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Role Played by Community, Farmers and Government during Eradication and Suppression of *Bactrocera dorsalis* (Diptera: Tephritidae) in Mopani District Municipality in Limpopo Province, South Africa

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Abstract: *Bactrocera dorsalis* syn *Bactrocera invadens* (Diptera: Tephritidae) (*B. dorsalis)* is a quarantine pest of Asian origin with host plants such as Mango (*Mangifera indica*), Guava (*Psidium guajava*), Citrus (*Citrus* spp.) and Papaya (*Carica papaya*). *B. dorsalis* is considered as a major threat to many countries due to its ability to establish and spread to new areas, the damage it causes to hosts and potential impact on market access. Due to this threat, the DALRRD (Department of Agriculture, Land Reform and Rural Development) placed traps to monitor *B. dorsalis* in Mopani District Municipality in 2010. The traps were serviced once a month. A single male specimen of *B. dorsalis* was detected for the first time on 27 April 2012, in the Deerpak area in Mopani District Municipality, of the Limpopo Province, South Africa. Other incursions occurred in Letsitele and Hoedspruit in the same district, in December 2012. Subsequent to the detections, the DALRRD initiated delimiting surveys. A quarantine area was implemented to regulate the removal of host fruits to contain the pest and to initiate an eradication program. The eradication and suppression methods focused on applications of BAT (Bait Application Technique), MAT (Male Annihilation Technique) and orchard sanitation. An integrated approach was followed by involving several role players which included rural communities, farmers, industry organizations, DALRRD and LDARD (Limpopo Department of Agriculture and Rural Development). After the initial detection in 2012, *B. dorsalis* was again detected in Deerpak and Letsitele in 2013, but, not in Hoedspruit. In 2014 however, *B. dorsalis* was detected in all three areas with higher numbers in summer, with the highest number of 11,953, 2,260 and 8 in Deerpak, Hoedspruit and Letsitele, respectively. This increase could have been attributed to the higher than normal rainfall and reduced phytosanitary efforts in some areas by affected parties. The results of this study revealed that *B. dorsalis* can be successfully eradicated and or suppressed provided that role players work together and invest their efforts and resources in an area-wide approach.

Key words: Quarantine, *B. dorsalis*, eradication, suppression, government, farmers, Mopani.

1. Introduction

South Africa hosts most fruit fly (Diptera: Tephritidae) species of economic importance, which are indigenous to Africa. This includes the genus *Ceratitis* MacLeay namely *C. capitata* (Wiedemann), *C. rosa* (Karsch) and *C. cosyra* (Walker) and *Dacus* such as *D. punctatifrons* (Karsch) and *D. bivititatus* (Bigot) [1-3].

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The genus *Bactrocera* Macquart comprises 651 described species and it is the most economically significant fruit fly genus with at least 50 species considered to be important pests [4]. The genus has a high rank on quarantine fruit fly pest lists worldwide due to their high mobility and dispersive capabilities, high reproductive rates and because they are polyphagous fruit flies [3-6].

The Oriental fruit fly (OFF), *Bactrocera dorsalis* (Hendel), syn [7] *B. invadens* Drew, White and

Tsuruta, is an invasive fruit fly species of Asian origin, a highly polyphagous pest and it is considered a quarantine pest of international significance. Oriental fruit fly is a major threat to many countries due to its invasive ability, the damage it causes to hosts and its potential impact on market access [8]. Major hosts include Mango (*Mangifera indica*), Papaya (*Carica papaya)* and Guava (*Psidium guajava*). Other recorded cultivated hosts include Apples (*Malus domestica*), Citrus (*Citrus* spp.), Table grapes (*Vitis vinifera*), Peach *(Prunus persica*), Persimmons (*Diospyros kaki*) and some wild hosts such as Marula (*Sclerocarya birrea*) [8-13].

Oriental fruit fly was reported for the first time in Africa in 2003 in Kenya soon after the completion of a program of monthly fruit collections carried out from February 1999 to January 2003 by R.S. Copeland [4, 13-15]. Since its introduction in Africa, the pest has been established at low altitudes and its high abundance in the field and infestation in different fruit species make it a serious pest [16]. Most important component of the environment affecting adult populations of *B. dorsalis* is the availability of suitable host plants which provide a favourable environment for establishment of *B. dorsalis* [17]. High temperatures, rainfall in summer months and availability of Mango and Longan (*Dimocarpus longan*) which were the most preferred host-plants for the fly) were reported to be essential factors influencing the population fluctuations of *B. dorsalis* in the Yuanjiang valley area in China [18]. This fruit fly species has a large socio-economic impact in rural areas where people depend on fruit to supplement their income [11]. Occurrence of large populations of fruit fly species leads to economic losses for the smallholder and subsistence farmers and a reduced source of essential dietary components, especially vitamins and minerals, to local and urban human populations [15].

