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The events that transpired during the 1990's in the western New York community of Irondequoit constitute a remarkable experiment in conservation. Irondequoit is an upscale suburb of Rochester. At issue was what to do with an exploding deer population. Citizen groups organized to advocate different solutions to the problem, some favoring hunting or culling the populations; others opposing any lethal actions. After a Citizen Task Force made recommendations that included culling the herd, opponents took their case to court. They lost, but that loss was not an end to the debate. Anger and frustration increased to the point that open dialog became almost impossible.

A more inclusive and constructive process began when a group of citizens prompted local government officials to explore contraception. With an extraordinary display of civic leadership, residents and public servants in the town built a grassroots political coalition. In turn, this coalition provided the catalyst for the formation of a partnership of local, county, and state governments, the state conservation agency and two major research universities. This report describes one of the products of that effort: the findings of a field study to assess the feasibility of using contraception to control the population growth of the deer population in Irondequoit.

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Funding provided by the New York State Legislature, Monroe County, the State University of New York College of Environmental Science and Forestry, the U.S. Geological Survey – Biological Resources Division, the Roosevelt Wild Life Station and the Humane Society of the United States.

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College of Environmental
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Contraception & Deer



The Irondequoit Report

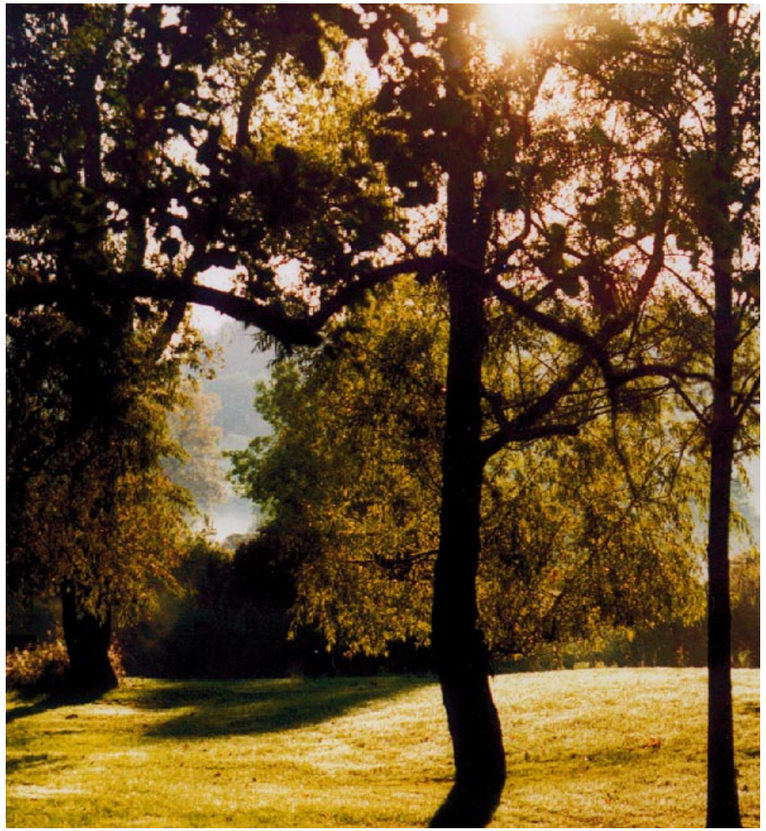
William F. Porter
H. Brien Underwood



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Contraception & Deer



The Irondequoit Report

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The Irondequoit Report

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PREFACE

Irondequoit was the first study in an environment typical of most suburban communities facing the dilemmas of deer management. At the outset of the study no one had direct experience with using contraception to control growth in a free–ranging deer population. Earlier work at Front Royale had focused on behavioral impacts of contraception.[1] Other trials at Fire Island were not applicable because of the unique nature of the deer population and the geography of the island.[2] Studies at the National Institute of Standards and Technology, and in Connecticut focused on small populations in environments with excellent access to deer. No one had attempted to deal with a population numbering hundreds of deer in an environment ranging from flat, grassy backyards to rugged, wooded ravines.

The field study conducted in Irondequoit was one component of a larger cooperative study commissioned by the New York State Legislature. With leadership provided by the New York Department of Environmental Conservation, scientists from the State University of New York College of Environmental Science and Forestry at Syracuse, and the College of Agriculture and Life Sciences at Cornell University undertook a four–year investigation. The intent of the overall study was to provide the people of New York with a comprehensive assessment of contraception as a technique for managing deer populations in parks and suburban environments.

We gratefully acknowledge the residents of the Town of Irondequoit who allowed us access to their property and reported sightings of marked deer. Without their support, this project would not have been possible.

