ
SH	l			
Asc	¡	ü		ü
Tris	¡			ü
FI	¡			
SG	¡			
BAT	¡			

Figure 6.9.1 *Ceratitis capitata* adult male © Fera

Background

Ceratitis capitata, commonly called Medfly or Mediterranean fruit fly is one of the most serious invertebrate pests of citrus and many other fruits in most countries with a warm, Mediterranean, tropical or subtropical climate. It is a highly invasive species with a high dispersal potential and an extensive host range. It therefore presents a potentially serious plant health threat to all the UK Overseas Territories with tropical or subtropical climates. It is a major pest of peach and other fruit hosts in St Helena where it has been present since at least 1882 (Anon, 1908).

Geographical Distribution

Native to sub-Saharan Africa, *C. capitata* is now widespread in Africa, and through accidental transport during trade has spread to other warm tropical and sub-tropical parts of the World including Mauritius, Reunion, Seychelles, St Helena, North Africa, Southern Europe, the Middle East, Western Australia and to parts of Central, South and North America.

Host Plants

Ceratitis capitata is a highly polyphagous species whose larvae develop in a very wide range of wild and cultivated host fruits, with a preference for tree fruit crops with thin skins. Host relationships vary from region to region and are dependent largely on which fruits are available.

Figure 6.9.2 *Ceratitis capitata* male orbital setae © Fera

Figure 6.9.3 *Ceratitis capitata* larva © Florida Division of Plant Industry, Florida

Figure 6.9.4 *Ceratitis capitata* pupae © Fera

Figure 6.9.5 Ugandan pepper with oviposition and larval exit holes made by *Ceratitis capitata* © Fera

Figure 6.9.6 *Ceratitis capitata* monitoring trap in *Citrus* orchard © Russell IPM

Figure 6.9.7 UK Plant Health Service inspectors examining imported fruit © Fera

Important hosts for the South Atlantic region include apple (*Malus* sp.), avocado (*Persea americana*), various *Citrus* spp., coffee (*Coffea* spp.), fig (*Ficus carica*), kiwifruit (*Actinidia deliciosa*), lychee (*Litchi* spp.), longan (*Dimocarpus longan*), , mango (*Mangifera indica*), pear (*Pyrus communis*), peppers (*Capsicum* spp.), peach (*Prunus persica*), guava (*Psidium guajava*), strawberry-guava (*Psidium cattleianum*) an a variety of endemic wild hosts (White & Elson-Harris, 1994; Cabi, 2019).

Description

Medfly adults (Fig. 6.9.1) are easily recognisable by external morphology. They have a wing length of 3.6-5 mm, a scutellum that is black with a narrow wavy yellow band across the base, and a distinctive wing pattern with yellow crossbands and a costal band distinct from the discal crossband. Males have a pair of orbital setae modified with black diamond-shaped tips (Fig. 6.9.2). De Meyer (2000) provides a key for the separation of similar species.

Third instar larvae are creamy-white to pale yellow in colour, medium-sized (3.9-8.7 mm), sub-cylindrical, with the cephalic-end pointed and the caudal-end broad (Fig. 6.9.3). The small tapering head has two heavily sclerotised mouth hooks, 9-11 oral ridges, an absence of accessory plates and paired anterior spiracles with 9-12 tubules. The posterior spiracles are positioned at the rear of the body and are a very useful taxonomic character at family level. The spiracles have 3 sub-parallel slits and are not present on raised lobes. Steck & Ekesi (2015) provide a very detailed larval description.

Pupae are cylindrical, 4 to 4.3 mm long, yellow-reddish brown, and resemble a swollen grain of wheat (Fig. 6.9.4).

Biology

All fruit flies have six developmental stages: egg, three larval instars, pupa and adult. Each adult female Medfly usually lays around 300 eggs over their 2-3-month lifespan. Up to 10 eggs are laid under the skins of fruit that is just beginning to ripen, sometimes where the skin is already broken. The eggs hatch within 2-3 days, and the larvae develop inside the fruit. Larvae tunnel and feed in the fruit for 6 to 11 days (depending on temperature and food availability). The larvae exit the fruit by making a small hole (Fig 6.9.5) and fall to the ground and pupate in soil. Depending on temperature, adult emergence occurs after 6-13 days (White & Elson-Harris, 1994).

