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The Invading Fly: Innovative Pest Management Solutions for Control of Bactrocera Invadens in Pemba, Zanzibar

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Table of Contents

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Abstract

An integrated pest management study was conducted targeting the invasive fruit fly, *Bactrocera invadens*, on the island of Pemba, Zanzibar. Male annihilation technique (MAT) traps were set in geographically dispersed sites featuring mango fruit hosts. Three locally sourced essential oils,eucalyptus citriodora, clove and lemongrass were tested against the standard attractant methyl eugenol. Rainfall quantities at each site were collected and interviews with local farmers were conducted on the subject of *B. invadens* infestation and management. Over the course of the two week study, April 2nd to April 18th, 2014, methyl eugenol baited traps had an average catch of 2465.75 flies per trap, which was significantly different than the 331.45 and 141.7 average fruit fly catch for eucalyptus citriodora oil and clove oil respectively. Lemongrass lagged even further with behind with a negligible number of five flies captured during the entirety of the study. These results represent the effectiveness of eucalyptus citriodora and clove oil as attractants in an integrated pest management (IPM) strategy to combat the infestation by this prolific invasive pest.

Introduction

In 2003, a devastating outbreak of a previously unseen fruit fly occurred in Kenya and later spread to the rest of the African continent. Two years later, this unknown fly was discovered to be a new species, *Bactrocera invadens*, of the tephritidae family of fruit flies (Rwomushana, Ekesi, Gordon, Ogol, 2008). By 2008, *B. invadens* had been detected in 24 countries across Sub-Saharan Africa, as shown in yellow in Figure 1 (Mohamed, Ekesi, & Hanna, 2008). Genus *Bactrocera* comprises one of the most agriculturally destructive fruit fly species worldwide (Rwomushana et al. 2008, Ekesi, Nderitu, &Rwomushana 2006). With traits such as high mobility, large dispersive power, rapid reproductive rates, and extreme polyphagy, *B. invadens* is among the most vicious agricultural pests (Ekesi et al. 2006).

Figure 1*B. invadens* infestation map of Africa adapted from d-maps.com

Ever since it first arrived from the Indian subcontinent, *B. invadens* numbers have steadily risen, displacing indigenous fruit fly species and causing a 40 percent loss in crop yield in some parts of Tanzania (Mwatawala, De Meyer, Makundi, & Maerere, 2006, Ekesi et al. 2006, Rwomushana et al., 2008). The economic impacts of *B. invadens* invasion are felt through the destruction of produce from infestation and the imposition of international quarantine by importing countries (Ekesi et al., 2006). Damage to the fruit and vegetable product occurs through the feeding of *B. invadens* larvae, often just before the product ripens for harvest. *B. invadens*is known to infest over 40 cultivated and wild fruits and vegetables (Ekesi et al., 2006), including mango, lemon, orange, tomato, banana, guava, avocado, custard apple and Indian almond (Ekesi et al., 2006, Mohamed et al., 2008). This polyphagous trait supplies *B. invadens*with sufficient reproductive bases throughoutevery growing season. However, mango is the preferred host of *B. invadens* and population levels are known to peak during the harvesting period of various mango cultivars (Mwatawala et al., 2006).

The rapid infestation that has occurred over the last decade has placed many African farmers in trying circumstances. The billions of dollars the governments of industrialized countries can devote to such areas dwarf government spending on agriculture in Zanzibar, specifically plant protection. While the Zanzibar government struggles to supply methyl eugenol in the relatively few traps it has distributed to farmers, the state of California, the largest agricultural producer in the United States, is able to supply 25,000 traps for the monitoring of fruit flies in the Los Angeles area alone (S. Yussuf, personal communicationMarch 7,2014, Shelly et al., 2010, USDA ERS, 2013). Lacking government support and the monetary means to combat the fruit fly problem on their own, farmers on Pemba and across the entirety of Sub-SaharanAfrica are grappling with continued infestations and loss of export potential as major importers such as the United States and the European Union have begun issuing import quarantines (Mohamed et al. 2008).

While the economic impact of the invader *B. invadens* has been immediate and felt throughout the African continent, the ecological impacts are still being assessed. The most apparent ecological impact is the displacement of indigenous fruit flies. Researchers at the

International Center for Insect Physiology and Ecology (ICIPE) in Nairobi, Kenya, monitoring the initial outbreak of *B. invadens* noted that in 2003, 82 percent of fruit fly emergence from mangos consisted of the indigenous species *Ceratitis cosyra* and 18 percent was *Bactrocera invadens*. The next year, these numbers were reversed, as 23 percent of infested mango emergence was comprised of *C. cosyra* while *B. invadens* constituted the remaining 76 percent. The following year, *B. invadens* accounted for 92 percent of emergence (Rwomushana, Ekesi, Ogol, & Gordon, 2009). The displacement of *C. cosyra* after two years of infestation is a reflection of *B. invadens'* destructive ability and could indicate future ecological changes.

Exhibiting characteristics of both *r* and *K* selection, *B. invadens* is an aggressive invader monopolizing available resources while possessing a high fecundity, allowing it to expand geographicalrange and host species each year (Mohamed et al., 2008). Recent genetic analysis and mapping through the use of ecological niche models (ENM) has shed light on the relationships between current levels of *B. invadens* and environmental predictor variables, such as temperature or rainfall, to better understand the ecological niche of this relatively new species and where in the world it may be headed next. Pemba's high year round temperatures, which hover between 24° and 28° C, are ideal for *B. invadens*, which has been shown to develop from egg to adult stages in seventeen days at temperatures around 30° C (Weatherbase, Ekesi et al., 2006). Additionally, *B. invadens* has the ability to rear in temperatures between 15° - 35° C, making it highly adaptable to new environments (Ekesi et al., 2011). Once they reach adulthood, *B. invadens* reach sexual maturity within seven days and the females produce most of their eggs between 8 and 22 days after achieving maturity (Rwomushana et al., 2009). A mature female has the capability of laying over 1000 eggs in her lifetime, 55 percent of which will develop to full adults. If conditions are suitable, a *B. invadens* population can grow by 11 percent everyday, and double after six days (Ekesi et al., 2006).

As an archipelago, the geography of Zanzibar presents a paradoxical situation. On one hand, should *B. invadens* be eradicated, Zanzibar could facilitate protection of further outbreaks through the strengthening of customs regulations. While on the other, both Pemba and Unguja have suffered heavily from deforestation, resulting in negligible amounts of wild fruits that would, to some degree, distract *B. invadens* as seenon mainland Tanzania (Mwatawala et al. 2009).

Currently, there are a number of methods proven to successfully eradicate and subsequently control fruit fly levels. According to the Food and Agriculture Organization of the United Nations (FAO) and the International Atomic Energy Agency (IAEA), The Male Annihilation Technique (MAT), Sterile Insect Technique (SIT), and good farm sanitation are effective control measures for suppressing fruit flies, including *B. invadens* (IAEA 2004, Mwatawala et al., 2009). MAT is used in both control and monitoring of fruit flies, whereby an attractant bait is coupled with a killing agent to attract and kill male fruit flies (IAEA 2004, Mwatawala et al. 2009). Female fruit flies are not targeted because an effective lure has yet to be discovered(Mwatawala et al. 2006).

Two African countries, Seychelles and South Africa, have successfully eliminated *B. invadens* within their borders and established subsequent monitoring programs to prevent further outbreaks. By first coupling MAT and an education campaign to inform farmers on the importance of farm sanitation, and then instituting SAT once *B. invadens* numbers were reduced, the Seychelles successfully eliminated the fruit fly threat. Once *B. invadens* had been eradicated, the island nation increased customs regulations and heavily monitored the imported produce to prevent another outbreak (Said Yussuf per comm., March 7, 2014). Meanwhile, South Africa never faced a serious outbreak and has instead relied on an extensive monitoring network and prevention program akin to a control operation carried out by the United States Department of Agriculture. This included the establishment of the *B. invadens* Steering Committee (BiSC), a government agency tasked with developing action plans in case of outbreak in South Africa. BiSC maintains a network of traps to detect outbreaks, and to manage communication and data generation on the spread and incidence of *B. invadens*. In the event of outbreak, the affected area is placed under immediate quarantine to control the movement of fruit, the number of traps in the area is increased, and field sanitation is intensified. These increased control methods are put in place for a minimum period of eight weeks, which may be extended if the outbreak persists (Manrakhan, Brown, Henter, Stones, & Daniel, 2012). Other African nations can learn from the success of Seychelles and South Africa in eradicating and controlling *B. invadens,* but for many, money remains the limiting factor in the implementation of similar practices.

