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Exploring the Feasibility of White-tailed Deer Fertility Control Programs

Technical Report NPS/NER/NRTR—2007/087

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**EXPLORING THE FEASIBILITY OF WHITE-TAILED DEER
FERTILITY CONTROL PROGRAMS**

by

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EXECUTIVE SUMMARY

Contraceptives that work through the immune system are increasingly viewed as an acceptable alternative to lethal methods of managing overabundant white-tailed deer (*Odocoileus virginianus*). However, a recent workshop demonstrated that fertility control is still in the experimental stages. No guidelines or tools exist to aid managers in making decisions as to when, or even if, to use fertility control in deer management plans. In order to examine aspects of deer biology and site-specific factors which impact the feasibility of fertility control programs, we conducted fieldwork at Morristown National Historical Park (MNHP), Morristown, NJ. We characterized deer density and herd composition on a seasonal basis from 1996-98 using distance sampling methods. In addition, we compared deer encounter rates between land cover-types and between moving vehicles and established bait sites. Finally, we marked sixteen deer to assess heterogeneity in individual encounter rates. We found that feasibility, using current technology, is affected by population density, herd composition, cover-type utilization, flight response and access to deer. The integration of these factors determines the encounter rate with deer and thereby the effort required to achieve population objectives. A simulation model of a fertility control program was created in order to describe the feasibility of using fertility control in a variety of circumstances, and to determine the resources needed in each scenario. The model, constructed using STELLA[®] Research and driven by our field data, was also used to explore the implications of using fertility control as a population reduction tool rather than a population maintenance tool.

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PREFACE

The white-tailed deer (*Odocoileus virginianus*) has attracted much attention in the eastern United States largely due to its conspicuous behavior, its tolerance of humans, and when at high density, its profound effect on the environment (Underwood 1997). In most areas of the northeast United States, deer populations made region-wide rebounds in the period from 1950 to 1970 due to increasing protection via enforcing game laws, changing land-use away from extensive agriculture, and increasing suburbanization (Cypher and Cypher 1988, Underwood and Porter 1997, Waller and Alverson 1997). By the mid- to late-1980s, deer numbers had increased dramatically, and these burgeoning regional populations have brought many serious resource management issues to the forefront (Messmer et al. 1997).

Traditionally, deer population control has been exerted via hunter harvest. While often effective, hunting is not always possible because it is either illegal, inappropriate for safety reasons, or socially unacceptable (Kirkpatrick and Turner 1985, Turner et al. 1996, Muller et al. 1997). The use of contraception for controlling fertility has emerged as a potential alternative for management of overabundant populations (Kirkpatrick et al. 1996). Several types of immunocontraceptives and methods of delivery have been researched; however, the remote delivery through darts of the porcine zona pellucida (PZP) antigen has emerged as one of the most promising for white-tailed deer. This new contraceptive has garnered attention because it is a protein which acts through the immune system to inhibit fertility, thus exhibiting benign food chain effects (Turner et al. 1992).

There have been several experiments testing the use of immunocontraception on both penned and free-ranging populations of white-tailed deer (Turner et al. 1992, Turner et al. 1996,

McShea et al. 1997). Projects on penned deer have shown that PZP does decrease the fertility of individual females (Turner et al. 1996, McShea et al. 1997), but no clear example of population control has been documented. Implementation on free-ranging populations has proven more complicated; experiments have demonstrated problems involving individual identification, female movements, and access to deer. With current technology, individuals must be treated each year, even twice in the first year; thus, implementation can become very time consuming and expensive. Although researchers continue to develop more effective vaccines, there is increasing pressure to implement immunocontraception on deer populations now.

Due to limited experience and potentially high expense, the feasibility of deer population management using contraception must be assessed prior to implementation. In this study, we explored methods and factors that most affect the feasibility of fertility control programs and combined them in a framework that can be applied more broadly than at a single location. Chapter One addresses the use of bait sites in applying contraception on a population level. Chapter Two integrates various factors and methods involved in fertility control through several different simulation models. Chapter Three uses these models to address the feasibility of fertility control programs.

STUDY AREA DESCRIPTION

This study was conducted at Morristown National Historical Park (MNHP), located in north-central New Jersey. MNHP is part of a relatively large area of woodland and openland mosaic (approximately 1,300 ha) situated in a heavily populated, suburban setting. The principal holding of the National Park Service (NPS), the Jockey Hollow area (JH; 545 ha), is located 15 km south of Morristown (40° 46' N 74° 32' W). It is a relatively contiguous woodland with a few

interspersed open areas maintained for historical interpretation. North and east of JH is a county park (467 ha) and a parcel owned by the Girl Scouts of America (213 ha). JH is bound on the east and south by mostly residential and commercial properties.

JH exhibits a modest ridge-and-valley topography with ridge lines running roughly southwest to northeast. The area is drained by 2 branches of Primrose Brook. Soils are derived from granitic gneiss and range from well-drained loams in the uplands to poorly drained and stony soils on the slopes and in valley bottoms (Dibeler and Ehrenfeld 1990). JH contains a diverse forest cover (Ehrenfeld 1982, 1977) including oak (*Quercus* spp.) and American beech (*Fagus grandifolia*) in mature stands, and tulip tree (*Liriodendron tulipifera*), ash (*Fraxinus* spp.), and black locust (*Robinia pseudoacacia*) in transitional stands. Two hundred years of postsettlement land use, secondary plant succession, and burgeoning white-tailed deer populations have contributed to the character and composition of current woodlands, although much of the oak-dominated forest apparently occupies sites retained throughout history as woodlots (Dibler and Ehrenfeld 1990).

The climate is characterized by short, cool summers and long, cold winters characteristic of the Highland Province (Dunlop 1967). Snow, when it occurs, is usually associated with coastal storms rather than synoptic air masses. Average annual rainfall is approximately 118 cm and the frost-free period is about 170 days, beginning approximately 95-100 days after 1 January (Schwartz and Marotz 1986).

The NPS maintains the woodlands of MNHP as a culturally significant natural resource reminiscent of the 18th century hardwood forest as it appeared to the Continental Army during the winter encampment of 1779-80. The resident deer population has been implicated in

accelerating potentially undesirable changes in the woodlands of MNHP over the last 2 decades (Christie and Sayre 1989). Deer populations in many eastern parks have been the focus of debate for 2 decades, as much for their nuisance potential as for their ecological significance (Cypher and Cypher 1988). The history of deer numbers in JH prior to 1980 is speculative, although deer likely have always occupied the area, their numbers waxing and waning with the activities of humans at the site.

Of significance to this project, a brief study of the deer population residing throughout JH was conducted in the mid-1980's (Christie and Sayre 1989). The park and surrounding open areas were found to act as a *de facto* sanctuary for the deer amidst residential and commercial areas that are continuing to develop. In addition, deer survival was closely linked with acorn production and the amount of open habitat for grazing (Christie and Sayre 1989) — 2 very important ecological factors across much of deer range (McCullough 1985, Harlow et al. 1975, McCaffery et al. 1974).

CHAPTER ONE

ASSESSING BAIT USE IN REMOTE DELIVERY OF CONTRACEPTIVES

INTRODUCTION

The use and success of fertility control for managing deer populations depends on 3 factors. The first is the development of a contraceptive that works on the species in question. The second is the ability to reliably assess population size and herd composition prior to implementation, as well as throughout treatment. The third is the ability to deliver the contraceptive in a safe and effective way. Presently, the largest obstacles to implementing remotely delivered contraception in field settings is the development and evaluation of methods for achieving factors 2 and 3 (Underwood 1997).

The ability to gain access to the number of females necessary to deliver the contraceptive safely and effectively is critical to the success of a fertility control program, but gaining access to deer can be challenging in parks and suburban areas. For example, relatively few opportunities exist to effectively deliver a contraceptive agent via current remote delivery technology in wooded areas due to interference from vegetation (Underwood 1997). However, dispersed among wooded areas of many parks are open fields and lawns maintained through periodic mowing or burning. Fields are used heavily by deer throughout the Northeast as feeding areas (Cypher and Cypher 1988, McCullough 1985) and could serve as sites for treating large numbers of deer.

Baiting is an effective means of concentrating many animals to a small, predictable area such as maintained fields and has been shown to increase hunter success (Darrow 1993). Baiting

also allows for closer encounters with deer, which is critical for safe remote delivery of contraceptives. Although the use of bait has been investigated in relation to hunting, there have been no studies concerning the use of bait to increase the efficacy of remote delivery in a contraceptive program.

We investigated the logistics of remotely delivering contraceptives over bait sites in several field locations in MNHP. To take advantage of deer behavior and habitat affinities, the use of bait sites was investigated during the hours prior to sunset. White-tailed deer are crepuscular animals (Cypher and Cypher 1988), and in Mississippi, one hour before sunset to one half hour after sunset accounted for the greatest percentage of bait site usage by all sex and age classes of deer when fed *ad libitum* (Darrow 1993). This pattern of field use was supported by previous observations of deer in MNHP (Christie and Sayre 1989, Underwood 1997); a greater number of deer were seen in the fields in the afternoon than in the morning surveys. Also, the use of random searches in the delivery of contraceptives was explored in the hours directly after sunrise and compared to the use of bait sites.

Any increase in the efficiency of remotely delivered fertility control is beneficial due to the expensive and time-consuming nature of the program. Increased encounter rates from the use of bait, alone or in conjunction with random searches, saves time and money as well as unnecessary stress on the deer from being pursued for an extended period of time. Use of minimal bait to attract deer to a central location also saves time and money. In addition, using the least amount of bait reduces the effect of human intervention on the natural feeding patterns of deer. Decreasing the time and money necessary for a successful program increases the feasibility of implementing fertility control for deer population management.

OBJECTIVES

1. Describe the minimum amount and frequency of baiting required to predictably attract the maximum number of deer and thereby increase encounter rates, while simultaneously minimizing the effect on deer feeding patterns.
2. Describe the patterns of deer use of bait sites, including arrival and departure times, length of stay, and differential use by sex and age classes.
3. Estimate the encounter rate of deer at bait sites and compare that rate to the frequency of random encounters.
4. Estimate heterogeneity in encounter rates and visits to multiple bait sites by individual females.

METHODS

Individual female identification

Sixteen breeding-age females were anesthetized remotely and tagged in the spring of 1998. Four bait sites were established throughout MNHP to target different groups of females (Fig. 1). Adult female deer were remotely injected during morning or evening hours, using 3cc or 4cc darts of anesthetic chemicals (Capture-All 5: a combination of Ketamine hydrochloride and Xylazine hydrochloride, 5 parts to 1, respectively). Researchers approached sedated deer after approximately 10 minutes or searched a predefined grid to look for an animal that may have wandered out of sight. All anesthetized animals were blindfolded, placed in left-lateral or sternal

recumbency, and restrained if necessary. All females received a large plastic tag in each ear to identify where it was captured and its number (e.g., W2 = Wick Orchard, No. 2). A xylazine antagonist (Tolazoline hydrochlorine) was administered a minimum of 50 minutes after remote anaesthetization to allow for substantive metabolization of the Ketamine. During the entire procedure, times of injection, onset, induction, and recovery were recorded when possible. Each deer was monitored closely for signs of capture-induced stress according to a protocol approved by the Institutional Animal Care and Use Committee of the College of Environmental Science and Forestry.

Establishment and monitoring of bait sites

Three bait sites were established in fields in JH based on their spatial relation to each other in the park, relative use by deer, and their proximity to features such as roads and houses. A fourth site was also established as a control where no bait was distributed. All sites were the same as those used previously in the tagging operation and named in accordance with MNHP names - Maryland Brigade, Grand Parade, Mt. Kemble, and Wick Orchard (Fig. 1). The bait was a specialty deer mix consisting of cracked corn, oats, barley, cane molasses, calcium carbonate, and salt (9.25% crude protein, 2.75% crude fat, 8.0% crude fiber, 0.5% calcium, 0.3% phosphorous, and 0.1% salt). Bait sites were established on 1 August and replenished through mid-October, 1998. Bait sites were established near field edges and bait was strewn in a long (10 m) line parallel to the field edge. Initially, bait was placed on a piece of burlap to facilitate

weighing bait remaining after a monitoring session. After a brief period of adjustment, deer quickly became accustomed to consuming bait directly off the burlap.

To attract deer, each bait site was primed with 18.7 kg of bait on the first day and followed with 9.3 kg of bait for 4 days (Table 1). The next week (Monday - Friday), each site was baited with 9.3 kg to further habituate the deer. Bait was then apportioned the following week to 2.3 kg at Maryland Brigade, 4.7 kg at Grand Parade, and 7.0 kg at Mt. Kemble per day. The apportioning was done to estimate the least amount of bait needed to consistently attract deer. Then, after a 10 day hiatus, each site was reactivated and baited at different frequencies with 4.7 kg of bait to determine how the frequency of baiting affected the encounter rate of deer. Maryland Brigade was baited every fourth day, Grand Parade every third day, and Mt. Kemble every other day for 13 consecutive days. For the final 4 weeks (25 days) of the experiment, each site was baited every third day with 4.7 kg.

Each bait site and the control (Wick Orchard) were monitored on a predetermined schedule for 2 hours prior to sunset to observe deer at one of their most active times of day. The number, sex, and age group (fawn or adult) of all deer were tallied during each monitoring session. For all sessions, encounter rates of deer at bait sites were computed as number of deer per hour. All average encounter rates and percentages are reported with associated standard errors in parentheses. Overall encounter rates are grand means calculated from the averages of each of the 3 baited sites. During August sampling sessions, the amount of bait consumed was measured as the difference between the amount distributed initially and the amount remaining after the monitoring session. Also during August, arrival and departure times of individual deer on the bait (i.e., actually directly at the bait feeding) were recorded, and total duration of feeding

at the bait site was calculated as the difference between them. For the months of September and October, the arrival and departure times of deer in to and out of the field where the bait was located were recorded, and total time in the field was calculated as the difference between the arrival and departure times. The length of time deer remained on the bait or in the field was summarized over 5-minute intervals.

Data from random searches were used to generate the number of deer observed per kilometer driven in JH and was calculated for each morning sampling session. Bait site encounter rates were compared directly to encounter rates derived from these random searches for deer from a moving vehicle and standardized to an hour's duration. Also, the distance needed to obtain an encounter rate equal to that at the bait sites was calculated.

Tagged females observed during all sampling sessions were noted. Mean number of sightings of marked deer per site are reported with their associated standard errors. Frequency distributions of encounter events for tagged deer at bait sites and during random searches are reported to explore encounter heterogeneity.

RESULTS

Deer response to amount and frequency of baiting

After priming, the amount of bait distributed at a bait site did not seem to have a large effect on the encounter rate (Fig. 2). The frequency at which the sites were baited did not have a noticeable effect on the encounter rate, although there was a slight decrease in encounter rate at Maryland Brigade as the interval between replenishment increased (Fig. 3).

Amount of bait consumed

In August, the mean amount of bait eaten per deer over all 3 bait sites was 0.54 kg (0.1), and the average amount of bait consumed per deer per hour was 0.35 kg (0.1). In general, the amount of bait consumed per deer decreased as the amount of bait distributed decreased; with 9.3 kg of bait, deer consumed an average of 0.58 kg (0.22) per individual, at 4.7 kg an average of 0.50 kg (0.07) per deer per day was consumed and at 2.3 kg each deer consumed an average of 0.29 kg (0.05).

Deer use of bait sites

On average, the greatest number of deer spent 0 - 5 minutes on the bait and in the field, followed closely by those spending 5 - 10 minutes. The distribution of both the time on bait and time in the field is characterized by tails toward the longer times (Fig. 4).

The distribution of deer arriving on the bait with respect to sunset was similar among all deer and for females. The greatest number of animals arrived in the 10-minute interval surrounding sunset, with 2 other peaks of arrival at 30 - 40 minutes before and after sunset (Fig. 5).

Encounter rates: bait and random encounters

The average number of deer encountered per hour in fields was 6.3 (0.4) and on bait was 3.5 (0.3) (Fig. 6a). The percentage of deer in fields that came to the bait was 56 (0.04). The encounter rate of females was 3.5 does per hour (0.2) in fields and 2.0 does per hour (0.2) on bait (Fig. 6b). Fifty-six percent (0.05) of all females in fields ultimately came to feed on bait. Of deer that came into fields, 57% (0.02) were females. Similarly, of deer that came to bait, 58%

(0.03) were female (Fig. 6c). Overall, encounters with deer were relatively consistent over time, with a slight increasing trend occurring during October (Fig. 6).

The average encounter rate for females within the 25-meter delivery range during morning random searches was 7.9 (1.1) does per hour. Of those females, an average of 1.7 (0.4) does per hour was in fields, providing a clear downrange trajectory for a dart. At bait sites, the encounter rate of does in the field was 3.5 (0.2) does per hour and of those, 1.9 (0.2) does per hour came in to feed at the bait.

Heterogeneity of bait encounter rates

During bait site observation sessions, tagged deer were observed at only one site, but a few did return to that one site frequently. The mean frequency of sighting for tagged deer at one bait site during all observation sessions was 23.6% (0.1). During the summer and autumn of 1998, an average of 2.7 (0.3) tagged females were observed during each morning random search. A small number of tagged deer, 3 and 2 respectively, accounted for a majority of the sightings at bait sites or on random searches, while the remaining tagged deer were seen only a few times or not at all (Fig. 7).

DISCUSSION

Christie and Sayre (1989) found that deer used fields extensively during all seasons of the year in MNHP. Therefore, it is not surprising that, after priming, the amount and frequency of baiting did not severely affect the encounter rate with deer at bait sites. There was an insufficient amount of activity at the control site to warrant analysis. Sampling was constrained by time, therefore there was one replicate for each trial, amount and frequency. One replicate precludes

the use of any comparative statistics, thus simple descriptive statistics were used (mean and standard error) to enable generalization of results for MNHP.

Deer were coming into the fields already, which is demonstrated further when deer returned to the bait site in large numbers after a 10-day break in baiting. Bait merely provided a means of gathering the deer in a predictable location within range for remote delivery of the contraceptive vaccine. Initially, there was a gradual discovery time, when deer become aware of the bait's specific location. Darrow (1993) found there was a discovery time when bait was offered *ad libitum* as well. Priming a site for a week with a large amount of bait is needed to allow time for discovery of the bait locations by the deer.