Dispersal and Detection

Medfly is a highly invasive pest with a very high dispersal potential, primarily through movement of fruit. Their very large host range, and a tolerance of both natural and cultivated habitats over a comparatively wide temperature range, has made them a successful invader in many tropical and subtropical parts of the World. A 1989 outbreak of medfly in California, USA is speculated as being caused by a deliberate act of bio-terrorism.

Fruit flies can be detected as eggs or larvae in fruits or as adults caught in traps (Fig. 6.9.6). Attacked fruit will often have puncture marks made by the female fly's ovipositor (Fig. 6.9.5). Fruit with a high sugar content may exude globules of sugar. A depression and discolouration may occur at the puncture site. Eggs or larvae may be found by carefully cutting into the fruit. It is necessary to rear them to adult for species identification. Pupae may also be found beneath the soil at the base of the host plant or in any packaging associated with imported fruit. A variety of specialist traps are available for trapping adult fruit flies. Male medfly are attracted to Tri-Med-Lure and both sexes can be monitored using BioLure or by sticky traps.

As part of the biosecurity programme on St Helena invasive fruitfies are monitored with pheromone baited Delta trapsa at ports of entry and in the main fruit growing areas of the island (Key, pers. comm.)

Economic and other Impacts

Ceratitis capitata is one of the World's most destructive fruit pests. It is an economically important pest in Africa and many other parts of the World where it has accidentally spread. Damage to fruit crops is frequently high and may reach 100% loss. It is the most damaging pest of citrus fruits in many areas it has invaded. Economic impacts include reduced production, the cost of eradication and surveillance, and lost export markets.

Medfly has been present on St Helena since the end of the 19th century (Anon, 1908) and was first first reported as an agricultural pest in 1904 (Ashmole & Ashmole, 2000). One of the island's most signifance agricultural pests, medfly attacks *Prunus* (peaches, apricot, plum and nectarines) and also breeds on wild trees with small to medium sized fruit (not harvested or used by people), including coffee berries and the prickly pear cactus fruit, being particularly abundant on the latter (Key, pers. comm.).

In 1998 a Medfly eradication campaign using protein splash baiting dramatically reduced the numbers of the pest, advice on pruning and clearing away alternative wild hosts was given and a seasonal spray programme was introduced (Key, pers. comm). Locally produced fresh or preserved fruit available in are a welcomed supplement the costly imported produce. Population numbers of the pest on Saint Helena are unortunately on the rise again (Key, pers. comm.)

6.10 Mango Fruit Fly

Order: Diptera
Family: Tephritidae
Species: *Ceratitis cosyra* (Walker)

	Present l Absent ¡	Threat		
		Bio	Hlth	Econ
SH	¡			ü
Asc	¡			ü
Tris	¡			ü
FI	¡			
SG	¡			
BAT	¡			

Figure 6.10.1 *Ceratitis cosyra* adult female, intercepted as larvae on mango from Kenya © Fera

Background

Ceratitis cosyra, commonly called Mango fruit fly or Marula fruit fly is one of the most important pests of mango across sub-Saharan Africa, where it negatively affects crop production on smallholding and commercial mango plantations. Besides mango, larvae of *C. cosyra* also feed on representatives of at least 17 different plant families, including other commercial hosts. When mango is out of season, the mango fruit fly shifts to alternative host plants such as marula, (*Sclerocarya birrea*) and soursop (*Annona muricata*) (references in Virgilio *et al.,* 2017).

Geographical Distribution

Native to sub-Saharan Africa where it is widespread, *C. cosyra* is absent in parts of southern Africa, largely coinciding with the distribution limit of the main wild host, marula (*Sclerocarya birrea)*. It has been recorded om Madagascar. It has not established outside of Africa.

Host Plants

Ceratitis cosyra is a highly polyphagous species, whose larvae develop in a very wide range of wild and cultivated host fruits, with a preference for tree fruit crops with thin skins. Host relationships vary from region to region and are dependent largely on which fruits are available.

Figure 6.10.2 *Ceratitis cosyra* adult male, intercepted as larvae on mango from Kenya © Fera

Figure 6.10.3 Fruitfly larva feeding on mango pulp © Fera

The main commercial fruit host the fly attacks is mango (*Mangifera indica*), although the invasive *Bactrocera dorsalis* has largely displaced it as the main fruit fly pest of this host in Africa (Ekesi *et al*., 2009). Others include guava (*Psidium guajava*), sour orange (*Citrus aurantium*), avocado (*Persea americana*), maroola/marula plum (*Sclerocarya birrea,* peach (*Prunus persica*) and custard apple (*Annona* spp.). It is highly polyphagous on wild hosts, including species of Apocynaceae, Canellaceae, Chrysobalanaceae, Ebenaceae, Euphorbiaceae, Fabaceae, Flacourtiaceae, Loganiacea, Passifloraceae, Polygalaceae, Rubiaceae and Sapotaceae. (White & Elson-Harris, 1992; Virgilio *et al*., 2014).