The following study aims to implement MAT using different baits that are locally sourced and come at a cheaper price than the preferred methyl eugenol. In order to aid in overcoming the economic hurdle of pest management facing the farmers of Pemba, alternative baits that do not rely on expensive imported chemicals and instead feed the local economy are desirable, not to mention more easily obtainable. Eugenol, a major component of methyl eugenol, is naturally found in numerous plants cultivated in Zanzibar, including clove and eucalyptus. The Zanzibar State Trading Corporation, a state run enterprise, operates an essential oil distillery that synthesizes clove stem oil, eucalyptus citriodora oil, and numerous other oils. Through baiting traps with locally produced, clove stem oil, eucalyptus citriodora oil, and lemongrass oil, we tested the efficacy of alternatives to methyl eugenol in search of more cost effective ways to fight this invasive species.

However, techniques, such as MAT, are only effective when coupled with strict farm sanitation practices and routine trap maintenance. As part of the study, local farmers were interviewed on the severity of the *B. invadens* infestation and the involvement of the Ministry of Agriculture in combating the issue. The information provided is intended for use by the Ministry to aid in future studies and education campaigns on the necessary steps farmers must take to combat *B. invadens*.

Rainfall data was also collected at each sight in order to contribute to current knowledge on the ecology of *B. invadens*. Numerous studies (Ekesi et al., 2006, Mwatawala et al., 2006, Rwomushana et al., 2008) have been conducted on the seasonality, host utilization, and temperature dependence of *B. invadens*, but little research has been completed to examine the effect of rainfall on *B. invadens* numbers. Increased rainfall equates to increased vegetation, and therefore an expected increase in *B. invadens* numbers. This information will be used to aid in future eradication practices and to better predict future outbreaks.

Study Area

The study was conducted on the island of Pemba in the Zanzibar archipelago located in the western Indian Ocean (Fig. 2). It lies at approximately S 5° 10' and E 39°47', approaching 50 km off the coast of mainland Tanzania, separated by the Pemba Channel. Pemba, also known as *Al Jazeera Al Khadra* or "The Green Island" in Arabic, holds an area of 988 km^2. The island is made up of coral rag substrate as well as loamy soil, apt and fertile for cultivation. The island experiences bimodal rainfall patterns with heavy precipitation periods from March to May and from September to November, known as *Masika* and *Vuli,* respectively. The tropical monsoon climate of Pemba, with average temperatures ranging from 24° to 28°C along with an annual average rainfall of 1435mm provides for lush, verdant vegetation (Weatherbase, 2014).

Figure 2 Map of Zanzibar Archipelago

Currently the flora of Pemba displays the residual traces of human impact throughout history. Much of the Island's established vegetation was cleared and replaced with clove trees, *Syzygium aromaticum* for export in the 19th century, in an attempt to stimulate a source of revenue for the economy of Zanzibar (Martin, 1991). At present, these areas suffer the consequences of monoculture and an aging tree stand as well as the tumult of the increasingly competitive world market for cloves (Walsh, 2009). The widespread plantation of cloves contributed to the distinctive agro-ecological zones that bisect Pemba, predominantly displaying plantations in the west and coral rag forest in the east, checkered with subsistence farming domains (Middleton, 1961).

As per the 2012 census, the island of Pemba is home to 406,847 people (National Bureau of Statistics, URT, 2012). The history of this population includes prior foreign and colonial rule that have left layered imbrues on the culture of Pemba. Foreign interest heightened as Zanzibar developed into a favorably located center of trade. In the 15th century, Zanzibar was enveloped by the Portuguese Empire and remained under loose Portuguese control until the Omani Sultanate assumed jurisdiction at the end of the 17th century. The Omani sultanate held an influential presence in Zanzibar during the 1800's and Pemba in particular was home to agricultural production for export fueled by slave labor (McHanon, 2006). The marring of slavery was not abolished until the strategic port of trade changed hands and fell under British rule beginning in the 19th century. Colonial dominion persisted in Zanzibar untilmetamorphosis toward independence began in the mid 20th century (Bhagat & Othman,1978). In April 1964, the freshly independent government of Zanzibar, including Pemba, was upturned by revolution. The union of Zanzibar and Tanganyika forming the United Republic of Tanzania marks the most recent monumental pivot in the political history of Pemba. Fifty years after the revolution, Zanzibar maintains a semi-autonomous status within the Union Government, ruled by a single political party.

As the predominant economic activity in Zanzibar, agriculture accounts for 30.2 percent of Gross Domestic Product (GDP) and represents roughly 75 percent of foreign exchange earnings. About 80 percent of the population of Zanzibar, relies directly or indirectly on the agriculture sector for their livelihoods (Rajab, 2013). Clove, coconuts, and formerly mangos before export quarantines, comprise the traditional export crops, while rice, cassava, banana, sweet potatoes, yams, and legumes are among the most common staple crops.

The secluded island of Pemba provides for a unique study area. The Island's geographic isolation is advantageous in the endeavor to eradicate the invasive polyphagous fruit fly *Bactrocera invadens.* Pemba is more vulnerable to infestationdue to the low levels of wild hosts that serve to diminish the destruction of cultivated crops in other regions. In this case the cultivated produce supporting the livelihoods and nourishment of the people of Pemba are the primary hosts in jeopardy of infestation. Thus, the island presents an exemplary study area. For the purposes of this integrated pest management investigation, ten geographically dispersed sites were chosen as representative samples within the study area of Pemba.

Methodology

The methodology used in this study falls under the following seven categories; sites, permission and awareness, trap construction, trap installation, interviews, data collection and data analysis.

Sites

Ten geographically dispersed locations in Pemba were chosen as representative sampling sites for the integrated pest management study of *Bactrocera invadens* (Fig. 3). Sites located in Northern Pemba include Ole (S 05°11’32.6’’, E 39°48’51.9”), Wingwi njuguni (S 05°01’36.8”, E 39°48’51.6”), Shenge Juu (S 05°4’39.7”, E 39°48’29”), Kambini (S 05°7’11.9”, E 39°48’46.4”) and Tumbe (S 04°56’54”, E 39°46’56.2”). While Vikunguni (S 05°12’38.7”, E 39°48’4.7”), Pujini (S 05°16’4.7”, E 39°47’22.1”), Wesha (S 05°13’48.8”, E 39°43’44.6”), Mkanyageni (S 5°23’54”, E 39°40’9.7”) and Ukutini (S 5°20’16.3”, E 39°45’18.9”) comprise the representative sites of Southern Pemba. These sites were chosen and approved by the Director of Plant Protection for the Ministry of Agriculture in Pemba. Each site featured a mature, fruiting mango tree with inveterate effects from *Bactrocera invadens* infestation. The trees examined in this study were under the ownership and management of local

Figure 3 Map of trap sites on Pemba

farmers willing to participate in the study or Ministry of Agriculture Research Stations.

Permission and Awareness

Prior to conducting the study, individuals responsible for each mango tree contained within the ten sites as well as the village leader or *Sheha*, was informed of the intention to perform an integrated pest management study and necessary permission was requested. In order to increase the security of the project and to avoid disruption or interference by nearby residents, public awareness meetings were held in the villages. These meetings served to inform the residents of the project's goals and methods as well as to create a forum to exchange ideas between the Director of Plant Protection and the farmers experiencing losses due to *Bactrocera invadens.* Explanation of the inauspicious introduction of this invasive species to Pemba, the life cycle, and possible management techniques were discussed in the context of the public awareness meetings.