Since the amount of bait distributed at a site is not critical to increasing the encounter rate, the least amount required should be distributed. In this experiment, 4.7 kg was used and at this rate, on average each deer consumed 0.5 kg per session. Even when larger amounts of bait (9.3 kg) were distributed, deer consumed on average 0.58 kg per deer per session. In Michigan, when fed *ad libitum*, an average of 95.8 kg per deer was consumed for the fall (Ozoga and Verme 1982). This amount equaled 1.26 kg per deer per day of a balanced pelleted ration. Though requirements will differ according to location and type of feed, we found that only 17-26% of this full daily requirement estimate is necessary to attract deer. This small amount, as well as the fact that it is only offered during treatment sessions (not daily or *ad libitum*), is consistent with the argument that we were baiting deer and not feeding them. Deer cannot subsist on bait alone, and therefore we are having a minimal impact on deer nutritional requirements.

Deer move into preferred feeding areas around sunset (Cypher and Cypher 1988) and at MNHP, these preferred feeding areas are fields. Greater numbers of deer were seen in fields

during evening surveys than morning surveys. Also, during evening sampling sessions, the highest numbers of deer were observed on bait at sunset. Even when fed *ad libitum*, deer came to the feeders in the greatest numbers around sunset (Ozoga and Verme 1982, Darrow 1993). Thus, sunset is the optimal time of day for attracting deer into close range with bait.

The encounter rate of females during random searches is seemingly very high. However, a large percentage of deer encountered when driving are either too far away or obscured by vegetation, and the encounter rate decreases greatly when these factors are taken into account. The morning encounter rate of females which are within 25m and also in fields during random searches compares favorably to the number of females encountered per hour feeding at bait sites in the evening. However, we encountered females loitering near the bait, within 25m, which also can be considered available for treatment. Including these females, we found that it would take twice as long to encounter the same number of females while driving as it would at a bait site field. Also, deer on a survey route have a high probability of fleeing when approached by vehicles, especially those within 25m. For a place like MNHP, treating deer over bait sites may offer a greater number of treatment opportunities than would random searches.

We determined that a few deer returned often, while many deer returned infrequently to the bait sites. Deer whose home ranges are associated with a bait site are more likely to be seen there (Sage et al. 1983, Darrow 1993). Deer offered bait outside of the home range do not shift their ranges; they may infrequently visit distant bait sites, but do not use them on a continual basis after discovery (Darrow 1993). Therefore, it would be beneficial to establish many bait sites to reach a greater number of females. More bait sites may also help in gaining access to subordinate females because dominant females in a specific area probably will be the ones most

frequently seen at bait sites, while subordinate deer will wait their turn to feed (Ozoga and Verme 1982).

The use of contraception to manage a white-tailed deer population is very expensive and time consuming, especially in comparison to other management options. Though the time and expense involved may eventually decrease through better technology, to minimize the cost now, current methods must be refined as much as possible. Analyzing alternative scenarios for varying techniques and determining the minimal materials needed for those techniques helps in decreasing the costs. Decreased costs increase economic feasibility and the minimal effect of delivery methods on the deer increases public acceptance of fertility control programs.

MANAGEMENT IMPLICATIONS

Bait sites can be used successfully to gain access to females for contraceptive delivery by attracting the deer to a predetermined location. After a short period of priming a site, deer will be attracted to the bait and stay for a reasonable length of time with a small amount of bait. Replenishment of the bait sites is required only when they are being used for treatment purposes; therefore, large amounts of bait are not necessary. Infrequent baiting and low amounts both save money and time on distributing bait unnecessarily.

Ozoga and Verme (1982) found that the longest visits to *ad libitum* feeders occurred in autumn, where they normally fed less than 15 minutes per visit. Most deer in MNHP spent up to 10 minutes feeding at the bait, although often deer did return after walking away for a few minutes. Opportunities for a clear, accurate shot are presented infrequently, and since deer only stay at the bait for 5 - 10 minutes, the decision to treat a doe with the contraceptive vaccine must be made quickly.

Bait site use is more efficient than random searches. However, using the 2 methods together, specifically with random searches directly after sunrise and bait sites before sunset will increase efficiency. Random searches help to gain access to more females in the population, perhaps in areas where there are no fields in which to establish bait sites, or where females come to bait sites infrequently.

Frequently encountered females at bait will be treated quickly, while the time necessary to treat those females which are observed infrequently will be much greater. Once frequently encountered females are treated, the efficiency of that particular site will decrease and it will be beneficial to move to another location to attract different females.

CHAPTER TWO

MODELING WHITE-TAILED DEER FERTILITY CONTROL PROGRAMS

INTRODUCTION

A recent workshop on the status and future of wildlife fertility control concluded that fertility control technology is still in experimental stages. The technology is available for use only in laboratory settings, pen studies, and limited field situations with small numbers of animals (Miller et al. 1998). For white-tailed deer, there have been several penned studies (Turner et al. 1992, Turner et al. 1996, McShea et al. 1997), and a few unpublished experiments on free-ranging populations which have used immunological contraception to render females infertile. These studies have been of short duration (2-4 years) and focused mostly on development of effective agents of contraception. Presently, the wildlife profession has a limited knowledge or experience base for developing effective management strategies for fertility control (Garrott 1995). Managers need to know details such as how many deer must be treated, how much time treatment will take, and how much the program ultimately will cost.

Simulation models can aid in understanding complex processes such as those inherent in fertility control programs. Models of fertility control, to date, have focused on population dynamics and the effect of contraception, rather than the process of implementation. Garrott (1991), Garrott and Siniff (1992), and Garrott et al. (1992) developed fairly simple population models to address questions of feasibility with respect to feral horses. Swihart and DeNicola (1995) extended this model for use with white-tailed deer, using a Leslie matrix to explore the effects of various contraceptive regimes on population growth, size, and sex ratio. Seagle and

Close (1996) simulated the temporal effects of contraception on deer population control and the interaction between contraception and uncertain immigration rates. Still needed is a model derived from empirical data, which integrates all feasibility factors to create a general framework which can be used easily by managers to determine the biological, logistical, and economic costs and benefits of a fertility control program.

Hall and Day (1977) put forth 3 uses of models to scientists: (1) understanding, (2) assessing, and (3) optimizing, all of which are important uses of models in fertility control contexts. Managers with no experience in conducting such a program can use the models to better understand the details involved in a contraception program prior to implementation. They can then use the models to assess what is needed in terms of resources and time to have a successful and worthwhile fertility control program. Finally, models can be used to find the best use of resources and time, creating a more efficient fertility control program.

To address these uses of models, we developed several dynamic simulation models which each examine fertility control programs on different time scales. Critical to the usefulness of models is style of presentation. The modeling process needs to be easy to use and accessible to all managers. Toward that end, we used an icon-based programming language, STELLA Research 5.1.1, specifically designed for dynamic systems modeling (Hannon and Ruth 1997). These models incorporate important biological and logistical processes, as well as the economics, associated with the delivery of fertility control agents at bait sites and by random searches from a moving vehicle.

OBJECTIVES

1. Develop simulation models that enable the exploration of the biological feasibility of fertility control programs.
2. Develop simulation models to aid in understanding the logistics involved in a fertility control program delivered over bait and during random searches.
3. Develop simulation models which estimate the economic requirements of a fertility control program.

MODELING APPROACH

Garrott (1995) lists 3 factors which would limit the level of contraceptive treatment attainable in the field: (1) the proportion of animals that can be detected, (2) the proportion of animals detected that can be successfully treated, and (3) the efficacy of the contraceptive agent. Thus, the feasibility of fertility control does not simply rest on how many females need to be treated to stop population growth, but rests on several other factors which also affect the number of females that can be treated.

The basic feasibility factors that must be addressed in a fertility control program include (1) the density of females, which is determined by population size, area, and percentage of females in the population; and (2) the behavior of the deer, including cover-type use and flight response. Both of these factors together affect the encounter rate, or the number of females observed within a safe and effective distance for treatment per unit time. Of those deer encountered, the number of those successfully treated is determined, in part, by the reliability of the equipment used and the efficacy of the vaccine.

To integrate these feasibility factors, 6 different models were created, with those of higher resolution laying the foundation for those of lower resolution. The first model describes the

delivery of the contraceptive over a bait site on a time scale of minutes. The second model extends the first, depicting the implementation of a contraceptive program over the time span of a season. This information then can be used in the population model, which describes what happens to a population through years of a fixed-rate of fertility control. Another model modified the encounter rate of deer over bait with changing deer density and combines the season and population models to show how differing contraception rates affect the population dynamics, program logistics and economics year-by-year. The next set of models describes the delivery of a contraceptive via random encounters with deer from a moving vehicle. One of the models describes the treatment of females in one season and the result from this model feeds into the population model. The final model integrates both the seasonal and yearly aspects of delivery of a contraceptive through random encounters, again allowing density to modify the encounter rate.

Central to all the models we created is a queuing sub-model. A queuing system can be described by its input or arrival process, its queue discipline, or the order in which individuals in the queue are served, and its service mechanism (Jacobs and Dixon 1982). The arrival process in a contraceptive program is driven by the encounter rate of the individuals of the sex and age needing treatment. The queue discipline is the random movement of deer to within a threshold distance at which selection of the deer and the decision to deliver the contraceptive can be made. The service mechanism is the process to which each deer is subjected to be rendered infertile, or in this case, being successfully treated by remote injection. The queuing model is the best approach to modeling and accurately describing the darter-deer interaction and has been shown to accurately predict harvest data from one hunting area to another (Jacobs and Dixon 1982, Cohen

1984). The interaction between darters and deer is a crucial part of the logistics of treating females with a contraceptive; being able to accurately describe this process is critical to a realistic model.

ASSUMPTIONS

There are several assumptions inherent in all the models. We assume immigration and emigration are negligible. We also assume that all animals in the population are accessible for treatment. We further assume some form of identification is being used to distinguish treated females from untreated females; therefore, there is no capture and handling time involved. Because we assume all females will eventually respond to treatment (i.e., success or failure is treated as a probability), all unsuccessfully treated females are put back into the pool of available animals. Thus, 100% efficacy is possible, even though some females will go through the darting process several times before being rendered infertile.

METHODS AND MODEL DESCRIPTIONS

STELLA Research 5.1.1 was used to create all models. This is an icon-based modeling program which is a multi-level, hierarchical environment for constructing and interacting with models (High Performance Systems 1996). The environment consists of 2 major layers, the high-level mapping layer, or user interface, and the model construction layer. There are several different objects on the high-level mapping layer to facilitate an end-user's interaction with the model, including buttons, switches, knobs, and sliders. On the model construction layer, there are 4 basic building blocks used in making a model - stocks, flows, converters, and connectors. Small clouds represent unlimited sources or sinks for flows.

The models presented here use information gathered from field work conducted, with 16 tagged females, in Morristown National Historical Park. As described in detail in Chapter One, 3 bait sites were monitored from August - October, 1998, to investigate the encounter rates of deer at bait. Random searches were also conducted to measure roadside encounter rates. Empirical data from MNHP is used in equations for the encounter rate/density relationship and for the probability of seeing new deer at the bait. Also, the ranges of many factors used to test model sensitivity were guesstimated from experience in darting deer in MNHP.

Daily time scale

The bait - day model (Fig. 8) describes the process of treating females with a contraceptive at a bait site on a time scale of minutes. The process of deer entering the field and approaching the bait is described by a mean encounter rate, which is the average number of deer arriving at the bait, distributed into 10-minute intervals from 70 minutes before to 70 minutes after sunset. At each 10-minute interval, the mean encounter rate is modeled as a Poisson distributed variable. This Poisson distribution generates a series of random numbers that conform to the Poisson distribution and a new random number is sampled in each iteration of a model run. The Poisson distribution describes a process where the random variable (the number of deer) takes discrete values during continuous sampling over time (Hilborn and Mangel 1997).

Upon arrival at the bait site, the average number of males and fawns is calculated and those individuals are removed from the process. Some time elapses before a female deer is selected and moves through the queuing, or selection process, where only one deer can be treated at a time (queuing submodel). The treatment is deemed successful or unsuccessful, depending on the overall efficacy. This includes events in which the dart either misses the animal, does not fire

properly, or the vaccine is ineffective. Once a female is treated, a predetermined period of time elapses before deer will return to the bait and another female is available for treatment.

Seasonal time scale

Four models incorporate the seasonal component, which is made up of 4 different sectors. The first sector is the population description, which consists of the area of interest, the size of the resident deer population, and the percentage of females in the population. The size of the deer population and the percentage of females in the population are multiplied to determine the number of females in the population at time 0. The time step for the seasonal component is days, and each day the number of females available to be treated is calculated by subtracting the number already treated from the number of initial females in the population.

The next sector, factors affecting feasibility, uses the number of available females along with the encounter rate and behavior to determine how many females will be darted per day at an average site. In each day of the simulation, an encounter rate is derived using a Poisson random number generator in which the mean encounter rate is its parameter. A random number is generated and then adjusted by a factor that accounts for the number of females which regularly return to a specific bait site or are regularly observed on roadside surveys, and therefore may have already been treated. Resampling Stats (Resampling Stats 1995) was used to determine the probability of obtaining at least one new female in a group of deer, encountered at rate (x), given that an individual returns to the bait, or is observed during roadside surveys once every (y) days. The method has the following logic: generate (x) random numbers between one and (y); total those equal to one (i.e., repeat encounters); score the result and repeat 999 additional times. Add those scores greater than one and divide by 1000 to convert it to a proportion or probability. We

used the average encounter frequency of all tagged does over a 22 day period as an estimate of (y) and varied (x) from 1 - 10 deer encountered per hour or per km driven.

Behavior of the deer is also incorporated as a feasibility factor and measured on a scale from 0 to 1 (e.g. 0 = unapproachable, 1 = tame). In addition, the percentage of encounters which are within the 25 meter range of darting and the percentage of encounters in which there is a clear trajectory between darter and deer are taken into account in the random encounters season model. All of these factors are treated as independent probabilities and are multiplied in-line.

The darting logistics sector of the seasonal component starts with the number of females to be treated and advances them through the queuing process where only one is treated at a time. The outflow of this process is multiplied by the number of operational bait sites. The number of treatment attempts is then modified by dart and drug efficacy. The dart efficacy calculates how many of the shots taken actually inject the vaccine into the animal successfully and drug efficacy is the proportion of successfully injected animals that respond to the vaccine. From these, the number of female deer successfully treated per day is calculated.

The final sector in this model is the cost calculation, where the number of treatment attempts is multiplied by the cost of supplies per deer (e.g., contraceptive agent, darts, and needles) to provide the total supplies cost. Also factored in the supplies cost is a start-up amount to cover the price of equipment and miscellaneous items. The second cost factor is labor, which is calculated from multiplying the number of workers by the per person per day expense. These 2 cost factors are added together to create the total start-up and maintenance cost of the fertility control program.

This seasonal component comprises the entirety of the bait - season model and the random encounters - season model (Fig. 9 and 10). It is also used in the bait - and random encounters - year models (Fig. 11 and 12), where the seasonal aspect of fertility control is combined with the population model.

In the year models, there are 2 modifications in the feasibility factors sector. First, the daily calculation of females treated in the combined models is modified by a constraint variable, which limits the number of females that can be treated at one bait site in one session. Second, the encounter rate is determined by the density, rather than a constant function. This was done using a queuing relationship. To estimate the parameters for the random encounters model, we regressed the encounter rate derived from the program DISTANCE (Laake et al. 1993) on the estimated density for 3 successive autumn surveys. Both linear and exponential models were explored.

To construct a similar relationship for bait sites where the encounter rate for only one density was known, we retained the slope parameter from the random encounters model and solved for the intercept using the average per hour encounter rate documented during the study.

Yearly time scale

The population model (Fig. 13) incorporates the effects of contraception and is comprised of 4 sectors. The female, male, and fawn sectors describe the change in the 3 cohorts of deer over time as determined by birth and death rates. The contraception rate, which is constant through the years in the population model and determined by the number of females treated in the season models, is multiplied by the number of females and the birth rate to generate the number of fawns born each year. The survival of these fawns can be determined by a fixed-rate input by

the user or by using the density-dependence sector. The relationship describing the density-dependent survival of fawns was derived from Downing and Guynn's (1985) generalized sustained yield table which describes fawn survival at different densities. This table has been adapted for areas where poor habitat does not allow deer to reach their full potential (e.g., where overabundant deer have degraded the habitat). The number of fawns which survive to be recruited to the yearling class are divided evenly between males and females and added into the next year's population.

RESULTS AND MODEL EVALUATION

The probability of obtaining at least one new female in a group of deer is an upward, asymptotic function of encounter rate. The relationship was similar for both the bait- and random encounters - year models (Fig. 14a and 14b).

In both the year models, the encounter rate is determined by the relationship between encounter rate and density, and is best described as a positive exponential (Fig. 15a and 15b). The queuing relationship derived for the bait sites is

$$\text{deer per hour} = 0.3311^{(.04961 * \text{old density})} \quad (1)$$

A similar equation was derived for the random encounters queuing relationship

$$\text{deer per km driven} = 3.0^{(.04961 * \text{old density})} \quad (2)$$

In the population model, as well as the population dynamics sector of the year models, the density-dependent survival of fawns was estimated by regressing the percentage of fawns

surviving to age one predicted by Downing and Guynn (1985) on the density relative to carrying capacity (i.e., n/k). A quadratic term for n/k was used to approximate the relationship as follows:

$$\% \text{ survival} = 12.3 + n/k * (-.165 + .006 * n/k), \quad (3)$$

where n is the total number of deer in the population and k is the carrying capacity of the area.

Sensitivity analysis provides insight into the relative importance of components of a model in affecting the behavior of the system (Cooperrider and Behrend 1980). Factors tested on each model presented here are those over which a manager has control (e.g., the number of workers is explored, but not the behavior of the deer; Table 2). The values at which all factors are held constant during sensitivity analysis are outlined in Table 3. All values used are those generated from data collected at MNHP.