We were assisted by a group of excellent field biologists. Dawn Gorham, Doug Little, and Daniel Bogan served as assistants during field work to collect data on darting and movement behavior. Dr. Dale Garner of the Iowa Department of Natural Resources assisted with aerial surveys. James Eckler and John Hauber of the Department of Environmental Conservation helped us collect data from deer removed during bait–and–shoot operations.

The project was a joint effort that included biologists from the College of Agriculture and Life Sciences at Cornell University, the New York State Department of Environmental Conservation, and the College of Environmental Science and Forestry in Syracuse. Dr. Milo Richmond, Leader of the Biological Resources Division Cooperative Research Unit, and Dr. Paul Curtis, Professor of Wildlife cooperated closely throughout the project, and directed the companion work at Seneca Army Depot. Drs. Barbara Knuth and Bruce Lauber of the Human Dimensions Research Unit in the College of Agriculture and Life Sciences at Cornell University directed the sociological surveys of the Town. The Department of Environmental Conservation provided administrative oversight and field assistance, and we gratefully acknowledge Dr. George Mattfeld, John O'Pezio, David Odell, John Hauber, and James Eckler.

The Humane Society of the United States provided the PZP vaccine/Adjuvant and we operated under their license. We appreciate the fine efforts of Dr. Allen Rutberg.

The residents and public servants in Monroe County and the Town of Irondequoit deserve tremendous thanks. James Mulley enabled us to move through the County system with ease. Town Supervisors Suzanne Masters, William Dillon and David Schantz worked long hours to ensure a cooperative spirit existed throughout the Town. Robert Brown, Maryann Haas and Sandy Baker served as a sounding board to our ideas and a link to the community. Sgt. Dunn provided great assistance during the course of the research.

We especially wish to thank Maryann Haas. In every large effort, there is one person working behind the scenes who makes the difference. She was that person. She brought the idea of a field test of immunocontraception to life in Irondequoit through endless meetings and telephone calls. She then made the project a success by introducing us to key people in the community and teaching us grassroots politics.

Genevieve Nesslage, Brent Rudolph and Jennifer Woodard assisted in development of the final report. Earlier drafts of this report were reviewed by George Mattfeld, Paul Curtis, David Schantz, Dale Garner, Brent Rudolph, Maryann Haas, James Mulley, and Bruce Lauber.

Funding for this project was provided through the New York State Legislature. We particularly acknowledge Assemblymen Richard Brodsky and Joseph Morelli, and Senator James Alesi. Additional funding was provided by Monroe County with this support of County Executive Jack Doyle, and the Town of Irondequoit with the support of Suzanne Masters, William Dillon and David Schantz.

Finally, special recognition must be extended to three bright young graduate students, Clay Nielsen, Brent Rudolph and Jennifer Woodard. Clay provided the initial analysis of data derived from the bait–and–shoot program. Brent took on the challenge of measuring the effort to capture and treat deer in the Town. Jennifer documented the movement behavior. Their dedication to the field work, analytical skills and insight were extraordinary. We could not have found more capable people.

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EXECUTIVE SUMMARY

A team of scientists from the State University of New York College of Environmental Science and Forestry at Syracuse was the first to study the feasibility of contraceptive treatments for managing white–tailed deer in a typical suburban environment. This team was part of a larger study that explored both the efficacy of immunocontraceptive drugs and the efficiency with which these drugs could be delivered to free–ranging deer. Other members of the team included scientists from the College of Agriculture and Life Sciences at Cornell University, and wildlife biologists with the New York State Department of Environmental Conservation. Most of the funding for the work was provided by the New York State Legislature.

This book reports on the findings of an investigation conducted in the Irondequoit, a suburb of Rochester, New York, during 1997 through 2000. The intent of the study was to identify and measure the influence of the factors that would determine the effort required to deliver contraceptive treatments via dart rifle. We used the immunocontraceptive vaccine, Porcine Zona Pallucida (PZP). We examined population density, physical condition, movement behavior and survival of deer, as well as the effort required to vaccinate deer. We describe the biology of using the immune system to effect contraception, the basis for predicting population growth, the importance of understanding movement behavior of deer.

Many of the conclusions from our study that may be helpful to communities considering using contraception in a deer management program.

- Contraception can be used to control deer populations under some circumstances.
- Estimating the cost of applying contraception is dependent on the number of females that must be treated, the rate at which females can be darted, and the efficacy of the treatment.
- The darting rate depends on population density and approachability of deer, and land access.
- Effort invested to treat each deer increases as the program progresses because as more deer are treated, those that remain to be treated comprise a pool of individuals whose behavior makes them more difficult to approach.
- Effort will be greater if the population is first reduced by culling because those deer surviving the cull are the individuals that will be more difficult to approach for darting.
- Attaching radiotransmitters to deer, while initially expensive, may be cost– effective because of reduced effort required to find deer for treatment.
- The minimum population size that can be maintained is determined by treatment efficacy; at 90% efficacy, the management goal will need to be a population that is larger than 25 % of ecological carrying capacity.
- To maximize cost efficiency, deer management should be occur at the geographic scale of a neighborhood.

