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Dispersal and Population Estimation of an Isolated Population of *Stomoxys calcitrans* (L.)

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Edward F. Gersabeck

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Richard W. Merritt
Major professor

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DISPERSAL AND POPULATION ESTIMATION OF AN ISOLATED POPULATION OF *STOMOXYS CALCITRANS* (L.)

by

Edward F. Gersabeck

A DISSERTATION

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ABSTRACT

DISPERSAL AND POPULATION
ESTIMATION OF AN ISOLATED
POPULATION OF *STOMOXYS
CALCITRANS* (L.)

By

Edward F. Gersabeck

Stomoxys calcitrans (L.) behavior in relation to sticky panel traps for the purpose of population estimation and management was investigated. Mark-release-capture (MRC) techniques were utilized to evaluate dispersal from known developmental areas and aggregation sites. In addition, MRC techniques were used to estimate total population levels and relate those estimates to panel trap catches and counts of stable flies feeding on horses.

Data indicated two peaks of stable fly flight activity at 1000 to 1300 h and at 1500 to 1800 h with more males than females being active in the early morning and late afternoon. Ninety five percent of the total trap catch occurred below 180 cm between 0800 and 2000 h. More females than males were trapped closer to the ground and the largest number of flies were captured where greatest equine host activity occurred.

Dispersal experiments confirmed the hypothesis of an isolated

population of stable flies at the study site. Further experiments demonstrated that both dispersal patterns and distance travelled from developmental areas were in relation to equine host distribution and activity levels.

MRC experiments indicated that adult population levels could be predicted from sticky panel trap catches once a function was generated from mark-release-capture studies. Population estimates based on counts of flies feeding on horses predicted that there were 115 stable flies resting in the environment for every fly observed feeding on a horse.

As a result of this study, an integrated pest management program was developed for Mackinac Island, Michigan. This program, being based on an understanding of the local fly ecology, was more cost effective than the previous broadcast spraying based control effort.

DEDICATION

I would like to dedicate this dissertation to my spouse, Linda S. Schweizer and family. Without their aid and continual support, this dissertation would not have been possible.

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Social and Political Aspects of a Stable Fly and House Fly Management Program

ABSTRACT

From 1945 through 1977, pestiferous fly control on Mackinac Island, Michigan was limited to broadcast spraying of insecticides against the adult life stage. This sole reliance on chemical methodology quickly led to the formation of resistance in the target pests. By 1977 Musca domestica L. and Stomoxys calcitrans (L.) were no longer controlled by available insecticides.

From 1978 through 1980, housefly and stable fly biology was investigated in order to provide a data base for the development of an integrated management program. Surveys, dispersal studies, and population estimates led to the evaluation of pilot control programs to use on the island.

As a result of the pilot studies, a management program was developed that had the potential for long term pest fly control. The basic components of this program were: 1) cultural practices to increase egg and larval mortality, 2) the release of parasitoids to increase pupal mortality, and 3) spot spraying of adults at certain aggregation sites.

INTRODUCTION

Mackinac Island is perhaps the oldest and most well known tourist attraction in the state of Michigan. The sole reliance on horses and horse drawn carriages for transportation is a unique aspect of the island. Approximately 400 - 600 horses are brought to the island each summer and removed for the winter. The utilization of this type of transportation is not without drawbacks. Despite efforts to dispose of both the horse manure and the prodigious amounts of garbage generated by the tourist trade, enough organic waste persists to allow the development of the housefly (Musca domestica (L.)) and the stable fly (Stomoxys calcitrans (L.)).

Before 1945, fly control on Mackinac Island consisted largely of sanitation. However, most stable owners spent more time catering to the tourist trade and made little effort to regularly dispose of the spilled feed and manure. Waste from these operations was frequently piled in alleys or dumped along roadsides and paths.

In 1945, DDT was released by the U.S. Army for civilian use. In 1946, DDT was utilized to rid the island of pest insects in preparation for a governor's convention. The results were so impressive, that the island's mayor held a special ceremony to burn several hundred old fly traps.

By 1949, the island's fly population showed high levels of resistance to DDT. This development is one of the first documented instances of insect resistance to synthetic organic pesticides in the United States. During the next five years, other clorinated hydrocarbons (i.e. methoxychlor, chlordane, lindane and dieldrin) were used in various combinations with the same results. That is, the fly population quickly developed resistance to these chemicals (Hoopingarner et al. 1966).

Malathion was subsequently used until 1964 when the fly population again developed resistance (Hoopingarner and Krause 1968). Dimethoate was used from 1964 until 1977 when resistance was suspected due to inadequate control. Resistance was verified in 1978 when Mackinac Island house flies, tested at the USDA Insects Affecting Man and Animals Research Laboratory, were found to be 50 to 100 times more resistant to dimethoate (Cygon™) than a susceptible strain of houseflies.

A second serious pest problem was detected on the island in the late 70's. An outbreak of the European fruit lecanium scale (*Lecanium corni* complex) had seriously affected many of the shade and fruit trees located in or near the city and park (Kennedy 1977). Dieback of branches and a general decline in vigor was observed in trees infested with large numbers of scale.

Scale insect populations are generally thought to be regulated by natural enemies. Lack of such regulation, i.e. scale outbreaks, often reflects the absence of natural enemies or a condition which renders them ineffective (DeBach et al. 1971). The most frequent explanations of these localized outbreaks is the proliferation of a scale population through chemical elimination of its natural enemies (DeBach et al. 1971, Croft and Brown 1975, Frankie and Ehler 1978). A well documented example of this scenario was a pine needle scale outbreak in the California resort area of Lake Tahoe (Dahlsten et al. 1969) during an intensive urban insecticide control program for mosquitoes (Roberts 1971).

Observations in 1977 (Kennedy 1977) indicated that large numbers of lecanium scale on Mackinac Island's trees in certain locations was associated with the application of dimethoate along city streets and horse trails for control of nuisance flies. The island's chemically based fly control program appeared to have caused two serious ecological problems: 1) increased insecticide resistance in the target population and 2) a secondary pest outbreak of the *Lecanium corni* complex.

PROGRAM DEVELOPMENT

With the cooperation of the Mackinac Island State Park Commission and the Mackinac Island City Council, a pilot project was initiated in 1978 by Michigan State University. The major goal was to demonstrate that an integrated fly management program could be developed for Mackinac Island. The objectives for the first year were: 1) to determine the major developmental sites for the housefly and stable fly on the island, and 2) to define and evaluate the magnitude of the island fly problem. This information would provide the baseline data needed to evaluate subsequent management methods. Too often, control programs have been initiated with insufficient baseline data, making it difficult to determine whether changes in pest populations were due to introduced control methods or natural population fluctuations (DeBach 1964). The second and third years objectives were to develop, implement, and evaluate other pest management techniques besides broadcast spraying.

PROBLEM IDENTIFICATION

A survey for major fly breeding sites was conducted by dividing the island into quadrants. In each quadrant samples of manure, garbage, and rotting vegetation from a variety of habitats were collected and examined for the presence of eggs, larvae, and pupae.

Alsynite™ panels have been shown to be highly attractive to adult stable flies (Williams 1973, Meifert et al. 1978). These panels were covered with an adhesive substance (Tack Trap™) and placed in areas where signigicant fly activity had been observed in order to sample the adult stable fly population. The number of stable flies caught per trap per 24 hours was recorded in addition to the number of adult stable flies feeding on horses (Dobson et al. 1970). Adult housefly populations were surveyed using the grid method designed by Murvosh and Thaggard (1966) and supplemented by using sticky fly tapes.

To investigate fly movement among different breeding sites on the island and between the island and the mainlands, known numbers of adult stable flies were dusted with Day Glo™ fluorescent dye and released both throughout the island and at selected areas on the mainlands.

Tourist attitudes toward the fly problem were sampled with a weekly public opinion questionaire (Figure 1.1) presented to 1,000 visitors during the adult fly season.

A survey of lecanium infested trees on the island was conducted to determine if a correlation existed between the location of the infested trees and their proximity to spray routes. Twig samples were taken at 3, 6, and 9m heights from trees both within and outside of the sprayed areas. Samples were examined for the presence of both scale insects and evidence of parasitism.

FINDINGS

Several situations were found to produce both stable flies and houseflies on Mackinac Island. Horse manure mixed with hay and urine, especially when in contact with soil, produced large numbers of flies in both stables and corrals. Accumulated feed and moisture in cracks and crevices at the base of horse stalls also provided an excellent developmental medium. In addition, many corrals were shaded by trees that restricted light and air movement, thereby preventing rapid dessication of the larval fly habitats. Manure wagons and boxes (areas of waste storage adjacent to stables) were not emptied on a regular basis, thus resulting in an optimum fly breeding medium. Several barns had seepage drains that allowed runoff from the stalls to drain into the yards. This resulted in small stagnant pools of waste materials that allowed larval development.

Numerous odors emanating from restaurants and fudge shops in the downtown area were particularly attractive to houseflies. In several establishments, poor construction and inadequate sealing

Figure 1.1 - Public opinion questionaire used to sample visitors to Mackinac Island.

Mackinac Island Pest Management

Public Opinion Survey

Dept. of Entomology

Michigan State University

(Please check the appropriate spaces)

__ Male __ Female

Were you bothered by flies on Mackinac Island?

__ Yes __ No (If yes, please continue)

__ I was bitten by flies

__ I was not bitten, but the flies were a nusiance

How many flies do you consider to be bothersome:

__ 1-3 __ 4-10 __ more than 10

Were you most bothered by flies

__ In restaurants __ Downtown streets

__ On biking, hiking or horse trails

__ On carriage tours

As a visitor, do you consider the flies on Mackinac Island to be

__ A serious problem __ A minor problem

__ No problem

I would not return to Mackinac Island because of the bothersome fly problem

__ True __ False

Thank you for your cooperation.

around doors and windows permitted flies to enter. Housefly adults were also attracted to garbage held in open bins in back of hotels and dining establishments. Overstuffed plastic bags would split when tossed into the holding areas, allowing food waste to accumulate at the bottom of the bins. Where these areas were not cleaned, larval development occurred.

The island's landfill presented a unique fly breeding situation. Since most commercial and private buildings did not contain garbage disposals, large volumes of food waste were hauled to the landfill. In addition, manure containing immature flies was also transported to the landfill. The limited amount of cover material available on the island necessitated first covering food waste and garbage with a layer of manure to deter seagulls from digging apart the day's fill. The mixture was then covered with approximately 0.3m of sand or crushed limestone. This layering of material resulted in a porous medium that created an ideal environment for fly production.

Results of adult stable fly mark-release-capture experiments indicated that adults did not remain around localized breeding sites but dispersed about the island, congregating along horse and carriage routes. In addition, there appeared to be little immigration of flies from the mainland or emigration from the island.

The public opinion survey showed that flies were not as serious a problem to the tourist as they were to residents, since only one out of 1,000 persons responding to the poll indicated that the flies would keep him/her from visiting the island again.

The lecanium scale survey indicated that the only scale infested trees on the island were located along the spray routes used for fly control. This provided strong circumstantial evidence that the spray program was eliminating the scale's natural enemies.

RECOMMENDED MANAGEMENT METHODS

Based on the results of the first year's pilot study, these were the suggestions for the integrated management of pestiferous flies on the island: a) improve sanitation, b) compost manure, c) release natural enemies, d) use insecticide coated panel traps, and e) localize spraying to areas of fly aggregation.

A. Sanitation

1) Horses should be fed from a manger located over a concrete or asphalt slab and the amount of feed restricted to what the animal would comsume in 24 hours; 2) automatic demand watering systems should be located away from feeding areas to prevent the development of wet areas in the stables and corrals; 3) drainage systems should be installed where moisture accumulates and defective plumbing fixed; 4) a weekly application of salt, lime, or sodium borate should be applied along the base of horse stalls to prevent adult oviposition and subsequent larval development; 5) manure wagons should be covered with black plastic or a tarpaulin to deter adults from feeding or ovipositing and to generate enough heat to kill developing larvae; and 6) corrals should be scraped out and barns thoroughly cleaned in the fall after the horses are removed from the island in order to reduce fly overwintering sites.

Other sanitary measures proposed included flyproofing of most buildings, garbage holding areas, and manure boxes by means of screens and positive pressure air systems. Air screens were also suggested for doorways giving access to stores, shops, and dining establishments.

B. Composting

The general absence of topsoil and transportation limitations on the island created an ideal situation for the use of a composting system. One system was designed for small scale, individual residence type of operations which involved covering organic waste with black plastic. A similar composting system, on a larger scale, was designed for the island's landfill.

C. Natural Enemies.

In collaboration with USDA scientist at Gainesville, Florida, parasitoids of the stable fly and housefly were released on the island. The two species that were selected, Splangia endius Walker and Muscidifurax raptor Girault and Saunders, are both pupal parasitoids of muscoid flies and have been shown to be effective in reducing population levels of the housefly and stable fly (Morgan et al. 1975, Weidhaas and Morgan 1977).

D. Panels and Traps

Another technique to increase stable fly mortality utilized the Alsynite™ panels already in use to monitor adult densities. The panels were coated with a contact insecticide instead of an adhesive material and placed around stable areas to increase adult mortality. USDA studies have shown that this method can successfully reduce susceptible stable fly populations around barns by 84-90% in 7 to 8 days (Meifert et al. 1978). Similar results were obtained using fiberglass strips coated with permethrin to control houseflies (Patterson et al. 1980). Since the permethrin coated panels were most effective against stable flies and were not legally registered for food handling operations (ie., restaurants and fudge shops), cone traps were recommended as a highly efficient, low maintenance method of reducing adult housefly populations in these areas.

E. Localized spraying

Even though the measures outlined above signigicantly reduced pest fly populations, there were days during the mid to late summer when ideal weather conditions favored the increased activity of the adult flies. When stable fly densities on the Alsynite™ panel traps exceeded 800 flies per 24 hours of exposure, commercial stable operators began to complain about flies bothering their horses. When this situration persisted for more than two days, fly aggregation sites (ie., ceilings of barns and stables, south facing walls, manure wagons) were treated with an insecticide using a hand held sprayer. The objective of this localized spraying was to achieve a quick knockdown of the adult fly population in a manner that minimized environmental contamination. It was also recommended that horses should be treated with topically applied repellents during times of increased fly activity.

SOCIAL AND POLITICAL ASPECTS OF PROGRAM DEVELOPMENT AND IMPLEMENTATION

A. Political Setting

There were several aspects of the island's social and political atmosphere that frequently created difficulties in the program's development and implementation. Many of these difficulties arose as a result of interaction between the two main power structures on the island: the Mackinac Island State Park Commission and the Mackinac Island City Council. These two groups have historically experienced an antagonistic relationship due to a continual struggly for independent jurisdiction over various island affairs. The state park owns and governs approximately 80% of the island while 80% of the population resides within the city's boundaries. This disparity between land area and population distribution often leads to disagreements in the distribution of responsibility between the park and the city. This was especially true in attempted joint endeavors that ultimately resulted in strained relations between the two parties. There also exist a strong laisse faire attitude by many of the residents toward the state park due to past governmental interference into local island matters.

Other influential groups on the island include the Chamber of Commerce whose members make up a majority of the City Council, and the Cottagers' Association that represents the interest of selected summer residents. The Association's membership is primarily the wealthier families that live on two separate bluffs, with each bluff claiming to have a higher social status that the other. Interestingly, these two vocal and very influential groups pay little property tax toward operating expenses on the island since the homes reside on state property and, therefore, are not taxable. In addition, merchants require municipal services during the tourist season; however, when taxes are levied in December, their inventories are greatly reduced resulting in little taxable property. Thus, summer residents and commercial businessmen who contribute to the fly problem, actually provide little money to the local government for necessary services.

B. Program Initiation

At the beginning of the program, horse owners and food handling operators on the island were contacted to discuss the following topics: 1) a brief history of their operation, 2) the concept of integrated pest management, 3) how integrated pest management was going to be applied to the fly problem on the island, and 4) why their operation was being considered in the program. If the potential cooperator was receptive, permission to use the property was obtained.

The program was introduced as a research project sponsored by Michigan State University utilizing the island as a unique ecosystem. Island people were receptive to this approach, but exhibited a general distrust of "experts". During the program's first year, cooperators were contacted for 1-2 hours per month to discuss their satisfaction or dissatisfaction with the fly management effort. It was clear from their input that there was a general impatience and lack of understanding by island residents of the scientific principals and methodology behind the management program. An education and information transfer program was started immediately to rectify this problem.

C. Program Information and Information Transfer

To reach the largest audience possible, the local newspaper was contacted and arrangements were made to publish approximately one article per week on the fly program in addition to regular newspaper coverage of related events, such as City Council meetings. The primary objective of these articles was to keep the public informed on the nature and progress of the fly management program. Soon after one of the first articles appeared in the local paper with the caption

"Tiny Wasps Could Replace Insecticides in Combating Flies", people were concerned that these insects would sting as do yellow jackets and hornets. Misconceptions also emerged rapidly regarding the interrelationships among wasps, flies, and scale insects. One councilman asked how the wasps would be eliminated once they killed the flies. Another commented, "I thought we were interested in fly control not tree scale control." Both of these statements reflected a traditional view of pest control by considering only individual components of the problem rather than viewing the system holistically.

Early in the program, it was evident that both the City Council and the State Park Commission wanted a program that would control flies within their respective boundaries without requiring mutual cooperation. One councilman commented that the city was paying to control flies that lived on state park property. He assumed that adults emerging at a particular site do not move any appreciable distance. The councilman's notion of city flies and state park flies was quickly dispelled by mark-release-capture studies that indicated that adult stable flies moved freely about the island without regard to property lines.

In an effort to increase public awareness of entomology, subsequent news articles contained brief discussions of general insect biology as it related to the fly program. In addition to newspaper articles, a 15 minute movie dealing with the life cycle of the housefly was shown to City Council members and made available to other interested individuals and groups. Also, a short program was prepared for a local radio station describing the Mackinac Island situation, general fly control principals, and application of those principales to other geographical areas.

After the first year, residents on the island polarized into those groups who would cooperate with the program to some degree and those who would not. Typically, the uncooperative people owned stables that were breeding significant numbers of flies on the island. At this time, peer pressure was brought to bear when a local television station did a short news story regarding the flies. In preparation of the film, sites were chosen where people either were not cooperating with the program or were not cooperating sufficiently to reduce fly development. Immediately after the T.V. report was aired, targeted individuals became the object of peer pressure jokes and comments in local bars and on the street. Although this program generated some hostility, many of the people did improve the sanitary effort around their operations.

Problems in the transfer of information to administrators had to be dealt with continually throughout the program. For example, efforts during the first year of the program were aimed at determining larval developmental sites and obtaining baseline data on adult fly densities rather that reducing pest fly populations. Therefore, one would have expected an increase in flies the year following the termination of the spray program (1978). Although quantitative data on fly densities prior to 1978 were not available, opinions expressed by some island residents provided some historical insights. One park administrator stated that the flies seemed no worse in 1978 than in past years when they were spraying for fly control. An opposing view was voiced by a city councilman who felt that 1978 had the worst fly problem he had seen in 20 years. Ironically, this same person expressed the same opinion in 1977 when the island was being sprayed every three days. These opinions and others obtained from island residents suggested that there was little change in the fly population between 1977 and 1978.

The State Park Commission and the City Council also had some basic misconceptions about the potential effectiveness of the fly program. They perceived insect pest management as an effective eradication technique that could instantly control over 90% of the flies. This view of insect pest management is not unique to the lay public on Mackinac Island, but may be the consequence of uniformed pest management proponents overselling its potential. This type of misunderstanding of the program's objectives led to further distrust by island administrators. One city councilman even accused us of holding up the parasitoid release component of the program because we did not want to put ourselves out of a job. It readily became obvious that the program was viewed as more of a commercial pest control operation than a demonstration project.

Other communication problems also became apparent. Initially, control strategies were aimed only at the housefly and stable fly. However, it was assumed by the local residents that anything with two wings would be included under the category of housefly or stable fly. Within a few weeks of the first summer's season, island administrators were demanding control of other pest species, such as: blow flies, mosquitoes, starlings, bats, etc. City Council members became incensed when we explained to them that control of these other pests was not considered to be part of the demonstration project involving the two species of pestiferous flies.

D. Sanitation

Historically, proper waste disposal was poorly practiced on Mackinac Island. Early records indicated that during the winter, solid wastes were simply hauled onto the ice of Lake Huron where the problem would dissappear with the spring thaw. In 1917, the State Department of Health made a recommendation to improve sanitation as a means of dealing with flies and such diseases a typhoid and dysentary. Subsequent studies on the fly problem in the 1920's and 1930's by the State Health Department also advocated the control of flies by elimination of breeding sites. However, any gains in waste management were lost when pesticides were introduced to the island in 1945.

