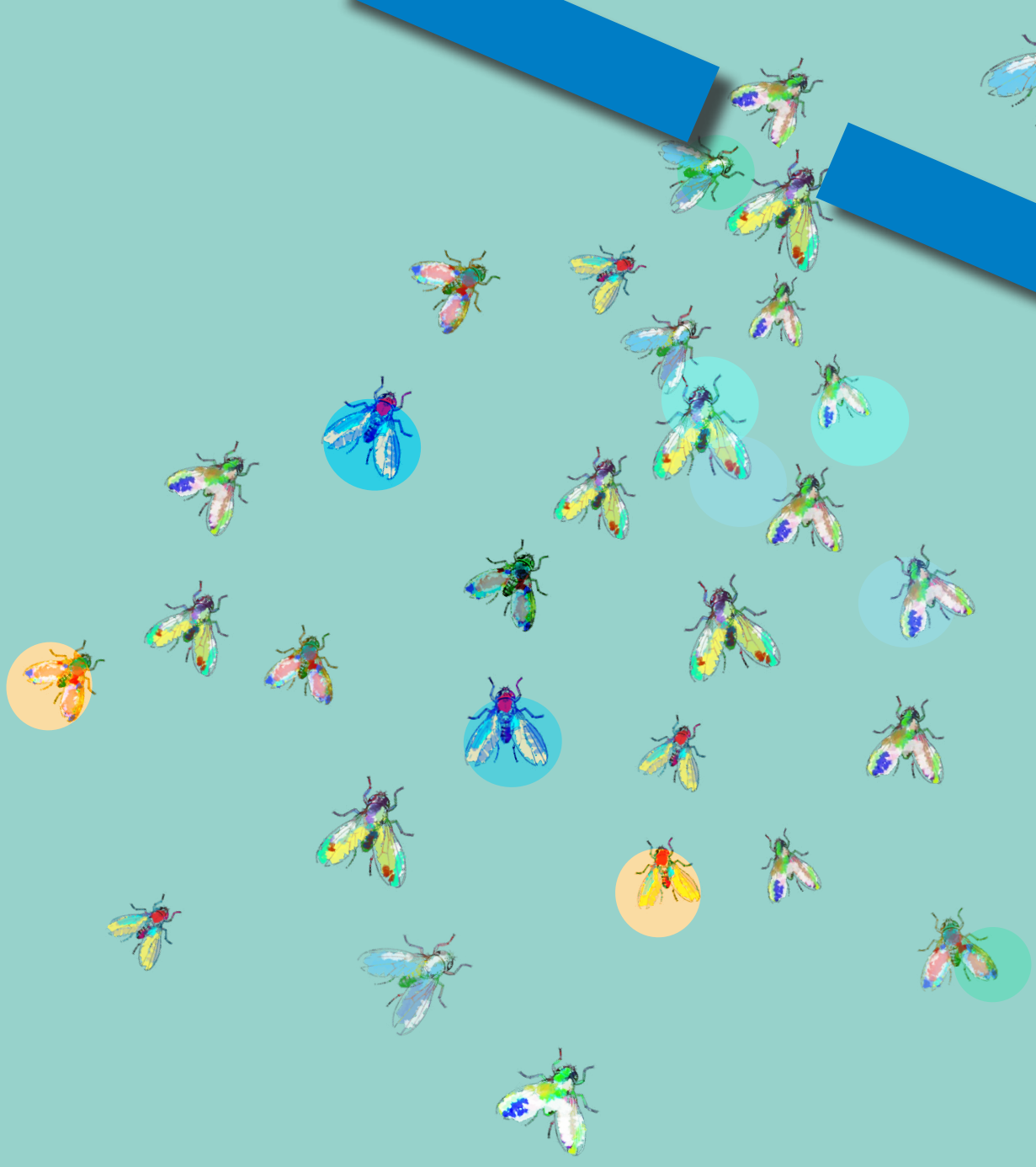
Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

Trapping guidelines

for area-wide fruit fly programmes



Trapping guidelines for area-wide fruit fly programmes

Second edition

Edited by

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Foreword

Tephritid fruit flies cause devastating direct losses to many fresh fruits and vegetables. In addition, few insects have a greater impact on international marketing and world trade in agricultural produce than tephritid fruit flies. With expanding international trade, fruit flies as major quarantine pests of fruits and vegetables have taken on added importance, triggering the implementation of area-wide control programmes at the local, national or regional (trans-boundary) level.

As part of globalization, trade in fresh fruits and vegetables is increasing and gradually being liberalized on a world-wide basis. The issues of this trade are considered in many fora, among them the WTO, the Codex Commission of the Joint FAO/WHO Food Standards Programme, the International Plant Protection Convention (IPPC) of FAO, and other organizations with a focus on SPS (Sanitary and Phytosanitary Standards) implementation. To export their products, all countries must comply with increasing stringent SPS measures. Among the major trading blocks, such as the EU, NAFTA, ASEAN and MERCOSUR, many SPS issues are addressed that are vital to the prosperity of Member States. Mechanisms must be found to facilitate production to meet these technical requirements and in turn provide trading opportunities to all countries. Newly adopted International Standards for Phytosanitary Measures under the IPPC of FAO serve to expand such opportunities through the establishment of pest free areas and areas of low prevalence as part of systems approaches.

Accurate methods for fruit fly population surveys are a prerequisite for effective decision-making in area-wide control programmes aimed at pest suppression, as well as those attempting to establish fruit fly free or low prevalence areas. The FAO/IAEA Division of Nuclear Techniques, as part of its mandate to support the implementation of integrated area-wide fruit fly control programmes involving the use of the Sterile Insect Technique, has carried out over the last decades two international coordinated research networks with the objective of developing and validating methods in the field fruit fly attractants and traps. As a result, improved fruit fly trapping systems have been developed that are being adopted by operational fruit fly control programmes.

At the 3rd Western Hemisphere Fruit Fly Workshop on Fruit Flies of Economic Importance, held July 1999 in Guatemala City, representatives of National Plant Protection Organizations (NPPOs) of 21 participating FAO and IAEA Member States expressed difficulties when interacting with trading partners as a result of a lack of uniformity in the application of the various trapping methodologies to survey fruit flies of economic importance. They recognized the acute need for some harmonization of trapping procedures in view of the increasing fruit fly-related trans-boundary interactions resulting from the rapidly growing travel, transport, tourism and trade. Thus they requested FAO and IAEA to develop some guidelines in support of their fruit fly survey activities for the various pest fruit flies.

These Trapping Guidelines for Fruit Flies of Economic Importance, developed in response to this request, provide strategic guidance and direction on where and how to implement surveys in support of fruit fly control and quarantine activities. This document is the summation of recommendations put forth by a multi-national group of fruit fly workers that has the objective of providing objective information on fruit fly survey tools to NPPOs and horticultural industry in FAO and IAEA Member States. These Trapping Guidelines are to be considered as a 'working' document to be regularly updated as survey techniques continue to improve and experience in fruit fly control programmes evolves.

Application of these recommendations will facilitate, however, will not guarantee access to trade in fruit and vegetable commodities by an exporting country with an importing country. The use of information in this working document does not preclude the need for early contact of the exporting country's NPPO with the respective NPPO of the importing country to negotiate the specific trapping protocols that will be needed to fulfil the quarantine requirements of the importing country.

The scope of this document is limited to trapping of fruit flies of economic and quarantine importance and does not include activities related to mass-trapping or other fruit fly control activities. It only covers trapping technology currently in use or that has been extensively validated and assumes that fruit fly

control programmes implementing the trapping activities are area-wide. Recommendations given for the different scenarios require customization to address the specific climatic and host conditions of the specific fruit fly control areas.

Valuable inputs to this guideline were provided by the following organizations:

Programa Nacional de Control y Erradicación de Mosca de los Frutos (PROCEM), SENASA Argentina; Organismo Internacional Regional de Sanidad Agropecuaria (OIRSA), Central América; Proyecto Moscas de la Fruta, Servicio Agrícola y Ganadero (SAG), Chile; Campaña Nacional Contra Moscas de la Fruta (CNCMF), SENASICA SAGARPA México; Centre for International Agriculture Research for Development (CIRAD-FLHOR), Reunion, France; Carambola Fruit Fly Programme, Suriname; USDA/APHIS/PPQ/HPPL, Waimanalo, Hawaii, USA.

This guideline is an updated version of the original guideline published by IAEA and FAO in 2003. It will be useful as a reference source to Appendix 1 “Fruit fly trapping” of International Standard for Phytosanitary Measures (ISPM) No. 26 “Establishment of pest free areas for fruit flies (Tephritidae)” of the International Plant Protection Convention (IPPC) (FAO 2016).

The officers responsible for this publication were W.R. Enkerlin and J. Reyes-Flores of the Joint FAO/IAEA Programme of Nuclear Techniques in Food and Agriculture.

1. Background

Fruit fly surveillance using traps has become a highly specialized and efficient pest management tool. This guideline provides detailed information for trapping under different pest situations for different fruit fly species (*Tephritidae*) of economic importance. The specific trapping system to be used should depend on the objective of the pest control programme, economic and technical feasibility, the target species of fruit fly and the phytosanitary condition of the delimited areas, which can be either an infested area, an area of low pest prevalence (FF-ALPP), or a pest free area (FF-PFA).

The information in this guideline may be used by NPPO's of FAO and IAEA member countries to aid them in developing FF-PFA and FF-ALPP in line with guidance provided in International Standards of Phytosanitary Measures (ISPMs) related to fruit flies such as ISPM No. 26 ("Establishment of Pest Free Areas for Fruit Flies (*Tephritidae*)"), ISPM No. 30 ("Establishment of Areas of Low Pest Prevalence for Fruit Flies (*Tephritidae*)") and ISPM No. 35 ("Systems Approach for Pest Risk Management of Fruit Flies", FAO 2006, 2008, 2012). It describes the most widely used trapping systems, including materials such as traps and attractants, trapping applications, as well as procedures for assessment of trap layouts and trap densities based on pest risk, data recording and analysis. There are other systems and procedures in use that may be applied to obtain equally valid results. The inclusion of brand names in this guideline does not imply endorsement.

2. Trapping types and pest situations

There are four types of trapping surveys (**Tables 4 and 6a–f**):

- **Monitoring surveys,** to verify the characteristics of the target pest population and to determine the efficacy of control measures (suppression and eradication) being applied. To verify characteristics of the target pest low trap density and long trap inspection interval are required. To determine efficacy of control measures medium to high trap density and normal inspection interval are required.
- **Detection surveys,** to determine if the pest is present in an area, includes intensive (or sentinel) trapping. Low to medium trap density and normal trap inspection interval are required.
- **Delimiting surveys,** to establish the boundaries of a pest incursion including an outbreak in an area considered free from the pest. High trap density and short trap inspection interval required.
- **Verification surveys**, to confirm pest status after the application of procedures to eradicate an outbreak. Medium trap density and normal trap inspection interval required.

There are five pest situations where trapping surveys may be applied:

- **Pest present without control**. The pest population is present but not subject to any control measures. Monitoring surveys are required to verify the characteristics of the pest population before the initiation of control measures.
- **Pest present under suppression.** The pest population is present and subject to control measures. Monitoring surveys are required to determine the timing, duration and sometimes efficacy of these suppression measures.
- **Pest present under eradication.** The pest population is present and subject to control measures. Monitoring surveys are required to evaluate the progress towards eradication of the pest population.
- **Pest absent under exclusion.** The pest is absent. Detection surveys are required in the PFA to detect any possible entry of the pest. An intensive trapping (or so called sentinel trapping) for detection may be applied in assessed high risk sites to improve early detection of the pest.
- **Pest transient, eradication of an incursion.** After detection of an incursion of the target pest, delimiting surveys should be implemented for three biological cycle of the pest (FAO 2016). One cycle to verify the nature and extent of the incursion. If the incursion is actionable (additional detections requiring eradication activities), monitoring surveys are required for two additional biological cycles of the pest from the last detection to determine eradication. Finally, and for the eventual reinstatement as a PFA, a verification survey may be required for one additional biological cycle.

3. Trapping scenarios

There are six possible scenarios illustrating the interactions of the four types of trapping and five pest situations. **Table 1** provides information on which type of trapping is required for each specific pest situation.

Based on the pest status there are two possible starting scenarios which gradually may progress towards the subsequent scenario.

Pest present: Staring from an established population with no control (scenario A), and gradually progressing to a pest control situation, which in some cases progresses towards an ALPP (scenario B), and eventually may reach a PFA (scenario C).

Pest absent: Starting from a PFA (scenario D) where an actionable incursion occurs (scenario E), and gradually progressing to a pest control situation aimed at regaining the PFA status (Scenario F).

- Scenario A: uncontrolled pest subject to monitoring surveys;
- Scenario B: pest under suppression subject to monitoring surveys;
- Scenario C: pest under eradication subject to monitoring and then verification surveys;
- Scenario D: no pest, detection surveys including intensive trapping for exclusion in a PFA;
- Scenario E: incursion detected through ongoing detection surveys, therefore additional implementation of delimiting surveys;
- Scenario F: pest outbreak under eradication requiring verification of pest eradication.

Table 1. Matrix of the different trapping required for different pest situations

	Pest situations				
Trapping	**Pest present without control**	**Pest present under suppression**	**Pest present under eradication**	**Pest absent under exclusion**	**Pest transient eradication of an incursion**
Monitoring	A	B	C		
Detection				D	
Delimiting					E
Verification			F		

4. Trapping systems — materials

The effective use of traps when undertaking fruit fly surveys relies on the combined ability of the trap, attractant and killing agent to attract and capture target fruit fly species and then to kill and preserve them for effective identification, counting data collection and analysis. Trapping systems for fruit fly surveys use the following materials:

- attractants (pheromones, parapheromones and food attractants);
- killing agents in dry trap with sticky material (physical action) or toxicant (with chemical action) and in wet trap with liquid (physical action) and a preservative;
- devices for trapping.

A number of fruit fly species of economic importance, as they may be determined by pest risk analysis conducted by the NPPO of the importing country, and the attractants commonly used to attract them, are presented in **Table 2**.

4.1. Attractants

4.1.1. Male-specific

The most widely used attractants are pheromones or parapheromones that are male-specific. The parapheromone trimedlure (TML) captures species of the genus *Ceratitis* (including *C. capitata* and *C. rosa*). Alternatives to TML include Capilure which is a type of TML with extenders to slow down volatilization and increase the service interval of the trap. Capilure is currently being used in *C. capitata* detection programme in South Africa (Hong et al. 2014). One other attractant analog of TML is the Ceralure found to be slightly more potent and persistent than TML. One of the problems preventing the adoption of Ceralure has been the development of a commercial cost-effective synthesis of the molecule (Hong et al. 2014). The parapheromone methyl eugenol (ME) captures a large number of species of the genus *Bactrocera* (including *B. dorsalis, B. zonata*, *B. carambolae*, *B. correcta* and *B. musae)*. The pheromone spiroketal captures *B. oleae*. The parapheromone cuelure (CUE) captures a large number of other *Bactrocera* species, including *B. tryoni* as well as *Zeugodacus cucurbitae*. Parapheromones are generally highly volatile, and can be used with a variety of traps. Examples are listed in **Table 3a**. Controlled-release formulations exist for TML, CUE and ME, providing longer-lasting attractants for field use. It is important to be aware that some inherent environmental conditions may affect the longevity of pheromone and parapheromone attractants.

4.1.2. Female-biased

Female-biased attractants (natural, synthetic, liquid or dry) that are commonly used are based on food or host odours (**Table 3b**). Historically, liquid protein attractants have been used to capture a wide range of different fruit fly species. Liquid protein attractants capture both females and males. These liquid attractants are generally less sensitive than the parapheromones. In addition, the use of liquid attractants captures a high number of non-target insects.

Several food-based synthetic attractants have been developed using ammonia and its derivatives. This may reduce the number of non-target insects captured. For example, for capturing *C. capitata* a synthetic food attractant consisting of three components (ammonium acetate, putrescine and trimethylamine) is used. For capture of *Anastrepha* species the trimethylamine component may be removed. A synthetic attractant will last approximately 4–10 weeks depending on climatic conditions, captures few non-target insects and captures significantly fewer male than female fruit flies, making such attractants suited for use in sterile fruit fly release programmes. New synthetic food attractant technologies are available for use, including the long-lasting three-component and two-component mixtures contained in the same patch, as well as the three components incorporated in a single cone-shaped plug (**Tables 2 and 4**).

Table 2. A number of fruit fly species of economic importance and commonly used attractants

Scientific name	Attractant
Anastrepha fraterculus (Wiedemann)[4]	Protein attractant (PA)
Anastrepha grandis (Macquart)	PA
Anastrepha ludens (Loew)	PA, 2C-1[1]
Anastrepha obliqua (Macquart)	PA, 2C-1[1]
Anastrepha serpentina (Wiedemann)	PA
Anastrepha striata (Schiner)	PA
Anastrepha suspensa (Loew)	PA, 2C-1[1]
Bactrocera carambolae (Drew & Hancock)	Methyl eugenol (ME)
Bactrocera caryeae (Kapoor)	ME
Bactrocera correcta (Bezzi)	ME
Bactrocera dorsalis (Hendel)	ME
Bactrocera kandiensis (Drew & Hancock)	ME
Bactrocera musae (Tryon)	ME
Bactrocera occipitalis (Bezzi)	ME
Bactrocera umbrosa (Fabricius)	ME
Bactrocera zonata (Saunders)	ME, 3C[2], ammonium acetate (AA)
Bactrocera neohumeralis (Hardy)	CUE
Bactrocera tau (Walker)	CUE
Bactrocera tryoni (Froggatt)	CUE
Bactrocera minax (Enderlein)	PA
Bactrocera cucumis (French)	PA
Bactrocera jarvisi (Tryon)	PA
Bactrocera latifrons (Hendel)	PA
Bactrocera oleae (Gmelin)	PA, ammonium bicarbonate (AC), spiroketal (SK)
Bactrocera tsuneonis (Miyake)	PA
Ceratitis capitata (Wiedemann)	Trimedlure (TML), Capilure (CPL), PA, 3C[2], 2C-2[3]
Ceratitis cosyra (Walker)	PA, 3C[2], 2C-2[3]
Ceratitis rosa (Karsch)	TML, PA, 3C[2], 2C-2[3]
Dacus ciliatus (Loew)	PA, 3C[2], AA
Myiopardalis pardalina (Bigot)	PA
Rhagoletis cerasi (Linnaeus)	Ammonium salts (AS), AA, AC
Rhagoletis cingulata (Loew)	AS, AA, AC
Rhagoletis indifferens (Curran)	AA, AC
Rhagoletis pomonella (Walsh)	butyl hexanoate (BuH), AS
*Toxotrypana curvicauda (Gerstaecker**p***	2-methyl-vinylpyrazine (MVP)
Zeugodacus cucurbitae (Coquillett)	Cuelure (CUE), 3C[2], AA

[1] Two-component (2C-1) synthetic food attractant of ammonium acetate and putrescine, mainly for female captures.
[2] Three-component (3C) synthetic food attractant, mainly for female captures (ammonium acetate, putrescine, trimethylamine).
[3] Two-component (2C-2) synthetic food attractant of ammonium acetate and trimethylamine, mainly for female captures.
[4] *Anastrepha fraterculus* consists of a complex of a number of different species.