Description

The following adult description is taken from De Meyer (1998), and De Meyer (2000) provides a key for the separation of similar species. It is important to note that the black spots on thorax may vary. Virgilio *et al* (2017) discussed the possibility of *Ceratitis cosyra* being a species complex. Currently all different forms are considered one and the same species (Meyr factsheet).

Body length: 4.43 (3.35 -5.40) mm; wing length: 4.17 (3.40-5.20) mm.

Male (Fig. 6.10.2)

Head: Antenna yellow-orange. Third antennal segment twice as long as second segment. Arista with short hairs over entire length. Frons with short scattered hairs which are distinctly darker than or same colour as frons; more flattened, not distinctly convex, in lateral view slightly projecting forwards at antennal implant. Lower eye margin with slightly darker marking. Chaetotaxy normal for subgenus, bristles dark reddish to black.

Thorax: Postpronotum white, with black spot. Ground colour of mesonotum pale with orange tinge; mesonotal pattern variable especially spots at mesal end of suture and prescutellar spots variable in size and colouration, anterior supra-alar spots usually continuous. Chaetotaxy normal for subgenus. Scapular setae pale. One anepisternal bristle. Scutellum white basally, otherwise yellow with three black separate markings apically; basally usually with two separate dark spots, sometimes spots are not distinct, and only present as slightly brown patches. Subscutellum pale with three dark separate spots except along dorsal margin where touching. Legs yellow; setation typical for subgenus, mainly pale especially on femora. Posterior and posterodorsal rows on fore femur pale. Ventral spines on fore femur yellowish or black.

Wing bands with markings extensively yellow; banding sometimes faint. Banding, marginal band continuous; cubital band free; medial band absent; crossvein r-m before middle of discal cell. Crossvein dm-cu position variable.

Abdomen: Pale yellow or more brownish. Setation and banding typical for subgenus.

Female (Fig 6.10.1)

As male except for the following characters: Oviscape shorter than abdominal terga 3-6 combined.

Third instar larvae (Fig 6.10.3) are creamy-white to pale yellow in colour, medium-sized (5.5–8mm), sub-cylindrical, with the cephalic-end pointed and the caudal-end broad. The small tapering head has two heavily sclerotised mouth hooks, 10-12 oral ridges, an absence of accessory plates and paired anterior spiracles with 11-12 tubules. The posterior spiracles are positioned at the rear of the body and are a very useful taxonomic character at family level. The spiracles have 3 sub-parallel slits and are not present on raised lobes. Description taken from Carroll *et al.* (2004)

Pupae are cylindrical, 4 to 4.3 mm long, yellow-reddish brown, and resemble a swollen grain of wheat.

Biology

All fruit flies have six developmental stages: egg, three larval instars, pupa and adult. *Ceratitis cosyra* adults can live up to 8 weeks (Manrakhan & Lux, 2006), females start laying eggs under the skin of fruit two weeks after emergence. The eggs hatch within 2-3 days, and the larvae develop inside the fruit. Larvae tunnel and feed in the fruit for 10 to 14 days at 28˚C (Ekesi *et al*., 2009). The larvae exit the fruit by making a small hole and fall to the ground and pupate in soil. The pupal stage lasts for 9 to 10 days at temperatures ranging from 26˚-30˚C (Grout & Stoltz, 2007), after which an adult fly emerges, and the cycle continues.

Dispersal and Detection

Mango fruit fly is potentially an invasive pest with a high dispersal potential, primarily through movement of fruit in trade. It has been repeadedly incepted in St. Helena on imported fruit (Pryce & Key, 2018).