Initial sanitation recommendations were aimed at the removal of organic material that served as fly developmental sites. Some members of the City Council expressed dissappointment in a plan that emphasized sanitation. As one councilman stated, "...the trouble with sanitation is that it might not get done. An effective sanitation program would require the city to hire personnel to enforce the sanitation regulations." The councilman was right: a sanitation program required the enforcement of existing and future ordinances, as well as cooperation between city and state park personnel and from residents and local businesses. In a small community such as Mackinac Island, people were reluctant to harass anyone about enforcement of a law. Ironically, this same ordinance required garbage to be held in metal covered containers which had to be cleaned and rinsed out with a 10% DDT solution weekly.

Midway through the program, I rewrote the sanitation ordinance and enlisted the police chief to review it from an enforcement point of view. The results was an effective samitation ordinance that the police were willing to enforce when a complaint was made. Unfortunately, only members of the fly management program were willing to lodge complaints. Local people were willing to relay complaints to the fly management team, but were not willing to approach the police. One resident expressed his view this way . . . "I have to live here, but you guys are going to be gone." Although no one wanted a fly problem, most people were unwilling to accept the social stigma of complaining to the police about their neighbors.

E. Response to Management Recommendations

During the third year, an effort was made to encourage the individual cooperators to manage their own fly programs. When the implementation burden rested on individual cooperators, each of the recommendations had components which were objectionable to some members of the community.

Although manger feeding was accepted in theory and implemented at several sites, no one was willing to have a proper foundation installed under the mangers because of the additional expense and labor. People were also reluctant to restrict or monitor the amount of food that was given to animals in their care. Horse owners generally associated good health with an overabundance of feed. Barn boys, in general, were transient and not interested in anything that would generate extra work. Automatic demand type watering systems reduced soil moisture levels in several corral situations; however, many of these devices proved to be mechanically unreliable and cooperators would return to water filled troughs when these malfunctioned.

Application of lime, salt, or sodium borate around the base of horse stalls was readily accepted and incorporated into horse management practices at several barns. This technique was adopted because it produced a visible result and it was similar to applying insecticides for fly control. The degree of cooperation improved as the recommended time intervals between applications were increased, thus reducing the cost of materials and the labor involved in implementation.

Natural enemy releases were met with mixed responses. Educated persons readily perceived the benefits associated with an organism that would actively seek out a host. However, some people still thought the wasps would have to be controlled once the flies were gone and were also concerned about being stung. Twice, releases were not made because of the cooperator's entomophobia of the wasps, despite an apparent understanding of their biology. During the last year of the program, there was a major setback with the parasitoid release. In 1980, Parvo virus had reached the island resulting in the death of several local dogs. Since this was also the first summer release of the parasitoids, we were accused of releasing the virus with the parasitoids. This coincidence of events reduced the credibility of the program and generated a certain amount of hostility among the few who were previously neutral.

Adoption of good sanitary practices in barns and corrals was limited to large commercial operations. People understood the reasons for keeping corrals well managed, but manual cleaning was too expensive. Covering manure wagons with black plastic worked well to inhibit fly development until full responsibility was given to the individual cooperators. Those using this method acknowledged that it reduced flies, as evidenced by the presence of dead maggots when the plastic was pulled back; however, cooperators did not want to purchase their own covering material. They firmly believed that expenses for fly control were the responsibility of the City Council and/or the State Park Commission rather than themselves.

Composting was enthusiastically accepted by both private and commercial operators. Individual cooperators had an interest in increasing the humus layer around their homes and commercial establishments such as the golf courses were anxious to receive all the compost they could get.

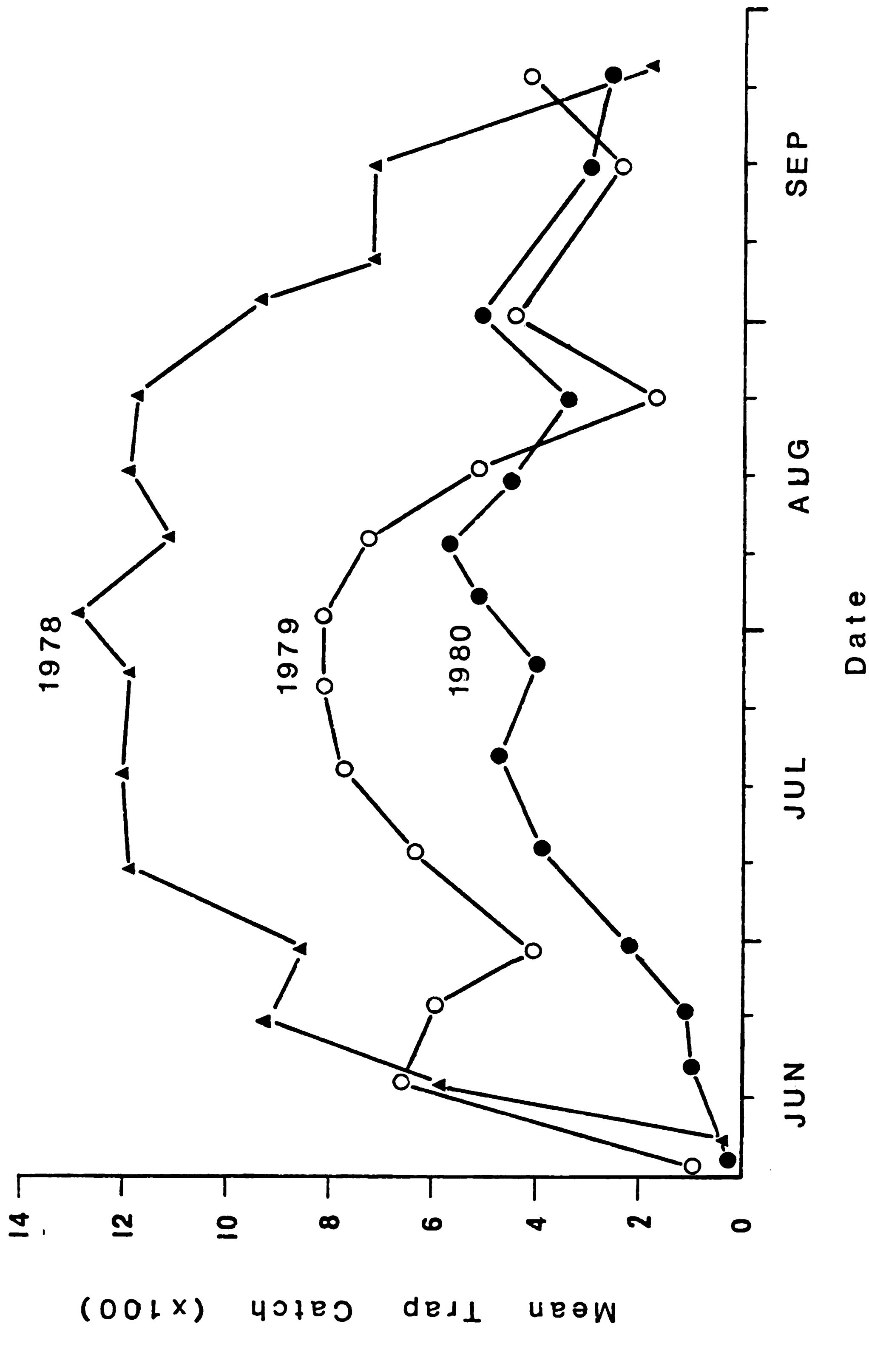
Concurrent with the fly management program was an effort by the State Department of Natural Resources (DNR) to close the island's landfill operation because of a suspected lechate problem that could pollute the surrounding lakes. At the time of the initial violation, a costly study recommended that all solid waste be compacted and barged off the island with composting being limited to reducing the volume of horse manure. The City Council, unhappy with this recommendation, decided to solicit funds from the State of Michigan to begin composting as a primary means of dealing with solid waste. Through grants and financial aid, the city contracted with an out-of-state firm to design and establish a composting system. The consultant, unfamiliar with the local ecosystem, recommended that the island's organic waste be formed into windrows and the piles turned when internal temperatures dropped. Within two weeks after the start of the program, the landfill became a commercially operated fly farm. Manure containing fly eggs, maggots, and pupae was being mixed with other organic material and formed into small rows several hundred meters long. This resulted in a large surface to volume ratio that was ideal for larval fly development. Densities became so great that larvae were crawling out from the base of the windrows in daylight despite the fact that the immatures are normally negatively phototrophic. Modifications in the system subsequently prevented fly breeding. However, this particular situation demonstrated that composting systems and recommendations for any biological system must take into account local ecological conditions.

PROGRAM RESULTS

Utilizing sanitary measures, composting, poison panel traps, parasitoid releases and localized spraying, a significant reduction in adult stable fly densities occurred by the end of the third year of the integrated fly management program (Figure 1.2). In 1979, there was an approximate 38% reduction in the mean numbers of adult stable flies caught per trap during a 24 h period. With the introduction of parasitoids during 1980 and continued sanitation efforts, there was a further 37% reduction in trap catch from the previous year.

One of the most important accomplishments of the program was the reduction in the amount of insecticide applied in the environment. During the year prior to the study, 235 gallons (2.67 lb ai/g) of dimethoate was applied to buildings and vegetation for fly control. In the last year of the program, less than five gallons of insecticide was applied throughout the island. The discontinuance of the insecticide was not without negative consequences. During 1978 and 1979, there were apparent increases in yellow jacket, mosquito, and midge populations, as well as an increase in the lilac leaf miner. Unlike the lecanium scale, these pests were all susceptible to dimethoate and had been inadvertently controlled by earlier mist blower

Figure 1.2 - Mean trap catch in areas where management techniques were being evaluated during the three years of the study.


1978
1979
1980
Mean Trap Catch (x100)
0
2
4
6
8
10
12
14
JUN
JUL
AUG
SEP
Date

sprays intended for pestiferous flies.

At the end of the program in 1980, a comprehensive report on housefly and stable fly management recommendations was prepared for Mackinac Island. The report was designed to allow personnel of the State Park Commission and/or the City Council to take over and implement the program.

Conslusions and Future Considerations

The fly management program was successful in terms of demonstrating the effectiveness of integrated control for a designated pest. Unfortunately, future implementation by island administrators is uncertain. They appear reluctant to budget, as a line item, the money required to implement the program themselves. Many communities may readily endorse pest management programs as long as state or federal dollars absorb the major costs (Anon. 1980). The ultimate test of program acceptance comes when the burden of financial responsibility lies totally with the community.

Despit its cloudy future, the Mackinac Island fly management program has produced permanent changes at many private stables that have significantly reduced the number of fly breeding sites. The management techniques incorporated by private cooperators will help maintain pest flies at tolerable levels and may influence other members of the island community to become actively involved in the program.

Epilogue

Late in the summer of 1981, members of the pest management program had the opportunity to visit the island unofficially and observe how the islanders were managing their pestiferous fly problem. Shortly after arrival, two observations were made. First, the adult housefly and stable fly problem was as bad or worse than at the beginning of the demonstration project four years previous. Second, the word quickly spread of our presence on the island. Instead of complaining about the flies, island residents were pleased to see us back and wanted advice on how to correct the current fly problem.

Actually, some progress had been made toward management of the fly problem. The Island City Council attempted to attack the overall problem by combining the job of humane officer with fly management. In theory, the person hired could make recommendations for fly control while examining the island's horses. Unfortunately, island administrators assumed that anyone with a general biology background, even an outsider, could initiate and maintain the fly management program without professional guidance. The individual hired had not received any formal educational training in entomology before this job, and therefore was not familiar with pest management theory or our proposed recommendations. From a management perspective, the central problem again surfaced that no one wanted to enforce the sanitation ordinance against their own neighbor(s). The hired person was also in a tempory position and he did not want to assume the "enforcer" role that would have alienated many people on the island. Consequently, this action resulted in an increase in larval developmental areas and adult resting sites for the flies. It was apparent that the personnel management problem together with the lack of parasitoid releases and population monitoring throughout the summer contributed to the 1981 pestiferous fly problem.

It was pleasing to learn that administrators on the City Council and State Park Commission had not yet advocated the return to a broadcast spray program to solve the fly problem. Perhaps the severity of the problem during the summer of 1981 will bring an awareness that a successful fly management program requires a permanent administrative commitment rather than temporary summer help.

Chapter 2

ABSTRACT

Vertical and Temporal Aspects of Alsynite™ Panel Sampling of Adult Stomoxys calcitrans (L.)

A 45 cm X 3 m vertical Alsynite™ panel coated with Tack Trap™ was used to study adult flight behavior of Stomoxys calcitrans (L.). The study was conducted at 181 and 213 m above sea level in three different land use areas. Data indicated two daily peaks of stable fly activity at 1000 to 1300 h and 1500 to 1800 h with more males than females being active in the early morning and late afternoon. Ninety five percent of the total trap catch occurred below 180 cm between 0800 and 2000 h. More females than males were trapped closer to the ground. The largest number of both male and female flies were captured where equine host activity was greatest.

INTRODUCTION

Traps constructed of Alsynite™ translucent panels covered with Tack Trap™ have been used in sampling adult populations of Stomoxys calcitrans (L.) (Williams 1973, Ruff 1979, Williams and Rogers 1976, Berry et al. 1981), but little work has been conducted on vertical or temporal effects on trap catch.

Williams and Rogers (1976) examined vertical flight behavior by exposing panel traps for one week intervals at selected heights below 22.9 m. Ninety one percent of their total trap catch occurred when traps were placed at 0.3 and 1.2 m heights above the ground with the remaining 9% being captured at heights of 2.1, 8.5, 15.2, and 22.9 m.

The basic operating principal of Alsynite™ panel traps is that as sunlight strikes the panel, ultraviolet light is reflected at a wavelength that is attractive to adult stable flies. In utilizing Alsynite™ panels for sampling or control of the stable fly, three factors are important. First, their attractancy decreases through time as trap catch increases or as debris coats their surface. Secondly, in a management application, panel traps would typically be located below 3 m in order to facilitate handling. Thirdly, since the flies response to the panels is a visible one, the traps must be placed in an area that would be both visible to the stable flies and in an area where light can reflect off the panels.

The objectives of this study were: 1) to determine if there was an optimal location for Alsynite™ panel traps near ground level to maximize attraction to adult stable flies; and 2) to determine temporal changes of male and female stable fly trap catch over a 24 hour period.

MATERIALS AND METHODS

Location

The study was conducted on the island of Mackinac which lies 12 km off the north eastern coast of Michigan's lower peninsula. The island has a surface area of approximately 990 ha with approximately 13 km of shoreline. The vegetation is primarily northern coniferous forest with ornamental trees and shrubs introduced into populated areas.

Historically, the island's economy and recreation have developed around tourism. During the summer, approximately 500 to 600 horses are brought to the island and utilized either as saddle horses or to pull carriages and wagons. The resulting feed and waste from the horses together with garbage from residents and tourists result in a favorable organic media for the development of the biting stable fly.

Sampling

To test for vertical and temporal activity patterns, 10 translucent Alsynite™ panels (30 cm x 45 cm) were coated with Tack Trap™ and arranged in a continuous vertical column on one stake. Thus, each experimental set of panels formed an Alsynite™ rectangle of 45 cm X 3 m with the base of the first panel located at ground level.
Each set of panels was left in place for one hour. At the end of that hour, the panels were labeled, removed from the stake, and placed within a screened enclosure. This enclosure prevented additional flies from attaching to the panel while in transit to the laboratory. New panels were then placed on the stake for another hour of exposure. When the panels were returned to the laboratory, data from each panel recorded the: number of female and male stable flies, height interval, date,

time of exposure, and site location. In addition, temperature and humidity were recorded on a hygrothermograph.

Each experimental run consisted of 24 sequential hours of exposure and 12 experimental runs comprised the experiment. In four of the 12 runs, the 10 panels were changed every hour for 24 hours. For the remaining 8 runs, only one set of 10 panels was left in place during the time interval 2200 to 0600 h since less than 0.1% of the total trap catch occurred during this time period.

The experiment was run at three locations on the island. One site was a dray operation where eight horses were stabled. This site was located outside the downtown city area and away from main roads used by animals and people. The second site was located within the city area adjacent to a high use road; however, no horses were held in corrals or stables at this site. The final site was a commercial horse drawn carriage tour operation that maintained approximately 300 horses and was located next to a main route for horse drawn wagons.

Analysis

An eta^2 value (sum of squares between treatments divided by the total sum of squares) was calculated to separate variability occuring between or within categories. Percent trap catch versus height or time was tested by using the t-test. Mean separations of sex ratios were made by Duncan's multiple range test. All statistical analysis were made at the 0.05 level of confidence.

RESULTS AND DISCUSSION

Temporal factors

Percentage of total trap catch and female to male sex ratios over time are presented in Figure 2.1. Mean temperature and humidity that occurred during the experimental runs are presented on an hourly basis in Figure 2.2. Two significant peaks of activity were observed during the study. The first peak occurred from 1000 to 1300 h when temperature was increasing and humidity was decreasing. The second peak of activity occurred between 1500 and 1800 h when temperature was near maximum and humidity approached the minimum daily value. These two peaks fell within the temperature range of 21 to 32°C during which time Voegtline and co-workers (1965) observed heavy biting activity of this species in the upper peninsula of Michigan. Assuming that trap catch reflects flight activity, the second peak occurred in contrast to stable fly flight activity reported by LaBrecque et al. (1975) in Florida where flight activity was minimal during peaks of temperature and light intensity. Other workers have reported two daily peaks of activity in the stable fly (Hafez and Gamal-Eddins 1959, Kunz and Monty 1976) but at other times of the day than found during this study.

Less than 0.1% of the total trap catch occurred between 2200 and 0600 h. This low trap catch reflects both the inability of the panels to be attractive in the absence of sunlight and the decrease in stable fly activity that occurs during dark conditions (Miller et al. 1969).

Sex ratios of flies collected from 0600 to 1000 h and 1600 to 1900 h were significantly lower than sex ratios occuring during other time intervals (Figure 2.1). These data suggested that a greater proportion

Figure 2.1 - Distribution of trap catch and sex ratios of stable flies captured at 1 h intervals throughout a 24 h period.