Table 3a. Attractants and traps for male fruit fly surveys

Fruit fly species	Attractant and trap (see below for abbreviations)																									
	TML/CPL											ME								CUE							
	CC	CH	ET	JT	LT	MM	ST	SE	TP	YP	VARs+	CH	ET	JT	LT	MM	ST	TP	YP	CH	ET	JT	LT	MM	ST	TP	YP
Anastrepha fraterculus																											
Anastrepha ludens																											
Anastrepha obliqua																											
Anastrepha striata																											
Anastrepha suspensa																											
Bactrocera carambolae												X	X	X	X	X	X	X	X								
Bactrocera caryeae												X	X	X	X	X	X	X	X								
Bactrocera citri (B. minax)																											
Bactrocera correcta												X	X	X	X	X	X	X	X								
Bactrocera cucumis																											
Bactrocera dorsalis												X	X	X	X	X	X	X	X								
Bactrocera kandiensis												X	X	X	X	X	X	X	X								
Bactrocera latifrons																											
Bactrocera occipitalis												X	X	X	X	X	X	X	X								
Bactrocera oleae																											
Bactrocera tau																				X	X	X	X	X	X	X	X
Bactrocera tryoni																				X	X	X	X	X	X	X	X
Bactrocera tsuneonis																											

Table 3a. Attractants and traps for male fruit fly surveys (cont.)

Fruit fly species	Attractant and trap (see below for abbreviations)																									
	TML/CPL											ME								CUE							
	CC	CH	ET	JT	LT	MM	ST	SE	TP	YP	VARs+	CH	ET	JT	LT	MM	ST	TP	YP	CH	ET	JT	LT	MM	ST	TP	YP
Bactrocera umbrosa												X	X	X	X	X	X	X	X								
Bactrocera zonata												X	X	X	X	X	X	X	X								
Ceratitis capitata		X	X	X	X	X	X	X	X	X	X																
Ceratitis cosyra																											
Ceratitis rosa		X	X	X	X	X	X	X	X	X	X																
Dacus ciliatus																											
Myiopardalis pardalina																											
Rhagoletis cerasi																											
Rhagoletis cingulata																											
Rhagoletis indifferens																											
Rhagoletis pomonella																											
Toxotrypana curvicauda Zeugodacus cucurbitae																				X	X	X	X	X	X	X	X

Attractant abbreviations

TML	Trimedlure
CPL	Capilure
ME	Methyl eugenol
CUE	Cuelure

Trap abbreviations

CC	Cook and Cunningham (C&C) trap
CH	ChamP trap
ET	Easy trap
JT	Jackson trap
LT	Lynfield
MM	Maghreb-Med or Morocco trap
ST	Steiner trap
SE	Sensus trap
TP	Tephri trap
VARs+	Modified funnel trap
YP	Yellow panel trap

Table 3b. Attractants and traps for female-biased fruit fly surveys

Fruit fly species	Attractant and trap (see below for abbreviations)																									
	3C							2C-2					2C-1	PA			SK+AC		AS (AA,AC)				BuH			MVP
	ET	SE	MLT	OBDT	LT	MM	TP	ET	MLT	LT	MM	TP	MLT	ET	McP	MLT	CH	YP	RB	RS	YP	PALz	RS	YP	PALz	GS
Anastrepha fraterculus															X	X										
Anastrepha grandis															X	X										
Anastrepha ludens													X		X	X										
Anastrepha obliqua													X		X	X										
Anastrepha striata															X	X										
Anastrepha suspensa													X		X	X										
Bactrocera carambolae															X	X										
Bactrocera caryeae															X	X										
Bactrocera citri (B. minax)															X	X										
Bactrocera correcta															X	X										
Bactrocera cucumis																										
Bactrocera dorsalis															X	X										
Bactrocera kandiensis															X	X										
Bactrocera latifrons															X	X										
Bactrocera occipitalis															X	X										
Bactrocera oleae														X	X	X	X	X			X	X				
Bactrocera tau															X	X										
Bactrocera tryoni															X	X										

Table 3b. Attractants and traps for female-biased fruit fly surveys (cont.)

Fruit fly species	Attractant and trap (see below for abbreviations)																									
	3C							2C-2					2C-1	PA			SK+AC		AS (AA,AC)				BuH			MVP
	ET	SE	MLT	OBDT	LT	MM	TP	ET	MLT	LT	MM	TP	MLT	ET	McP	MLT	CH	YP	RB	RS	YP	PALz	RS	YP	PALz	GS
Bactrocera tsuneonis															X	X										
Bactrocera umbrosa															X	X										
Bactrocera zonata			X												X	X										
Ceratitis capitata	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X										
Ceratitis cosyra			X						X						X	X										
Ceratitis rosa		X	X						X						X	X										
Dacus ciliatus			X												X	X										
Myiopardalis pardalina															X	X										
Rhagoletis cerasi																			X	X	X	X	X	X	X	
Rhagoletis cingulata																					X	X		X	X	
Rhagoletis indifferens																				X	X					
Rhagoletis pomonella																			X		X	X	X			
Toxotrypana curvicauda																										X
Zeugodacus cucurbitae			X												X	X										

Attractans abbrevitations

3C	(AA+Pt+TMA)
2C-2	(AA+TMA)
2C-1	(AA+Pt)
PA	protein attractant
SK	spiroketal
AC	ammonium (bi)carbonate

Trap abbreviations

AS	ammonium salts
BuH	butyl hexanoate
MVP	papaya fruit fly pheromone (2-methyl-vinilpyrazine)
Pt	putrescine
TMA	trimethylamine
CH	ChamP trap
ET	Easy trap
GS	Green Sphere
LT	Lynfield trap
MM	Maghreb-Med or Morocco trap
McP	McPhail trap
MLT	Multilure trap
OBDT	Open bottom dry trap
PALz	Fluorescent yellow sticky ‘cloak’ trap
RB	Rebell trap
RS	Red sphere trap
SE	Sensus trap
TP	Tephri trap
YP	Yellow pane

Table 4. List of attractants, field longevity and service intervals in relation to survey type

Common name	Acronym	Formulation	Field longevity[1] (weeks)	Survey programme			
				Monitoring/Detection		Delimiting/Verification	
				Inspection[2] (days)	Service[3] (rebait) (weeks)	Inspection[2] (days)	Service[3] (rebait) (weeks)
Para-pheromones							
Trimedlure	TML	Polymeric plug (2 & 3 grs)	6–8	7–14	6–10	3–7	6
		Laminate (3 & 10 gr)	8–12	7–14	4–6	3–7	8
		Liquid	1–4	7–14	2–4	3–7	1
		PE bag	4–5	7–10	4–5	3–7	4
Methyl eugenol	ME	Polymeric plug	4–10	7–14	8–10	3–7	4
		Liquid	4–8	7–14	6–8	3–7	4
Cuelure	CUE	Polymeric plug	4–10	7–14	8–10	3–7	4
		Liquid	4–8	7–14	6–8	3–7	4
Capilure (TML plus extenders)	CPL	Liquid	12–36	7–14	12–26	3–7	12
Pheromones							
Papaya fruit fly (T. curvicauda) (2-methyl-6-vinylpyrazine)	MVP	Patches	4–6	7–14	5–6	2–3	4
Olive Fly (spiroketal)	SK	Polymer	4–6	7–14	5–6	2–3	4
Food-based attractants							
Torula yeast/borax	PA	Pellet	1–2	7–14	2	2–3	1
Protein derivatives	PA	Liquid	1–2	7–14	2	2–3	1
Ammonium acetate	AA	Patches	4–6	7–14	5–6	2–3	4
		Liquid	1	7–14	1	2–3	1
		Polymer	2–4	7–14	3–4	2–3	2
Ammonium (bi)carbonate	AC	Patches	4–6	7–14	5–6	2–3	4
		Liquid	1	7–14	1	2–3	1
		Polymer	1–4	7–14	3–4	2–3	1
Ammonium salts	AS	Salt	1	7–14	1	2–3	1
Putrescine	Pt	Patches	6–10	7–14	8–10	2–3	6
Trimethylamine	TMA	Patches	6–10	7–14	8–10	2–3	6
Butyl hexanoate	BuH	Vial	2	7–14	2	2–3	1
Ammonium acetate Putrescine Trimethylamine	3C	Cone/patches	6–10	7–14	8–10	2–3	6
Ammonium acetate Putrescine Trimethylamine	3C	Long-lasting patches	18–26	7–14	24–26	2–3	18
Ammonium acetate Trimethylamine	2C	Patches	6–10	7–14	8–10	2–3	6
Ammonium acetate Putrescine	2C	Patches	6–10	7–14	8–10	2–3	6
Ammonium acetate Ammonium carbonate	AA/AC	PE bag with alufoil cover	3–4	–10	4	2–3	4

[1] Based on half-life; attractant longevity is indicative only; actual timing should be supported by field testing and validation

[2] Inspection refers to interval between checking traps for target fruit fly captures

[3] Service refers to rebaiting period of the trap based on half-life of the attractant. Other factors such as weathering of traps, density of flies trapped and longevity of killing agents are not considered.

In addition, because food-foraging female and male fruit flies respond to synthetic food attractants at the sexually immature adult stage, these attractant types are capable of detecting female fruit flies earlier and at lower population levels than parapheromone-based attractants.

4.2. Killing and preserving agents

The attracted fruit flies are retained in a variety of traps. In some dry traps, killing agents are a sticky material or a toxicant such as dichlorvos, malathion, fipronil and pyrethroids (such as deltamethrin). However, some organophosphates may act as a repellent at higher doses. In some cases spinosad can be used in dry traps for *Bactrocera dorsalis* and *Zeugodacus cucurbitae*, as an environmentally-friendly substitute of other insecticides. The use of insecticides in traps will be subjected to the products being registered and approved for use in the respective national plant protection legislation.

In other traps, liquid is the killing agent. When liquid protein attractants are used, borax 3% concentration is incorporated into the liquid solution to preserve the captured fruit flies. There are protein attractants that are formulated with borax, and thus no additional borax is required. When water is used in hot climates, 10% propylene glycol is added to prevent evaporation of the attractant and to preserve captured flies.

4.3. Trapping devices

Based on the killing agent, there are three types of traps commonly used:

- **Dry traps**. The fly is caught on a sticky material board or killed by a chemical agent. Some of the most widely used dry traps are Cook and Cunningham (C & C), ChamP, Jackson/Delta, Lynfield, Open bottom dry trap (OBDT) or Phase IV, Red sphere, Steiner and Yellow panel/Rebell;
- **Wet traps**. The fly is captured and drowns in the attractant solution or in water with surfactant. One of the most widely used wet traps is the McPhail trap. The Harris trap is also a wet trap with a more limited use;
- **Dry or wet traps**. These traps can be used either dry or wet. Some of the most widely used are Easy trap, Multilure trap and Tephri trap.

Commonly used traps are described in **Annex 1**.

5. Trapping procedures

5.1. Establishing trapping networks based on pest risk

Area-wide fruit fly programmes often operate thousands of traps in order to cover extensive areas to determine the presence or absence of pests (Lance and Gates 1994). Large numbers of traps are common in high risk pest free areas. They often result, not from a response to a pest situation, but from programme management reacting to the low efficiency of most fruit fly traps (i.e. the perception that more traps represent a higher likelihood of detection), as well as from the lack of clear guidance or misinterpretation of trapping protocols, which provide general recommendations on using a certain trap layout and trap density per unit surface.

Trap layout (spatial distribution of traps) and trap density are influenced by various factors, including type of survey (monitoring, detection, delimiting, verification), trap efficiency and assessed pest risk. The type of survey will determine the required level of sensitivity of the trapping network, with the lowest sensitivity required for monitoring and the highest for delimiting surveys (see Trapping Survey **Section 2** and **Tables 6a–f**). Information on trap efficiency (in terms of probability of capture) is essential for determination of trap densities with the least efficient traps requiring the highest trap densities and the most efficient ones requiring the lowest densities (for trap efficiency see **Annex 2**). Pest risk assessment will identify the risk areas, with the lowest risk areas requiring no traps, or the lowest trap densities, and the highest risk areas requiring the highest trap densities, given the type of survey and the trap efficiency.

An essential factor for cost-effective management of trapping networks is the 'Risk Factor'. Assessment of the risk of pest incursion, introduction (establishment) and spread is fundamental for decision-making on trap deployment (spatial distribution) and required trap density, since fruit fly population density is structured over large areas and changes over time (Castrignano et al. 2012). The first step in risk assessment is to identify and characterize the risk factors. The second step is to assess the risk posed by each factor and the sum of the total risk factors present in the target area (ISPM No. 11, FAO 2011). With this information, the assessed risk in terms of quarantine pests can be plotted in maps to create a thematic map with a mosaic of risk areas that are used as the basis for trap deployment in the field.

Risk factors can vary according to the specific conditions of each area. Risk factors that are commonly identified and characterized in fruit fly intervention programmes are:

- Host availability (number of species present, abundance and distribution over space and time)
- Host preference (primary and secondary hosts)
- Climatic factors (temperature, rain, relative humidity, winds)
- Commercial and non-commercial movement of fruit hosts
- Human settlements (urban, sub urban, rural)
- Distance to infested areas
- Historical profile of pest occurrence and recurrence

Assessing the individual and added effect of these factors on the likelihood (i.e. risk) of fruit fly pest incursions, establishment and spread is essential in optimization of fruit fly trapping.

5.2. Pest risk assessment for trap layout and density

As a general guideline for trap layout, in areas where continuous compact blocks of commercial orchards are present and in urban and suburban areas where hosts exist, traps are usually deployed in a grid system which may have a uniform distribution. In areas with scattered commercial orchards, rural areas with hosts and in marginal areas where hosts exist, trap network arrays are irregular, normally distributed along roads that provide access to host material. In area-wide exclusion, suppression and eradication programmes, an extensive trapping network should be deployed over the entire area that is subject to surveillance and control actions, based on the assessed risk.

In terms of trap density, and as a general guideline, densities increase as a gradient from production areas to marginal areas, urban areas and points of entry. Therefore, in a pest free area, a higher density of traps is required at high risk points of entry and a lower density in commercial orchards. Or, in an area where suppression is applied, such as in an area of low pest prevalence or an area under a systems approach where the target species is present, the reverse occurs, and trapping densities for that pest should be higher in the production field and decrease toward points of entry. Other situations such as high risk urban areas should be taken into consideration when assessing trapping densities. However, the establishment of a trap layout and densities should be guided by a more science-based approach that is grounded on a pest risk assessment of the various risk factors identified, as follows:

A qualitative value (i.e. in terms of likelihood of the event occurring) needs to be given to each risk factor. The sum of total values for all risk factors should add up to 100 points. The highest value for each risk factor should be assigned to the condition which best fits the requirements for pest establishment of the fruit fly species in question. Some risk factors may be of greater importance than others, thus, the values need to be weighed against each other in order to reflect their relative importance. Areas with a low assessed pest risk should not be considered for trap deployment, whereas, medium to high pest risk areas should be trapped and trap density adjusted to the level of risk, so that higher trap densities are used for higher risk areas; an example is presented in **Table 5**.

The risk values for each risk factor are added and the total value compared against the set values for high, medium and low risk. In the example, area II resulted in a high risk value whereas area I in a low risk value. In this case, the highest trap density would be used in area II (2 traps/km^2) for early

Table 5. Risk assessment as a decision-making tool for trap placement and densities

Risk factor	Risk value	Assessed risk		
1. Distance to infested areas	12.0	Area I	Area II	Area III
0–50 Km	7 to 12		12	
51–100 km	4 to 6			
101–150 km	0 to 3	3		3
2. Host availability	20.0			
High	11 to 20		11	
Medium	6 to 10	6		8
Low	0 to 5			
3. Climatic factors (temp., rain, winds)	15.0			
Highly suitable	7.6 to 15			9
Suitable	3.9 to 7.5	5	6	
Unsuitable	0 to 3.8			
4. Host movement	23.0			
Frequent	11.6 to 23		23	
Sporadic	5.9 to 11.5			11
Rear	0 to 5.8	3		
5. Pest historical profile	30.0			
2009–2010	16 to 30		30	
2008–2007	7.6 to 15			10
2006–2004	0 to 7.5	0		
Total	100.0			
High risk: 51–100; medium risk: 26–50; low risk: 0–25		**17**	**82**	**31**
Traps/square kilometer (0 to 2 traps/km^2)		**0.5**	**2**	**1**

detection, whereas, in area I trapping would be done using the lowest trap density (0.5 traps/km^2 or 1 trap every 2 km^2, and trap inspection reduced to only once every two weeks).

This procedure has been applied in large-scale fruit fly control programmes to restructure and optimize the trapping network (Moscamed 2011). As a result, trap numbers have been reduced or eliminated from low risk areas and traps have been added, where required, in medium to high risk areas resulting in a more efficient trapping network with significantly less number of traps. **Figure 1** shows a thematic map with the assessed risk areas forming a mosaic of pest risks areas. The maps are used as the basis for deployment of trapping routes that together will constitute a trapping network. **Figure 2** shows the number and spatial distribution of traps prior and after the application of the risk factor concept.