Trap Construction

Figure 4 Trap used in present study

Traps were constructed from 1 L screw-top plastic containers manufactured by Cello® Industries Ltd., in Dar es Salaam (Fig 4.). The trap design was similar to a "McPhail" trap with three, 2cm diameter holes perforated in the walls of the trap for flies to enter. Small holes at the base of the trap were drilled for drainage purposes as well as a hole in the lid for hanging. A medium-width wire was fastened around rolled strips of 25g Absorbent Cotton Wool manufactured by Neosafe©, in the United Kingdom. The wire-caged rolls of cotton were hung inside the traps at the height of the perforated entry holes.

Using precautionary protective gear consisting of latex gloves and respiratory masks at each site, the cotton rolls were soaked in 50 ml Nuvan®500EC diluted to a concentration of 6 ml per 200 ml of water. Nuvan is a fast acting, broad-spectrum insecticide registered by AMVC Chemical UK Ltd. Nuvan contains the organophosphate insecticide Dichlorvos that acts by interfering with cholinesterase, an enzyme responsible for the proper function of the nervous system (Dichlorvos, 1993). Ministry of Agriculture officials recommended Nuvan for having a minimal deterrent effect on flies. Following dosage in Nuvan, the cotton was soaked in 50 ml of one of four attractants. In order to avoid cross contamination separate vessels were used for soaking. The attractants consisted of methyl eugenol, clove oil, lemongrass oil and eucalyptus citriodora oil.

Methyl eugenol is an allyl alkoxy-benzene chemical that is naturally occurring at varying quantities in approximately 450 plant species, particularly in those of ethnopharmacological importance (Tan & Nishida, 2012). Synthetic methyl eugenol has been developed extensively for use as a flavoring agent in many processed foods, as well as in perfumery and essential oil aromatherapy. Tephritidae attraction to methyl eugenol was first discovered by Howlett (1915) when *Bactrocera diversa* was observed as being attracted to citronella oil, used as an insect repellent at the time (Tan& Nishida, 1996). Field studies have since proven that methyl eugenol acts as an attractant for male *Bactrocera invadens* and has been used in integrated pest management methods, including SIT (Mwatawala et al., 2006). The remaining three attractants were sourced from the Zanzibar State Trading Corporation Essential Oil Distillery in Pemba.

The essential oils were made from locally grown cultivars and were processed using steam distillation.

Trap Installation

Four traps were hung at each site, in each of the four directions under the canopy of a fruit bearing mango tree (Fig 5). Traps were suspended between 1.5 and 2 meters off the ground on upright poles, not directly on the mango tree as to eliminate the natural predator effect of *maji moto* or weavers ants, that could misguide capture tallies. In addition, rain gauges were placed at each site in order to monitor possible correlations between rainfall and specimen abundance.

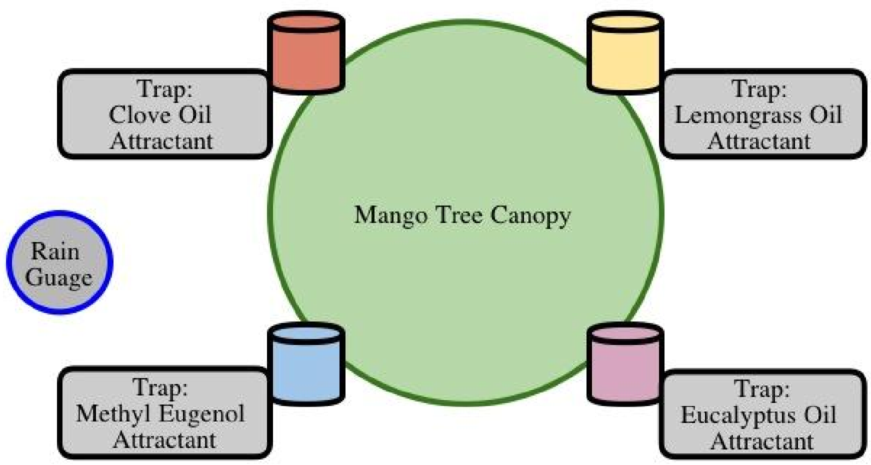

Figure 5 Diagram of site configuration

Interviews

Upon visits to the sites, interviews with resident farmers were conducted. Individual interviews were conducted in Kiswahili, with the aid of a translator. A consistent structure for the interviews was maintained (See Appendix A). Interviews took place at the trap sites on April 9th, 10th and 11th, 2014.

Data Collection

The study was conducted over the span of two weeks during the *Masika* heavy rainfall period during the month of April, 2014. Data was collected from each site, once weekly. Each week's data represents a replicate, for a total of two replicates for each attract and each test site. Capture totals for each trap featuring different attractants at each site were tallied and recorded. The captured flies were buried as to prevent any chance of larvae survival. Rainfall was recorded each week at each site.

Data analysis

A two factor ANOVA and simple correlation were performed using JMP® 9.0 (SAS Institute, Cary, NC).A two factor ANOVA was used to determine a significant difference ($\alpha <$ 0.05) among trap locations and attractants, using the number of flies captured as the measurement variable. In order to meet the assumptions of ANOVA, a Shapiro-Wilke goodness of fit test and Bartlett's test were used to test for normality and equal variance, respectively. The twofactor ANOVA also tested for the interaction between trap location and attractant. A Tukey Honestly Squared Difference (HSD) was performed to determine which specific sites and attractants differed from one another. A multiple correlation was performed to determine if there is a relationship between rainfall and the number of fruit flies captured using each attractant.

Results

The results of this study are categorized into the following two sections; fly trapping and interview results.

Fly Trapping

The statistical results from this study found a significant effect of location on the number of flies captured (F = 19.85, DF = 9, p = < 0.0001). When averaging the catch of all four traps at each site, Tumbe registered the smallest number of flies at 229.50, while Vikunguni recorded the largest average number of flies at 1402.74 (Fig. 6). A multiple comparison test revealed that the sites Vikunguni, Ole, and Pujini were not significantly different, while the sites Pujini and Ukutini were not significantly different. While the sites Ukutini, Mkanyageni, Kambini, Wesha, Shenge Juu, and Wingwi were not significantly different, and the sites Mkanyageni, Kambini, Wesha, Shenge Juu, Wingwi, and Tumbe were not significantly different (Tukey HSD).