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Irondequoit is one of many communities across the US where white–tailed deer (*Odocoileus virginianus*) have grown dramatically over the past 30 years. The suburban landscape is composed largely of residential neighborhoods and parks that provide deer with high quality sources of food such as ornamental plants and shrubs. Many suburban residents enjoy seeing deer and consider deer to be an asset to their community. However, as deer populations have grown, so have conflicts with humans.[3] Automobile collisions, browsing of ornamental plants, and concerns about the possible transmission of Lyme disease are on the rise. Local governments are faced with the dilemma of whether or not deer abundance should be actively controlled, and, if so, how control should be implemented.

Irondequoit is located in Monroe County, New York (43o12'N, 77o35'W), approximately 6 km north of the city of Rochester (Figure 1). The Town is approximately 17 square miles in size, bounded by Lake Ontario to the north, the City of Rochester to the south, the Genesee River to the west, and Irondequoit Bay to the east.



Suburban residents often consider deer to be a nuisance because of their browsing of ornamental vegetation found around homes and suburban parks. Trees and plants may be surrounded by fences to prevent deer from browsing.

Photo by: William Porter



Deer–car collisions are often the most significant cause of mortality of deer in a suburban environment.

Photo by: Jennifer Woodard

The Town is composed of five principal types of land cover:

Urban (45%) – both commercial and residential development;

Hardwood Forest (35%) – mature deciduous forest consisting of beech (*Fagus grandifolia*), birches (*Betula* spp.), sugar maple (*Acer saccharum*), and oaks (*Quercus* spp.)[4];

Open Land (15%) – largely mowed lawns and parks, including a golf course;

Coniferous Forest (2%) – scattered conifer plantations consisting of hemlock (*Tsuga canadensis*) and white pine (*Pinus strobus*);

Shrub Areas (0.1%).



Aerial photo of the Town of Irondequoit, NY.

Figure 1.0



Photo by: William Porter

Many suburban communities across the US have seen their deer populations increase dramatically. Lawns, gardens, and parks provide favorable habitat, there are few predators, and many people feed the deer during winter months.

About half of the town is considered to be intensely developed for housing or commerce. Intense development is defined as having more than 50 % of the ground area of a 1 kilometer square (0.38 square miles) developed as structures or roadways. Commercial development transitions from mostly residential development in the south to primarily parkland in the north. Development was least intense where erosion by numerous creeks has produced a steep ridge and valley relief. The northern part of the Town includes the 1,000 acre Durand–Eastman Park which is owned by Monroe County. In the western part of the Town is an area known locally as the Flats, a low–lying floodplain created by an historic oxbow of the Genesee River. This area has low–intensity residential development.

The residential and park areas of Irondequoit were partitioned into four locales, identified as the Flats, Central, East, and Bay. The locales were delineated by man–made boundaries, such as highways and commercial districts. Traffic speed limits range from 25 to 35 MPH in all locales, with four–lane divided highways present in the Bay and East locales.

The Flats is an area of limited residential development, created by an oxbow of the Genesee River in the west–central portion of the town. The Flats contains large (> 7 acre), open grassy areas. Seneca Park, which is located in the Flats, provides softwood and mixed hardwood cover. The Flats is separated from the Central locale by a heavily traveled road.



Photo by: William Porter

The Central locale includes the portion of Durand–Eastman Park west of King's Highway. The Central and East locales are characterized by medium to high levels of residential development, with no developed areas located in Durand–Eastman Park.



Photo by: Jennifer Woodard

The East locale includes Durand–Eastman Park east of King's Highway. The East and Bay locales have steep ridge–and–valley relief dominated by hardwood forest and shrub areas.

The Bay locale includes Irondequoit Bay Park, which is located in the southeastern portion of town. The Bay locale is separated from the other locales by a four–lane highway. Residential development in the Bay locale is high with the exception of Irondequoit Bay Park.

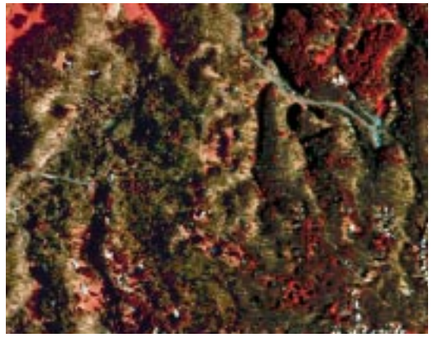


(top) The Town of Irondequoit is composed of a variety of habitat types. Most of northern Irondequoit is characterized by residential neighborhoods, forested areas and a 1,000 acre county park. (middle–left) The Flats is a neighborhood in west–central Irondequoit with low housing density, many areas of open land, and a few areas of a forested landscape.

