ABSTRACT

Title of Thesis: THE EFFECTS OF SPRAYING DELTAMETHRIN AGAINST TSETSE FLIES ON INSECTIVOROUS BIRDS IN THE OKAVANGO DELTA, BOTSWANA

Frank Nielson Pendleton, Master of Science, 2003

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I investigated the effects of spraying deltamethrin for tsetse fly control on bird populations in the Okavango Delta, Botswana. Because deltamethrin has low toxicity to vertebrates, effects on birds would have been indirect and caused by reductions in insect food supplies, not by poisoning. The northern half of the Delta was sprayed in 2001 and the southern half in 2002. I monitored resident bird populations at four sites (two in each spray block), using point counts to monitor forest birds, and transects to monitor acacia thornveld birds and water dependent birds. Birds were classified by diet as insectivorous or non-insect-dependent in order to check for declines in insectivorous birds which did not occur in non-insect-dependent birds. Sections of the 2002 spray block burned just as the spraying started. In the 2001 spray block, there were no declines of insectivorous birds, and varied results for non-insect-dependent birds. In the 2002 spray block, the Chitabe site showed declines in insectivorous forest birds, which were not strongly correlated with the spraying, and Nxaraxa showed no such declines. Greybacked bleating warblers (*Cameroptera brachyura*) decline at Chitabe, but not at Nxaraxa or either of the

2001 spray block sites. There was not a decline in the number of water dependent or acacia thornveld species detected before and after the spraying. While immediate large-scale population declines in insectivorous birds were not detected, small-scale and long-term declines could not be ruled out. Effects on behavior, diet, and reproductive success were not assessed.

THE EFFECTS OF SPRAYING DELTAMETHRIN AGAINST TSETSE FLIES ON INSECTIVOROUS BIRDS IN THE OKAVANGO DELTA, BOTSWANA

By

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CHAPTER 1.

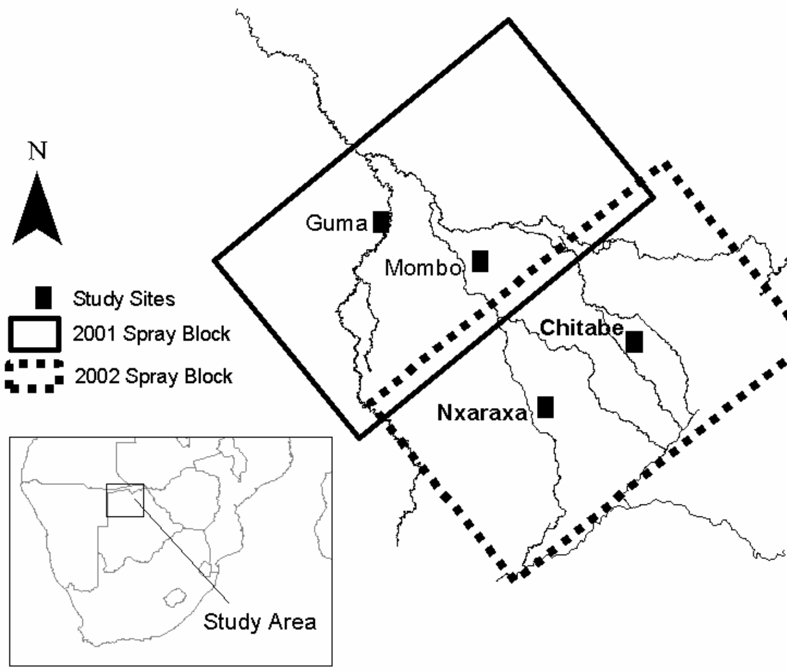
INTRODUCTION

In 2001 and 2002 the Okavango Delta of Botswana (Figure 1) was sprayed with the insecticide deltamethrin for the control of tsetse flies (*Glossina morsitans*). The spraying was part of the integrated program to eradicate tsetse from the Ngamiland district launched by the Tsetse Control Division of the Botswana Department of Animal Health and Production (DAHP). Since deltamethrin is a synthetic pyrethroid which breaks down quickly and does not bioaccumulate, it is unlikely to affect birds directly by poisoning; however, losses due to the effects of reduced food supplies are possible. I looked at the effects of the spraying on insectivorous and non-insect-dependent bird guilds to see if there were reductions in bird populations due to the spraying. Greybacked bleating warblers (*Cameroptera brachyura*) were also analyzed separately because they are a common, insectivorous bird which holds a territory making them an ideal species for statistical comparisons.

TSETSE FLIES AND TRYPANOSOMIASIS

Tsetse flies (*Glossina* spp.) can be a serious problem in the Okavango Delta and throughout much of Africa because they are the vector of *Trypanosoma* spp., the blood parasite that causes trypanosomiasis (Rozendaal 1997). This disease is known as sleeping sickness in humans and nagana in livestock, and it can be deadly if left untreated. Many wildlife populations act as reservoirs for *Trypanosoma* spp. without suffering any ill

Figure 1. Map showing the location of study sites used to study the effects of spraying deltamethrin for tsetse fly control on birds in the Okavango Delta, Botswana.



effects. The disease is spread when people and livestock enter areas with infected wildlife and tsetse flies. Once in the livestock or human population, the disease can be transmitted from infected livestock or people to uninfected livestock or people.

There are six species of *Trypanosoma* in the Okavango that can cause nagana, including *T. brucei*, the species that causes sleeping sickness (Meynell 2001a). There are two subspecies of *T. brucei* which cause different forms of sleeping sickness. The subspecies *T. b. rhodesiense* occurs in the Okavango, and causes East African sleeping sickness, the acute form of the disease which can cause death in a matter of weeks (Rozendaal 1997, Meynell 2001a). The subspecies *T. b. gambiense*, which does not occur in the Okavango, causes West African sleeping sickness, the chronic form of the disease which may last several years (Rozendaal 1997, Meynell 2001a).

While there are over 20 species of tsetse flies, only *Glossina morsitans* occurs in Botswana (Meynell 2001a). All tsetse flies have a similar life cycle, which was taken into account when the spraying regime was planned (Department of Animal Health and Production 2000). Tsetse flies live three to five months, with females living slightly longer than males. Females only mate once, shortly after emerging from their pupa stage, and store this sperm for the rest of their lives. A single larva will go through partial development in an egg inside the female and then will be deposited into the ground to complete development. A female will deposit eight to 12 larvae into the ground during the course of her life. The larvae pupate in the ground and emerge as adult flies after about 30 days at 25 degrees Celsius (Meynell 2001b). Underground development time increases as temperature falls below 25 degrees Celsius. Once a fly emerges it must take its first blood meal in order to harden its exoskeleton and complete development. Adult tsetse flies tend to feed every three to five days (Meynell 2001a).

TSETSE CONTROL HISTORY IN BOTSWANA

Tsetse control has a long and sordid history in Botswana. Due to a rinderpest epidemic in the late 1890's, many wildlife populations in the Delta were greatly reduced. This caused a crash in the tsetse population, however, they did survive in small pockets. As wildlife populations recovered so did tsetse populations, and by the 1940s tsetse control efforts began (Davies 1980). The earliest efforts were rather drastic, involving mass brush clearing, mass killing of wildlife host species, and the erection of game fences (Davies 1980). In the 1960s control efforts converted to pesticide spraying of dieldrin and some use of DDT. Heavy doses were sprayed at the bases of trees to ensure a lasting residual effect. In 1973, control efforts shifted to aerial spraying of areas of highest tsetse concentrations. This spraying involved endosulfan, deltamethrin, and alphamethrin either individually or in various cocktails and continued until 1991 (Meynell 2001b).

While aerial spraying operations greatly reduced tsetse populations, they did not eradicate them, so in 1992 tsetse control efforts shifted to odor-baited targets (OBTs) (Meynell 2001a). An OBT is composed of a meter square piece of black and blue fabric which is dipped in an insecticide. Tsetse flies are attracted by the odor of the slow-release bait and the moving blue and black fabric as it vibrates in the wind. Tsetse flies are killed when they touch the target and are exposed to the insecticide (Meynell 2001a). For OBTs to be effective, the bait must be dispensed at a certain rate, the target must be regularly soaked in insecticide, and broken OBTs must be replaced promptly. Lack of maintenance and use of improper bait dispensing bottles greatly reduced the effectiveness of OBTs, and as a result the tsetse fly population in the Delta grew rapidly between 1992 and 2001 (Meynell 2001a).

THE INTEGRATED PROGRAM TO ERADICATE TSETSE FLIES AND TRYPANISOMIASIS FROM NGAMILAND

As the result of reduced tsetse populations caused by earlier spraying operations, trypanosomiasis was absent from Botswana from 1985 until 1998. However, in 1998 new cases of nagana were reported, and by July 2000 over 300 cattle had died of the disease. There were no new cases of sleeping sickness reported (Department of Animal Health and Production 2000).

In response to the outbreak of nagana, the Tsetse Control Division of the Department of Animal Health and Production (DAHP) launched an integrated program to eradicate tsetse from the Ngamiland district. The program has three components:

1) Substantially reduce tsetse fly populations by aerial spraying of deltamethrin.
2) Prevent tsetse flies from returning to previously sprayed areas using odor-baited targets (OBTs).
3) Completely eradicate tsetse flies by releasing sterile male flies to compete for mates with the wild males.

As part of this program, the northwestern Delta was sprayed five times between June and August 2001, and the southeastern Delta was sprayed 5 times between May and August 2002 (Figure 1), with OBTs placed between the spray blocks to prevent movement of tsetse flies between blocks. Almost the entire Delta was sprayed, including most of the Moremi Game Reserve and several wildlife concession areas outside the reserve (L. S. Bien, Harry Oppenhiemer Research Center, University of Botswana, pers. comm.).

Planes flew at 10 – 20 meters above the canopy spraying deltamethrin as an ultra-low volume aerosol at a rate of 260 mg/ha (Meynell 2001a). The spraying took place during winter nights, because winters are dry with little wind, and an inversion layer forms at night. This maximized the nights available for flying while minimizing drift of the pesticide. The intense spraying operation reduced the tsetse fly population to such a level that it should be possible to release enough sterile males to effectively compete with wild, non-sterile males to actually eradicate tsetse from the Delta (DAHP 2000).

EFFECTS OF DELTAMETHRIN AND OTHER PESTICIDES ON BIRDS

Deltamethrin ($C_{22}H_{19}Br_2NO_2$) is the strongest of the synthetic pyrethroids, a group of broad spectrum, man-made insecticides based on the chemical structure of pyrethrum, an extract from chrysanthemums (C*hrysanthemum* spp.) (Extoxnet 2001). Although less powerful and with a shorter half life than synthetic pyrethroids, the plant extract is an effective insecticide (Perry et al. 1998).

Deltamethrin is less problematic than many other pesticides because it has a low toxicity to vertebrates, breaks down quickly, and adheres to the top layer of soil instead of percolating through to the water table or into streams (Elliot et al. 1978, WHO 1990, Perry et al. 1998, Extoxnet 2001). Degradation of deltamethrin occurs within days in the air or on the surface of plants, and within weeks in the soil (Extoxnet 2001). When absorbed by plants or eaten by vertebrates, deltamethrin is metabolized and broken down in a matter of days (WHO 1990). Because it breaks down quickly and is metabolized by plants and animals, it does not bioaccumulate (WHO 1990, Perry et al. 1998, Extoxnet 2001).

Deltamethrin is highly unlikely to kill birds directly by poisoning due to the low concentration of the spray (260 mg/ha) compared to the LD_{50} of birds (1000 – 10,000 mg/kg of body weight) (Elliot et al., 1978, Hudson et al., 1984, WHO 1990, Exotoxnet 2001). Even when taking a conservative approach and using a cut off of 1000 mg/kg, a 10 gram greybacked bleating warbler (*Camaroptera brevicaudata*) would have to eat 1 mg of deltamethrin to be killed by ingestion. This would be all the deltamethrin sprayed on 38 m^2. Considering the amount of deltamethrin that sticks to leaves or ends up in the soil, this level of ingestion is nearly impossible. I did not see or hear reports of dead birds as a result of the spraying operation.

On the other hand, deltamethrin is highly lethal to a broad range of insects. A comparative study of the effects of 8 insecticides used for locust control in northern Africa found that deltamethrin was the most toxic to the greatest diversity of aquatic insects in temporary ponds in the Sahel (Lahr 1998). It rapidly paralyzes insects by interrupting their peripheral nervous system, and ultimately kills them by interrupting the central nervous system (Costa 1997, Perry et al. 1998). The quick action on the peripheral nervous system leads to a quick knock down effect, which causes an “insect rain.” If the deltamethrin does not reach the central nervous system, many insects recover from this initial knock down and ultimately survive (Extoxnet 2001, Meynell 2001b). I did witness many insects recovering from the spray. However, many do not survive and deltamethrin did have serious effects on Okavango Delta insects from several different orders (Dangerfield 2003).

Reductions in insect populations can affect birds in various ways depending on the severity of the decline and the coping mechanisms of the species of interest. The effects can range from behavioral changes or reduced body weight in individual birds, to reduced fecundity and detectable drops in populations (Cooper et al. 1990, Whitmore et al. 1993, Sample et al. 1993). In some cases, insects are not limiting to bird populations, and significant reductions in insect numbers may not necessarily cause biologically significant change to bird food supplies. Malathion sprayed at ultra-low volumes in steppe habitat in America had a significant effect on insect numbers and biomass, but did not kill nestling passerines, and had no consistent indirect effects (Howe et al. 1996).

However, birds may suffer effects that are not detectable at the population level. A team studying the effects of the spraying of the Lepidoptera-specific insecticide diflubenzuron (DIMILIN) for gypsy moth control found that it substantially reduced caterpillar numbers and caused different reactions in different insectivorous bird species. Five of nine species changed their diets, seven of nine species had reduced fat reserves, and red-eyed vireos (*Vireo olivaceus*) increased the size of foraging areas (Whitmore et al. 1993, Sample et al. 1993). However, these effects did not lead to population declines in any of the 21 bird species examined (Cooper et al. 1990).

Homles (1998) found that while a Lepidoptera-specific insecticide reduced spruce budworm (*Choristoneura fumiferana*) populations by over 75%, Tennessee warblers (*Vermivora peregrine*) continued to specialize on these caterpillars. He found no changes in the number of eggs per nest or fledgling rates, but females on nests in sprayed blocks spent more time foraging than females in control blocks. And Hunter et al. (1984) found that ducklings of American black ducks (*Anas rubripes*) and mallards (*Anas platyrhynchos*) in ponds sprayed with carbaryl, spent more time foraging but gained less weight than ducklings in a control pond.

There are cases where insecticide-caused reductions in insect numbers did lead to negative effects in reproductive success or population levels of birds. Deltamethrin caused dramatic declines in grasshopper populations, which led to reduced fledgling rates in chestnut-collared longspurs (*Calcarius ornatus*) (Martin et al. 1998). Rodenhouse and Holmes (1992) found that reduced caterpillar numbers did not reduce clutch size or the number of young fledged per nest in black-throated blue warblers (*Dendroica caerulescens*). However, they changed their diet, and reduced the number of second nesting attempts, bringing productivity below the level needed to balance mortality. And Rands (1985) found that spraying with various herbicides and fungicides reduced insect numbers and led to significantly smaller brood sizes of grey partridges (*Perdix perdix*) in sprayed fields than in unsprayed fields.

Due to the fact that synthetic pyrethroids are highly toxic to a broad range of insects, the amount of insecticide used can be a vital factor. In North America, deltamethrin drift from crop spraying killed butterflies and reduced the size of pupae at concentrations below 1% of the field application rate (Cilgi and Jepson 1995). Different application rates of the synthetic pyrethroid cypermethrin reduced insect numbers to varying degrees, which had differing effects on blue tit (*Parus caeruleus*) nesting success. At high application rates (75 g/ha) insect populations were devastated, and blue tits suffered catastrophic reductions in breeding success. However, at lower application rates (3.75 g/ha), insects were significantly reduced but not devastated, and blue tit breeding success was still reduced, but far less dramatically (Pascual and Peris 1992).

Studies on the effects of aerial spraying in Southern Africa have focused on endosulfan and DDT, because they have been the primary insecticides used for tsetse control. While these studies are of interest because they are based on Southern African tsetse fly spraying operations, these insecticides are very different than synthetic pyrethroids. They are much more toxic to vertebrates, and most of the detrimental effects detected in African birds have been the result of bioaccumulation and kills of fish that piscivorous birds depend on for food.

Douthwaite (1980) monitored bird populations along 4 transects in the Delta and found that repeated spraying of endosulfan did not lead to catastrophic declines, but small population reductions would not have been detected by his presence / absence methods. In a later study focused on pied kingfisher (*Ceryle rudis*), Douthwaite (1982) found that endosulfan-induced fish kills in the Delta led to changes in eating habits and accumulation of endosulfan in bird brains. However, bird numbers at roosts remained stable (Douthwaite 1982). Endosulfan was the original insecticide of choice for the 2001 – 2002 Okavango Delta spraying operation, but it was changed to deltamethrin by the Environmental Impact Statement team, partially due to concerns about fish kills.

In Zimbabwe, DDT used for tsetse fly control accumulated in several bird species and was correlated with population declines in certain guilds (Douthwaite 1995, 1992a). It was also correlated with eggshell thinning which probably led to nest failure in African goshawks (*Accipiter tachiro*) (Hartley and Douthwaite 1994) and African fish eagles (*Haliaeetus vocifer*) (Douthwaite 1992b).

THE EFFECT OF SPRAYING IN THE DELTA ON INSECT POPULATIONS

A team of biologists was contracted by the Harry Oppenheimer Okavango Research Center (HOORC) to monitor the effect of the 2002 spray operation on insects. Insects were monitored by sampling before, during, and after the spray operation to look for declines in populations and changes in insect diversity. Canopy dwelling insects that fell from trees during spray events were collected in 3 m^2 sheets placed below trees. Nearby trees were sprayed with a handheld fogger using a much higher dose of deltamethrin in an effort to knock down as many remaining insects as possible (Dangerfield et. al. 2003). Beetles (Coleoptera), flies (Diptera), true bugs (Hemiptera), and spiders were the most common taxa collected. The average number of insects collected per sheet from the 1st spray event and the 5th spray event declined from 217 to 122 (44%). Changes varied between taxonomic groups, with beetles suffering the greatest declines from 114 to 39 (66%), while flies actually increased from 6 to 33 (550%). When beetles and flies were excluded from the calculation, total insects decreased from 97 to 50 (48%). Most of the decline in beetle numbers was attributed to drastic declines in 3 morphospecies (groups of similar looking species). The increase in flies was attributed to the emergence of adult flies brought on by warmer weather and the arrival of the annual flood (Dangerfield et. al. 2003).