Because of the damage caused by *B. dorsalis* and the frequency of its interceptions, many countries are concerned about its risk of introduction. Based on the potential damage this pest poses on the agricultural industry, South Africa developed an early warning system and contingency plans to ensure early detection, rapid response to reduce population numbers and to minimize pest damage. Contingency plans included an action plan to eradicate pest incursions in new areas [8]. A proactive steering committee, BISC (*Bactrocera invadens* Steering Committee) was constituted to provide a platform for multi-stakeholder cooperation in 2008 before the first Oriental fruit fly outbreaks occurred in 2010. The BISC developed national action plan against *B. dorsalis* namely SABIFF (South African *Bactrocera invadens* Fruit fly Action Plan) [19]. One of the key elements to ensure successful control actions is community engagement. Involving the local community ensures that the applicability of several programs becomes more viable as capacity and resource need to respond are met. Communication plays a major role in influencing people's behavior regarding pest management [20].

The purpose of eradication is to eliminate a fruit fly population in an infested area in order to establish a fruit fly pest free area. Suppression of a fruit fly population is aimed to implement control measures to lower the pest population to such an extent that pest damage is limited and that it is economically viable. It can also lead to the establishment of areas of low pest prevalence for fruit flies. Historically, *B. dorsalis* has established and been eradicated after establishment from a number of places, including Ryukyu Islands in Japan, and Nauru, Guam and Northern Mariana Islands in the Pacific [21, 22]. Prior to eradication from Nauru, *B. dorsalis* infested 95% of Mangoes and 90% of Guavas. Since the implementation of eradication methods, the damage on Mango has decreased [8].

The main methods being used for the eradication and suppression of *B. dorsalis* are the BAT (Bait Application Technique) and MAT (Male Annihilation

Technique). The BAT is directed at killing both male and female flies whereas MAT attracts and kills male flies through the use of a fiber board block which is impregnated with an insecticide and a male lure [23]. The BAT can be applied through the placement of an array of protein hydrolysate and insecticide impregnated bait stations in an affected area or with coarse droplet aerial and ground bait sprays consisting out of a mixture of a protein hydrolysate and insecticide [24]. GF-120 as a protein bait sprays (containing Spinosad), it is a low based-insecticide which kills flies after ingestion. It is widely used to control fruit flies in fruit orchards [25]. Studies by [25] showed that the level of fruit fly infestation in mango orchards in Benin was 81% in 2006 after 7 weeks of application and 89 % after 10 weeks of application. MAT alone is able to provide adequate control of male fruit fly numbers over a long period of time while bait application can reduce the number of female flies to prevent them from damaging the fruits [11]. MAT has been successfully used for control and eradication of *B. dorsalis* in a number of cases [26]. Eradication with MAT was first achieved on Rota Island in 1963 [27] and later in the Okinawa Islands in 1982 [28].

Other measures included in the eradication program are orchard and field sanitation which entail the collection and destruction of all fallen fruit containing eggs and fruit fly larvae [3, 8, 23, 24]. This method can contribute towards the reduction of fruit fly population numbers in an orchard as the rapid and regular removal of fallen fruit as it prevents third instar larvae from penetrating the soil to pupate [24].

In South Africa, *B. dorsalis* was detected for the first time in Weipe area, Vhembe District in the Northern part of Limpopo Province, on 5 May 2010, in a Methyl eugenol baited surveillance trap. A delimiting survey was carried out to determine the extent of spread of the pest in the area, by trapping with both Methyl eugenol and Biolure® Fruit Fly (3-component lure) baited traps. After the detection of two flies a quarantine area of approximately 1,100 km^2 (surrounding the area of detection) was implemented to restrict movement of host fruit out of and through the affected area [29-32].