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The Central locale includes the portion of Durand–Eastman Park west of King's Highway. The locale is characterized by medium to high levels of human development outside the park.



The East locale includes the portion of Durand–Eastman Park east of King's Highway. The locale is characterized by medium levels of human development outside the park. The East is also characterized by many ravines with forest cover.

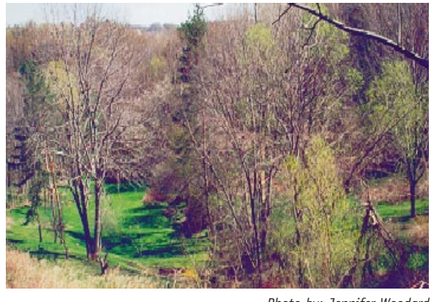


Photo by: Jennifer Woodard

The Bay locale includes Irondequoit Bay Park and is composed mostly of high human development. The park is predominantly forested and sparsely developed. Major roads and highways are prevalent in this locale.

The New York State Department of Environmental Conservation (DEC) first began receiving complaints regarding abundant deer in Irondequoit in 1974.[5] Deer Management Unit (DMU) 96 was formed in 1976 to focus deer management efforts in the Greater Rochester area and increase the number of harvest permits. However, firearms discharge regulations prohibited hunting within the Town of Irondequoit and Durand–Eastman Park. An exception to the discharge ordinance was made in 1983 so that deer could be legally harvested during a bow hunt with a DEC–issued damage permit.

Increased concern of Town residents regarding automobile accidents, damage to native and ornamental vegetation, and declining health of the deer population led to a call for a more comprehensive solution.6 A public forum attended by more than 500 residents was held in 1989 to discuss deer management. In 1990, the Irondequoit Deer Action Committee (IDAC) was formed to address deer management issues in the Town of Irondequoit. IDAC proposed three options for deer management: (1) translocation of deer to a farm, (2) trap and slaughter, and (3) bait–and–shoot.

These recommendations did not result in public consensus on management and in 1991, the DEC organized an 11–member Citizen Task Force to provide deer management recommendations for the entire DMU96 in Rochester. The task force recommended that the optimal density would be 20 deer/mi^2 and suggested culling to decrease the deer population over the next four or more years.[3] The task force also recommended standardizing deer–vehicle collision reporting, collecting data on habitat impacts and physical condition of deer, developing accurate techniques to estimate deer population, and using immunocontraception as a long–term control. In response, Monroe County and the Town of Irondequoit passed legislation permitting culling of deer in Durand–Eastman Park.

However, debate about deer management grew acrimonious and groups opposed to lethal control of deer began to look for alternatives. The Monroe County Alliance for Wildlife Protection (MCAWP), a member of the Citizen Task force remained active and vocal in the community, urging investigation of contraception as an option. The following year, another group of residents formed Save Our Deer (SOD) to promote the humane management of deer in Irondequoit. In 1993, government officials appointed a Long–Term Deer Management Team to suggest specific techniques and methods to implement deer management goals. This team included members of the Irondequoit Town Board as well as representatives from county departments such as parks, sheriff, public safety, and transportation. This group recommended culling to reduce population size, followed by contraception to prevent regrowth of the population.

Opposition to the culling continued and two national organizations became involved: the Humane Society of the United States (HSUS) and the Fund for Animals. These groups filed a legal suit asking for a court injunction to delay removal of deer. The case was unanimously overturned by the New York State Appellate Court and the first bait–and–shoot program occurred in 1993. In accordance with the recommendation of the DEC and the Citizen

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Task Force, 80 deer were culled by Monroe County Sheriff's Office sharpshooters. DEC biologists collected data on all deer culled. The bait–and shoot program was limited to Durand–Eastman Park.

Still searching for a way to build consensus, the Supervisor of the Town of Irondequoit commissioned a new committee in 1994. Membership of this new group was open to all, so long as each person was willing to commit to a series of training sessions to learn how to participate in constructive dialog and work toward a solution to which all groups could agree. Members of SOD and MCAWP teamed with members of IDAC, and others joined to form the Irondequoit Deer Evaluation and Alternatives (IDEA) Committee. The IDEA committee responded to the Irondequoit Town Board by recommending that a field study be commissioned to assess the feasability of using immunocontraception to control deer.

In 1995, a resolution was passed authorizing the Town and the HSUS to develop a formal plan. The Town appointed a citizen's committee, the Irondequoit Immunocontraception Proposal Committee, to oversee the program. Membership of this committee was chosen from among those on the IDEA committee, and they reported to the IDEA committee for approval before making recommendations to the Town. The Proposal committee released a status report in April of 1995 and held a town meeting. The committee suggested a program schedule for immunocontraception and criteria for potential immunocontraception program sites. The HSUS evaluated 18 sites and chose 6 potential areas for application of immunocontraception.[7]

At the same time, these same issues were being debated in suburban communities near New York City. In December, 1995, responding to pressure from downstate communities, the New York State Legislature asked that the DEC undertake a study of contraception as a management technique for deer in urban areas. The DEC sought the assistance of the two public research universities in the state with expertise in deer biology and management: the College of Environmental Science and Forestry in Syracuse, and the College of Agriculture and Life Sciences at Cornell University.