Fruit flies can be detected as eggs or larvae in fruits or as adults caught in traps. Attacked fruit will often have puncture marks made by the female fly's ovipositor. Fruit with a high sugar content may exude globules of sugar. A depression and discolouration may occur at the puncture site. Eggs or larvae may be found by carefully cutting into the fruit. It is necessary to rear them to adult for species identification. Pupae may also be found beneath the soil at the base of the host plant or in any packaging associated with imported fruit. A variety of specialist traps are available for trapping adult fruit flies, general information can be found in IAEA (2013). Males are attracted to terpinyl acetate, Enrichd Ginger Oil (EGO) lure and both sexes can be lured and monitored using BioLure, protein baits or by sticky traps. More specific information on efficacy of trapping and lures for *C. cosyra* is given in Manrakhan *et al*., (2017).

Economic and other Impacts

Ceratitis cosyra is one of the most important pests of mango across sub-Saharan Africa, where it negatively affects crop production on smallholding and commercial mango plantations (Lux et al.,2003; Vayssières *et al*., 2009). Besides mango, larvae of *C. cosyra* also feed on representatives of at least 17 different plant families, including other commercial hosts. The economic impact of *C.cosyra* followed the increased commercialization of mango (Li *et al*., 2009). Economic loss originates from direct feeding damage (that ranges from 20% to 80% of crop production) as well as from fruit quarantine restrictions (Ekesi *et al*., 2009).

Prior to the establishment of the exotic invasive species *Bactrocera dorsalis*, it was the main pest species on this crop but is now largely replaced by the latter. Seasonal studies in western Africa show that *C. cosyra* is predominant in the dry season, compared to B*. dorsalis* which occurs predominantly in the rainy season (Vayssières et al., 2015) causing a higher risk for early mango varieties.

Management for this species is, as for most fruit fly pests, most efficient using an IPM (Integrated Pest Management) program, including aspects such as orchard sanitation, bait sprays, mass trapping among others. No Sterile Insect Technique has been developed for this species (Virgilio *et al*., 2014).

6.11 Pumpkin Fly

Order: Diptera
Family: Tephritidae
Species: *Dacus bivittatus* (Bigot)

	Present l Absent ¡	Threat		
		Bio	Hlth	Econ
SH	¡			ü
Asc	¡			ü
Tris	¡			ü
FI	¡			
SG	¡			
BAT	¡			

Figure 6.11.1 *Dacus bivittatus* adult reared from *Lagenaria siceraria* ex Ghana © Fera

Background

Dacus bivittatus, commonly called Pumpkin fly or Greater pumpkin fly, is primarily a pest of cucurbits but is known to attack other host families. It has a high dispersal potential the potential to be an invasive pest. It therefore presents a potentially serious plant health threat to all territories with tropical climates in the South Atlantic, particularly those that cultivate cucurbits and other preferred hosts.

Geographical Distribution

Dacus bivittatus is widespread throughout sub-Saharan Africa apart from drier areas of southern Africa. It is present in Madagascar and the Comoro archipelago (De Meyer *et al.*, 2012), and reported from Mahé (Seychelles) but apparently not established. It has not established outside of Africa. It has been repeadedly incepted in St. Helena on imported fruit (Pryce & Key, 2018).

A distribution map for *D. bivittatus* in Africa, based upon specimen records with geo-references, is available at http://projects.bebif.be/fruitfly/taxoninfo.html?id=211.

Figure 6.11.2 *Dacus bivittatus* larvae on *Lagenaria siceraria* Ex Ghana ©Fera

Figure 6.11.3 *Dacus bivittatus* pupae on *Lagenaria siceraria* Ex Ghana ©Fera

Figure 6.11.4 *Dacus bivittatus* larval tunnels in *Lagenaria siceraria* Ex Ghana ©Fera

Figure 6.11.5 UK Plant Health Service inspectors examining imported fruit © Fera

Host Plants

Dacus bivittatus is one of the main fruit fly pests found on wild and cultivated Cucurbitaceae. Major cucurbit hosts include watermelon (*Citrullus lanatus*), *Coccinia palmata*, melon (*Cucumis melo*), cucumber (*C. sativus*), *Cucurbita moschata*, gourd (*Cucurbita pepo*), pumpkin and squash (*Cucurbita* spp.), *Lagenaria abyssinica*, bottle gourd (*L. siceraria*), *L. sphaerica,* ridged gourd (*Luffa acutangula*), *Momordica balsamina*, bitter melon (*M. charantia*), *Mukia maderaspatana, Peponium* mackenii, *Peponium vogelii*, chayote (*Sechium edule*) and oysternut (*Telfairia pedata*) (White & Elson-Harris, 1992).