The successful eradication of *B. dorsalis* in the Vhembe District Municipality was accomplished through the use of MAT, BAT and orchard sanitation. Eradication measures were carried out for a period equivalent to the duration of estimated period of which the OFF would have completed three life cycles after the last OFF specimen was detected in the quarantine area. This was equal to a period of 12 weeks. After eight weeks, MAT blocks were removed while surveillance continued for a period of four weeks to confirm eradication. The removal of the MAT blocks played a critical role as they may interfere with the sensitivity of the delimiting traps since both the MAT blocks and the traps make use of Methyl eugenol as an attractant [29]. No *B. dorsalis* was captured within a period of 12 weeks (approximately three generations) after the last fly was detected in the area and the area was subsequently declared as eradicated [29].

Bactrocera dorsalis was detected for the first time on 27 April 2012 in the Deerpark area in the Mopani District Municipality (23.3089° S, 30.7160° E), of the Limpopo Province in South Africa. The area is approximately 322 km from Vhembe District Municipality. A single male fly specimen was collected in a Mango orchard, in a village about 12 km from the Tzaneen town in a McPhail Methyl eugenol baited trap. The trap formed part of the nation-wide network of traps, as part of surveillance of exotic fruit fly program for the control of fruit flies [19].

Mopani District Municipality is one of Limpopo's richest agricultural areas, which contributes to job creation, export market (mostly subtropical/tropical fruits) and the climatic conditions allow for the cultivation and harvesting of a wide variety of agricultural produce, ranging from tropical and subtropical fruits such as Bananas (*Musa spp.*), Mangoes, Papaya, Guava, Citrus, Litchis (*Litchi*

chinensis), Macadamia nuts (*Macadamia integrifolia*) and Avocadoes (*Persea americana*), to cereals such as Maize (*Zea mays subsp. Mays*) and Wheat (*Triticum aestivum*), and vegetables such as Tomatoes (*Solanum lycopersicum*) and Potatoes (*Solanum tuberosum*) and wild fruits such as Marula (*Sclerocarya birrea*) and commercial and indigenous forestry [33].

This paper will examine how *B. dorsalis* was eradicated and or suppressed, as well as how these phytosanitary methods applied were effective.

2. Materials and Methods

The eradication and suppression methods were carried out from December 2012 to December 2014 in the three areas, namely Deerpak, Hoedspruit and Letsitele, in the Mopani District Municipality in Limpopo Province, South Africa. All these measures were implemented according to the provisions of Control Measures, R.110, of the Agricultural Pests Act (Act No. 36 of 1983), and pre-approved SABIFF [31, 32]. The program was funded by DALRRD (Department of Agriculture, Land Reform and Rural Development) as an outcome from the BISC. This was a joint effort between relevant fruit industries and LDARD (Limpopo Department of Agriculture and Rural Development).

2.1 Detections of B. dorsalis in Mopani District Municipality

The delimiting surveys were conducted according to the SABIFF within a 5 km radius from the detection point as well as 100 km transect radiating from the detection traps from the first detection area in April 2012 (Fig. 1). No further specimens were detected after 12 weeks of delimiting. One male specimen was again detected immediately after completion of delimiting surveys in August 2012, followed by two male specimens at the end of November 2012 in the same area. Subsequently, two males of *B. dorsalis* were again recorded in the same area, approximately 10 km from the first detection area in another trap in December 2012 and in the new areas in Letsitele and Hoedspruit [30]. All these incursions led to the implementation of eradication measures in the affected areas. In addition, these areas were all placed under quarantine to regulate the removal of host material from the affected areas in an effort to contain the pest in the area and to reduce crop loss as far as possible.