Bait - day model

The bait - day model simulates a treatment session at sunset for a time period of 180 minutes, or 3 hours, and was tested for sensitivity to set up time, recovery time and overall efficacy. The set-up time ranged between 5 - 25 minutes in the sensitivity analysis, and each simulation the same number of females was treated (Fig. 16a). When the model was tested for sensitivity to the recovery time with values ranging from 10 - 50 minutes, only one female was treated at 50 minutes, while 4 were treated when there was a recovery time of 10 or 20 minutes (Fig. 16b). Overall efficacy ranged from 0.1 to 0.9 in the sensitivity analysis. While no females were successfully treated when the efficacy was at 0.1, 4 were treated when the efficacy was at least 0.7 (Fig. 16c).

Bait - season model

The bait - season model simulates one season of fertility control treatments over a 60-day time period. Model sensitivity was explored with respect to 3 factors: the number of darters, dart efficacy, and drug efficacy. One darter affected only 58 females, while 3, 5 and 7 darters were able to affect upwards of 80 deer total. The advantage to having a greater number of darters was demonstrated in the amount of time to attain a given number of treatments. For example, with 3 darters it took approximately 26 days to treat 75 females, while with 9 darters it only took about 6 days (Fig. 17a). When both the dart and drug efficacy were varied over 5 simulations in the sensitivity analysis at the same ranges of 0.6 through 1.0, both factors produced similar trends in their effect on the number of females treated (Figs. 17b and 17c). The higher the efficacy, the greater the number of females treated.

Population model

The population model simulates the change in population size and density over 10 years as a fertility program is implemented. In the sensitivity analysis, where contraception rates ranged from 0.2 - 1.0, the population size decreased from 126 to about 35 deer at a contraception rate of 1.0. However, with a contraception rate of only 0.6, the population grew from 126 to 230. A decrease in population size over 10 years was achieved only with a contraception rate ≥ 0.8 with a fixed non-density-dependent fawn survival (Fig. 18).

Random encounters - season model

Over 60 days, the random encounters - season model simulates driving through a study area and treating deer from random encounters directly after sunset. While all other factors were held constant, the distance driven in one session was tested for its effect on the number of deer treated. Five distances were used, ranging from 5 to 25 km, and there was a larger difference

between 5 and 10 km than between any other distances (Fig. 19). For ≥ 10 km, the number of females treated increased in proportion to the increase in the distance driven.

Bait - year model

The bait - year model simulates a management program over a period of 10 years, with the contraception program running for 30 days out of each year. When tested for sensitivity to the value of the constraint factor, or the maximum number of deer that can be treated in one day, we found a large difference between 1, 2, and the remaining values (4, 8, 12). When a constraint of ≥ 4 deer per day was implemented, the resultant effect on the population size change was negligible (Fig 20).

Random encounters - year model

This model also simulates a 10 year fertility control program, with the contraception program being conducted for 30 days out of each year. The sensitivity of the model to the number of darters was tested at values of 1, 3, 5, 7 and 9. With 3 or more darters, a stationary or declining population was achieved, while with one darter the population increased over 10 years; the difference between 1 and 3 darters was large (Fig. 21).

DISCUSSION

Given that the assumptions of the models are true and the parameters used are accurate, the models presented here can successfully answer questions regarding the biology, logistics, and economics of a fertility control program.

Previous modeling efforts (Garrott 1991, Garrott and Siniff 1992, Garrott et al. 1992, Swihart and DeNicola 1995 and Seagle and Close 1996) have focused mainly on the biological aspect of fertility control (i.e., affecting a change in population size). Garrott (1995) reported

that many of the population models in the literature do not incorporate potential density-dependent population responses. Our population model addresses density-dependence to the extent that it impacts the recruitment of fawns, usually the first demographic effect of increased density (McCullough 1996).

The models do not address immigration and emigration, 2 factors that are very difficult to assess quickly and accurately in the field. Seagle and Close (1996) addressed immigration and contraception through modeling, but did not investigate whether their predictions for necessary treatments could be implemented logistically. In many areas considering the use of contraception, populations are somewhat isolated, either contained on islands, fenced, or limited to areas surrounded by inhospitable landscapes (Garrott 1995). Thus, immigration and emigration may be negligible when analyzing population size change brought about by contraception.

Swihart and DeNicola (1995) examined the effect of various contraceptive management strategies on population attributes of deer, but did not determine if these strategies could be implemented and if so, how much time and money would be involved. Though these discussions are important for determining the overall feasibility of fertility control, they are lacking in practical value. Our models all address the logistics involved in a fertility control program, from short to long intervals of time, and are the first to integrate the actual processes involved and population dynamics.

Encounter rate is the most important link in the contraception models, as it is critical in determining how many females can be treated in one day. Encounter rate becomes pivotal when dealing with small populations (Rudolph et al. In press). The queuing equation derived from

density estimates and observed encounter rates in MNHP is similar to the one presented by Jacobs and Dixon (1982) to describe the inter-arrival times between hunters and deer. The slopes were virtually identical, although an exponential model was a better fit to the data than a linear one. The Jacobs and Dixon (1982) model was an accurate predictor of deer hunting season harvest. Cohen (1984) validated the Jacobs and Dixon (1982) model and a binomial adaptation with an independent data set, and suggested queuing models be explored in greater detail. The effect of animal density on encounter rate is very powerful and may be an important and robust feature that transcends landscape complexity. Further research in determining the generality of the queuing relationship is warranted.

The economic aspects of population management has received limited attention despite their importance in evaluating the feasibility of fertility control programs (Garrott 1995). The addition of economics into these models was fairly simple, only requiring a few extra calculations. This section addresses a very important aspect of feasibility that previously has been neglected.

MANAGEMENT IMPLICATIONS

Modeling of logistics allowed for the determination and definition of the most important feasibility factors, which in turn will help managers by enabling them to focus efforts on those factors which have the greatest effect on the success of fertility control. Sensitivity analysis especially helps in exploring the effects of the factors over which managers have some control. Our models demonstrate that both the set-up and recovery times can have a direct effect on the number of deer treated in one session, although recovery time has a greater effect due to the

greater time involved. Thus, a manager would want to minimize these times as much as possible in the field. Mechanics is another area which can be closely controlled by the manager; using good, reliable equipment and qualified darters can make the difference between treating 2 or 4 females per day. The cumulative operational improvements can significantly impact the total number of deer which can be treated each season and can profoundly affect the overall success of the program.

These models can be used by managers to assess site-specific feasibility. The use of STELLA enabled the construction of an interactive, intuitive user interface, which, to use, does not require advanced computer programming or modeling skills. The data input in the models can be collected quickly and easily at different locations to estimate local requirements, following methods similar to those presented in Chapter One. The models also will help managers in understanding the factors and processes involved in a contraception program prior to implementation.

For future research, the models could be consolidated to incorporate all methods of contraceptive delivery into one model. Also, a model which incorporates not only fertility control, but also traditional methods of population control such as culling or controlled public hunts, would enable the evaluation of the best use of all or various combinations of programs, as well as the ability to compare and contrast all methods.

CHAPTER THREE

MANAGING WHITE-TAILED DEER POPULATIONS

THROUGH FERTILITY CONTROL

INTRODUCTION

The use of fertility control for managing white-tailed deer is relatively new, with the first report of successful contraception of individual females in 1992 (Turner et al.). However, a clear example of controlling a free-ranging population still has not been demonstrated. Population level questions have been addressed through simple birth, death, immigration and emigration process models (Garrott 1991, Hone 1992, Swihart and DeNicola 1995, Nielsen et al. 1997). However, population effects are only one aspect of fertility control which needs to be addressed when considering its use as a population management tool. Unfortunately, practical guidelines for implementation of a fertility control program have yet to be adequately developed (Swihart and DeNicola 1995). Models to date lack integration between biological, logistical, and economic considerations.

The success of fertility control programs depends on costs and the ease with which animals can be treated effectively (Garrott 1995). Thus, an exploration of the logistics and economics involved in implementation is required, not simply the effect of the treatment on population dynamics. McCullough (1996) cautions that costs of fertility control may be prohibitive, but few reported studies (Rudolph et al. In press) help managers determine the costs of a program. Costs not only include the vaccine, equipment and supplies, but more significantly, the cost of labor throughout implementation of a program.

We developed several dynamic simulation models which incorporate biological, logistical, and economic factors involved in fertility control and combined them in a generalized framework (see Chapter 2). The general nature of the models and their use of field data broadly extends their application. Model inputs for the simulations presented here are based on data collected on a deer population in north-central New Jersey (see Study Area Description).

The models will be used to address one of the more important and interesting questions surrounding the use of fertility control - when should it be applied? For instance, fertility control is often considered a means of maintaining a population following reduction through other means such as sharp-shooting or controlled public hunting (Hone 1992, Swihart and DeNicola 1995). However, this scenario has not been thoroughly evaluated. Our goal is to use the models as tools to explore the feasibility of fertility control by identifying the factors that are most important and then demonstrating how to estimate and use them without incurring significant costs.

OBJECTIVES

1. Determine the contraceptive rates required to maintain or reduce a population of deer in north-central New Jersey, determine the effort and costs involved, and compare implementation at bait sites and during random searches.
2. Outline the scenarios of best use of fertility control for managing white-tailed deer populations.

METHODS

Population characterization

Deer abundance, as well as herd composition and cover-type use, were estimated using distance sampling (Buckland et al. 1993). With this method, perpendicular distances are

measured from the designated survey route to a deer or deer group. These distances are used to generate a function which describes how the detection of deer changes as a function of distance. From this function, the area around the transect in which deer are counted can be computed and the density estimated. This computation allows for the fact that some deer in the search area will not be detected, except for those directly on the transect line, alleviating the need to correct for missed animals (Underwood et al. 1998).

Similar to Christie and Sayer (1989), the survey route was defined by the Tour Road in the Jockey Hollow area (JH; Fig. 1). The road was traversed by motorized vehicle at <16 kph. Due to existing traffic patterns and to cover most of JH, 2 overlapping loops were made through the survey area and all areas were thoroughly searched for deer. Upon detection of a deer group (or individual), the perpendicular distance was measured using a laser rangefinder. If the perpendicular distance could not be obtained, the angle and sighting distance were recorded. A deer group was identified using a nearest neighbor criterion and behavioral cues (Underwood et al. 1998). Deer were classified according to sex (male, female, or unknown), age (fawns, adults, or unknown), and initial activity (active or inactive). The cover type (woodland or field) as well as the section of the park (Fig. 1) in which the group or individual was encountered were recorded. Surveys were conducted periodically at dawn and dusk until sufficient observations were made to estimate density with reasonable precision ($CV \leq 20\%$). Density estimates were computed using DISTANCE software, following recommendations by Buckland et al. (1993). Data were pooled by season, with individual surveys treated as replicate counts.

Female deer abundance also was calculated from mark-resight data collected on a sample of tagged deer. Lincoln-Peterson and Chapman estimators were used, following procedures

outlined by Davis and Winstead (1980). Also, we used the program NOREMARK (White 1996) to estimate the size of the female component of the population using the joint hypergeometric maximum likelihood estimator (JHE) and the Minta-Mangel estimator.

Herd composition was summarized from transect data as the proportion of males, females, and fawns of the total sample and converted to males and fawns per 100 yearling and adult females. Only observations where all group members were classified according to sex and age were used in the analysis. Standard errors for the proportions were calculated using a binomial approximation (Bowden et al. 1984).

An estimate of the carrying capacity for MNHP was calculated by comparing point estimates of density and a 13 year series of spotlighting data. We used point estimates of density from 2 periods 10 years apart and examined them with respect to trends in the spotlighting surveys, particularly peaks and valleys. Carrying capacity was estimated crudely by eye and the standard deviation was taken as the range divided by 4.

Simulation experiments

We used models presented in Chapter 2 to analyze the feasibility of fertility control programs. First, all 6 models are used to provide a thorough analysis of the feasibility of fertility control implementation in MNHP. The models are sequential in regards to time scale, and those of higher resolution lay the foundation for those of lower resolution. One model determines how many deer can be treated in one day and this information is then used in the next model to determine, at that constraint, how many females can be treated in one season and what reproductive rate that generates. These are modeled for both bait site treatment and random

searches from vehicles. Finally, this seasonal information is used in a population model to estimate the effects of 10 years of fertility control implementation.

Second, the bait - year model (Fig. 9) was used to investigate and map a general schema of the feasibility of fertility control programs. In this model, the 2 basic parts, the season and population models, are linked by the contraception rate and density. The realized contraception rate in one season of treatment determines the birth rate for the next spring. The density-dependent survival of those fawns adds to the population size, and along with the subtraction of adult deaths, generates subsequent autumn population sizes. The resultant density then determines the encounter rate through a queuing relationship, which in turn affects the realized contraception rate.

The bait - year model was run with 4 different population sizes for 10-year simulations to determine the effect of change in population size and deer behavior on the realized contraception rate. All treatment seasons were 30 days long. Because the area and percentage of females in the population were held constant in all simulations (5.45 ha and 60%, respectively) as the population size increased, the density and number of females in the population also increased. Each population size, calculated in factorial-like increments (15, 30, 60, 120 deer/km²), was run at 5 different deer behavior levels, 0.2, 0.4, 0.6, 0.8, 1.0, for a total of 20 simulations.

RESULTS

Population characterization

For the autumn (September, October, November) of 1996, overall population density in JH was estimated to be 60.5 deer/km² (Underwood 1997; Table 4). Yearling and adult males comprised about 12% of the total population, or about 13:100 yearling and adult does (Table 5).

The distribution of deer observations by cover type revealed very different use patterns between morning and evening surveys. While the density of deer in woods verses fields was similar during evening surveys, a substantially higher (14x) density of deer was estimated in the woods than fields for morning surveys (Underwood 1997).

Overall population density in the autumn of 1997 was estimated at 30.6 deer/km² in JH (Table 4). Density estimates varied from 3.8 deer/km² in the fields in the afternoon to 22.3 deer/km² in the woods in the morning. Density estimates for woods during afternoon surveys could not be calculated due to low sample size. In a total of 9 surveys, 109 groups and 232 deer were counted – 76 groups and 145 individuals in the morning and 33 groups and 87 individuals in the afternoon. Yearling and adult males comprised approximately 10% of the total population in morning surveys and 16% in afternoon surveys, or about 17:100 yearling and adult does in the morning and 27:100 in the afternoon (Table 5). Patterns of cover-type utilization were consistent with 1996.

In 1998, surveys were conducted in both the summer (June, July and August) and autumn. Summer density was 37.2 deer/km² while the autumn density was 23.0 deer/km² (Table 4). In 12 surveys conducted during the summer, a total of 483 deer in 320 groups was tallied. In the autumn, 502 deer in 264 groups were seen in a total of 17 surveys. The population was comprised of 56% yearling and adult females in the summer and 62% in the autumn surveys. Yearling and adult males comprised approximately 24 and 47% of the population in morning and evening surveys in the summer, respectively, or approximately 43:100 yearling and adult does in the morning surveys and 100:100 yearling and adult does in the evening surveys (Table 5). In the autumn, yearling and adult males comprised about 12% of the total population in the morning

surveys, but only 6% in the evening surveys. Males were approximately 22:100 and 10:100 yearling and adult does in the summer morning and evening surveys, respectively (Table 5). Again, cover-type utilization was consistent with 1996 observations.

Abundance estimates for autumn 1998 were compared with results from several mark-recapture estimates of the number of females in the population (Table 6). All 4 estimators generated comparable results, consistent with the DISTANCE estimate of 96 yearling and adult females. Carrying capacity for MNHP was estimated at 50 deer/km², or 273 deer (SD = 55).

Model Parameter Values

The area used in all models is 5.45 ha, and the initial population size is 163 animals, 59% of which are females, or 96 females. A dart efficacy of 85% and a drug efficacy of 90% were used in all model simulations following unpublished estimates from on-going white-tailed deer fertility control studies (Rudolph et al. In press). For MNHP, deer behavior was estimated at 0.8, the female survival rate was estimated at 90%, the male survival rate at 75%, the birth rate at 1.0, and the fawn survival was modeled as a density-dependent function with carrying capacity at 273 deer with a standard deviation of 55. The cost per person per day is \$75 and the cost per deer is \$50, which includes the cost of drugs, darts, needles, syringes, and charges needed for one injection. Also included is a start-up cost of \$500.

For the random encounters - season model, the vegetation interference was set at 50%, 41% of females were within 25m, the distance driven in one session was 11km and the mean encounter rate was 1.5 deer per kilometer driven, as derived from the program DISTANCE.

Management Simulations

During a 30-day treatment program implemented over bait, 83 deer were treated, while in a 60-day program, 87 deer were treated. These numbers represent 88% and 93% contraception. Over numerous trials, costs ranged from around \$12,000 for 26 days of work to \$17,000 for 52 days of work, both to attain 89% realized contraception.

Extending this result by using the population model, a contraception rate of 88% over 10 years of fertility control reduced the modeled population from 163 to 85 animals. With a contraception rate of 93%, the population was reduced to 66 animals. A realized contraception rate of 70% was required to achieve a stationary population over 10 years; a realized rate of 89% was necessary to reduce the population in half over 10 years.

Constraining the average number of deer which can be treated in one day at one bait site to 3, the population was reduced from 163 to 72 animals in 10 years, using 3 active bait sites to affect treatment. The average realized contraception rate was 92%, but ranged from 88 to 96%, which is consistent with the previous basic simulation.

When implemented from random encounters with deer along roadsides, 76 females were treated in 60 days, generating a realized contraception rate of 81%, while in 30 days, 69 females were treated, yielding a contraception rate of 73%. When integrating changing encounter rates with density, the population grew from 163 to 195 deer. Encounter rates varied over time from 1.46 - 1.97 does per kilometer driven and generated an average realized contraception rate of 70%.

From the factorial-like simulations, the contraception rate is the highest (>85%) at female population sizes of 100 - 300, regardless of behavior (Fig. 22). Once the number of females increases beyond 300, the contraception rate steadily declines. On the other end of the spectrum,

when the number of females is < 100 , the contraception rate is more sensitive to the behavior variable. At a behavior of 1.0 (i.e., tame) and a small number of females, the contraception rate is very high, however, at lower behavior levels, the contraception rate drops precipitously. Contraception rate is higher in all instances when the level of the behavior variable is high.