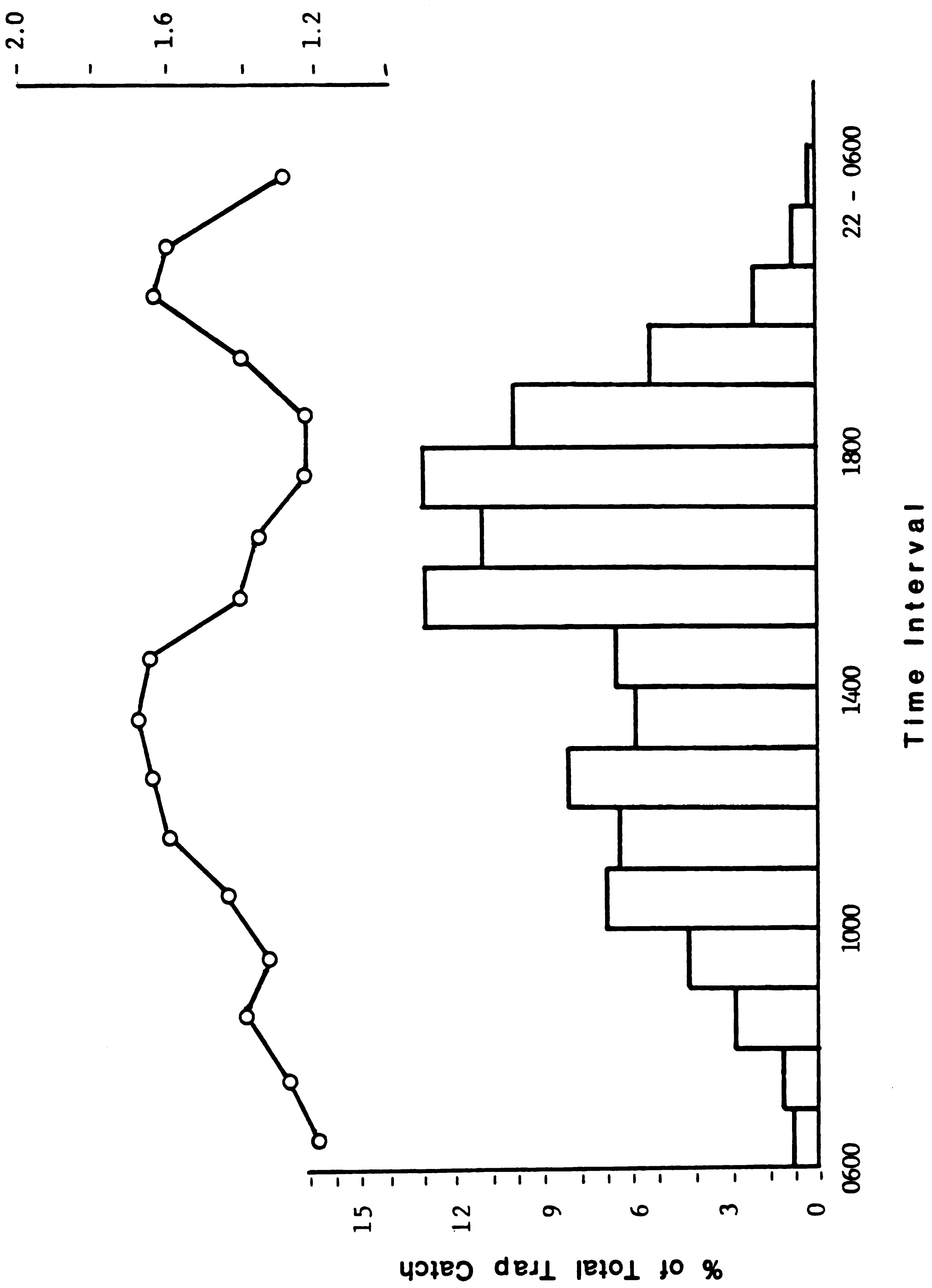
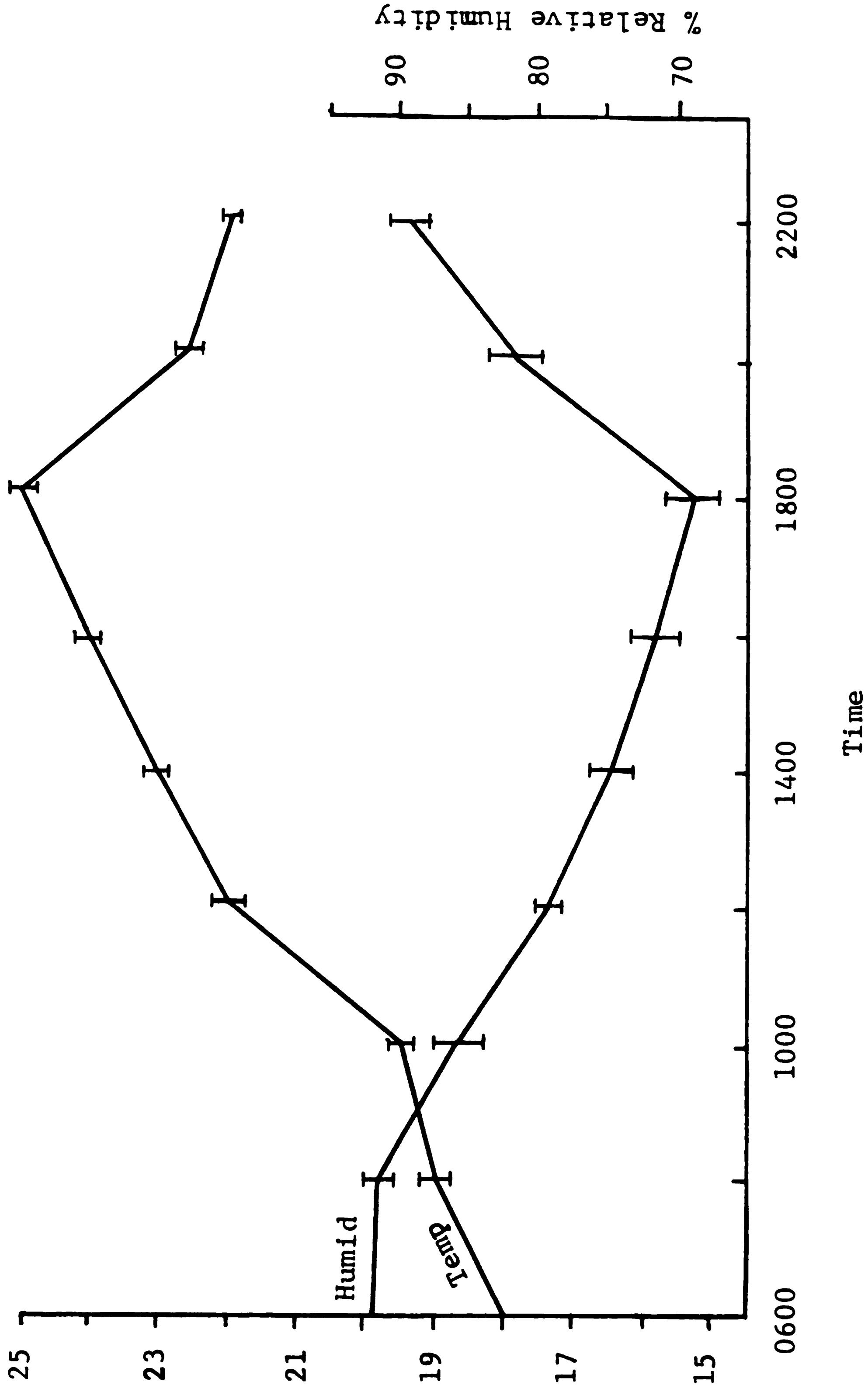

F/M
2.0
1.6
1.2
% of Total Trap Catch
15
12
9
6
3
0
0600
1000
1400
1800
22 - 0600
Time Interval

Figure 2.2 - Mean temperature and humidity that occurred during the experiment.



Temperature (C0)
25
23
21
19
17
15
% Relative Humidity
90
80
70
Humid
Temp
0600
1000
1400
1800
2200
Time

of male stable flies were actively flying in the early morning and late afternoon. This hypothesis is supported by the work of Charlwood and Lopes (1981) who found increased biting activity of male stable flies in Brazil during similar time periods.

Height factors

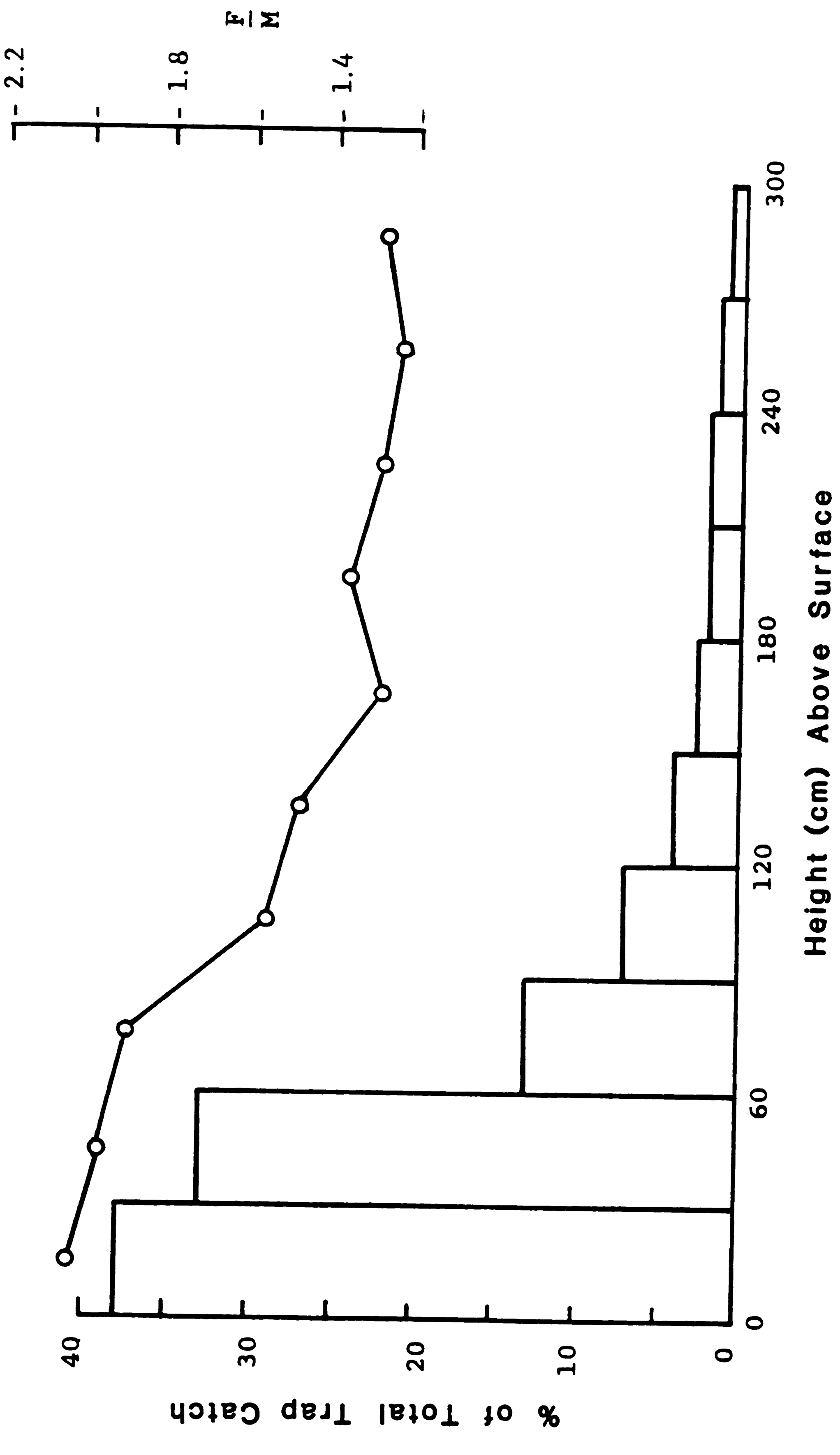
Figure 2.3 shows the percentage of total trap catch as a function of height above ground level with respective sex ratios for each height. An eta^2 value of 0.96 suggested that variability was between treatment means rather than within treatments. Partitioning of the trap catch revealed that 96% of the total trap catch occurred below 180 cm. Sex ratios occurring below and above 90 cm were significantly different from each other with more females than males being captured close to ground level.

A large difference in the percent of captured flies occurred between those flies caught below 60 cm and flies caught above this height. Since stable flies had the opportunity to land anywhere between 0 and 3 m, the data indicated that optimal trap placement for maximizing stable fly attraction to Alsynite™ panels would occur below a 60 cm height above the ground.

Location

Adult stable fly movement and aggregation at a particular site has been associated with host odors (Gatehouse and Lewis 1973) and in the case of females, a search for suitable ovipositional media. Thus, adult activity at a particular location should reflect both host activity and the presence of organic waste.

Figure 2.3 - Distribution of trap catch and sex ratios of stable flies captured at 30 cm intervals above ground level.



% of Total Trap Catch
0
10
20
30
40
Height (cm) Above Surface
0
60
120
180
240
300
F/M
1.4
1.8
2.2

Table 2.1 separates panel trap catches and sex ratios by location. The largest total trap catch occurred at the barns of the commercial tour operation and the lowest catch occurred at the dray operation. Although no horses were maintained at the city site, the continual passage of working horses at this location would have provided a greater volume of host odors at this site in contrast to the dray operation. These data suggested that the density of adult stable flies in an area reflected host activity patterns.

Overall sex ratios at all locations for trapped stable flies ranged from 1.50 to 1.61 : 1 females to male. These ratios lie within the normal population range of 1.4 to 1.6 : 1 (females to male) reported by Kuntz and Monty (1976) for this species. Since the sex ratios at these locations were not significantly different, the observed variation in total trap catch could not be attributed to changes in activity of a particular sex.

Table 2.1 - Mean number of captured stable flies, associated sex ratios, and number of stabled horses at each study location.

Location	Elevation above sea level (m)	Mean No. captured flies	Mean F/M ratio	No. of stabled horses
Dray	183	2223	1.57 : 1	8
City	180	2543	1.50 : 1	0
Barn	213	2914	1.61 : 1	300

CONCLUSIONS

Two peaks of stable fly flight activity were observed at 1000 to 1300 h and at 1500 to 1800 h. More males than females were active early in the morning and late in the afternoon and more females than males were captured nearer to ground level. Over 95% of the total trap catch occurred between 0800 and 2000 h and below 180 cm. The greatest numbers of flies were recovered at locations that either had the largest density of stabled horses or those located near high use roads.

Chapter 3

Dispersal of Adult *Stomoxys* *calcitrans* (L.) from Known Immature Developmental Areas

ABSTRACT

Mark-release-capture experiments were conducted on Mackinac Island to examine the dispersal behavior of an isolated population of adult stable flies from known developmental areas. Results indicated that dispersal patterns and distance travelled were in relation to equine host distribution and activity.

INTRODUCTION

Stomoxys calcitrans (L.) is considered a major livestock pest in the United States (Steelman 1978) and throughout the world (Muir 1914) because it has the potential for two types of damage: 1) a direct effect from biting and blood loss, and 2) transmission of disease agents such as the virus causing equine infectious anemia (Hyslop 1966). In addition, large outbreaks of stable flies can disrupt recreational activities at tourist resorts and recreation areas (Newson 1977).

In past years, the major method used for controlling stable flies has been insecticidal sprays either on animals or surrounding structures (ARS-USDA 1976, Campbell and Hermanussen 1971); however, current stable fly control efforts have utilized alternative methods in a pest management mode (Merritt et al. 1981, Meifert et al. 1978, Weidhaas et al. 1977, Weidhaas and Morgan 1977).

In a pest management program, it is important to know the distribution and dispersal patterns associated with the target organism in order to develop a management strategy. Basic research concerned with the dispersal of adult stable flies is sparse. Eddy et al. (1962) found that stable flies traveled 8 km in 24 h. Flight mill studies by Bailey et al. (1973) demonstrated the flight potential of adult stable flies to be 7 km per 24 hours. In the field, Bailey et al. (1973) found that stable flies would travel at least 3.2 km in search of a blood meal. Assuming an average life span for an adult stable fly of 20 days (Harwood and James 1980), this previous research suggested that to provide control at a specific site, population management must occur within a 140 km radius (7 km/day for 20 days) around that site. Thus, although the distance an insect will travel is an important component of a management program (Bailey et al. 1973), dispersal behavior must be characterised by more than flight distance if realistic management efforts are to be made.

The objective of this study was to examine the patterns and distances of dispersal of adult stable flies from known developmental areas on an island, utilizing mark-release-capture procedures.

MATERIALS AND METHODS

Location

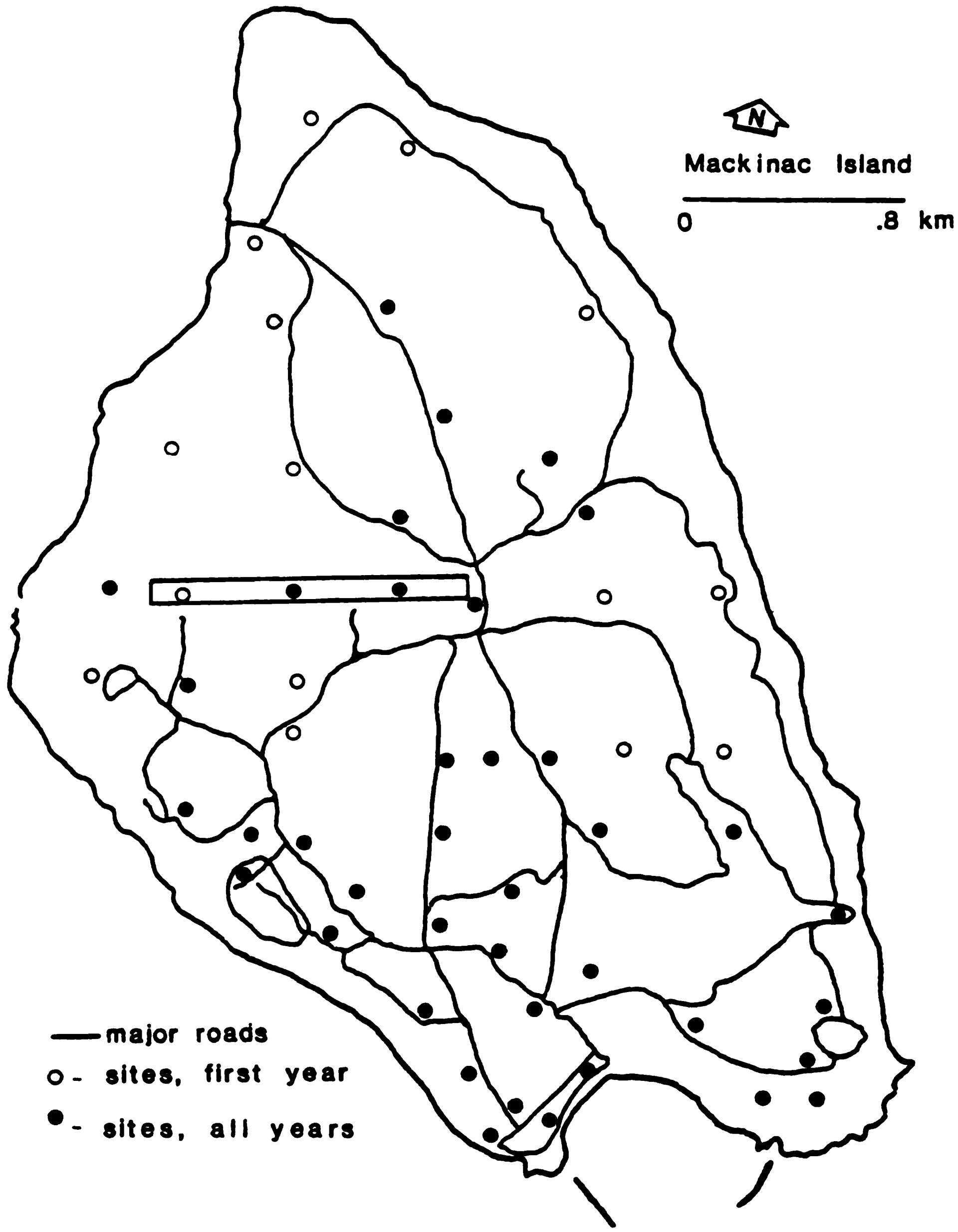
The study was conducted on the island of Mackinac which lies 12 km off the north eastern coast of Michigan's lower peninsula. The island has a surface area of aproximately 990 ha with 13 km of shoreline. The bedrock of the island is essentially fractured limestone and dolomite covered by thin layers of sand, gravel, and humus. Surface vegetation is primarily northern coniferous forest with ornamental trees and shrubs introduced into populated areas.

The island's economy and recreation have developed around tourism. Each summer, 500 to 600 horses are brought to the island and used either as saddle horses or for pulling carriages and wagons. On an annual basis, these horses could associated with over 2,000 tons of spilled feed, bodily waste, and bedding material (Hemmingson et al. 1978) with approximately 85% of that material generated between 1 June and 30 September. This organic waste served as suitable developmental media for the stable fly as well as other filth breeding organisms.

Trapping

During the first year of the study, panel traps (Williams 1973) were located throughout the island (Figure 3.1) to evaluate adult flight activity. Trap placement was not uniform for the following reasons: 1) all traps were located near roads since transportation was limited to bicycles; 2) no traps were placed within shaded areas since the traps require sunlight to work; and 3) curiosity of the tourist and animals with associated vandalism precluded the use of certain desired sites.

Figure 3.1 - Location of Alsynite™ panel traps on Mackinac Island, Michigan.


N
Mackinac Island
0
.8 km
major roads
sites, first year
sites, all years

During the first year of the study, several traps consistently captured less than 10 flies per 24 hours (Figure 3.1 open circles). Because of the low trap catch, these sites were considered too labor intensive to justify their continued operation and therefore were dropped from the sampling scheme.

Panel traps in operation from 1 June through 15 September for all three years were: 1) exposed for 24 hours, 2) operated for five days per week, 3) placed lower than 1 m, 4) transported to and from the study site within an enclosure, and 5) changed prior to 1000 h each day. Data from the panel traps recorded the: 1) total numbers of stable flies, 2) location of the trap, 3) date of recovery, 4) length of exposure, 5) number of marked flies, and 6) color of marking.

Mark-Release-Capture (MRC)

Adult flies were obtained as pupae from the USDA Insects Affecting Man and Animals Research Laboratories at Gainesville, Florida. The flies were dusted with four colors of Day Glo™ flourescent dye (rocket red, saturn yellow, horizon blue, and signal green) in a recirculated air chamber (modified from Williams et al. 1979). Although more colors were available, it was difficult to separate other color groups with confidence when dealing with large numbers of stable flies (greater than 500 per panel).