2.2 Measures Taken for the Eradication and Suppression of B. dorsalis in the Production/Farms Areas

The methodology used during the eradication and suppression of *B. dorsalis* in the production areas consisted out of three main strategies namely, the application of the MAT, BAT and a strict fruit sanitation protocol. Additional to these, phytosanitary measures were also applied to regulate the removal of fruit through and out of the affected areas. BAT (using M3 Fruit Fly bait station) (River Bioscience (Pty) Ltd., Humewood, South Africa) and GF-120 NF Naturalyte Fruit Fly Bait sprays (Dow Agro-sciences Southern Africa (Pty) Ltd., Bryanston, South Africa) were applied in the affected areas together with MAT (using MAT blocks) (River Bioscience (Pty) Ltd., Humewood, South Africa). Small-scale farmers were provided with the MAT blocks, M3 bait stations and GF-120 for ground bait sprays, while the commercial farmers were provided with GF-120 for weekly aerial bait sprays. The weekly aerial bait sprays were implemented with the application of premixed with GF-120 covering the quarantine area at 1 L per ha in a spray mix with 1-3 L of water (100 L per km^2 and 2,500 L per 25 km^2). The ground bait sprays were applied using 20 L knapsack sprayer. For the ground bait application of GF-120, the dilution of 1-1.2 L (100 L in 2,000 L per km^2 and 2,500 L in 50,000 L per 25 km^2) in 4-29 L of water, was applied, to every hectare. MAT blocks (5 cm × 50 cm), 1.3 cm thick fibre-board blocks soaked in a mixture incorporated with about 6 g of 67% Methyl eugenol and 1 g of malathion

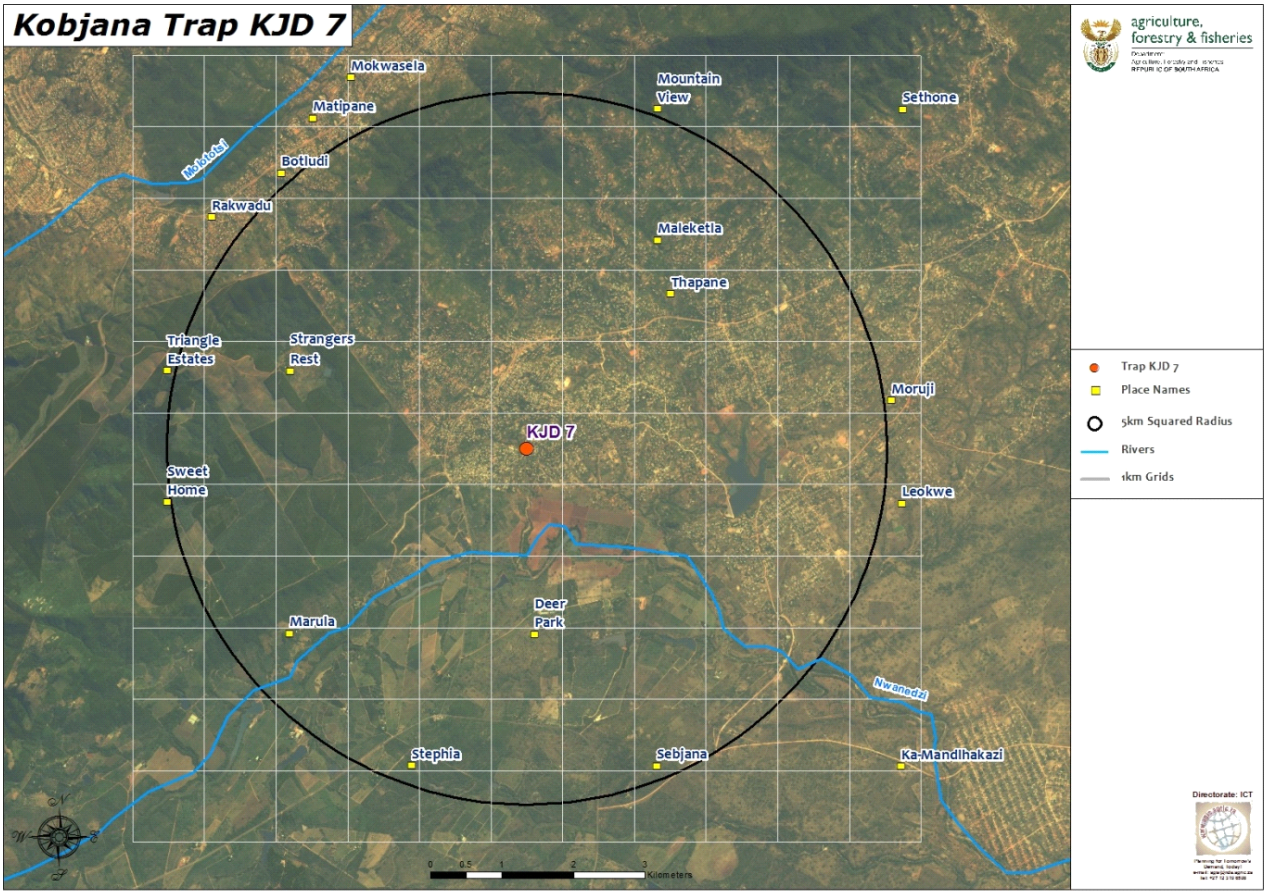

Fig. 1 Map of the Deerpak area in Greater Tzaneen Local Municipality used to indicate the delimited area of 5 km2 (surrounding the area of detection) under quarantine after the detection of two flies, in 2013.