DISCUSSION

For MNHP, it may be feasible to reduce the deer population by one-half by sustaining a contraception rate of 89% over 10 years. A planning horizon of at least 5-10 years for significant deer population reduction, even with 100% efficacy of contraception has been suggested previously (Seagle and Close 1996); however, the public often is looking for a quick resolution to overabundant deer problems (Swihart and DeNicola 1995). Planning horizons will obviously depend on current population sizes with respect to population goals. However, significant changes will not be realized within a year or 2. Although our results indicate that there are circumstances where fertility control can reduce a deer population size, the resources and time required to meet population reduction goals are greater than those necessary for traditional means of herd reduction (McCullough 1996).

The monetary estimates generated from the models suggest \$12,000 - \$17,000 is required per year of fertility control. For MNHP, this translates to \$140 - \$200 per deer per year. These numbers compare favorably to those presented at the Workshop on the Status and Future of Wildlife Fertility Control at the Wildlife Society 5th Annual Conference, 1998. Though the estimates are similar, cost per deer can be a misleading way of reporting expenses. The time required to treat a certain number of females depends heavily on site-specific factors and the

competency of the crew. Thus, it is more informative to analyze costs of supplies and labor separately.

Several model results elucidated problems which may be encountered during implementation of a fertility control program. For MNHP, in over 40 simulations, the number of animals treated did not exceed 87, out of 96 total, demonstrating that often there will be females in the population which are unavailable for treatment. This accurately reflects both the difficulty in encountering the remaining untreated females and the differing behavior of individual deer; often there will be animals which are not encountered, making 100% contraception impossible. Also, there was not a large difference among simulations that ran for 30 or 60 days. Both scenarios reduced the population size, exhibiting a realized contraception rate $> 70\%$. These simulations demonstrate that after the more visible deer are treated, the less visible animals take increasingly more time to treat. This result is consistent with findings that observation rates for highly visible deer are out of proportion to the representation of these individuals in the population (Sage et al. 1983). Thus, it may not be worth the extra time and effort to run a program for 60 days due to diminishing returns if the program goals can be satisfactorily reached in only 30 days.

In regards to general feasibility, our results demonstrate that effort is optimized at population sizes of 100 - 300 and at high levels of the behavior variable (Fig. 22). With population sizes larger than 300, realized contraception rates decline due to time constraints. With so many females to treat, even though the number treated in 30 days may be large, they only represent a small percentage of the overall female population. Thus, net reproduction of non-treated females will still be higher than the cumulative death rate and the population will

increase. However, often in high density populations, natural density-dependent factors such as decreased fawn survival, delayed sexual maturity and decreased pregnancy rates may already be in place (Garrott 1995, McCullough 1996). Therefore, the decrease in reproduction caused by contraception must surpass this natural decrease from density-dependent factors for it to have any impact on population size. To do so, close to 100% of females must be treated since it is impossible to preferentially target those that will successfully raise fawns. Contraception is inefficient for control of populations already experiencing density-dependent decline and exhibiting low biotic potential for growth.

The use of fertility control has been suggested to be the most effective at times when the rate of increase of the population is the highest, before it reaches the point of surpassing carrying capacity (Swihart and DeNicola 1995, Hone 1992, Garrott 1995, McCullough 1996). Here, a large percentage of females would be reproducing and contraception would have the greatest and most noticeable impact. This result leads to the conclusion that overabundant populations must first be culled to bring them from the point of density-dependence to a point of high rate of increase. Then fertility control would be used to maintain the population at that level.

However, a danger in using another method to reduce a population to a lower level is reducing it to such a low level that fertility control cannot be used efficiently. Our results indicate that treating the necessary number of females in small populations is unpredictable and time-consuming due to highly variable and generally low encounter rates (Fig. 22). Moreover, the ability to affect treatment is highly dependent on the behavior of females and if population density has been lowered previously through culling, for example, deer behaviors are likely to be at lower levels. It has been found in several studies of hunting on deer behavior (Grau and Grau

1980, Holsworth 1973, Roseberry et al 1969) that hunter success and kill rate decline as the season progresses. This is in part due to the decreased density, but also to the increased wariness of deer toward humans. The response of deer to people is greatly modified by experience; deer are more weary and run more frequently when hunted than when not hunted (Behrend and Lubeck 1968). Attempting to remotely deliver contraception to a population that has recently been hunted may require more time due to the increased avoidance behavior of the deer. These factors inhibit the application of fertility control by exponentially increasing the time necessary to treat the number of females required to reach population reduction goals, and thereby greatly increasing the cost of the program.

In general, deer in high density populations will be higher on the behavior scale, while at lower densities behavior diminishes and then at very low densities, plummets. In Figure 22, this phenomenon would be depicted by a line coming from the back right corner of the graph and arcing over to the front left corner.

MANAGEMENT IMPLICATIONS

Our results indicate that, at least at MNHP, implementing fertility control over bait would be more efficient and reliable than through random encounters. When using random searches, with effort similar to that over bait sites, the contraception rate was 12% lower for 60 days and 15% lower for 30 days than bait site contraception rates. Hence, for this modeled scenario, where there are openings in a predominately forested park, bait sites should be used as the primary means for remotely delivering contraception, with random searches serving as a supplementary method.

Others have suggested population sizes as maximums for use of fertility control, such as 200 (McCullough 1996) or 500 (Swihart and DeNicola 1995). Our simulations indicate that the optimal female population sizes for the use of fertility control are those that are mid-range, i.e. 100 - 300. This result is based largely on the logistics and economics involved, irrespective of optimizing contraception in relation to the rate of increase or carrying capacity.

Many factors are involved in determining the success of a fertility control program, and encounter rate is the most important. The effort required also depends on population density, proportion of breeding females in the population, and treatment efficacy (Rudolph et al. in press). General guidelines, such as those depicted in Figure 22, help to determine roughly whether or not a population could be reduced or maintained through fertility control, but site-specific factors still must be investigated before implementation. Models can help in understanding processes involved in fertility control, but models will not predict exactly what will take place when fertility control is implemented in the field.

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Table 1. The amount of bait and the frequency with which it was distributed for all 3 established bait sites in MNHP, August - October 1998. Priming and trials ran for 2 weeks and one week, respectively, while observations were carried out for 4 weeks, in their respective order.

Baiting	Maryland Brigade	Grand Parade	Mt. Kemble
Priming	9.3 kg daily	9.3 kg daily	9.3 kg daily
Amount trial	2.3 kg daily	4.7 kg daily	7.0 kg daily
Frequency trial	4.7 kg every 4 th day	4.7 kg every 3 rd day	4.7 kg every 2 nd day
Observations	4.7 kg every 3 rd day	4.7 kg every 3 rd day	4.7 kg every 3 rd day

Table 2. The base values and tested values for factors explored in 6 models of simulated fertility control for white-tailed deer (data derived from MNHP).

Model Factor	Base Value	Values Tested
<i>Bait - day model</i>		
set up time	10	5, 10, 15, 20, 25
recovery time	30	10, 20, 30, 40, 50
overall efficacy	.70	0.1, 0.3, 0.5 , 0.7, 0.9
<i>Bait - season model</i>		
darters	1	1, 3, 5, 7, 9
dart efficacy	.95	0.6, 0.7, 0.8, 0.9, 1.0
drug efficacy	.95	0.6, 0.7, 0.8, 0.9, 1.0
<i>Population model</i>		
contraception rate	.90	0.6, 0.7, 0.8, 0.9, 1.0
<i>Random encounters - season model</i>		
distance driven (km)	11	5, 10, 15, 20, 25
<i>Bait - year model</i>		
constraint	3	1, 2, 4, 8, 16
<i>Random encounters - year model</i>		
darters	1	1, 3, 5, 7, 9

Table 3. Base values for factors in 6 models of simulated fertility control on white-tailed deer (data derived from MNHP).

Model Factor	Base Value	Model Factor	Base Value
<i>Bait -day model</i>			
mean encounter rate	graphical function	percent male/fawn	47%
<i>Bait - season model</i>			
area	5.45 km ²	mean encounter rate	graphical function
deer population	163	tags	graphical function
percent females	59%	behavior	0.8
<i>Population model</i>			
birth rate	90%	female survival rate	90%
fawn survival rate	80%	initial females	94
male survival rate	75%	initial males	32
<i>Random encounters - season model</i>			
area	5.45 km ²	behavior	0.8
deer population	163	mean encounter rate	1.54 deer km ⁻¹
percent female	59%	darters	1
vegetation interference	50%	within 25m probability	41%
dart efficacy	95%	drug efficacy	95%

Table 3. Continued

<i>Bait - year model</i>			
area	5.45 km ²	behavior	0.8
deer population	163	females at bait	54%
initial females	96	birth rate	90%
initial males	32	fawn survival rate	80%
initial fawns	35	male survival rate	75%
mean encounter rate	graphical function	female survival rate	90%
tags	graphical function	darters	1
dart efficacy	95%	drug efficacy	95%
<i>Random encounters - year model</i>			
area	5.45 km ²	distance driven	11 km
deer population	163	percent females	59%
initial females	96	behavior	0.8
initial males	32	birth rate	90%
initial fawns	35	fawn survival rate	80%
male survival rate	75%	female survival rate	90%
vegetation interference	50%	within 25m probability	41%
dart efficacy	95%	drug efficacy	95%
mean encounter rate	1.54 deer km ⁻¹		

Table 4. Estimates of white-tailed deer density for the Jockey Hollow area of MNHP, 1996 - 1998.

Year	Cover Type	Number/km ² (%CV)	
		AM	PM
Autumn 1996	Woods	57.0 (12.1)	28.3 (9.5)
	Fields	3.5 (26.5)	32.2 (17.7)
	Total	60.5	60.5
Autumn 1997	Woods	22.3 (25.2)	-
	Fields	8.3 (21.9)	3.8 (21.1)
	Total	30.6	-
Summer 1998	Woods	29.3 (18.2)	14.5 (30.5)
	Fields	7.9 (21.8)	13.8 (10.2)
	Total	37.2	28.3
Autumn 1998	Woods	17.0 (13.8)	11.4 (17.3)
	Fields	6.0 (15.1)	10.9 (29.8)
	Total	23.0	22.3

Table 5. Herd composition data for the white-tailed deer population in Jockey Hollow, MNHP, 1996 - 1998.

Date	Time	No. of Groups	Mean Group Size (SE)	Proportion Male (SE)	Males:100 Females	Proportion Fawn (SE)	Fawns:100 Females
Autumn 1996	AM	51	1.84 (0.16)	0.10 (0.04)	11.32	0.40 (0.05)	66.04
	PM	87	1.99 (0.18)	0.13 (0.03)	14.29	0.29 (0.03)	40.18
Autumn 1997	AM	76	1.91 (0.12)	0.10 (0.03)	16.87	0.29 (0.04)	46.99
	PM	33	2.64 (0.38)	0.16 (0.05)	27.27	0.28 (0.06)	48.48
Summer 1998	AM	220	1.59 (0.05)	0.24 (0.02)	43.24	0.22 (0.02)	39.46
	PM	100	1.33 (0.07)	0.47 (0.04)	100.00	0.07 (0.02)	14.46
Autumn 1998	AM	200	1.92 (0.09)	0.12 (0.02)	22.07	0.32 (0.02)	56.34
	PM	64	1.84 (0.11)	0.06 (0.02)	9.72	0.31 (0.04)	48.61

Table 6. Estimates for female population size in MNHP, summer and autumn 1998, using several different estimators.

Estimator	Estimate	Lower 95% Confidence Limit	Upper 95% Confidence Limit
DISTANCE	96	-	-
Lincoln-Peterson	115	98	133
Chapman	88	78	99
JHE	109	89	136
Minta-Mangel	109	91	129

Figure 1. Tour road traveled for random searches and bait site locations in MNHP.

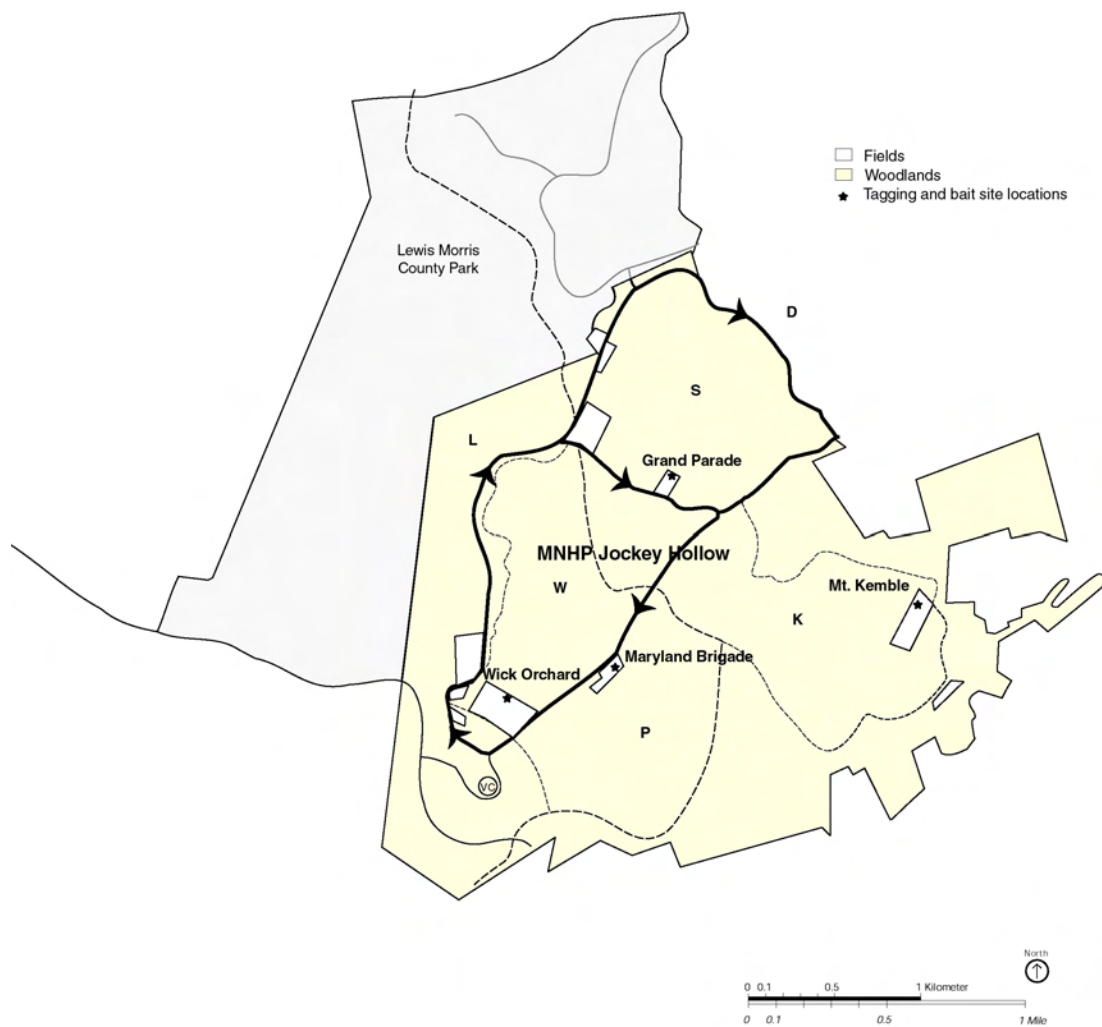


Figure 2. At differing amounts of bait, mean encounter rates (deer per hour) of female deer calculated from daily averages with associated standard errors for Mt. Kemble (a; 7.0 kg: n = 5, 9.3 kg: n = 6), Grand Parade (b; 4.7 kg: n = 5, 9.3 kg: n = 6) and Maryland Brigade (c; 2.3 kg: n = 5, 9.3 kg: n = 6) bait sites in Morristown National Historical Park, Morristown, NJ, August 1998.