A proposal for a four–year study was submitted to the Legislature in March of 1996. The proposal recommended an integrated study involving an evaluation of the efficacy of two contraceptive vaccines and a field study of the logistical feasibility of treating free–ranging deer with vaccines. The efficacy trials were conducted at the Seneca Army Depot and the feasibility study in 2 communities. Partial funding for the initial year of research was approved by the Legislature in the summer of 1996. Funding was not sufficient to undertake studies at three sites, so the study was scaled back to field trials in Irondequoit and efficacy trials at Seneca Army Depot. Irondequoit was chosen over other communities because of the greater depth and breadth of information available on its deer population and the strong interest among residents.

A protocol for implementation of the immunocontraception program was submitted for approval to the US Food and Drug Administration in December, 1996 under the sponsorship of the HSUS. Authorization was received in January, 1997, and the study got underway with the College of Agriculture and Life Sciences working on vaccines at Seneca Army Depot, and the College of Environmental Science and Forestry studying field application of the vaccine in Irondequoit. A third dimension to the study was added to document knowledge and attitudes of residents of Irondequoit, and the surrounding Monroe County, to deer management. This work was conducted by the Human Dimensions Research Unit at Cornell University.[8]

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Legislative funding for the four–year project ceased after the third year. The trials at Seneca Army Depot were completed with funding from DEC and the National Wildlife Research Center of the US Department of Agriculture. Funding for the final year in Irondequoit was provided by Monroe County.

SCIENTIFIC PEER RE VIEW OF FINDINGS

Technical reports arising from the project began emerging in 1997. These reports were submitted for review by scientists who had familiarity with the issues and techniques, but no direct connection to the project. The first report from the work in Irondequoit involved synthesis of data from aerial surveys and bait–and–shoot programs to depict the growth pattern of the deer population. The results received favorable evaluation from the scientific community in the spring of 1997. A technical paper was published in the Wildlife Society Bulletin in summer of 1997. These initial results formed the basis for designing the field studies to apply the vaccine. Field studies were completed in 1999 and results were presented for review by scientific community. These results were received favorably and a technical paper was published in the Journal of Wildlife Management in April, 2000. The technical findings presented in these two technical papers are the primary focus of the information presented in this book.9,10

Contraception as a solution to deer population management is often suggested because we have a common reference: human reproduction and the Pill. Further, application of contraception appears easy because many deer in Irondequoit are easy to approach. If a contraceptive vaccine could be delivered via injection with a dart, then controlling growth in the population should present little problem. The difficulty lies in the fact that not all deer that are easily approached, and some are so wary that they are infrequently seen. Questions arise about the feasibility of applying contraceptive treatments. How many deer are wary and reclusive? How many must be treated with a vaccine? How much effort will it take to treat them?

These questions are at the heart of a solid assessment of the feasibility of contraception as a management technique. Answering these questions is a bit more complicated than a back–of–the–envelope calculation. The findings of our research speak to the complexity of applying this management approach cost–effectively. Consequently, understanding the science underlying these findings requires some background. Below is a brief summary of the biology of immunocontraception and population growth in deer.

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A BRIEF LESSON IN BIOLOGY

BIOLOGY OF IMMUNOCONTRACEPTION

We know that the Pill prevents pregnancy by introducing hormones into the reproductive system of women. A hormone–based system is not a good option for contraception in wildlife because dosage and timing of delivery is critical for the drug to work effectively. Daily dosage is impossible to accomplish in free–ranging wildlife populations. Further, synthetic hormones like the Pill can be passed along the food chain, affecting animals that consume a treated deer. Immunocontraception is a creative alternative to the Pill that circumvents both of these problems.

The word, immunocontraception, is a combination of the words immuno, as in immunological, and contraception. As the word implies, immunocontraception operates through the immune system.11 We can understand the biology underlying immunocontraception by relating it to a common human experience. We are all familiar with the basics of stimulating the immune system with vaccines. For instance, many of us get tetanus shots periodically. The injection contains the tetanus organism in a form that has been altered so that it will stimulate the body to produce antibodies without causing illness. Once the antibodies are present, the body eliminates the tetanus organism whenever it is encountered. To maintain sufficiently high levels of antibodies to resist tetanus, we receive a booster shot every 5 to ten years.