5.3. Balancing the assessed risk

For final determination of the most appropriate layout of the trapping network and trap density in a given area, an additional element has to be considered. This is balancing the assessed pest risk and the consequences of pest establishment (cost of control actions and cost due to yield loss and market restrictions) against the cost of operating a trapping network (Enkerlin et al. 1997). Therefore, the risk of the event happening is determined by the product of multiplying the probability of the event occurring by the value of the potential loss in the event of pest introduction (Risk = Probability × Loss) (USDA 1992). A situation where the probability of the event occurring is high and the value of

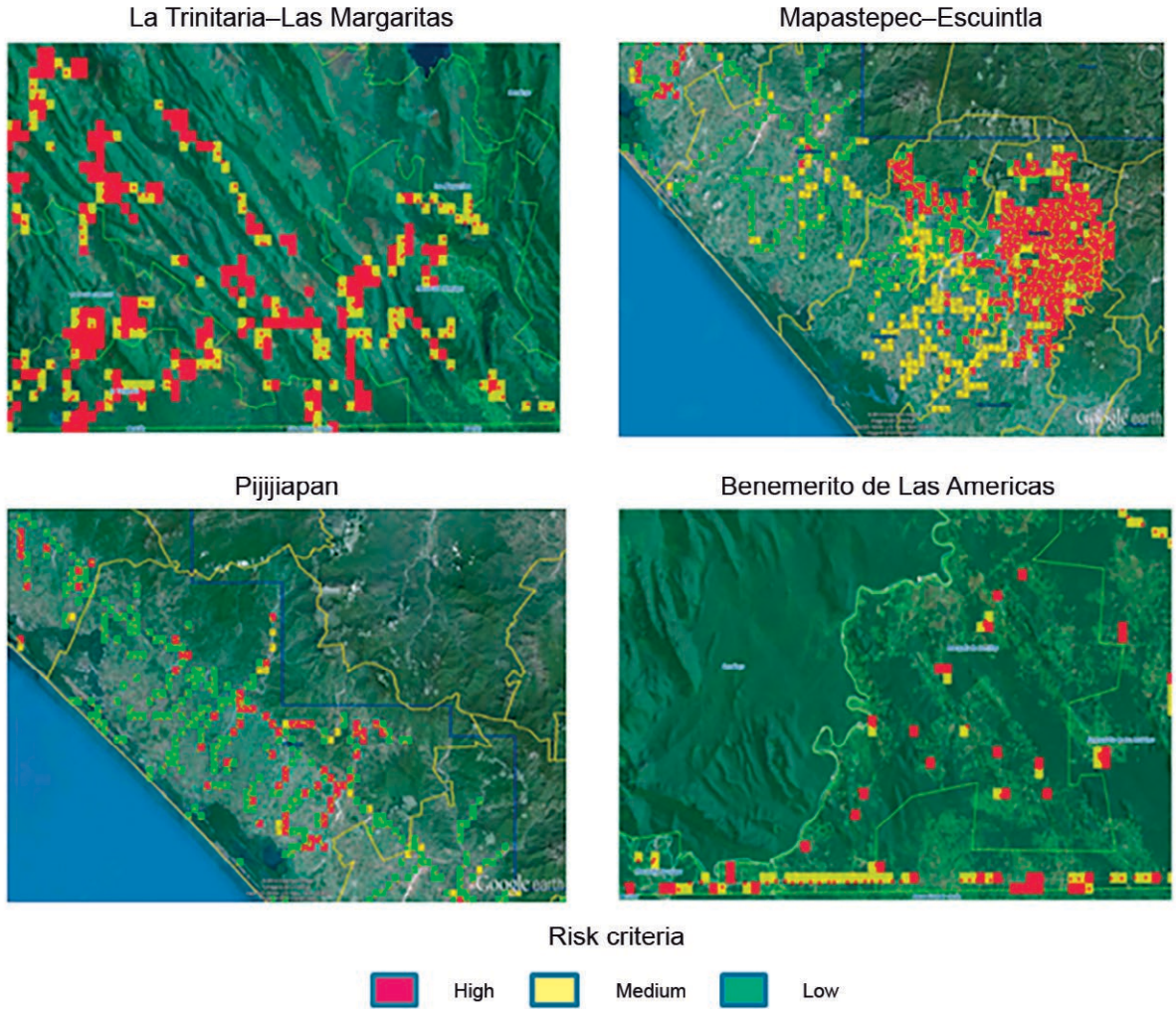


Figure 1. Mediterranean fruit fly high, medium and low risk areas in four different regions of the state of Chiapas, Mexico, where the Moscamed Regional Programme operates.

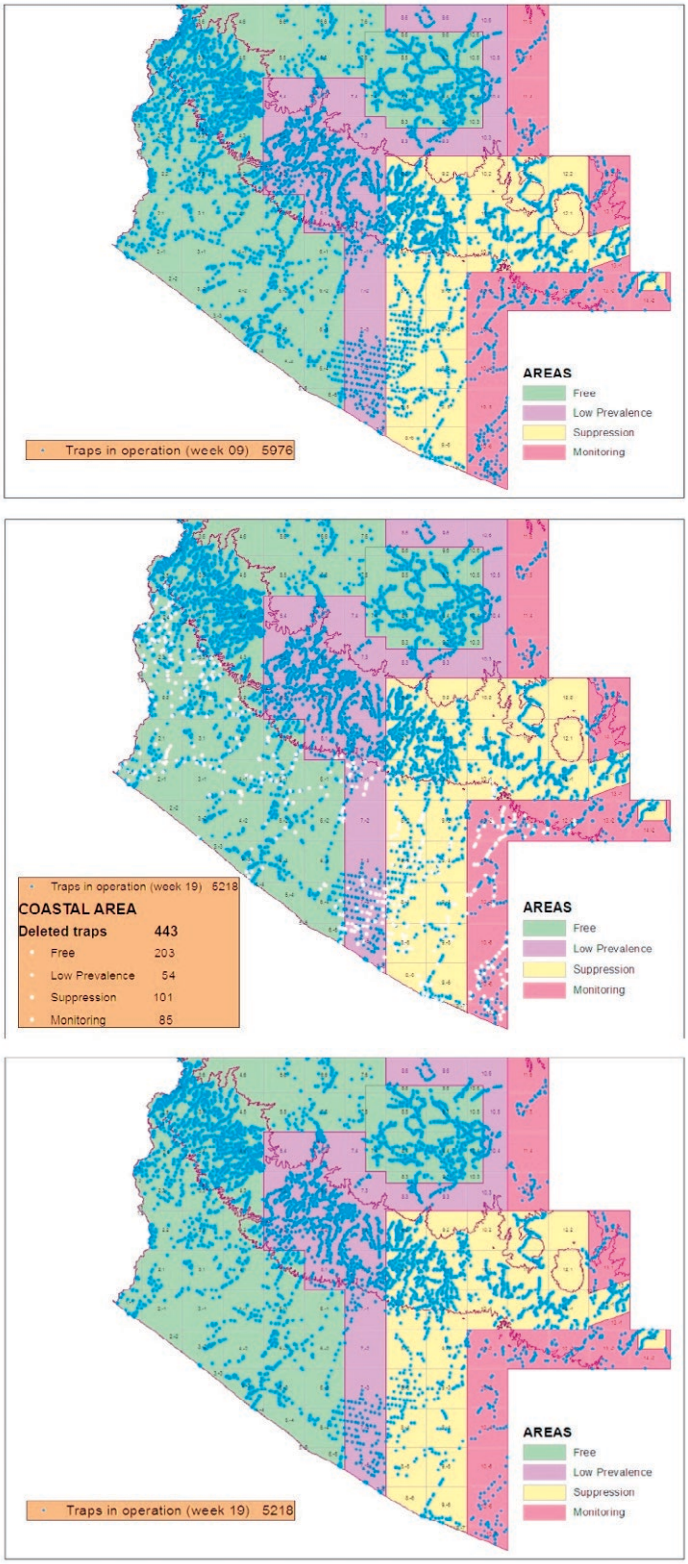


Figure 2. Trapping network in Western Guatemala before and after the application of the risk factor concept for traps located along the Pacific Coast only.

Table 6a. Trap densities for *Anastrepha* spp.

Scenario	Trap type[1]	Attractant	Trap density[2] / square km			
			Production area	Marginal	Urban	Points of entry[3]
A. Monitoring surveys, no control	MLT/McP	2C/PA	0.25–1	0.25–0.5	0.25–0.5	0.25–0.5
B. Monitoring surveys for suppression	MLT/McP	2C/PA	2–4	1–2	0.25–0.5	0.25–0.5
C. Monitoring surveys for eradication	MLT/McP	2C/PA	3–5	3–5	3–5	3–5
D. Detection surveys for exclusion (includes intensive trapping)	MLT/McP	2C/PA	1–2	2–3	3–5	5–12
E. Delimitation surveys after incursion in addition to detection survey[4]	MLT/McP	2C/PA	2–32	2–32	2–32	2–32
F. Verification surveys after eradication of pest outbreak[5]	MLT/McP	2C/PA	10–15	10–15	10–15	10–15

1 Different traps can be combined to reach the total number.
2 Refers to the total number of traps.
3 Including other high-risk sites.
4 This range includes high-density trapping in the immediate area of the detection (core area) and decreasing towards the surrounding trapping zones (**Section 6, Figure 3**).
5 Applies only to core area and first surrounding zone (**Figure 3**)

Trap type		Attractant	
McP	McPhail trap	2C	(AA+Pt)
MLT	Multilure trap	PA	protein attractant

Table 6b. Trap densities for *Bactrocera* spp. responding to methyl eugenol (ME), cuelure (CUE) and food attractants[1] (PA — protein attractants)

Scenario	Trap type[2]	Attractant	Trap density[2] / square km			
			Production area	Marginal	Urban	Points of entry[4]
A. Monitoring surveys, no control	JT/ST/TP/LT/MLT/McP/TP	ME/CUE/PA	0.5–1.0	0.2–0.5	0.2–0.5	0.2–0.5
B. Monitoring surveys for suppression	JT/ST/TP/LT/MLT/McP/TP	ME/CUE/PA	2–4	1–2	0.25–0.5	0.25–0.5
C. Monitoring surveys for eradication	JT/ST/TP/MLT/LT/McP/TP	ME/CUE/PA	3–5	3–5	3–5	3–5
D. Detection surveys for exclusion exclusion (includes intensive trapping)	CH/ST/LT/MLT/McP/TP/ YP	ME/CUE/PA	1	1	1–5	3–12
E. Delimitation surveys after incursion in addition to detection survey[5]	JT/ST/TP/MLT/LT/McP/YP	ME/CUE/PA	2–20	2–20	2–20	2–20
F. Verification surveys after eradication of pest outbreak[6]	JT/ST/TP/MLT/LT/McP/YP	ME/CUE/PA	5–10	5–10	5–10	5–10

where is 3?

1 *Bactrocera zonata*, *Z. cucurbitae* (3- and 2-component attractants and other ammonium-based synthetic food attractants).
2 Different traps can be combined to reach the total number.
3 Refers to the total number of traps.
4 Including other high-risk sites.
5 This range includes high-density trapping in the immediate area of the detection (core area) and decreasing towards the surrounding trapping zones (**Section 6, Figure 3**).
6 Applies only to core area and first surrounding zone (**Figure 3**).

Trap type			
CH	ChamP trap	MLT	Multilure trap
JT	Jackson trap	ST	Steiner trap
LT	Lynfield trap	TP	Tephri trap
McP	McPhail trap	YP	Yellow panel trap

Table 6c. Trap densities for *Bactrocera oleae*

Scenario	Trap type[1]	Attractant	Trap density[2] / square km			
			Production area	Marginal	Urban	Points of entry[3]
A. Monitoring surveys, no control	MLT/CH/YP	AC+SK/PA	0.5–1.0	0.25–0.5	0.25–0.5	0.25–0.5
B. Monitoring surveys for suppression	MLT/CH/YP	AC+SK/PA	2–4	1–2	0.25–0.5	0.25–0.5
C. Monitoring surveys for eradication	MLT/CH/YP	AC+SK/PA	3–5	3–5	3–5	3–5
D. Detection surveys for exclusion exclusion (includes intensive trapping)	MLT/CH/YP	AC+SK/PA	1	2	2–5	3–12
E. Delimitation surveys after incursion in addition to detection survey	MLT/CH/YP	AC+SK/PA	2–30[4]	2–30	2–30	2–30
F. Verification surveys after eradication of pest outbreak5	MLT/CH/YP	AC+SK/PA	10–15	10–15	10–15	10–15

[1] Different traps can be combined to reach the total number.
[2] Refers to the total number of traps.
[3] Including other high-risk sites.
[4] This range includes high-density trapping in the immediate area of the detection (core area) and decreasing towards the surrounding trapping zones (**Section 6, Figure 3**).
[5] Applies only to core area and first surrounding zone (**Figure 3**).

Trap type		Attractant	
CH	ChamP trap	AC	ammonium bicarbonate
MLT	Multilure trap	PA	protein attractants
YP	Yellow panel trap	SK	spiroketal

the potential loss is also high, will result in a high risk situation thus requiring the use of high trap densities to allow for early detection and prevention of major loss. In this situation the cost of operating an extensive high density trapping network will be outweighed by preventing loss. However, other scenarios may include a high risk of the event occurring with a low value of the potential loss. In this case, running a high density trapping network might be too expensive compared against the value of the loss, thus, low to medium trap densities might be more appropriate (for more detailed information see **Annex 2**).

Example: California operates a trapping programme of 94 000 traps using trap densities that range from 1.6 to 8 traps per km^2, according to an assessed risk of fruit fly introduction. This trap density allows for early detection of fruit fly introductions and timely implementation of a contingency plan to eradicate any incipient population (USDA/APHIS/PPQ 2006).

In 2005, California spent US $20 million per year in the trapping programme to protect fruits and vegetables susceptible to Medfly infestation, which were valued at US $5.2 billion per year in 2002 (USDA/APHIS/PPQ 2006). Early detection of fruit fly incursions the using a sensitive trapping network that uses relatively high trap densities can save millions of dollars in suppression and eradication measures and enforcement of quarantines that restricts exports. Thus, for high value assets with a high risk of fruit fly incursions and outbreaks, a highly sensitive trapping network is economically justifiable. Less sensitive trapping networks that use lower trap densities would be more appropriate in cases of lower risk of outbreaks and/or lower value of the assets being protected.

Tables 6a–6f show recommended trap densities for various fruit fly species. Trap densities are also dependent on associated survey activities, such as the type and intensity of fruit sampling to detect immature stages of fruit flies. In those cases where trapping survey programmes are complemented with equivalent fruit sampling activities, trap densities can be lower than the recommended densities shown in **Tables 6a–f**.

The density recommendations presented in **Tables 6a–f** have been made taking into account:

- various survey types and pest situations (**Table 1**),
- target fruit fly species (**Table 2**),
- relative trap efficiency,
- pest risk associated with the different working areas (production and other areas).

Within a delimited area, established after an incursion, the suggested trap density should be applied in areas with a significant likelihood of capturing fruit flies such as areas with primary hosts and possible pathways (e.g. production areas and entry points), and other prevailing risk factors in the target area and associated pest risk.

Table 6d. Trap densities for *Ceratitis* spp.

Scenario	Trap type[1]	Attractant	Trap density[2] / square km			
			Production area	Marginal	Urban	Points of entry[3]
A. Monitoring surveys, no control[4]	JT/MLT/McP/OBDT/ST/SE/ET/LT/TP/VARs+	TML/CPL/3C/2C/PA	0.5–1.0	0.25–0.5	0.25–0.5	0.25–0.5
B. Monitoring surveys for suppression[4]	JT/MLT/McP/OBDT/ST/SE/ET/LT/TP/VARs+	TML/CPL/3C/2C/PA	2–4	1–2	0.25–0.5	0.25–0.5
C. Monitoring surveys for eradication[5]	JT/MLT/McP/OBDT/ST/ET/LT/TP/VARs+	TML/CPL/3C/2C/PA	3–5	3–5	3–5	3–5
D. Detection surveys for exclusion5 exclusion (includes intensive trapping)	JT/MLT/McP ST/ET/LT/CC/VARs+	TML/CPL/3C/PA	1	1–2	1–5	3–12
E. Delimitation surveys after incursion in addition to detection survey[6]	JT/YP/MLT/McP/OBDT/ST/ET/LT/TP/VARs+	TML/CPL/3C/PA	4–50	4–50	4–50	4–50
F. Verification surveys after eradication of pest outbreak7	JT/YP/MLT/McP/OBDT/ST/ET/LT/TP/VARs+	TML/CPL/3C/PA	10–15	10–15	10–15	10–15

[1] Different traps can be combined to reach the total number.
[2] Refers to the total number of traps.
[3] Including other high-risk sites.
[4] 1:1 ratio (1 female trap per male trap).
[5] 3:1 ratio (3 female traps per male trap).
[6] This range includes high-density trapping in the immediate area of the detection (core area) and decreasing towards the surrounding trapping zones (ratio 5:1, 5 female traps per male trap) (**Section 6, Figure 3**).
[7] Applies only to core area and first surrounding zone (**Figure 3**).

Trap type

CC	Cook and Cunningham (C&C) Trap (with TML for male capture)
ET	Easy trap (with 2C and 3C attractants for female-biased captures)
LT	Lynfield trap (with TML for male capture)
JT	Jackson trap (with TML for male capture)
MLT	Multilure trap (with 2C and 3C attractants for female-biased captures)
McP	McPhail trap
OBDT	Open Bottom Dry Trap (with 2C and 3C attractants for female-biased captures)
ST	Steiner trap (with TML for male capture)
SE	Sensus trap (with CE for male captures and with 3C for female-biased captures)
TP	Tephri trap (with 2C and 3C attractants for female-biased captures)
VARs+	Modified funnel trap
YP	Yellow panel trap

Attractant

2C	(AA+TMA)
3C	(AA+Pt+TMA)
AA	Ammonium acetate
CPL	Capilure
PA	Protein attractant
PA	Protein attractant
Pt	Putrescine
TMA	Trimethylamine
TML	Trimedlure

Table 6e. Trap densities for *Rhagoletis* spp.

Scenario	Trap type[1]	Attractant	Trap density[2] / square km			
			Production area	Marginal	Urban	Points of entry[3]
A. Monitoring surveys, no control	RB/RS/PALz/YP/McP	BuH/AS	0.5–1.0	0.25–0.5	0.25–0.5	0.25–0.5
B. Monitoring surveys for suppression	RB/RS/PALz/YP/McP	BuH/AS	2–4	1–2	0.25–0.5	0.25–0.5
C. Monitoring surveys for eradication	RB/RS/PALz/YP/McP	BuH/AS	3–5	3–5	3–5	3–5
D. Detection surveys for exclusion exclusion (includes intensive trapping)	RB/RS/PALz/YP/McP	BuH/AS	1	0.4–3	3–5	4–12
E. Delimitation surveys after incursion in addition to detection survey[4]	RB/RS/PALz/YP/McP	BuH/AS	2–32	2–32	2–32	2–32
F. Verification surveys after eradication of pest outbreak[5]	RB/RS/PALz/YP/McP	BuH/AS	10–15	10–15	10–15	10–15

1 Different traps can be combined to reach the total number.
2 Refers to the total number of traps.
3 Including other high-risk sites.
4 This range includes high-density trapping in the immediate area of the detection (core area) and decreasing towards the surrounding trapping zones (**Section 6, Figure 3**).
5 Applies only to core area and first surrounding zone (**Figure 3**).

Trap type		Attractant	
McP	McPhail trap	AS	Ammonium salt
RB	Rebell trap	BuH	Butyl hexanoate
RS	Red sphere trap	PALz	Fluorescent yellow sticky trap

Table 6f. Trap densities for *Toxotrypana curvicauda*

Scenario	Trap type[1]	Attractant	Trap density[2] / square km			
			Production area	Marginal	Urban	Points of entry[3]
A. Monitoring surveys, no control	GS	MVP	0.25–0.5	0.25–0.5	0.25–0.5	0.25–0.5
B. Monitoring surveys for suppression	GS	MVP	2–4	1	0.25–0.5	0.25–0.5
C. Monitoring surveys for eradication	GS	MVP	3–5	3–5	3–5	3–5
D. Detection surveys for exclusion exclusion (includes intensive trapping)	GS	MVP	2	2–3	3–6	5–12
E. Delimitation surveys after incursion in addition to detection survey[4]	GS	MVP	2–32	2–32	2–32	2–32
F. Verification surveys after eradication of pest outbreak[5]	GS	MVP	10–15	10–15	10–15	10–15

1 Different traps can be combined to reach the total number.
2 Refers to the total number of traps.
3 Including other high-risk sites.
4 This range includes high-density trapping in the immediate area of the detection (core area) and decreasing towards the surrounding trapping zones (**Section 6, Figure 3**).
5 Applies only to core area and first surrounding zone (**Figure 3**).

Trap type		Attractant	
GS	Green sphere	MVP	Papaya fruit fly pheromone (2-methyl-vinyl-pyrazine)

5.4. Trap deployment (placement)

Trap deployment involves the actual placement of the traps in the field. One of the most important factors of trap deployment is selecting an appropriate trap site. It is important to have a list of the primary, secondary and occasional fruit fly hosts, their phenology, distribution and abundance. With this basic

information, it is possible to properly place and distribute the traps in the field, and it also allows for effective planning of a programme of trap relocation.