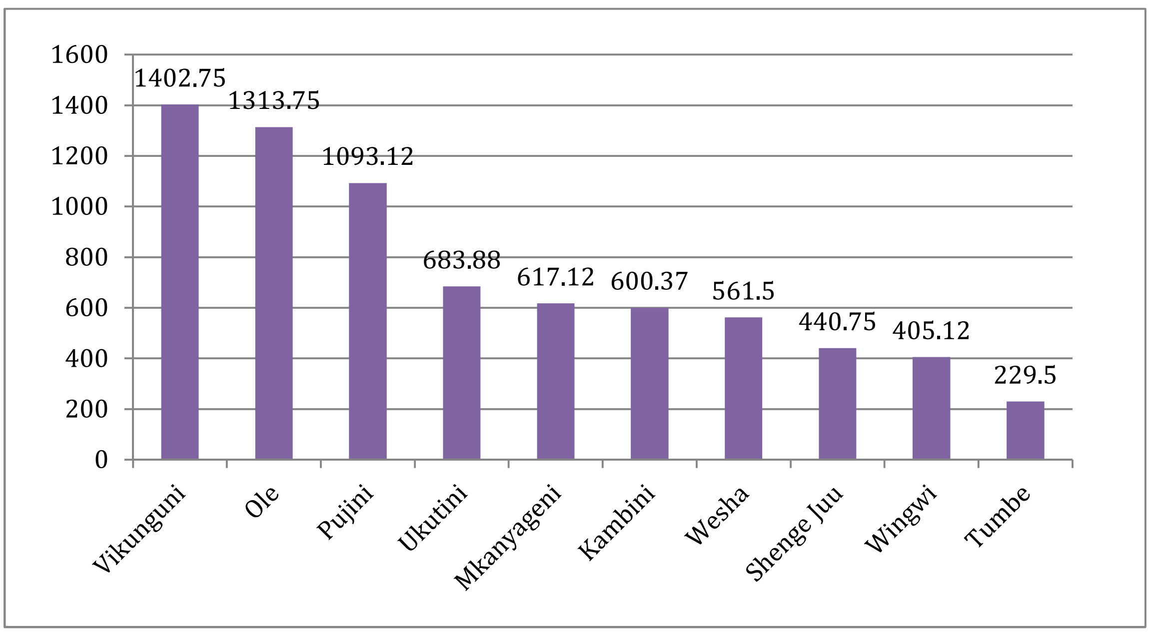

Figure 6 Average fruit fly catch at each test site

There was a significant effect of attract on the number of flies trapped (*F* = 423.18, DF = 3, *p* = <0.0001). The highest average number of flies trapped was recorded for methyl eugenol at 2465.75 flies per trap, while eucalyptus citriodora oil averaged 331.45 flies per trap, clove oil averaged 141.70 flies per trap, and lemongrass oil averaged 0.25 flies per trap (Fig. 7). A multiple comparison test revealed that the number of flies captured in methyl eugenol baited traps were significantly different than the rest of the attractants (Tukey HSD). The same test also showed that the number of flies captured in traps baited with eucalyptus citriodora oil and traps baited with clove oil were not significantly different, as well as traps baited with clove oil and lemongrass oil were not significantly different.

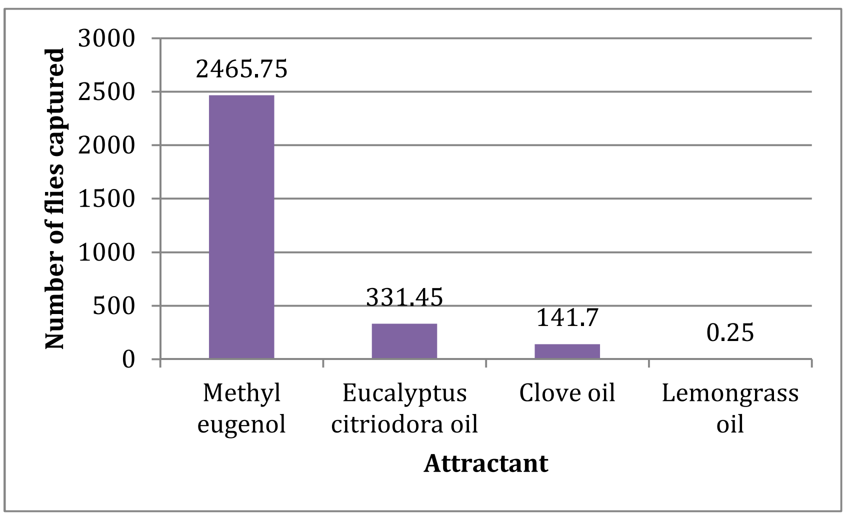

Figure 7 Graph of average catch per attractant

The two factor ANOVA also demonstrated a significant interaction between location and attractant (*F* = 7.44, DF = 27, *p* = < 0.0001). Table 1 shows the relationship between average catch of each attractant at each site. Values connected by the same color-letter combination are not significantly different.Eucalyptus citriodora oil and methyl eugenol had a large range of catch levels across the 10 test sites. Vikunguni, Ole, and Pujini again had the highest levels, and ecucalyptus citriodora oil at Vikunguni had a higher catch rate than methyl eugenol at Tumbe.

The cumulative data of the two replicates are displayed in Figure 8. Catch comparisons of total numbers of fruit fly specimens are revealed for each attractant at each respective data collection site.

Table 1 Fly catch averages for attractants at each test site

Attractant	Vikunguni	Ole	Pujini	Ukutini	Mkanyageni	Kambini	Wesha	Shenge Juu	Wingwi	Tumbe
Methyl eugenol	3893.5 A	4175.5 A	3502.5 A	2348.5 B	2409.5 B	2269.5 B C	2022.5 B C	1575.5 B C D	1564.5 B C D E	897 D E F G
Eucalyptus citriodora oil	1268 C D E F	572.0 D E F G	673.5 D E F G	304 F G	34.5 G	119 G	139.5 G	145.5 G	43.5 G	14.5 G
Clove oil	449.5 F G	508 E F G	196.5 G	82.5 G	24.5 G	12 G	84 G	42 G	11.5 G	6.5 G
Lemongrass oil	0 G	0 G	0 G	0.5 G	0 G	1 G	0 G	0 G	1 G	0 G

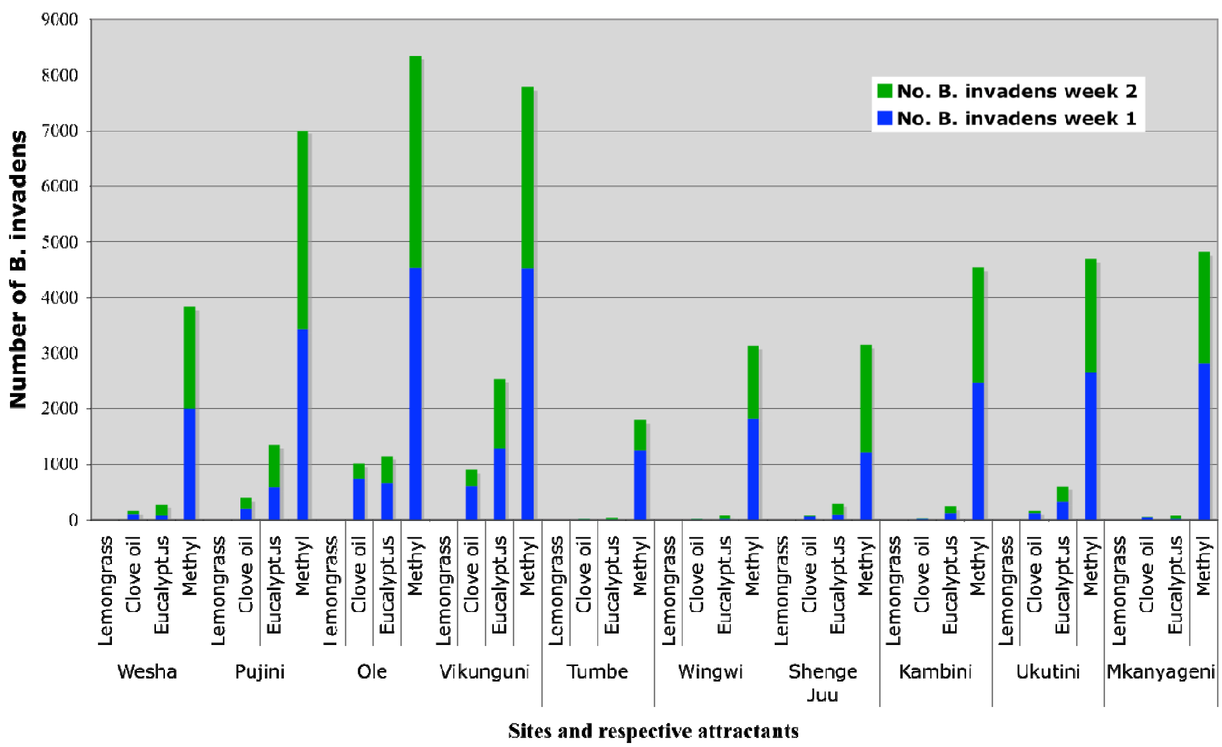

Figure 8 Attractant catch comparisons of test sites

There was no significant correlation between rainfall and the number of flies captured at each site ($r = 0.2814$, $p = 0.258$). Average rainfall was 490 ml, as the highest level was recorded at Tumbe, reaching 960 ml, and the lowest level was observed at Ukutini with 60 ml (Fig 8).