Marked flies were released at 12 sites on the island as shown in Figure 3.2 (A through L). Immature stable fly development occurred at all sites except at location H. Land use in each of these areas differed and are briefly described in Table 3.1. By releasing flies

Figure 3.2 - Locations on Mackinac Island, Michigan where marked stable flies were released.

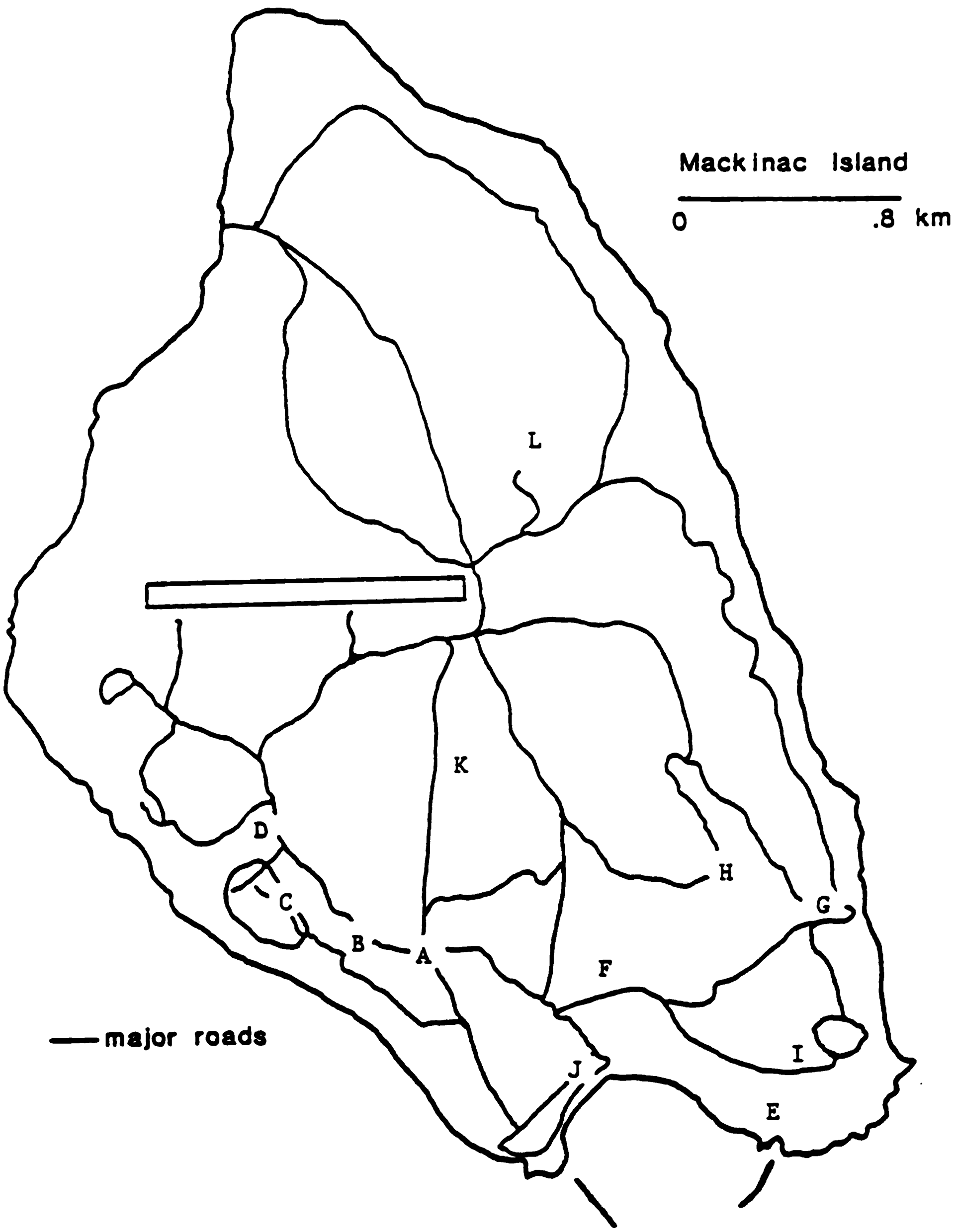

Mackinac Island
0
.8 km
L
K
D
C
B
A
H
G
F
I
J
E
major roads

Table 3.1 - Land use in the areas where marked stable flies were released.

Release	Description
A,E,F,J,K	Commercial area, high public use, high density of resident people and horses
B,C,D,I	Private residential area, low public use, low density of resident people and horses
G,L	State Park Area, high use area, no resident people or horses
H	State Park Area, low public use area, no resident people or horses

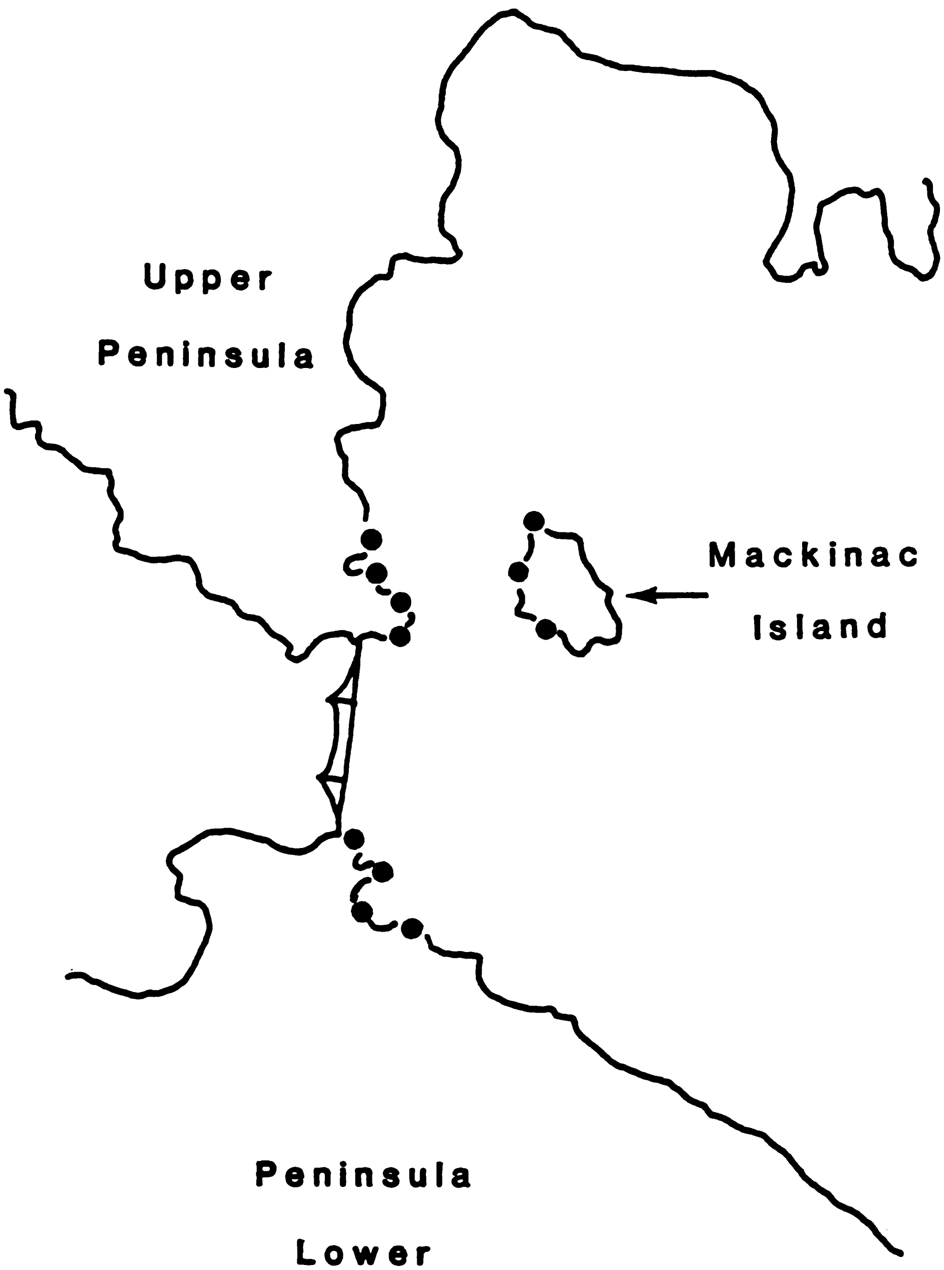
at different land use areas, patterns of dispersal from developmental sites could be related to factors such as host movement or host density in addition to environmental conditions such as wind direction.

At each of the 12 release sites, 3,000 to 4,000 laboratory reared adult stable flies were released. Flies were transported to the release site in 0.03 m^3 cages and released by allowing the insects to fly out. Those insects that would not fly were not counted as part of the number released. At each release point, a different color was utilized through time so that no one color was reused within a 14 day period. This time period was based on preliminary investigations that indicated less than 0.1% of the marked population would be recovered beyond day 11 post release and was in agreement with the work of Bailey et al (1973). Their recovery averaged 9.2 days from release to the last day of recovery.

Emigration - Immigration

In addition to intra-island studies, long range dispersal activity was investigated between the island and the mainland. Distances between the island and the mainland, along major compass points, are as follows: North (St. Martin Bay) 18 km, South (Michigan Lower Peninsula) 10 km, East (Canada) 100 km, and West (St. Ignace) 6 km. Because of the logistics involved, dispersal activity was studied with respect to the two nearest mainland areas: St. Ignace, Michigan and Mackinac City, Michigan (SW 11 km). Traps were located at 0.4 km intervals for 1.6 km along the respective adjacent shorelines (Figure 3.3). Ten thousand to 15,000 marked stable fly adults were released along each shore with each release event being replicated once with a different color.

Figure 3.3 - Location of panel traps and release sites for dispersal studies between Mackinac Island and the mainland.



Michigan

RESULTS AND DISCUSSION

Release/Recovery of Marked Flies

Table 3.2 lists the number of flies released at each study site and total recovery of those flies over the duration of the experiment. Mean percent recovery for all released marked flies used in this study was 10.08%. This recovery is much higher than expected based on the work of Eddy et al. (1962) who only recovered 0.16% of their released marked stable flies.

Actual total recovery was higher than the reported 10%. This was due to several release sites being in close proximity to certain traps such that part of the observed total catch was reflecting panel trap attractancy rather than natural adult dispersal. To eliminate this bias, those traps that were in line of sight of the release points and captured greater than 25% of the total recovery on the first day after release were eliminated from the data set. This procedure resulted in lower percent recoveries especially at sites J and K which prior to adjustment had 22% and 20% recoveries respectively.

Intra-island dispersal

Few studies have dealt with orientation behavior in the adult stable fly. Lewis (1972) discovered the presence of carbon dioxide receptors on stable fly antennae thus demonstrating that this species has the potential for odor orientation. Further work by Gatehouse and Lewis (1973) showed that carbon dioxide induced what they called imprecise upwind flight orientation with host odors inducing precisely directed upwind flight. In a field situation, Eddy et al. (1962) reported that stable fly flight patterns favored upwind direction.

Table 3.2 - Percent recovery of released marked stable flies with associated: number of released insects, color of marking, release site, and date of the experiment

Date	Site	Color	Number Released	Number Recovered	% Recovery
08 Aug 79	A	Green	2880	461	16
	B	Red	3000	510	17
	C	Blue	3000	750	25
	D	Yellow	2900	232	8
21 Aug 79	E	Red	3000	240	8
	F	Yellow	3000	360	12
	G	Green	2800	252	9
	H	Blue	3000	210	7
29 Aug 79	I	Red	2730	218	8
	J	Yellow	2250	68	3
	K	Green	2690	54	2
	L	Blue	3000	180	6
$\bar{x}$					10

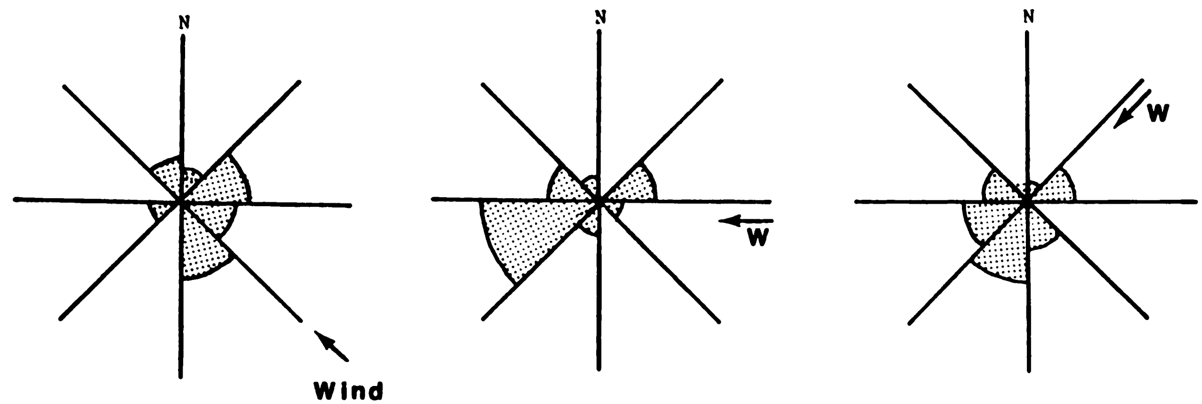
Thus, in a release procedure, expected recovery of marked insects would be upwind of the release sites.

In this study, only those flies released at sites A, B, C, and D were recovered predominantly upwind (Figure 3.4, Table 3.3) from their release points. While 90% of the flies were recovered within 0.8 km of their release sites, flies released at the other eight sites dispersed much farther. In addition, mean percent recovery from these four sites was much greater (17%) than from the remaining sites (7%).

The observed patterns of dispersal suggested that other factors besides wind direction influenced dispersal patterns. Bailey et al. (1973) speculated that once stable flies found a source of blood, they they would tend to feed and rest in the immediate area for several days. In the vicinity of sites A through D, horses were kept within stables or corrals and were relatively immobile when compared to horse activity around sites E through L which were located near high use roads. At sites A through D, the adult flies could obtain a blood meal within 0.8 km of their release sites. In addition, because these horses were in restricted areas, these host feeding sites also contained suitable breeding material in the form of straw and hay mixed with urine and feces. Thus, as observed by Bailey et al. (1973), flies tended to remain in the general area where they found food, resting and mating sites, and ovipositional material.

Stable flies released at sites E through L dispersed farther than those from sites A through D and in a non-windward orientation. Since the physiological age of all the flies was approximately the same, other factors were influencing these dispersal patterns. Typically, sites E

Figure 3.4 - Distribution of recovered marked stable flies from their release points grouped by release date with associated distances to 50% and 90% of total recovery.



Grouping	A,B,C,D	E,F,G,H	I,J,K,L
Date	8 Aug 79	21 Aug 79	29 Aug 79
Distance to 50% recovery	0.3 km	0.8	0.6
Distance to 90% recovery	0.8	1.4	1.6

Table 3.3 - Distribution of recovered marked stable flies from their release points grouped by release date with associated distances to the recovery points.

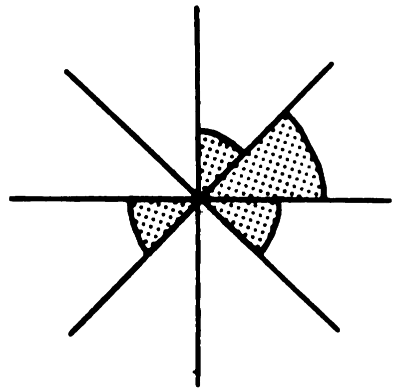
	% Recovery / Date		
Compass Heading	A,B,C,D 8 Aug 79	E,F,G,H 21 Aug 79	I,J,K,L 29 Aug 79
NNE	9.2	0.6	3.2
ENE	14.7	17.2	16.5
ESE	21.2	5.6	2.7
SSE	25.7	3.5	15.3
SSW	0.0	8.2	25.3
WSW	9.8	39.2	22.3
WNW	2.7	18.9	13.9
NNW	16.6	6.8	0.8
Distance (km) from the release site			
0.0 - 0.4	72.8	34.2	30.8
0.4 - 0.8	17.4	23.9	32.8
0.8 - 1.2	6.6	25.9	16.8
1.2 - 1.6	2.0	10.1	10.0
1.6 - 2.0	0.7	4.3	5.5
2.0 - 3.0	0.5	1.6	4.2
Predominant wind direction during recovery			
	SE	E	ENE

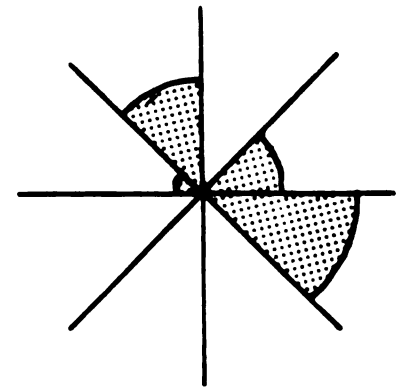
through L were in close proximity to roads on which host movement was relatively constant throughout the daylight hours. Studies by Mitzmain (1913) and Harris et al. (1974) reported that a stable fly will feed approximately four minutes twice per day. Therefore, a fly released at sites E through L may initially have been attracted to a horse via an upwind orientation to host odors; however, the final distribution of that fly in both time and space will be a function that includes: host activity patterns, length of time spent feeding, and the potential flight ability of the stable fly. If this hypothesis is true, then the dominant direction of dispersal should be toward areas of host activity.

Figure 3.5 and Table 3.4 separate release sites by the dominant direction of dispersal of the released flies. In all cases, primary patterns of movement were toward areas where higher host activity than at the release areas occurred (Table 3.5). Flies released from sites A, B, and K aggregated around large horse barns where 50 to 300 horses were maintained. In the direction ENE of site G was a 10 minute rest stop for horses pulling commercial tour buggies between 0900 and 1800 h. Near sites E, F, H, I, and L were major highways along which most of the flies released at these sites were recovered. Flies released at site J which was in the city area, mainly stayed within the city area. Similarly, flies released at sites C and D also were recovered near the release sites since these were located within a private residential area.

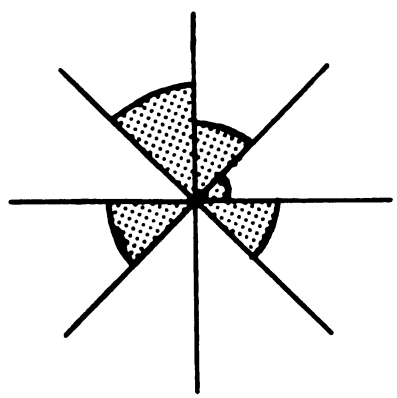
Adult stable flies dispersed from several of the release sites in more than one major direction of movement. Typically, these sites were situated in the midst of several areas that served as stable

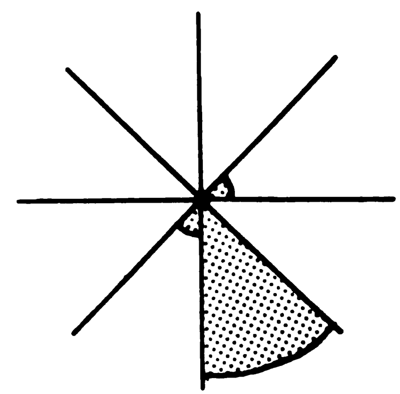
Figure 3.5 - Distribution of recovered marked stable flies from their release points grouped by greatest direction of dispersal with associated distances to 50% and 90% of total recovery.