Reported non-cucurbit hosts include Anacardiaceae: mango (*Mangifera indica*o); Caricaceae: papaya (*Carica papaya*); Passifloraceae: giant granadilla (*Passiflora quadrangularis*); Solanaceae: *Solanum aethiopicum*, tomato (*S. lycopersicum*), aubergine (*S. leongena*) and Sterculiaceae: coshwood (*Cola natalensis*). Reports of it attacking coffee (*Coffea* sp.) are considered doubtful.

Description

Greater pumpkin fly adults (Fig. 6.11.1) are distinguishable by external morphology. They are predominantly dark orange to red-brown in colour, the scutum has lateral and medial yellow stripes and the scutellum lacks any dark patterning apart from the basal margin. They have a wing length of 6.4-8.5 mm, the costal band is complete and deep with an apical expansion. An anal streak is present. Virgilio *et al.* (2014) provide an interactive key for the separation of similar species.

The larval stage of *D. bivittatus* (Fig. 6.11.2) have not been fully described, however in general, third instar *Dacus* larvae are creamy-white to pale yellow in colour, roughly 8-10 mm in length, sub-cylindrical, with the cephalic-end pointed and the caudal-end broad. The small tapering head has two heavily sclerotised mouth hooks with large preapical teeth. The posterior spiracles are positioned at the rear of the body and are a very useful taxonomic character at family level. The spiracles have three sub-parallel slits and are not present on raised lobes. Pupae (Fig 6.11.3) are cylindrical, 4-6 mm long, yellow-reddish brown, and resemble a swollen grain of wheat.

Biology

Very little has been published about the biology of *D. bivittatus*. In general, fruitflies have six developmental stages: egg, three larval instars, pupa and adult. The females deposit their elongated eggs just under the surface of the host fruit with their long extendible ovipositor. Some species use a pheromone to mark fruit in which they have oviposited to signal to other females that the fruit has been attacked. Based on Fera lab observations: The eggs hatch within two to seven days, and the larvae develop inside the fruit. Larvae tunnel (Fig. 6.11.4) and feed in the fruit for 6-15 days (depending on temperature and food availability). The larvae exit the fruit by making a small hole and fall to the ground to pupate in the soil. Depending on temperature, adult emergence occurs after 10-20 days.

Dispersal and Detection

Fruit flies can be detected as eggs or larvae in fruits (Fig. 6.11.5) or as adults caught in traps. Attacked fruit will often have puncture marks made by the female ovipositor. Fruit with a high sugar content may exude globules of sugar. A depression and discolouration may occur at the puncture site. Eggs or larvae may be found by carefully cutting into the fruit. It is necessary to rear them to adult for species identification. Pupae may also be found beneath the soil at the base of the host plant or in any packaging associated with imported fruit. A variety of specialist traps are available for trapping adult fruit flies. Both sexes of *D. bivittatus* are attracted to protein bait products such as liquid protein baits (Torula Yeast), protein bait capsules (Questlure) and the three component Biolure, and both sexes can be monitored using BioLure or by sticky traps. Male flies can be attracted by Cuelure (Virgilio *et al.*, 2014). Information on trapping, types of traps, and lures be found in IAEA (2013).

Economic and other Impacts

Fruit flies are one of the World's most destructive pest groups. The larvae of many species inflict heavy losses on fruit and vegetable crops. Economic effects of pest species include not only direct loss of yield and increased control costs, but also the loss of export markets and/or the cost of constructing and maintaining fruit treatment and eradication facilities. In many countries, the exportation of most commercial fruits is severely restricted by strict quarantine laws to prevent the spread of fruit fly species.

Cucurbits are among the most valuable food crops in various developing countries of sub-Saharan Africa, and *Dacus bivittatus* is one of the most economically important cucurbit pests. Management for this species is, as for most fruit fly pests, most efficient using an IPM (Integrated Pest Management) program, including aspects such as orchard sanitation, bait sprays, mass trapping among others.

6.12 Spotted Wing Drosophila

	Present l Absent ¡	Threat Bio	Threat Hlth	Threat Econ
SH	¡			ü
Asc	¡			ü
Tris	¡			ü
FI	¡			
SG	¡			
BAT	¡			

Order: Diptera
Family: Drosophilidae
Species: *Drosophila suzukii* (Matsumura)

Figure 6.12.1 *Drosophila suzukii* adult male © Fera

Background

Drosophila suzukii is an Asian species of vinegar fly with a wide host range. In the past decade it has invaded North America, South America and Europe. Most species of *Drosophila* are secondary pests, their larvae only developing in previously damaged or rotting fruit. The biology of *D. suzukii*, however, is unusual in that the female can oviposit directly into healthy ripening fruit, still attached to the plant, and so the larvae can cause primary damage to soft-skinned fruit crops. The pest has spread rapidly in Europe and North America due to global trade and the initial lack of regulation over the spread of any *Drosophila species and* is a serious economic threat to soft summer fruit such as cherry, berry and peach crops. *Drosophila suzukii* has a high reproductive rate and short generation time; it can have up to 13 generations per year.