A systematic rotation of traps would be necessary for best results. Traps should be relocated following the fruiting and maturation phenology of the fruit hosts present in the area and accordance with the biology of the fruit fly target species. By relocating the traps, it is possible to follow the fruit fly population throughout the year and increase the number of sites being checked for fruit flies.

When possible, pheromone traps should be placed in mating areas. Fruit flies normally mate in the crown of host plants or close by, selecting semi-shaded spots and usually on the upwind side of the crown. Other suitable trap sites are the eastern side of the tree which gets the sun light in the early hours of the day, resting and feeding areas in plants that provide shelter and protect fruit flies from strong winds and predators.

Traps should be deployed in the middle to the top part of the host plant canopy, depending on the height of the host plant, and oriented towards the upwind side. Traps should not be exposed to direct sunlight, strong winds or dust. It is of vital importance to have the trap entrance clear from twigs, leaves and other obstructions such as spider webs to allow proper airflow and easy access for the fruit flies. In specific situations and for some trap types, trap hangers may need to be coated with an appropriate insecticide to prevent ants from eating captured fruit flies.

Protein traps should be deployed in shaded areas in host plants. In this case traps should be deployed in primary host plants during their fruit maturation period. In the absence of primary host plants, secondary host plants should be used. In areas with no host plants identified, traps should be deployed in plants that can provide shelter and protection to adult fruit flies.

Placement of several traps in the same tree, baited with different attractants, should be avoided because it may cause interference among attractants and a reduction of trap efficiency. For example, placing a *C. capitata* male-specific TML trap and a protein attractant trap in the same tree will cause a reduction of female capture in the protein traps because TML acts as a female repellent.

5.5. Trap mapping

Once traps are placed in carefully selected sites at the correct density and distributed in an adequate array, the location of the traps must be recorded. It is recommended that the location of traps should be geo-referenced with the use of global positioning system (GPS) equipment. A map or sketch of the trap location and the area around the traps should be prepared (IAEA, 2006).

The application of GPS and geographic information systems (GIS) in the management of trapping network has proved to be a very powerful tool. GPS allows each trap to be geo-referenced through geographical coordinates, which are then used as input information in a GIS database.

In addition to GPS location data, or in the event that GPS data is not available for trap locations, reference for the trap location should include visible landmarks. In the case of traps placed in host plants located in suburban and urban areas, references should include the full address of the property where the trap was placed. Trap reference should be clear enough to allow those servicing the traps, control brigades and supervisors to find the trap easily.

A database or trapping book of all traps with their corresponding coordinates needs to be kept, together with the records of trap services, rebaiting, trap captures etc. GIS provides high-resolution maps showing the exact location of each trap and other valuable information such as exact location of fruit fly finds (fruit fly entries or outbreaks), historical profiles of the geographical distribution patterns of the fruit flies, relative size of the populations in given areas and spread of the fruit fly population in case of an incursion. This information is extremely useful in planning control activities, ensuring that bait sprays and sterile fruit fly releases are accurately placed and cost-effective in their application.

5.6. Trap servicing and inspection

Trap servicing (i.e. rebaiting) intervals are specific to each trap system (**Table 4**). Capturing fruit flies will depend, in part, on how well the trap is serviced. Trap servicing includes rebaiting and maintaining the trap in a clean and appropriate operating condition. Traps should be in a condition to consistently kill and retain in good condition any target flies that have been captured.

Attractants have to be used in the appropriate volumes and concentrations and replaced at the recommended intervals, as indicated by the manufacturer. The release rate of attractants varies considerably with environmental conditions. The release rate is generally high in hot and dry areas, and low in cool and humid areas. Thus, in hot climates traps will have to be rebaited more often than under cool conditions.

Inspection intervals (i.e. checking for and collecting fruit fly captures) should be adjusted according to the prevailing environmental conditions and pest situations. The interval can range from one day up to 30 days. However, the most common inspection interval is seven days in areas where fruit fly populations are present and 14 days in lower risk areas of fruit fly free areas. In the case of delimiting surveys after the detection of an incursion, inspection intervals are more frequent (**Table 4**). Inspection intervals must of course take into account the biology of the target fruit fly.

Avoid handling more than one lure type at a time if more than one lure type is being used at a single locality. Cross contamination between traps of different attractant types (e.g. CUE and ME) reduces trap efficacy and makes laboratory identification unduly difficult. Most importantly, when changing attractants it is essential to avoid spillage or contamination of the external surface of the trap body or the ground. Attractant spillage or trap contamination would reduce the chances of fruit flies entering the trap. For traps that use a sticky insert to capture fruit flies, it is important to avoid contaminating areas in the trap that are not meant for capturing fruit flies with the sticky material. This also applies to leaves and twigs that are in the trap surroundings. Attractants, by their nature, are highly volatile and care should be taken when storing, packaging, handling and disposing of lures to avoid compromising the lure and operator safety.

The number of traps serviced per day per person will vary depending on type of trap and survey, and the environmental and topographic conditions of the trapping route and the experience of the operators.

5.7. Trapping records

The following information should be included in the database or trapping book in order to keep proper trapping records as they provide confidence in the survey results: trap location, plant where the trap is currently placed, trap and attractant type, latest servicing and inspection dates, and target fruit fly capture. Any other information considered necessary can be added to the trapping records. Retaining results for longer can provide useful information for various types of analyses, including the spatial and temporal changes in the fruit fly population.

5.8. Flies per trap per day

Flies per trap per day (FTD) is a population index that indicates the average number of flies of the target species captured per trap per day during a specified period in which the trap was exposed in the field.

The function of this population index is to have a comparative measure of the size of the adult pest population in a given space and time. It is used as baseline information to compare the size of the population before, during and after the application of a fruit fly control programme. The FTD should be used in all reports of trapping surveys.

The FTD is comparable within a programme; however, for meaningful comparisons between programmes, it should be based on the same fruit fly species, trapping system, trap density and environmental and climatic factors.

FTD is obtained by dividing the total number of captured fruit flies by the product obtained from multiplying the total number of inspected traps by the average number of days the traps were exposed. The formula is as follows:

$$FTD = \frac{F}{T \times D}$$

where:
F is total number of fruit flies,
T is number of inspected traps,
D is average number of days traps were exposed in the field between two inspections.

5.8.1. FTD interpretation

The FTD has been used for decades by programme managers as the basic population index to support decisions on fruit fly control. It has been used as a relative index of population fluctuation and abundance and as an action threshold to support decision-making on the implementation of suppression and eradication measures. For example, in some area-wide Mediterranean fruit fly control programmes it has been established that an FTD value of 0.05 or above triggers population suppression measures (e.g. sprays of insecticide-bait), whereas, a value below 0.05 would be appropriate for sterile fly releases aimed at population eradication.

Nevertheless, FTD values which are computed for large numbers of traps covering an extensive geographical area as a broad average number tend to be unrepresentative of local situations, thus, of little use in interpreting variation in population density over space and time. For example, FTD values obtained from a trapping network that extends over a large geographical area that covers lowlands, where fruit hosts are scattered and where tropical climate conditions prevail, as well as highlands, where continuous hosts are present and where subtropical and temperate climatic conditions prevail, cannot be computed in a single average. Environmental and climatic conditions in these two areas will affect in different ways population density and spatial distribution as well as trap efficiency. To overcome the problem of using a single average FTD value, the total area covered by the trapping network needs to be stratified according to variations that occur in space (geographical range) and time of key environment and climatic factors and the resulting FTD values need to be analyzed and classified separately. This will provide a more approximate figure of the relative population size in a given space and time, allowing better decision-making on the type of control measures required for population suppression and eradication.

Furthermore, trap efficiency plays a key role affecting capture numbers (**Annex 2**). Understanding it will result in better interpretation of the FTD and thus in the assessment of population density. Therefore, assessing trap efficiency under a range of environmental and climatic conditions is fundamental. For example, an FTD value of 0.5 in the lowlands has a completely different meaning than the same value in the highlands, as described above.

Determination of trap efficiency is complex as each type of trap is subjected to intrinsic factors (variations in trap design, color, attractant) and external factors (variations in host presence (scattered or continuous) and phenology (with or without susceptible fruits), climatic factors (high or low temperatures, mild or heavy rain, high or low relative humidity, strong or mild winds and scattered or dense cloud cover) and population density (low or high density)).

Different methods have been proposed to assess trap efficiency in terms of estimating absolute population size. Cunningham et al. (1986), highlighted the need for a mathematical approach to understand trap performance, nevertheless, little effort has been made in using more analytical methods. Methods that are used in support of operational programmes are based on more simple and practical approaches such as probability models based on likelihood of catching one fly out of a given population size (Calkins et al. 1984, Cunningham and Couey 1986, Lance and Gates 1994, Shelly 2014; see also **Annex 2**) and extrapolating trap catches for determination of absolute populations using the mark-release-recapture

method (FAO/IAEA 2016). Absolute populations can also be estimated using the mark-release-recapture method through simple or multiple linear or non-linear regression and correlation analysis (Gomez and Gomez 1984, Enkerlin 1997, Itô and Yamamura 2005).

A known number of marked sterile flies are released at different distances from a trap under a range of environmental and climatic factors (independent variables). Recaptured flies (dependent variable) are used to determine the relationship between the proportion of recaptured flies and the independent variables (i.e. distance from the trap, temperature, rain, etc). From the regression analysis the equation to estimate the proportion of flies captured at any distance from the trap for a given range of environmental and climatic factors (fly response function) can be obtained; for simple non-linear regression the equation would be:

$$Y = \alpha\ (\beta)^x$$

where: Y is the proportion of flies released at distance x in meters from the trap which are captured; α is the intercept to the y axis and β is the slope of the curve or probability of capture as a function of the distance of flies to the trap.

Repeating this procedure as many times as necessary for the range of factors that occur in the different strata, will produce a series of values of proportions of captured flies. These proportions can be transformed into FTD values, which can then be used to infer population size based on this population index. For example, a trapping grid of 10 traps placed equidistant 100 meters apart (equivalent to 100 ha or 1 km^2) captures 250 released sterile flies, resulting in an FTD value of 3.6 (250 flies/(10 traps) × (7 days)). Since the absolute number of released sterile flies is known (in this example 5000), the 250 recaptured sterile flies will represent 5% of the total released population in 1 km^2. From this mark-release-recapture experiment conducted in a given stratum and under given environmental and climatic conditions, one can infer that an FTD value of 3.6 is equivalent to an approximate number of wild population of 5000 adult flies in one square kilometer under these conditions.

5.8.2. FTD and the SIT

In area-wide fruit fly control programmes that integrate the SIT as part of an IPM approach, the FTD is used as a relative measure of wild and sterile fly population densities and sterile to fertile ratios. Assessing population density of wild flies in space and time in terms of FTD is required in order to release the appropriate sterile fly density to either suppress or eradicate the wild population. The wild and sterile fly FTD is transformed into a sterile to wild ratio and compared against the established ratio for population suppression and eradication (FAO/IAEA 2017). When the sterile to wild ratio is below the minimum ratio, additional sterile flies need to be released in order to achieve the desired effect on the wild population. When the ratio is above the required level, reduction of the sterile fly release density would be appropriate in order to optimize the use of sterile flies. However, when the ratio over a large area is computed, it only represents a broad average that is unrepresentative of hot spots at specific locations, and therefore is often meaningless for decision-making at that level.

5.8.3. Sterile:fertile ratios vs male:female trap catches

Trapping networks in fruit fly control programmes are composed of traps that use para-pheromone attractants that are male specific (e.g. trimedlure and methyl eugenol), as well as traps that use protein-based attractants that capture both males and females (e.g. Biolure, and Nulure). Protein-based attractants are female-biased, capturing on average 60% females and 40% males. In the case of Mediterranean fruit fly suppression and eradication programmes, this type of trap is normally used in areas subjected to only male sterile fly releases to avoid recapturing large numbers of sterile released males and to focus detection on wild females. However, capturing both males and females in the same trap generates confusion in terms of which sex should be considered in computing the sterile:fertile ratio.

One method is to add both male and female wild catches and use the sum to divide by the total sterile male catches. This method underestimates the sterile:fertile ratio since the wild populations are

overestimated. Underestimating the ratio would produce a negative effect as sterile fly release density would have to be unnecessarily increased at an additional cost for the programme. Nevertheless, one could assume that adding male and female wild catches would compensate for the greater number of sterile male flies captured in traps as a result of the massive aerial releases often covering the same areas as the traps.

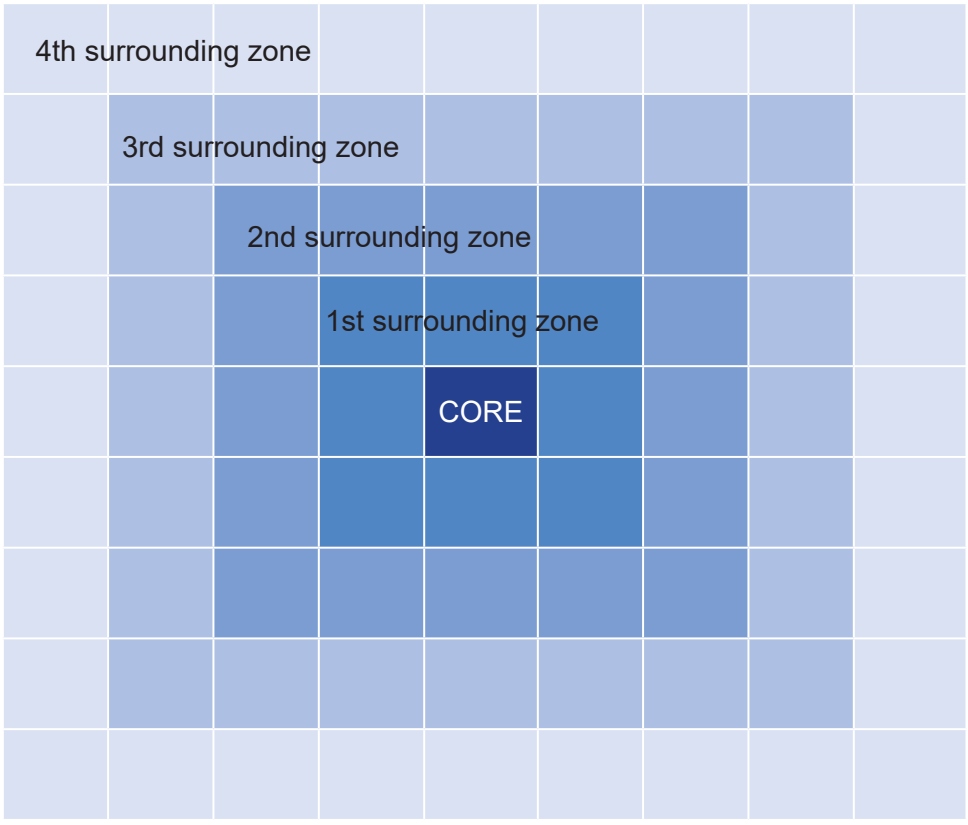
Another method of computing the sterile:fertile ratio is to use the number of wild female catches only and divide the number by the sterile male captures. In protein-baited traps, female captures are on average 20% greater than male catches, thus female captures would be a better estimate of the wild male population considering a one to one sex ratio.

And a final method, and the one often used in operational programmes, is computing the sterile:fertile ratio by using the number of wild male captures and dividing the number by the sterile male captures. This method assumes no compensation for a possible reduced quality of the released sterile males or for a female biased-trap, thus it poses a greater risk of overestimating the sterile:fertile ratio, therefore of wrongly decreasing the sterile fly release density.

Considering the uncertainties of the relative population estimates given by trap data, reducing sterile fly density might not be the best decision even when the ratio appears to be overestimated, unless the resulting ratio is way off the established value for eradication (FAO/IAEA 2017).

6. Trapping for delimiting surveys in free areas

A delimiting survey is designed to determine the boundaries of a fruit fly pest incursion into a free area. Trap density may vary by situation (climatic conditions, biology of species, etc.), but there are some commonalities. The area immediately surrounding each detection is termed a core area that is defined by a set radius surrounding each find. The size of the core area may vary depending on the species of fruit fly, types of traps and other considerations. The area defined by the radius is often squared off to produce a grid. The trapping density in the core area is higher than that used for detection surveys (**Table 6 a–f**). Around the core area may be one or more surrounding zones where the trap density is higher than for detection surveys, but usually lower than that of the core area, as appropriate. Trap densities in the surrounding zones may be proportionally tiered in a decreasing density the further away they are from the core area. Examples of delimiting surveys for single and multiple core areas are presented in **Figures 3 and 4**, respectively.



Surrounding zones	km²	*Anastrepha spp.* McP	*Bactrocera spp.* CUE + McP	*B. dorsalis, B. carambolae* ME + McP	*Ceratitis capitata* TML + MLT (MLT core only)
Core	1	32	20 + 10	10 + 10	40 + 10
1st	8	16	10	2	20
2nd	16	8	6	2	10
3rd	24	4	4	2	8
4th	32	2	2	2	4

Figure 3. Example of delimiting survey using a single km² core around the detection, and surrounding zones for various fruit flies and attractants/trap types (number of traps per km²).

10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10
10	10	20	20	20	20	10	10
10	10	20	40	40	20	10	10
10	10	20	40	40	20	10	10
10	10	20	20	20	20	10	10
10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10

Surrounding zones	km^2	Number of traps per km^2	Total traps
Core	4	40	160
1st	12	20	240
2nd	48	10	480

Figure 4. Example of delimiting survey showing a multiple km^2 core around the detection, and surrounding zones (number in squares represent traps per km^2).

A delimiting survey should be implemented immediately after the initial detection of a target fruit fly species. The duration of a delimiting survey is dependent on the biology of the species. In general, delimiting survey trapping continues for three life cycles beyond the last trap capture for multivoltine species (ISPM 26, FAO 2006).

7. Supervision activities

Supervision of trapping activities includes assessing the quality of the materials used and reviewing the effectiveness and timeliness of the use of these materials and trapping procedures.

The materials used should perform effectively and reliably at an acceptable level for a prescribed period of time. The traps themselves should maintain their integrity for the entire duration that they are anticipated to remain in the field. The attractants should be certified or bioassayed for an acceptable level of performance based on their anticipated use.

Official independent evaluations should occur periodically to assess the effectiveness of trapping. The timing of evaluations will vary by programme, but it is recommended to occur at least twice a year in programmes that run for six months or longer. The evaluation should address all aspects related to the ability of trapping to detect targeted fruit flies within the timeframe required to meet programme outcomes, e.g. early detection of a fruit fly entry into a free area. Aspects of an evaluation include quality of trapping materials, record-keeping, layout of the trapping network, trap mapping, trap placement, trap condition, trap servicing, trap inspection frequency and capability for fruit fly identification.

The trap deployment should be evaluated to ensure that the prescribed types and densities of traps are in place. Field confirmation is achieved through inspection of individual routes.

Trap placement should be evaluated for appropriate host selection, trap relocation schedule, height, light/shade balance, fruit fly access to trap, and proximity to other traps. Host selection, trap relocation and proximity to other traps can be evaluated from the records for each trap route. Host selection, placement and proximity can be further evaluated by field examination.

Proper record-keeping is crucial to the appropriate functioning of trapping. The records for each trap route should be inspected to ensure that they are complete and up to date. Field confirmation can then be used to validate the accuracy of the records.