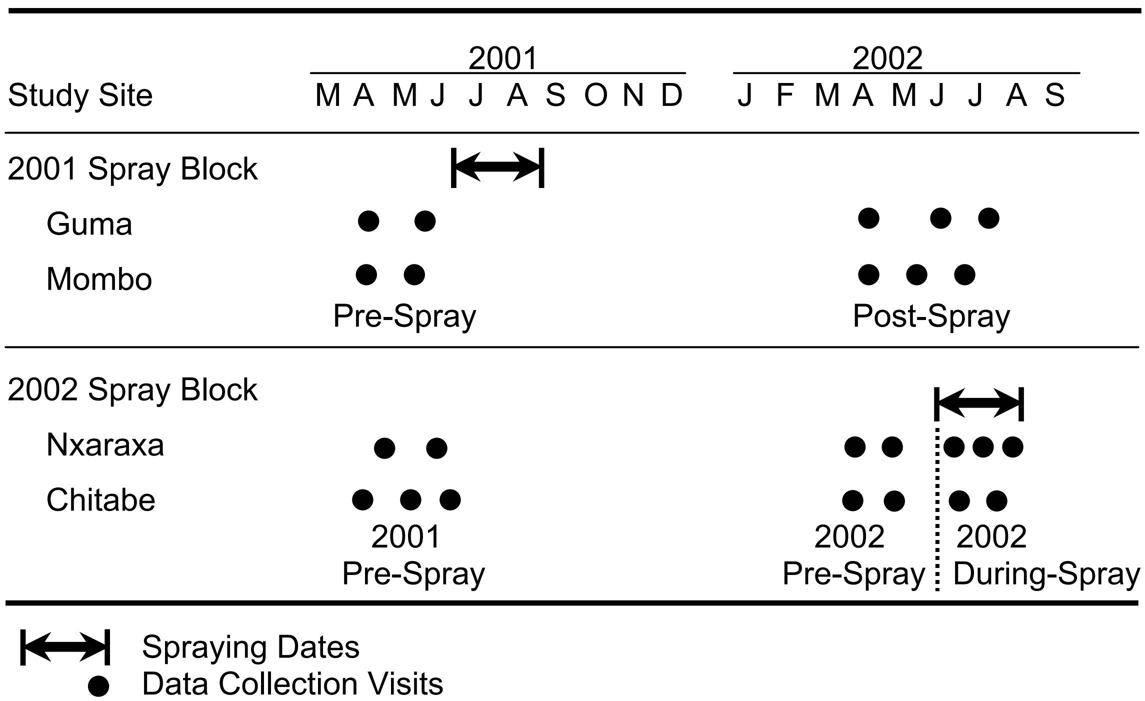
Because the Delta has a different composition of tree species than the surrounding area and nearly the entire Delta was sprayed, there were no suitable controls for most of the tree species in the Delta. However, there were sufficient mopane (*Colophospermum mopane*) woodlands inside and outside of the spray area to provide suitable test and control areas. Comparisons in the mopane sites were made between pre 1st spray fogging, and post 5th spray fogging data. The average number of specimens collected per sheet in the sprayed mopane woodland, declined from around 700 before to around 300 (-57%) after, and the total number of beetles collected from all sheets combined decreased from 4592 to 55 (-99%). In the control area average number of specimens collected per sheet increased from around 650 to around 850 (31%), and the total number of beetles collected from all sheets increased from 4894 to 8523 (74%) (Dangerfield et. al. 2003).

POPULATION MONITORING

In order to assess the immediate short term effects of the spraying operation on bird populations, I monitored sites in the 2001 and 2002 spray blocks before, during and after spraying operations (Figure 2). The goal of this monitoring program was to collect baseline data on Okavango bird populations, and to monitor for large scale, short term declines of bird populations correlated with the spraying.

While spraying may affect birds by changing foraging behavior or diet, population declines are the most vital. In order to provide the most valuable benchmark for birds in general, I felt it was necessary to collect sufficient data on as many species as possible to be able to detect population declines. To meet this goal, I chose population

Figure 2. Chronological distribution of spray dates and data collection dates in the Okavango Delta. For analyses, data collected in the 2001 spray block (Guma and Mombo) were divided into two categories: Pre-spray and post-spray. Data collected in the 2002 spray block were divided into three categories: 2001 Pre-spray, 2002 Pre-spray, and 2002 During-spray.



monitoring techniques over intensive single species monitoring techniques, such as studying foraging behavior or nesting success.

I used point counts and transects to collect population level data on many species at the same time. While these techniques are the best choice for developing a benchmark for a broad species base and detecting large scale bird declines, they cannot pinpoint the mechanism of a population decline (die offs, emigration, reduced breeding success), nor the ultimate cause of a population decline (deltamethrin, fires, rain).

EXTERNAL FACTORS

It is rarely possible to attribute change in wildlife populations to a single factor, and as with many ecological studies, there were many external factors affecting the number of birds detected. Rainfall and fire were very different in 2001 and 2002, and the three month duration of the spraying makes it difficult to separate before and after spray comparisons from seasonal changes.

Abiotic factors such as weather and fire can affect bird populations and activity rates. The Okavango received slightly more rain in 2001 (355 mm) than in 2002 (320 cm), but more importantly, it was spread out more evenly throughout the rainy season from November 1 to May 1 (P. Wolski, Harry Oppenhiemer Okavango Research Center, University of Botswana, pers. comm.). Rainfall patterns can affect bird food supplies for herbivores as well as insectivores. This may increase bird numbers, since increased food supplies can lead to longer breeding seasons and higher fledgling success rates. And increases in breeding activity, such as singing and territory defense, can increase the number of birds detected, even if populations do not increase. Fire can lead to changes in bird activity as well, and 2002 was a much bigger fire year than 2001. Chitabe and Nxaraxa burned in May 2002, after the last pre-spray survey, but before the first post-spray survey (Figure 2). This makes it difficult to differentiate changes in bird numbers caused by the fires from changes caused by the spraying.

Many birds change behavior from season to season and year to year. Some birds migrate or display smaller scale local movements, and many birds change daily activity patterns such as singing and foraging rates which can lead to changes in detectability. Because the spraying takes three months, factors unrelated to the spraying are changing, making it difficult to assign causality in before and after comparisons within the same year.

With these factors as part of the equation, small effects of the spraying cannot be separated from other factors. But catastrophic effects, such as large declines in species or guilds, should still be readily detectable. In addition to detecting immediate catastrophic declines, the results from this study will provide a benchmark for bird populations which will be vital to future monitoring efforts.

While the techniques I used are effective at detecting large-scale reductions in bird numbers, I can not draw conclusions about reductions in nesting success rates, reductions in body weight, or changes in diet resulting from the spraying. My study is disaster detection, not an in-depth study of all the possible effects on birds. While it would have been ideal to study the effects on several aspects of bird biology, this could only have been accomplished with several specialists on the ground at all times. Limited time and resources required a choice between in depth monitoring of one or two species breeding biology, or in depth monitoring of populations. I felt a broad study looking for large scale population declines was more appropriate than an in depth study of a few species.

RELEVANCE TO PATTEC

This study is particularly timely since the Pan African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC) was officially launched in October 2001 by the Organization of African Unity (OAU) and the World Health Organization (WHO). The goal of PATTEC is to create and maintain tsetse free areas, using integrated eradication programs and making stepwise progress until tsetse flies are eradicated from Africa (WHO 2001a). As one of the first areas where this integrated program has been tried, the spraying of deltamethrin in the Okavango Delta provides an excellent chance to learn about ecological impacts of tsetse fly control. The knowledge gained from this operation will be valuable in efforts to reduce impacts on non-target species in future spraying operations throughout Africa.

RESEARCH OBJECTIVES AND EXPECTATIONS

The goal of my study was to look for population or guild level declines in bird numbers correlated with the spraying operations (Figure 2). If the spraying was having a large-scale, short-term effect, insectivorous bird numbers would be expected to decline following the spraying, while non-insect-dependent bird numbers would be expected to remain stable (Figure 3). If a year is required for negative effects to take place, the number of insectivorous birds in the 2001 spray block would be expected to be lower in the 2002 surveys than in the 2001 surveys, and no changes would be expected in the 2002 spray block. However, if negative effects take place in a matter of days or weeks, the number of insectivorous birds in the 2002 spray block would be expected to remain stable for the 2001 and 2002 pre-spray surveys, but would be expected to decline following the onset of the spraying in May 2002. While variation is expected, drastic declines correlated with spraying would be evidence of a serious spray effect.

Ultimately, the null hypothesis I tested was:

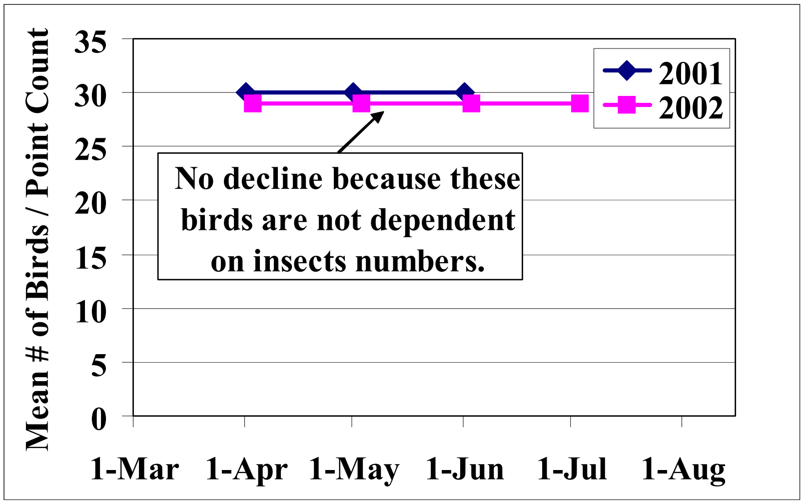
There was no large-scale, short-term difference in insectivorous bird populations of the Okavango Delta correlated with the spraying of deltamethrin at 260 mg/ha.

With the alternative hypothesis being:

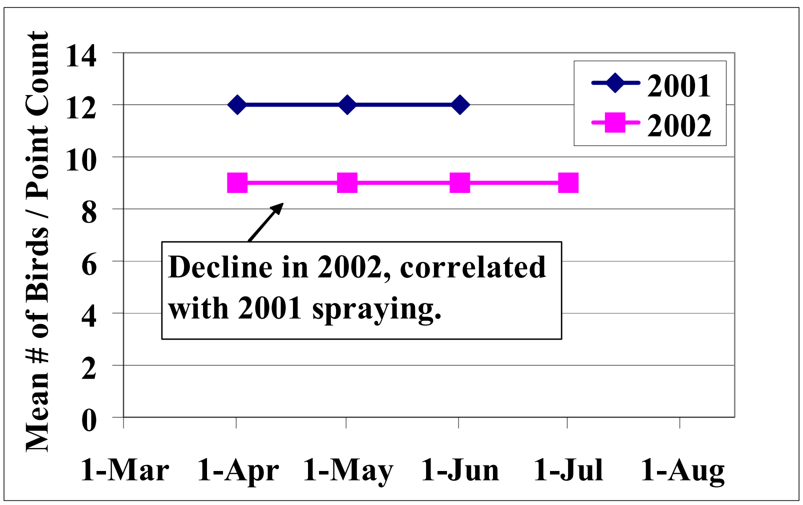
There is a large-scale, short-term decline in insectivorous bird populations of the Okavango Delta correlated with the spraying of deltamethrin at 260 mg/ha.

Because I had four study sites, and looked at forest, wetland, and acacia thornveld habitats, this null hypothesis can not be rejected or not rejected based on a single statistical test. Evidence for or against this null hypothesis is drawn from each study site, and each habitat type. If several of my studies detect declines correlated with the spraying, my null hypothesis would be refuted; if none of the studies detect declines correlated with the spraying my null hypothesis would be supported.

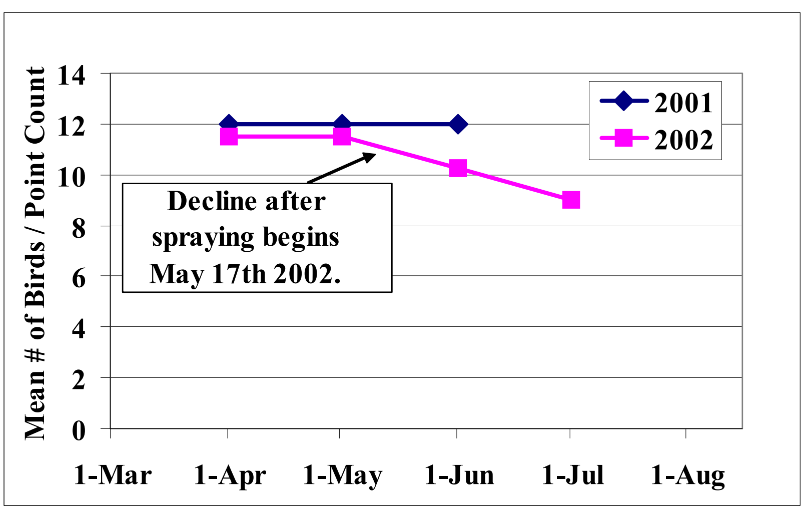
Figure 3. Expected trends for bird populations were having large-scale short-term population declines as the result of aerial spraying of deltamethrin against tsetse flies.



Graph A.
Non-insect-dependent birds would not be expected to decline regardless of whether they were in the 2001 or 2002 spray block.



Graph B.
Insectivorous birds in the 2001 spray block, would be reduced in 2002. 2001 data are pre-spray, and 2002 data are after-spray data, collected 9-14 months after spraying started in June 2001.



Graph C.
Insectivorous birds in the 2002 spray block would be expected to decline once the 2002 spraying operation began. 2001 and 2002 data are pre-spray data, and 2002 data from after May 17th is during-spray data.

CHAPTER 2.

METHODS

STUDY AREA

Botswana is located in southern Africa, just north of the country of South Africa (Figure 1). Most of Botswana is in the Kalahari Desert, an arid area of wind blown sands covering over 500,000 km^2 in several southern African countries. Northwestern Botswana is an arid and harsh environment, with an average annual rainfall of 50 cm, mostly falling during the hot season from December to March (Main 1988). Due to the sandy soils and hot temperatures, much of the rain quickly soaks into the sand or evaporates. Acacia trees and shrubs (*Acacia* spp.) dominate most of the Kalahari vegetation.

The Okavango Delta is the largest inland delta in Africa and the dominant feature of northeastern Botswana. It is the result of the Okavango River dividing into many smaller rivers and dispersing over a shallow basin in the Kalahari sands caused by parallel fault lines (Ross 1987, Main 1988). The head waters of the Okavango River are in the mountains of Angola which receive higher annual rain fall than Botswana. Depending on how much rain falls in Angola, the Delta can vary in size from 16,000 km^2 in drier years to 22,000 km^2 in wetter years. Because it takes 2-4 months for the water to reach the top of the Delta, and 2-4 more months for it to flow through the Delta, the annual flood occurs during the dry season. Being a permanent source of water in the arid Kalahari, the Delta is a very unique ecosystem with a great diversity of plants and animals (Ross 1987, Main 1988).

Upstream sections and areas closer to main channels tend to be permanently flooded, while down stream sections and areas farther from main channels tend to be seasonally flooded. As with many deltas, river channels fill with sediment causing the river to jump its banks, leaving areas of higher elevation. These dry river beds often form long, slightly raised sections of land, which serve as seasonal or permanent islands depending on their location. These islands are dominated by a more diverse grouping of trees than the acacia scrub outside of the Delta, including figs (*Ficus* spp.), sausage trees (*Kigelia africana*), knobthorns (*Acacia nigrescens*), raintrees (*Lonchocarpus capassa*), large fever-berry (*Croton megalobotrys*), and wild date palm (*Phoenix reclinata*). The channels between the islands are either permanently or seasonally flooded wetlands.

I collected data from two study sites that were sprayed between June and August 2001 (Mombo and Guma), and two that were sprayed between May and August 2002 (Chitabe and Nxaraxa) (Figure 1). Forest bird surveys were conducted at all sites on the tree islands described above. Water bird surveys were conducted at Guma Lagoon, a permanent lagoon surrounded by common reed (*Phragmites austalis*) and papyrus (*Cyperus papyrus*). Acacia thornveld bird surveys were conducted in an upland of acacia scrub at Mombo.

The study design was planned as a before-after-control-impact study, but the spraying covered almost the entire Delta, making suitable unsprayed control sites unavailable. I monitored a control site in the Maun Education Reserve in 2001, but dropped it in 2002 because it was added to the 2002 spray block. A site at Khwai in the Moremi Game Reserve was monitored three times in 2002 but dropped because the vegetation and bird community were not similar enough to the other sites to provide a fair comparison.

Ultimately, I used a before-during-after-impact study design (Figure 2). I monitored the 2001 spray block (Mombo and Guma) before it was sprayed (March – June 2001), and the year after it was sprayed (March – August 2002). I monitored the 2002 spray block (Chitabe and Nxaraxa) a year before it was sprayed (March – June 2001), just before it was sprayed (March – May 2002), and during the spray operation (June – August 2002).

TECHNIQUES

Because of the variety of habitat types and bird species, I used several monitoring techniques at each site. Circular point counts were used for monitoring forest birds, driving transects for monitoring acacia thornveld species, and boat surveys for monitoring water dependent species (Table 1).

Point Counts

There were nine forest point count stations at Nxaraxa and ten at the other study sites. One was dropped from Nxaraxa due to excessive noise caused by palm trees rustling in the wind. Stations were located on tree islands a minimum of 300 m apart, and coordinates were recorded using a Garmin GPS III+ set to the WGS 84 datum

Table 1. The number of surveys stations at each study site for studying the effects of spraying deltamethrin for tsetse fly control on birds in the Okavango Delta, 2001-2002.

	Point Count	Water Surveys		
Location	**Stations**	**Type of Survey**	**Distance**	**# of Points**
Guma	10	Lagoon boat survey	5 km	
Mombo	10	River walking survey	600 m*	
Nxaraxa	9	Pool point counts		5**
Chitabe	10			

* The Mombo river transect was canceled due to habitat change caused by the flooding.
** The Nxaraxa pool surveys were canceled because the pools dried up.

(Appendix A). I recorded the number of each bird species seen or heard, and the distance from point center (0-20 m, 20-50 m, 50 -100 m, and >100 m), following the methods of Buckland (1987), Bibby et al. (1992), and Buckland et al. (1993). Point counts were surveyed for 10 minutes between 6:00 – 10:00 AM, and in the same order each time to minimize variance due to time of day effects. Point counts were recorded using a semi-directional microphone (Sony ECM-MS 907) and digital minidisk recorder (Sony MD Walkman MZ-R700), making it possible to verify questionable songs and calls later.