EC (500 g/L) were hung on the host trees at the rate of 4 MAT blocks per hectare. MAT blocks were replaced after every 8 weeks. M3 bait stations were also deployed at a density of 300-400 units per hectare and were replaced after 1-4 months. Collected fruit were discarded in trenches dug in most production areas and covered with a soil layer of approximately 500 mm.

2.3 Measures Taken for the Eradication and Suppression of B. dorsalis in the Villages, Towns and Road Transects in the Quarantine Areas

The eradication area also included towns, road transects, public areas and the villages. High numbers of fruit trees are cultivated in these areas as backyard trees such as Mangoes, Papaya and Guava as well as wild fruit such as Marula. In these areas only MAT blocks and M3 bait stations were placed. Orchard sanitation was also conducted in the villages by the community members through collection of fruit into black plastic bags of at least 22 microns and left in the sun to produce sufficient heat to kill eggs and larvae. Government personnel from DALRRD and LDARD and farm workers were responsible for placement of MAT blocks and M3 bait stations along side roads, some villages, public areas and towns. MAT blocks were placed by fixing onto the trunk or branches of host trees or any other available trees at the rate of one per household, while in town, public places and road transects, they were placed one per every 50 m. M3 bait stations were applied at a ratio of one in each street tree. Community members in villages were provided with MAT blocks and M3 bait stations to place in their backyard gardens and orchards and they

were also provided with black plastics to collect the fallen fruits from the ground. Eradication teams were provided with awareness material to distribute to the communities, which included *B. dorsalis* bookmarks and leaflets providing information regarding fruit sanitation.

2.4 Awareness and Training of the Role- Players

Public awareness was facilitated through meetings with the community members and farmers and by distributing bookmarks, pest alert leaflets, posters, as well as semi-scientific and newsletter articles. Steps were taken to elevate awareness within South African fruit industries, among official ports of entry and within, local Departments of Agriculture, traditional leaders and local communities were also alerted about the danger of a *B. dorsalis* incursion. These awareness actions were carried out to encourage cooperation and support of role-players, but also served to address uncertainties and fears on community level regarding *B. dorsalis*. Awareness was carried out through official letters sent to traditional leaders, mayoral Municipalities and schools and through private and three local public radio stations. Suppliers of agricultural chemicals provided training to affected farmers on how to apply the chemicals, particularly GF-120, while government officials demonstrated the method of collection of fallen fruits and placement of MAT blocks and M3 bait stations to the community members and the farmers.

2.5 Evaluation

The Chempac and McPhail Methyl- eugenol baited traps were used. These were initially placed around detection points, according to SABIFF [30-32]. A total of 437 traps have been set in the quarantine areas in the Mopani District Municipality. In addition, about 30 McPhail protein Biolure® baited traps, were also placed in this district. Traps were checked weekly for a period of 5 months, and thereafter, they were checked,

Fig. 2 Farmers' meeting during the distribution of chemicals funded by government for eradication and suppression of *B. dorsalis* in Deerpak area, Greater Tzaneen Municipality.

on a monthly basis, during the eradication and suppression program, in the quarantine areas. Data was captured in a database and the number of fruit fly was monitored in terms of FTD (fruit flies per trap per day) to measure the effectiveness of measures implemented as recommended by [21, 22]. The FTD is the average number of the target fly (*B. dorsalis*), captured per trap per day during a specified (30 days) period, in which the trap was exposed in the field. The FTD of an area at any specified time was obtained by dividing the total number of target flies captured by the product of the total number of inspected traps in the area and the average number of days that the traps were exposed.

$$FTD = F / T \times D$$

where:

F = total number of flies;

T = number of inspected traps; and

D = average number of days' traps were exposed in the field.