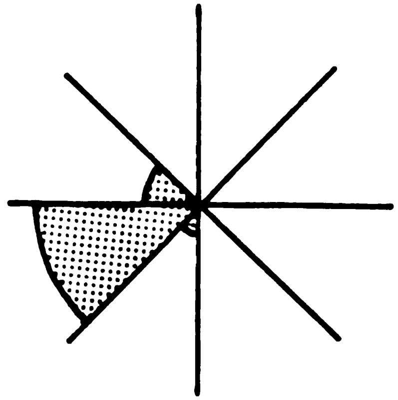
Group	A	B
Distance to:		
50% recovery	0.4 km	0.3
90% recovery	0.9	0.9

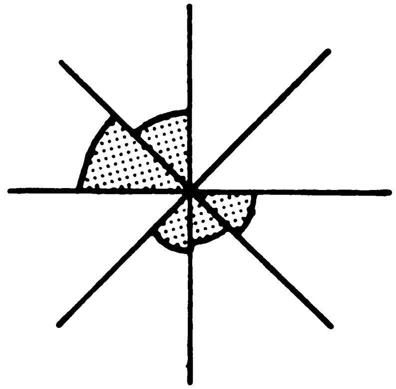




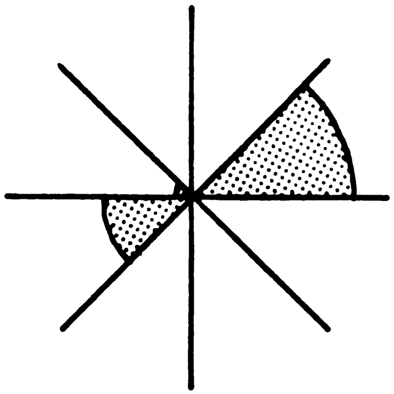
Group	C	D,K
Distance, to:		
50% recovery	0.3	0.3
90% recovery	1.1	1.2

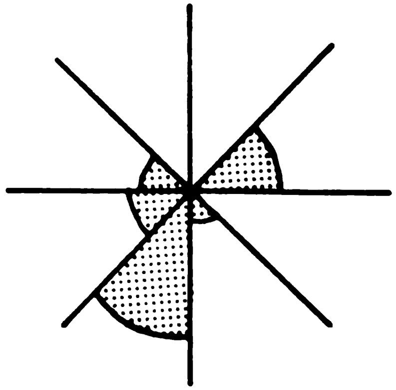
Figure 3.5 - Continued





Group	E,H,I	F
Distance to:		
50% recovery	0.9 km	0.6
90% recovery	1.5	1.0





Group	G	J,L
Distance to:		
50% recovery	0.3	0.5
90% recovery	1.6	2.0

Table 3.4 - Distribution of recovered marked stable flies from their release points grouped by the dreatest direction of dispersal with associated distances to the recovery points.

Compass Heading	% Recovery per Group							
	A	B	C	D,K	E,H,I	F	G	J,L
NNE	16.5	0.0	19.1	3.4	3.2	0.3	0.1	0.0
ENE	29.5	20.8	8.4	10.6	3.0	2.1	58.1	21.9
ESE	21.7	42.7	19.8	1.6	3.6	15.5	0.0	2.2
SSE	5.6	0.0	0.0	70.6	0.5	12.8	0.0	8.5
SSW	0.0	0.0	0.0	12.1	6.2	14.1	3.8	36.7
WSW	17.4	0.4	21.5	1.4	58.6	5.1	32.3	15.3
WNW	3.4	7.4	0.3	0.0	22.8	28.8	5.2	14.5
NNW	5.9	28.8	31.0	0.5	2.2	21.3	0.7	0.9
Distance (km) from release sites								
0.0 - 0.4	54.2	61.3	77.2	63.5	18.6	29.9	59.2	43.3
0.4 - 0.8	33.7	27.1	8.8	16.5	27.9	46.1	1.5	31.6
0.8 - 1.2	10.6	9.9	5.7	12.8	34.3	22.7	7.7	5.7
1.2 - 1.6	0.3	0.0	7.6	5.6	13.9	0.8	17.8	4.3
1.6 - 2.0	1.3	0.2	0.0	1.4	3.8	0.0	10.2	8.0
2.0 - 3.0	0.0	1.4	0.7	0.0	1.5	0.5	3.6	7.4

Table 3.5 - Potential hosts in the greatest direction of stable fly dispersal from each release site.

	Sites											
Area Description	A	B	C	D	E	F	G	H	I	J	K	L
300 Horse Barn	X	X									X	
City Area		X			X					X		
Residential Area Private Corrals		X	X	X								
Major Horse Routes					X	X	X	X	X			X
Rest Stop for Tour Horses							X					
Variable Host Locations			X	X			X					

fly attraction sites. For example, movement from site B was toward a commercial 300 horse barn (ESE) and privately stabled horses (NNW). Release site C was surrounded by several private homes with corraled horses and movement from site G was toward a major hourse route (WSW) and horse resting area (ENE). These data indicated that, within Mackinac Island, adult stable fly dispersal was not uniform either in direction or distance but rather could be related to host activity patterns.

Emigration - Immigration

The population of stable flies on Mackinac Island was hypothesised to be isolated for two reasons. First, Voegtline et al. (1965) reported that adult stable flies will aggregate along shorelines rather than fly out over water. Thus, the island, being surrounded by a minimum of 10 km of water, would be relatively isolated from the mainland. Second, Williams traps placed along mainland shorelines adjacent to the island on the upper and lower peninsulas of Michigan captured fewer than 10 stable flies per week. Therefore, mainland populations of stable flies occurred in very low densities during this study. Confirmation of the hypothesis of an isolated population of stable flies on the island would produce two important results: 1) a reduction in confounding factors in the MRC results, and 2) it would increase the potential for a successful management program.

No marked flies were recovered either in Mackinac City or at St. Ignace when adult stable flies were released along the coast of Mackinac Island. In a reverse experiment, only five marked flies or less than 0.03% of the total number of flies released at St. Ignace were recovered on Mackinac Island during five days of trapping. None of the marked flies released at Mackinac City were recovered on the island.

CONCLUSIONS

Stable fly dispersal patterns, within an isolated island ecosystem, tended to follow the activity patterns of the resident large mammals. That is, adult stable flies on Mackinac Island: 1) moved to the nearest horse holding area, 2) aggregated along major horse traffic routes, or 3) moved to large horse holding areas after leaving a host. In addition, the stable fly population on Mackinac island was not significantly influenced by immigration from or emigration to adjacent mainland areas.

Chapter 4

Relationship of Alsynite™ Panel Trap Catches to Population Estimates Based on Horse Counts and Mark-Release-Capture Experiments

ABSTRACT

A study was conducted to determine the relationship among three estimators of adult *Stomoxys calcitrans* (L.) population density or activity: 1) sticky panel traps, 2) counts of flies on animals, and 3) mark-release-capture techniques. Results indicated that adult population density could be predicted from sticky panel trap catches once a function was generated from mark-release-capture experiments. Population estimates based on counts of flies on horses predicted that there were 115 stable flies resting in the environment for every fly observed feeding on a horse.

INTRODUCTION

The Williams trap has frequently been used to sample and index adult *Stomoxys calcitrans* (L.) population levels (Williams 1973, Williams and Rogers 1976). The basic operating principal of the trap is that as sunlight strikes the Alsynite™ panel, ultraviolet light is reflected at a wavelength that is attractive to adult stable flies. An inherent problem with the trap is that as progressively more flies and miscellaneous material are captured, there is a concurrent decrease in the reflective surface area and consequently a reduction in ultraviolet reflectance of the trap. Thus, as naturally occurring population levels increase, changes in panel catch becomes increasingly non-representative of actual population levels. This may not be a problem if one simply wants to know whether or not a change in adult density has occurred; however, quantitative information as to reliable estimates of the true population level is required for biologically based management programs.

Two other techniques are used for estimating adult stable fly densities. LaBrecque et al. (1975) based an estimate on animal counts that predicts the number of flies resting in the environment for every fly feeding on cattle. Mark-release-capture techniques (Begon 1979, Blower et al. 1980, Berry et al. 1981) with known numbers of marked flies also produce population estimates. However, both these techniques only provide estimates of the adult population at one point in time.

In locations where environmental conditions are relatively constant, point estimates may be satisfactory. But in areas such as Michigan which have a large tourist industry, the distribution of potential hosts for the stable fly can vary widely throughout the year. In this latter situation, a population estimator that would both integrate fly activity over some time period "t" and could be easily useable in the field would be of more value than procedures that provide only point estimates.

The objective of this study was to compare population estimates of the stable fly based on mark-release-capture techniques and the number of flies feeding on horses. In addition, comparisons were made between panel trap catches and population estimates generated from mark-release-capture experiments and horse counts to determine if actual population levels could be predicted from trap catch alone.

MATERIALS AND METHODS

Study site

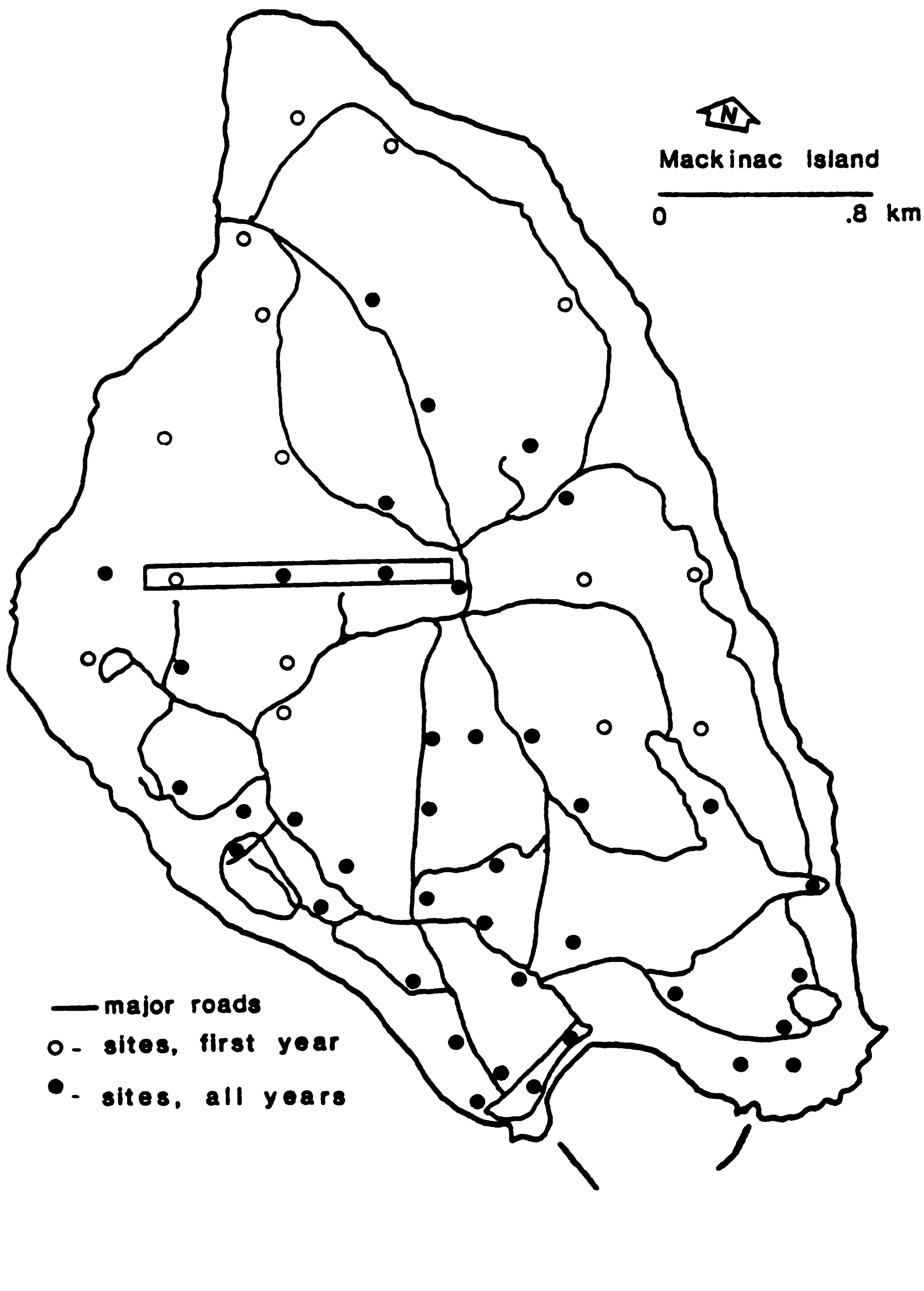
This study was conducted on the island of Mackinac which lies 12 km off the coast of Michigan's lower peninsula. The island can be characterised as having a fractured limestone and dolomite bedrock covered by thin layers of sand, gravel, and humus. The surface vegetation is primarily northern coniferous forest with ornamental trees and shrubs introduced into populated areas.

The island's economy and recreation have developed around tourism. Each summer, 500 to 600 horses are brought to the island and used either as saddle horses or for pulling carriages and wagons. On an annual basis, the horses can be associated with over 2,000 tons of feed, waste, and bedding material with approximately 85% of that material generated between 1 June and 30 September (Henningson et al. 1978). This organic waste served as suitable developmental media for the stable fly as well as other filth breeding organisms.

Trapping

During the first year of the study, panel traps (Williams 1973) were located throughout the island (Figure 4.1) to evaluate adult flight activity. Trap placement was not uniform following reasons: 1) all traps were located near roads since transportation was limited to bicycles, 2) no traps were placed within shaded areas since the traps require sunlight in order to work, and 3) coursity of tourist and animals together with associated vandalism also precluded several potential sites.

Figure 4.1 - Location of Alsynite™ panel traps on Mackinac Island, Michigan.


Mackinac Island
0
.8 km
major roads
- sites, first year
- sites, all years

During years two and three of the study, several traps consistently captured less than 10 flies per 24 h (Figure 4.1, open circles). Because of the low trap catch, these sites were considered too labor intensive to justify their continued operation and therefore were dropped from the sampling scheme.

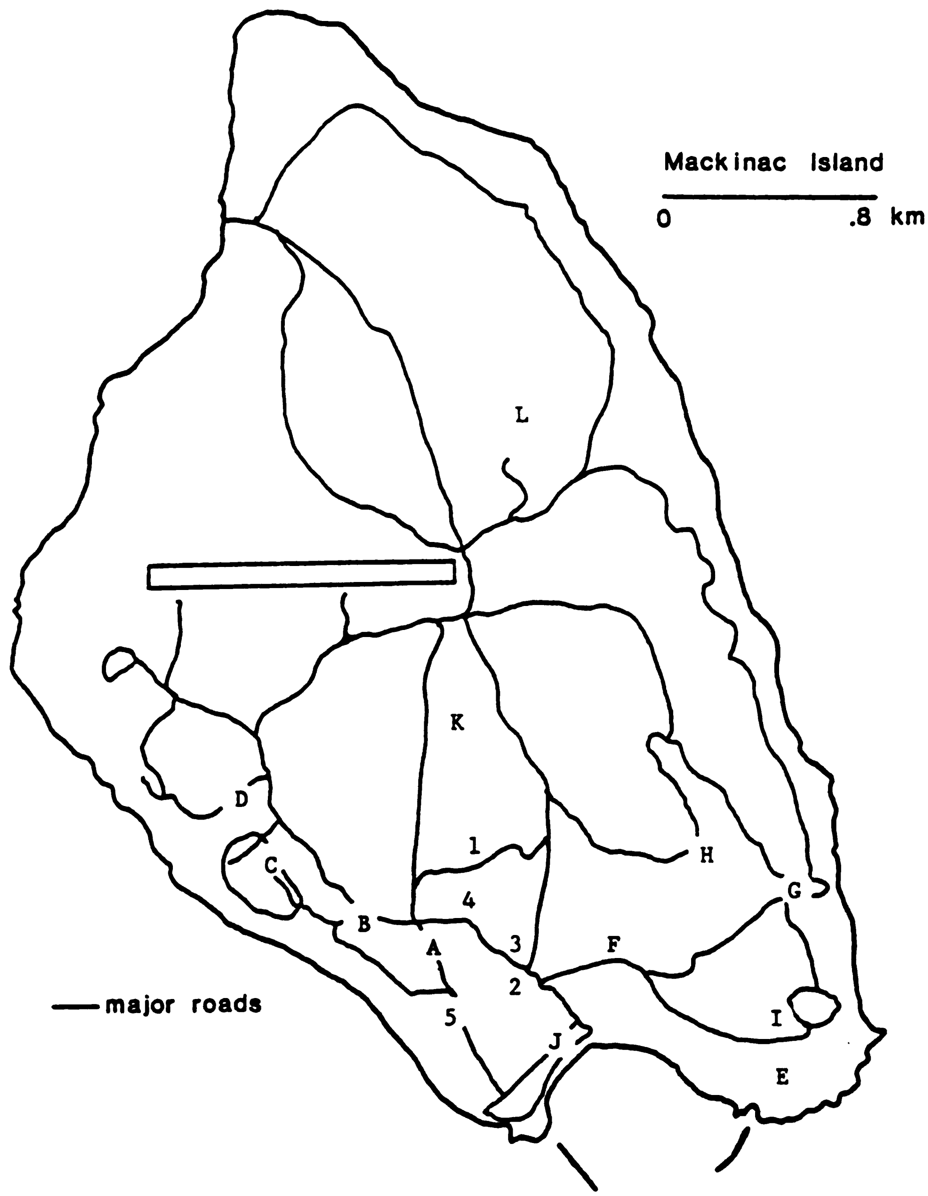
All traps were changed at 24 h intervals prior to 1000 h and returned to the laboratory within enclosures where the stable flies were identified, sexed, and counted on a per site basis.

Mark-Release-Capture (MRC)

Stable fly pupae were obtained from the USDA Man and Animals Research Laboratory at Gainesville, Fl. in order to release known numbers of marked flies. The pupae were allowed to ecclose at ambient conditions and citrated whole beef blood was made available up to the time of marking. Adult flies were marked with flourescent powder in a recirculated air chamber (modified after Williams et al. 1979). Four colors (saturn yellow, rocket red, horizon blue, signal green) of Day Glo™ flourescent dye were used is such a manner that no one color was reused within a 14 day period. Preliminary investigations indicated that very few marked flies would be recovered beyond day 11 post release. This time period is in aggrement with the work of Bailey et al. (1973) who averaged 9.2 days from release to the last day of recovery. No more than four colors were utilized because of the difficulty in separating additional colors with confidence when processing large numbers of stable flies (greater than 500 per panel).

During 1979, 3,000 to 4,000 marked adult nulliparous stable flies were released at the points indicated by letters in Figure 4.2. During

Figure 4.2 - Location of marked stable fly release sites on Mackinac Island, Michigan. Letters = 1979 releases, numbers = 1980 releases.


Mackinac Island
0
.8 km
L
K
D
C
B
A
1
4
3
2
5
J
F
H
G
I
E
major roads

1980, 5,000 to 7,000 marked adult nulliparous and parous stable flies were released at the sites indicated by numbers in Figure 4.2. Since each of these age groups were marked with a different color, recovered marked individuals could be separated into three age categories: nulliparous alone, nulliparous and parous, and parous alone.

Marked adult stable flies recovered in traps subsequent to release events were identified under ultraviolet light, counted, and sexed.

Population estimates were generated from the MRC data by utilizing Jackson's positive method which allows addition to the population during the trapping period. Losses due either to emmigration or death are assumed to affect both the marked and unmarked populations equally (Begon 1979). Briefly, the procedure is as follows.

On day 0, r(0) individuals are marked and released into the wild population. At some later time, n(i) individuals are captured of which m(i) individuals are marked. The proportion then of day i sample that are marked (q(i)) is:

$$q(i) = \frac{m(i)}{n(i)} \qquad 1$$

As i increases, q(i) decreases because of additions of wild individuals but no further additions of marked individuals. Similarly,

$$q(o) = \frac{r(0)}{N(0)} \qquad 2$$

where N(0) is the population level at the time of release. If we let b equal the additions to the population from time i to i+1, then:

$$q(i) = q(0)*(1-b)^{i}$$

or

$$\ln(q(i)) = i(\ln(1-b)+\ln(q(0))) \qquad 3$$

Realizing that as m(i) becomes smaller the sampling errors increase, we can use the m(i) values as weighting factors in the estimate of ln(1-b) and ln(q(0)), such that:

$$\ln(1-b) = \frac{m(i)*(\ln(q(i))-\overline{\ln(q)})*(i-\bar{i})}{m(i)*(i-\bar{i})} \qquad 4$$

and

$$\ln(q(0)) = \overline{\ln(q)}-\ln(1-b)*\bar{i} \qquad 5$$

By substituting equation 4 into 5 and 5 into 2 we then can get an estimate of the total population at the time of marked fly release.

In using the previous equation, the original data were weighted as follows. For each release event, there was a unique distribution of marked adults within the wild population. Inclusion of trap catches outside this distribution would, therefore, result in an over estimate of the actual population.
Initial calculations were based only on those traps within the expected flight range of the marked adults. This subsample of the total trap catch was then used to estimate total adult populations based on the total trap catch at the time of marked fly release.