Traps should be evaluated for their overall condition, correct attractant, appropriate trap servicing and inspection intervals, correct identifying markings (such as trap identification and date placed), evidence of contamination and proper warning labels. This is performed in the field at each site where a trap is placed.

Evaluation of identification capability can occur via target fruit flies that have been marked in some manner in order to distinguish them from wild trapped fruit flies. These marked fruit flies are placed in traps in order to evaluate the operator's diligence in servicing the traps, competence in recognizing the targeted fruit fly species, and knowledge of the proper reporting procedures once a fruit fly is found. Commonly used marking systems are fluorescent dyes and/or wing clipping.

In some programmes that survey for eradication or exclusion, the fruit flies may also be marked by using sterile irradiated fruit flies in order to further reduce the chances of the marked fruit fly being falsely identified as a wild fruit fly and resulting in unnecessary actions by the programme. A slightly different method is necessary under a sterile fruit fly release programme in order to evaluate the screeners on their ability to accurately distinguish target wild fruit flies from the released sterile fruit flies. In this case the marked fruit flies used are also sterile but lack the fluorescent dye; instead they are marked physically by wing clipping or some other method. These fruit flies are placed into the trap samples after they have been collected in the field, but before they are inspected by the operators (Guillen et al. 2016).

The independent evaluation should be summarized in a report detailing how many inspected traps on each route were found to be in compliance with the accepted standards in categories such as trap mapping, placement, condition, and servicing and inspection interval. Aspects that were found to be deficient should be identified, and specific recommendations should be made to correct these deficiencies.

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Annex 1
Commonly used traps

Cook and Cunningham (C&C) Trap

General description

The C&C trap consists of three removable creamy white panels, spaced approximately 2.5 cm apart. The two outer panels are made of rectangular paperboard measuring 22.8 cm × 14.0 cm. One or both panels are coated with sticky material (**Figure 1**). The adhesive panel has one or more holes which allow air to circulate through. The trap is used with a polymeric panel containing an olfactory attractant (usually TML), which is placed between the two outer panels. The polymeric panels come in two sizes – standard and half panel. The standard panel (15.2 cm × 15.2 cm) contains 20 g of TML, while the half size (7.6 cm × 15.2 cm) contains 10 g. The entire unit is held together with clips, and suspended in the tree canopy with a wire hanger.

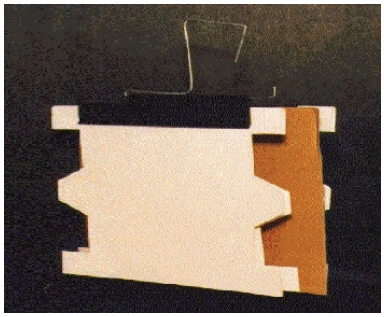

Figure 1. Cook and Cunningham (C&C) trap

Use

As a result of the need for economic highly sensitive delimiting trapping of *C. capitata*, polymeric panels were developed for the controlled release of greater amounts of TML. This keeps the release rate constant for a longer period of time reducing hand labour and increasing sensitivity. The C&C trap with its multi-panel construction has significant adhesive surface area for fly capture.

- Used for the following species — see **Table 3a**.
- For attractants used and rebaiting — see **Tables 3 and 4**.
- For use under different scenarios and recommended densities — see **Table 6d**.

ChamP Trap (CH)

General description

The ChamP trap is a hollow, Yellow panel-type trap with two perforated sticky side panels. When the two panels are folded, the trap is rectangular in shape (18 cm × 15 cm), and a central chamber is created to place the attractant **(Figure 2)**. A wire hanger placed at the top of the trap is used to place it on branches.

Figure 2. ChamP trap.

Use

The ChamP trap can accommodate patches, polymeric panels, and plugs. It is equivalent to a Yellow panel/Rebell trap in sensitivity.

- Used for the following species — see **Table 3a**.
- For attractants used and rebaiting — see **Tables 3 and 4**.
- For use under different scenarios and recommended densities — see **Tables 6b and 5c**.

Easy Trap (ET)

General description

The Easy trap is a two-part rectangular plastic container with an inbuilt hanger. It is 14.5 cm high, 9.5 cm wide, 5 cm deep and can hold 400 mL of liquid (**Figure 3**). The front part is transparent and the rear part is yellow. The transparent front of the trap contrasts with the yellow rear enhancing the trap's ability to catch fruit flies. It combines visual effects with parapheromone and food-based attractants.

Figure 3. Easy trap.

Use

The trap is multipurpose. It can be used dry baited with parapheromones (e.g. TML, CUE, ME) or synthetic food attractants (e.g. 3C and both combinations of 2C attractants) and a retention system such as dichlorvos. It can also be used wet baited with liquid protein attractants holding up to 400 mL of mixture. When synthetic food attractants are used, one of the dispensers (the one containing putrescine) is attached inside to the yellow part of the trap and the other dispensers are left free.

The Easy trap is one of the most economic traps commercially available. It is easy to carry, handle and service, providing the opportunity to service a greater number of traps per man-hour than some other traps.

- Used for the following species — see **Table 3b**.
- For attractants used and rebaitings — see **Tables 3 and 4**.
- For use under different scenarios and recommended densitiess — see **Table 6d**.

Fluorescent yellow sticky 'cloak' trap (PALz)

General description

The PALz trap is prepared from fluorescent yellow plastic sheets (36 cm × 23 cm) (**Figure 4**). One side is covered with sticky material. When setting up, the sticky sheet is placed around a vertical branch or a pole in a 'cloak-like' manner, with the sticky side facing outward, and the back corners are fastened together with clips.

Figure 4. PALz trap.

Use

The trap uses the optimal combination of visual (= fluorescent yellow) and chemical (= cherry fruit fly synthetic bait) attractant cues. The trap is kept in place by a piece of_wire, attached to the branch or pole. The bait dispenser is fastened to the front top edge of the trap, with the bait hanging in front of the sticky surface. The sticky surface of the trap has a capture capacity of ca. 500 to 600 fruit flies. Insects attracted by the combined action of these two stimuli are caught on the sticky surface.

- Used for the following species — see **Table 3a**.
- For attractants used and rebaiting — see **Tables 3 and 4**.

- For use under different scenarios and recommended densities — see **Table 6e**.

Jackson Trap (JT) or Delta Trap

General description

Figure 5. Jackson trap or Delta trap.

The Jackson trap is hollow, delta shaped and made of a white waxed cardboard. It is 8 cm high, 12.5 cm long and 9 cm wide (**Figure 5**). Additional parts include a white or yellow rectangular insert of waxed cardboard which is covered with a thin layer of adhesive known as 'sticky material' used to trap fruit flies once they land inside the trap body; a polymeric plug or cotton wick in a plastic basket or wire holder; and a wire hanger placed at the top of the trap body.

Use

This trap is mainly used with parapheromone attractants to capture male fruit flies. The attractants used with JT/Delta traps are TML, ME and CUE. When ME and CUE are used a toxicant must be added.

For many years this trap has been used in exclusion, suppression and/or eradication programmes for multiple purposes, including population ecology studies (seasonal abundance, distribution, host sequence, etc.); detection and delimiting trapping; and surveying sterile fruit fly populations in areas subjected to sterile fly mass-releases. JT/Delta traps may not be suitable for some environmental conditions (e.g. rain or dust).

The JT/Delta traps are some of the most economic traps commercially available. They are easy to carry, handle and service, providing the opportunity of servicing a greater number of traps per man-hour than some other traps.

- Used for the following species — see **Table 3a**.
- For attractants used and rebaiting — see **Tables 3a and 4**.
- For use under different scenarios and recommended densities — see **Tables 6b and 6d**.

Lynfield Trap (LT)

General description

Figure 6. Lynfield trap.

The conventional Lynfield trap consists of a disposable, clear plastic, cylindrical container measuring 11.5 cm high with a 10 cm diameter base and 9 cm diameter screw-top lid. There are four entry holes evenly spaced around the wall of the trap (**Figure 6**). Another version of the Lynfield trap is the Morocco trap (**Figure 7**).

Use

The trap uses an attractant and insecticide system to attract and kill target fruit flies. The screw-top lid is usually colour-coded to the type of attractant being used (red, CAP/TML; white, ME; yellow, CUE). To hold the attractant a 2.5 cm screw-tip cup

hook (opening squeezed closed) screwed through the lid from above is used. The trap uses the male-specific parapheromone attractants CUE, Capilure (CE), TML and ME.

CUE and ME attractants, which are ingested by the male fruit fly, are mixed with malathion. However, because CE and TML are not ingested by either C. capitata or C. rosa, a dichlorvos-impregnated matrix is placed inside the trap to kill fruit flies that enter.

- Used for the following species — see **Table 3a.**
- For attractants used and rebaiting — see **Tables 3 and 4.**
- For use under different scenarios and recommended densities — see **Tables 6b and 6d.**

Figure 7. Morocco trap.

McPhail (McP) Trap type

General description

The conventional McPhail (McP) trap is a transparent glass or plastic, pear-shaped invaginated container. The trap is 17.2 cm high and 16.5 cm wide at the base and holds up to 500 mL of solution (**Figure 8**). The trap parts include a rubber cork or plastic lid that seals the upper part of the trap and a wire hook to hang traps on tree branches. A plastic version of the McPhail trap is 18 cm high and 16 cm wide at the base and holds up to 500 mL of solution (**Figure 9**). The top part is transparent and the base is yellow.

Figure 8. McPhail trap.

Figure 9. Plastic McPhail trap.

Use

For this trap to function properly it is essential that the body stays clean. Some designs have two parts in which the upper part and base of the trap can be separated allowing for easy service (rebaiting) and inspection of fruit fly captures.

This trap uses a liquid food attractant, based on hydrolysed protein or torula yeast/borax tablets. Torula tablets are more effective than hydrolysed proteins over time because the pH is stable at 9.2. The level of pH in the mixture plays an important role in attracting fruit flies. Fewer fruit flies are attracted to the mixture as the pH becomes more acidic.

To bait with yeast tablets, mix three to five torula tablets in 500 mL of water. Stir to dissolve tablets. To bait with protein hydrolysate, mix protein hydrolysate and borax (if not already added to the protein) in water to reach 5–9% hydrolysed protein concentration and 3% of borax.

The nature of its attractant means this trap is more effective at catching females. Food attractants are generic by nature, and so McP traps tend to also catch a wide range of other non-target tephritid and non-tephritid fruit flies in addition to the target species.

McP-type traps are used in fruit fly management programmes in combination with other traps. In areas subjected to suppression and eradication actions, these traps are used mainly to monitore

female populations. Female catches are crucial in assessing the amount of sterility induced to a wild population in a sterile insect technique (SIT) programme. In programmes releasing only sterile males or in a male annihilation technique (MAT) programme, McP traps are used as a population detection tool by targeting feral females, whereas other traps (e.g. Jackson traps), used with male-specific attractants, catch the released sterile males, and their use should be limited to programmes with an SIT component. Furthermore, in fruit fly-free areas, McP traps are an important part of the non-indigenous fruit fly trapping network because of their capacity to capture fruit fly species of quarantine importance for which no specific attractants exist.

McP traps with liquid protein attractant are labour intensive. Servicing and rebaiting take time, and the number of traps that can be serviced in a normal working day is half that of some other traps described in this annex.

- Used for the following species — see **Table 3b**.
- For attractants used and rebaiting — see **Tables 3 and 4**.
- For use under different scenarios and recommended densities — see **Tables 6a, 6b and 6e**.

Modified funnel trap (VARs+)

General description

It consists of a plastic funnel and a lower catch container. The top roof has a large (5 cm diameter) hole, over which an upper catch container (transparent plastic) is placed (**Figure 10**).

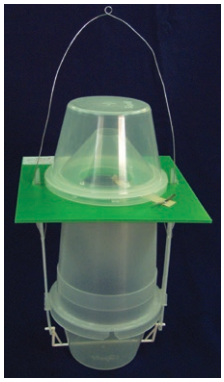

Figure 10. VARs+ trap.

Use

Since it is a non-sticky trap design, it has a virtually unlimited catch capacity and very long field life. The bait is attached to the roof, so that the bait dispenser is positioned into the middle of the large hole on the roof. A small piece of matrix impregnated with a killing agent is placed inside both the upper and lower catch containers to kill fruit flies that enter.

- Used for the following species — see **Table 3a.**
- For attractants used and rebaiting — see **Table 3a and 4**.
- For use under different scenarios and recommended densities — see **Table 6d**.

Multilure Trap (MLT)

General description

The Multilure trap (MLT) is a version of the McPhail trap described previously. The trap is 18 cm high and 15 cm wide at the base and can hold up to 750 mL of liquid (**Figure 11**). It consists of a two-piece plastic invaginated cylinder-shaped container. The top part is transparent and the base is yellow. The upper part and base of the trap separate, allowing the trap to be serviced and rebaited. The transparent upper part of the trap contrasts with the yellow base enhancing the trap's ability to

Figure 11. Multilure trap.

catch fruit flies. A wire hanger, placed on top of the trap body, is used to hang the trap from tree branches.

Use

This trap follows the same principles as those of the McP trap. However, an MLT used with dry synthetic attractant is more efficient and selective than an MLT or McP trap used with liquid protein attractant. Another important difference is that an MLT with a dry synthetic attractant allows for a cleaner servicing and is much less labour intensive than a McP trap. When synthetic food attractants are used, dispensers are attached to the inside walls of the upper cylindrical part of the trap or hung from a clip at the top. For this trap to function properly it is essential that the upper part stays transparent.

When the MLT is used as a wet trap a surfactant should be added to the water. In hot climates 10% propylene glycol can be used to decrease water evaporation and decomposition of captured fruit flies.

When the MLT is used as a dry trap, a suitable (non-repellent at the concentration used) insecticide such as dichlorvos or a deltamethrin (DM) strip is placed inside the trap to kill the fruit flies. DM is applied to a polyethylene strip placed on the upper plastic platform inside the trap. Alternatively, DM may be used in a circle of impregnated mosquito net and will retain its killing effect for at least six months under field conditions. The net must be fixed on the ceiling inside the trap using adhesive material.

- To be used for the following species — see **Table 3b.**
- For attractants used and rebaiting — see **Tables 3b and 4**.
- For use under different scenarios and recommended densities — see **Tables 6a, 6b, 6c, 6d.**

Open Bottom Dry Trap (OBDT) or (Phase IV) Trap

General description

This trap is an open-bottom cylindrical dry trap that can be made from opaque green plastic or wax-coated green cardboard. The cylinder is 15.2 cm high and 9 cm in diameter at the top and 10 cm in diameter at the bottom (**Figure 12**). It has a transparent top, three holes (each of 2.5 cm diameter) equally spaced around the wall of the cylinder midway between the ends, and an open bottom, and is used with a sticky insert. A wire hanger, placed on top of the trap body, is used to hang the trap from tree branches.

Figure 12. Open bottom dry trap (Phase IV).

Use

A food-based synthetic chemical female-biased attractant can be used to capture *C. capitata*. However, it also serves to capture males. Synthetic attractants for are attached to the inside walls of the cylinder. Servicing is easy because the sticky insert permits easy removal and replacement, similar to the inserts used in

the JT. This trap is less expensive than the plastic or glass McP-type traps.

- To be used for the following species — see **Table 3b**.
- For attractants used and rebaiting — see **Tables 3b and 4**.
- For use under different scenarios and recommended densities — see T**able 6d**.

Red Sphere Trap (RS)

General description

The trap is a red sphere 8 cm in diameter (**Figure 13**). The trap mimics the size and shape of a ripe apple. A green version of this trap is also used. The trap is covered with a sticky material and baited with the synthetic fruit odour butyl hexanoate, which has a fragrance like a ripe fruit. Attached to the top of the sphere is a wire hanger used to hang it from tree branches.

Figure 13. Red sphere trap.

Use

The red or green traps can be used unbaited, but they are much more efficient in capturing fruit flies when baited. Fruit flies that are sexually mature and ready to lay eggs are attracted to this trap.

Many types of insects will be caught by these traps. It will be necessary to positively identify the target fruit fly from the non-target insects likely to be present on the traps.

- To be used for the following species — see **Table 3b.**
- For attractants used and rebaiting — see **Tables 3b and 4**.
- For use under different scenarios and recommended densities — see **Table 6e**.

Sensus Trap (SE)

General description

The Sensus trap consists of a vertical plastic bucket 12.5 cm in high and 11.5 cm in diameter (**Figure 14**). It has a transparent body and a blue overhanging lid which has a hole just underneath it. A wire hanger placed on top of the trap body is used to hang the trap from tree branches.

Figure 14. Sensus trap.

Use

The trap is dry and uses male-specific para-pheromones or, for female-biased captures, dry synthetic food attractants. A dichlorvos block is placed in the comb on the lid to kill the flies.

- To be used for the following species — see **Tables 3a and 3b**.
- For attractants used and rebaiting — see **Tables 3 and 4**.
- For use under different scenarios and recommended densities — see **Table 6d**.

Steiner Trap (ST)

General description

The Steiner trap is a horizontal, clear plastic cylinder with openings at each end. The conventional Steiner trap is 14.5 cm long and 11 cm in diameter (**Figure 15**). Other versions of the Steiner traps are 12 cm long and 10 cm in diameter (**Figure 16**) and 14 cm long and 8.5 cm in diameter (**Figure 17**). A wire hanger, placed on top of the trap body, is used to hang the trap from tree branches.

Figure 15. Conventional Steiner trap.

Figure 16. Steiner trap.

Figure 17. Steiner trap.

Use

This trap uses the male-specific parapheromone attractants TML, ME and CUE. The attractant is suspended from the centre of the inside of the trap. The attractant may be a cotton wick soaked in 2–3 mL of a mixture of parapheromone or a dispenser with the attractant and an insecticide (usually malathion, dibrom or deltamethrin) as a killing agent.

- Used for the following species — see **Table 3a**.
- For attractants used and rebaiting — see **Tables 3a and 4**.
- For use under different scenarios and recommended densities — see **Tables 6b and 6d**.

Tephri Trap (TP)

General description

The Tephri trap is similar to a McP trap. It is a vertical cylinder 15 cm high and 12 cm in diameter at the base and can hold up to 450 mL of liquid (**Figure 18**). It has a yellow base and a clear top, which can be separated to facilitate servicing. There are entrance holes around the top of the periphery of the yellow base, and an invaginated opening in the bottom. Inside the top is a platform to hold attractants. A wire hanger, placed on top of the trap body, is used to hang the trap from tree branches.

Figure 18. Tephri trap.

Use

The trap is baited with hydrolysed protein at 9% concentration; however, it can also be used with other liquid protein attractants as described for the conventional glass McP trap or with the female dry synthetic food attractant and with TML in a plug or liquid as described for the JT/Delta and Yellow panel traps. If the trap is used with liquid protein attractants or with dry synthetic attractants combined with a liquid retention system and without the side holes, the insecticide will not be necessary. However, when used as a dry trap and with side holes, an insecticide solution (e.g. malathion) soaked into a cotton wick or other killing agent is needed to avoid escape of captured insects. Other suitable insecticides are dichlorvos or deltamethrin (DM) strips placed inside the trap to kill the fruit flies. DM is applied in a polyethylene strip, placed on the plastic platform inside the top of the trap. Alternatively, DM may be used in a circle of impregnated mosquito net and will retain its killing effect for at

least six months under field conditions. The net must be fixed on the ceiling of the inside of the trap using adhesive material.