Basic identification and sorting of collected specimens was done by DALRRD personnel from the division Early Warning Systems (Directorate Plant Health) using the guidelines for the key identification of fruit flies according to [4]. All suspected specimens were sent to a fruit fly expert, in the Citrus Research International, for further identification and confirmation. Verification was done by the internationally recognized fruit fly taxonomist, from the Royal Museum for Central Africa in Belgium. All the detections were reported on IPPC (International Plant Protection Convention) portal and relevant trading partners.

3. Results

Trap catches of *B. dorsalis* in the Mopani District Municipality in three different areas are provided in Fig. 3. The *B. dorsalis* trap catches were dominated by male specimens which were collected from Methyl eugenol baited fruit fly traps. A few male *Dacus* species were also collected from Methyl eugenol baited traps. Few females of *B. dorsalis*, *Dacus* and *Ceratitis* species were collected from Biolure® baited

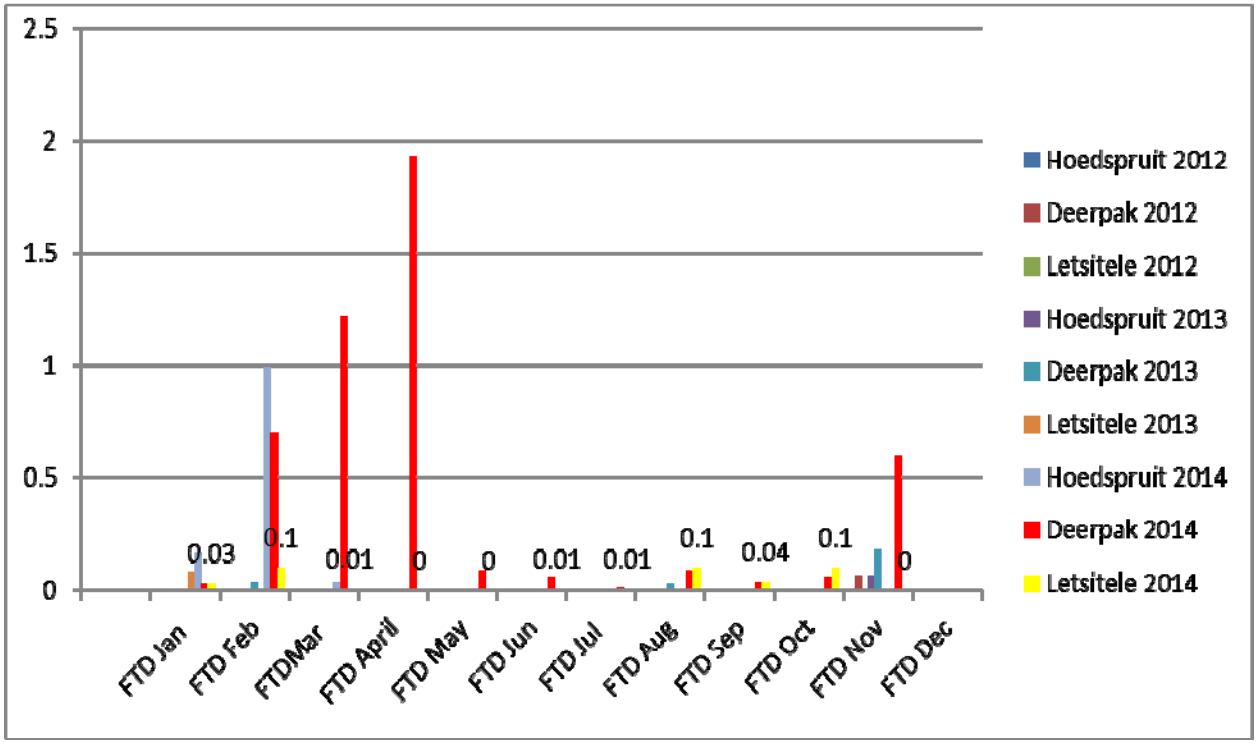

Fig. 3 Showing flies per trap per day ratios for the detections of *B. dorsalis* in Deerpak, Hoedspruit and Letsitele areas during the eradication attempt in Mopani District from January 2012 to December 2014.

traps, which are indigenous in South Africa. However, all the detections were less than 10% from all active traps in the Mopani District Municipality during the study.