Horse counts

Estimates of the number of stable flies feeding on horses were generated as follows. On days when marked flies were released, personnel were stationed along major horse routes on the island. As the horses passed, the number of feeding adult stable flies on 1/2 of each animal was recorded for the first 60 to 120 animals. Individual counts were doubled to provide the total number of feeding flies per horse. Concurrent with the MRC experiments and horse counts, a census was taken of the number of horses present on the island. An average number of flies per horse was generated from the horse counts and multiplied by the number of horses on the island to yield the number of feeding flies present at the time of marked fly release. Dividing the total population estimate generated from the MRC experiment by the estimated number of feeding flies on the island produced the fraction of the total adult population that was represented by stable fly feeding activity.

Two other estimators were utilized in conjunction with the horse counts to estimate stable fly population levels. Work by Harris (1974) demonstrated that a stable fly spends 3.9 minutes feeding (4.0 minutes for males, 3.8 minutes for females) twice per day. Therefore, feeding behavior observed for one hour implies that 7.8 flies have fed. Observing that adult stable flies actively fed for 13 to 15 h per day on Mackinac Island, each feeding fly would have represented 101 to 117 flies not feeding based on the work of Harris (1974). In addition, LaBrecque et al. (1975) calculated that for every stable fly feeding on a cow, there were approximately 56 flies resting in the environment. Therefore, both the Harris and the LaBrecque et al. estimators were multiplied times the estimated number of feeding flies to produce a total population estimate at the time flies were counted on horses.

RESULTS AND DISCUSSION

Panel Traps

Figure 4.3 depicts the results obtained from panel trap catches. In this study, data from 39 traps were averaged over five day intervals for the three years of the study. Several observations are readily apparent. First, for all years, the populations initially increased rapidly, fluctuated around a 15 to 20 day cycle, and decreased toward the end of the season. Efforts directed toward population mamagement during years two and three are reflected by an overall reduction in trap catch when compared to trap catch in 1978.

Trap catch information was also used to: 1) identify locations where adult flight behavior was occurring disproportionately to overall population changes, 2) for indexing population levels throughout a particular time period within one season, and 3) to compare population levels over several seasons. However, trap catch alone does not provide an estimate of real population levels on which to base biological control measures.

Recovery of Marked Insects

Table 4.1 indicates % recovery of marked released insects from all study sites. The mean percent recovery of 13% for all events is higher than other reported rates of recovery for the stable fly (0.16% - Eddy et al. 1962). This high recovery rate was most likely due to the intensity of trapping within the isolated island habitat.

Actual percent total recovery was higher in certain cases than indicated in table 4.1. This was due to the release sites being in close proximity to certain traps such that part of the total recovery

Figure 4.3 - Mean number of adult stable flies captured on 39 panel traps from 1979 through 1980.

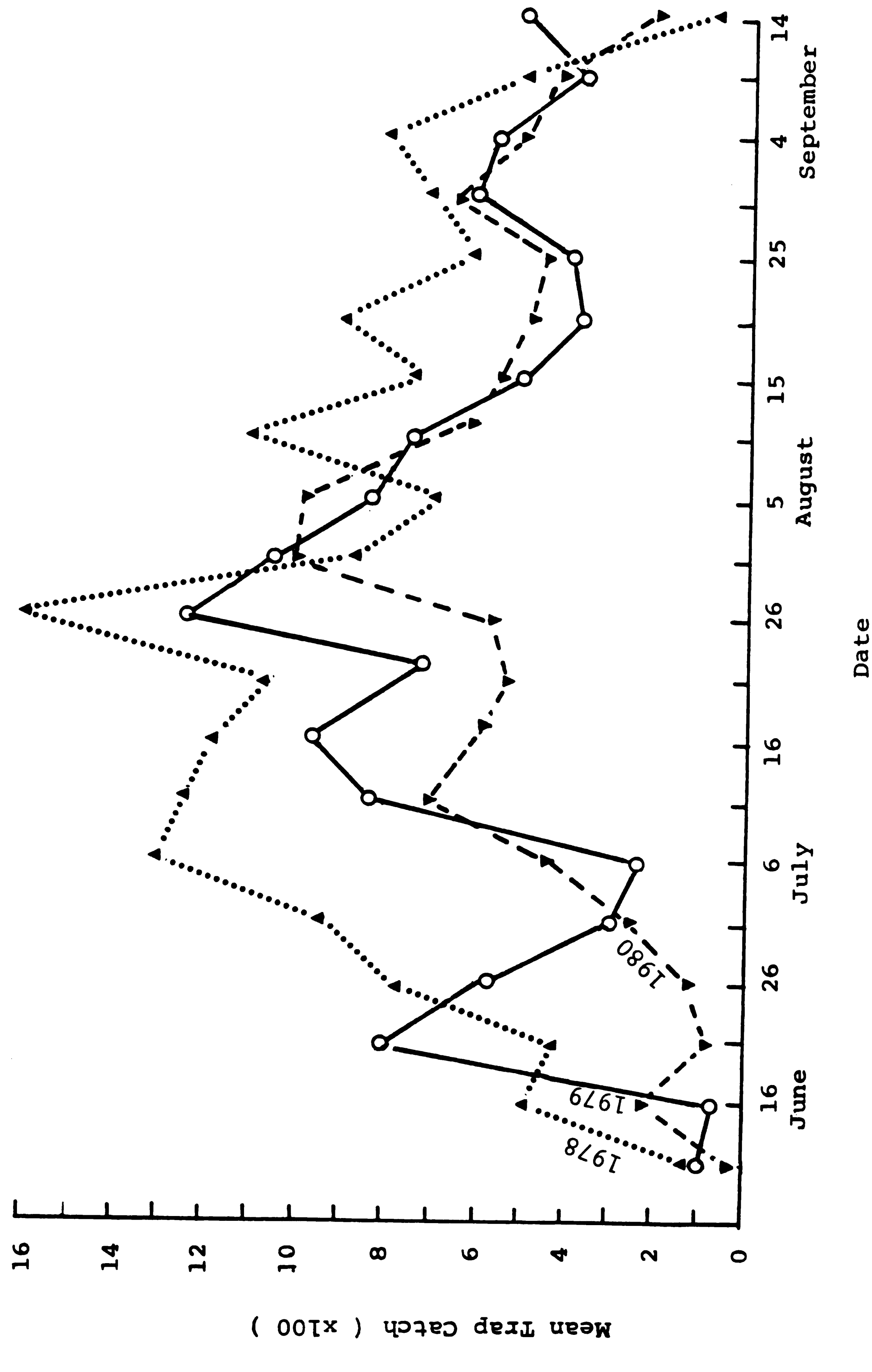

Mean Trap Catch (x100)
0
2
4
6
8
10
12
14
16
Date
June
16
26
July
6
16
26
August
5
15
25
September
4
14
1978
1979
1980

Table 4.1 - Estimates of the total population of adult stable flies on Mackinac Island, Michigan based on mark-release-capture experiments. r(i) = number of marked flies released, N = population estimate, N' = mean population estimate, x = mean total trap catch, p = parous, n = nulliparous.

Date	Color	Age	r(i)	% recovery	N $x10^3$	N' $x10^3$ ± S.E.	x
08 Aug 79	Green	n	2880	16	452	424 ± 137	720
	Red	n	3000	17	220		
	Blue	n	3000	25	226		
	Yellow	n	2900	8	801		
21 Aug 79	Red	n	3000	8	275	321 ± 79	280
	Yellow	n	3000	12	178		
	Green	n	2800	9	286		
	Blue	n	3000	7	547		
29 Aug 79	Red	n	2730	8	615	986 ± 225	550
	Yellow	n	2250	3	801		
	Green	n	2690	2	1739		
	Blue	n	3000	4	789		
08 Jul 80	Blue	n	6620	15	445	447 ± 31	460
	Red	p	6590	11	508		
14 Jul 80	Red	n	5200	25	475	539 ± 64	590
	Blue	p	5290	17	603		
20 Jul 80	Green	n	3390	11	480	417 ± 64	520
	Yellow	p	2900	14	353		
30 Jul 80	Green	p	340	18	257	399 ± 100	1090
	Red	p	380	11	412		
	Yellow	p	350	19	249		
	Blue	p	360	7	676		
04 Aug 80	Green	p	4600	11	977	918 ± 59	1080
	Yellow	n	4600	24	858		
10 Aug 80	Green	p	6300	7	518	510 ± 8	660
	Red	n	6100	13	501		
17 Aug 80	Red	p	4750	20	335	290 ± 45	610
	Green	n	4830	24	246		
$\bar{x}$				13			

reflected panel trap attractancy rather than adult dispersal. In cases where a single trap recovered greater than 25% of a single color in 24 hours and was in line of sight with the release site, that trap's data was eliminated from the overall data set.

The mean percent recovery for releases made during 1979 was 10.08%. Examination of individual release events revealed large variability in recovery patterns that ranged from 2% to 25% of the marked released insects. Modifications to the release procedures were made in 1980 that resulted in an increased rate of recovery (15.44%) and a narrower range of percent recoveries (7% to 25%).

Mark-Release-Capture

Table 4.1 summarizes the results of MRC experiments with the population estimates for each color and an average population estimate based on each day of release. During 1979, four point source releases were made on each release date. In theory, these four releases should have provided independent replicate population estimates of the same population. However, differences in recovery rates resulted in estimates that varied on the average by 313,000 flies.

Situations such as the green MRC event dated 29 AUG 79, were confounded by bias in the release site with respect to the proximity of nearby traps. That is, the release site was close enough to nearby traps such that patterns of movement reflected panel attractancy rather than adult fly dispersal. However, the remaining variability between population estimates could not be explained so easily. These data suggested that the variability in dispersal between single point release sites precluded the use of single point release methods for providing accurate total population estimates.

During 1980, procedures were modified such that on each release day equal numbers of each color were released at several different locations near areas of high activity of potential hosts. This procedure resulted in the average variation between population estimates being reduced to 64,000 flies or only 20% of the average variability observed during the 1979 population estimates.

Comparison of the 1979 and 1980 data suggested that stable flies do not randomly disperse from areas where they are known to develop. Although the point source release experiments (1979) had large variability, they did provide information regarding dispersal from particular sites that proved to be a neccessary data base for subsequent studies involving population estimation.

Table 4.2 separates population estimates based on the age grouping of the marked released insects. In five out of the six MRC events, the nulliparous flies produced a lower population estimate than the parous flies. Part of this difference may be attributable to the parous flies having been physiologically older and kept in cages longer than the nulliparous flies, thereby affecting dispersal patterns and recovery rates. Nevertheless, the data indicated that age composition of the marked released stable flies needs to be similar to the age composition of the wild population being estimated for improved accuracy in total population estimates.

Horse Counts

Table 4.3 presents data and results for population estimates based on MRC techniques and the number of adult stable flies feeding on horses.

Table 4.2 Population estimates separated by age grouping of the marked released insects

Date	Age Group: Nulliparous-color (x1000)	N + P (x1000)	Parous - Color (x1000)
08 Jul 80	445 blue	477	508 red
14 Jul 80	475 red	539	603 blue
20 Jul 80	480 green	417	353 yellow
04 Aug 80	858 yellow	918	977 green
10 Aug 80	501 red	510	518 green
17 Aug 80	246 green	290	335 red
$\bar{x}$	500	525	549

Table 4.3 Population estimates based on horse counts. N=Population estimate; M-R-C=Mark-Release-Capture; L.=LaBrecque; NNF=Number not feeding per each feeding fly.

Date	No. of Sampled Horses	Flies per Horse	Horses per Island	Total Feeding Flies	$\bar{X}$ Trap Catch	N M-R-C ($X10^3$)	N L. ($X10^3$)	N Harris ($X10^3$)	NNF
08 Aug. 79	60	9.3	460	4287	720	424	236	460	135
21 Aug. 79	40	3.7	515	1906	280	321	105	205	113
29 Aug. 79	80	7.1	520	3692	550	735	204	397	199
08 Jul. 80	80	14.1	337	4852	460	477	267	521	75
14 Jul. 80	120	8.9	480	4272	590	539	235	459	110
20 Jul. 80	120	7.4	525	3885	520	417	214	418	107
04 Aug. 80	120	12.6	511	6439	1080	918	354	692	136
10 Aug. 80	120	8.3	531	4407	660	510	242	474	120
17 Aug. 80	120	7.2	540	3888	610	290	214	418	125
									$\bar{X}$=115

The latter estimates used the work of LaBrecque et al. (1975) and the work of Harris (1974). Examination of the three population estimates show that the MRC and the LaBrecque et al. estimates differ by an average of 251,000 flies, the MRC and Harris estimates differ by 26,000 flies, and the LaBrecque et al. and Harris estimates differ by 219,000 flies. It is apparent that the MRC and Harris estimates of total population levels were in much closer agreement than other paired estimates.

The MRC population estimate was divided by the estimated number of feeding flies to generate the fraction of the stable fly population that was feeding at the time of the MRC population estimate. This calculation produced an average value of 115 flies not feeding per observed feeding fly which is in aggrement with the Harris value but is approximately twice the value reported by LaBrecque et al.

It is not readily apparent why the LaBrecque et al. estimator should underestimate either the Harris based estimator or the value derived in this study by approximately 1/2. This study was performed on horses, whereas the other two values were generated from data based on cattle. Yet if host physiology were responsible for the difference, then the Harris and LaBrecque et al. studies should be in aggreement and both differ from the results presented in this study. Clearly, further research is needed to clarify these differences.

RELATIONSHIPS BETWEEN ESTIMATORS AND ESTIMATES

MRC and Trap Catch

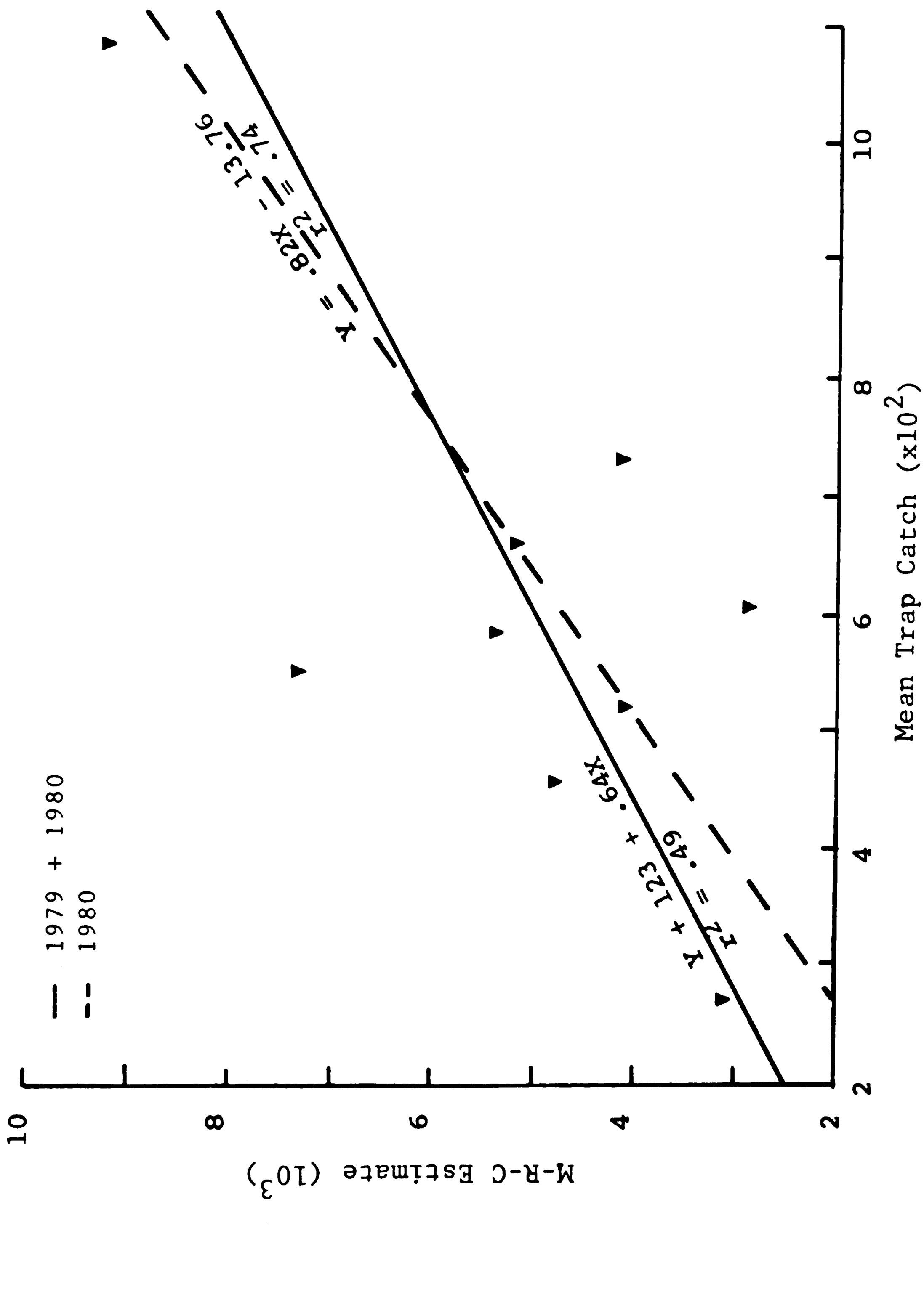
Figure 4.4 presents the relationship between MRC estimates and mean trap catch. A linear equation ($y = 123 + 0.64x$) best fits the data points with an r of 0.7. However, population estimates based on the 1979 MRC experiments were observed to have much larger variability than the 1980 population estimates. If the release events during 1979 are eliminated from the data set, then the r value rises to 0.86 ($y = 0.82x - 13.76$) indicating closer agreement.

With the mean panel trap catch below 1100 flies per 24 hours, the marked-release-capture experiments generated a reasonably predictive function for population estimation based on panel trap catch. However, it is clear that agreement of the mathematical function with true population levels was a function of the methodology in the marked-release program (1979 versus 1980 data). The release of marked insects must, therefore, take into account flight distribution patterns relative to known developmental areas and aggregation sites in addition to host movement patterns.

Horse Counts and Trap Catch

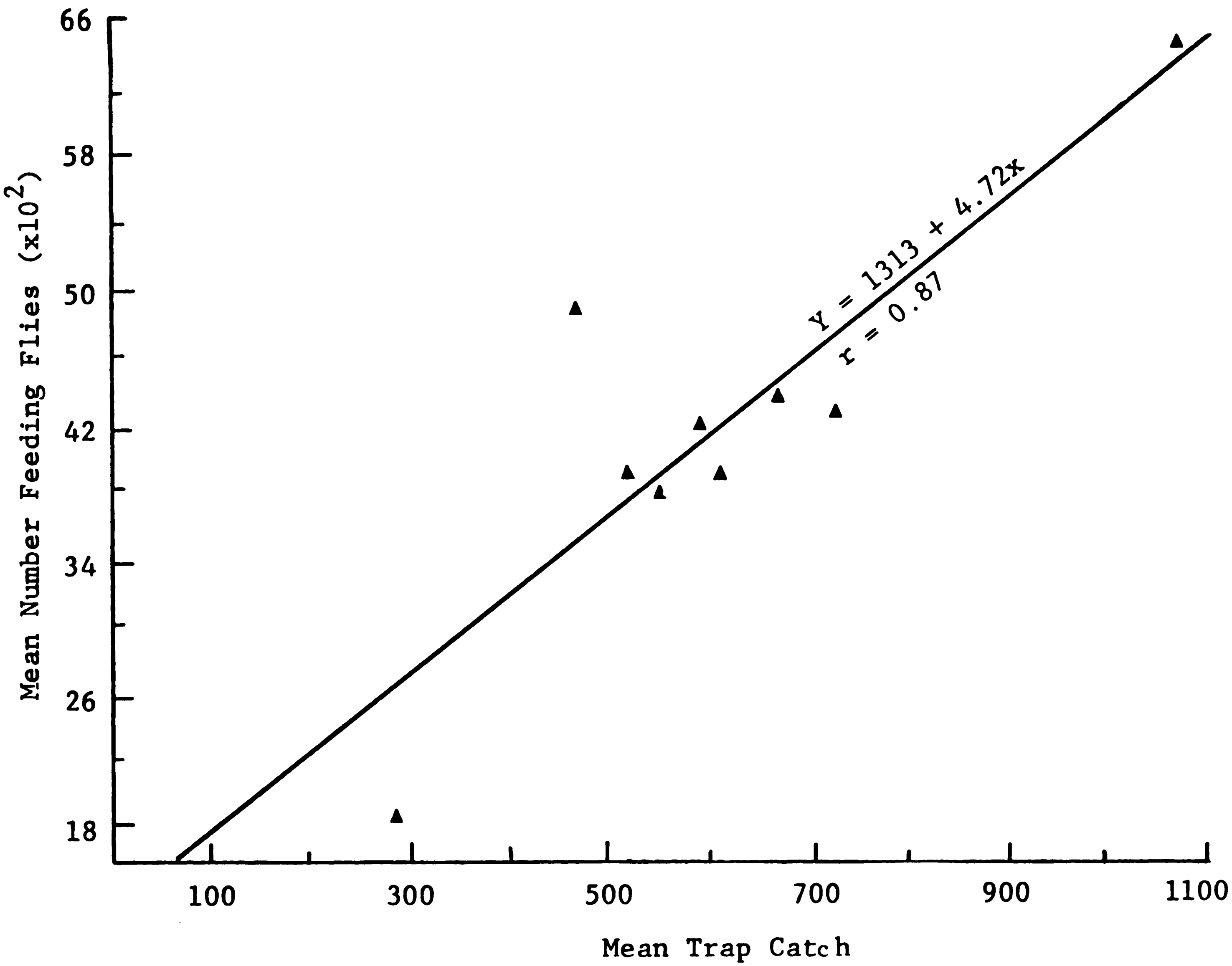
Both counts of flies on horses and panel trap catches are independent estimators of adult stable fly activity. Figure 4.5 compares these estimators for the same adult stable fly population measured on the same date. A Pearson product moment correlation coefficient of 0.87 suggested that this relationship was strong. That is,

Figure 4.4 - Population estimates generated from mark-release-capture experimants compared to trap catch data.