Before any analyses were conducted, point count data sets were cleaned to 2 standards to create an “All Birds” data set, and a “Less Common Birds” data set. For the All Birds data set birds over 100 meters from point center were removed in order to prevent recounting birds. Non-resident species were removed because they can have population changes caused by factors outside the Delta. And flocks of more than 20 birds were removed for two reasons. First, they are usually nomadic and may only be moving through the point count station. So they have a large effect on the data set even though they are not necessarily representative of the bird population at the point. And second, they lead to the violation of statistical assumptions. Sightings of individual birds in a flock are not independent, and they skew the data set dramatically.

Aside from the All Birds data set just discussed, I made a sub data set of Less Common Birds by removing the most abundant species, sunbirds, and flocks of greater than 5 birds. Very abundant species can mask changes in populations of less common species. To mitigate this effect, I sorted the species according to the number of times they were detected, and removed all species and species groups that were detected over 190 times. Sunbirds were removed because their numbers greatly increase with the blooming of mistletoe in the Delta, and data were recorded during the 2002 bloom, but not the 2001 bloom. This resulted in the removal of 19 species and 6 species groups (Appendix B).

Acacia Thornveld Bird Surveys (Road Transects)

I conducted road transects by riding in the back of an open vehicle and recording any birds I saw while a driver followed the same four km stretch of road going as slowly as possible without stalling the vehicle (5k/hr). These transects were tried at all sites, but only yielded enough data to be worthwhile at Mombo. Nine surveys were conducted in 2001 and eight in 2002.

Water Bird Surveys

Water surveys were problematic due to changes in habitats caused by the seasonality of the flood. While I conducted various water surveys at different sites, only the Guma Lagoon boat survey was consistent enough to have meaningful results. Boat surveys were conducted by driving a boat approximately 5 km along the edge of the lagoon and counting all birds that were seen. The driver used a Garmin GPS III to help maintain 5 km/hr. We maintained a distance of about 30 meters from the edge of the lagoon, allowing us to detect most birds while minimizing the number of birds flushed. Care was taken to avoid repeat counts of birds that flushed and flew forward along the transect.

SAMPLING EFFORT

Since 2001 was the first season of the project, there was considerable set up time. Once sites were established they were surveyed once per visit before going on to the next site. This was changed early in the 2001 season with each site being surveyed three times per visit in order to reduce travel time and expense. Under ideal conditions, this took three days, but visits often lasted four or more days due to wind and other factors making it necessary to stop collecting data before all stations were surveyed. Table 2 summarizes the survey effort for forest birds.

I conducted a total of 580 point counts and detected a total of 14,977 birds from 135 species, 104 genera, 52 families, and 19 orders (Appendix B) (Appendix C). There were also 18 species groups that included birds that were detected and identified at a taxonomic level higher than species, such as hornbill, dove, babbler, or woodpecker. A list of the number of insectivorous and non-insect-dependent birds detected during each point count survey is presented in Appendix D.

Not all survey techniques were well suited for all study sites. Road surveys were tried at all four sites, but only Mombo yielded enough data to be worthwhile. The Nxaraxa water survey consisted of a series of five pools, but water levels were highly variable, and four of the pools dried up during 2002. Therefore, the Nxaraxa water survey

Table 2. The number of point count surveys conducted for forest birds at four study sites to monitor the effects of spraying deltamethrin for tsetse fly control in the Okavango Delta.

Location	# of Days		# of Point Counts	
	2001	2002	2001	2002
Guma	7	10	47	79
Mombo	4	11	30	85
Nxaraxa	8	17	45	112
Chitabe	9	17	64	118

was dropped and no analysis completed. The Mombo river survey was also dropped due to habitat changes throughout the year caused by the flooding cycle.

Two control sites were tested but neither location was suitable. The Maun Education Reserve was not in the original spray plan, so I collected pre-spray data there in 2001; however, the reserve was later added to the 2002 spray block. The habitat at Khwai was too different from the rest of the sites to be a suitable control. Therefore, sites were compared to themselves before and after spraying (Figure 2).

DIET GUILDS

The purpose of the diet guild analyses was to look for obvious trends related to diet. Because deltamethrin is more likely to affect birds indirectly by reducing insect food supplies than by directly killing birds (Elliot *et al*., 1978, Hudson *et al.,* 1984, Perry et al. 1998), the effects of the spraying can be monitored by looking at changes in insectivorous bird numbers and comparing them with changes in non-insect-dependent bird numbers. If the decline in insects caused by the spraying was detrimental to birds, it would be expected that insectivorous birds would suffer greater declines than non-insect-dependent birds. To make this analysis possible, each species was assigned to one of four diet groups; Herbivore, Carnivore, Omnivore, and Insectivore, and each of the four groups was further divided into three or four secondary groups based on food preferences (Maclean 1993). The secondary grouping emphasizes preferences within the primary grouping (Table 3, Appendix B). For example, a species that ate mostly insects but also ate seeds, berries and carrion would have a primary classification of Omnivore and a

Table 3. Diet categories for birds detected in the Okavango Delta. Birds in the shaded diet groups were considered insectivores in all diet analyses, and birds in unshaded groups were considered non-insect-dependent.

Primary	**Secondary**	**Description of Diet**
Herbivore	General	Herbivore with a varied diet.
	Aquatic	Eats mostly aquatic plants.
	Fruits	Eats mostly fruits.
Carnivore	General	Vertebrates, insects, carrion, mollusks.
	Aquatic	Fish, frogs, tadpoles.
	Aquatic inverts	Aquatic insects, mollusks.
	Insects	Carnivore with insects as a large part of the diet.
Omnivore	General	Very general diet.
	Aquatic	Water plants, fish, mollusks, aquatic insects.
	Herbivore	Varied diet but concentrates on plant material.
	Insects	Varied diet but concentrates on insects.
Insectivore	General	General insect eater.
	Larvae	Larvae specialist.
	Terrestrial	Flying and crawling insects, not aquatics.

secondary classification of insects. Birds were then classified as insectivorous or non-insect dependent, depending on the amount of insects in their diet. Because of the high percentage of insects in the diet of Omnivore / insects and Carnivore / insects groups, they were classified as insectivorous for analyses. It is not surprising that the majority of birds are in the Omnivore / general category, as many common birds are generalists (Table 4, Appendix B).

MEAN COMPARISONS

Due to the repetitive sampling of study sites and point count stations, the data have a hierarchal structure. Surveys were repeated within visits and within treatment categories (before, during, after spraying). Because of this hierarchal structure, data from each point count were averaged within a visit or category before they were used to calculate the mean number of birds per point count. Therefore, standard errors are calculated with n = 10 or n = 9 even though they are based on up to 124 point counts.

The mean number of birds per point count was calculated for each visit to each study site. Each time I visited a site I tried to survey all 10 stations 3 days in a row. The goal was to calculate means based on 30 point counts per visit, but wind, rain, lions and other factors often foiled this plan. In order to look for trends in forest birds, the mean ($\pm$ SE) number of birds per point count for each visit was graphed with both years on the same axes. This made it easy to see trends within a year as well as between years. Paired two-tailed t-tests were used for before / after comparisons. Point count stations were the observational unit for pairing. In the case of the 2001 spray block (Guma and Mombo),

Table 4. Number of birds detected by diet grouping. Birds that usually travel in flocks and very abundant birds were removed from some analyses and so are presented here as a separate group. Shaded areas are for birds considered insectivorous in analyses, while unshaded groups were considered non-insect-dependent.

Primary Diet	Secondary Diet	All Birds Number	All Birds Percent	Less Common Species Number	Less Common Species Percent
Carnivore	Aquatic	84	0.6%	83	1.6%
	General	117	0.8%	117	2.2%
	Insects	1519	10.1%	524	10.1%
	Aquatic Invertebrates	184	1.2%	184	3.5%
	Total	**1904**	**12.7%**	**908**	**17.4%**
Herbivore	Aquatic	68	0.5%	68	1.3%
	Fruits	695	4.6%	175	3.4%
	General	78	0.5%	78	1.5%
	Total	**841**	**5.6%**	**321**	**6.2%**
Insectivore	General	121	0.8%	121	2.3%
	Larvae	115	0.8%	115	2.2%
	Terrestrial	2380	15.9%	995	19.1%
	Total	**2616**	**15.5%**	**1231**	**23.6%**
Omnivore	General	6449	43.1%	2110	40.5%
	Herbivore	823	5.5%	189	3.6%
	Insects	2344	15.7%	446	8.6%
	Total	**9616**	**64.3%**	**2745**	**52.7%**
Insectivore Total		**6479**	**43.3%**	**2201**	**42.3%**
Grand Total		**14,977**	**100%**	**5205**	**100%**

the 2001 mean for each point count station was paired with the 2002 mean for that same station (Figure 2).

In the case of the 2002 spray block (Chitabe and Nxaraxa), pre-spray data from 2001 and 2002 were averaged for each point count station, and compared with 2002 during-spray data (Figure 2). Two-tailed t-tests were used in order to detect population increases as well as declines.

Data from the 2002 spray block were also compared using Analysis of Variance (ANOVA). The treatment categories were 2001 before spray, 2002 before spray, and 2002 during spray. Tukey's HSD was used to detect differences between means for ANOVAs with significant F-values.

Statistical comparisons were made using the JMP software package (SAS Institute Inc. 2000). I used a critical value of $P = 0.10$, because I was more concerned with accepting false null hypotheses than rejecting true null hypotheses. This study was based on data from several sites, and was not strongly based on any one statistical test. Therefore the increased chance of rejecting a true null hypothesis was balanced by repetition of methods.

PRESENCE / ABSENCE COMPARISONS

Presence / absence analyses were conducted by looking at species that were detected on at least two surveys, and counting the number of species in the following categories:

1. Lost species = Present in 2001 but absent in 2002.
2. Gained species = Absent in 2001 but present in 2002.
3. Unchanged species = Detected both years.

Only counting species that were seen at least two times reduced the number of incidental species causing inflated numbers of species gained or lost in the second year.

The loss of a species in this survey may have been a real reduction in the species, or an artifact of sample effort. Not all species are detected on every survey, so as the number of surveys increased, so did the number of species detected. Small changes were not cause for concern, but if far more species had been lost than gained, there would be cause for concern.

CHAPTER 3.

RESULTS

DIET GUILD POPULATION ANALYSES

Guma and Mombo were sprayed from mid-June through August 2001. No changes were detected in the insectivorous bird population at Guma or Mombo for the all birds and less common birds data sets (Tables 5 and 6) (Figures 4 - 7). Increases in non-insect-dependent species at Guma were significant for all bird data ($P = 0.035$), and nearly significant less common bird data ($P = 0.103$). However, non-insect-dependent species declined at Mombo for all bird data ($P = 0.016$) and less common bird data ($P = 0.007$).

In the 2002 spray block (Nxaraxa and Chitabe), spraying began May 16th 2002 and continued until mid-August 2002 (Figure 2). I concentrated on these sites in 2002 and managed four visits to Chitabe and five visits to Nxaraxa. The results from these two sites were inconsistent with Nxaraxa showing no changes in insectivorous species, and Chitabe providing limited evidence of a decline (Figures 8 – 11) (Tables 5 – 8).

At Nxaraxa, all insectivorous bird data peaked in late July 2002, after 2 months of spraying (Figure 10). This peak was mirrored in non-insect-dependent birds as well and may have been related to the fires that took place in May 2002. However, Chitabe burned at the same time and showed no such peak (Figures 10 and 11). For less common insectivorous birds, 2002 numbers were still fairly high in July, but not a substantial peak (Figure 11).

Table 5. Results of two-tailed t-tests comparing the number of birds detected at point counts before and after the spraying of deltamethrin. For the 2002 spray block (Nxaraxa and Chitabe), 2001 data was combined with 2002 pre-spray data and compared with 2002 during-spray data (after May 17, 2002). For the 2001 spray block (Guma and Mombo), 2001 pre-spray data were compared with 2002 post-spray data (9-14 months post-spray).

Data sets compared	**P-value***	
	Insectivorous birds	**Non-insect dependent birds**
(Guma 2001) to (Guma 2002)	P = 0.998	(P = 0.035) up
(Mombo 2001) to (Mombo 2002)	P = 0.155	(P = 0.016) down
(Nxaraxa 2001 & 2002b)** to (Nxaraxa 2002a)	P = 0.778	P = 0.408
(Chitabe 2001 & 2002b) to (Chitabe 2002a)	(P < 0.0001) down	(P = 0.024) up

* P-values in parentheses ( ) are statistically significant.
Up = population increased from pre-spray to during or post-spray.
Down = population decreased from pre-spray to during or post-spray.

** 2002b is 2002 data before spraying started.
2002a is 2002 data after spraying started.

Table 6. Results of two-tailed t-tests comparing the number of **less common** birds detected at point counts before and after the spraying of deltamethrin. **Very abundant species were excluded for this comparison.** For the 2002 spray block (Nxaraxa and Chitabe), 2001 data was combined with 2002 pre-spray data and compared with 2002 during-spray data (after May 17, 2002). For the 2001 spray block (Guma and Mombo), 2001 pre-spray data was compared with 2002 post-spray data (9-14 months post-spray).

Data sets compared	**P-value***	
	Insectivorous birds	**Non-insect dependent birds**
(Guma 2001) to (Guma 2002)	P = 0.956	P = 0.103
(Mombo 2001) to (Mombo 2002)	P = 0.339	(P = 0.007) down
(Nxaraxa 2001 & 2002b)** to (Nxaraxa 2002a)	P = 0.531	(P = 0.067) down
(Chitabe 2001 & 2002b) to (Chitabe 2002a)	(P < 0.0001) down	(P = 0.003) down

* P-values in parentheses ( ) are statistically significant.
Up = population increased from pre-spray to during or post-spray.
Down = population decreased from pre-spray to during or post-spray.

** 2002b is 2002 data before spraying started.
2002a is 2002 data after spraying started.

Figure 4. Median number of birds detected per point count in the 2001 spray block (Guma and Mombo). 2001 data is pre-spray, and 2002 data is from the year after the spraying.

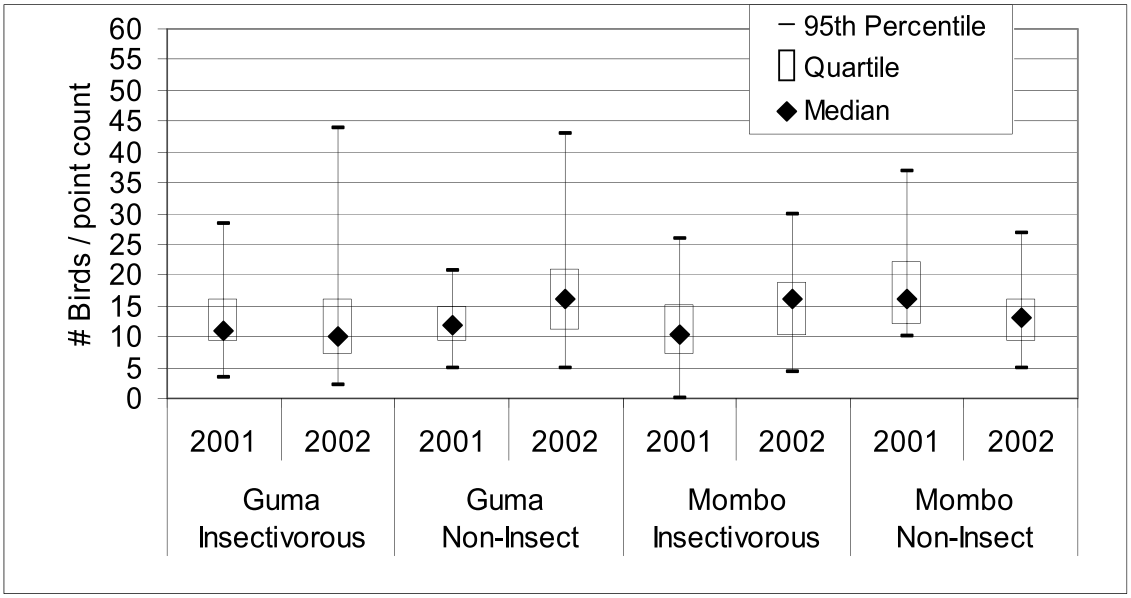


Figure 5. Median number of less common birds detected per point count in the 2001 spray block (Guma and Mombo). 2001 data is pre-spray, and 2002 data is from the year after the spraying.

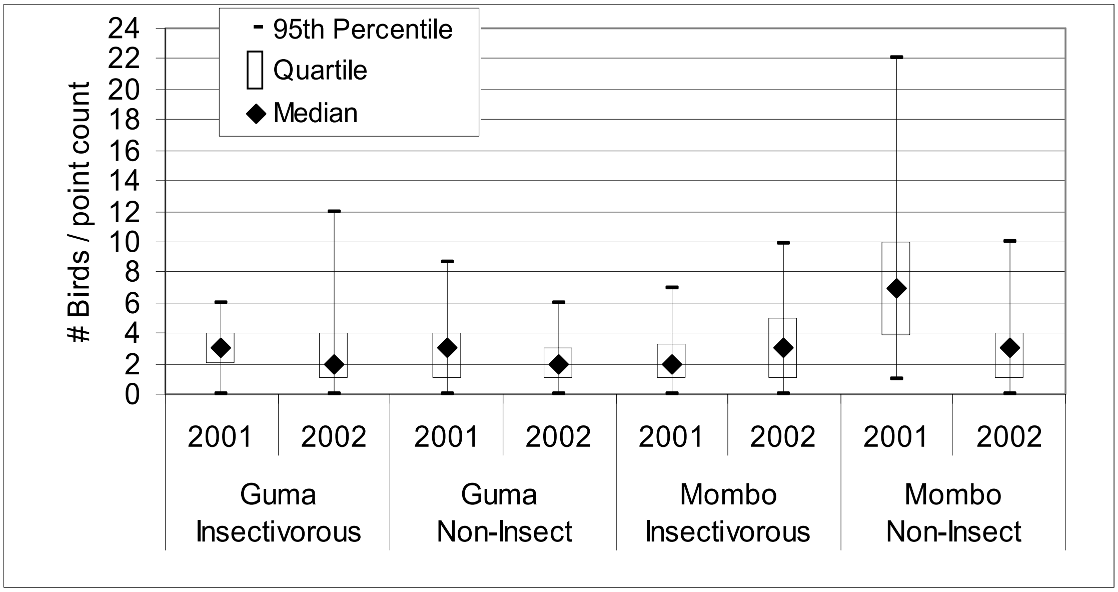
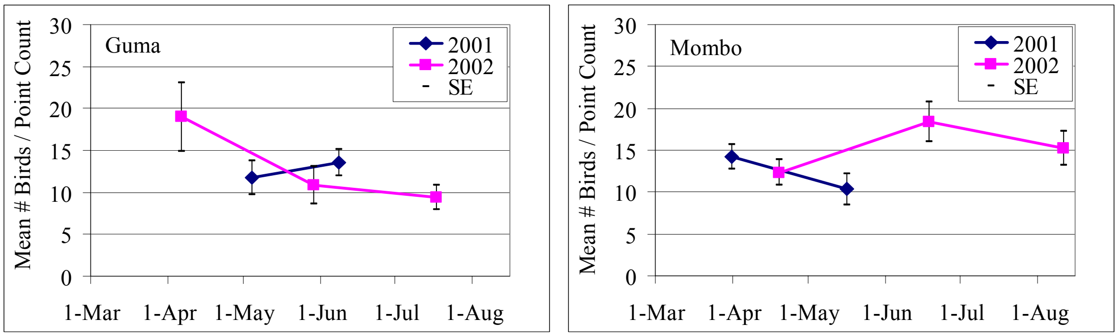


Figure 6. Mean number of birds detected per point count in the 2001 spray block (Guma and Mombo). Spraying (June – August 2001) began during the June 2001 surveys at Guma, so March – May 2001 was pre-spray, and June 2001 was during-spray. 2002 data collection began 9 months after spray began.