- Used for the following species — see T**ables 3a and 3b**.
- For attractants used and rebaiting — see **Tables 3a, 3b and 4**.
- For use under different scenarios and recommended densities — see **Tables 6b, 6c, 6d and 6d.**

Yellow Panel Trap (YP)/Rebell Trap (RB)

General description

The Yellow panel (YP) trap consists of a yellow rectangular cardboard plate (23 cm × 14 cm) coated with plastic (**Figure 19**). The rectangle is covered on both sides with a thin layer of sticky material. The Rebell trap is a three-dimensional YP-type trap with two crossed yellow rectangular plates (15 cm × 20 cm) made of plastic (polypropylene) making them extremely durable (**Figure 20**). The trap is also coated with a thin layer of sticky material on both sides of both plates. A wire hanger, placed on top of the trap body, is used to hang it from tree branches.

Figure 19. Yellow panel trap.

Use

These traps can be used as visual traps alone and baited with TML, spiroketal or ammonium salts (ammonium acetate). The attractants may be contained in controlled-release dispensers such as a polymeric plug. The attractants are attached to the face of the trap. The attractants can also be mixed into the cardboard's coating. The two-dimensional design and greater contact surface make these traps more efficient, in terms of fly captures, than the JT and McPhail-type traps. It is important to consider that these traps require special procedures for transportation, submission and fruit fly screening methods because they are so sticky that specimens can be destroyed in handling. Although these traps can be used in most types of control programme applications, their use is recommended for the post-eradication phase and for fly-free areas, where highly sensitive traps are required. These traps should not be used in areas subjected to mass-release of sterile fruit flies because of the large number of released fruit flies that would be caught. It is important to note that their yellow colour and open design allow them to catch other non-target insects including natural enemies of fruit flies and pollinators.

Figure 20. Rebell trap.

- Used for the following species — see **Tables 3a and 3b**.
- For attractants used and rebaiting — see T**ables 3a, 3b and 4**.
- For use under different scenarios and recommended densities — see **Tables 6b, 6c, 6d and 6e**.

Annex 2

Procedure to determine trap efficiency

1. Introduction

Trap efficiency is influenced by a number of factors including: Fruit fly species, trap type (design and attractant), host presence and phenology and climatic factors such as temperature, relative humidity and wind. Therefore, trap efficiency should be assessed for each trap type and fruit fly species, and throughout the range of relevant factors (and intrinsic variations) present in the target area.

A practical procedure to determine trap efficiency is based on the mark-release-recapture method (Barclay et al. 2012) and data analysis through simple regression and probability distribution (Enkerlin et al. 1997). The information used is: Proportion of fruit flies captured, population size (based on generations from P to F_6), risk of pest introduction, pest status (detection or outbreak), cost of trapping networks and value of what is being protected on a square kilometre basis. This procedure is intended to be of practical use for programme managers. Compared to other methods, this provides additional tools for decision-making by weighing trap efficiency against economic returns produced by different trap densities and also by showing how optimum trap density varies with different levels of risk of fruit fly outbreaks.

2. Release-Recapture Method

Trap efficiency can be assessed by using the mark-release-recapture method, which allows determination of the fruit fly response curve by computing the proportion of flies captured when known populations of sterile flies are released at a range of distances from traps over the life span of each group of released sterile flies (cohort). This procedure is illustrated with the Mediterranean fruit fly (Medfly).

A yellow panel trap baited with TML is placed within a mango orchard. One thousand newly emerged sterile male Medflies are released at 1, 5, 25, 50, 75 and 100 m from the trap in a cruciform pattern with 250 flies released in each distance from the trap at each cardinal point (N, S, E, W). A total of 6000 male Medflies are released every three days, eight times (replicates) over a period of four weeks.

In order to discriminate among fly captures and their corresponding distance from the trap, the sterile flies released should be dyed using six different colours, one for each distance from the trap. Traps are checked every three days during four weeks. The three day interval between trap checks accounted for the expected life span of the fruit fly cohort. For each replicate the total number of flies captured in the trap is quantified for each distance and recorded for statistical analysis.

3. Regression Analysis

Data need to be submitted to a regression analysis, in which the independent variable y is the selected distance from the trap and the dependent variable x the mean proportion of males captured from each starting distance from the trap. The dependent variable is made linear by natural logarithm transformation. Using these data the relationship between the proportion of males captured and initial distance from the trap is assessed.

The coefficient of determination (R^2) is computed for the mean values of fly capture for each distance from the trap to determine the goodness of fit of the values to the regression line (Gomez et al. 1984).

In the Medfly example, the mean number of males captured from each distance to the trap showed a clear exponential trend. 42% of the male flies were captured when released at 1 m from the trap in a three day period (the estimated cohort life span). At 5 m from the trap the percentage captured over

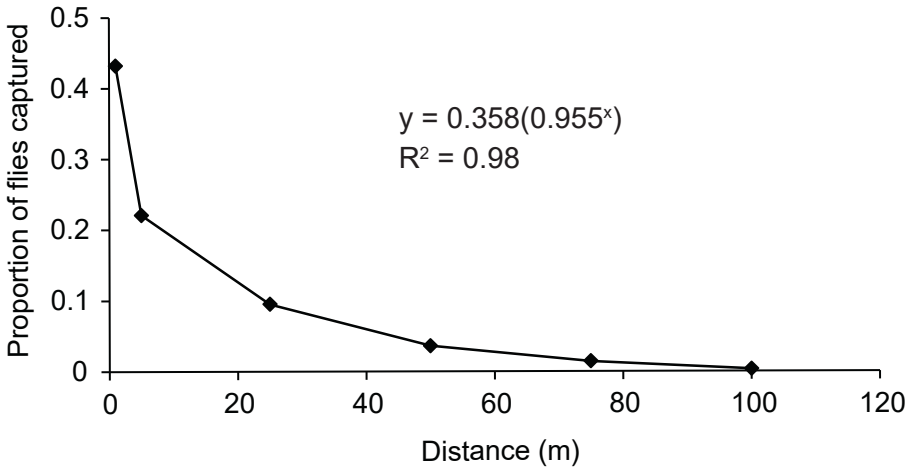

Figure 1. Sterile male response curve using a yellow panel trap (YPT).

three days decreased to 22.1% and to 9.5% at 25 m. Less than 1% of the flies released at 100 m from the trap were captured.

The means of male Medflies captured from 8 replicates were fitted by the exponential equation:

$$y = a(b)^x$$

$$y = 0.358(0.955)^x \quad (1)$$

where: y is the proportion of flies released at distance x in meters from the trap which are captured; a (0.358) (the intercept to the y axis) and b (0.955) (the probability of capture as a function of the distance of males to the trap) are constants. In this case, the coefficient of determination (R^2) for fitting the mean values from 8 replicates at each distance was 0.98 for the total period.

As **Figure 1** shows, the intercept (0.432) is very far from 100%. Less than 50% of the male sterile flies released were captured after three days at a distance of 1 m from the trap. This difference highlights the importance of performing this type of experiment for each different trap type, fly species and also for each different environment.

Findings show that the fruit fly response to its lure is exponential rather than linear, logarithmic or parabolic. It also shows that TML is a relatively weak attractant for Medfly detection purposes in fly free areas or in areas where fruit fly populations are at very low levels. Normally in Medfly action programmes this weakness must be overcome by placing in the field large numbers of traps. For example, when the exotic fruit fly trapping network that operates continuously in the state of California, USA, detects a fly, an additional 1000 traps/2.6 sq km are deployed around detection sites as a means to establish the status of the find (Lance et al. 1994).

4. Probability of Capture

Probability distribution is used to estimate the likelihood of capturing at least one fruit fly from different population size (cohorts). A similar methodology to estimate probability of capture has been applied by authors such as Calkins et al. (1984), Cunningham et al. (1986) and Lance et al. (1994).

To compute the probability of Medfly capture for a given population size the following assumptions are made:

1) Quarantine efforts fail and Medfly infested fruit is introduced into a Medfly free area;
2) A pair of Medflies survives to adult stage;
3) This pair of adult flies (P) will be followed for six generations (F_1 to F_6) in a year;

4) Each generation increases six-fold so the number of adult individuals per generation is: 2(P), 12(F_1), 72(F_2), 432(F_3), 2,592(F_4), 15,552(F_5) and 93,312(F_6). Assuming a 1:1 sex ratio and considering that the TML used to capture flies is male specific, only male Medfly numbers are used for the computations: 1(P), 6(F_1), 36(F_2), 1,296(F_4), 7,776(F_5) and 46,656(F_6);

5) The adults have a uniform distribution within the square area formed by the trapping grid;

6) If only one individual is caught and no further individuals are caught as a result of delimiting trapping then the fly population is considered to be in the P generation and the fly capture is defined as a 'detection' and no further control action is taken (FAO, 2001);

7) If more than one adult Medfly is found in the delimiting trapping at a standard density it is defined as an 'outbreak' (FAO, 2001). Depending on the number of individuals captured by the trapping, the fly population is assumed to have been caught in any of generations F_1 to F_6. An outbreak will require eradication actions;

8) Failure to capture a fly in the P generation will allow the population to produce subsequent generations and by definition an 'outbreak' will be produced and eventually detected. The F_1 generation will produce an O_1 outbreak if at least two male Medflies are caught from the F_1 generation. If the trapping network fails to capture two or more individuals in the F_1 generation, an F_2 generation will be produced and thus an O_2 outbreak could occur. Over the course of a year this could continue and eventually an F_6 generation could be reached and an O_6 outbreak produced;

9) Each level of outbreak, as determined by the delimiting trapping, requires a different level of intensity and time frame in the eradication actions and produces different magnitude of costs and level of loss.

The regression equation obtained from the fly response curve field experiment to compute the probability p of capturing a fly at each release distance from the trap is used to estimate the expected probability of capture for different trap densities and for each individual Medfly generation as follows:

$$p = ab^d \tag{2}$$

where: a is the intercept, b is the slope of the curve of probability of capture, and d is the initial distance of a fly from a trap.

This p value is entered in a probabilistic formula proposed by Lance et al. (1994) to calculate the probability of capturing zero flies from a given population. The formula is:

$$P_0 = (1 - p)^n \tag{3}$$

Where,
P_0 is probability of capturing zero flies,
p is probability of capturing at least one fly,
n is population size.

After estimating the probability of capturing zero flies P_0, the probability of detecting at least one fly q is given by the binomial expansion,

$$q = 1 - P_0 \tag{4}$$

Binomial expansion is applied to samples of any size from a population in which objects occur independently in only two classes (dead or alive, male or female, zero flies or one or more flies, etc).

The probability q was predicted for trapping networks with traps arranged in a grid and placed at distances between traps that range from 32 to 1000 m, equivalent to densities from 1 to 1000 traps per square kilometre. Standard trapping protocols (Appendix 1, ISPM 26, FAO 2006) call for a density of 1 to 12 traps per square kilometre for a Medfly detection depending on the working area and assessed risk. An estimate of the probability of capturing a single fly p is needed in order to calculate P_0 and q (**Equations 3 and 4**). Traps are arranged on a square grid with a half trap distance D. Flies are assumed

to have a uniform distribution within a square area formed by the grid of traps (though other patterns could be assumed by adjusting the distribution of distances of individuals within the population from traps). In a uniform pattern the expected probability of capturing a single fly in the area within a square grid surrounding a trap $E(p/D)$ is given by:

$$E(p/D^2) = 1/D^2 \int_0^D \int_0^D ab\sqrt{x^2 + y^2}\,dy\,dx \quad (5)$$

where: D is the half trap distance in the square grid of traps (always the same because traps are assumed to be on a square grid system), a and b are parameters in the expression for the probabilities of capture of a fly, a function of distance from the trap (**Equations 1 and 2**), and x and y are the initial distances on the horizontal and vertical axes that a fly is from the trap. This integral was estimated numerically for the half trap distance D.

4.1. Probability Model

To calculate the probability of capture for any half trap distance or trap density at any point within each square area a probability model is used. The model goes through the following basic steps:

1) For each trap density, with half trap distance D, the position of the flies within the square area (x, y) is randomly determined by a random function which generates a uniformly distributed random variable on the interval (0,1). The distance from the trap d is given by $d = \sqrt{(x^2 + y^2)}$;
2) Using the parameters a (intercept to the y axis) and b (slope of the curve or probability of capture) from the exponential **Equation 2**, the model calculates the expected probability of capture for the distance d using **Equation 5**;
3) Steps 1 and 2 are repeated (Monte Carlo simulations (Binder, 1995)) many times;
4) The model calculates the average probability of capture across all Monte Carlo simulations.

This procedure is developed into a spreadsheet model to facilitate calculations. For each of the selected trap densities the model is run once to compute the expected probability of fly capture for each of the six Medfly generations. This is done by entering the half trap distance for each trap density. For each trap density the model performed 10,000 different positions of the flies within the square area, calculating the probability of capture for each and then took the average number. The model is set in a way that any of the input data can be changed, including number of simulations, number of individuals per generation and half trap distance.

The next step in this procedure is to assess the probability of Medfly capture across generations, the cumulative probability *CP*. The probability of capturing at least one fly for any trap density increases as the number of individuals per generation increases. A trapping grid will have very low probability of at least one capture in the initial generations due to the low number of flies. The probability of a capture in the initial generations adds cumulatively to the probability of capture in each subsequent generation. For example, to compute the *CP* of capture in the F_2 generation, the probability of not capturing a fly in the F_2 generation is multiplied by the probability of not capturing a fly in the F_1 generation and by the probability of not capturing a fly in the P generation. The resulting value is subtracted from the total probability or 1. The equation is as follows:

$$CP_{(2)} = (1 - p_{(\text{capture gen. 2})})\,(1 - p_{(\text{capture gen. 1})})\,(1 - p_{(\text{capture gen. P})}) \quad (6)$$

This procedure is repeated for each generation to compute its cumulated probability of capture.

Moreover, each trap density will have a probability of capturing a fly in each of the different generations over the course of a year so the total number of potential outcomes is seven (one probability of outcome per generation plus all other possibilities). For example, outcome number 1 is a capture in generation P. Outcome number 2 is a capture in generation F_1 and not a capture in generation P. Outcome number 3 is a capture in generation F_2 and not a capture in generation P and F_1 and so on until outcome 7. In the case of outcome 7 (i.e. all other possibilities) it will be more likely with low trap densities since medium or high trap densities will have very high probabilities of capture in the previous outcomes. Outcome 7 will lead to the highest costs and greatest losses. To assess the probability of each outcome the CP of

Table 1. Accumulated probability of any fly capture and probability of outcome for generations P to F_3 for different trap densities during the life span of the adult males

Traps/km^2	Probability of outcome P(1)	Cumulative prob. P(1)[1]	Probability of outcome F_1(6)	Cumulative prob. F_1(6)	Probability of outcome F_2(36)	Cumulative prob. F_2(36)	Probability of outcome F_3(216)	Cumulative prob. F_3(216)
1	0.00102	0.00102	0.00611	0.00713	0.03593	0.04307	0.18987	0.23294
5	0.00526	0.00526	0.03096	0.03622	0.16652	0.20274	0.54180	0.74454
10	0.01056	0.01056	0.06107	0.07163	0.29490	0.36653	0.56953	0.93606
15	0.01581	0.01581	0.08975	0.10556	0.39050	0.49605	0.48783	0.98388
20	0.02089	0.02089	0.11655	0.13744	0.45936	0.59681	0.39899	0.99579
50	0.04689	0.04689	0.23862	0.28551	0.58769	0.87320	0.12680	1.00000
60	0.05399	0.05399	0.26797	0.32196	0.58611	0.90807	0.09193	1.00000
70	0.06074	0.06074	0.29434	0.35508	0.57734	0.93242	0.06758	1.00000
100	0.07760	0.07760	0.35428	0.43188	0.53710	0.96899	0.03101	1.00000
200	0.11576	0.11576	0.46157	0.57733	0.41762	0.99496	0.00504	1.00000
500	0.17123	0.17123	0.56022	0.73145	0.28823	0.99969	0.00031	1.00000
1000	0.21036	0.21036	0.59822	0.80858	0.19139	0.99996	0.00004	1.00000

[1]Number in parenthesis represents the number of male individuals in the corresponding generation.

capture of the current generation is subtracted from the *CP* of capture of the previous generation. For example, the probability of outcome 3 (i.e. capture in F_2 and not in P or F_1) is the *CP* of capture in F_2 minus the *CP* of capture in F_1.

Table 1 presents the cumulative probability of capture for some selected trap densities and for each generation or population size. Even with traps placed 32 meters apart (1000 traps/km^2 or 10 traps/km^2) the probability of capturing one male fly in its entire adult life span is only 21% in a P generation which assumes one male. Several experiments on behaviour of Medfly in relation to the Jackson trap might explain this finding. For example, Villeda et al. (1988), found that only 26.4% of the flies that approach a trap were caught in a 30 min. observation period. However, they assume that as interactions continue throughout the day, the cumulative daily capture might be much higher. Hendrichs et al. (1989), in a similar experiment found that, overall, the number of flies caught in standard Jackson traps represented only 60–65% of the flies observed in and around traps in a 50 cm radius.

The data in **Table 1** show that as trap density and population size increases the probability of capturing a fly in the life span of the adult males also increases. However, at some point (see shaded areas for generations F_2 and F_3) the marginal increase in probability of capture begins to decline, whereas costs of trapping continue to increase at the same rate with each additional trap. This has implications for the economic returns of the different trap densities, as will be discussed further on.

If a population of 6 male individuals (or F_1 generation) is in an area where traps are placed at 140 m apart (i.e. 100 traps/km^2) the probability of capturing at least one fly by that stage is 43%. The probability increases to 97% with a population of 36 males (or F_2) and to almost 100% probability of catching one male with a population of 216 males (or F_3). Moreover, if a population of 6 male individuals (or F_1 generation) is in an area where traps are placed at 71 m apart (i.e. 200 traps/km^2) the probability of capturing at least one fly is 58%. The probability increases to 99% with a population of 36 males (or F_2). The same is true for a population of 216 male individuals (or F_3) in an area where traps are placed at 224 m apart (i.e. only 20 traps/km^2) (**Table 1**).

The theoretical model demonstrates that the cumulative probability of detecting at least one Medfly adult during the adult life span over three generations (F_3) is 99% if a distance between traps of 224 m is used (i.e. 20 traps/km^2 or 1 trap every 5 hectares). For fruit flies with more powerful attractants, lower trapping densities are required to achieve the same probability of outcome (**Figure 2**).