1979 + 1980
1980
Y = .82X - 13.76
r2 = .74
Y + 123 + .64X
r2 = .49
M-R-C Estimate (10^3)
Mean Trap Catch (x10^2)
2
4
6
8
10

Figure 4.5 - Comparison of the number of feeding stable flies with the number of adult flies captured on panel traps.


Y = 1313 + 4.72x
r = 0.87
Mean Number Feeding Flies (x10²)
66
58
50
42
34
26
18
100
300
500
700
900
1100
Mean Trap Catch

as total population activity increased, both trap catch and feeding activity increased albeit not perfectly. Thus, either method provided similar information regarding adult population activity.

MRC and Horse Counts

Mark-release-capture estimates have been shown to correlate with changes in trap catch and are assumed to provide a reasonable estimate of actual population levels. A comparison of this estimator with the number of feeding flies at the time of the marked fly population estimate is presented in Figure 4.6. This relationship is linear ($r=0.84$) and somewhat expected since the marked fly estimate is, in part, a function of trap catch. The inference can be made that the MRC estimate is a reasonable predictor of total population size since it followed changes in both mean trap catch and the total number of feeding flies through time.

Estimates from MRC and Horse Counts

Total population estimates made from horse counts utilizing the work of LaBrecque et al. (1975) and Harris (1974) were compared with the MRC estimates (Figure 4.7). Both horse count based estimates increased as did the MRC estimate and they showed good agreement with a linear relationship ($r=0.94$). However, the LaBrecque estimate rises at a lower rate ($b = 0.23$) than does the Harris ($b = 0.46$) estimate. If all three estimators were good independent estimators of actual population levels, then slopes of one would be expected. In this respect, the larger slope in the Harris estimate would suggest that this estimator was better than the LaBrecque estimator. However,

Figure 4.6 - Comparison of mark-release-capture population estimates with the mean number of feeding flies.

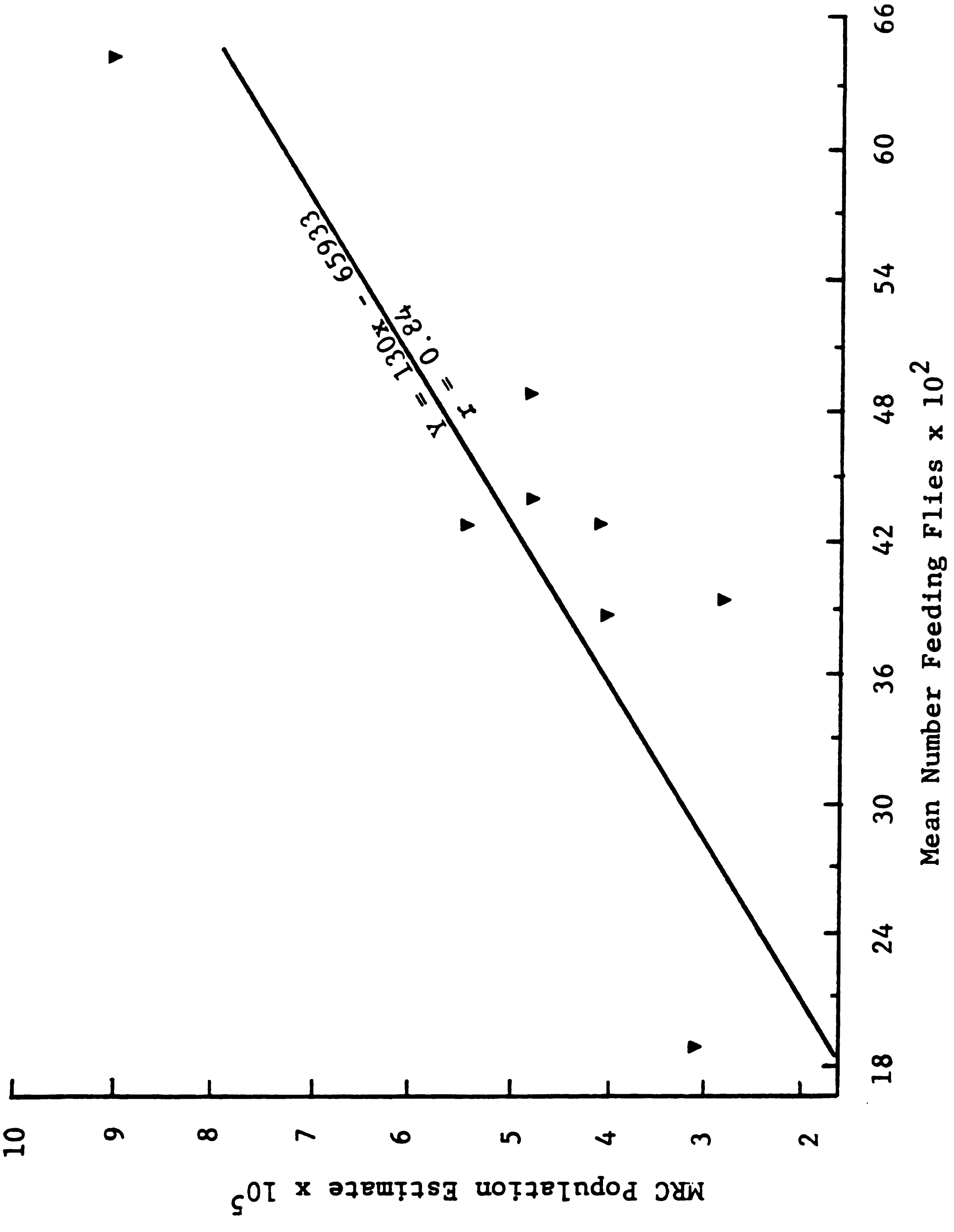
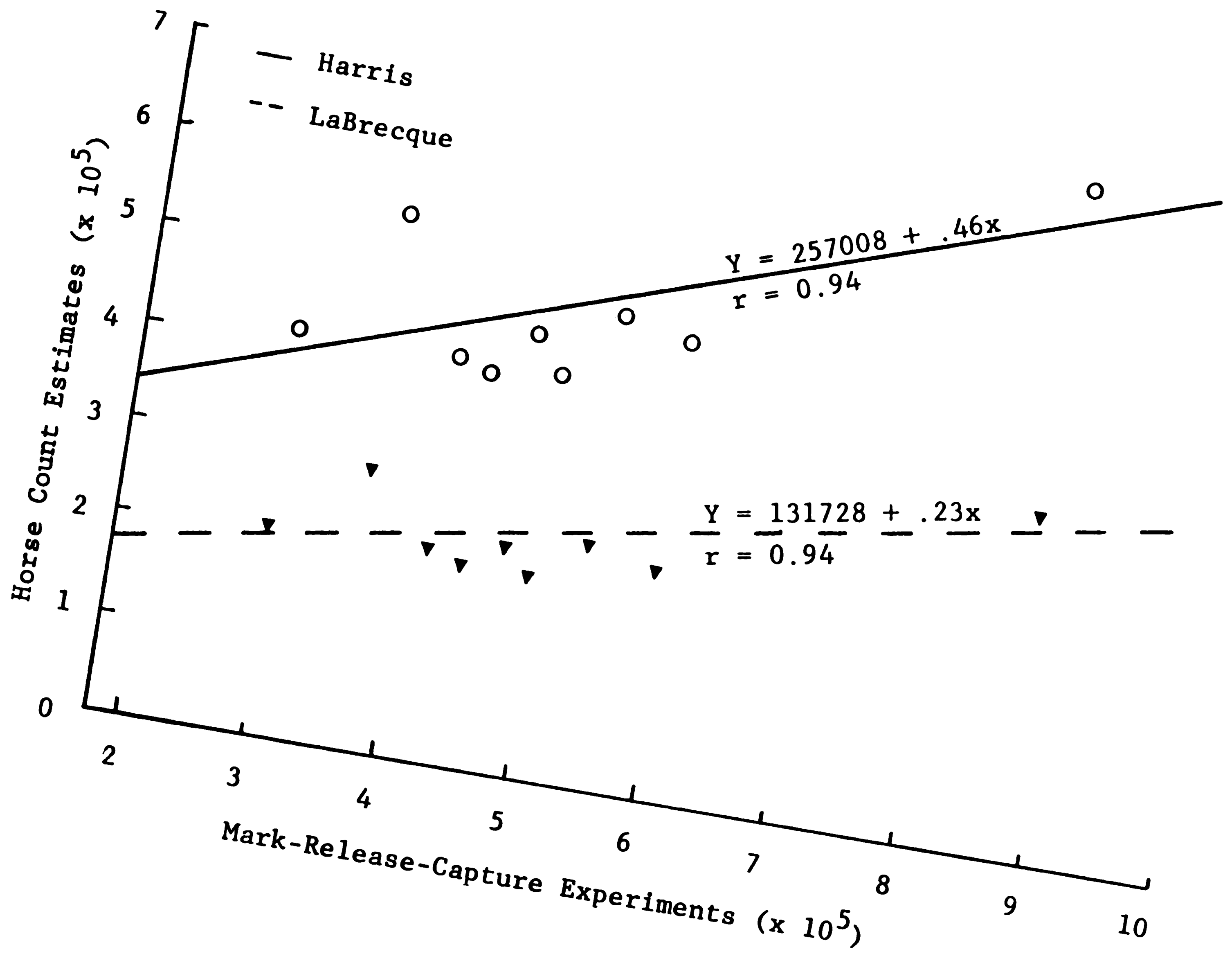

Y = 130x - 65933
r = 0.84
Mean Number Feeding Flies x 10^2
18
24
30
36
42
48
54
60
66
MRC Population Estimate x 10^5
2
3
4
5
6
7
8
9
10

Figure 4.7 - Comparison of population estimates generated from counts of flies on horses and mark-release-capture experiments.



Harris
LaBrecque
Y = 257008 + .46x
r = 0.94
Y = 131728 + .23x
r = 0.94
Horse Count Estimates (x 10^5)
Mark-Release-Capture Experiments (x 10^5)
0
1
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part of the disparity is due to the lack of data points at higher population levels (MRC = 600,000 to 1,000,000; trap catch = 700 to 1100; feeding flies = 4800 to 6600).

CONCLUSIONS

Mark-release-capture procedures involving point source releases did not provide accurate total adult population estimates for the stable fly. Releasing marked flies concurrently from multiple sites provided more accurate population estimates than did the point source release procedures. The point source release information did provide the necesssary data base from which accurate population density studies could be generated. In addition, the age composition of marked release flies was shown to influence resulting total population estimates.

MRC experiments, mean trap catch, and the number of adult stable flies feeding on horses can all be used to estimate activity of adult stable fly populations. The accuracy of the MRC estimate will depend on the methodology used for the release procedures. The LaBrecque et al. (1975) estimates of 56 flies in the environment for each feeding fly does not agree with the experimentally determined value of 115 obtained in this study or the estimate of 101 - 115 generated from the work of Harris (1974).

APPENDIX A

APPENDIX A

The Contribution of *Splangia endius* and *Muscidifurax raptor* to a Stable Fly Management Program on Mackinac Island Michigan: A Question of Effort

INTRODUCTION

Mackinac Island is perhaps the oldest and most well known tourist attraction in the state of Michigan. It is located between Michigan's upper and lower peninsula in the Straits of Mackinac and encompasses ca 996 ha with 13 km of coastline.

The sole reliance on horse drawn carriages for transportation, automobiles are prohibited, is perhaps the most important feature of the island. Approximately 500 to 600 horses are needed to meet the transportation needs of over 750,000 tourist who visit the island each summer (Kennedy and Merritt 1980). The utilization of this type of low energy transportation is not without drawbacks. The most serious problem associated with the presence of large numbers of horses is the enormous accumulation of dung and subsequent increase in breeding sites for pestiferous flies. Despite efforts to dispose of both the horse manure and the prodigious amounts of garbage generated by the tourist trade, enough persists to allow the development of intolerable numbers of the housefly (*Musca domestica* L.) and the biting stable fly (*Stomoxys calcitrans* (L.)).

Before 1945, fly control on Mackinac Island consisted largely of sanitation. In 1945, DDT was released by the U.S. Army for civilian use and was promptly tested on Mackinac Island for fly control. The results were very impressive; however, by 1949 the new "miracle drug" had lost its effectiveness. The island's fly population showed high levels of resistance to DDT. During the next five years, other chlorinated hydrocarbons (e.g. methoxychlor, chlordane, lindane, and dieldrin) were used in various combinations with the same results: the fly population quickly developed resistance to these chemicals (Hoopingarner et al. 1966). This situation represented one of the earliest manifestations of the "pesticide treadmill" effect in the U.S.

Malathion was subsequently used until 1964 when the fly population again developed resistance (Hoopingarner and Krause 1968). Cygon™ (dimethoate) was used from 1964 until 1977 when resistance was suspected due to inadequate control (Kennedy and Merritt 1980). Resistance was verified in 1978 when Mackinac Island houseflies tested at the USDA Insects Affecting Man and Animals Laboratory in Gainesville Florida were found to be five times more resistant to Cygon than a multiple resistant laboratory strain.

A second serious pest problem was dected on the island in the late 70's. An outbreak of the European fruit lecanium scale (_Lecanium corni_ complex) had seriously affected many of the shade and fruit trees located in or near the city and park (Kennedy 1977). Dieback of branches and a general decline in vigor was observed in trees infested with large numbers of scale. Our observations indicted that the dramatic increase in lecanium scale numbers on the island°s trees was associated with weekly application of Cygon™ along city streets and horse trails for control of the filth flies. This broad spectrum pesticide had eliminated the scale's natural enemies (parasites and predators) and allowed the pest to increase to damaging levels (Kennedy and Merritt 1980, Merritt et al. 1981).

Therefore, the island's previous fly control program caused three serious ecological problems: 1) increasing insecticide resistance in the target pest populations, 2) a secondary pest outbreak, and 3) increasing human exposure to toxic chemicals. Clearly, alternatives to this type of unilateral control program were needed to avoid these adverse ecological consequences.

DEVELOPMENT OF AN INTEGRATED FLY MANAGEMENT PROGRAM

With the cooperation of the Mackinac Island State Park Commission and the Mackinac Island City Council, a pilot project was initiated in 1978. The major goal was to demonstrate that an integrated fly management program could be developed for Mackinac Island.

The program began with a survey of major fly breeding sites. Samples of manure, garbage and rotting vegetation from a variety of habitats were collected and examined for the presence of eggs, larvae, and pupae. Alsynite™ panels, which are highly attractive to adult stable flies (Williams 1973, Meifert et al. 1978), were covered with an adhesive substance and placed in areas where significant numbers of adults had been observed. Adult housefly populations were surveyed using the grid method designed by Murvosh and Thaggard (1966) and supplemented by using sticky fly tapes.

Several situations were found to produce both stable and house flies on Mackinac Island. Horse manure mixed with hay and urine, especially when in contact with the ground, produced large numbers of flies in stables and corrals. Accumulated feed and moisture in cracks and crevices at the base of horse stalls also provided an excellent developmental medium. Manure wagons and boxes (areas of waste storage adjacent to stables) were not emptied on a regular basis, thus resulting in an optimum fly breeding medium. Several barns had seepage drains that allowed runoff from the stalls to drain into the yards. This resulted in small stagnant pools of waste materials that allowed larval breeding. In our survey, we found no parasitoids emerging from house or stable fly pupae on the island. It was likely that the past insecticide practice of spraying barns and stables with Cygon™ eliminated any parasitoids that might have been previously established.

Based on the results of the first year's pilot study, the following methods were recommended for the integrated management of pest flies on the island: 1) source reduction through sanitation, 2) composting manure to prevent larval and pupal development, 3) the placement of Alsynite™ panels coated with the insecticide permethrin around stable areas to increase adult mortality, 4) localized insecticide spraying at fly aggregation sites when ideal weather conditions favored the increased activity of adult flies, and 5) natural enemy release.

NATURAL ENEMY RELEASE

In collaboration with USDA scientists in Gainesville, Florida, we decided to release parasitoids of the stable and house fly on the island. The two species selected, Splangia endius Walker and Muscudifurax raptor Girault and Saunders, are both pupal parasitoids of muscoid flies and have been shown to be effective in reducing numbers of house and stable flies in the field (Morgan et al. 1975, 1976, Weidhaas and Morgan 1977). S. endius was obtained through the USDA laboratory at Gainesville, Florida. Other pteromalids were obtained through commercial suppliers and subsequently determined to be M. raptor. In addition to periodic releases throughout the adult fly season, our major aim was to release parasitoids in the late fall and early spring to reduce the overwintering fly population.

Considerable effort was involved in the parasitoid release component of the fly management program. Table A.1 shows a breakdown of the effort into various categories. Each category is accompanied by an estimate of the proportional amount of labor expended. Approximately one-half of the labor was involved in determining fly developmental sites. We felt it was neccessary to identify all major breeding areas within the flight range of the stable fly on the island. A map was divided into grids and representative sample sites from each section were examined for the presence of eggs, larvae or pupae. Once an estimate of fly production at each site was determined, a priority system for parasitoid releases was established based on fly pupal densities.

Many islanders associated hymenopteran parasitoids with hornets

Table A.1 Partitioning of effort in the parasitoid release program

Categories of Effort	% Effort
Determination of Sites	50
Education	25
Obtaining access to property	8
Training personnel	8
Shipping, Handling, Distribution	2
Social and Political Interactions	2
Evaluation of Parasitoids	5
Rearing	?
Total	100
Proportion of Total Management Effort	30

and yellow jackets. To overcome this "entomophobia," an educational program was initiated to increase the public's general knowledge of entomology before the parasitoid release was made. This effort requiring approximately 25% of our time, took the form of weekly newspaper articles in addition to a radio and television program.

Once the general public was exposed to information on parasitoid behvior and biology, access to property of individuals for potential release sites had to be obtained (Table A.1). Although many people claimed they understood the biology of the parasitoids, some thought the wasps would have to be controlled once the flies were gone while others were still concerned about being stung. In two instances, releases were not made because of the cooperator°s entomophobia of wasps.

Other social and political interactions involved maintaining a liason between the local City Council and State Park Commission to keep them informed on the parasitoid release program. Since these two groups supported and funded the program, they were concerned about their liability if the wasps started to sting tourist on the island. In addition, island administrators had to be convinced that biological control agents were not used in the same manner as conventional pesticides.

Although the shipping, handling and the distribution of parasitoids did not take a great deal of time (Table A.1), it created some of our greatest problems. Shipping and receiving times had to coincide with the pest fly's biology to be effective. Also, because live material was being shipped, postal officials had to alerted so that they would not inadvertently kill the insects through mishandling or storage. This was not a problem when the parasitoids were shipped from the USDA laboratory in Gainesville, since containers were clearly marked that they contained live insects. However, in dealing with commercial suppliers, we encountered problems in guaranteed shipping dates, poor packaging and unmarked containers which made it impossible for postal authorities to alert us immediately after receiving a shipment.