Immunocontraception uses a vaccine to stimulate the body to produce antibodies against the proteins produced by the reproductive system. Like the tetanus shot, immuno–contraception involves injecting a protein into the body. One protein now being used is Porcine Zona Pellucida, or PZP. Zona pellucida is a scientific name for the protein membrane that occurs on the outside of all mammalian eggs. Biologists obtain the protein from eggs in the ovaries of pigs, hence the name, Porcine Zona Pellucida. When we introduce this protein into the body of a deer, the immune system begins to produce antibodies that recognize and attack the Zona Pellucida protein. So when the deer's own ovary releases an egg, the antibodies mistake the deer Zona Pellucida as a foreign protein and attack the egg, preventing conception (Figure 2).

Experience with PZP shows that 2 shots are required in the first year to prevent conception in the first year and at least one shot, annually, thereafter to maintain the contraceptive effect. To reach the high levels of antibodies necessary to prevent fertilization, PZP must be combined with an adjuvant.[12] An adjuvant is a chemical compound that causes exceptional stimulation of the immune system.

To deliver PZP to deer, we create a vaccine by combining the PZP with the adjuvant, and load the mixture into a dart. The dart contains a syringe and hypodermic needle that inject the vaccine. We shoot the dart from a specially–designed rifle into the large muscle mass of the hip of the deer. The dart contains a small charge of gunpowder that explodes when the dart hits the deer. The charge pushes the plunger of the syringe, injecting the drug. The dart then falls out and is recovered by the biologist.

Legal Regulations – Although the effects of PZP are well under–stood, use of PZP is regulated by the US Food and Drug Administration. PZP is considered to be an experimental drug and all application to free–ranging deer must occur under license of the Food

Immunocontraception – A method of preventing pregnancy by stimulating the immune system. In Irondequoit, we injected females with a vaccine called Porcine Zona Pallucida, or PZP. This vaccine stimulates production of antibodies that attack the egg cell when it is released from the ovary.

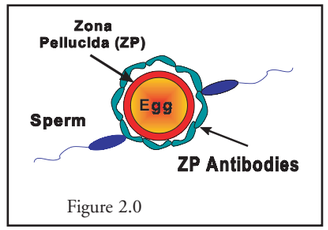


Figure 2.0

Porcine zona pellucida introduced into the body of a female deer stimulates the immune system to produce ZP antibodies, which attack the egg, preventing conception

and Drug Administration. The license agreement requires that all free–ranging animals treated with PZP be clearly marked with identifying tags before treatments can be administered. Following initial capture for marking, treatments may be delivered remotely with a dart gun.

POPULATION MANAGEMENT OF DEER

Answering questions like how many deer must be treated with contraceptives to prevent growth in a population requires a basic understanding of how deer populations change over time.[11] Factors affecting the age of first reproduction, the net growth of a population, and the upper limit to population size play important roles in determining how to manage the population.

Reproduction in deer is a product of day length and nutrition.[13] Breeding occurs in autumn when changes in day length stimulate the hormone system in both males and females. Females are able to breed for the first time as early as 6 months of age, and many give birth to their first fawn on their first birthday. However, the age at which females reach sexual maturity is variable. For instance, nearly every female in an agricultural area of Ohio breeds for the first time at 6 months of age.14 In northern New York, some females breed at 18 months, but most are not breeding until 2.5 years of age.[15] In parts of the desert Southwest, the age at which a fawn reaches maturity depends on nutrition which is determined in large measure by the weather.16 In wet years when grasses are abundant, maturity occurs at six months; in drought years, maturity is attained at 18 months or 2.5 years.



Photo by: William Porter

Immunocontraception is achieved remotely by using a dart–firing rifle. Biologists can thus be 20–40 meters away from the deer and administer treatment.

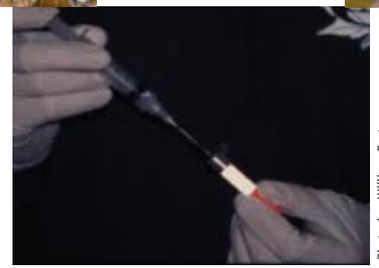


Photo by: William Porter

To deliver contraceptive agents to a deer, the PZP must be mixed with an adjuvant, then loaded into a hollow dart.

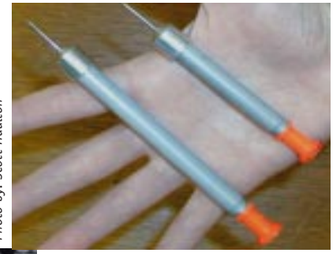


Photo by: Scott Haulton

Darts of various sizes can be used to immobilize deer, depending upon the kinds of drugs used.

The difference in age of sexual maturity is related to nutrition, especially energy. Nearly all fawns receive the same nutrition during the first eight weeks when they feed on milk produced by their mother. After eight weeks, fawns become increasingly dependent on plant diets. The higher the nutrient and energy content of vegetation, the faster fawns grow. Fawns that are born in agricultural landscapes are surrounded by plants that have the highest nutrient and energy value. Fawns born in forested habitats do not have access to such highly nutritious food. Consequently, fawns born in agricultural environments tend to reach physical and sexual maturity earlier than those in forested environments.