A. Insectivorous Species



B. Non-Insect-Dependent Species

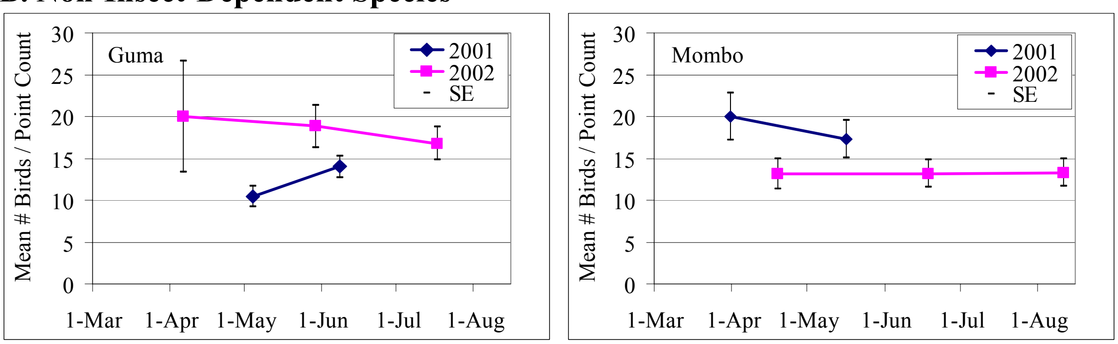
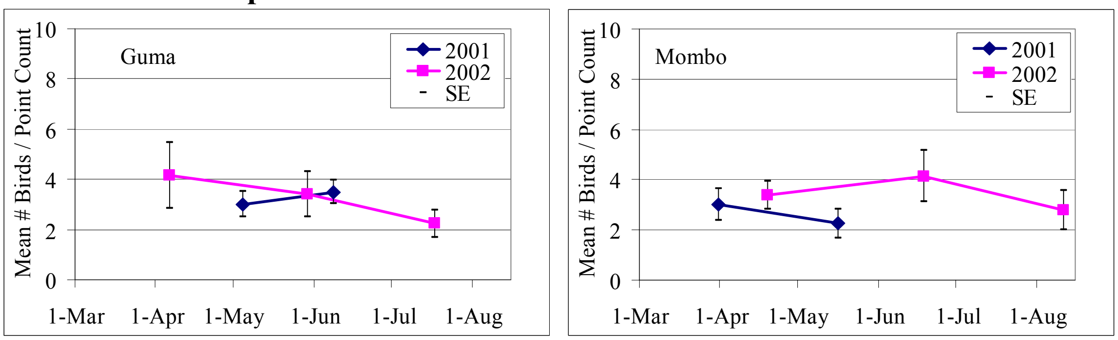


Figure 7. Mean number of **less common** birds (excluding most abundant and flocking species) detected per point count in the 2001 spray block (Guma and Mombo). Spraying (June – August 2001) began during the June 2001 surveys at Guma, so March – May 2001 was pre-spray, and June 2001 was during-spray. 2002 data collection began 9 months after spray began.

A. Insectivorous Species



B. Non-Insect-Dependent Species

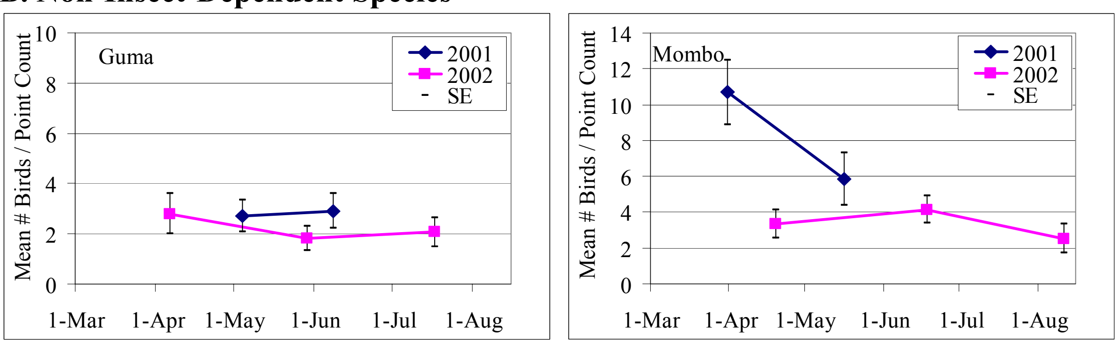
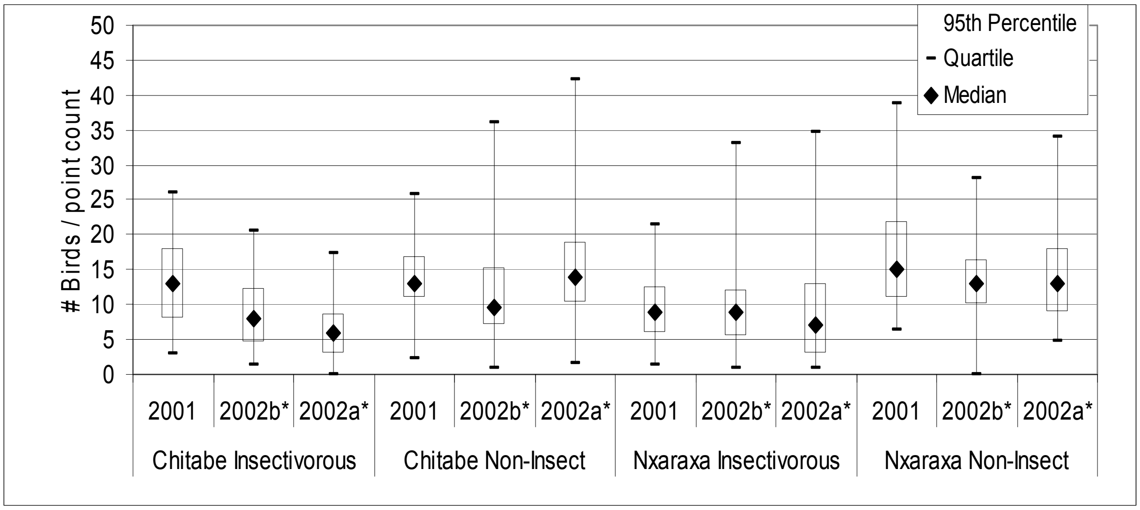
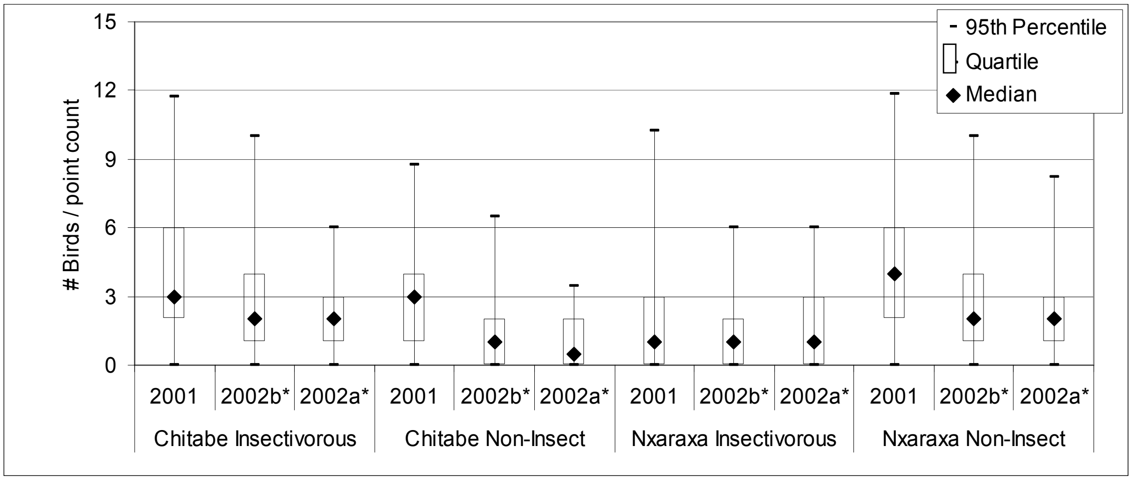


Figure 8. Median number of birds detected per point count in the 2002 spray block. Spraying began in May 2002.



*2002b is data collected in April and May 2002, just before the spraying started.
2002a is data collected in June and July 2002, while the spraying was taking place.

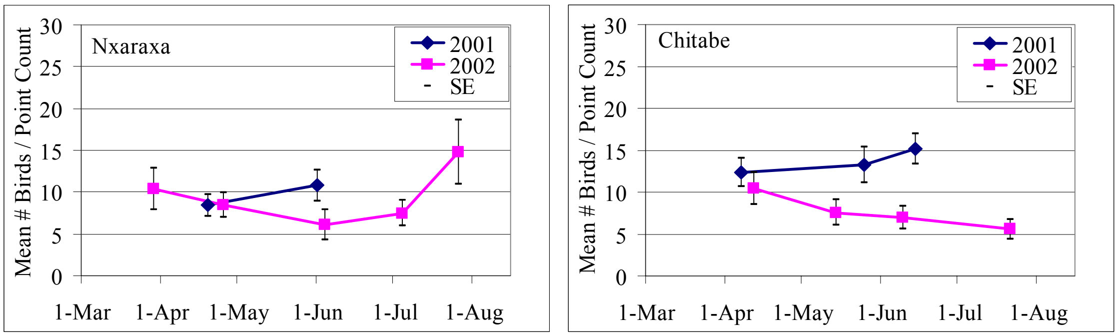
Figure 9. Median number of uncommon birds detected per point count in the 2002 spray block. Spraying began in May 2002.



*2002b is data collected in April and May 2002, just before the spraying started.
2002a is data collected in June and July 2002, while the spraying was taking place.

Figure 10. Means of **insectivorous** birds detected per point count in the 2002 spray block (Nxaraxa and Chitabe). Spraying began May 17th 2002, so 2001 data were pre-spray, 2002 data collected before May 17th were pre-spray, and 2002 data collected after May 17th were during-spray data.

A. Insectivorous Species



B. Non-Insect-Dependent Species

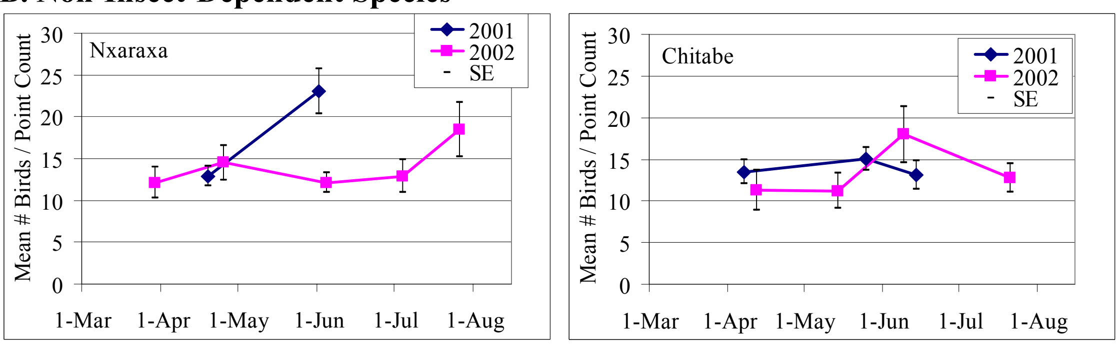
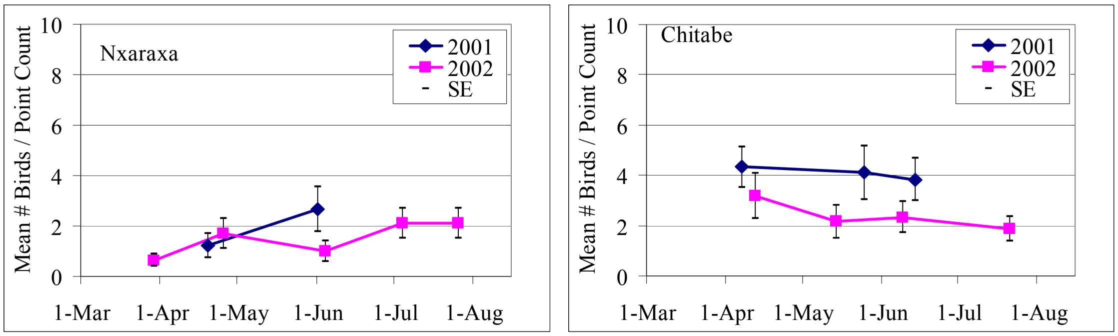


Figure 11. Means of **insectivorous** birds detected per point count in the 2002 spray block (Nxaraxa and Chitabe) **excluding most abundant species**. Spraying began May 17th 2002, so 2001 data and 2002 data collected before May 17th were pre-spray, while 2002 data collected after May 17th were during-spray data.

A. Insectivorous Species



B. Non-Insect-Dependent Species

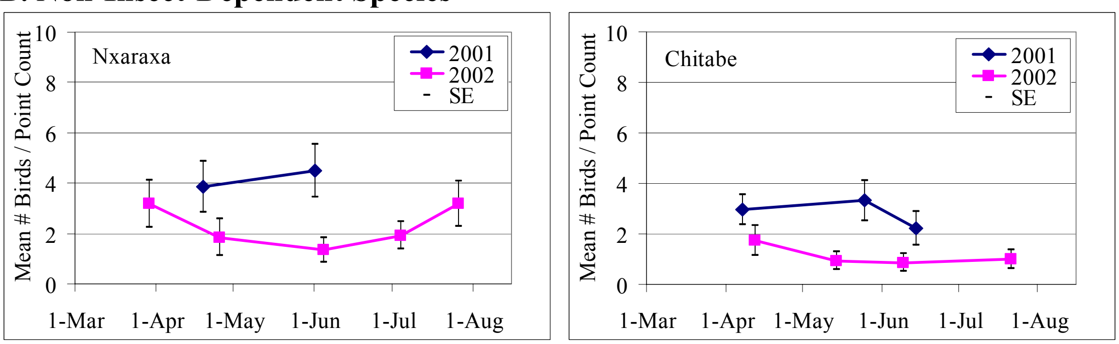


Table 7. Results of Analysis of Variance for Nxaraxa forest birds. Nxaraxa had 9 point count stations, and data from each station was averaged within groups. Therefore, n = 27 but means are based on 156 point counts. A critical value of 0.10 was used because I was more concerned with accepting false null hypotheses than rejecting true ones. Means were compared using Tukey's HSD, and are represented by the letters A B and C after the means. If two means do not share a letter they are significantly different.

A. Nxaraxa insectivorous birds.

Source	df	F Ratio	P
Between	2	0.0141	0.986
Within	24		
Total	26		

Category	Mean $\pm$ SE		
2001	9.2 $\pm$ 0.78	A	
2002 pre-spray	9.3 $\pm$ 0.92	A	
2002 during-spray	9.5 $\pm$ 1.55	A	

B. Nxaraxa non-insect-dependent birds.

Source	df	F Ratio	P
Between	2	3.3423	0.052
Within	24		
Total	26		

Category	Mean $\pm$ SE		
2001	17.0 $\pm$ 0.93	A	
2002 pre-spray	13.3 $\pm$ 0.77		B
2002 during-spray	14.4 $\pm$ 1.31	A	B

C. Nxaraxa insectivorous birds excluding very abundant and flocking species.

Source	df	F Ratio	P
Between	2	0.8247	0.45
Within	24		
Total	26		

Category	Mean $\pm$ SE		
2001	2.6 $\pm$ 0.39	A	
2002 pre-spray	2.0 $\pm$ 0.30	A	
2002 during-spray	2.8 $\pm$ 0.60	A	

D. Nxaraxa non-insect-dependent birds excluding very abundant and flocking species.

Source	df	F Ratio	P
Between	2	0.9775	0.391
Within	24		
Total	26		

Category	Mean $\pm$ SE		
2001	4.9 $\pm$ 0.42	A	
2002 pre-spray	4.1 $\pm$ 0.62	A	
2002 during-spray	4.0 $\pm$ 0.49	A	

Table 8. Results of Analysis of Variance for Chitabe forest birds. Chitabe had 10 point count stations, and data from each station was averaged within groups. Therefore, n = 30 but means are based on 181point counts. A critical value of 0.10 was used because I was more concerned with accepting false null hypotheses than rejecting true ones. Means were compared using Tukey's HSD, and are represented by the letters A B and C after the means. If two means do not share a letter they are significantly different.