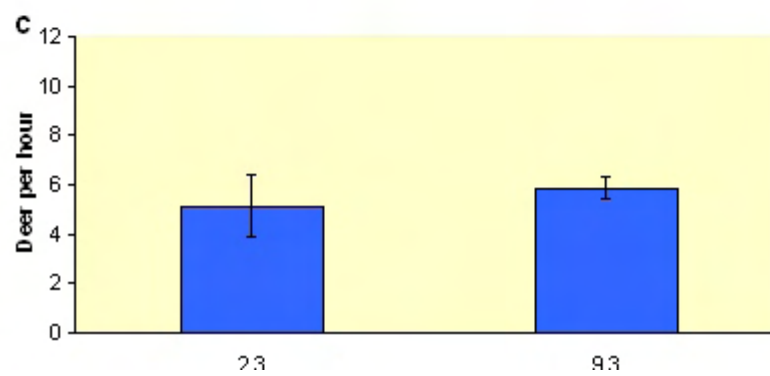
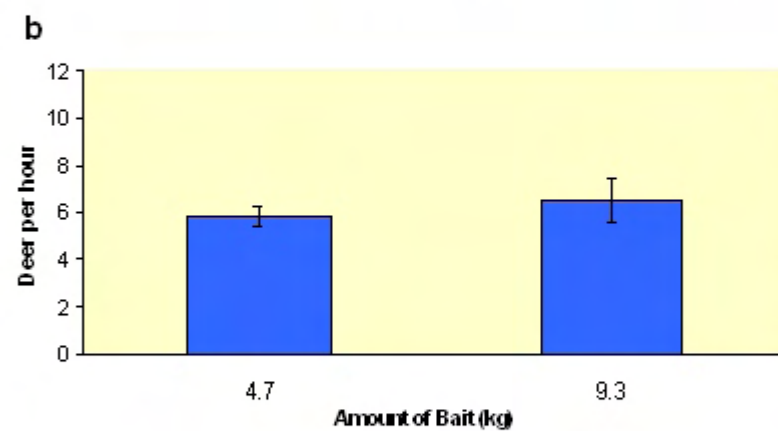
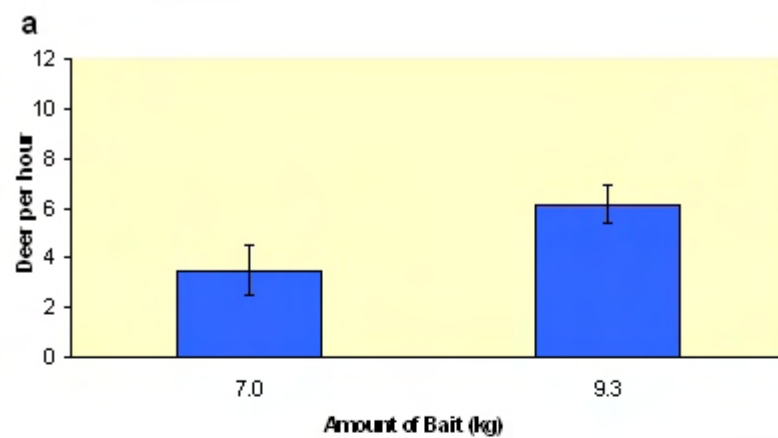
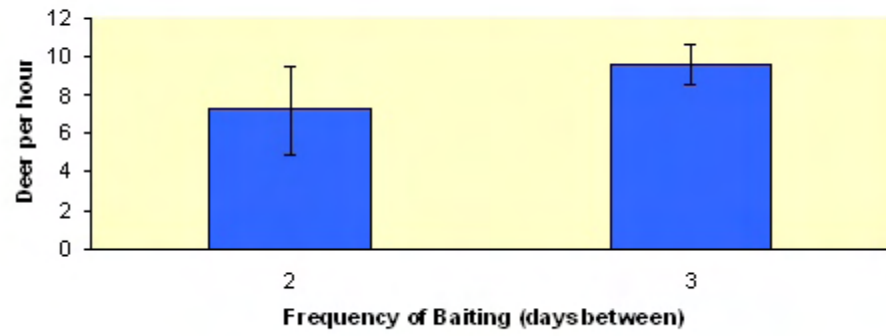
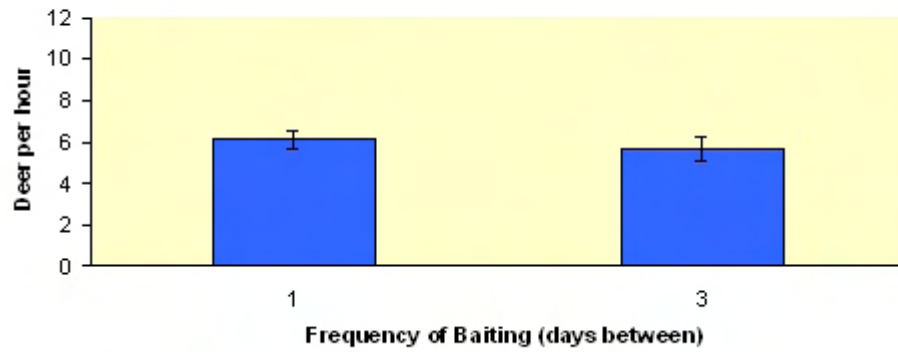


Figure 3. At different baiting frequencies, mean encounter rates (deer per hour) of female deer calculated from daily averages with associated standard errors for Mt. Kemble (a; 2: n = 4, 3: n = 6), Grand Parade (b; 1: n = 5, 3: n = 8) and Maryland Brigade (c; 3: n = 5, 4: n = 3) bait sites in Morristown National Historical Park, Morristown, NJ, September 1998.

a



b



c

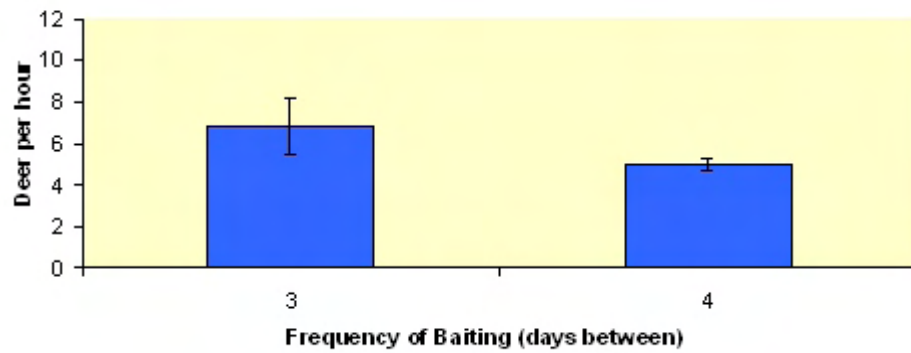
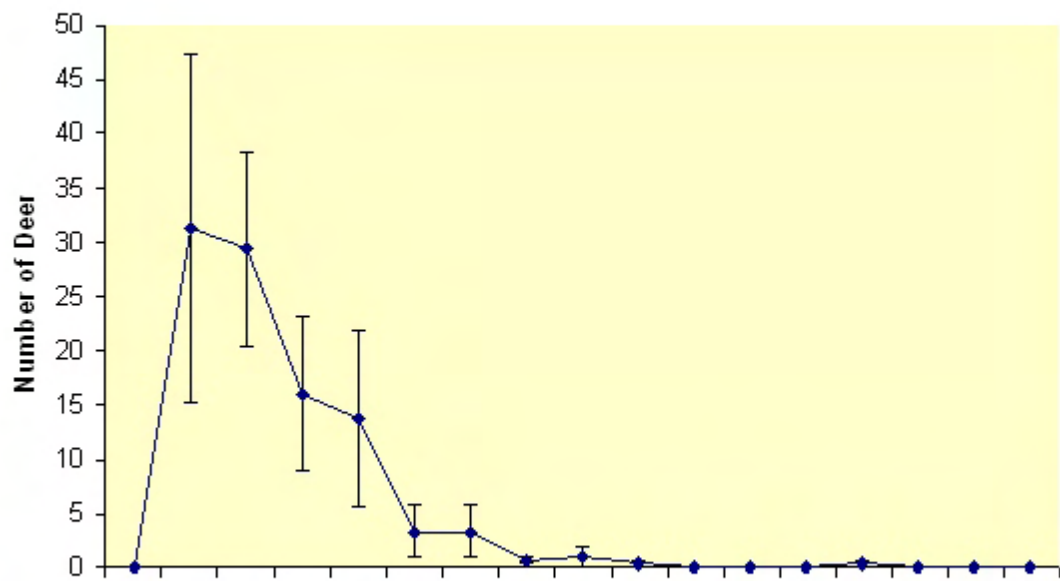


Figure 4. Frequency distribution of time on bait (a) and time in field (b) for all deer averaged from the average distribution of time for each of 3 sites ($n = 3$) in Morristown National Historical Park, Morristown, NJ, August - October 1998.

a



b

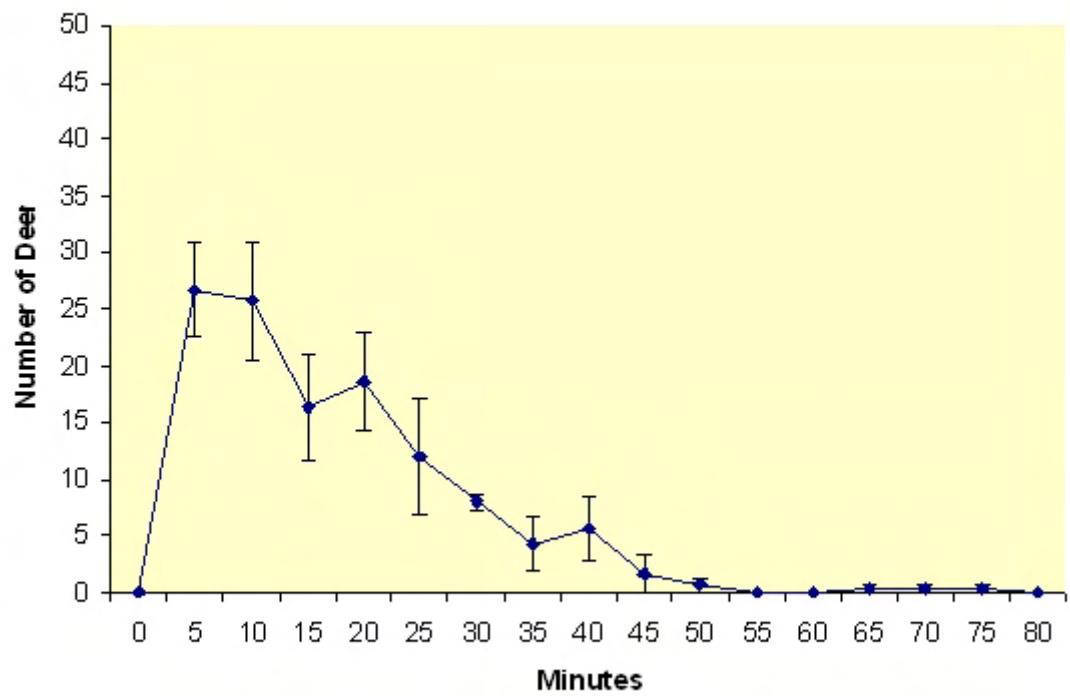


Figure 5. Frequency distribution of arrival times of all deer (a) and females (b) into the field and on the bait pooled from the averages of each of 3 sites ($n = 3$) in Morristown National Historical Park, Morristown, NJ, August - October 1998.

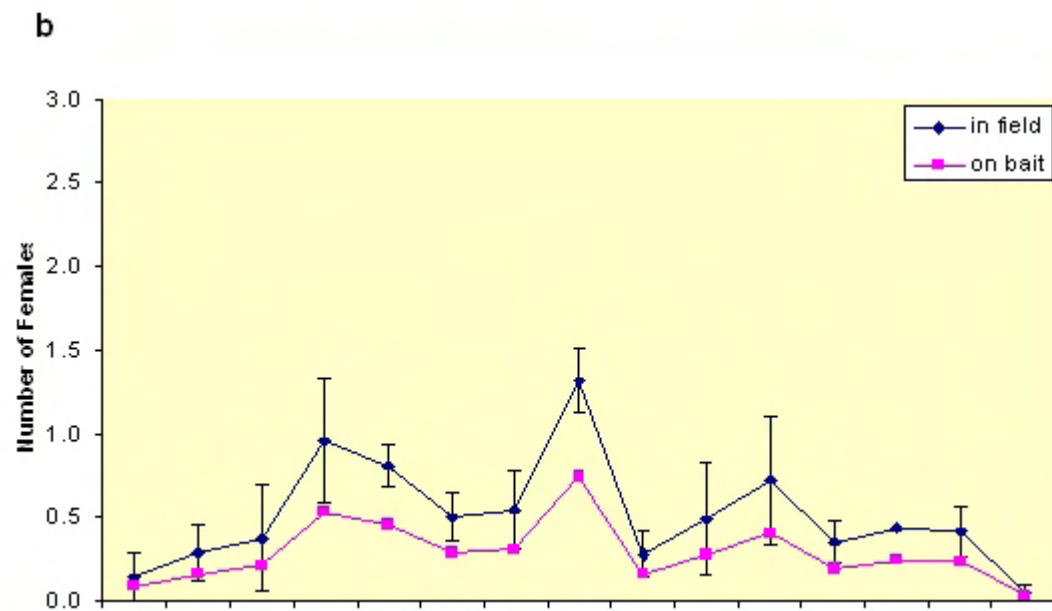
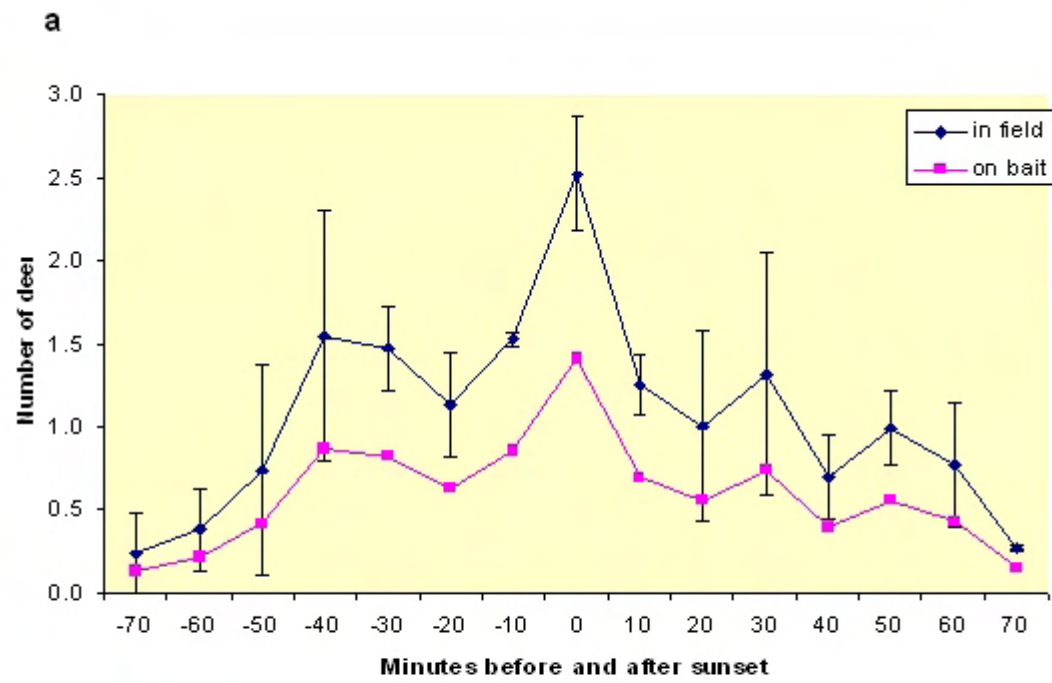


Figure 6. Encounter rates (deer per hour) on the bait and in the field of all deer (a; bait and field: n = 41) and females (b; bait and field: n = 42), and the percent females on the bait and in the field (c; bait and field: n = 35) for all sampling sessions at all 3 sites in Morristown National Historical Park, Morristown, NJ, August - October 1998.

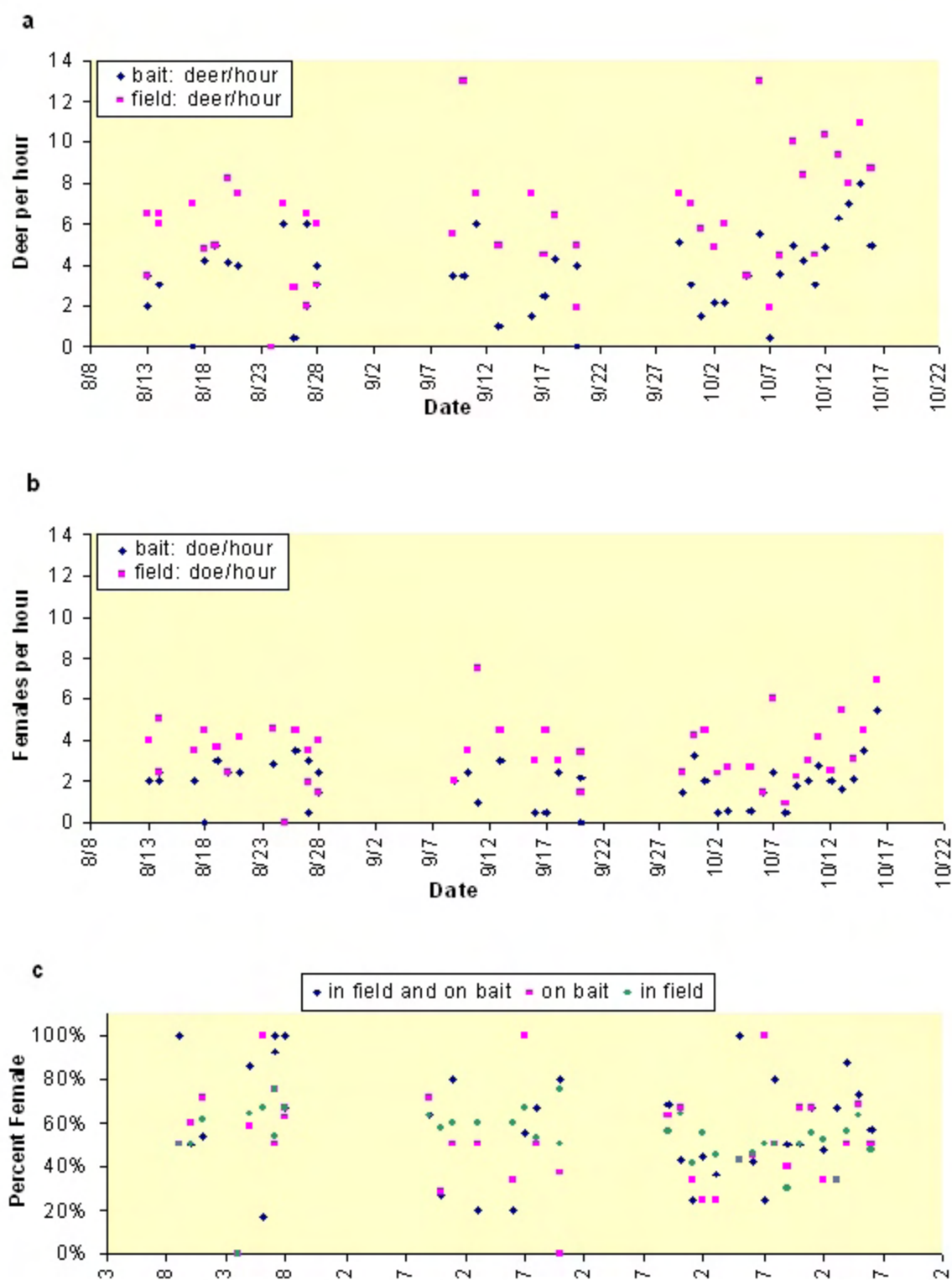


Figure 7. The number of sightings of each tagged female during both bait site observations and random searches in Morristown National Historical Park, Morristown, NJ, August - October 1998.