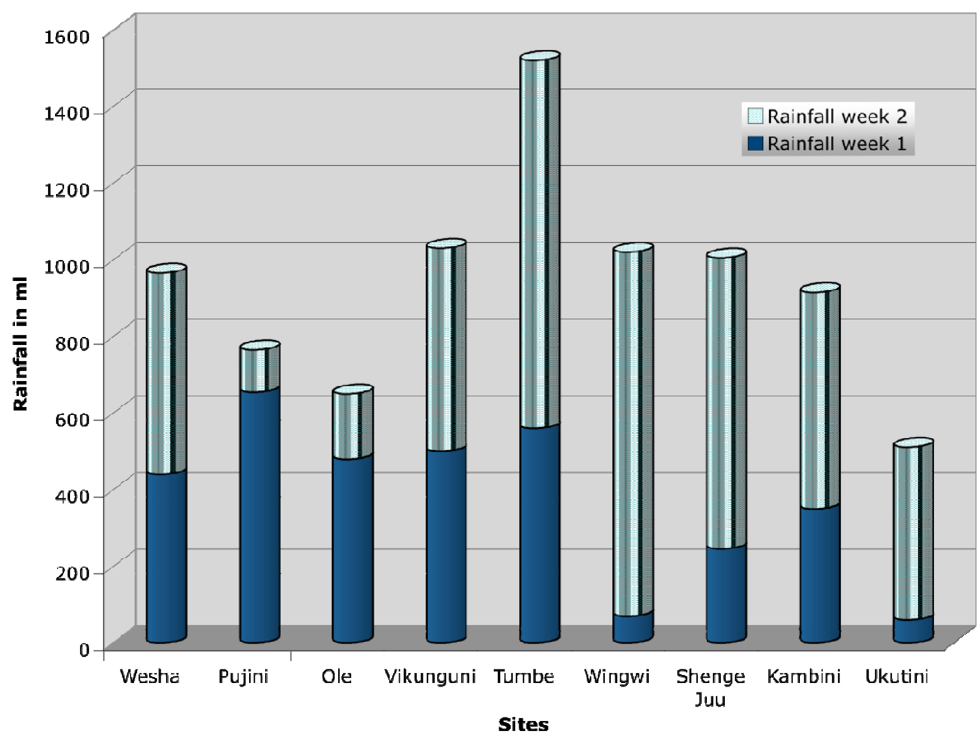

Figure 8 Cumulative Rainfall at test sites

Interview results

A total of ten individual interviews were conducted. The age of respondents ranged from 18 to 65 with a mean age of 38.5. Nine of the respondents were male and one was female. Each of the respondents contributed to a collective list of crops cultivated by interviewees. The list is comprised of mango, pineapple, eggplant, tomato, rice, beans, cassava, ground nuts, orange, pineapple, coconut, banana, yams, cane sugar, watermelon, amaranth, onions, sweet peppers, jackfruit, maize, cloves, and mandarins. Of the 25 aforementioned cultivated crops, *B. invadens*rear on a total of nine cultivars (Fig. 9). The frequency of reported damage caused due to the invasive fruit fly was dominated by the mango crop, as can be seen in Figure 9.

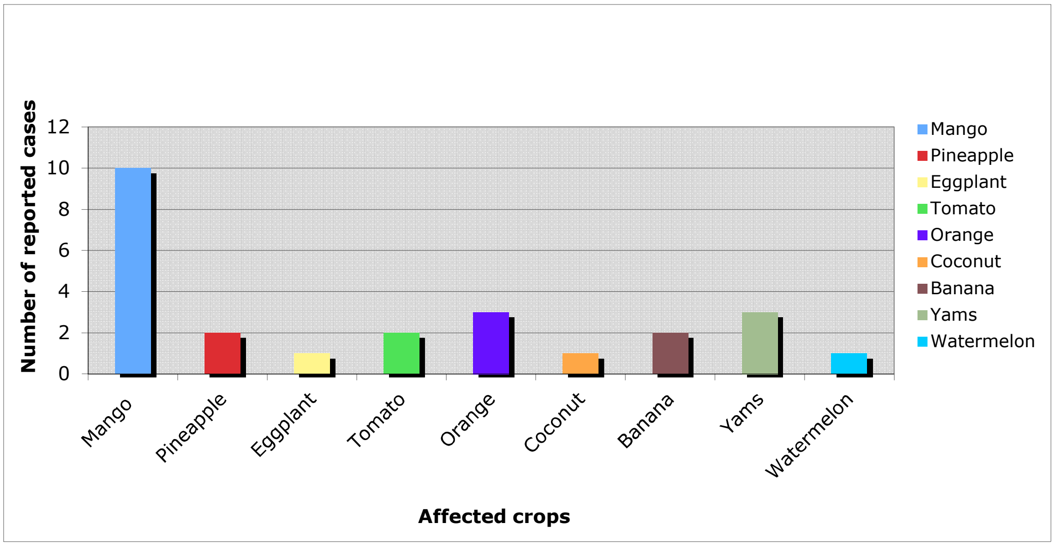

Figure 9 Frequency of infestation of affected crops

Of the crops affected, the average percentage of crop loss due to fruit fly infestation was reported to be 98.5%, with five respondents having suffered 100% losses.

The management methods used by farmers to combat the infestation of *B. invadens* relayed during interviews ranged from a ‘do nothing’ approach to the use of methyl eugenol baited traps(Fig. 10). The use of traps was reported to be the most effective known method of suppression of *B. invadens***.** Yet, less than one third of the respondents reported using traps to halt the invasion of the devastating fruit fly.

Respondents also reported on the advice they had received from the Ministry of Agriculture regarding recommended management techniques. A total of six respondents communicated having been advised by the Ministry of Agriculture officials to implement the baited trap technique for fruit fly management (Fig. 11). Meanwhile, only two interviewees reported having been supplied with traps to initiate this practice. In addition, it was disclosed that those traps set by the Ministry of Agriculture were no longer effective due to the need for reapplication of attractants and killing agents. A second method of management was reported by two respondents that involved the use of dimethoate insecticide spray to combat the fruit fly

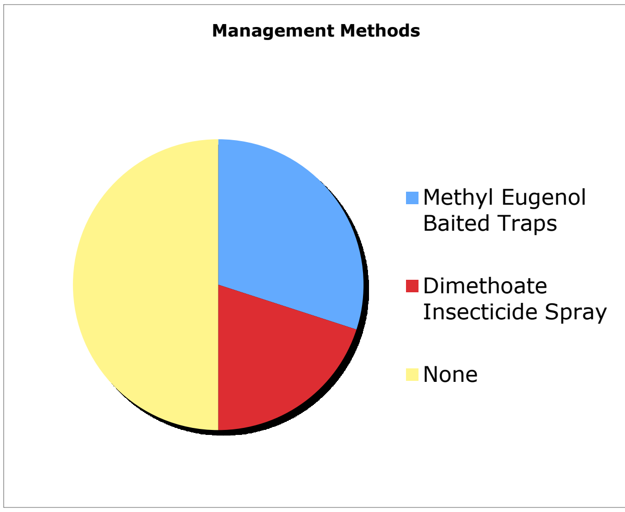

Figure 10 Management methods

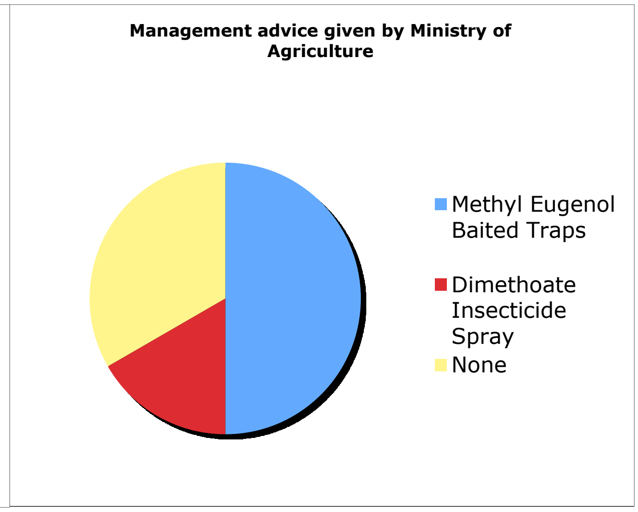

Figure 11 Management advice given by Ministry of Agriculture

infestation, in accordance with advice given by the Ministry of Agriculture officials. The remaining four respondents reported having had no dialogue with officials from the Ministry of Agriculture regarding management methods and as a result did not practice any control technique.