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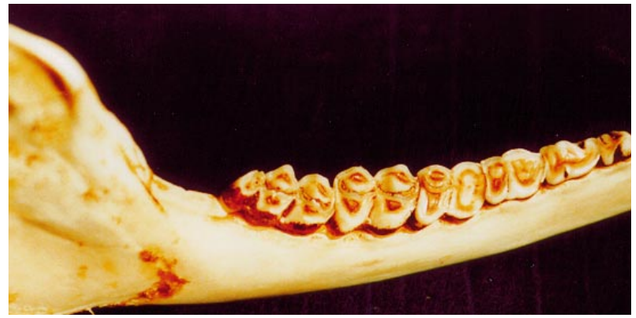
The age at which a fawn reaches sexual maturity is dependent on nutrition and day length. In areas where food is abundant, fawns may breed during their first autumn. Fawns born in agricultural landscapes tend to reach sexual maturity earlier than fawns in forested environments because of the highly nutritious food they consume. High-energy food also enables adult females to produce twins and sometimes triplets, due to their excellent body condition.

Photo by: Jennifer Woodard

The biological switch that turns on the reproductive system is body fat.[17] Deer are the same as most other mammals, including humans, in this respect.[18] Fat is essential to the function of the organs and hormones of the reproductive system. Skeletal muscle, and other structural growth compete with the accumulation of fat reserves. Fawns in highly productive environments get enough nutrition to not only grow, but to accumulate the fat necessary to turn on the reproductive hormone system by their first autumn. In less productive environments, females need another summer, and sometimes two summers, to finish body growth and accumulate fat.

The number of young produced depends on nutrition as well.[19] Females that breed for the first time most often produce a single offspring. Thereafter, females produce twins, and sometime triplets. The longevity of deer is not well known in the wild.[20] Most deer succumb to hunters, predators or accidents and few live beyond the age of ten years. Deer have been reported to reproduce in the wild up to age 15 years.[21] As deer age, their teeth wear down and, ultimately, declining nutrition probably ends reproduction.

The initial rate at which the population grows is dependent on nutrition and the number of mature females in the population.[22] Let's use a hypothetical example to illustrate this concept. Suppose we introduce a male and a female, both adults, into an area of 1,000 acres that has no deer. Our area contains an ideal combination of forest and open fields that provides the cover and food deer need. With only two deer, the female gets as much food



As deer age, their teeth wear down. These are the teeth of an 8-year old female. Once the teeth wear down to the gum line, the inability to obtain adequate nutrition leads to the decline in reproduction and eventually death.

Photo by: Jennifer Woodard

as she needs, so her nutritional state is high. She is likely to produce twins, perhaps a male and a female. Nutrition for the female fawn is high, so she reaches sexual maturity at 6 months of age and breeds. Now there are two females producing young. For simplicity, assume that the young female produces a female fawn and that female fawns of both this young doe and her mother deer survive to maturity. The female segment of the population has grown from 1 to 2 to 4. Next year it will grow to 8, and then to 16. Notice that population growth is accelerating.

2 females produce 2 new females Total females is 4
4 females produce 4 new females Total females is 8
8 females produce 8 new females Total females is 16
16 females produce 16 new females Total females is 32
32 females produce 32 new females Total females is 64

Remember that most females are producing twins each year and males are also being born. Some adults are dying each year, but very few are lost when populations are low. In six years, the population has grown from 1 female to 64, and it is conceivable that our total population, including males, numbers more than 100 deer. Biologists call such growth exponential because the mathematical equation representing such growth carries an exponent.

$$Nt = N0 * t.$$

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Female deer that live in areas with highly nutritious food and no limitations on the amount they can consume, will often have twins or triplets. Her offspring may include a female, which will be able to breed early because of the highly nutritious food she consumes. A population can increase quickly under these conditions.

Photo by: Jennifer Woodard

This equation looks formidable because of the subscripts, a Greek letter, and a superscript. All it says is that the population, designated by the letter "N" at some time in the future, represented by "t", is equal to the population in the initial year, shown as N0, multiplied by a growth factor. We use the Greek symbol, lambda or to represent that growth factor. The "t" is an exponent and is the number of time intervals over which the population has grown. Many people may see the similarity of this equation to calculating compound interest on savings accounts at the bank. In our example above, a population of one pregnant female will produce a population of 64 female deer in six years, assuming each female produces two female young each year and every fawn survives:

$$64 = 1 * 26.$$

This is obviously a little simplistic because deer do not generally produce 2 female fawns every year, and not every deer survives. The point is that, like interest on savings accounts, growth is slow when the account has only a few dollars in it, but with time, the rate of growth accelerates.