There were no detections of *B. dorsalis* in Hoedspruit in 2013. However, in December 2013, there were detections in Deerpak and Letsitele, with the highest number of 687 and 12 in Deerpak and Letsitele areas, respectively. In Deerpak area, the average FTD value of 0.001 per year was calculated. In 2014, *B. dorsalis* was detected in all three areas with high numbers detected during summer period. The highest number was detected in Deerpak (11,953), followed by Hoedspruit (2,260) and Letsitele with 8 specimens during March 2014. The average FTD of *B. dorsalis* was the highest in March and April 2014 for Deerpak with 1.22 and 1.93, respectively as compared to Hoedspruit with 0.99 and 0.44, with Letsitele at 0.01 (Fig. 3). Out of the total 23,253 specimens collected during 2012, 2013 and 2014 period, the majority was from February-May with the highest number collected in the Deerpak area.

4. Discussion

The average low trap catches in Letsitele in 2013 and zero detections of OFF in Hoedspruit in 2013 might be due to the fact that, the farmers conducted an area-wide weekly aerial bait applications using food bait (GF-120) covering more than 8,000 hectares where host plants are produced. This was in addition to the implementation of ground application of BAT, placement of four MAT blocks per hectare, and diligent sanitation practices.

The monthly rainfall [34] received in Mopani District was below normal (25-50 mm), normal to above normal (100-200 mm) and above normal rainfall (200-2000 mm) during March and April in 2012, 2013 and 2014, respectively in all areas, where a variety of host plants are cultivated such as Mango, Guava, Papaya and wild fruit such as Marula, might have played the most important role. According to a study conducted in China [35], the population of *B. dorsalis* decreased when the monthly rainfall amount was lower than 50 mm, but increased when the amount ranged between 100 and 200 mm.

The government continued to provide farmers with MAT blocks, M3 bait stations and GF-120 to support the continued eradication and suppression of OFF. However, in March 2014, the government reduced efforts for provision of MAT blocks and M3 bait stations to the rural communities due to reduced efforts/lack of interest by community members in the villages. It is believed that the reduced efforts, together with the high number of host plants during fruiting period in villages and potential wild hosts in the district might have contributed to the high number of detections during 2014 in all these areas. In addition, the above normal rainfall received in 2014, might have also contributed to high numbers detected in the Mopani District Municipality.

5. Conclusion

The results of the present study revealed that *B. dorsalis* can be successfully eradicated in areas where stakeholders work together and invest their time, efforts and resources as carried out in the Hoedspruit and Letsitele areas. The involvement of several role-players assisted in the early detection and eradication of *B. dorsalis* as all stakeholders are made aware of the pest, its identification, its significance and every stakeholder roles and responsibilities. This was achieved through the implementation of a combination of government-led community and farmer's awareness campaigns, implementing MAT, BAT and diligent orchard sanitation by small-scale and commercial farmers.

It was also clear that consistent efforts were necessary for effective and sustainable eradication or suppression of the pest as reduced or interruptions of the efforts caused an increase in the numbers trapped.

However, in 2014, despite several attempts of the application of available eradication measures, there

were a high number of detections observed in all areas and as a result it was no longer feasible to eradicate the pest in the Mopani District Municipality.

The study also showed that any interruptions of this initiative resulted in failure of the eradication or suppression efforts which was observed in 2014 and the pest could no longer be eradicated which led to the change in the status of the pest in the Mopani District Municipality. The current status of *B. dorsalis* in the Mopani District Municipality, described in the appropriate terminology of the IPPC, is as follows: "it is present, but under official control".

The most appropriate responses to the suppression of *B. dorsalis* in the Mopani District Municipality are an effective application of SABIFF, the development of effective proper monitoring systems to ensure that the pesticides provided to the farmers and rural community members are indeed applied. In addition, it is critical for government to maintain the good public-private relationship with the role players, particularly the relationship with the rural communities as their villages produce some hosts of *B. dorsalis*, if nothing or less efforts are made in the villages, the pest might breed in the villages, which will lead to less yield, which might in turn affect food security and less income by the communities. The lessons learned during the study include the need for understanding and synergy between different role-players as well as the importance of awareness and public participation. A real commitment by all role-players (particularly indefinite funding and continuous distribution of chemicals by Government) is crucial and a full cooperation between the small-scale farmers and commercial farmers in carrying out an area-wide control and the implementation of integrated pest management strategies which protects environment, as well as linking up with research efforts and experiences from other stakeholders and role-players to more fully explore synergies and partnerships.

Further studies are needed to determine how rainfall average during different fruit production periods affects *B. dorsalis* population numbers.

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