A. Chitabe insectivorous birds.

Source	df	F Ratio	P
Between	2	23.221	<0.0001
Within	27		
Total	29		

Category	Mean $\pm$ SE		
2001	13.6 $\pm$ 3.57	A	
2002 pre-spray	9.8 $\pm$ 1.46		B
2002 during-spray	6.2 $\pm$ 1.80		B

B. Chitabe non-insect-dependent birds.

Source	df	F Ratio	P
Between	2	2.556	0.0962
Within	27		
Total	29		

Category	Mean $\pm$ SE		
2001	13.7 $\pm$ 1.04	A	B
2002 pre-spray	11.1 $\pm$ 1.56		B
2002 during-spray	15.5 $\pm$ 1.45	A	

C. Chitabe insectivorous birds excluding very abundant and flocking species.

Source	df	F Ratio	P
Between	2	2.955	0.0691
Within	27		
Total	29		

Category	Mean $\pm$ SE		
2001	4.49 $\pm$ 0.58	A	
2002 pre-spray	3.4 $\pm$ 0.37	A	B
2002 during-spray	2.98 $\pm$ 0.36		B

D. Chitabe non-insect-dependent birds excluding very abundant and flocking species.

Source	df	F Ratio	P
Between	2	5.323	0.0112
Within	27		
Total	29		

Category	Mean $\pm$ SE		
2001	3.7 $\pm$ 0.53	A	
2002 pre-spray	1.85 $\pm$ 0.37		B
2002 during-spray	3.74 $\pm$ 0.51	A	

The only significant change at detected using paired t-tests at Nxaraxa, was a decline in less common non-insect-dependent birds ($P=0.067$) (Tables 5 and 6). Nxaraxa showed no change in the number of all insectivorous birds (Table 5) or less common insectivorous birds (Table 6). When an ANOVA was used to test for differences between 2001 pre-spray data, 2002 pre-spray data, and 2002 during-spray data, only all non-insect-dependent birds showed a significant difference ($F = 0.052$) (Table 7). The 2001 and 2002 pre-spray data were significantly different from each other; however, neither was significantly different from the 2002 during-spray data, providing no evidence of a spray effect.

Chitabe insectivorous birds showed a decline correlated with the spraying, with the lowest numbers recorded during the spraying for all birds (Figure 10) as well as less common birds (Figure 11). Paired t-tests detected significant declines for all birds ($P < 0.0001$) and less common birds ($P < 0.0001$); however, ANOVAs were not so clear cut. There were statistically significant differences in all four data sets, but there was no case where both pre-spray categories were equal to each other, and greater than the during-spray data (Table 8). In both insectivorous bird data sets a decline was detected from the 2001 pre-spray surveys to the 2002 post-spray surveys. For all insectivorous birds, numbers were higher in 2001 than either 2002 category ($F < 0.0001$), suggesting that the decline started before the spraying and continued through the spraying. Less common insectivorous birds showed a significant decline between 2001 pre-spray, and 2002 during-spray data ($F = 0.069$). However, there was not a difference between 2002 pre-spray data and either of the other two categories. Therefore, while there were declines in insectivorous birds at Chitabe correlated with the spraying, these declines began before the spraying started. It is definitely possible that the spraying contributed to these declines, but it is also possible that the fires or some other cause may have had a stronger effect than the spraying.

Chitabe all non-insect-dependent birds peaked in June 2002 due to an increase in doves (Figures 10). This peak was correlated with the spraying and the fires. It was more likely the result of the fires removing grass cover and providing better access to seeds on the ground, than a result of the spraying. Less common insectivorous birds did not display this same peak (Figure 11). In fact, t-tests comparing before-spray to during-spray data showed an increase for all non-insect-dependent birds (P = 0.024), but a decrease for less common non-insect-dependent birds (P = 0.003) (Tables 5 and 6). While ANOVAs were significant for all non-insect-dependent birds (F = 0.096) and less common non-insect-dependent birds (F = 0.011), these differences were not correlated with the spraying (Table 8).

GREYBACKED BLEATING WARBLERS

Greybacked bleating warblers are a good species for monitoring change in insectivorous birds for three reasons. First, they call regularly throughout the year, so detections are not likely to decline as a result of calling behavior. Second, they do not form flocks, avoiding the statistical problems of clumped observations. And third, they are residents (non-migratory), making it unlikely for numbers to change due to factors outside the Delta.

Chitabe showed a statistically significant decline in the number of greybacked bleating warblers when all before data were compared with 2002 after spray data (P = 0.003) (Figures 12, Table 9). An ANOVA showed no difference between 2001 and 2002 pre-spray data, but both were significantly larger than 2002 during-spray (F = 0.079). The differences were due to the drop off in the number of detections in the July 2002 surveys (Figure 12). This may have been a delayed response to the spraying or the fire. However, Nxaraxa was sprayed and burned at the same time and showed no such reductions. None of the other sites had statistically significant declines in Greybacked bleating warbler numbers (Figure 12, Table 9).

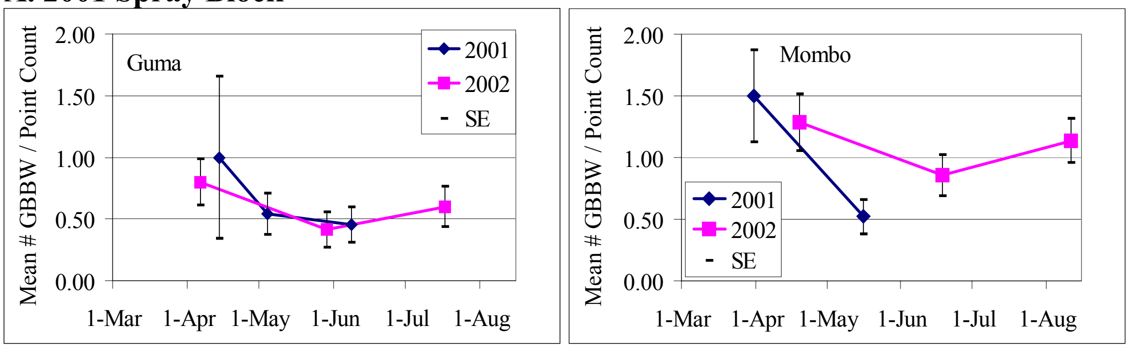
MOMBO ACACIA THORNVELD BIRDS

Based on 5 surveys in 2001 and 6 surveys in 2002, bird species in the Mombo thornveld were lost or gained at similar rates regardless of diet (Tables 10 and 11). Overall, more species were gained in 2002 than lost. Insectivorous birds were lost at a lower rate than non-insect-dependent birds, but due to the small sample size of insectivorous bird species (n=19), this slight difference should not be interpreted as a serious decline.

When grouped by diet guild, there was no significant change in the mean number of insectivorous birds between 2001 and 2002 (P = 0.157), but there was a significant reduction in non-insect-dependent species (P = 0.012) (Table 12).

Figure 12. Mean number of greybacked bleating warblers detected at all study sites. In the 2001 spray block, spraying (June – August 2001) began during the June 2001 surveys at Guma, so March – May 2001 was pre-spray, and 2002 data collection began 9 months after spraying began. In the 2002 spray block, spraying began May 17th 2002, so 2001 data and 2002 data collected before May 17th were pre-spray, while 2002 data collected after May 17th were during-spray data.

A. 2001 Spray Block



B. 2002 Spray Block

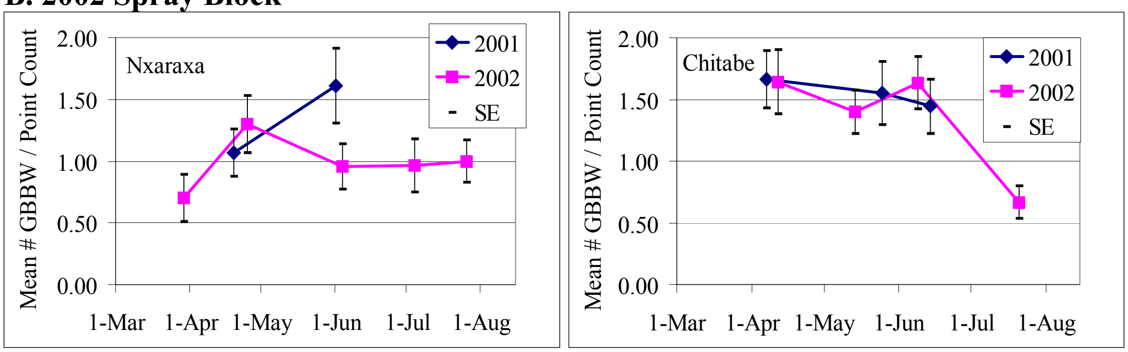


Table 9. Results of paired two-tailed t-tests comparing greybacked bleating warbler numbers at all 4 sites before and after the spraying of deltamethrin. For the 2002 spray block (Nxaraxa and Chitabe) 2001 data was combined with 2002 pre-spray data and compared with 2002 during-spray data (after May 17, 2002). For the 2001 spray block (Guma and Mombo) 2001 data is pre-spray, and 2002 data is 9-14 months post-spray.

Data sets compared	P-value*
(Chitabe 2001 & 2002b) to (Chitabe 2002a)**	(P = 0.003) down
(Nxaraxa 2001 & 2002b) to (Nxaraxa 2002a)	P = 0.268
(Guma 2001) to (Guma 2002)	P = 0.815
(Mombo 2001) to (Mombo 2002)	P = 0.966

* P-values in parentheses ( ) are statistically significant.
Up = population increased from pre-spray to during or post-spray.
Down = population decreased from pre-spray to during or post-spray.

** 2002b is 2002 data before spraying started.
2002a is 2002 data after spraying started.

Table 10. Summary of species presence / absence data from Mombo acacia thornveld driving surveys. Birds were surveyed along a 4 km driving transect before (2001) and after (2002) the spraying of deltamethrin for tsetse fly control.

	# of species Present both years		Absent in 2001 and present 2002 (gained)		Present in 2001 and absent 2002 (lost)		Total
Non-Insect-Dependent	21	60.0%	8	22.9%	6	17.1%	35
Insectivorous	11	57.9%	6	31.6%	2	10.5%	19
Total	32	59.3%	14	25.9%	8	14.8%	54

Table 11. List of birds that were detected in 2001 or 2002, but not both years during Mombo acacia thornveld surveys. Birds considered insectivorous in analyses are Shaded. (Scientific names can be found in Appendix B).

Birds absent in 2001 but Present in 2002 (up)	**Birds present in 2001 but Absent in 2002 (down)**
Blackwinged Stilt	Pearlspotted Owl
Whitebacked Vulture	Gabar Goshawk
Doublebanded Sandgrouse	Laughing Dove
Redfaced mousebird	Ostrich
Glossy Starling	Eastern Paradise Whydah
Helmeted Guineafowl	Whitebellied Sunbird
Melba Finch	Pied Babbler
Crested Francolin	Arrowmarked Babbler
Bennett's Woodpecker	
Little Bee-eater	
Oxpecker	
Chestnutvented Titbabbler	
Blackcrowned Tchagra	
Striped Kingfisher	

Table 12. Results of two-tailed t-tests comparing the number of birds detected in acacia thornveld (Mombo driving transect) before (2001) and 9-14 months after (2002) the spraying of deltamethrin.

Data sets compared	**P-value**	
	Insectivorous birds	**Non-insect-dependent birds**
Mombo 2001 to Mombo 2002	P = 0.157	(P = 0.012) down

P-value in parentheses ( ) are statistically significant.
Up = population increased from pre-spray to during or post-spray.
Down = population decreased from pre-spray to during or post-spray.

WATER BIRDS (GUMA LAGOON SURVEYS)

Based on 11 surveys in 2001 and nine surveys in 2002, species in Guma Lagoon were lost or gained at similar rates regardless of diet (Tables 13 and 14). Insectivorous birds were lost at a higher rate than non-insect-dependent birds, but due to the small sample size of insectivorous bird species (n=14), this slight difference should not be viewed as a significant decline.

For all species combined and non-insect-dependent species, more species were gained than lost in 2002. For insectivorous species, more species were lost than gained in 2002. Due to the small sample size, the slightly higher loss of insectivorous species is no cause for concern.

When grouped by diet guild, there was no significant change in the number of insectivorous birds between 2001 and 2002 ($P = 0.238$) but non-insect-dependent birds increased ($P = 0.076$) (Table 15). However, the April 2002 surveys coincided with the annual fish kill caused by the low oxygenated water arriving with the flood (Gee Makaplan, Guma Camp, pers. comm.). Pied kingfishers (*Ceryle rudis*) and terns (*Chlidonias* spp.) opportunistically feeding on the dead and dying fish were partially responsible for this increase. It is unlikely that this increase in non-insect-dependent birds was due to the spraying. Therefore, while there were changes in species composition, there was not a drop in the number of birds from either diet guild.

Table 13. Summary of species presence / absence data from Guma Lagoon boat surveys. Birds were surveyed along a 5 km lagoon edge before (2001) and after (2002) the spraying of deltamethrin for tsetse fly control.

	# of species present both years		Absent 2001 and present 2002 (gained)		Present 2001 and absent 2002 (lost)		Total
Non-Insect-Dependent	21	70.0%	6	20.0%	3	10.0%	30
Insectivorous	9	64.3%	2	14.3%	3	21.4%	14
Total	30	68.2%	8	18.2%	6	13.6%	44

Table 14. List of birds that were detected in 2001 or 2002, but not both years during Guma Lagoon water bird surveys. Birds considered insectivorous in analyses are Shaded. (Scientific names can be found in Appendix B)

Birds absent in 2001 but Present in 2002 (up)	**Birds present in 2001 but Absent in 2002 (down)**
Dabchick	Blacksmith Plover
Little Egret	Purple Heron
Rufousbellied Heron	Redshouldered Widow
White Winged Tern	Tawneyflanked Prinia
African Marsh Harrier	Copperytailed Coucal
Redeyed Bulbul	Cisticola
Redwinged Pratincole	
Warbler	

Table 15. Results of two-tailed t-tests comparing the number of birds detected in Guma Lagoon (Boat surveys) before (2001) and 9-14 months after (2002) the spraying of deltamethrin.

Data sets compared	**P-value**	
	Insectivorous birds	**Non-insect-dependent birds**
Guma 2001 to Guma 2002	P = 0.238	(P = 0.076) up

P-value in parentheses ( ) are statistically significant.
Up = population increased from pre-spray to during or post-spray.
Down = population decreased from pre-spray to during or post-spray.

CHAPTER 4

DISCUSSION

The effects of sub-lethal levels of toxins in the environment can be very difficult to detect (Peterle 1991). They are often subtle and difficult to distinguish from effects caused by other factors such as weather and fire. Even in cases of drastic declines, it is often difficult to assign causality to the toxin as other factors may be correlated with the decline. Such was the case when a colony of South Polar skuas (*Catharacta maccormicki*) suffered 100% nest failure correlated with an oil slick. Even though this was a case of a toxin directly affecting the animal, there was controversy as to whether the chicks died as a result of reduced parental care caused by the oil induced stresses on the parents (Eppley and Rubega 1989, Eppley 1992) or if it was a case of natural variation in skua reproductive success (Tivalpiece et al. 1990). As connections become indirect, such as reductions in insect food sources caused by the spraying of deltamethrin, it becomes more difficult to attribute population reductions to the toxin.

The techniques used in this study were appropriate for detecting the most serious effects of the spraying; immediate, large-scale population declines. Population declines are ultimately caused by effects to many individuals. These effects may be direct through poisoning, or indirect through any number of pathways. In this case, direct poisoning can be ruled out due to the low toxicity of deltamethrin to birds (Elliot et al., 1978, Hudson et al., 1984, WHO 1990, Exotoxnet 2001), and the fact that concentrations of dead birds were not found. But indirect effects can also cause population declines in the short-term. Reductions in insect populations can cause food shortages leading to death by starvation or emigration out of the area. In the longer-term, bird populations may decline due to reduced breeding success (Peterle 1991).

The spraying of deltamethrin in the Okavango Delta reduced insect numbers and biomass on the order of 50% (Dangerfield 2003). If factors aside from insect numbers are responsible for limiting insectivorous bird numbers, a reduction of this magnitude might not be large enough to affect insectivorous birds. However, if such a reduction in insect numbers sufficiently reduced the amount of food available, insectivorous birds would have been expected to decline more than non-insect-dependent birds. Because insect populations were reduced but not eliminated, population declines would more likely be caused by decreases in reproduction and increases in emigration than by immediate mass die-offs from starvation. Large changes in bird populations caused by large-scale emigration would have been detectable; however, small population changes caused by small-scale emigration would have been difficult to detect. Reductions in reproductive success could take years to cause population declines, and would not be detected during this study.

The diet guild analysis from the point count data provided the most powerful test of the effects of the spraying on bird populations because it was based on the largest data set and included the broadest range of species of any of sampling techniques used. The only site that showed signs of an effect that could be correlated with the spraying was Chitabe. The lowest numbers recorded for insectivorous birds (Figures 10 and 11) and greybacked bleating warblers (Figure 12) were in July 2002 after the spraying started. This was what would be expected if the spraying was having an immediate effect. However, there were several reasons why these declines could not be viewed as convincing evidence of declines caused by the spraying. First, only greybacked bleating warblers showed a drastic decline which clearly jumped out as something beyond natural variation. Second, the decline in insectivorous birds began before the spraying started. Third, there were not concurrent declines at Nxaraxa, which was in the same spray block. And fourth, the declines were also correlated with fires. Therefore, while it is possible these declines may have been partially or fully caused by the spraying, other factors are likely to have contributed to these declines.

There were fires throughout the Okavango Delta during the 2002 spray season which may have caused local or large scale movements of birds. Local bird populations may have increased or declined as birds migrated in or out of the area in response to the fire itself, or the corresponding changes in habitat. The fires at Nxaraxa and Chitabe just before the spraying started make it difficult to assign changes in bird populations to the spraying. Birds may have emigrated from Chitabe in response to the spraying, the fires, or a combination of factors. Evidence of a decline caused by the spraying would have been much stronger if Nxaraxa had similar population declines as Chitabe.

There was no evidence of migrations of insectivorous birds out of sprayed areas, and into unsprayed areas. If this was happening, Nxaraxa and Chitabe insectivorous bird numbers would have been higher at the beginning of the 2002 surveys, due to an influx of birds from the 2001 spray block. This was not the case. And while insectivorous bird numbers did show a slight increase at Mombo, they declined at Guma as spraying began in the 2002 spray block. The only case where a decrease at one site could possibly be explained by an increase at another site is from Chitabe to Nxaraxa in 2002 (Figures 10 and 11). This was probably not caused by the spraying since both sites were in the same spray block.

All these analyses taken together provide strong evidence that the spraying did not have an immediate catastrophic effect on insectivorous birds as a group. These findings are in agreement with other population level studies of sub-lethal doses of pesticides on birds (Douthwaite 1980, Cooper et al. 1990, Howe et al. 1996). It seems that while insect numbers were clearly reduced, they were not reduced enough to cause immediate population declines. Insects may have been a hyper-abundant food supply, able to withstand a large reduction without becoming a limiting factor on insectivorous bird populations. However, the effects on individual birds were not assessed. Doses of pesticide that did not lead to immediate population declines in birds have caused changes in feeding behavior (Douthwaite 1982, Sample et al. 1993) and weight loss (Whitmore et al. 1993). Such physiological and behavioral changes can lead to reduced reproductive success and may lead to population declines in the long term (Cooper et al. 1990). It can not be concluded that the spraying had no effects on birds, only that there was not an immediate large-scale decline.