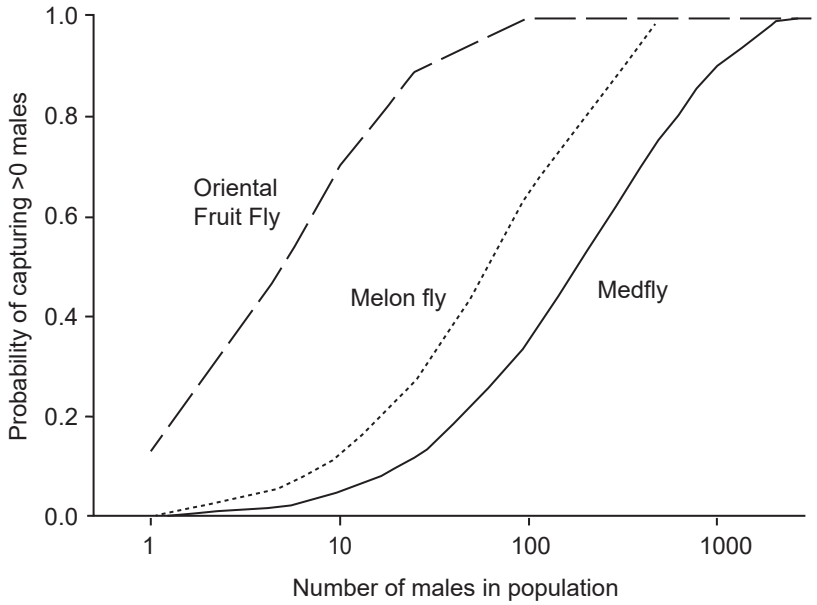

Figure 2. Probability of detecting one or more males of three pest species of tephritid fruit flies (the Mediterranean fruit fly, *Ceratitis capitata*, the melon fly, *Zeugodacus* (formerly *Bactrocera*) *cucurbitae*, and the oriental fruit fly, *Bactrocera dorsalis*) under standard trapping grid conditions in California (10 male lure traps/ mile^2 for *C. capitata* and 5 male lure traps/mile^2 for the other two species) (From McInnis et al. 2017).

For a number of fruit flies of major economic importance such as Medfly, Mexican fruit fly (*Anastrepha ludens*), West Indian fruit fly (*A. obliqua*) and Oriental fruit fly (*Bactrocera dorsalis*), three generations with zero detections after the last find is being used by a number of large-scale operational programmes as the basic criteria to declare the eradication of an outbreak (ISPM 26, FAO 2006). In practice, once a single adult or immature fruit fly stage is detected, delimiting trapping is enforced using trap densities which are substantially higher than 20 traps/km^2. The delimiting trapping is aimed at characterizing the fly find, which includes assessing if it is a 'detection' (only one individual fly caught) or an 'outbreak' (more than one adult caught), and assessing the extent of the infestation. These trapping procedures provide the quarantine security required by importing countries, demonstrated by at least 25 years of trap and fruit sampling records available in operational programmes (Programa Moscamed, 2010). Based on basic knowledge on population biology and ecology supported by the practical experience from operational programmes confirming these results, the three generations (or life cycles) principle was incorporated in the International Standard on Phytosanitary Measures on Fruit Fly Pest Free Areas (ISPM 26) as one of the criteria for reinstatement of the phytosanitary status after an outbreak has been eliminated in a fruit fly free area (FAO, 2016).

However, it is also important to note that due to the exponential nature of the fly response to trap distance, the probability of capture decreases sharply with distance between deployed traps. For example, the 36 male individuals (or F_2) that are in an area where traps are placed at 71 m spacing (i.e. 200 traps/km^2) will have 99% probability of capture during the life span of the adults, but with traps placed 258 m apart (i.e. 15 traps/km^2) there will be approximately 50% probability of a capture, and with traps placed 1000 m apart (i.e. 1 trap/km^2) only about 4.3% probability (**Table 1**). This is an indication that in most cases in action programmes that use low density area-wide trapping networks, populations are not detected until they build up to larger numbers. In this case study with 5 traps/km^2, the population would build up to its third generation (or 216 male individuals per square kilometre) before reaching a level of high detection probability (i.e. 74% probability of detection). Although this number of adult flies seems large, it could also be only a small population that could develop in a few mango trees bearing susceptible fruit. If one male fly from this population is captured by the trapping grid of 5 traps/km^2, this would trigger delimiting trapping and eradication actions and the outbreak would be eliminated in time to avoid serious damage. However, there is also the risk (26% probability of

not detecting a fly) of missing this relatively small population, which eventually could spread and start nuclei of new populations. Such a scenario could produce a situation of widespread multiple outbreaks, and eventually an establishment of the pest, with substantial economic implications. For example, until 1995 the average cost of a Medfly outbreak in California has been estimated to be US $33 million per year because of the costs of eradication, potential reductions in fruit yield and potential export market loss due to enforcement of stringent quarantine measures by trading partners. Mangel et al. (1984) state that if trap density is low, or if traps are inspected infrequently, information on the extent of the infestation can be ineffective in providing economic control. They state that the low trap density (0.4 traps/km^2) used in California to survey Medfly contributed to the initial underestimate of an infestation in Northern California that occurred in 1980. To minimize this risk, trap density could be increased to, for example, 10 traps/km^2 in areas that have been assessed as high risk areas. According to our findings this would detect with a 94% probability one male fly over the life spans of three generations leading to a population of 216 males (or F_3). Increasing trap density to 70/km^2 would achieve this same probability of detection, but for a population of only 36 males (or F_2). However, at this point it is important to mention that intensive trapping is expensive and it is necessary to find a balance between the number of traps, probability of fly capture, cost of trapping`, risk of pest introductions and economic returns.

5. Economic returns of different trap densities

As will be shown in the following section, the operation of trapping networks can be done cost-effectively if an economic factor is included in the assessment of optimum trap density. The introduction of an economic factor allows for an input-output relationship that can determine the maximum profit or return from different trap densities.

The gross revenue *GR* per square kilometre was estimated based on an assumed fruit commodity being produced and sold. The cost *C* per square kilometre was also estimated for each trap density *C1*. In addition a cost per square kilometre was assessed for a detection (single fly find) and for the different outbreak levels. If a fly find consists of only one individual, as a result of a delimiting trapping, then the fly capture is defined as a 'detection' and no further action is taken (FAO, 2001). A cost per square kilometre for the delimiting trapping is assessed *C2*. If as a result of the delimiting trapping the fly find consists of more than one individual then the fly find is defined as an 'outbreak' (FAO, 2001). The status of an outbreak is assessed according to the number of individuals caught by the delimiting trapping. This will indicate in which generation (i.e. F_1 to F_6) the fruit fly population is at the time of the fly find. Each generation will have its corresponding level of outbreak as follows: F_1 will be outbreak 1 (O_1), F_2 will be outbreak 2 (O_2) and so on up to F_6 with an O_6 outbreak level. An outbreak will require eradication actions. A cost per kilometre for eradication actions *C3* and quarantine enforcement *C4* is estimated for each level of outbreak. It is assumed for the purposes of this analysis that only a level of outbreak O_4, O_5 and O_6 trigger quarantine enforcement and loss of market.

For each trap density the net-revenue *NR* on a per square kilometre basis is estimated, by subtracting the costs of operating the trapping network *C1,* the cost of a fly find triggering delimiting trapping, *C2* and the cost of different outbreak levels (*C3* and *C4*) from the gross revenue *GR* obtained ($NR = GR - (C1+C2+C3+C4)$).

In this model, for each trap density the probability of the outcome of each event (i.e. probability of capturing one fly in a particular generation and not in the others) is multiplied by its corresponding net-revenue (i.e. net-revenue for detection if generation P and net-revenue for outbreak if generation F_1 to F_6) and summed across generations to give a single figure of economic return for each trap density across generations. In this way the physical information (i.e. outcome probability) is transformed into monetary terms. This single figure is used in a pay-off matrix to compare returns obtained from the different trap densities.

6. Accounting for the risk of an outbreak

The effective operation of a trapping network needs to account for the risk or probability of an outbreak. For example, in some very isolated areas the risk of an outbreak is small, but in other areas that are not far from infested areas or are subjected to constant introductions of infested fruit loads the risk is high. Using estimates of the economic returns of different trap densities this analysis allows a programme manager to decide on the optimum trap density for a given probability of outbreak.

Economic returns are computed for each trap density under different levels of risk of having a fruit fly outbreak. This is done by multiplying the net-revenues obtained for each trap density when no outbreak occurs (detection) by the probability of an outbreak not occurring; also the net-revenues obtained when an outbreak occurs (outbreak) by the probability of an outbreak occurring. The two values obtained from the multiplications are added to give a single value of net-revenues for each trap density and probability of outbreak (**Table 2**) (Norton, 1984).

To establish the probability of outbreak for different areas within a region, a risk analysis of fruit fly introductions and establishment must be conducted (APHIS/USDA, 1992).

The economic returns of different trap densities are a function of the probability of capture in a particular generation or population size and the probability of the event occurring. The main use of the trapping model is to help assess the trap density that yields the optimum balance between cumulative probability of detection and the probability of the event occurring. This optimum balance will produce maximum economic returns.

The economic returns obtained by the different trap densities can be seen in **Figure 3**. As trap density increases net-revenues increase but only up to a certain point. In this case study 130 traps/km^2 produce the highest economic returns. 130 traps/km^2 will have a low probability of capturing a fly in its first (P) generation. However, the probability of capture, as well as the probability of the event occurring, will improve substantially in the next two generations F_1 (6 male individuals) and F_2 (36 male individuals). The cumulative probability of detection by the F_2 generation is 98% and the probability of the event occurring is almost 50%. 130 traps/km^2 will detect populations in an early stage before substantial damage occurs and this will pay off for the operation of a high density trapping network. The results

Table 2. Net-revenues for different trap densities and for different probabilities of Medfly outbreak during the life span of adult males

Traps/km^2	Pest Status	Net-revenue unadjusted	Probability of outbreak	Net-revenue adjusted for outbreak probability	Total ('000 US $/km^2)
10	Detection	332	0.9	299	
	Outbreak	136	0.1	13	312
100	Detection	320	0.9	288	
	Outbreak	194	0.1	19	307
1000	Detection	203	0.9	183	
	Outbreak	109	0.1	11	194
10	Detection	332	0.5	166	
	Outbreak	136	0.5	68	234
100	Detection	320	0.5	160	
	Outbreak	194	0.5	97	257
1000	Detection	203	0.5	102	
	Outbreak	109	0.5	54	156

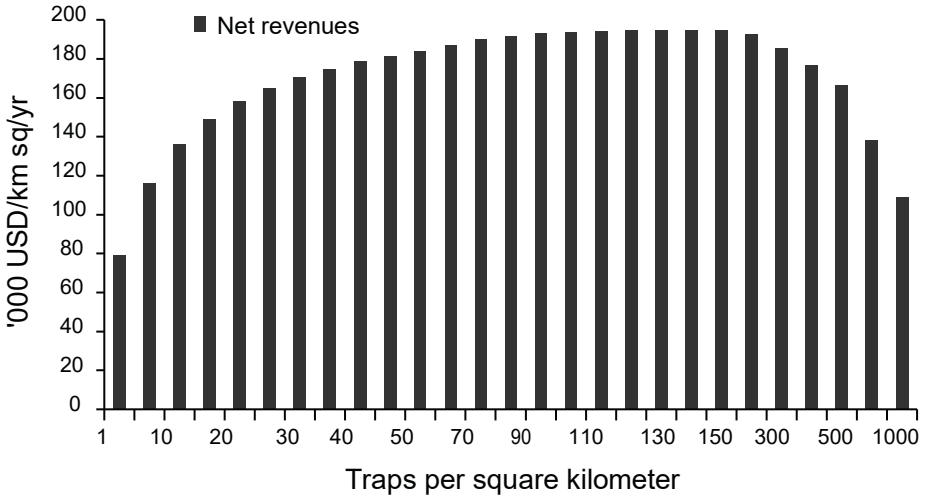

Figure 3. Economic returns per year of different trap densities.

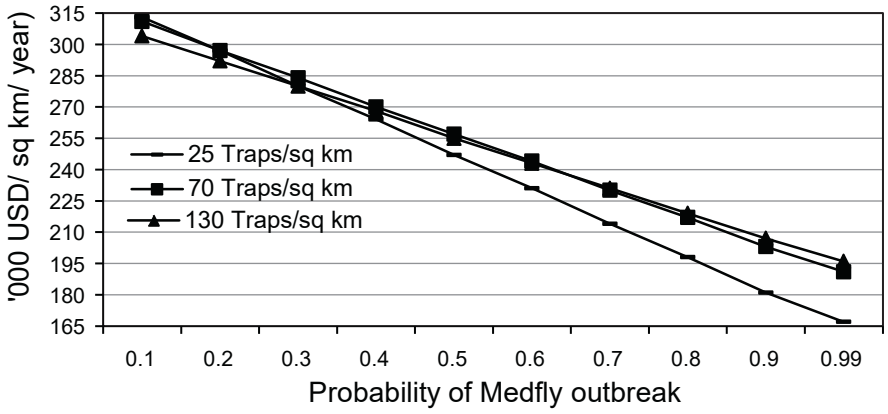

Figure 4. Trap density economic returns using different outbreak probabilities.

presented above assume a frequent outbreak situation. However, things might change substantially in terms of optimum trap density if different levels of risk or probabilities of outbreak are used.

For example, for a 1% outbreak probability, 1 trap/km^2 provides the highest returns and 15 traps/km^2 for a 5% outbreak probability. If the probability of outbreak is increased to 10% the highest returns are obtained using 25 traps/km^2. The change in optimum trap density for different outbreak probabilities can be clearly observed in **Figure 4**.

So the 130 traps/km^2 recommended as the optimum density in the initial analysis (without the probability distribution analysis) can be reduced to 1 trap/km^2 in the case of a low risk scenario (outbreak probability is equal or <1%), whereas the 130 traps are required only under high risk situations (outbreak probability is equal or >90%).

It is also possible to obtain the break-even probability for different trap densities. For example, 35 traps/km^2 and 90 traps/km^2 intersect at 22% probability of outbreak (**Figure 5**). To the left of the breakeven probability a programme manager should not increase the number of traps.

By assessing levels of risk of fly introductions in different areas, trap density could be handled accordingly, thus allowing programme managers a much more accurate and cost effective management of trapping networks.

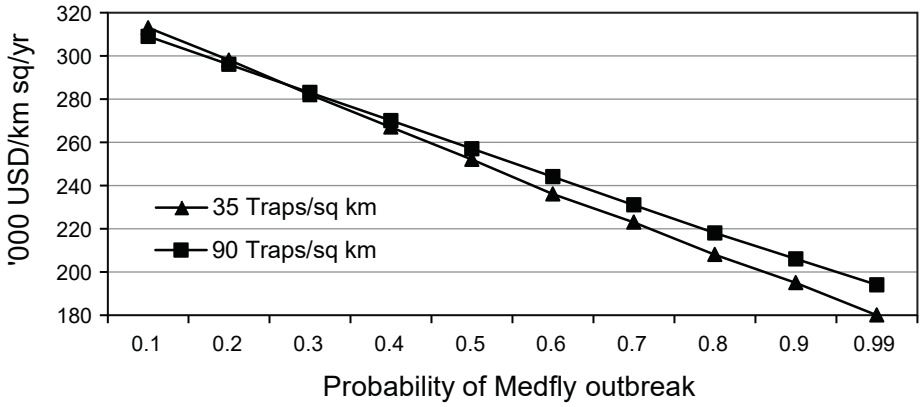

Figure 5. Break-even probability of trap densities.

Economic thresholds for fruit fly control also play a vital role in decision-making on optimum trap density. The general rule is that for low economic thresholds higher trap densities are required to detect populations at an early stage, before they build to economic levels. For higher economic thresholds, there is more damage tolerance and higher trap densities are not required as pest populations can build-up to larger numbers and still be detected before economic damage is inflicted.

For example, for fruit production aimed at local markets and based on biological and demographic parameters of this pest, a population of 1,296 adult flies per km^2 (or F_4) might not be able to inflict economic damage and 5 traps/km^2 (99.9% probability of detection for that particular population size) would be enough to detect the populations in time for economical control. With an even higher economic threshold a greater fruit fly population could be tolerated in the field without reaching economic damage, in which case trap density could be reduced even further.

If fruit is being produced in a fruit fly free area for exports to fruit fly free markets the situation is radically different. According to ISPM 26 (FAO, 2016), one of the technical criteria for declaring a fruit fly outbreak is the presence of just two males or a single gravid female. An outbreak would result in the enforcement of quarantine measures and the export market would be temporally lost. Thus, in this case of a very low population threshold, populations need to be detected as early as possible by using higher trap densities, as previously discussed.

For example, California operates a trapping programme of 94,000 traps using trap densities that range from1.6 to 8 traps per km^2, according to an assessed risk of fruit fly introduction. This trap density has been effective as it allows for early detection of fruit fly introductions and timely implementation of a contingency plan to eradicate the population (USDA/APHIS/PPQ, 2006). In 2005, California spent US $20 million per year in the trapping programme to protect fruits and vegetables susceptible to Medfly infestation, which were valued at US $5.2 billion per year in 2002 (USDA/APHIS/PPQ, 2006). Early detection of fruit fly populations using a sensitive trapping network that uses relatively high trap densities can save millions of dollars in suppression and eradication measures and enforcement of quarantine that restricts exports. Thus, for high value assets with a high risk of fruit fly outbreaks, a highly sensitive trapping network is economically justifiable. Less sensitive trapping networks that use lower trap densities would be more appropriate in cases of low risk of outbreaks and/or low value of the assets being protected.

This procedure to estimate economic returns in relation to the risk of an outbreak has shown the exponential nature of fruit fly response to traps. It also shows how trap density can be optimized by including an economic factor and a probability distribution analysis. The procedure is flexible and sensitive to variations in fruit fly response to the trap, population sizes, trap densities and outbreak probabilities. The procedure provides programme managers with a tool for decision-making on optimum trap density. It shows how trap densities used in large-scale surveillance programmes need

to be weighed against the value of the commodity being protected and the frequency of introduction of fruit fly pests.