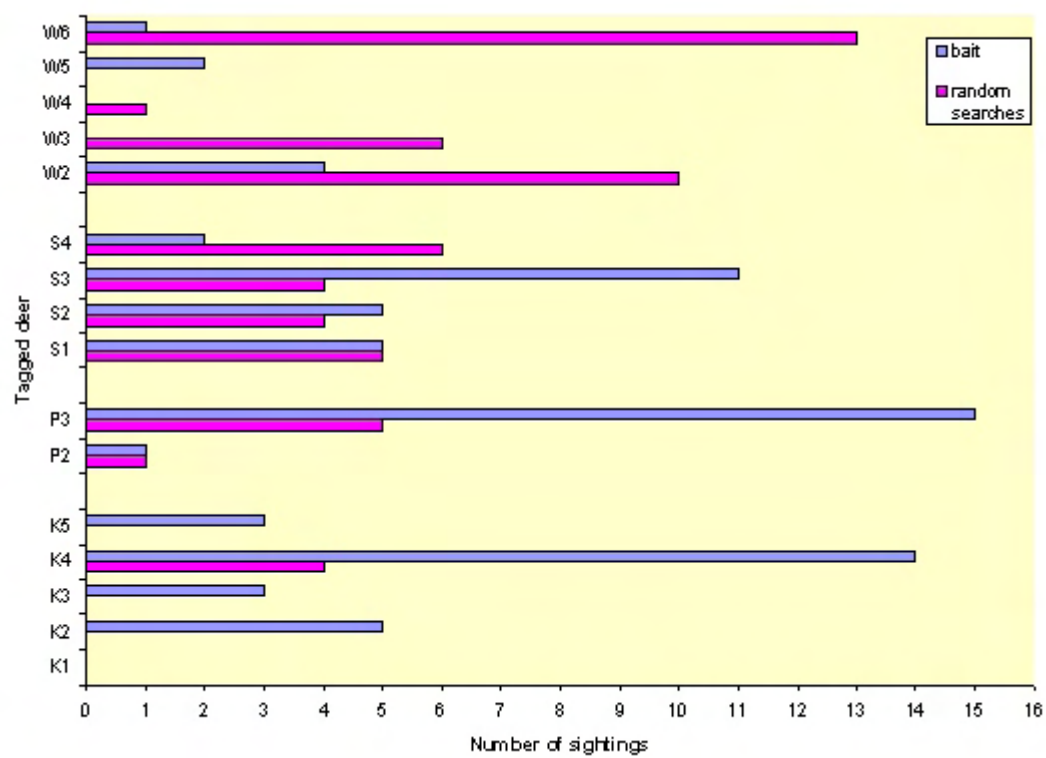
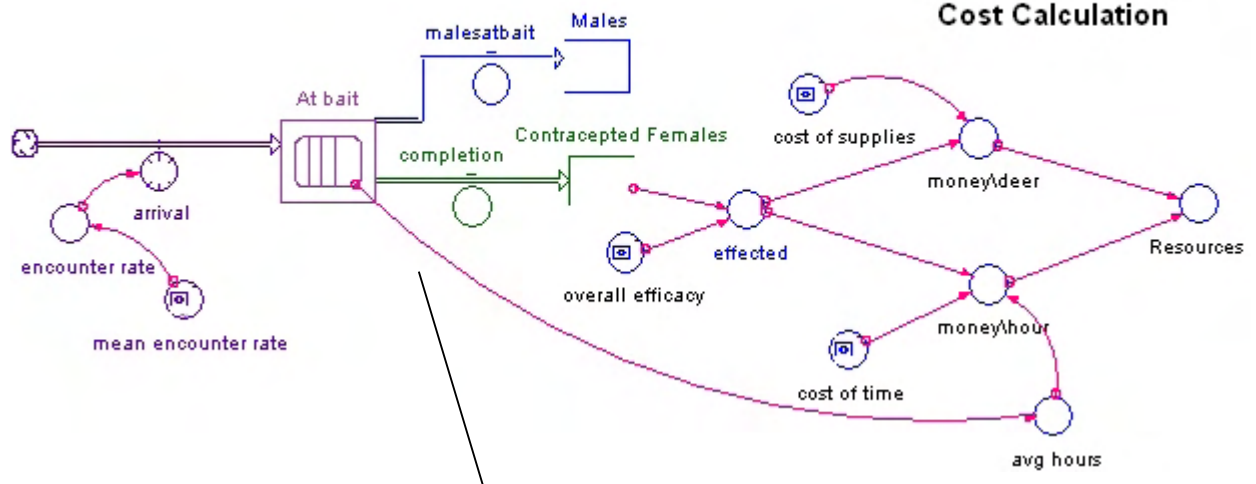


Figure 8. Flow diagram of bait-day model.

Darting Program



Queuing Submodel

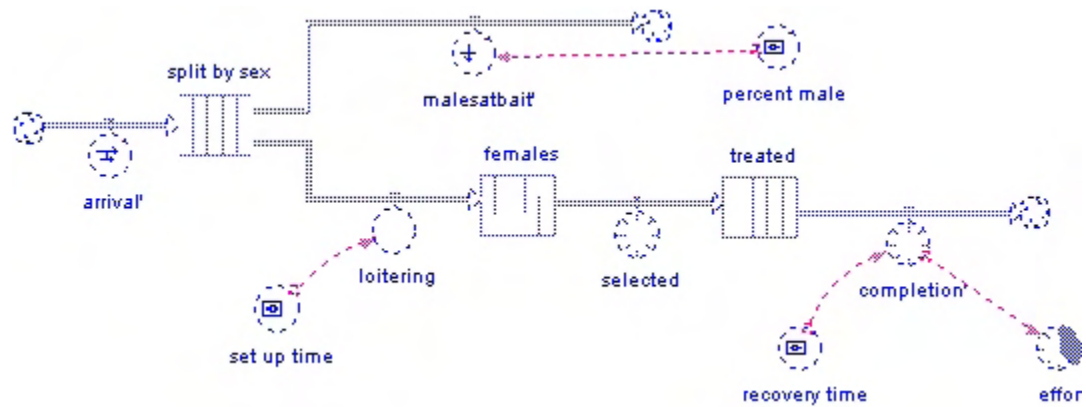
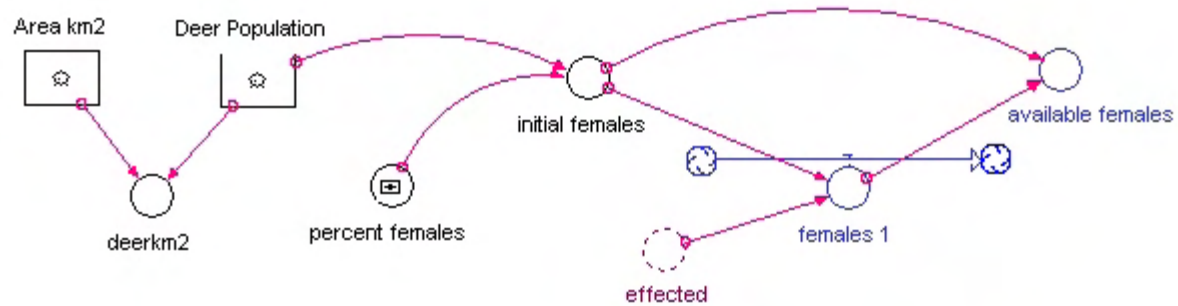
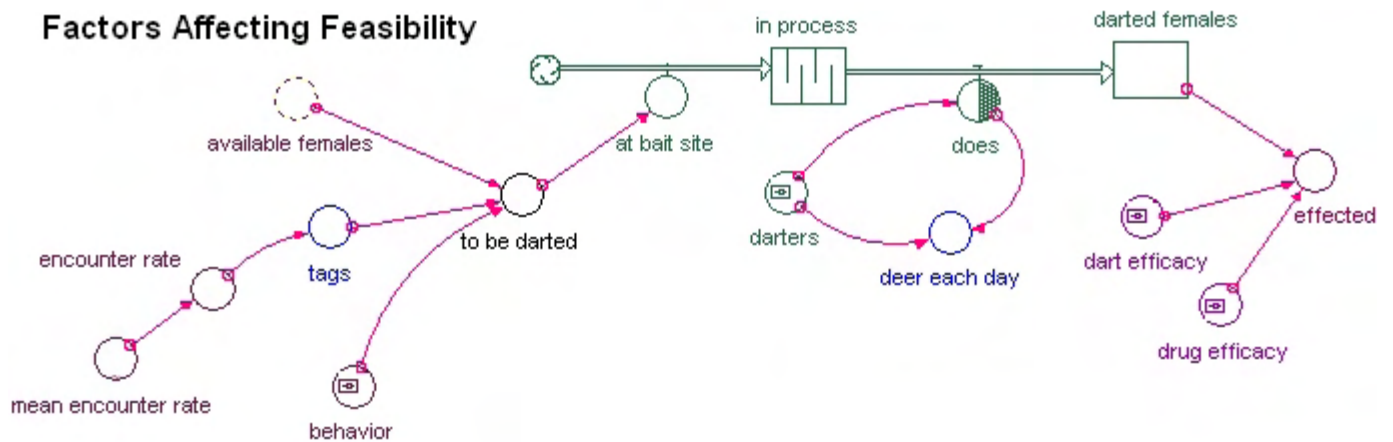


Figure 9. Flow diagram of bait-season model.

Population Description



Darting Logistics



Cost Calculation

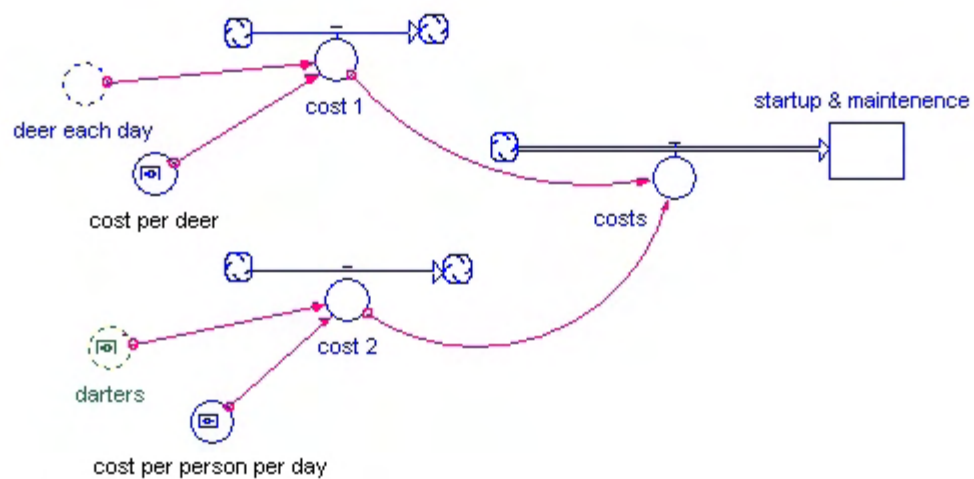
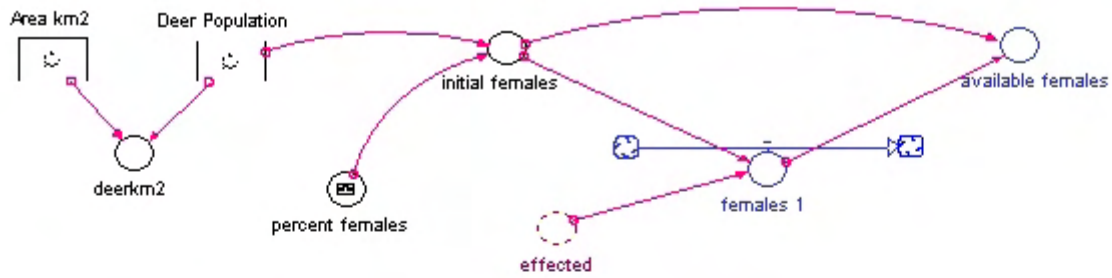
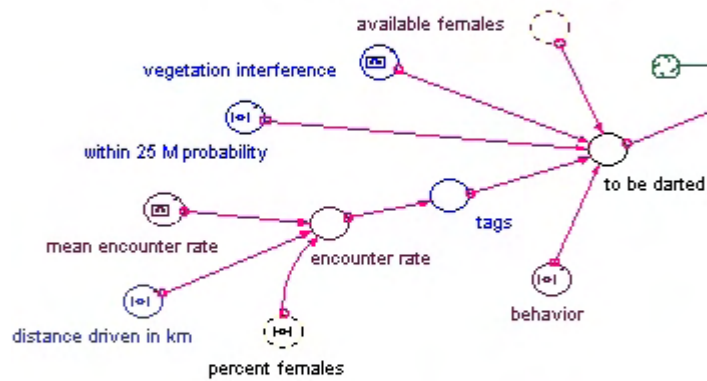


Figure 10. Flow diagram of random encounters-season model.

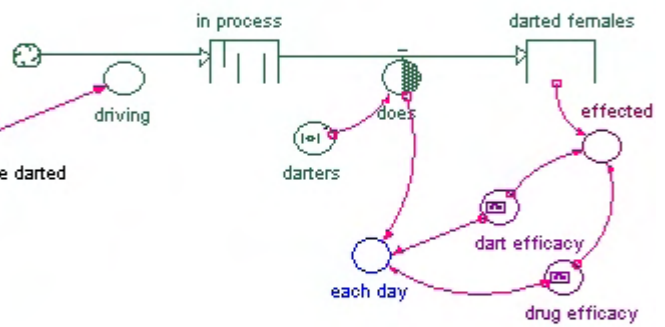
Population Description



Factors Affecting Feasibility



Darting Logistics



Cost Calculation

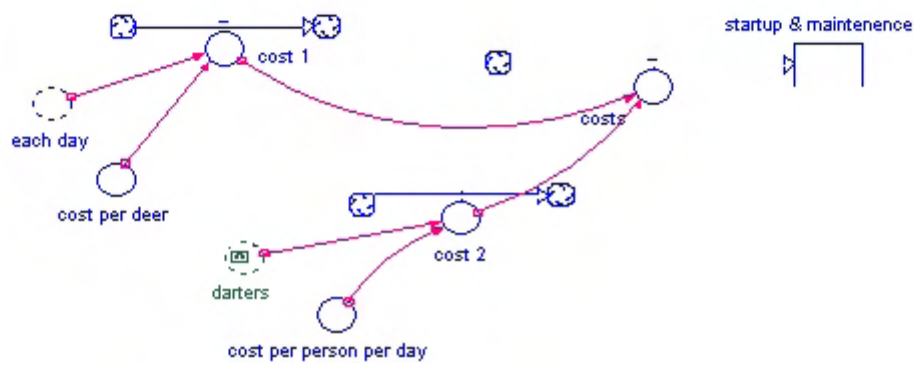


Figure 11. Flow diagram of population model.

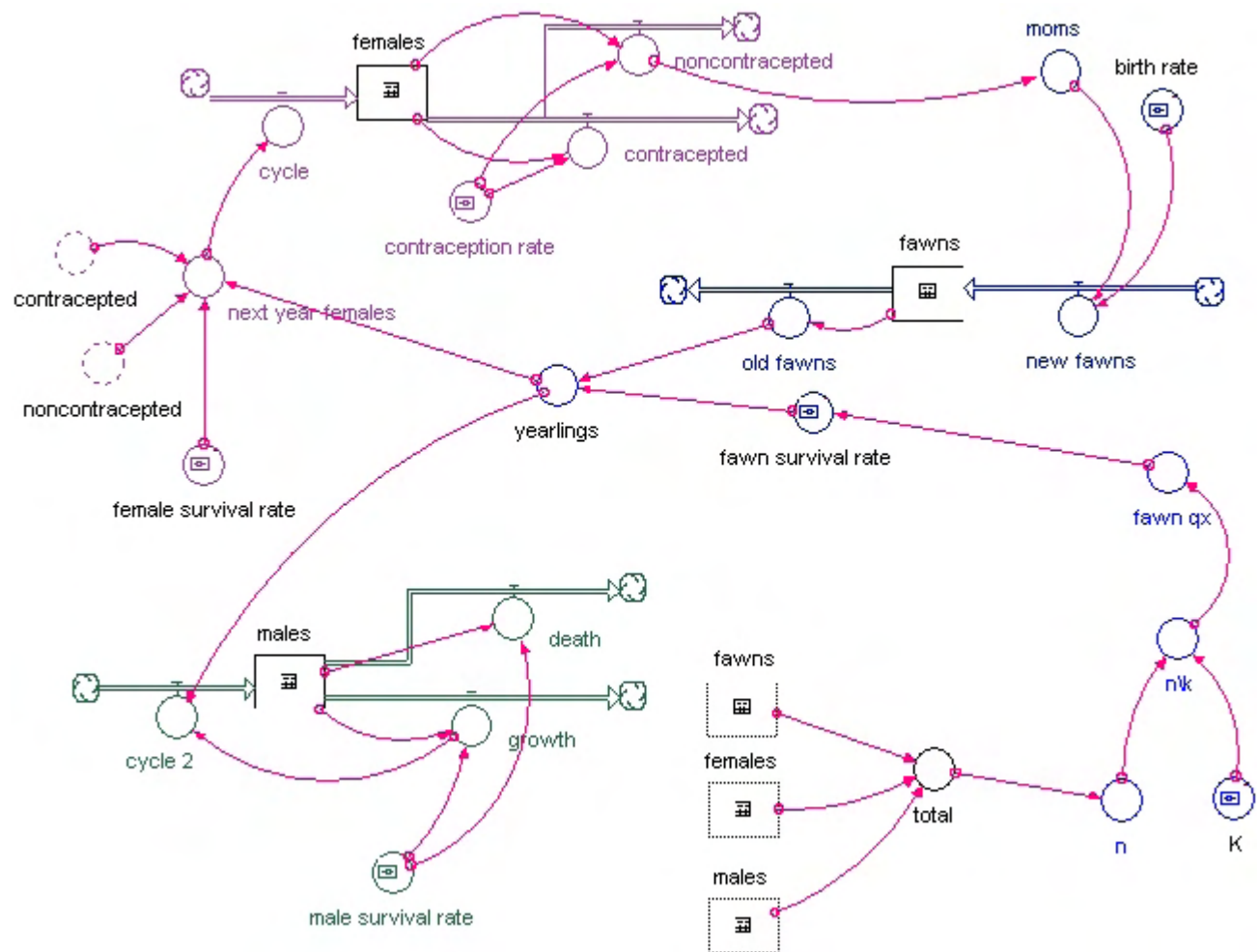


Figure 12. Flow diagram of bait-year model.