SUMMARY

The basic premise of any environmental monitoring program is to look for changes in a dependent variable in response to an independent variable. This was a population level study with bird numbers dependent on the spraying of deltamethrin. While this study suggests that there were not immediate large-scale declines in the numbers of insectivorous birds as a result of the spraying, it can not be concluded that there were no immediate effects at other levels. Population declines are ultimately the result of changes in mortality, emigration, and reproduction. Stresses such as food reductions may have significant effects on these life history traits, which may not be translated into detectable, short-term population declines (Whitmore et al. 1993, Sample et al. 1993, Cooper et al. 1990). Due to the short duration of this study, declines in populations could only be detected if they are caused by death or emigration. Population declines caused by reductions in breeding success may take place over several years.

Ultimately there were some local changes in populations during the spraying, but changes were neither catastrophic nor clearly correlated with the spraying. However, due to the problems of delayed response to changes in insect numbers and other factors affecting local populations, it can not be said that the spraying had no effect. Effects of the spraying on bird populations may have been too small to be statistically significant, or may not have happened yet. Effects on reproductive success, feeding behavior, or physiology of birds would not have been detected by these methods.

RECOMMENDATIONS FOR FUTURE MONITORING

The techniques used in this study were appropriate for looking at natural variation in bird detections, and monitoring the effects of the spraying on bird populations, but future researchers into spraying operations may be well advised to monitor a variety of life history characteristics. Studies that look into population effects as well as breeding success, foraging behavior and physiological changes in response to spraying operations are very rare, and no change may be detected at the population level while significant changes are taking place at other levels (Cooper et al. 1990, Whitmore et al. 1993, Sample et al. 1993).

Time and resources are often limited in ecological studies and a researcher or research team is usually forced to collect certain types of data at the expense of others. An ideal study design would involve multiple researchers, collecting data on several traits at each study site. In the absence of multiple researchers, I would suggest reducing the number of point counts in order to collect data on other traits.

If a single researcher was to repeat my study, I would suggest continuing the point count visits to each study site with an extra day or two for collecting data on foraging behavior. A significant amount of foraging behavior data can be collected in a day, including the amount of time spent foraging, the number of sorties per hour, and the percent of successful sorties. Bee-eaters are particularly suitable for foraging behavior studies since they are conspicuous insect-dependent birds. If the correct permits are obtained, birds may be taken and stomachs examined in order to look for dietary changes.

Monitoring nests yields data on reproductive success, such as the number of clutches per year, the number of eggs per clutch, and the number of chicks fledged. Intense nest monitoring can be combined with foraging data and used to examine the amount of food each chick receives. Safari guides and local bird clubs can provide useful information on nest locations.

Ultimately the more types of information that can be collected the better understanding a researcher will have of the effects of a spraying operation on birds, and if there are population declines the better a researcher will understand the mechanisms of the decline.

Appendix A. The location of forest point count survey stations in the Okavango Delta. Locations are given in decimal degrees and were collected using a Garmin GPS III with the datum set to WGS 84.

STATION	LATITUDE	LONGITUDE
CH1	S19.53076	E23.38035
CH2	S19.53018	E23.37756
CH3	S19.53092	E23.37406
CH4	S19.53238	E23.37143
CH5	S19.53348	E23.36936
CH6	S19.53363	E23.36624
CH7	S19.53473	E23.36467
CH8	S19.53386	E23.36194
CH9	S19.51970	E23.38922
CH10	S19.51973	E23.39200
GD1	S18.96592	E22.36854
GD2	S18.96812	E22.36543
GF1	S18.96541	E22.37082
GF2	S18.96721	E22.37116
GF3	S18.97070	E22.37150
GF4	S18.97170	E22.37363
GF5	S18.97391	E22.37471
GF6	S18.97674	E22.37616
GF7	S18.97847	E22.37737
MO1	S19.21105	E22.77155
MO2	S19.21061	E22.76940
MO3	S19.20789	E22.77015
MO4	S19.20559	E22.77146
MO5	S19.20333	E22.76984
MO6	S19.20397	E22.76759
MO7	S19.20392	E22.76441
MO8	S19.20328	E22.76177
MO9	S19.20173	E22.76020
MO10	S19.19979	E22.75879
XX2	S19.54493	E23.17809
XX3	S19.54134	E23.17497
XX4	S19.53745	E23.17986
XX5	S19.53508	E23.18054
XX6	S19.52797	E23.18461
XX7	S19.53085	E23.18332
XX9	S19.54352	E23.20032
sXX10	S19.54407	E23.20391
XX11	S19.54437	E23.20705

Appendix B. List of species detected at point count stations by abundance, including diet categories used for guild analysis. Species listed in **bold type** were not used in analyses that excluded the most abundant species. Latin names from Maclean (1993).

COMMON NAME	LATIN NAME	PRIMARY DIET	SECONDARY DIET	TOTAL
Redbilled Francolin	***Francolinus adspersus***	**Omnivore**	**General**	**1301**
Burchell's Starling	***Lamprotornis australis***	**Omnivore**	**Insects**	**1126**
Unknown Dove	***Streptopelia* spp.**	**Omnivore**	**General**	**896**
Red Eyed Dove	***Streptopelia semitorquata***	**Omnivore**	**General**	**831**
Grey Lourie	***Corythaixoides concolor***	**Omnivore**	**Herbivore**	**634**
Blackeyed Bulbul	***Pycnonotus barbatus***	**Omnivore**	**General**	**634**
Greybacked Bleating Warbler	***Cameroptera brachyura***	**Insectivore**	**Terrestrial**	**619**
Cape Turtle Dove	***Streptopelia capicola***	**Omnivore**	**General**	**596**
Arrowmarked Babbler	***Turdoides jardineii***	**Carnivore**	**Insects**	**587**
African Palm Swift	***Cypsiurus parvus***	**Insectivore**	**Terrestrial**	**575**
Meyers Parrot	***Poicephalus meyeri***	**Herbivore**	**Fruit**	**520**
Meve's Longtailed Starling	***Lamprotornis mevesii***	**Omnivore**	**Insects**	**507**
Forktailed Drongo	***Dicrurus adsimilis***	**Insectivore**	**Terrestrial**	**377**
Unknown Weaver	***Ploceus* spp.**	**Omnivore**	**General**	**325**
Blue Waxbill	***Uraeginthus angolensis***	**Omnivore**	**General**	**301**
Hartlaub's Babbler	***Turdoides hartlaubii***	**Carnivore**	**Insects**	**299**
Swamp Boubou	***Laniarius bicolor***	**Omnivore**	**Insects**	**221**
Blackcollared Barbet	***Lybius torquatus***	**Omnivore**	**General**	**196**
Unknown Swallow	***Hirundo* spp.**	**Insectivore**	**Terrestrial**	**191**
Grey Hornbill	*Tockus nasutus*	Carnivore	Insects	190
Marico Sunbird	***Nectarinia mariquensis***	**Omnivore**	**General**	**183**
Crested Francolin	*Francolinus sephaena*	Omnivore	Herbivore	178
African Green Pigeon	*Treron calva*	Herbivore	Fruit	174
Blacksmith Plover	*Vanellus armatus*	Carnivore	Aquatic Invertebrates	159
Green spotted Dove	*Turtur chalcospilos*	Omnivore	General	151
Glossy Starling	*Lamprotornis nitens*	Omnivore	Insects	149
Redbilled Buffalo Weaver	*Bubalornis niger*	Omnivore	General	127
Unknown Starling	***Lamprotornis* spp.**	**Omnivore**	**Insects**	**116**
Unknown Hornbill	*Tockus* spp.	Omnivore	General	114
Chinspot Batis	*Batis molitor*	Insectivore	Terrestrial	113

COMMON NAME	LATIN NAME	PRIMARY DIET	SECONDARY DIET	TOTAL
Unknown Babbler	***Turdoides* spp.**	**Carnivore**	**Insects**	**109**
Heuglin's Robin	*Cossypha heuglini*	Omnivore	Insects	101
Crested Barbet	*Trachyphonus vaillantii*	Carnivore	Insects	100
Unknown Cisticola	*Cisticola* spp.	Insectivore	General	93
Redbilled Hornbill	*Tockus erythrorhynchus*	Omnivore	General	88
Unknown Sunbird	***Nectarinia* spp.**	**Omnivore**	**General**	**87**
Redbilled Quelea	***Quelea quelea***	**Omnivore**	**General**	**81**
Blackbacked Puffback	*Dryoscopus cubla*	Insectivore	Terrestrial	72
Swainson's Francolin	*Francolinus swainsonii*	Omnivore	General	70
Unknown Oxpecker	*Buphagus* spp.	Insectivore	Terrestrial	69
Unknown Woodpecker		Insectivore	Larvae	68
White Helmetshrike	*Prionops plumatus*	Insectivore	Terrestrial	65
Unknown Canary	*Serinus* spp.	Omnivore	General	61
Whitebrowed Robin	*Erythropygia leucophrys*	Omnivore	Insects	59
Whitebellied Sunbird	***Nectarinia talatala***	**Omnivore**	**General**	**58**
Redbilled Firefinch	*Lagonosticta senegala*	Omnivore	General	51
Redbilled Woodhoopoe	*Phoeniculus purpureus*	Carnivore	Insects	50
Southern Greyheaded Sparrow	*Passer diffuses*	Omnivore	General	50
Spurwinged Goose	*Plectropterus gambensis*	Herbivore	Aquatic	49
Bluegrey Flycatcher	*Muscicapa caerulescens*	Insectivore	Terrestrial	49
Laughing Dove	*Streptopelia senagalensis*	Omnivore	General	48
Little Bee-eater	*Merops pusillus*	Insectivore	Terrestrial	43
Orange Breasted Bush Shrike	*Telophorus sulfureopectus*	Insectivore	Terrestrial	43
Redfaced Mousebird	*Urocolius indicus*	Herbivore	General	42
Blackcrowned Tchagra	*Tchagra senegala*	Carnivore	Insects	36
African Mourning Dove	*Streptopelia decipiens*	Herbivore	General	33
Helmeted Guineafowl	*Numida meleagris*	Omnivore	General	30
Bateleur	*Terathopius ecaudatus*	Carnivore	General	29
Redbilled Helmetshrike	*Prionops retzii*	Insectivore	Terrestrial	28
Southern Yellowbilled Hornbill	*Tockus leucomelas*	Omnivore	General	27
Kurrichane Thrush	*Turdus libonyana*	Omnivore	Insects	27
Lilacbreasted Roller	*Coracias caudata*	Carnivore	Insects	26

COMMON NAME	LATIN NAME	PRIMARY DIET	SECONDARY DIET	TOTAL
Swallowtailed Bee-eater	*Merops hirundineus*	Insectivore	Terrestrial	25
Bearded Woodpecker	*Thripias namaquus*	Insectivore	Larvae	25
Pied Kingfisher	*Ceryle rudis*	Carnivore	Aquatic	23
Crowned Plover	*Vanellus coronatus*	Carnivore	Insects	23
Rattling Cisticola	*Cisticola chiniana*	Insectivore	Terrestrial	22
Tawnyflanked Prina	*Prinia subflava*	Insectivore	Terrestrial	22
Cardinal Woodpecker	*Dendropicos fuscescens*	Insectivore	Larvae	21
Whitebacked Vulture	*Gyps africanus*	Carnivore	General	20
African Redeyed Bulbul	*Pycnonotus nigricans*	Omnivore	General	20
Wattled Starling	*Creatophora cinerea*	Omnivore	General	20
African Hoopoe	*Upupa epops*	Carnivore	Insects	19
White-browed Sparrow Weaver	*Plocepasser mahali*	Omnivore	General	19
Fantailed Cisticola	*Cisticola juncidis*	Insectivore	Terrestrial	18
Longbilled Crombec	*Sylvietta rufescens*	Insectivore	Terrestrial	18
Threestreaked Tchagra	*Tchagra australis*	Carnivore	Insects	17
Hamerkop	*Scopus umbretta*	Carnivore	Aquatic	16
Yellowbilled Stork	*Mycteria ibis*	Carnivore	Aquatic	15
African Fish Eagle	*Haliaeetus vocifer*	Carnivore	Aquatic	15
Collard Sunbird	*Anthreptes collaris*	Omnivore	General	15
Greater Honeyguide	*Indicator indicator*	Omnivore	General	15
Unknown Goshawk		Carnivore	General	14
Yellow Bellied Bulbul	*Chlorocichla flaviventris*	Omnivore	General	14
Chestnutvented Titbabbler	*Parisoma subcaeruleum*	Omnivore	Insects	14
Whitebrowed Coucal	*Centropus burchellii*	Carnivore	Insects	13
Longtailed Shrike	*Corvinella melanoleuca*	Carnivore	Insects	13
Southern Black Tit	*Parus niger*	Insectivore	General	13
Bennett's Woodpecker	*Campethera bennettii*	Insectivore	General	13
Unknown Coucal	*Centropus* spp.	Carnivore	Insects	12
Copperytailed Coucal	*Centropus cupreicaudus*	Carnivore	Insects	12
Yellowbreasted Apalis	*Apalis flavida*	Omnivore	Insects	12
Brubru	*Nilaus afer*	Insectivore	Terrestrial	11
Pearlspotted Owl	*Glaucidium perlatum*	Carnivore	General	11
Golden Weaver	*Ploceus xanthops*	Omnivore	General	9
Gabar Goshawk	*Micronisus gabar*	Carnivore	General	8

COMMON NAME	LATIN NAME	PRIMARY DIET	SECONDARY DIET	TOTAL
Egyptian Goose	*Alopochen aegyptiacus*	Herbivore	Aquatic	7
Sacred Ibis	*Threskiornis aethiopicus*	Carnivore	Aquatic Invertebrates	7
Unknown Firefinch	*Lagonosticta* spp.	Omnivore	Herbivore	7
Striped Kingfisher	*Halcyon chelicuti*	Carnivore	Insects	6
Knob billed Duck	*Sarkidiornis melanotos*	Herbivore	Aquatic	6
Jamesons Firefinch	*Lagonosticta rhodopareia*	Omnivore	General	6
Longtoed Plover	*Vanellus crassirostris*	Carnivore	Aquatic Invertebrates	5
African Jacana	*Actophilornis africanus*	Carnivore	Aquatic Invertebrates	5
Bradfields Hornbill	*Tockus bradfieldi*	Omnivore	General	5
Unknown Eagle		Carnivore	General	5
Black Crake	*Amaurornis flavirostris*	Carnivore	Aquatic Invertebrates	5
Chirping Cisticola	*Cisticola pipines*	Insectivore	Terrestrial	5
Yellow White eye	*Zosterops senegalensis*	Omnivore	Insects	5
Whitefronted Bee-eater	*Merops bullockoides*	Insectivore	Terrestrial	4
Scimitar Billed Woodhoopoe	*Rhinopomastus cyanomelas*	Omnivore	Insects	4
Senegal Coucal	*Centropus senegalensis*	Carnivore	Insects	4
Unknown Francolin	*Francolinus* spp.	Omnivore	General	4
Melba Finch	*Pytilia melba*	Omnivore	General	4
Yellowfronted Tinker Barbet	*Pogoniulus chrysoconus*	Omnivore	Herbivore	4
Yellowbilled Duck	*Anus undulata*	Herbivore	Aquatic	3
Whitefaced Duck	*Dendrocygna viduata*	Herbivore	Aquatic	3
Grey Heron	*Ardea cinerea*	Carnivore	Aquatic	3
Egret	*Egretta* spp.	Carnivore	Aquatic	3
Little Egret	*Egretta garzetta*	Carnivore	Aquatic	3
Saddlebilled Stork	*Ephippiorhynchus senagalensis*	Carnivore	Aquatic	3
Unknown Raptor		Carnivore	General	3
Unknown Vulture		Carnivore	General	3
African Marsh Harrier	*Circus ranivorus*	Carnivore	General	3
Black Shouldered Kite	*Elanus caeruleus*	Carnivore	General	3
African Hawk Eagle	*Hieraaetus spilogaster*	Carnivore	General	3
Hooded Vulture	*Necrosyrtes monachus*	Carnivore	General	3
Southern Whitecrowned Shrike	*Eurocephalus anguitimens*	Omnivore	Insects	3

COMMON NAME	LATIN NAME	PRIMARY DIET	SECONDARY DIET	TOTAL
Marico Flycatcher	*Melaenornis mariquensis*	Insectivore	Terrestrial	3
Pallid Flycatcher	*Melaenornis pallidus*	Insectivore	Terrestrial	3
Scarletchested Sunbird	*Nectarinia senagalensis*	Omnivore	General	3
Paradise Whydah	*Vidua paradisaea*	Omnivore	General	3
Unknown Kingfisher		Carnivore	Insects	2
Unknown Harrier	*Circus* spp.	Carnivore	General	2
Black Cheeked Waxbill	*Estrilda erythronootos*	Omnivore	General	2
Black Flycatcher	*Melaenornis pammelaina*	Insectivore	Terrestrial	2
Terestrial Bulbul	*Phyllastrephus terrestris*	Omnivore	General	2
Yellowbellied Eremomela	*Eremomela icteropygialis*	Insectivore	Terrestrial	2
Southern Pied Babbler	*Turdoides bicolor*	Insectivore	General	2
Barred Owl	*Glaucidium capense*	Carnivore	General	2
Sandpiper		Carnivore	Aquatic Invertebrates	1
Unknown Heron		Carnivore	Aquatic	1
Openbilled Stork	*Anastromus lamelligerus*	Carnivore	Aquatic Invertebrates	1
Hadeda Ibis	*Bostrychia hagedash*	Carnivore	Aquatic Invertebrates	1
Namaqua Dove	*Oena capensis*	Herbivore	General	1
Little Banded Goshawk	*Accipiter badius*	Carnivore	General	1
Little Sparrowhawk	*Accipiter minullus*	Carnivore	General	1
Ovambo Sparrowhawk	*Accipiter ovampensis*	Carnivore	General	1
Western Banded Snake Eagle	*Circaetus cinerascens*	Carnivore	General	1
Black Breasted Snake Eagle	*Circaetus pectoralis*	Carnivore	General	1
Whiteheaded Vulture	*Trigonoceps occipitalis*	Carnivore	General	1
Unknown Falcon	*Falco* spp.	Carnivore	General	1
Unknown Kestral	*Falco* spp.	Carnivore	General	1
Wattled Crane	*Bugeranus carunculatus*	Omnivore	Aquatic	1
Unknown Tchagra	*Tchagra* spp.	Carnivore	Insects	1
Unknown Oriole	*Oriolus* spp.	Omnivore	General	1
Eastern Blackheaded Oriole	*Oriolus larvatus*	Omnivore	General	1
Neddicky	*Cisticola fulvicapilla*	Insectivore	Terrestrial	1
Steelblue	*Vidua chalybaeta*	Herbivore	General	1

COMMON NAME	LATIN NAME	PRIMARY DIET	SECONDARY DIET	TOTAL
Widowfinch				
African Darter	*Anhinga melanogaster*	Carnivore	Aquatic	1
Acacia Pied Barbet	*Tricholaema leucomelas*	Herbivore	Fruit	1
Goldentailed Woodpecker	*Campethera abingoni*	Insectivore	Larvae	1
Double Banded Sandgrouse	*Pterocles bicinctus*	Herbivore	General	1
				14977

Appendix C. Number of birds detected at all point counts from each family and order.