Geographical Distribution

Drosophila suzukii is native to eastern and south eastern Asia, including China, Japan and Korea. Since the first find outside Asia in 1980 in Hawaii, the fly has rapidly expanded its geographical range. In 2008 it reached North America and is currently present in Canada, USA and Mexico. It simultaneously reached Spain and Italy in 2008 and is believed to be established throughout Europe (EPPO, 2017). It was first recorded in South America in 2013 (southern Brazil) and has since spread to Argentina, Chile and Uruguay (Andreazza *et al.*, 2017). Reports of the pest in Costa Rica in the late 1990's have been unproven.

Figure 6.12.2 *Drosophila suzukii* adult male (left) and female (right) © Fera

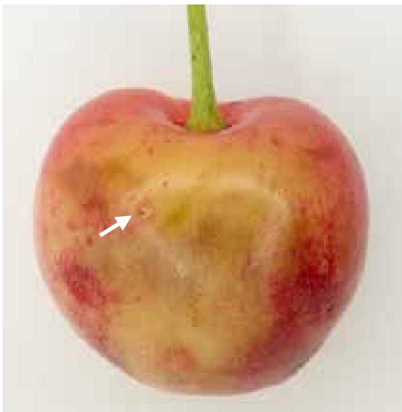

Figure 6.12.3 *Drosophila suzukii* oviposition puncture in a cherry © Fera

Figure 6.12.4 *Drosophila suzukii* larval feeding damage and eggs © Fera

Figure 6.12.5 *Drosophila suzukii* larva. © Frank A. Hale, University of Tennessee, Bugwood.org

Host Plants

Drosophila suzukii is a polyphagous pest infesting a wide range of soft fruit crops and many wild fruits. Major hosts include: dogwood (*Cornus kousa*), persimmon (*Diospyros*), Surinam cherry (*Eugenia uniflora*), strawberry (*Fragaria ananassa*), mulberry (*Morus* spp.), orange jasmine (*Murraya paniculata*), Chinese bayberry (*Myrica rubra*), *Prunus* spp., sweet cherry (*P. avium*), plum (*P. domestica*), peach (*P. persica*), Asian pear (*Pyrus pyrifolia*), currants (*Ribes* spp.), *Rubus* spp., Himalayan blackberry (*R. armeniacus*), loganberry (*R. loganobaccus*), raspberry (*R. idaeus*), evergreen blackberry (*R. laciniatus*), marionberry (*R. ursinus*), *Vaccinium* spp. (blueberry, cranberry) and grape (*Vitis vinifera*). In the neotropics it is also recorded attacking Cherry of the Rio Grande (*Eugenia involucrata*), strawberry guava (*Psidium cattleianum*) and common guava (*P. guajava*).

A number of hard fruits may be attacked if the skin is already broken: kiwi (*Actinidia* spp.), persimmon (*Diospyros kaki*), loquat (*Eriobotrya japonica*), fig (*Ficus carica*), tomato (*Solanum lycopersicum*), apple (*Malus domestica*) and pear (*Pyrus* spp.) (Mann & Stelinski, 2017).

Drosophila suzukii prefers to infest undamaged, ripening fruit. If there is no suitable fruit available, however, then it will attack damaged or deteriorating fruit.

Description

Drosophila suzukii adults are small (3-4 mm) yellowish-brown flies with red eyes, a pale brown or yellowish-brown thorax and black bands on the abdomen (Figs 6.12.1-2). The antennae are short and stubby with branched arista. Males have a distinguishing dark spot along the front edge of each wing. Females are larger than males and possess a large serrated ovipositor. There are a number of other species of Drosophila that could easily be confused with *D. suzukii* due to their spotted wings therefore, expert examination by a specialist is needed for positive identification.