In response to a question regarding the observed changes over time in *B. invadens* infestation, interviewees reported a year-round presence with increased levels during peak ripeness of host crops. In the opinion of the respondents, the most viable solution for combating *B. invadens* was to increase the number of traps on the island of Pemba and supply those traps with sufficient and consistent attractants and killing agents. This sentiment was shared by 100% of the interviewees.

Discussion

Over the two weeks of trapping, a grand total of 58,694 flies were captured in all 40 traps. A similar study conducted in the Morogoro region of Tanzania by Mwatawala et al. (2006) over a period of 61 weeks, using 39 traps at four sites captured a total of 202,191 flies. The present study captured more than a fourth of the flies caught during the Mwatawala study, in just three percent of the time. Additionally, the Mwatawala study recorded the majority of the *B. invadens* catch during the peak of mango and guava seasons, while the present study was conducted in between the two mango seasons that occur annually on Pemba. Current literature reports that increases in *B. invadens* are directly linked with the ripening periods of different mango species (Vaysierres et al. 2005, Mwatawala et al. 2006). If this trend occurs on Pemba, then *B. invadens* abundance will rise above the alarmingly large *B. invadens* numbers recorded in the current study. However, considering *B. invadens* ability to rear on more than 40 cultivated fruits and vegetables, the fruit fly population on Pemba may find sufficient hosts in other cultivars to maintain a large year-round population (Mohamed et al. 2008). Host availability and abundance are key factors in determining population size of all *B. invadens* species (Mwatawala et al., 2005, Vargas et al., 1990). A year round study would reveal exactly how much fluctuation occurs in relation to the availability of different hosts. The levels of *B. invadens* recorded during this study are worryingly high and indicate a massive, island-wide infestation.

Methyl eugenol outperformed the three other attractants tested by a significant margin. However, eucalyptus citriodora oil and clove oil both demonstrated an ability to attract flies. Eucalyptus citriodora oil appears to be a more effective attractant than clove oil with an average of 331.45, although not significantly different than cloves average catch of 141.7. At each site where a large number of flies were recorded in the standard attractant, methyl eugenol, a high number was also recorded in the traps baited with eucalyptus citriodora oil and clove oil. Higher numbers reflect a higher density of flies in that area (Shelley et al., 2010). The high levels of flies caught in the eucalyptus citriodora (1268) and clove oil (572) traps at Vikunguni reveal the potential ability of these attractants to lure a high number of fruit flies.

A cost factor analysis was calculated to draw a comparison between the cost of using methyl eugenol as compared to essential oil attractants (Table 2). In a past study of *B. invadens* in relation to methyl eugenol as an attractant an attraction range was found to be 0.8 square kilometers (Shelly et al, 2010). With an assumed attraction range of $0.8km^2$, a cost value of supplying the Island of Pemba with an area of $988km^2$ with one trap per attraction range was calculated. Due to a lack of proven attraction ranges for the essential oil attractants, a conservative estimate of half the attraction power was calculated (Bureau of Statistics, URT, 2012). The price value of 90,000 Tsh or $56.25 USD per liter was taken from the quoted price for essential oils per liter according to the Pemba Essential Oil Distillery. The price of methyl eugenol, $73.00 USD per liter, was derived from the selling price according to Sigma Aldrich®, the manufacturer from which the Ministry of Agriculture sourced the methyl eugenol (Sigma Aldrich). Consistent with the methodology, 50 ml of attractant was allotted per trap and calculations were computed accordingly. As can be seen in Table 2 the total cost as well as the cost per trap to supply the island of Pemba with methyl eugenol baited traps is higher than the cost to supply each trap with an essential oil attractant. This is true for both assumed attraction ranges.

Table 2 Cost factor analysis

Attraction range	0.8 km^2	Attraction range	0.4km^2
Number of traps needed	1235	Number of traps needed	2470
Total cost of methyl eugenol	$4507USD	Total cost of methyl eugenol	$9015.50USD
Total cost of essential oil	$3473.44USD	Total cost of essential oil	$6452.88USD
Cost per methyl eugenol trap	$3.65USD	Cost per methyl eugenol trap	$3.65USD
Cost per essential oil trap	$2.81USD	Cost per essential oil trap	$2.61USD

For *B. invadens*, and over 80 other *Bactrocera* species, methyl eugenol is the only known chemical attractant (Tan & Nishida, 2012). Methyl eugenol is a naturally occurring substance in over 450 species of plants in over 80 families (Tan&Nishida, 2012) and *Bactrocera* species are known to feed on a number of these plants. *B. invadens* males are highly attracted to methyl eugenol as it acts as an enhancer of male fruit fly sex pharamonal components in the rectum of the male *Bactrocera,* resulting in increased male mating competitiveness (Tan & Nishida, 2012). The methyl eugenol used in traps is present in much higher concentrations than found anywhere in nature, resulting in high capture rates. Eucalyptus and cloves are known to synthesize eugenol naturally. It is likely that Eucalyptus citriodora oil and clove oil contain some amount of eugenol, methyl eugenol, or a similar analogue that attracts the fruit fly, but more studies are needed to determine which component of eucalyptus citriodora oil and clove oil are acting as the attractant.

All three working attractants also displayed a wide range of catch quantity over the 10 sites. Three of the sites, Vikunguni, Ole, and Pujini, had average catches above 1000 flies per week, while another three sites, Shenge Juu, Wingwi, and Tumbe, had catches below 500 flies per week. Fruit fly frequency is influenced by the architecture of the local environment and will differ between centrally organized habitats of a single or few hosts and unorganized habitats with hosts and non-hosts interspersed. Environmental structure, including vegetation, human infrastructure, and geological formations, also has a powerful effect on the odor dynamics, resulting it different attractants possessing different spatiotemporal characteristics in organized versus unorganized habitats (Shelly et al., 2010). Organization of the local environment and its impact on the appetitive flights of fruit flies and the olfactory influence of the attractants are the most probable reason for the varied results between sites and must be taken into account in future studies.

The present study also revealed no significant correlation between rainfall and fruit fly abundance, despite the fact that some previous studies have demonstrated a positive correlation between the two (Veyssieres et al., 2005). Moreover, Pemba experiences highly variable rainfall levels. For example, during one week of our study, Wingwi experienced 70 ml of rainfall, while Ole and Pujini, each within 20 km, received 480 ml and 655 ml respectively. It is probable that high levels of rain in one area could lead to a large emergence of fruit flies, which then spread to areas of less rainfall. Additionally, a year round study would likely reveal a positive correlation between rainfall and fruit fly abundance, as a two week study is not enough time for rainfall levels to have a strong influence on vegetative growth and ultimately fruit fly populations.

Interestingly, *B. invadens* was the only fruit fly species captured in our traps, despite the known presence of four indigenous flies on Pemba, one of which, *Ceratitis cosyra*, is attracted to methyl eugenol (Mwatawala et al., 2006). Declines in indigenous fruit fly species have been recorded elsewhere on the continent, with *C. cosyra* reportedly nearing extinction in neighboring Kenya (Ekesi et al., 2006, Mwatawala et al., 2006). Rapid infestations, such as that of *B. invadens*, have caused widespread ecological damage in the past and the disappearance of *C.*

cosyra could be an indication of further disaster. Disappearance of species such as *C. cosyra* can have profound implications for upper and lower trophic levels. It is not improbable, that *C. cosyra* habits contribute to the destruction of an unwanted plant or help desirable plants to pollinate and reproduce. It is equally likely that *C. cosyra* represents an important source of food for various predators. Prolonged *B. invadens* infestation could trigger a cascade of catastrophic ecological events, severely hindering the structure and function of the local ecosystem and its key members.