ORDER	ORDER TOTAL		FAMILYS	FAMILY TOTAL
Alcediniformes	103		Alcedinidae	31
			Meropidae	72
Anseriformes	68		Anatidae	68
Apodiformes	575		Apodidae	575
Charadriiformes	193		Charadriidae	187
			Jacanidae	5
			Scolopacidae	1
Ciconiiformes	53		Ardeidae	10
			Ciconiidae	19
			Plataleidae	8
			Scopidae	16
Coliiformes	42		Coliidae	42
Columbiformes	2730		Columbidae	2730
Coraciiformes	523		Bucerotidae	424
			Coraciidae	26
			Phoeniculidae	54
			Upupidae	19
Cuculiformes	41		Cuculidae	41
Falconiformes	119		Accipitridae	117
			Falconidae	2
Galliformes	1583		Numididae	30
			Phasianidae	1553
Gruiformes	6		Gruidae	1
			Rallidae	5
Musophagiformes	634		Musophagidae	634

Appendix C. Continued.

ORDER	ORDER TOTAL		FAMILY	FAMILY TOTAL
Passeriformes	7328		Buphagidae	69
			Dicruridae	377
			Estrildidae	371
			Fringillidae	61
			Hirundinidae	191
			Laniidae	16
			Malaconotidae	401
			Muscicapidae	170
			Nectariniidae	346
			Oriolidae	2
			Paridae	13
			Ploceidae	611
			Prionopidae	93
			Pyconotidae	670
			Sturnidae	1918
			Sylviidae	826
			Timaliidae	997
			Turdidae	187
			Viduidae	4
			Zosteropidae	5
Pelecaniformes	1		Anhingidae	1
Piciformes	444		Indicatoridae	15
			Lybiidae	301
			Picidae	128
Psittaciformes	520		Psittidae	520
Pterocliformes	1		Pteroclidae	1
Strigiformes	13		Strigidae	13
Grand Total	**14977**			**14977**

Appendix D. The number of birds detected during each point count survey by station and diet preference.

SITE	STATION	DATE	INSECTIVOROUS	NON-INSECT-DEPENDENT	TOTAL
Guma	GD1	5/5/2001	25	8	33
Guma	GD1	6/8/2001	15	19	34
Guma	GD1	6/10/2001	17	12	29
Guma	GD1	6/11/2001	18	15	33
Guma	GD1	4/6/2002	14	11	25
Guma	GD1	4/8/2002	16	11	27
Guma	GD1	5/30/2002	10	31	41
Guma	GD1	5/31/2002	8	18	26
Guma	GD1	6/1/2002	15	34	49
Guma	GD1	7/17/2002	9	25	34
Guma	GD1	7/18/2002	14	10	24
Guma	GD1	7/19/2002	8	22	30
Guma	GD2	5/5/2001	5	15	20
Guma	GD2	6/11/2001	15	6	21
Guma	GD2	4/7/2002	26	24	50
Guma	GD2	4/8/2002	8	8	16
Guma	GD2	5/30/2002	3	14	17
Guma	GD2	5/31/2002	19	23	42
Guma	GD2	6/1/2002	11	19	30
Guma	GD2	7/17/2002	7	9	16
Guma	GD2	7/18/2002	3	13	16
Guma	GD2	7/19/2002	11	24	35
Guma	GF1	4/14/2001	17	12	29
Guma	GF1	5/4/2001	9	5	14
Guma	GF1	5/5/2001	10	18	28
Guma	GF1	6/8/2001	9	13	22
Guma	GF1	6/10/2001	12	13	25
Guma	GF1	6/11/2001	11	13	24
Guma	GF1	4/6/2002	20	12	32
Guma	GF1	4/8/2002	17	5	22
Guma	GF1	5/29/2002	7	11	18
Guma	GF1	5/30/2002	22	16	38
Guma	GF1	5/31/2002	17	16	33
Guma	GF1	7/17/2002	7	14	21
Guma	GF1	7/18/2002	1	17	18

SITE	STATION	DATE	INSECTIVOROUS	NON-INSECT-DEPENDENT	TOTAL
Guma	GF1	7/19/2002	5	15	20
Guma	GF2	4/14/2001	10	12	22
Guma	GF2	5/4/2001	8	5	13
Guma	GF2	5/5/2001	6	13	19
Guma	GF2	6/11/2001	9	19	28
Guma	GF2	4/7/2002	6	6	12
Guma	GF2	4/8/2002	38	4	42
Guma	GF2	5/29/2002	5	7	12
Guma	GF2	5/30/2002	2	12	14
Guma	GF2	5/31/2002	5	15	20
Guma	GF2	7/17/2002	12	9	21
Guma	GF2	7/18/2002	3	17	20
Guma	GF2	7/19/2002	6	17	23
Guma	GF3	4/14/2001	13	5	18
Guma	GF3	5/4/2001	6	9	15
Guma	GF3	5/5/2001	22	7	29
Guma	GF3	5/6/2001	29	17	46
Guma	GF3	6/8/2001	13	17	30
Guma	GF3	6/10/2001	11	15	26
Guma	GF3	6/11/2001	9	14	23
Guma	GF3	4/6/2002	16	43	59
Guma	GF3	4/8/2002	44	98	142
Guma	GF3	5/29/2002	5	36	41
Guma	GF3	5/30/2002	7	33	40
Guma	GF3	5/31/2002	6	35	41
Guma	GF3	7/17/2002	7	20	27
Guma	GF3	7/18/2002	7	24	31
Guma	GF3	7/19/2002	8	18	26
Guma	GF4	4/14/2001	10	9	19
Guma	GF4	5/4/2001	15	5	20
Guma	GF4	5/5/2001	14	11	25
Guma	GF4	5/6/2001	11	9	20
Guma	GF4	6/11/2001	4	15	19
Guma	GF4	4/7/2002	8	15	23
Guma	GF4	4/8/2002	6	29	35
Guma	GF4	5/29/2002	7	21	28
Guma	GF4	5/31/2002	11	21	32
Guma	GF4	7/17/2002	10	6	16
Guma	GF4	7/18/2002	6	13	19

SITE	STATION	DATE	INSECTIVOROUS	NON-INSECT-DEPENDENT	TOTAL
Guma	GF4	7/19/2002	15	22	37
Guma	GF5	4/14/2001	9	9	18
Guma	GF5	5/4/2001	17	7	24
Guma	GF5	5/5/2001	8	16	24
Guma	GF5	5/6/2001	5	8	13
Guma	GF5	6/8/2001	20	14	34
Guma	GF5	6/10/2001	16	10	26
Guma	GF5	6/11/2001	24	19	43
Guma	GF5	4/6/2002	19	5	24
Guma	GF5	4/8/2002	11	19	30
Guma	GF5	5/29/2002	8	14	22
Guma	GF5	5/31/2002	2	14	16
Guma	GF5	6/1/2002	14	19	33
Guma	GF5	7/17/2002	14	19	33
Guma	GF5	7/18/2002	16	19	35
Guma	GF5	7/19/2002	17	24	41
Guma	GF6	4/14/2001	3	9	12
Guma	GF6	5/4/2001	15	12	27
Guma	GF6	6/11/2001	12	20	32
Guma	GF6	4/7/2002	48	14	62
Guma	GF6	4/8/2002	9	16	25
Guma	GF6	5/30/2002	8	8	16
Guma	GF6	5/31/2002	32	7	39
Guma	GF6	6/1/2002	10	18	28
Guma	GF6	7/17/2002	6	30	36
Guma	GF6	7/18/2002	14	7	21
Guma	GF6	7/19/2002	17	16	33
Guma	GF7	4/14/2001	8	9	17
Guma	GF7	5/4/2001	11	17	28
Guma	GF7	6/8/2001	14	21	35
Guma	GF7	6/10/2001	10	13	23
Guma	GF7	6/11/2001	5	14	19
Guma	GF7	4/6/2002	14	14	28
Guma	GF7	4/8/2002	33	9	42
Guma	GF7	5/30/2002	17	21	38
Guma	GF7	5/31/2002	18	16	34
Guma	GF7	6/1/2002	13	19	32
Guma	GF7	7/17/2002	13	8	21
Guma	GF7	7/18/2002	6	15	21

SITE	STATION	DATE	INSECTIVOROUS	NON-INSECT-DEPENDENT	TOTAL
Guma	GF7	7/19/2002	7	17	24
Guma	GF13	5/5/2001	9	14	23
Guma	GF13	6/8/2001	20	11	31
Guma	GF13	6/10/2001	21	8	29
Guma	GF13	6/11/2001	13	7	20
Guma	GF13	4/7/2002	23	36	59
Guma	GF13	4/8/2002	4	21	25
Guma	GF13	5/29/2002	4	11	15
Guma	GF13	5/30/2002	9	16	25
Guma	GF13	5/31/2002	20	21	41
Guma	GF13	7/17/2002	7	11	18
Guma	GF13	7/18/2002	9	16	25
Guma	GF13	7/19/2002	18	26	44
Mombo	MO1	4/1/2001	12	11	23
Mombo	MO1	5/16/2001	16	10	26
Mombo	MO1	5/18/2001	19	12	31
Mombo	MO1	4/19/2002	17	18	35
Mombo	MO1	4/20/2002	22	14	36
Mombo	MO1	6/18/2002	26	14	40
Mombo	MO1	6/19/2002	20	11	31
Mombo	MO1	6/20/2002	25	12	37
Mombo	MO1	8/12/2002	16	20	36
Mombo	MO1	8/13/2002	22	17	39
Mombo	MO1	8/14/2002	27	21	48
Mombo	MO2	4/1/2001	9	12	21
Mombo	MO2	5/16/2001	10	23	33
Mombo	MO2	5/18/2001	5	30	35
Mombo	MO2	4/20/2002	15	15	30
Mombo	MO2	4/21/2002	10	14	24
Mombo	MO2	6/18/2002	18	19	37
Mombo	MO2	6/19/2002	22	13	35
Mombo	MO2	6/20/2002	28	15	43
Mombo	MO2	8/11/2002	16	15	31
Mombo	MO2	8/12/2002	18	11	29
Mombo	MO2	8/13/2002	23	20	43
Mombo	MO2	8/14/2002	13	20	33
Mombo	MO3	4/1/2001	21	17	38
Mombo	MO3	5/16/2001	7	14	21
Mombo	MO3	5/18/2001	11	15	26

SITE	STATION	DATE	INSECTIVOROUS	NON-INSECT-DEPENDENT	TOTAL
Mombo	MO3	4/19/2002	9	15	24
Mombo	MO3	4/20/2002	18	8	26
Mombo	MO3	4/21/2002	15	16	31
Mombo	MO3	6/18/2002	16	15	31
Mombo	MO3	6/19/2002	27	13	40
Mombo	MO3	6/20/2002	32	6	38
Mombo	MO3	8/11/2002	23	19	42
Mombo	MO3	8/12/2002	22	14	36
Mombo	MO3	8/13/2002	19	14	33
Mombo	MO3	8/14/2002	21	11	32
Mombo	MO4	4/1/2001	9	35	44
Mombo	MO4	5/16/2001	12	12	24
Mombo	MO4	5/17/2001	6	10	16
Mombo	MO4	5/18/2001	0	14	14
Mombo	MO4	4/20/2002	5	12	17
Mombo	MO4	4/21/2002	10	17	27
Mombo	MO4	6/18/2002	17	10	27
Mombo	MO4	6/19/2002	10	16	26
Mombo	MO4	6/20/2002	10	5	15
Mombo	MO4	8/11/2002	5	9	14
Mombo	MO4	8/12/2002	7	9	16
Mombo	MO4	8/13/2002	5	8	13
Mombo	MO4	8/14/2002	11	12	23
Mombo	MO5	4/1/2001	13	16	29
Mombo	MO5	5/16/2001	14	20	34
Mombo	MO5	5/17/2001	10	13	23
Mombo	MO5	5/18/2001	6	19	25
Mombo	MO5	4/19/2002	16	6	22
Mombo	MO5	4/21/2002	7	10	17
Mombo	MO5	6/18/2002	18	27	45
Mombo	MO5	6/19/2002	6	21	27
Mombo	MO5	6/20/2002	10	7	17
Mombo	MO5	8/11/2002	18	7	25
Mombo	MO5	8/12/2002	17	11	28
Mombo	MO5	8/13/2002	17	9	26
Mombo	MO5	8/14/2002	20	5	25
Mombo	MO6	4/1/2001	17	19	36
Mombo	MO6	5/17/2001	6	13	19
Mombo	MO6	5/18/2001	4	16	20

SITE	STATION	DATE	INSECTIVOROUS	NON-INSECT-DEPENDENT	TOTAL
Mombo	MO6	4/20/2002	8	7	15
Mombo	MO6	4/21/2002	8	10	18
Mombo	MO6	6/18/2002	16	21	37
Mombo	MO6	6/19/2002	17	9	26
Mombo	MO6	6/20/2002	30	4	34
Mombo	MO6	8/11/2002	11	11	22
Mombo	MO6	8/12/2002	12	7	19
Mombo	MO6	8/13/2002	30	10	40
Mombo	MO6	8/14/2002	17	7	24
Mombo	MO7	4/1/2001	10	34	44
Mombo	MO7	5/17/2001	7	12	19
Mombo	MO7	5/18/2001	10	19	29
Mombo	MO7	4/19/2002	12	7	19
Mombo	MO7	4/21/2002	11	13	24
Mombo	MO7	6/18/2002	16	17	33
Mombo	MO7	6/19/2002	10	13	23
Mombo	MO7	6/20/2002	24	15	39
Mombo	MO7	8/11/2002	11	19	30
Mombo	MO7	8/12/2002	18	15	33
Mombo	MO7	8/13/2002	15	22	37
Mombo	MO7	8/14/2002	13	10	23
Mombo	MO8	4/1/2001	13	23	36
Mombo	MO8	5/17/2001	10	19	29
Mombo	MO8	5/18/2001	13	37	50
Mombo	MO8	4/20/2002	18	8	26
Mombo	MO8	4/21/2002	6	16	22
Mombo	MO8	6/18/2002	4	14	18
Mombo	MO8	6/19/2002	15	7	22
Mombo	MO8	6/21/2002	26	10	36
Mombo	MO8	8/12/2002	7	20	27
Mombo	MO8	8/13/2002	18	14	32
Mombo	MO8	8/14/2002	19	11	30
Mombo	MO9	4/1/2001	17	22	39
Mombo	MO9	5/17/2001	26	25	51
Mombo	MO9	4/19/2002	14	15	29
Mombo	MO9	4/21/2002	17	33	50
Mombo	MO9	6/18/2002	27	15	42
Mombo	MO9	6/19/2002	17	17	34
Mombo	MO9	8/12/2002	12	7	19

SITE	STATION	DATE	INSECTIVOROUS	NON-INSECT-DEPENDENT	TOTAL
Mombo	MO9	8/13/2002	10	10	20
Mombo	MO9	8/14/2002	18	12	30
Mombo	MO10	4/1/2001	21	11	32
Mombo	MO10	5/17/2001	15	13	28
Mombo	MO10	4/20/2002	14	9	23
Mombo	MO10	4/21/2002	7	13	20
Mombo	MO10	6/18/2002	15	9	24
Mombo	MO10	6/19/2002	13	14	27
Mombo	MO10	8/12/2002	1	26	27
Mombo	MO10	8/13/2002	7	15	22
Mombo	MO10	8/14/2002	11	11	22
Nxaraxa	NX2	4/19/2001	13	10	23
Nxaraxa	NX2	4/20/2001	11	13	24
Nxaraxa	NX2	4/27/2001	6	13	19
Nxaraxa	NX2	4/29/2001	12	12	24
Nxaraxa	NX2	6/1/2001	22	18	40
Nxaraxa	NX2	6/3/2001	15	10	25
Nxaraxa	NX2	3/29/2002	18	17	35
Nxaraxa	NX2	3/31/2002	8	17	25
Nxaraxa	NX2	4/1/2002	8	9	17
Nxaraxa	NX2	4/25/2002	4	11	15
Nxaraxa	NX2	4/27/2002	6	12	18
Nxaraxa	NX2	6/4/2002	10	12	22
Nxaraxa	NX2	6/5/2002	6	7	13
Nxaraxa	NX2	6/6/2002	17	12	29
Nxaraxa	NX2	7/4/2002	10	18	28
Nxaraxa	NX2	7/5/2002	19	18	37
Nxaraxa	NX2	7/6/2002	12	23	35
Nxaraxa	NX2	7/26/2002	28	17	45
Nxaraxa	NX2	7/28/2002	51	32	83
Nxaraxa	NX3	4/19/2001	9	12	21
Nxaraxa	NX3	4/20/2001	15	14	29
Nxaraxa	NX3	4/29/2001	8	13	21
Nxaraxa	NX3	6/1/2001	13	17	30
Nxaraxa	NX3	6/3/2001	7	23	30
Nxaraxa	NX3	3/30/2002	9	16	25
Nxaraxa	NX3	3/31/2002	9	0	9
Nxaraxa	NX3	4/1/2002	33	10	43
Nxaraxa	NX3	4/26/2002	11	18	29