The eggs are 0.4 to 0.6 mm long, oval, milky-white and with two filaments (spiracles) at one end. The larvae are milky-white and cylindrical with black mouthparts. The body is tapered anteriorly with elevated posterior spiracles. First instar larvae are approximately 0.07 mm in length and mature larvae up to 6 mm in length.

The pupae are spindle-shaped, reddish-brown and bear two stalks with small finger-like projections, 3.5 mm long and 1.2 mm wide.

Biology

The pest has a high reproductive potential. It has multiple generations per year (up to 13 in Japan and 10 in California), and under optimal conditions a single life cycle could be as short as 8-14 days. Females may lay up to 60 eggs per day and between 200-600 eggs in their lifetime. On average, each female lays 1-3 eggs per fruit, but many different females may lay eggs in the same fruit so up to 60-70 flies may eventually emerge from a single fruit. Adults are highly mobile (CABI, 2017).

Drosophila suzukii larvae (Fig. 6.12.5) cause damage by feeding on the pulp inside fruit and berries; very quickly the fruit begins to collapse around the feeding site (Fig. 6.12.4). The initial signs of attack are small scars or depressions on the fruit surface at the points where the females have used their specially adapted ovipositors to deposit their eggs into the fruit (Fig. 6.12.3). The oviposition scar exposes the fruit to secondary infection by fungal or bacterial pathogens and other insect pests, including other vinegar flies such as *D. melanogaster*, which may cause rotting.

Adults generally live 20-56 days, but under extended suboptimal cold conditions will overwinter, living for more than 200 days (Kanzawa, 1935). *Drosophila suzukii* has been reported to vector yeasts and bacteria (Hamby *et al.*, 2012).

Dispersal and Detection

Accidental dispersal through movement of infested host fruits is the main pathway of introduction for this pest. Its rapid worldwide spread is in part due to increasing global fresh fruit trade and the cryptic nature of larvae hidden inside fruit. Detection of larvae inside the fruits can be done by careful visual inspection under optical magnification or by immersion of fruit samples in sugar or salt solution. After crushing the fruit the larvae float to the surface of the solution after 10 minutes (BCMA, 2013).

The presence of adult *D. suzukii* in the field can be monitored by using traps baited with different attractants. Traps can be made cheaply from lidded plastic pots, punched with holes and filled with a bait solution to attract the flies, or traps specifically for *D. suzukii* can be purchased commercially (e.g. DROSO-TRAP and Drososan). Some trap designs include red or black colouration, and this will help increase captures, but the bait is the most important component of the trap for attracting the flies and encouraging them to enter the trap. Typical components of bait solutions include yeast, sugar, fruit purees, apple cider vinegar, wine, and ethanol. Pre-made commercial lures are available for *D. suzukii*. Traps can be used for early detection in potentially newly-invaded areas, such as near fruit markets, warehouses of food retailers and sites where rotten fruits are disposed of (Cabi, 2017).

Economic and other Impacts

Drosophila suzukii is a polyphagous pest infesting a wide range of soft fruit hosts, including several economically important crops. Damage to fruit crops is frequently high and may reach 100% loss of unprotected fruits. The damaged fruits are considered unmarketable and economic impacts include reduced production, the cost of control, eradication, surveillance, sanitation, post-harvest sorting and significantly, lost export markets. In addition to economic losses, the global spreading of *D. suzukii* may have high social and environmental costs. Excessive use of insecticides has wide ranging environment and human health risks and chemical control can result in the rejection of fruits for export and consumption due to insecticide residues (Haviland & Beers, 2012).

The economic impact of *D. suzukii* has been studied in the United States (Bolda *et al.*, 2010), Switzerland (Mazzi *et al.*, 2017) and in Italy (De Ros *et al.*, 2015; Ioriatti *et al.*, 2012). In the Italian region of Trentino, the overall economic impact of *D. suzukii* on the production of *F. ananassa*, *Vaccinium* sp. (blueberries), *Rubus* spp. (raspberry and blackberry) and *P. avium* in 2010 was estimated at 3–4 million EUR. In 2008 economic losses (based on maximum reported yield losses) for California, Oregon and Washington were estimated at 40% for *Vaccinium* sp. (blueberries), 50% for caneberries, 33% for *P. avium* and 20% for *F. ananassa*. Production in these three states could sustain 511 million US$ in damages annually because of *D. suzukii* (Bolda *et al.*, 2010). In Brazil, the spread of *D. suzukii* is predicted to result in serious economic losses, approximately 30 million US$ for peach and fig production (Benito *et al.*, 2016).