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Annex 3

List of *Bactrocera* species responding to methyl eugenol and cuelure

Species that respond to cuelure

Bactrocera (Afrodacus) hypomelaina Drew
Bactrocera (Afrodacus) jarvisi (Tryon)
Bactrocera (Afrodacus) minuta (Drew)
Bactrocera (Afrodacus) ochracea Drew
Bactrocera (Asiadacus) apicalis (Meijere)
Bactrocera (Asiadacus) maculifacies (Hardy)
Bactrocera (Asiadacus) melanopsis (Hardy)
Bactrocera (Bactrocera) abdonigella (Drew)
Bactrocera (Bactrocera) abscondita (Drew & Hancock)
Bactrocera (Bactrocera) abundans Drew
Bactrocera (Bactrocera) aemula Drew
Bactrocera (Bactrocera) aeroginosa (Drew & Hancock)
Bactrocera (Bactrocera) affinidorsalis (Hardy)
Bactrocera (Bactrocera) albistrigata (Meijere)
Bactrocera (Bactrocera) allwoodi (Drew)
Bactrocera (Bactrocera) alyxiae (May)
Bactrocera (Bactrocera) ampla (Drew)
Bactrocera (Bactrocera) andamanensis (Kapoor)
Bactrocera (Bactrocera) anfracta Drew
Bactrocera (Bactrocera) anomala (Drew)
Bactrocera (Bactrocera) anthracina (Drew)
Bactrocera (Bactrocera) antigone (Drew & Hancock)
Bactrocera (Bactrocera) aquilonis (May)
Bactrocera (Bactrocera) assita Drew
Bactrocera (Bactrocera) aterrima (Drew)
Bactrocera (Bactrocera) atriliniellata Drew
Bactrocera (Bactrocera) aurantiaca (Drew & Hancock)
Bactrocera (Bactrocera) beckerae (Hardy)
Bactrocera (Bactrocera) bimaculata Drew & Hancock
Bactrocera (Bactrocera) breviaculeus (Hardy)
Bactrocera (Bactrocera) brevistriata (Drew)
Bactrocera (Bactrocera) bryoniae (Tryon)
Bactrocera (Bactrocera) caledoniensis Drew
Bactrocera (Bactrocera) carbonaria (Hendel)[1]
Bactrocera (Bactrocera) cibodasae Drew & Hancock
Bactrocera (Bactrocera) cinnamea Drew
Bactrocera (Bactrocera) circamusae Drew
Bactrocera (Bactrocera) cognata (Hardy & Adachi)
Bactrocera (Bactrocera) congener Drew
Bactrocera (Bactrocera) curreyi Drew
Bactrocera (Bactrocera) curvipennis (Froggatt)
*Bactrocera (Bactrocera) decumana (*Drew*)*

Bactrocera (Bactrocera) distincta (Malloch)
Bactrocera (Bactrocera) dyscrita (Drew)
Bactrocera (Bactrocera) enochra (Drew)
Bactrocera (Bactrocera) epicharis (Hardy)
Bactrocera (Bactrocera) erubescentis (Drew & Hancock)
Bactrocera (Bactrocera) facialis (Coquillett)
Bactrocera (Bactrocera) fagraea (Tryon)
Bactrocera (Bactrocera) frauenfeldi (Schiner)
Bactrocera (Bactrocera) fuliginus (Drew & Hancock)
Bactrocera (Bactrocera) fulvicauda (Perkins)
Bactrocera (Bactrocera) fulvifemur Drew & Hancock
Bactrocera (Bactrocera) furfurosa Drew
Bactrocera (Bactrocera) furvescens Drew
Bactrocera (Bactrocera) furvilineata Drew
Bactrocera (Bactrocera) fuscitibia Drew & Hancock
Bactrocera (Bactrocera) gombokensis Drew & Hancock
Bactrocera (Bactrocera) holtmanni (Hardy)
Bactrocera (Bactrocera) inconstans Drew
Bactrocera (Bactrocera) indecora (Drew)
Bactrocera (Bactrocera) kinabalu Drew & Hancock
Bactrocera (Bactrocera) kirki (Froggatt)
Bactrocera (Bactrocera) kraussi (Hardy)
Bactrocera (Bactrocera) lata (Perkins)
Bactrocera (Bactrocera) lateritaenia Drew & Hancock
Bactrocera (Bactrocera) laticosta Drew
Bactrocera (Bactrocera) latissima Drew
Bactrocera (Bactrocera) limbifera (Bezzi)
Bactrocera (Bactrocera) lineata (Perkins)
Bactrocera (Bactrocera) lombokensis Drew & Hancock
Bactrocera (Bactrocera) longicornis Macquart
Bactrocera (Bactrocera) luzonae (Hardy & Adachi)
Bactrocera (Bactrocera) makilingensis Drew & Hancock
Bactrocera (Bactrocera) malaysiensis Drew & Hancock
Bactrocera (Bactrocera) manskii (Perkins & May)
Bactrocera (Bactrocera) melanotus (Coquillett)
Bactrocera (Bactrocera) melastomatos Drew & Hancock
Bactrocera (Bactrocera) merapiensis Drew & Hancock
Bactrocera (Bactrocera) moluccensis (Perkins)
Bactrocera (Bactrocera) morobiensis Drew
Bactrocera (Bactrocera) morula Drew
Bactrocera (Bactrocera) mucronis (Drew)
Bactrocera (Bactrocera) mulyonoi (Hardy)
Bactrocera (Bactrocera) neocognata Drew & Hancock
Bactrocera (Bactrocera) neohumeralis (Hardy)
Bactrocera (Bactrocera) nigrescentis (Drew)
Bactrocera (Bactrocera) nigrotibialis (Perkins)
Bactrocera (Bactrocera) obfuscata Drew
Bactrocera (Bactrocera) oblineata Drew
Bactrocera (Bactrocera) obscura (Malloch)
Bactrocera (Bactrocera) parafrauenfeldi Drew
Bactrocera (Bactrocera) paramusae Drew
Bactrocera (Bactrocera) passiflorae (Froggatt)

Bactrocera (Bactrocera) pedestris (Bezzi)
Bactrocera (Bactrocera) penecognata Drew & Hancock
Bactrocera (Bactrocera) peninsularis (Drew & Hancock)
Bactrocera (Bactrocera) perkinsi (Drew & Hancock)
Bactrocera (Bactrocera) phaea (Drew)
Bactrocera (Bactrocera) pisinna Drew
Bactrocera (Bactrocera) propinqua (Hardy & Adachi)
Bactrocera (Bactrocera) pseudocucurbitae White
Bactrocera (Bactrocera) pseudodistincta (Drew)
Bactrocera (Bactrocera) psidii (Froggatt)
Bactrocera (Bactrocera) pusilla (Hardy)
Bactrocera (Bactrocera) quadrata (May)
Bactrocera (Bactrocera) quasisilvicola Drew
Bactrocera (Bactrocera) recurrens (Hering)
Bactrocera (Bactrocera) redunca (Drew)
Bactrocera (Bactrocera) rhabdota Drew
Bactrocera (Bactrocera) robertsi Drew
Bactrocera (Bactrocera) robiginosa (May)
Bactrocera (Bactrocera) rubigina (Wang and Zhao)
Bactrocera (Bactrocera) rufescens (May)
Bactrocera (Bactrocera) rufofuscula (Drew & Hancock)
Bactrocera (Bactrocera) rufula (Hardy)
Bactrocera (Bactrocera) russeola (Drew & Hancock)
Bactrocera (Bactrocera) sembaliensis Drew & Hancock
Bactrocera (Bactrocera) silvicola (May)
Bactrocera (Bactrocera) simulata (Malloch)
Bactrocera (Bactrocera) sumbawaensis Drew & Hancock
Bactrocera (Bactrocera) thistletoni Drew
Bactrocera (Bactrocera) tinomiscii Drew
Bactrocera (Bactrocera) trifaria (Drew)
Bactrocera (Bactrocera) trifasciata (Hardy)
Bactrocera (Bactrocera) trilineola Drew
Bactrocera (Bactrocera) trivialis (Drew)
Bactrocera (Bactrocera) tryoni (Froggatt)
Bactrocera (Bactrocera) turneri Drew
Bactrocera (Bactrocera) unifasciata (Malloch)
Bactrocera (Bactrocera) unilineata Drew
Bactrocera (Bactrocera) usitata Drew & Hancock
Bactrocera (Bactrocera) ustulata Drew
Bactrocera (Bactrocera) varipes (Malloch)
Bactrocera (Bactrocera) vishnu Drew & Hancock
Bactrocera (Bactrocera) vulgaris (Drew)
Bactrocera (Gymnodacus) petila Drew
Bactrocera (Javadacus) scutellaria (Bezzi)
Bactrocera (Javadacus) trilineata (Hardy)
Bactrocera (Niuginidacus) singularis Drew
Bactrocera (Papuodacus) neopallescentis Drew
Bactrocera (Paradacus) abdopallescens (Drew)
Bactrocera (Paradacus) angustifinis (Hardy)
Bactrocera (Paradacus) aurantiventer Drew
Bactrocera (Paradacus) citroides Drew
Bactrocera (Paradacus) longicaudata (Perkins)[2]

Bactrocera (Semicallantra) aquila Drew
Bactrocera (Sinodacus) angusticostata Drew
Bactrocera (Sinodacus) buvittata Drew
Bactrocera (Sinodacus) chonglui (Chao & Lin)
Bactrocera (Sinodacus) hochii (Zia)
Bactrocera (Sinodacus) infesta (Enderlein)
Bactrocera (Sinodacus) paulula Drew
Bactrocera (Sinodacus) perpusilla (Drew)
Bactrocera (Sinodacus) qiongana (Chao & Lin)
Bactrocera (Sinodacus) quaterna (Wang)
Bactrocera (Sinodacus) salamander (Drew & Hancock)
Bactrocera (Sinodacus) strigifinis (Walker)
Bactrocera (Sinodacus) surrufula Drew
Bactrocera (Sinodacus) transversa (Hardy)
Bactrocera (Sinodacus) triangularis (Drew)
Bactrocera (Sinodacus) univittata (Drew)
Bactrocera (Zeugodacus) abdoangusta (Drew)
Bactrocera (Zeugodacus) abnormis (Hardy)
Bactrocera (Zeugodacus) amoena (Drew)
Bactrocera (Zeugodacus) atrifacies (Perkins)
Bactrocera (Zeugodacus) bogorensis (Hardy)
Bactrocera (Zeugodacus) brachus (Drew)
Bactrocera (Zeugodacus) caudata (Fabricius)
Bactrocera (Zeugodacus) chorista (May)
Bactrocera (Zeugodacus) cilifera (Hendel)
Bactrocera (Zeugodacus) cucurbitae (Coquillett)
Bactrocera (Zeugodacus) curta (Drew)
Bactrocera (Zeugodacus) daula Drew
Bactrocera (Zeugodacus) diaphora (Hendel)
Bactrocera (Zeugodacus) dubiosa (Hardy)
Bactrocera (Zeugodacus) elegantula (Hardy)
Bactrocera (Zeugodacus) emittens (Walker)
Bactrocera (Zeugodacus) fallacis (Drew)
Bactrocera (Zeugodacus) gracilis (Drew)
Bactrocera (Zeugodacus) heinrichi (Hering)
Bactrocera (Zeugodacus) incisa (Walker)
Bactrocera (Zeugodacus) ishigakiensis (Shiraki)
Bactrocera (Zeugodacus) isolata (Hardy)
Bactrocera (Zeugodacus) macrovittata Drew
Bactrocera (Zeugodacus) persignata (Hardy)
Bactrocera (Zeugodacus) reflexa (Drew)
Bactrocera (Zeugodacus) scutellaris (Bezzi)
Bactrocera (Zeugodacus) scutellata (Hendel)
Bactrocera (Zeugodacus) sicieni (Chao and Lin)
Bactrocera (Zeugodacus) synnephes (Hendel)[3]
Bactrocera (Zeugodacus) tau (Walker)
Bactrocera (Zeugodacus) trichota (May)
Bactrocera (Zeugodacus) vultus (Hardy)
Bactrocera (Zeugodacus) yoshimotoi (Hardy)[4]
Dacus (Callantra) ambonensis Drew & Hancock
Dacus (Callantra) axanus (Hering)
Dacus (Callantra) calirayae Drew & Hancock

Dacus (Callantra) capillaris (Drew)
Dacus (Callantra) discors (Drew)
Dacus (Callantra) formosanus (Tseng and Chu)
Dacus (Callantra) lagunae Drew & Hancock
Dacus (Callantra) leongi Drew & Hancock
Dacus (Callantra) longicornis (Wiedemann)
Dacus (Callantra) mayi (Drew)
Dacus (Callantra) nanggalae Drew & Hancock
Dacus (Callantra) ooii Drew & Hancock
Dacus (Callantra) ramanii Drew & Hancock
Dacus (Callantra) siamensis Drew & Hancock
Dacus (Callantra) solomonensis (Malloch)
Dacus (Callantra) sphaeroidalis (Bezzi)
Dacus (Callantra) tenebrosus Drew & Hancock
Dacus (Callantra) trimacula (Wang)
Dacus (Callantra) vijaysegarani Drew & Hancock
Dacus (Dacus) absonifacies (May)
Dacus (Dacus) alarifumidus Drew
Dacus (Dacus) badius Drew
Dacus (Dacus) bakingiliensis Hancock
Dacus (Dacus) bellulus Drew and Hancock
Dacus (Dacus) bivittatus (Bigot)
Dacus (Dacus) concolor Drew
Dacus (Dacus) demmerezi (Bezzi)
Dacus (Dacus) diastatus Munro
Dacus (Dacus) durbanensis Munro
Dacus (Dacus) eclipsus (Bezzi)
Dacus (Dacus) humeralis (Bezzi)
Dacus (Dacus) ikelenge Hancock
Dacus (Dacus) newmani (Perkins)
Dacus (Dacus) pecropsis Munro
Dacus (Dacus) pleuralis Collart[5]
Dacus (Dacus) punctatifrons Karsch
Dacus (Dacus) sakeji Hancock
Dacus (Dacus) santongae Drew & Hancock
Dacus (Dacus) secamoneae Drew
Dacus (Dacus) signatifrons (May)
Dacus (Dacus) telfaireae (Bezzi)
Dacus (Dacus) xanthopterus (Bezzi)
Dacus (Didacus) aequalis Coquillett
Dacus (Didacus) africanus Adams
Dacus (Didacus) chiwira Hancock
Dacus (Didacus) devure Hancock
Dacus (Didacus) dissimilis Drew
Dacus (Didacus) eminus Munro
Dacus (Didacus) famona Hancock
Dacus (Didacus) frontalis Becker
Dacus (Didacus) hardyi Drew
Dacus (Didacus) kariba Hancock
Dacus (Didacus) langi Curran
Dacus (Didacus) pallidilatus Munro
Dacus (Didacus) palmerensis Drew

[1] *B. atramentata* (Hering) is a synonym.
[2] *D. vinnulus* Hardy is a synonym.
[3] *D. ubiquitus* Hardy is a synonym.
[4] Needs confirmation.
[5] *D. masaicus* Munro is a synonym

Species that respond to methyl eugenol

Bactrocera (Apodacus) cheesmanae (Perkins)
Bactrocera (Apodacus) neocheesmanae Drew
Bactrocera (Apodacus) visenda (Hardy)
Bactrocera (Bactrocera) abdolonginqua (Drew)
Bactrocera (Bactrocera) aethriobasis (Hardy)
Bactrocera (Bactrocera) affinis (Hardy)
Bactrocera (Bactrocera) amplexiseta (May)
Bactrocera (Bactrocera) atrifemur Drew & Hancock
Bactrocera (Bactrocera) bancroftii (Tryon)
Bactrocera (Bactrocera) batemani Drew
Bactrocera (Bactrocera) biarcuata (Walker)
Bactrocera (Bactrocera) cacuminata (Hering)
Bactrocera (Bactrocera) carambolae Drew & Hancock
Bactrocera (Bactrocera) caryeae (Kapoor)
Bactrocera (Bactrocera) collita Drew & Hancock
Bactrocera (Bactrocera) confluens (Drew)
Bactrocera (Bactrocera) correcta (Bezzi)
Bactrocera (Bactrocera) curvifera (Walker)
Bactrocera (Bactrocera) dapsiles Drew
Bactrocera (Bactrocera) decurtans (May)
Bactrocera (Bactrocera) diallagma Drew[1]
Bactrocera (Bactrocera) diospyri Drew
Bactrocera (Bactrocera) dorsalis (Hendel)
Bactrocera (Bactrocera) ebenea (Drew)
Bactrocera (Bactrocera) endiandrae (Perkins and May)
Bactrocera (Bactrocera) floresiae Drew & Hancock
Bactrocera (Bactrocera) froggatti (Bezzi)
Bactrocera (Bactrocera) fuscalata Drew
Bactrocera (Bactrocera) honiarae Drew
*Bactrocera (Bactrocera) humilis (*Drew & Hancock)
Bactrocera (Bactrocera) impunctata (Meijere)
Bactrocera (Bactrocera) indonesiae Drew & Hancock
Bactrocera (Bactrocera) infulata Drew & Hancock
Bactrocera (Bactrocera) invadens (Drew, Tsuruta & White)[2]
Bactrocera (Bactrocera) kandiensis Drew & Hancock
Bactrocera (Bactrocera) kelaena Drew
Bactrocera (Bactrocera) lampabilis (Drew)
Bactrocera (Bactrocera) laticaudus (Hardy)
Bactrocera (Bactrocera) latilineola Drew & Hancock
Bactrocera (Bactrocera) mayi (Hardy)
Bactrocera (Bactrocera) melanogaster Drew
Bactrocera (Bactrocera) mimulus Drew
Bactrocera (Bactrocera) minuscula Drew & Hancock
Bactrocera (Bactrocera) musae (Tryon)
Bactrocera (Bactrocera) neonigritus (Drew)

Bactrocera (Bactrocera) nigella (Drew)
Bactrocera (Bactrocera) nigrescens (Drew)
Bactrocera (Bactrocera) occipitalis (Bezzi)
Bactrocera (Bactrocera) ochromarginis (Drew)
Bactrocera (Bactrocera) ochromarginis (Drew)
Bactrocera (Bactrocera) opiliae (Drew & Hardy)
Bactrocera (Bactrocera) pallida (Perkins and May)
Bactrocera (Bactrocera) papayae Drew & Hancock[2]
Bactrocera (Bactrocera) parabarringtoniae Drew & Hancock
Bactrocera (Bactrocera) pepisalae (Froggatt)
Bactrocera (Bactrocera) philippinensis Drew & Hancock[2]
Bactrocera (Bactrocera) picea (Drew)
Bactrocera (Bactrocera) prolixa Drew
Bactrocera (Bactrocera) reclinata Drew
Bactrocera (Bactrocera) retrorsa Drew
Bactrocera (Bactrocera) ritsemai (Weyenbergh)
*Bactrocera (Bactrocera) romigae (*Drew & Hancock)
Bactrocera (Bactrocera) seguyi (Hering)
Bactrocera (Bactrocera) sulawesiae Drew & Hancock
Bactrocera (Bactrocera) tenuifascia (May)
Bactrocera (Bactrocera) tuberculata (Bezzi)
Bactrocera (Bactrocera) umbrosa (Fabricius)
Bactrocera (Bactrocera) unimacula Drew & Hancock
Bactrocera (Bactrocera) unistriata (Drew)
Bactrocera (Bactrocera) verbascifoliae Drew & Hancock
Bactrocera (Bactrocera) versicolor (Bezzi)
Bactrocera (Bactrocera) zonata (Saunders)
Bactrocera (Hemigymnodacus) diversa (Coquillett)
Bactrocera (Javadacus) melanothoracica Drew
Bactrocera (Javadacus) montana (Hardy)
Bactrocera (Javadacus) unirufa Drew
Bactrocera (Notodacus) xanthodes (Broun)
Bactrocera (Paratridacus) alampeta Drew
Bactrocera (Paratridacus) atrisetosa (Perkins)
Bactrocera (Semicallantra) memnonius Drew
Bactrocera (Trypetidacus) invisitata Drew
Bactrocera (Zeugodacus) pubescens (Bezzi)[3]
Dacus (Callantra) melanohumeralis Drew
Dacus (Callantra) pusillus (May)

[1] Questionable (see Drew et al. 1999).
[2] Synonymised with B. *dorsalis* (Hendel)
[3] Two records show it is attracted to ME, but still needs confirming, as this is the only *Zeugodacus* to respond to it

Trapping guidelines for area-wide fruit fly programmes

These Trapping Guidelines for Fruit Flies of Economic Importance provide strategic guidance and direction on where and how to implement surveys in support of fruit fly control and quarantine activities. This document is the summation of recommendations put forth by a multi-national group of fruit fly workers that has the objective of providing objective information on fruit fly survey tools to NPPOs and industry in FAO and IAEA Member States. These Trapping Guidelines are to be considered as a 'working' document to be regularly updated as survey techniques continue to improve and experience in fruit fly control programmes evolves.

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