Our results may have been affected by a few sources of error and limiting factors. More replicates dispersed over a larger area would have yielded more information on localized regions of *B. invadens* infestation. A longer study period and concurrent monitoring of more environmental factors such as temperature and humidity would have shed light on the seasonality of the*B. invadens* population on Pemba.

The results gathered by means of interviews can be placed within the greater context of the important role agriculture sustains in the lives of Zanzibaris. Embedded deeply in the history and culture of Zanzibar, the practice of farming extends beyond subsistence and self-sustainability (Reid, 2012). The impact of a pest plague affecting a host of crops at the magnitude reported by respondents has reverberating and profound effects. Not only are the farmers suffering substantial economic losses, the viability of a way of life is threatened. According to the informants of this study,the degree to which crops are damaged by *B. invadens*, are unprecedented. Yet, the disproportionate level of management is meager in comparison with the reported severity of the issue. The largest inhibiting factor in management for farmers is evidently a combination of lack of knowledge and lack of resources. Those who have been in contact with the Ministry of Agriculture, the authority responsible for plant protection, are aware of the management options, but a lack of funding remains a hindrance. Yet the most concerning result in this study was the lack of knowledge and implementation of low-cost alternatives such as farm sanitation. At the time of study, no management practices were in progress, representing the immense need for education on the options available as well as sufficient support to carry them out. This finding reflects on a breakdown of communication between the Ministry of Agriculture and farmers regarding the urgent need for management and in particular, sanitation practices.

In planning the development of an effective IPM strategy certain factors need to be taken into consideration. Firstly, the diversity of hosts needs to be surveyed for the island, as it is a major factor in determining fruit fly abundance. Consistent monitoring of infestation rates and degree of crop damage is necessary. A strategic plan of eradication or at least control can then be launched. Further research into cultural practices must be completed, as has been done in India where a neem-based product, azadirachtin, has been used in defense against *B. dorsalis*. (Mwatawala et al., 2009). A combination of chemical, practice-based and cultural solutions is integral to the implementation of a cost conscious and effective pest management plan. Also supporting the success of an IPM strategy is the collaboration between various government agencies and civil society organizations. A cooperative approach should combine the authority of the Ministry of Agriculture, customs for prevention of external infestation, enforcement agencies to support quarantine regulations as well as media outlets for an educational campaign including training for proper management. In the event that the fruit fly population is controlled, effective monitoring, legislative controls and consistent trap maintenance must be put into place to prevent the reoccurrence of outbreak. An example of a successful management campaign is that which is found in South Africa. Due to the creation of the BiSC, a governmental agency tasked solely with combating fruit fly invasions, South Africa has yet to experience outbreaks and infestation of *B. invadens* at the levels experienced in neighboring and nearby countries. Through the maintenance of a monitoring network of more than 1,500 traps and outbreak contingency plans involving quick responses, heavy quarantine, increased farm sanitation, and increased protein bait spray, BiSC has so far been successful in keeping South African farms free of *B. invadens* (Manrakhan et al. 2012).

If no IPM strategy is implemented then *B. invadens* will continue to act as a detriment to agricultural activity on the island of Pemba. With increasing global trade, tourism, fragile global quarantine networks, and underprepared personnel, the high levels of *B. invadens* in Pemba will aid in its spread to other regions of the world, compounding an already complex issue (Mohamed, 2012).

Conclusion

The staggering total capture values of *B. invadens* over the course of this brief study indicate the magnitude of infestation that faces the farmers of Pemba. In attempts to manage this swelling inundation, integrated pest management solutions must be implemented and tailored to match the needs and constraints of the infested area. With limited funding, the highly effective attractant methyl eugenol is not at present a feasible or sustainable component for MAT fruit fly traps. This study found that both clove oil and eucalyptus citriodora oil have significant potential as alternative attractants. Traps featuring these locally sourced, economical replacements in combination with rigorous farm sanitation strategies could be foundational steps toward overcoming the current fruit fly infestation. The results of this study provide preliminary insight into the importance of establishing an organized, informed and appropriate IPM strategy. If an effective IPM strategy is implemented in Pemba, it has the potential to prevent the devastation caused by *B. invadens* and serve as a model of resourceful pest management at the forefront of a global crisis.

Recommendations

Further study of the incidence of infestation by *B. invadens* on the island of Pemba over an extended period of time is necessary to map trends associated with climatic as well as seasonal changes. Consistent monitoring of infestation levels over the course of a year would provide the Ministry of Agriculture with the baseline information necessary to launch an effective annihilation campaign. In conjunction with a long-term study, increased numbers of traps are compulsory for success. An agricultural survey on the island of Pemba of fruit crop densities, location of where they are grown, and period of ripeness would facilitate a better understanding of the hosts for *B. invadens,* while target areas for management could be established.

Further study of the various isolated components of clove and eucalyptus oils and their attraction influences is necessary to determine if a more concentrated level of attraction agent could be derived from the essential oils. This, along with dosage dependent studies for each attractant could produce a more efficient or effective lure.

The efficacy of other attractants, including essential oil of sweet basil (*Ocimum canum*) and eugenol extracted from clove oil has yet to be tested. Both of the aforementioned substances are periodically produced from local cultivars at the Pemba Essential Oil Distillery. Due to the presence of eugenol in their composition, there is potential for successful attraction of *B. invadens* that should be investigated.

Founded on the information gathered from interviewees, an education campaign appears to be essential in the combat against fruit fly infestation. By soldering strong communication links between the Ministry of Agriculture and the farmers responsible for fruit production, the future damage caused by *B. invadens* could be significantly diminished. Education on proper farm sanitation techniques such as burying affected fruit is indispensable, and remains the single most cost effective, albeit labor-intensive, method of management.

Given the international scope and proliferation of the problem at hand, an appeal for international support and funding for suppression and management is advisable. The costs for management techniques such as MAT, are at present insurmountable for the local Ministry of Agriculture. Thus, external aid is required to launch a successful eradication operation.

References

Bhagat, H., & Othman, H. (1978). Colonialism and class formation in Zanzibar.*Utafiti(3)*, 193.

The intricacies of historical tensions resulting from colonialism and the formation of classes in Zanzibar referenced in this study were informed by this source.

Dichlorvos. (1993). *Extension Toxicology Network*. Retrieved April 28, 2014, from http://pmep.cce.cornell.edu/profiles/extoxnet/carbaryl-dicrotophos/dichlorvos-ext.html

Information on the toxicity of Nuvan as an insecticide was gathered from this website compiled by Cornell University.

Ekesi, S., Maniania, N., Mohamed, S. (2011). Efficacy of soil application of and the use of GF-12 spinosad bait spray for suppression of (Diptera: Tephritidae) in mango orchards. *Biocontrol Science and Technology, 21(6),* 299-316.

Effect of a new bait spray on *B. invadens* control and the environmental health risks it poses to areas where it is practiced.

Ekesi, S., Nderitu P.W., Rwomushana, I. (2006).Field infestation, life history and demographic parameters of the fruit fly Bactrocera invadens (diptera: tephritidae) in Africa.*Bulletin of Entomological Research, 96*, 379-386.

A study on the life cycle and population trends of *B. invadens*. Included pertinent data on reproductive rates and lengths of different key development stages.

IAEA. (2004). *Trapping Guidelines for Area-Wide Fruit Fly Programmes*.Vienna.

TheInternational Atomic Energy Association produced guidelines effective for pest management for control of various fruit fly species in an agricultural setting.

JMP®, Version 9.0.4. SAS Institute Inc., Cary, NC, 1989-2013.

The statistics software used for data analysis.

Martin, P.J. (1991). The Zanzibar clove industry. *Economic Botany,45*(4), 450-459.http://link.springer.com/journal/12231

This historical view of the impacts, economically and otherwise, of the plantation of cloves for exportation in the islands of Zanzibar was used to inform the study area aspect of this study.

McMahon, E. (2006). "A solitary tree builds not": heshima, community and shifting identity in post-emancipation Pemba island. *International Journal Of African Historical Studies, 39*(2), 197-219.