Population Description

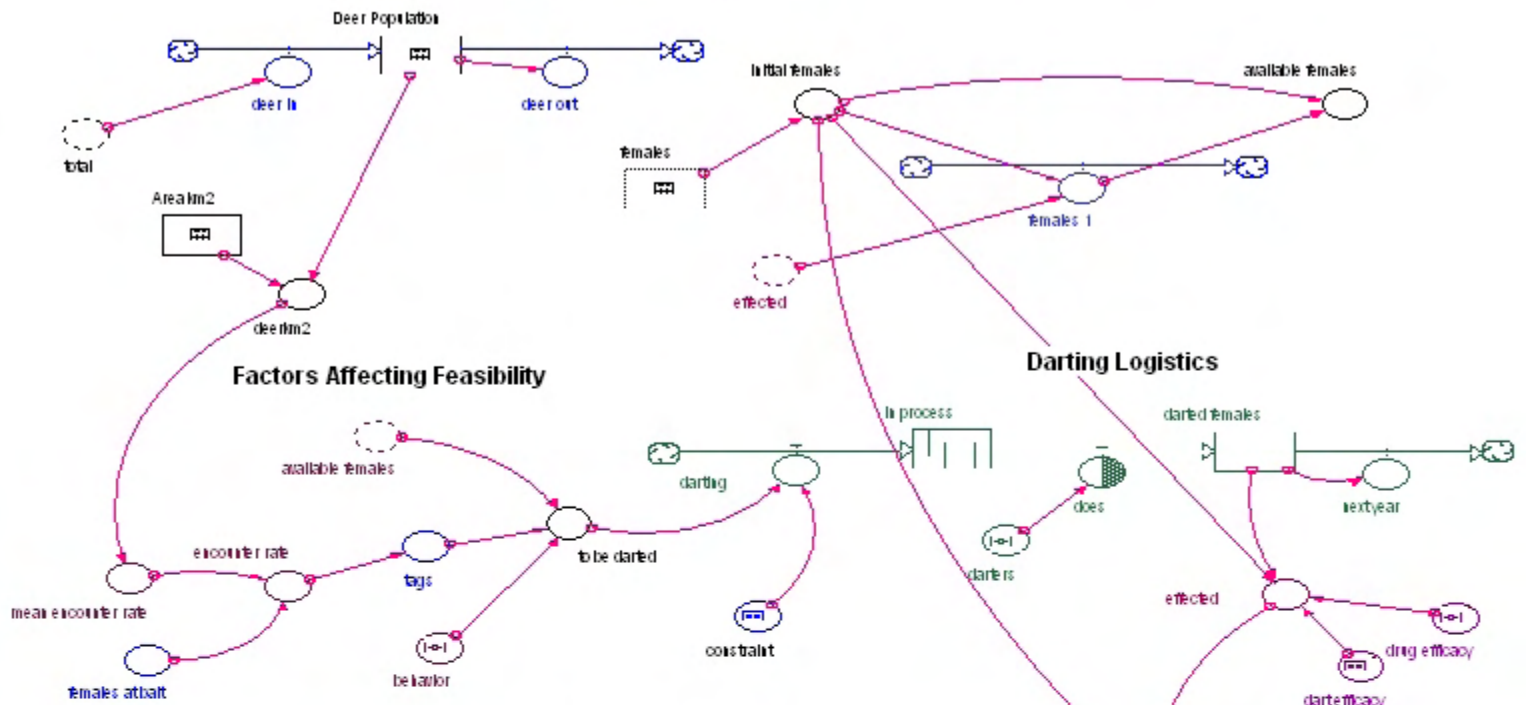


Figure 13. Flow diagram of random encounters-year model.

Population Description

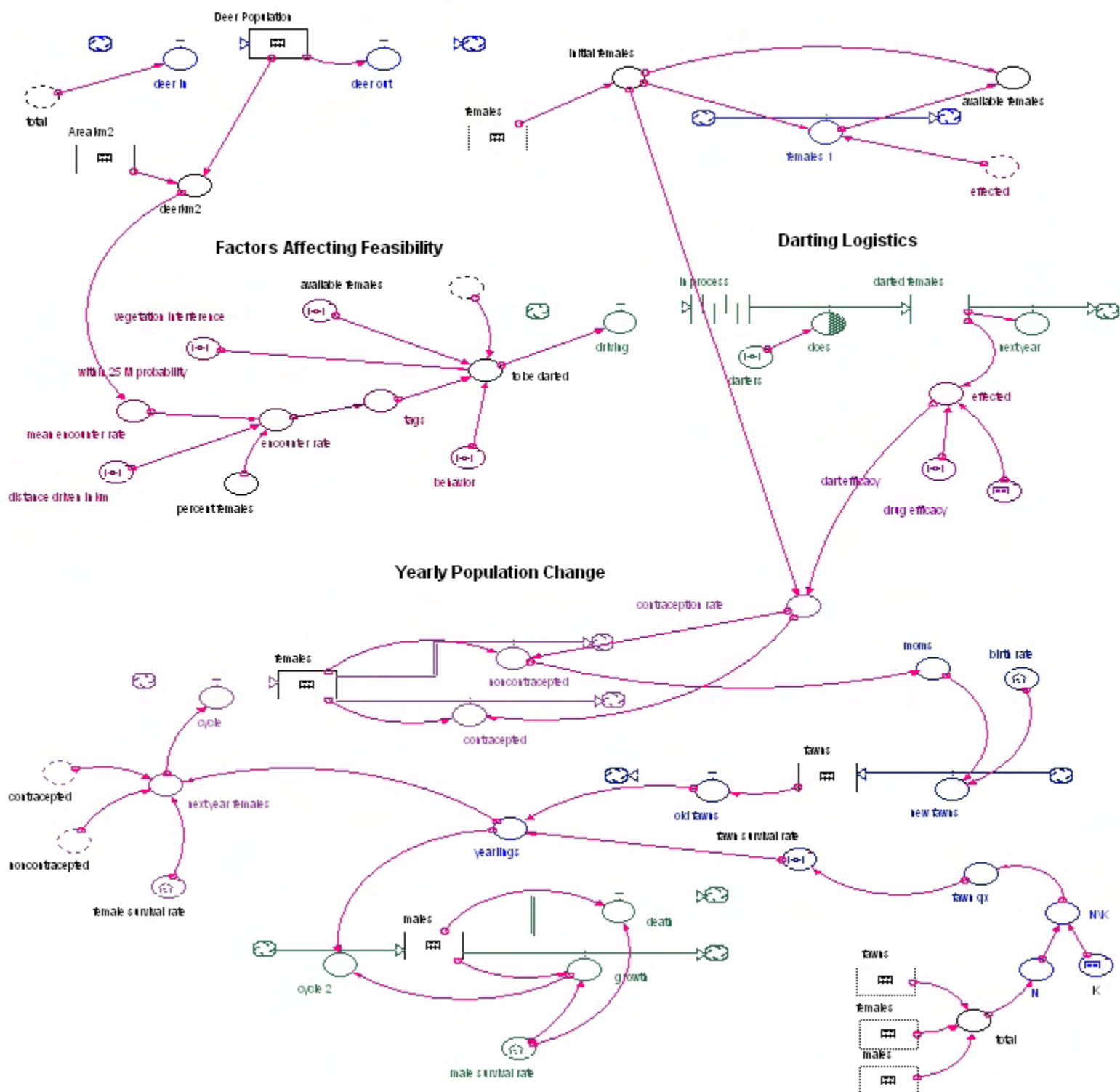
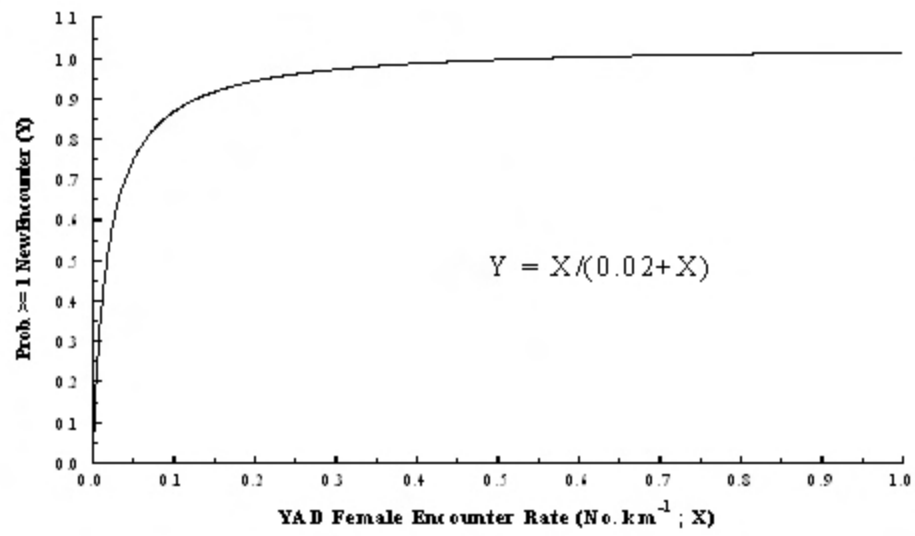


Figure 14. For each encounter with a female, the probability of that animal being a new yearling or adult female deer for random searches (a) and at a bait site (b) in Morristown National Historical Park, Morristown, NJ, August – October 1998.

a



b

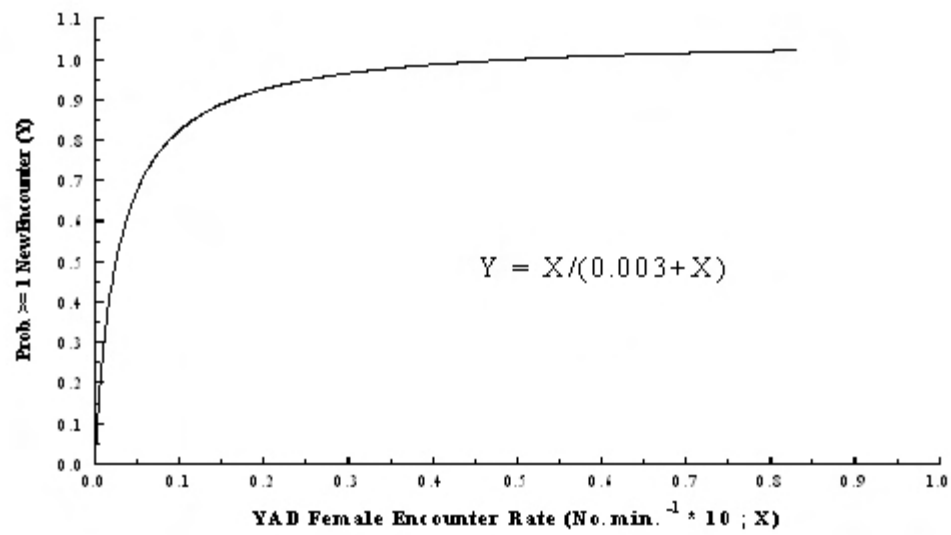


Figure 15. The queuing relationship between density estimates from autumn 1996 – 1998 and encounter rates for random encounters with female deer in Morristown National Historical Park, Morristown, NJ, August – October 1998.

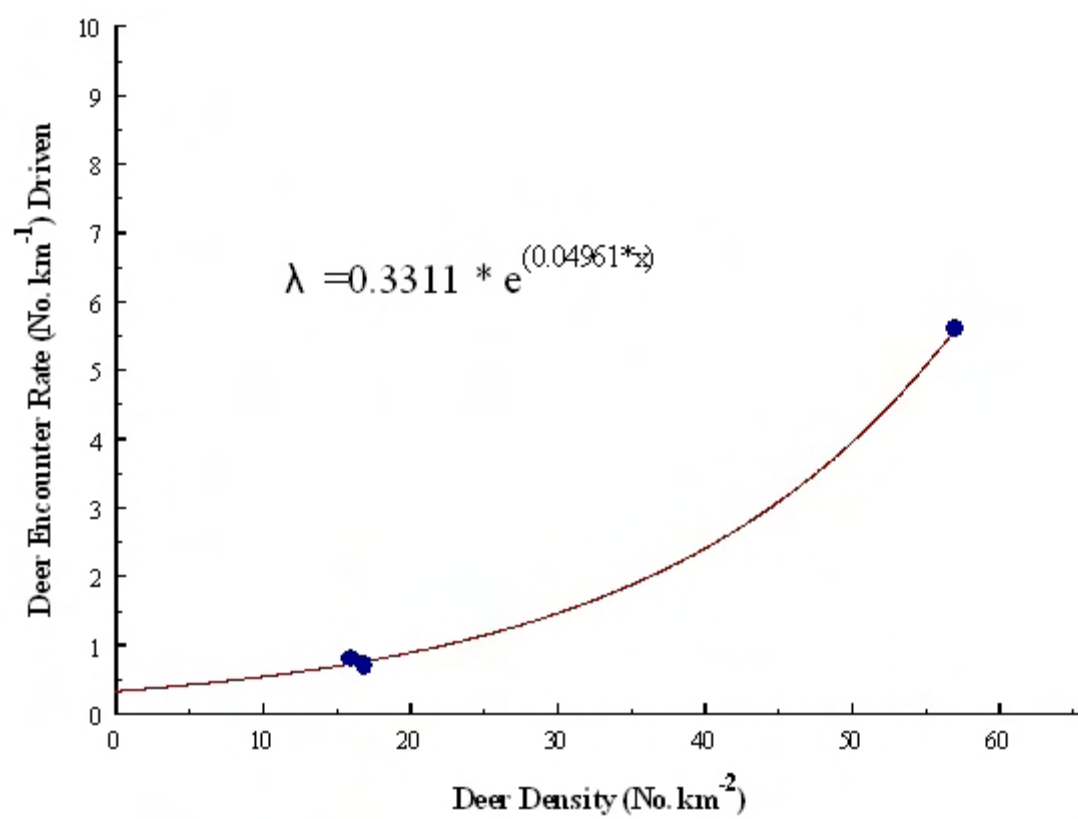
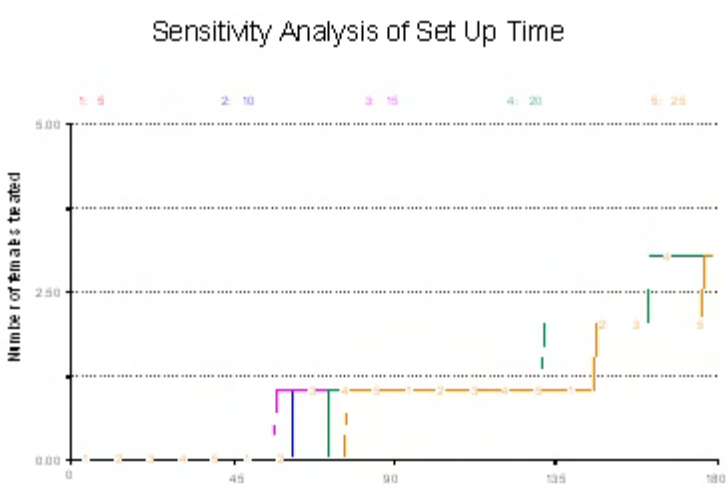
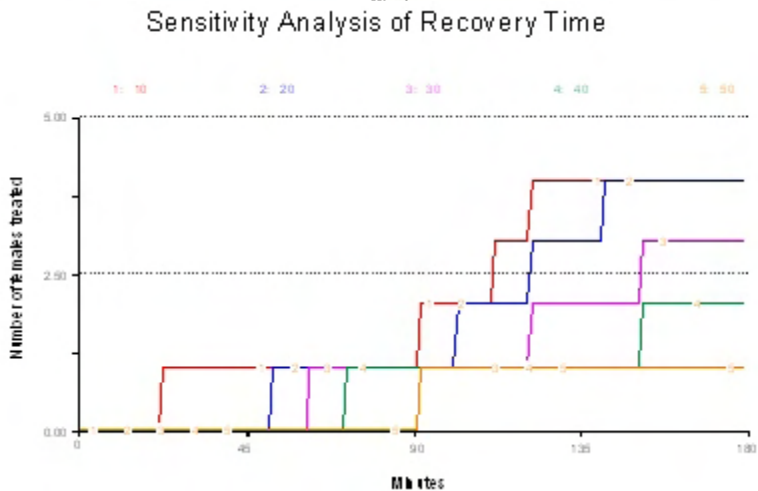


Figure 16. Sensitivity analysis of bait-day model to setup time (a), recovery time (b) and overall efficacy (c).

a



b



c

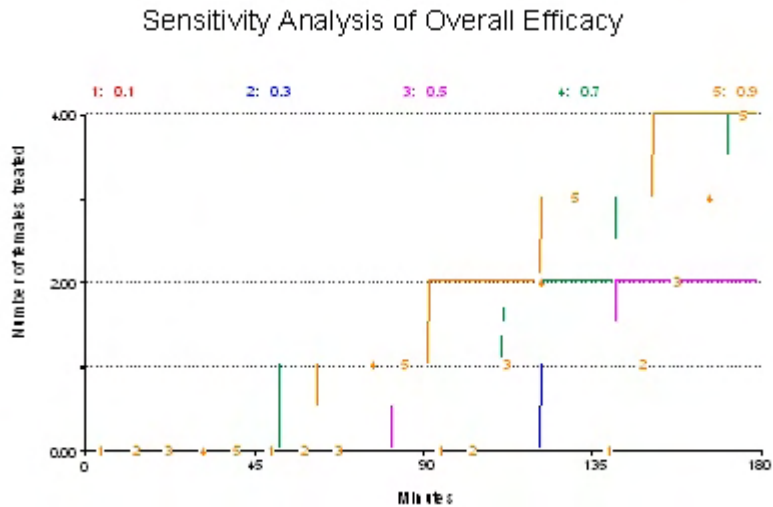
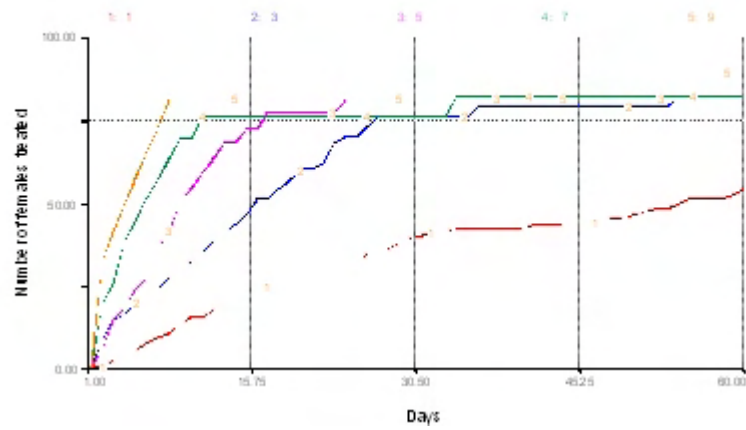


Figure 17. Sensitivity analysis of bait - season model to the number of darters [a], the dart efficacy [b] and the drug efficacy [c].