Although commercial suppliers contracted with us to send _S. endius_, several shipments contained pure colonies of _M. raptor_. Also, suppliers claimed that 5-7 parasitoids could be expected to emerge from each fly pupa; however, for the above species, generally one and rarely two parasitoids have been reported to develop from a single pupa (Weidhaas and Morgan 1977), Weidhaas et al. 1977). As a consequence, shipments usually contained fewer numbers of parasitoids than specified in the original agreement.

The successful distribution of parasitoids in the field involved first placing wire mesh bags containing parasitized pupae in areas where they were not subject to human vandalism or animal curiosity. Evaluation of the introduced parasitoids required additional effort by trained technicians (Table A.1). Pupal samples had to be collected from developmental sites, sorted, counted and held for parasitoid emergence in the laboratory. The information obtained on parasitization rates at different sites influenced the numbers of parasitoids released and the timing of subsequent releases.

CONCLUSIONS

The baseline data we collected in 1978 provided an index of adult stable fly densities during the fly season. In 1979, we estimated that source reduction through sanitation (without parasitoids) reduced the overall stable fly population by 35-37%. After the second year (1980), we achieved an additional 34-35% reduction in stable flies which we attributed to parasitoids as well as increased cooperation with sanitation efforts by island residents (Merritt et al. 1981). Houseflies also declined 25-30% during the same time periods based on larval densities and cone trap counts. Sampling of muscoid pupae during the last year of the program revealed that 25-30% of those sampled were parasitized, whereas, no parasitized pupae were found prior to the release program.

Our research indicatedthat pupal parasitoids of Diptera can produce significant mortality in isolated populations of pestiferous flies. However, the success of the parasitoid release required approximately 30% of our total management effort (Table A.1). It is doubtful that the parasitoid release, in the absence of a total management program, would hve produced equivalent results.

We felt that if parasitoids were to be a permanent and successful component of the integrated fly management program on the island, they would have to be reared locally. This would have required a rearing facility, technical help and supplies for which the percent of effort could not be accurately determined (Table A.1). However, a significant amount of effort was required, in addition to simply releasing parasitoids, to make them an integral component of the fly management program.

ACKNOWLEDGMENTS

We would like to thank Drs. R.S. Patterson and P.B. Morgan of the USDA Insects Affecting Man and Animals Laboratory, Gainesville, Florida for supplying us with *S. endius* throughout the study. Research partially supported by USDA/SEA Competitive Animal Health Grant No. 59-2261-0-2-060-0.

APPENDIX B

APPENDIX B

Housefly and Stable Fly Management Recommendations for Mackinac Island, Michigan

by

E. F. Gersabeck, R.W. Merritt, M.K. Kennedy

CONTENTS

INTRODUCTION

In 1977, the Department of Entomology at Michigan State University was contacted regarding the poor state of health of Mackinac Island's ornamental trees and shrubs. Studies confirmed the hypothesis that the former spray program for pestiferous flies resulted in a secondary outbreak of scale insects. This scale comples resulted in increased plant mortality along the spray routes that coincided with high use areas. At this point, an objective was formulated to develop a management program for housefly (*Musca domestica*) and stable fly (*Stomoxys calcitrans*) control that would not depend on broadcast spraying.

The following fly management program is the result of three years of research on the ecology of the target pests as they occur on Mackinac Island, Michigan. It is important to note that this program is only designed for the stable fly and housefly and is not intended to be effective against any other nuisance organism.

MANAGEMENT THEORY

Historically, attempts to eradicate pest species have rarely been successful. Those organisms that we call pests typically have high dispersal abilities, high reproductive capabilities and the capacity to adapt to a wide variety of habitats. Another factor is the ability of the target organism, especially insects, to develop either behavioral or genetic resistance to pesticides used for control. As resistance to pesticides develops, material has to be applied in greater concentrations and/or with greater frequency of application in order to achieve desired control levels.

Pesticides may produce other effects such as: contamination of other ecological systems, destruction of non-target organisms and the inducement of potentially serious health hazards. These problems have led to the concept of pest management rather than pest eradication.

Pest management is the intelligent selection and use of pest control actions that will ensure favorable economic, ecological and sociological consequences. It is based upon an understanding of the biology of the organism and its ecosystem together with an objective to prevent damage to other ecosystems. Pest management will never eliminate flies from Mackinac Island, but it can maintain their populations at tolerable levels.

The following management tools, when properly applied, will reduce fly breeding and consequently reduce overall adult population levels. The procedures are presented as general principles since the situations on the island are dynamic. That is, both the people and animals are transient and change in numbers over time.

It is important to note that a totally fly-free environment is neither possible nor desirable since the flies serve as food for many beneficial organisms. The lower the desired population level is set, the greater will be the amount of effort that must go into the program. Population levels should be realistically set at levels below which no damage or financial loss occurs.

PROGRAM EVALUATION

Periodic sampling will provide information on the relative numbers of the target pest present, thus allowing a realistic evaluation of a management program. Examination of trap catch can also provide positive identification of nuisance organisms in a particular area. This information will assist the pest manager in making a correct decision. Sampling methodology is listed in Appendix I.

DEVELOPMENTAL AREAS

Table 1 lists those sites where significant numbers of immature flies were found in horse related situations from 1978 through 1980. This is not intended to be a complete list of all fly developmental areas on the island. These sites do provide locations where your initial program should begin its efforts. In general, other areas that should be examined for fly development include places where three or more horses are kept, where manure/organic material is stored or stockpiled and where garbage holding areas are not properly cleaned.

A significant amount of breeding, development and attraction of flies occurred at the landfill. However, because of the current flux of management policy for this area, no specific fly control recommendations can be made. The following situations were examined and did not produce house flies or stable flies: 1) garbage cans around the periphery of the island, 2) dried manure on roads and 3) manure that accumulated along the sides of roads.

MANAGEMENT RECOMMENDATIONS

Immature Flies

The following situations have been identified as breeding areas for houseflies and stable flies on Mackinac Island, Michigan. The suggested recommendations have been tried at one or more sites on the Island and have been found to increase fly mortality in these situations.

Horses in Corrals

Horses are often fed by throwing hay into corrals. Uneaten hay mixed with feces, urine and soil result in a fly breeding media.

Recommendations:

1) Horses should be fed from a manger that is located in a sunlit area away from the watering source. The manger should be located over a concrete or asphalt foundation so that the overflow of hay cannot come into contact with the soil. In conjunction, the amount of feed should be limited to what the animal will consume per 24 hours. This will inhibit the animal from tossing food outside of the manger.
2) Animals should be watered from an automatic demand watering system

Table B.1 - Horse related areas where significant housefly and stable fly development occurred from 1978 through 1980.

Sites
Bankard Corral
Benser Barn
Carriage Tour Area
Cindy's Riding Stable
Crougan's Corral
Drayline
Goodwin's Corral
Dale Gough Hourly Taxi Barn
Grand Hotel Stable Area
Inn on Mackinac's Drayline
Jack's Livery Stable
Landfill
Porter's Corral
State Corral and Barn
Strauz's Corral

adjusted so that a minimum amount of standing water is present at any one time.

Horse Stalls

Horse stalls are a significant egg laying and developmental site for flies. Once the eggs are hatched, immature flies move among the organic material that accumulates in cracks and crevices. These immatures either work their way under the stalls or are mechanically moved to manure boxes or wagons as the stalls are cleaned. In both situations, the flies are able to complete development.

Recommendations:

1) A weekly application of salt, lime, or sodium borate should be applied around the base of the stalls.
2) Feed that accumulates in the front of the stalls should be removed as frequently as the manure.
3) Where possible, wood shavings should be used instead of hay or straw as bedding material.

Manure Wagons

Manure wagons act as developmental sites for both housefly and stable fly immatures and as housefly feeding areas.

Recommendations:

1) Manure holding wagons should be parked over a concrete or asphalt foundation to facilitate cleaning of spilled material or seepage.
2) Wagons containing manure should be covered with a tarp or black plastic. This will cause the manure to heat sufficiently to kill developing flies. In addition, this prevents access for flies to

oviposit or feed.

3) After emptying the wagon, it should be swept out thoroughly with particular emphasis directed at the fly pupae that will be found at the bottom. Also, an application of salt, lime, or sodium borate should be made around the interior edges of the wagon before reuse.

Manure Boxes

Manure holding areas for privately owned horses consistently produce large numbers of flies. They also provide the developing flies with an overwintering site.

Recommendations:

1) Manure holding areas must be constructed so as to be flyproof. That is, all ventilation openings must be screened and the doors should close tightly.
2) Manure boxes should be constructed on a concrete slab so that spilled material does not come into contact with the soil.
3) The boxes should be emptied at a maximum time interval of two weeks. When emptying, care should be directed along the edges where the largest concentration of pupae will collect. Before reuse, salt, lime, or sodium borate should be applied along the floor-wall interface.

Corrals

A shaded corral with accumulated organic material holds moisture, attracts adult flies to the area, and is conductive to fly production. Development was observed where organic material was mixed with soil and subsequently undisturbed such as along fences and buildings.

Recommendations:

1) Repair any water carrying system that is leaking.
2) Selectively cut trees to allow sunlight and air into the area around feeding and watering sites.
3) Areas that accumulate organic material should be periodically cleaned.
4) A final thorough cleaning in the fall, after the horses are removed, will reduce overwintering fly populations.

Food Waste

The relative absence of garbage disposals on the island has resulted in food material being stored for some period of time before it is picked up and disposed of at the landfill. Food that falls out of bags and remains along the ground becomes developmental sites for flies.

Recommendations:

1) All food waste should be stored in clean fly-proof containers.
2) The area around holding areas should be cleaned weekly.
3) A food waste holding site should be chosen such that proper ventilation will keep the area dry.

Fly Pupae

The immature fly management techniques will also reduce the number of fly pupae at a developmental site. However, the high mobility of the late instar stage of the immature fly will allow some pupae to escape the best sanitation efforts. Parasitic wasps, released at the developmental sites, can increase mortality of this stage in the life cycle of the fly.

Splangia endius, a pteromalid wasp, was determined to be an effective pupal parasite on Mackinac Island. When these are purchased from a commercial supplier, a contract should be drawn guaranteeing both the species and the number of parasites shipped.

These organisms should be released at the rate of 1,000 wasps per horse. Effective parasitation was achieved when releases were made early in September, June, and July. The parasites should be released in small screened cages at areas where immature flies are found. The cages prevent the immature parasitoids from being eaten by other organisms.

Adult Flies

The large number of fly developmental areas on the island lowers the probability that satisfactory fly control will be achieved at all times by source reduction and/or parasitoids alone. At those times, adult fly populations can be reduced using repellants, traps, and hand operated sprayers at fly aggregation sites.

Horses

The most significant pest of horses on Mackinac Island was the adult stable fly. It was also noted that not all horses are bitten by the same number of flies. For those animals that are bothered, topically applied repellants should be used. The following products were tested during the study and are listed in order of decreasing effectiveness: Super Shield™, Horse Spray™, and Wipe™. These products are available or can be ordered through any tack shop.

For horses in corrals, alsynite™ panels can be strung along fences and coated with a residual formulation of an insecticide registered for fly control. Currently useable materials are listed in Table 2.

Manure Wagons

Manure wagons act as an attraction site for adult stable flies and houseflies. When fly densities exceed an economic threshold, these areas can be treated with a hand operated sprayer. The most effective application technique was to spray all manure wagons on the island at the same time. Greatest concentrations of flies at these sites occurred between 1300 and 1700 h.

Care should be taken that only fly resting areas on the wagons are treated. Improperly applied material (i.e., poor spraying technique or excessive drift) will kill beneficial organisms in adjacent areas. In addition, overspraying (either in frequency of application or concentration of material or both) will induce further development of resistance to legally useable material.

Buildings

Prevention is always more desirable than control. Doors and windows should be tight fitting and in good repair. Mechanical or air screens should be properly installed and maintained.

Cone traps (Beneficial Biosystems, Emeryville, CA 94608) provided a highly efficient, low maintenance method of reducing adult fly populations at specific areas. These traps can be used in both food handling and non-food handling situations. The traps should be placed outside of buildings and away from doorways so that flies are attracted away from an entranceway. Directions for mixing the bait are provided with the traps.

Table B.2 - Insecticides applied on fly resting areas.

Chemical	Formulation you buy	Rate	Remarks
Ravap (Rabon and Vapona)	EC (23% and 5.7%)	1 gal / 25 gal of water	Apply as a course spray to barn walls, ceilings, and other fly resting areas. Use 1 gal of diluted spray per 1000 ft^2 of surface. See label.
Permectrin (Permethrin)	10% EC	2 oz / 15 gal (low rate) or 32 oz / 25 gal (high rate)	Use 1/2 gallon of low rate solution per 450 - 1000 ft^2 of surface at two week intervals or 1/2 gallon of high rate solution per 1000 ft^2 at 4 week intervals (see label). Do not repeat more than 15 times per season.
Ciovap (Crotoxyphox and Vapona)	10% + 2.3% EC (Crotoxyphos and Vapona)	1 pt to 1 1/2 - 3 gal of water	Thouroughly wet ceilings, walls, and other fly resting areas. Spray twice per month.
Raybon	50% WP	Use 1/2 lbs in 1 1/2 - 3 gal of water	See label for mixing 1 or 2% solutions. Use 1 gal of diluted spray / 500 ft^2 of surface.
Batex	93% LC	1/2 pt / 5 gal water	See label for specific mixing instructions.
Diazinon	50% P	2 lbs / 25 gal water	Remove animals for at least 4 hours.

Table B.2 - Cont.

Chemical	Formulation you buy	Rate	Remarks
Dylox (trichlorfon)	80 SP	5 lbs / 40 gal water	Remove animals before spraying
Methoxychlor	2 lbs / gal EC (24.8%)	1 pt / 2 1/2 gal water	Use as a space and contact spray to walls, ceilings, and other resting areas. Animals should not be present when spraying
Vapona (DDVP, Dichlorvos)	23.4% EC	1 pt / 6 gal of water	Use 0.5% surface spray mist. See label directions.
	20% slow release strip	1 strip / 1000 ft^3	Use only in rooms or buildings where doors and windows are kept closed. Flies are controlled by the fumes released from the strip.
Malathion	57% EC	5 Tbl / gal of water or 1 qt / 12 gal of water	Use 1 gal of spray per 1000 ft^2 on unpainted surfaces where flies alight or congregate.
Pyrethrins + synergist	0.1 to 0.2% aerosol	as directed	An oil spray that contains a synergist such as piperonyl butoxide or MKG - 264. Apply as a space spray for quick knockdown of flies in stalls or barns

Table B.3 - Insecticides applied on horses for fly control.

Chemical	Formulation	Rate	Remarks
Rabon Horse Spray-n-wipe	EC	See label	Both spray-n-wipe and fly free gel act as insecticides and repellents for nuisance and blood sucking flies. Use as needed according to labeled directions
or Fly Free Gel	Gel	See label	
Ciovap (Dichlo-vos & Crotosyphos)	10% and 2.3% EC mixture	1 oz / animal	Do not wet animals to skin; do not apply to horses under 6 months of age. Not more than 1 oz / spray / animal.
Vapona	23.3% EC	1 pt / 3 gal	Apply 1 - 2 oz per animal as a fine mist spray. Do not exceed 2 oz / animal.
Pyrethrins and Piperonyl butoxide	0.1% + 1% mist solution	1 - 1 1/2 oz / animal	See label for instructions.
Corral (Cousmaphos)	1% dust; 25% WP	Dust evenly; 2 Tbl / gal	Do not use more than 2 oz per animal.

Table B.4 - Insecticides applied on immature fly developmental areas: Baits*.

Chemical	Formulation	Remarks
Bomyl	1% Bait	1/4 lb / 1000 ft^2 - use outside only
Dipterex	1% Bait	Use 4 oz (2/3 cup) prepared bait per 1000 ft^2 of area, or pour 4 oz (2/3 cup) prepared bait in 1 gal water, add 2 cups sugar or corn syrup.
Ravap	EC	Use 1% solution, apply 1 gal / 100 ft^2
Malathion	57% EC	Bait spray: mix 5 Tbl of 57% EC Malathion, 7 Tbl sugar or molasses or corn oil + 1 gal of water. Apply bait spray over the surface of manure or straw bedding.
Diazinon	50% WP	Use 1/2 lb plus 1 lb of sugar in 2 1/2 gal water. See label.
Vapona	2 lbs / gal EC	1 - 2 qt of 0.5% solution per 100 ft^2. see label for mixing instructions.

*Apply dry or wet baits to window sills, doors, and litter at daily intervals for 3 to 4 days, then as needed. Avoid the contamination of water, feed, and equipment with the bait material. Do not use any of the bait materials in milk rooms or dwellings.

APPENDIX I

Sampling Techniques

STABLE FLY ADULTS

Adult stable flies are best sampled with a William's trap (Williams, 1973). Essentially, Alsynite™ panels are arranged in an X formation and mounted upon wooden stakes. Each panel is coated with a thin layer of Tack Trap™ and allowed to remain exposed for 24 hours. Upon recovery, the total number of adult stable flies can be counted. The resulting information can be compared with historical data to determine the effectiveness of current management efforts. It is important to note that once sites have been chosen, all subsequent sampling should be done at the same site.

HOUSEFLY ADULTS

Pull down sticky traps (Aeroxon™ Fly Catchers), exposed for 24 hours will provide a relative index of housefly activity at selected areas. As with the panel sampling for stable flies, the same sampling location should be used throughout time in order to make comparisons valid.

HOUSEFLY AND STABLE FLY IMMATURES

Both the housefly and stable fly tend to develop in similar locations on Mackinac Island. Adult females will lay their eggs in a variety of decaying organic material. The following situations should be examined for the presence of eggs, larvae, and pupae. In barns, examine around the base of stalls where feed, feces, and urine accumulate. Outside of the barns, examine where organic material builds up such as: horse washing areas, hay unloading areas, along fences and edges of barns, around manure wagons or boxes, etc. The base of garbage holding areas where seepage or fallen food might accumulate should also be examined.

APPENDIX II

Housefly Biology

Houseflies (Musca domestica) are a potential menace to human health because of their attraction to human food and drink after feeding and breeding in garbage, excrement, and dead plant and animal material. Because houseflies have sponging mouthparts, they can only take in liquid food. The fly must first vomit on material in order to liquefy the solid material in order to suck the food back up. Often while feeding, flies will deposit droplets of excrement. The large numbers of hairs present on the legs and tarsi (feet) of the fly also give them the potential for mechanical transmission of disease pathogens.

The adult female lays 3 to 6 batches of eggs every 3 to 4 days with 100 to 150 eggs per batch. These eggs are usually laid on material suitable for larval development and hatch within 8 - 12 hours. Larval development lasts for approximately 5 days followed by a resting or pupal stage for 4 - 5 days before they emerge as adults. Total development period from egg to adult takes approximately 10 days at 80^oF. With colder temperatures, the developmental time will take longer, up to 44 days at 60^oF. Once the adult housefly has emerged, it may live from 14 to 28 days during a hot, dry summer and up to 60 days during cool, moist weather. Adults can fly from 0.5 to 2 miles, but where flies are abundant, they usually can be found developing in the immediate vicinity.

APPENDIX III

Stable Fly Biology

Both male and female stable flies (Stomoxys calcitrans) will preferentially feed on horses and cattle, but will readily feed on humans or any other warm blooded animal. Their biting habit makes them an annoyance to everything they feed on. This is especially a concern on the island where many public services use horses and horse drawn wagons. The blood feeding habit generates two medical concerns. First, disease pathogens may be readily transmitted host to host. Secondly, the bite leaves an open wound that is susceptible to secondary infection.

The stable fly breeds in fresh manure that has been mixed with straw or hay and in decaying vegetative material. One of its preferred developmental sites is in the bottom or underneath feeding mangers or troughs both indoors and outside. The female usually lays a small number (20 - 50) of eggs in loose material and may lay 20 batches of eggs during her lifetime. The eggs generally hatch in 23 hours to 5 days. The larvae feed and grow for approximately 20 days (at 75°F) and then pupate (resting stage) for 16 days. Total time from the egg to adult stage will vary from 30 - 40 days depending on temperature. Both the males and females start feeding within 24 hours after emerging from the pupae. Five to 10 days later, they mate and the female begins to lay eggs.

APPENDIX IV

Sources for *Splangia endius*

Beneficial Biosystems
1603 63rd Street, Dept. 0
Emeryville, CA 94608

Spalding Laboratories
Route 2
Box 737 Printz Road
Arroya Grande, CA 93420

Rincon-Vitova Insectaries, Inc.
P.O. Box 95
Dept. TMEN
Oakview, CA 93022

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