Historical information on cultural identity in post-emancipation Pemba and how it related to community structures was gathered from this source.

Middleton, J. (1961). Land tenure in Zanzibar, *Colonial Research Studies*, *33*. 15-88.

The land-ownership dynamics of Zanzibar and a historical view of class structures throughout history as they relate to land tenure is articulated in this research.

Methyl eugenol. (n.d.). *Sigma Aldrich*. Retrieved April 21, 2014, from http://www.sigmaaldrich.com/catalog/product/aldrich/w247502?lang=en®ion=TZ

The current market price for methyl eugenol was gathered from this website for calculations of cost fact analysis.

Mohamed, S. (2012).Biology and management of fruit flies in Africa, their risk of invasion and potential impact in the Near East. Symposium on the management of fruit flies in the Near East countries, Hammamet, Tunisia, 6-8 November, 2012, Hammamet.

This Powerpoint presentation was referenced for the state of *B. invadens* infestation in Sub-Saharan Africa, methods used to prevent it and where it is thought to spread next.

Mohamed, S.A., Ekesi, S., Hanna, R. (2008) Evaluation of the impact of *Diachasmimorpha longicaudata*on *Bactrocera invadens* and five African fruit fly species.*Journal of Applied Entomology, 132*, 789-797.

This study was referenced for information on the possibility of biological control of *B. invadens* by the introduction of an endoparasite, for use in an integrated pest management scheme.

Mwatawala, M., De Meyer, M., Makundi, R., & Maerere, A. (2009). Design of an ecologically-based IPM program for fruit flies (Diptera: Tephritidae) in Tanzania.*Fruits*, *64*(3), 803-90. Retrieved April 11, 2014, from DOI: 10.1051/fruits/2009003

This detailed design for integrated pest management was referenced for a sequential and effective approach to eradication of a devastating invasive family of fruit flies.

Mwatawala, M.W., De Meyer, M, Makundi, RH, Maerere, A.P. (2006). Seasonality and host utilization of the invasive fruit fly, Bactrocera invadens, (dipt., tephritidae) in central Tanzania. *Journal of Applied Entomology, 130*(9-10), 530–537.

A study on host preference of *B. invadens*, whereby researchers placed traps under different hosts to determine which fruits the invasive species were inclined to rear on, and at during was seasons.

National Bureau of Statistics, Tanzania (2012, December 8). GeoHive - Tanzania population statistics. Retrieved from http://www.geohive.com/cntry/tanzania.aspx.

National Census of Tanzania for the year 2012. It provided data on individual regions.

Rajab, M. (2013). Socio Economic Survey. *Zanzibar Official Statistics Provider,March 2013*. Retrieved April 29, 2014, from www.ocgs.go.tz

This statistical report on the socio-economic status of Zanzibar gave essential information on the contribution of the agricultural sector to the Gross Domestic Product of Zanzibar.

Reid, E., (2012). How does climate change affect agricultural stability in southeast Unguja? An assessment of the threats to agriculture and food security from rising temperature and changes in predictability and intensity of rainy seasons.Independent Study Project (ISP) Collection. Paper 1278.http://digitalcollections.sit.edu/isp_collection/1278\

Past ISP on the public perception of climate change as it relates to agricultural production and food security. Farmers were interviewed on the impact of climate change on their livelihoods and any changes in relating factors, such as inconsistent rainy seasons.

Rwomushana, I., Ekesi, S., Ogol, C. K., & Gordan, I. (2009). Mechanisms contributing to the competitive success of the invasive fruit fly *Bactrocera invadens* over the indigenous mango fruit fly, *Ceratitis cosyra*: the role of temperature and resource pre-emption. *Entomologia Experimentalis et Applicata*, *133*, 27-37. Retrieved April 1, 2014, from the EBSCOHOST database.

The development stages of two fruit fly species, the invasive *B. invadens* and the indigenous *C. cosyra,* were compared to understand factors contributing to recent decline of *C. cosyra* and rise of *B. invadens* and possible wider ecological implications.

Rwomushana, I., Ekesi, S., Ogol, C.K.P.O., Gordon, I. (2008). Host plants and host plant preference studies for Bactrocera invadens (diptera: tephritidae) in Kenya, a new invasive fruit fly species in Africa. *Annals of the Entomological Society of America, 101*(2), 331-340.

This detailed study served to provide information on the host preferences for *B. invadens,* and also demonstrated that host availability is one of the largest factors in *B. invadens* population levels.

Shelly, T., Nishimoto, J., Diaz, A., Leathers, J., War, M., Shoemaker, R., (2010). Capture Probability of Released Males of TwoSpecies (Diptera: Tephritidae) in Detection Traps in California. *Journal of Economic Entomology*, *103*(6), 2042-2051. Retrieved April 9, 2014, from the BioOne database.

A study to better understand trap capture effectiveness and the ability of monitoring systems to detect outbreaks and estimate population sizes. The study also compared trap effectiveness in urban versus agricultural environments.

Tan, K.H., Nishida, R., (2012). Methyl eugenol: Its occurrence, distribution, and role in nature, especially in relation to insect behavior and pollination. *Journal of Insect Science 12*(56). Retrieved from http://www.insectscience.org/12.56.

This article was used to better understand the role of methyl eugenol, its chemical effect on *B. invadens* and its prevalence in nature.

Tan, K. H., & Nishida, R. (1996). Sex pheromone and mating competition after methyl eugenol consumption in the Bactrocera dorsalis complex.*Fruit fly pests: a world assessment of their biology and management.* St. Lucie Press, Delray Beach, FL, 147-153.

This study relayed information on the attraction of the genus *Bactrocera,* why these species they are attracted, and its effect on reproductive success. This information is crucial as it pertains to conducting an effective management plan involving male annihilation techniques.

USDA ERS - Home: FAQs. (2013). *USDA ERS - Home: FAQs*. Retrieved April 21, 2014, from http://www.ers.usda.gov/faqs.aspx#10

TheUnited States Department of Agriculture web page provided quick facts about the agricultural productivity of different states and the structure and function of the Department of Agriculture.

Walsh, M. T. (2009). The use of wild and cultivated plants as famine foods on Pemba island, Zanzibar. *Etudes Océan Indien, 42/43 (Special issue: Plantes et Sociétés dans l'océan Indien occidental)*, 217-241.

An intriguing historical view of subsistence agriculture as it relates to famine and food security on the Island of Pemba. This article provided information on the resourceful uses of flora by the inhabitants of Pemba.

Vargas RI, Stark JD, Nishida T, (1990). Population dynamics,habitat preference and seasonal distribution patterns of Oriental fruit fly and Melon fly (Diptera: Tephritidae)in an agricultural area. *Environmental Entomology. 19*, 1820–1828.

Insight was gained from this comparative study of two cohabitant species regarding their competitive displacement.

Vayssières J., Goergen G., Lokossou O., Dossa P., AkponsonC., (2005). A new *Bactrocera* species in Benin among mangofruit fly (Diptera: Tephritidae) species.*Fruits, 60,* 371-377.

Vayssière et al. produced an informative study of a *Bactrocera* species relaying pertinent information on host preferences.

Yussuf, S., personal communication, March 7, 2014.

Interview with Said Yussuf, Director of Plant Protection, about prevalence of fruit flies on Pemba and how the Ministry of Agriculture is responding.

Zanzibar, Tanzania Weather. (n.d.).*Weatherbase*. Retrieved April 18, 2014, from http://www.weatherbase.com/weather/weather.php3?s=7836.

Weatherbase provided temperature records for the Island of Pemba.

Appendix A

Farmer Interview questions:

1. What is your Name?

2. What is your age?

3. What crops do you cultivate?

4. Which crops are affected by fruit fly infestation?

5. What percentage of crops are lost due to fruit fly damage?

6. Have you noticed a change in presence of fruit fly damage over time?

7. What management techniques have you used to combat this problem, if any?

8. Have you received advice from the Ministry of Agriculture on management methods?

9. What, in your opinion is the solution to the infestation of fruit flies on the Island of Pemba?