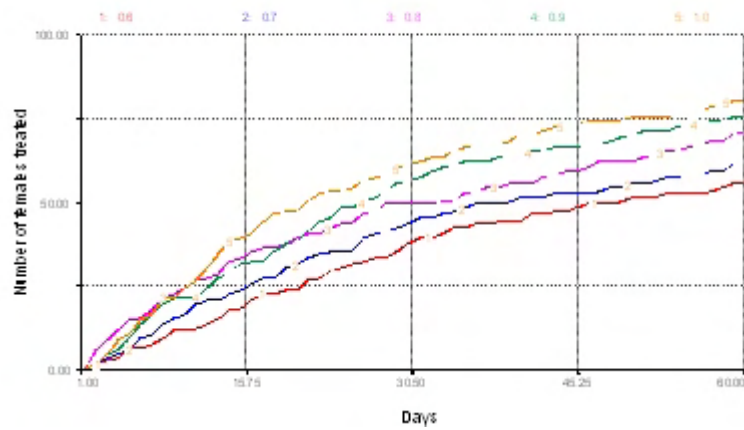
a_____

Sensitivity Analysis of Darters



b_____

Sensitivity Analysis of Dart Efficacy



c_____

Sensitivity Analysis of Drug Efficacy

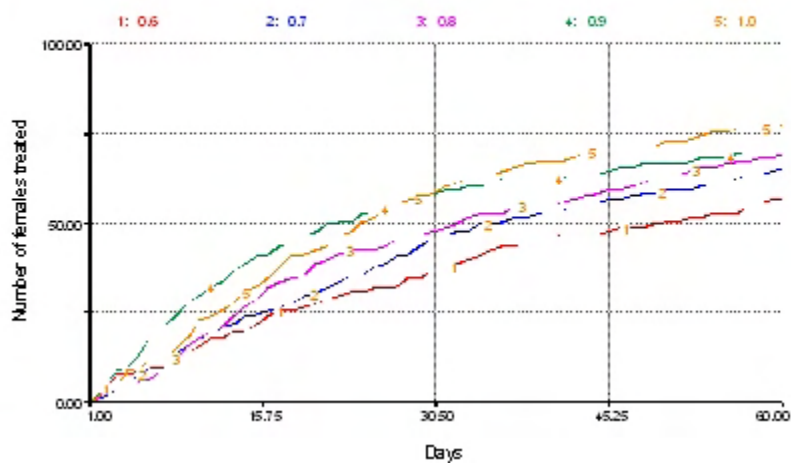


Figure 18. Sensitivity analysis of population model to contraception rate.

Sensitivity Analysis of Contraception Rate

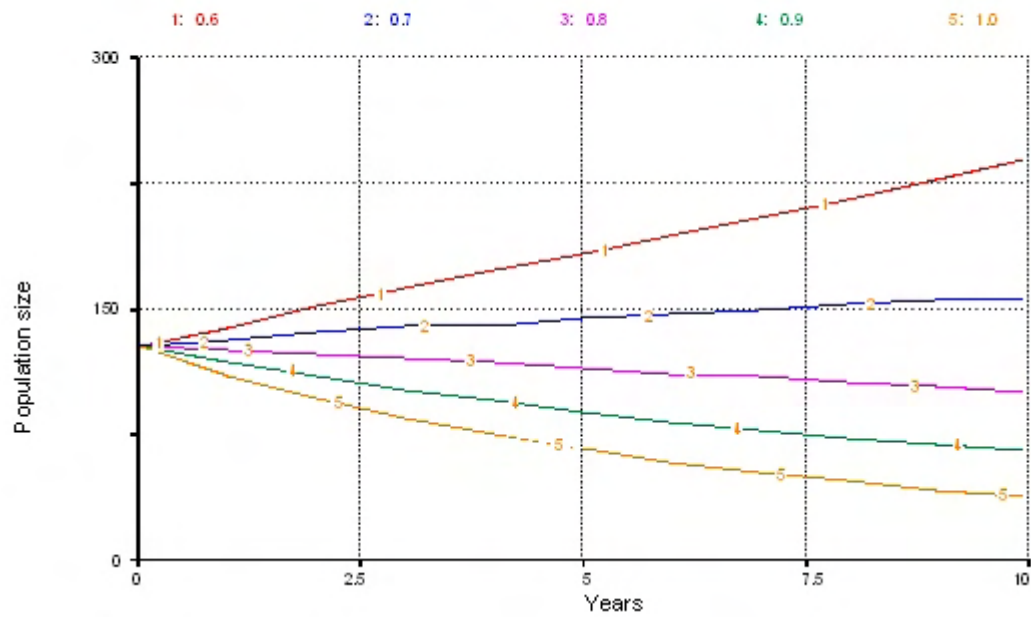


Figure 19. Sensitivity analysis of random encounters - season model to the distance driven.

Sensitivity Analysis of Distance Driven (km)

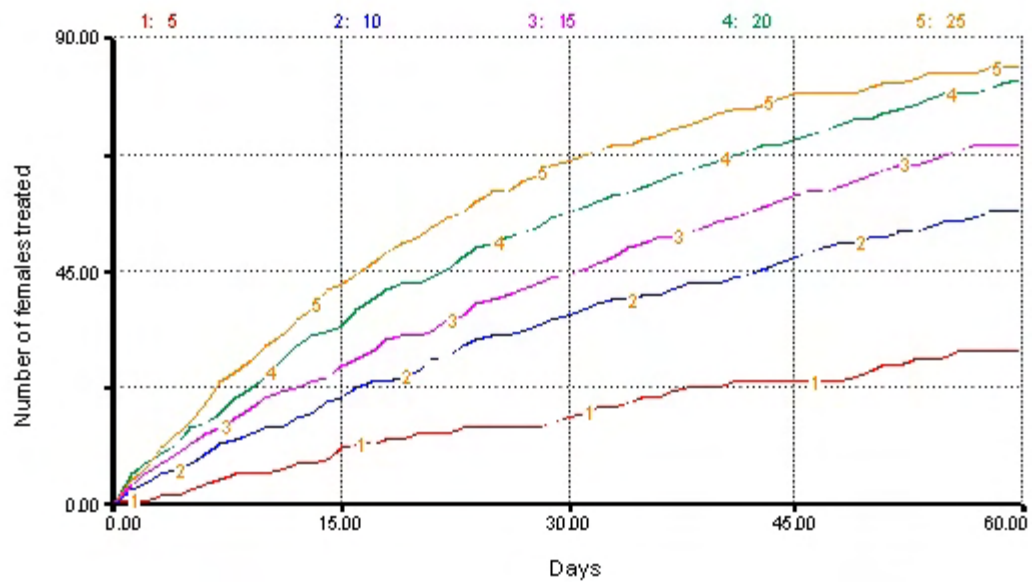


Figure 20. Sensitivity analysis of bait - year model to constraint.

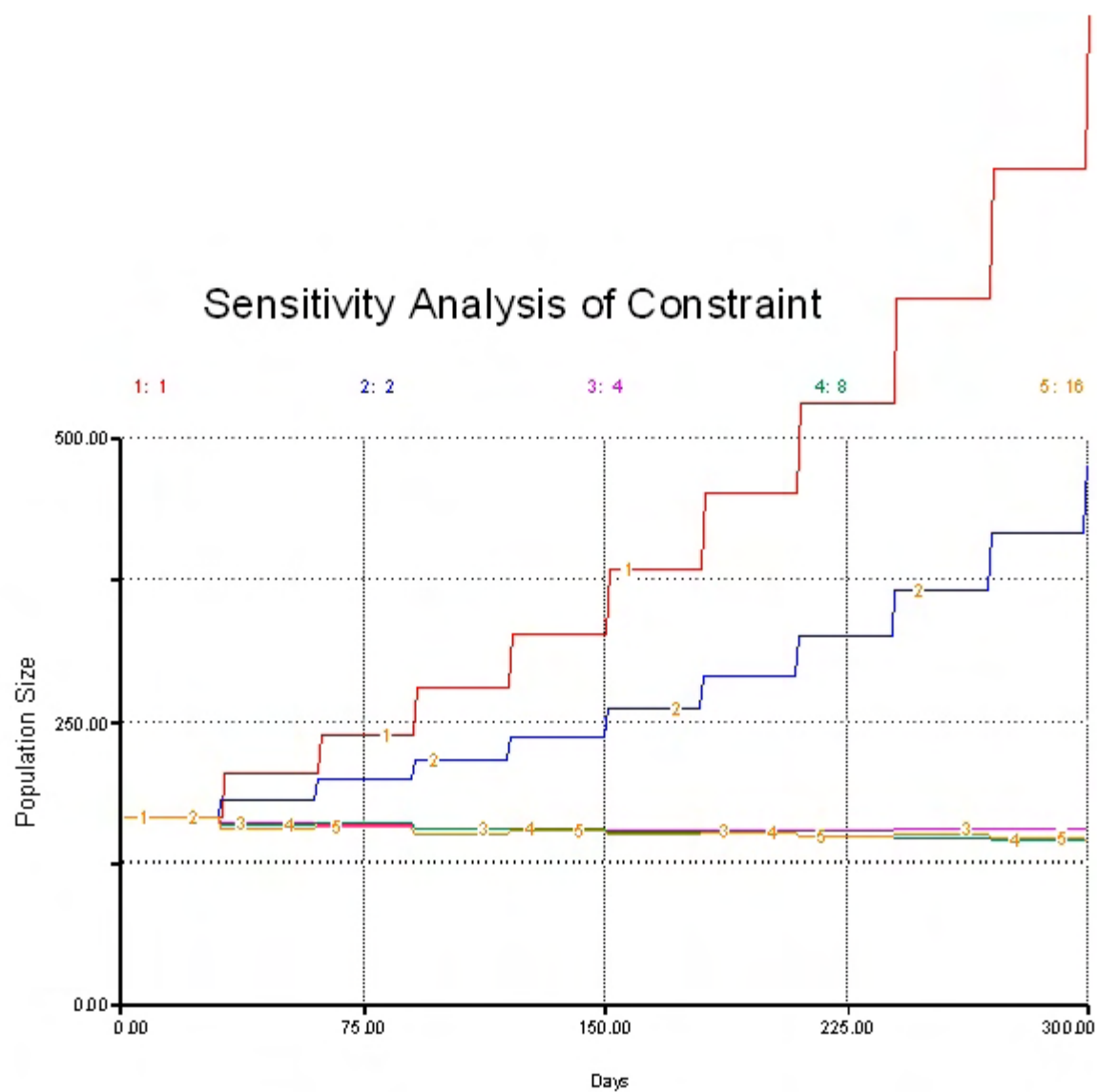


Figure 21. Sensitivity analysis of random encounters - year model to number of darters.

Sensitivity Analysis of Darters

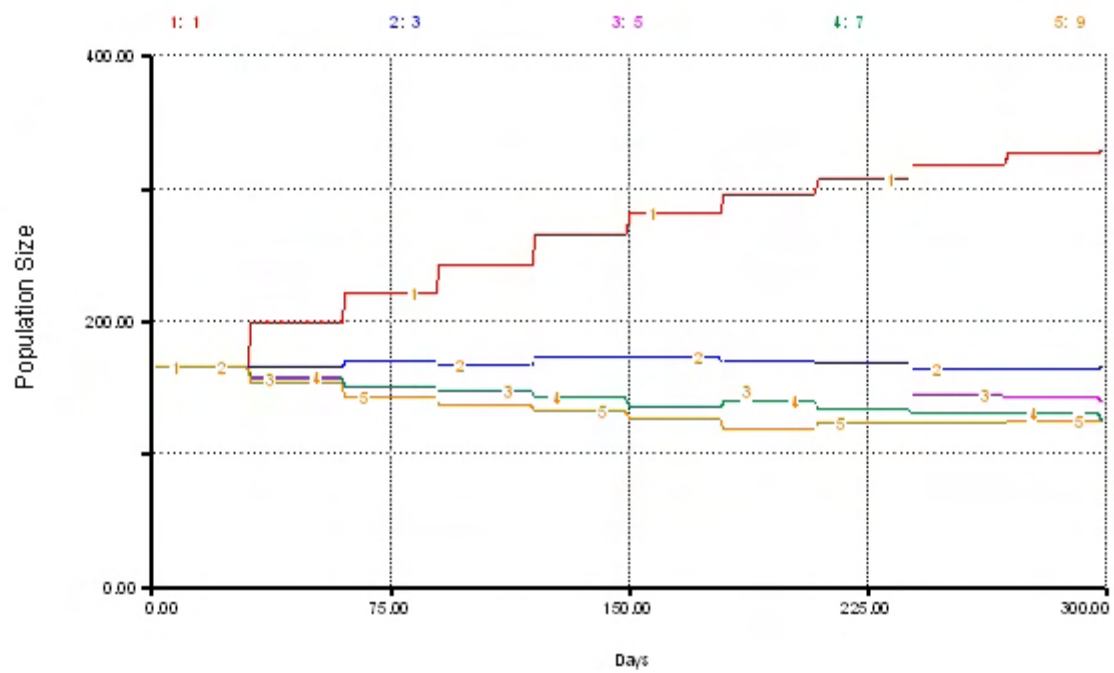
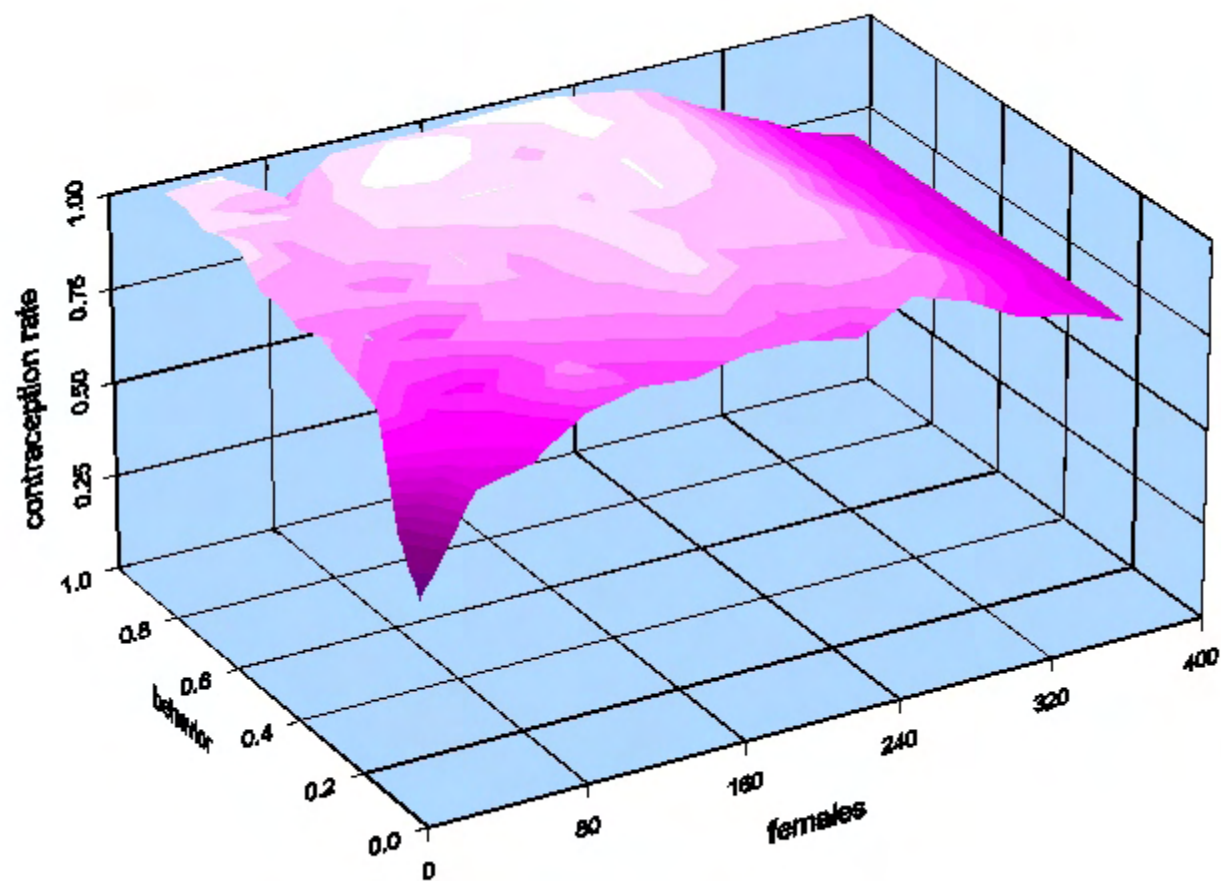


Figure 22. Graph of change in number of females, behavior and contraception rate variables over 40 simulations with the bait - year model using data collected in Morristown National Historical Park, Morristown, NJ. White represents high contraception rates while as the shades of pink get darker, they represent a lowering contraception rate.



As the nation's primary conservation agency, the Department of the Interior has responsibility for most of our nationally owned public land and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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