SITE	STATION	DATE	INSECTIVOROUS	NON-INSECT-DEPENDENT	TOTAL
Nxaraxa	NX3	4/27/2002	14	7	21
Nxaraxa	NX3	6/4/2002	10	13	23
Nxaraxa	NX3	6/5/2002	22	13	35
Nxaraxa	NX3	6/6/2002	4	7	11
Nxaraxa	NX3	7/4/2002	10	17	27
Nxaraxa	NX3	7/5/2002	7	12	19
Nxaraxa	NX3	7/6/2002	7	15	22
Nxaraxa	NX3	7/26/2002	8	12	20
Nxaraxa	NX3	7/27/2002	12	20	32
Nxaraxa	NX3	7/28/2002	15	21	36
Nxaraxa	NX4	4/20/2001	4	13	17
Nxaraxa	NX4	4/29/2001	7	9	16
Nxaraxa	NX4	6/1/2001	7	16	23
Nxaraxa	NX4	6/3/2001	19	27	46
Nxaraxa	NX4	3/29/2002	9	4	13
Nxaraxa	NX4	3/31/2002	4	13	17
Nxaraxa	NX4	4/25/2002	13	12	25
Nxaraxa	NX4	4/27/2002	14	11	25
Nxaraxa	NX4	6/4/2002	6	8	14
Nxaraxa	NX4	6/5/2002	15	10	25
Nxaraxa	NX4	6/6/2002	5	6	11
Nxaraxa	NX4	7/4/2002	8	9	17
Nxaraxa	NX4	7/5/2002	5	10	15
Nxaraxa	NX4	7/6/2002	16	10	26
Nxaraxa	NX4	7/26/2002	33	18	51
Nxaraxa	NX4	7/27/2002	16	20	36
Nxaraxa	NX4	7/28/2002	18	12	30
Nxaraxa	NX5	4/20/2001	14	18	32
Nxaraxa	NX5	4/28/2001	9	10	19
Nxaraxa	NX5	4/29/2001	11	10	21
Nxaraxa	NX5	6/2/2001	10	31	41
Nxaraxa	NX5	6/3/2001	11	40	51
Nxaraxa	NX5	3/30/2002	9	23	32
Nxaraxa	NX5	3/31/2002	11	12	23
Nxaraxa	NX5	4/26/2002	16	15	31
Nxaraxa	NX5	4/27/2002	2	7	9
Nxaraxa	NX5	4/28/2002	9	13	22
Nxaraxa	NX5	6/4/2002	4	9	13
Nxaraxa	NX5	6/5/2002	4	11	15

SITE	STATION	DATE	INSECTIVOROUS	NON-INSECT-DEPENDENT	TOTAL
Nxaraxa	NX5	6/6/2002	4	14	18
Nxaraxa	NX5	7/4/2002	2	14	16
Nxaraxa	NX5	7/5/2002	8	17	25
Nxaraxa	NX5	7/6/2002	10	9	19
Nxaraxa	NX5	7/26/2002	9	15	24
Nxaraxa	NX5	7/27/2002	7	13	20
Nxaraxa	NX5	7/28/2002	13	18	31
Nxaraxa	NX6	4/20/2001	12	14	26
Nxaraxa	NX6	4/28/2001	6	15	21
Nxaraxa	NX6	4/29/2001	6	18	24
Nxaraxa	NX6	6/1/2001	16	31	47
Nxaraxa	NX6	6/3/2001	9	20	29
Nxaraxa	NX6	3/29/2002	11	13	24
Nxaraxa	NX6	3/31/2002	5	10	15
Nxaraxa	NX6	4/25/2002	6	28	34
Nxaraxa	NX6	4/27/2002	8	28	36
Nxaraxa	NX6	4/28/2002	7	9	16
Nxaraxa	NX6	6/4/2002	3	9	12
Nxaraxa	NX6	6/5/2002	4	16	20
Nxaraxa	NX6	6/6/2002	1	12	13
Nxaraxa	NX6	7/4/2002	5	13	18
Nxaraxa	NX6	7/5/2002	6	22	28
Nxaraxa	NX6	7/6/2002	13	28	41
Nxaraxa	NX6	7/26/2002	13	21	34
Nxaraxa	NX6	7/27/2002	21	23	44
Nxaraxa	NX6	7/28/2002	1	52	53
Nxaraxa	NX7	4/20/2001	4	15	19
Nxaraxa	NX7	4/28/2001	15	11	26
Nxaraxa	NX7	4/29/2001	9	11	20
Nxaraxa	NX7	6/2/2001	1	21	22
Nxaraxa	NX7	6/3/2001	4	31	35
Nxaraxa	NX7	3/30/2002	1	20	21
Nxaraxa	NX7	3/31/2002	2	10	12
Nxaraxa	NX7	4/26/2002	17	15	32
Nxaraxa	NX7	4/27/2002	10	11	21
Nxaraxa	NX7	4/28/2002	3	14	17
Nxaraxa	NX7	6/4/2002	2	18	20
Nxaraxa	NX7	6/5/2002	7	17	24
Nxaraxa	NX7	6/6/2002	0	14	14

SITE	STATION	DATE	INSECTIVOROUS	NON-INSECT-DEPENDENT	TOTAL
Nxaraxa	NX7	7/4/2002	14	5	19
Nxaraxa	NX7	7/5/2002	8	8	16
Nxaraxa	NX7	7/6/2002	3	5	8
Nxaraxa	NX7	7/26/2002	23	13	36
Nxaraxa	NX7	7/27/2002	14	7	21
Nxaraxa	NX7	7/28/2002	10	16	26
Nxaraxa	NX9	4/20/2001	6	10	16
Nxaraxa	NX9	4/28/2001	9	16	25
Nxaraxa	NX9	4/29/2001	3	11	14
Nxaraxa	NX9	6/2/2001	14	32	46
Nxaraxa	NX9	6/3/2001	17	27	44
Nxaraxa	NX9	3/30/2002	13	13	26
Nxaraxa	NX9	4/26/2002	8	13	21
Nxaraxa	NX9	4/28/2002	6	13	19
Nxaraxa	NX9	6/4/2002	2	13	15
Nxaraxa	NX9	6/6/2002	3	17	20
Nxaraxa	NX9	7/4/2002	3	9	12
Nxaraxa	NX9	7/5/2002	9	18	27
Nxaraxa	NX9	7/6/2002	1	16	17
Nxaraxa	NX9	7/26/2002	3	30	33
Nxaraxa	NX9	7/27/2002	18	24	42
Nxaraxa	NX9	7/28/2002	7	18	25
Nxaraxa	NX10	4/20/2001	7	23	30
Nxaraxa	NX10	4/28/2001	3	17	20
Nxaraxa	NX10	4/29/2001	4	11	15
Nxaraxa	NX10	6/2/2001	5	10	15
Nxaraxa	NX10	6/3/2001	8	15	23
Nxaraxa	NX10	3/29/2002	18	10	28
Nxaraxa	NX10	4/28/2002	5	17	22
Nxaraxa	NX10	6/4/2002	2	11	13
Nxaraxa	NX10	6/6/2002	7	11	18
Nxaraxa	NX10	7/4/2002	3	11	14
Nxaraxa	NX10	7/5/2002	2	9	11
Nxaraxa	NX10	7/6/2002	2	4	6
Nxaraxa	NX10	7/26/2002	7	13	20
Nxaraxa	NX10	7/27/2002	3	9	12
Nxaraxa	NX10	7/28/2002	2	6	8
Nxaraxa	NX11	4/20/2001	12	6	18
Nxaraxa	NX11	4/28/2001	9	14	23

SITE	STATION	DATE	INSECTIVOROUS	NON-INSECT-DEPENDENT	TOTAL
Nxaraxa	NX11	4/29/2001	3	10	13
Nxaraxa	NX11	6/2/2001	10	23	33
Nxaraxa	NX11	6/3/2001	6	23	29
Nxaraxa	NX11	3/30/2002	9	9	18
Nxaraxa	NX11	4/26/2002	7	11	18
Nxaraxa	NX11	4/28/2002	4	25	29
Nxaraxa	NX11	6/4/2002	3	19	22
Nxaraxa	NX11	7/4/2002	3	11	14
Nxaraxa	NX11	7/5/2002	9	6	15
Nxaraxa	NX11	7/6/2002	7	12	19
Nxaraxa	NX11	7/27/2002	31	25	56
Nxaraxa	NX11	7/28/2002	7	6	13
Chitabe	CH1	4/8/2001	12	15	27
Chitabe	CH1	4/9/2001	11	17	28
Chitabe	CH1	5/25/2001	24	14	38
Chitabe	CH1	5/26/2001	12	12	24
Chitabe	CH1	6/14/2001	21	9	30
Chitabe	CH1	6/16/2001	16	14	30
Chitabe	CH1	4/12/2002	20	38	58
Chitabe	CH1	4/14/2002	5	16	21
Chitabe	CH1	4/15/2002	12	9	21
Chitabe	CH1	5/14/2002	18	12	30
Chitabe	CH1	5/15/2002	5	8	13
Chitabe	CH1	5/16/2002	3	4	7
Chitabe	CH1	6/9/2002	8	20	28
Chitabe	CH1	6/11/2002	0	39	39
Chitabe	CH1	7/21/2002	7	13	20
Chitabe	CH1	7/22/2002	3	17	20
Chitabe	CH1	7/23/2002	11	16	27
Chitabe	CH2	4/8/2001	26	23	49
Chitabe	CH2	4/9/2001	14	8	22
Chitabe	CH2	5/25/2001	22	13	35
Chitabe	CH2	5/26/2001	23	12	35
Chitabe	CH2	6/15/2001	17	11	28
Chitabe	CH2	6/16/2001	19	10	29
Chitabe	CH2	4/13/2002	20	8	28
Chitabe	CH2	4/14/2002	8	8	16
Chitabe	CH2	4/15/2002	5	7	12
Chitabe	CH2	5/14/2002	13	11	24

SITE	STATION	DATE	INSECTIVOROUS	NON-INSECT-DEPENDENT	TOTAL
Chitabe	CH2	5/15/2002	5	8	13
Chitabe	CH2	5/17/2002	14	9	23
Chitabe	CH2	6/9/2002	7	24	31
Chitabe	CH2	6/12/2002	11	14	25
Chitabe	CH2	6/15/2002	12	20	32
Chitabe	CH2	6/16/2002	16	13	29
Chitabe	CH2	7/21/2002	6	14	20
Chitabe	CH2	7/22/2002	0	5	5
Chitabe	CH2	7/23/2002	6	10	16
Chitabe	CH3	4/8/2001	20	10	30
Chitabe	CH3	4/9/2001	18	9	27
Chitabe	CH3	5/25/2001	15	11	26
Chitabe	CH3	5/26/2001	6	11	17
Chitabe	CH3	6/16/2001	20	14	34
Chitabe	CH3	4/13/2002	21	16	37
Chitabe	CH3	4/14/2002	7	13	20
Chitabe	CH3	4/15/2002	1	8	9
Chitabe	CH3	5/14/2002	9	15	24
Chitabe	CH3	5/15/2002	11	20	31
Chitabe	CH3	5/17/2002	6	13	19
Chitabe	CH3	6/9/2002	2	39	41
Chitabe	CH3	6/12/2002	6	15	21
Chitabe	CH3	6/15/2002	4	19	23
Chitabe	CH3	7/21/2002	8	6	14
Chitabe	CH3	7/22/2002	2	13	15
Chitabe	CH3	7/23/2002	5	10	15
Chitabe	CH4	4/8/2001	9	10	19
Chitabe	CH4	4/9/2001	11	9	20
Chitabe	CH4	4/10/2001	8	15	23
Chitabe	CH4	5/25/2001	7	11	18
Chitabe	CH4	5/26/2001	8	13	21
Chitabe	CH4	6/15/2001	16	19	35
Chitabe	CH4	6/16/2001	7	11	18
Chitabe	CH4	4/13/2002	17	8	25
Chitabe	CH4	4/14/2002	16	10	26
Chitabe	CH4	4/15/2002	6	2	8
Chitabe	CH4	5/14/2002	10	1	11
Chitabe	CH4	5/15/2002	2	8	10
Chitabe	CH4	5/17/2002	9	9	18

SITE	STATION	DATE	INSECTIVOROUS	NON-INSECT-DEPENDENT	TOTAL
Chitabe	CH4	6/9/2002	5	30	35
Chitabe	CH4	6/15/2002	5	6	11
Chitabe	CH4	6/16/2002	6	7	13
Chitabe	CH4	7/21/2002	6	19	25
Chitabe	CH4	7/22/2002	7	12	19
Chitabe	CH4	7/23/2002	13	11	24
Chitabe	CH5	4/8/2001	7	12	19
Chitabe	CH5	4/9/2001	11	13	24
Chitabe	CH5	4/10/2001	13	3	16
Chitabe	CH5	5/26/2001	12	14	26
Chitabe	CH5	6/14/2001	26	10	36
Chitabe	CH5	6/16/2001	15	11	26
Chitabe	CH5	4/13/2002	2	6	8
Chitabe	CH5	4/14/2002	12	13	25
Chitabe	CH5	4/15/2002	10	7	17
Chitabe	CH5	5/14/2002	2	14	16
Chitabe	CH5	5/15/2002	4	10	14
Chitabe	CH5	5/17/2002	19	13	32
Chitabe	CH5	6/9/2002	9	15	24
Chitabe	CH5	6/15/2002	1	20	21
Chitabe	CH5	6/16/2002	7	5	12
Chitabe	CH5	7/21/2002	4	11	15
Chitabe	CH5	7/22/2002	2	24	26
Chitabe	CH5	7/23/2002	1	14	15
Chitabe	CH6	4/8/2001	15	18	33
Chitabe	CH6	4/9/2001	8	15	23
Chitabe	CH6	4/10/2001	20	15	35
Chitabe	CH6	5/26/2001	13	17	30
Chitabe	CH6	5/27/2001	24	20	44
Chitabe	CH6	6/16/2001	20	10	30
Chitabe	CH6	4/13/2002	19	5	24
Chitabe	CH6	4/14/2002	10	18	28
Chitabe	CH6	4/15/2002	4	2	6
Chitabe	CH6	5/14/2002	7	10	17
Chitabe	CH6	5/15/2002	9	7	16
Chitabe	CH6	5/17/2002	6	6	12
Chitabe	CH6	6/9/2002	7	15	22
Chitabe	CH6	6/15/2002	12	46	58
Chitabe	CH6	6/16/2002	9	25	34

SITE	STATION	DATE	INSECTIVOROUS	NON-INSECT-DEPENDENT	TOTAL
Chitabe	CH6	7/21/2002	2	14	16
Chitabe	CH6	7/22/2002	3	2	5
Chitabe	CH6	7/23/2002	8	16	24
Chitabe	CH7	4/8/2001	8	15	23
Chitabe	CH7	4/9/2001	18	14	32
Chitabe	CH7	4/10/2001	16	15	31
Chitabe	CH7	5/26/2001	8	18	26
Chitabe	CH7	5/27/2001	23	16	39
Chitabe	CH7	6/14/2001	8	13	21
Chitabe	CH7	6/16/2001	13	13	26
Chitabe	CH7	4/13/2002	9	8	17
Chitabe	CH7	4/14/2002	18	5	23
Chitabe	CH7	5/14/2002	2	9	11
Chitabe	CH7	5/15/2002	7	17	24
Chitabe	CH7	5/17/2002	2	17	19
Chitabe	CH7	6/9/2002	8	12	20
Chitabe	CH7	6/15/2002	11	26	37
Chitabe	CH7	6/16/2002	3	14	17
Chitabe	CH7	7/21/2002	5	12	17
Chitabe	CH7	7/22/2002	2	10	12
Chitabe	CH7	7/23/2002	8	11	19
Chitabe	CH8	4/8/2001	3	7	10
Chitabe	CH8	4/9/2001	9	12	21
Chitabe	CH8	4/10/2001	6	11	17
Chitabe	CH8	5/26/2001	6	13	19
Chitabe	CH8	5/27/2001	16	9	25
Chitabe	CH8	6/15/2001	20	9	29
Chitabe	CH8	6/16/2001	8	1	9
Chitabe	CH8	4/13/2002	10	7	17
Chitabe	CH8	4/14/2002	8	1	9
Chitabe	CH8	5/14/2002	3	1	4
Chitabe	CH8	5/15/2002	15	3	18
Chitabe	CH8	5/17/2002	7	4	11
Chitabe	CH8	6/9/2002	0	1	1
Chitabe	CH8	6/15/2002	9	5	14
Chitabe	CH8	6/16/2002	4	2	6
Chitabe	CH8	7/21/2002	5	6	11
Chitabe	CH8	7/22/2002	6	7	13
Chitabe	CH8	7/23/2002	0	5	5

SITE	STATION	DATE	INSECTIVOROUS	NON-INSECT-DEPENDENT	TOTAL
Chitabe	CH9	4/8/2001	11	22	33
Chitabe	CH9	4/9/2001	10	13	23
Chitabe	CH9	4/10/2001	15	20	35
Chitabe	CH9	5/25/2001	9	27	36
Chitabe	CH9	5/27/2001	11	14	25
Chitabe	CH9	6/14/2001	13	18	31
Chitabe	CH9	6/16/2001	14	18	32
Chitabe	CH9	4/12/2002	4	21	25
Chitabe	CH9	4/13/2002	18	22	40
Chitabe	CH9	4/15/2002	8	16	24
Chitabe	CH9	5/14/2002	14	9	23
Chitabe	CH9	5/15/2002	9	20	29
Chitabe	CH9	5/16/2002	4	34	38
Chitabe	CH9	6/9/2002	7	13	20
Chitabe	CH9	6/10/2002	19	16	35
Chitabe	CH9	6/11/2002	5	18	23
Chitabe	CH9	7/21/2002	14	22	36
Chitabe	CH9	7/22/2002	3	12	15
Chitabe	CH9	7/23/2002	9	23	32
Chitabe	CH10	4/8/2001	9	16	25
Chitabe	CH10	4/9/2001	19	10	29
Chitabe	CH10	4/10/2001	6	17	23
Chitabe	CH10	5/25/2001	5	20	25
Chitabe	CH10	5/27/2001	8	21	29
Chitabe	CH10	6/15/2001	3	25	28
Chitabe	CH10	6/16/2001	17	20	37
Chitabe	CH10	4/13/2002	8	13	21
Chitabe	CH10	4/14/2002	10	18	28
Chitabe	CH10	4/15/2002	5	11	16
Chitabe	CH10	5/14/2002	6	14	20
Chitabe	CH10	5/15/2002	4	20	24
Chitabe	CH10	5/16/2002	2	11	13
Chitabe	CH10	6/9/2002	3	18	21
Chitabe	CH10	6/11/2002	3	18	21
Chitabe	CH10	6/16/2002	10	25	35
Chitabe	CH10	7/21/2002	3	12	15
Chitabe	CH10	7/22/2002	8	16	24
Chitabe	CH10	7/23/2002	10	19	29
Grand Total			6479	8498	14977

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