Is there an upper limit to growth in deer populations? Yes. Exponential growth will continue until it is limited by food and other resources, such as space. If we assume that the food available on our 1,000 acres is constant from year to year, the number of deer in the area eventually reaches the point where each female is not getting enough food. Nutritional state of at least some females suffers and reproduction declines. The impact of declining nutrition on reproduction results in a decreasing number of new females added to the population each year through births.

Ultimately, the population reaches a size where even though the number of females is high, the number of fawns that reach maturity exactly equals the number of adults dying of malnutrition and other causes, each year. This point is known as ecological carrying capacity (K). Under this definition, deer populations that grow to densities near K will cause changes to the vegetation and some of the deer in the population will be malnourished. However, the vegetation that is able to persist at these levels of browsing and grazing by deer is sufficient to support the population. The fact that some deer are malnourished may conflict with human values, but ecologically, most are surviving and some are successfully producing young that become adults.

The pattern of growth in deer populations is best illustrated by thinking in terms of the increment of growth. Increment of growth represents the net annual increase in the female population — those added by reproduction and immigration minus females lost through mortality and emigration. The number of females fawns surviving to 6 months of age are known as recruits.23 While the age at which recruitment is defined is arbitrary, 6 months is generally accepted as the benchmark because, in many populations, sexual maturity is attained at this age. The number of recruits is small at first, but grows. In our previous example, the population added 1 recruit, then 2, then 4, then 8, then 16 and then 32. As nutrition of some females begins to decline, the number of recruits decreases. Suppose that 64 females was the greatest

Ecological Carrying Capacity – Often abbreviated as K. Maximum population density of deer that can be supported by an environment. For purposes of population management, K is the maximum population density at which annual recruitment equals annual mortality.



Photo by: Jennifer Woodard

When deer populations grow to densities near the ecological carrying capacity (K) fawns, such as this one (a) will suffer from malnutrition and will not survive to reproduce. Populations that are at, or near K, will suffer from many losses due to the lack of food (b).

number that our 1,000 acres could support when every female had enough food to be in peak physical condition. The following year, the population would be 128 females. However, some of these would not get the food needed to reach sexual maturity. Consequently, not every female would reproduce in the next year and the number of recruits would be fewer. Nutrition would be an even greater problem and recruitment would decrease again the next year. To continue our hypothetical example:

64 females produce 64 new females Total females is 128
128 females produce 32 new femalesTotal females is 160
160 females produce 16 new femalesTotal females is 176
176 females produce 8 new femalesTotal females is 184
184 females produce 4 new females Total females is 188
188 females produce 2 new females Total females is 190
190 females produce 1 new females Total females is 191
191 females produce 0 new females Total females is 191

These numbers can be plotted on a graph. If we subtract the number of adult females that die from the number of new females being added to the population, we know the net growth, or what biologists refer to as the increment of growth. Biologists call the relationship between the increment of growth and population size in the subsequent year an increment of growth curve. The relationship closely resembles the shape of parabola (Figure 3).

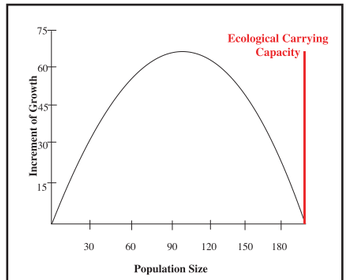
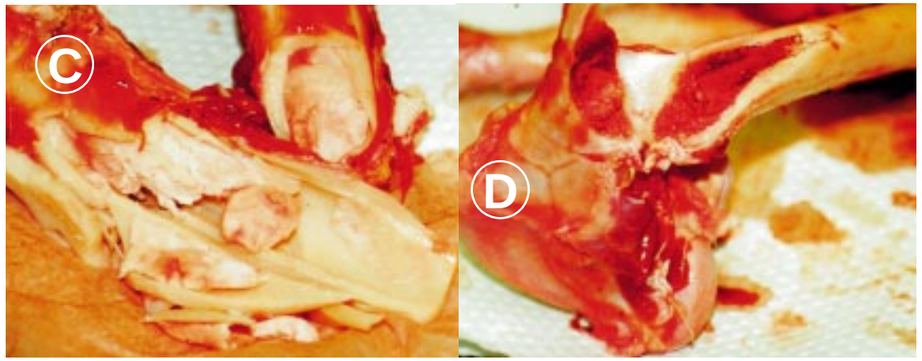


Figure 3.0

Increment of growth curve showing ecological carrying capacity (K).

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Photos by: Jennifer Woodard

Bone marrow of the femur is a good indicator of the health and condition of the deer at the time of death. A deer in good condition will have whitish–pink bone marrow with a thick, waxy consistency (c). A deer in poor condition will have red bone marrow with a soft, crumbly consistency (d).

Increment of Growth – Net change in a population from 1 year to the next. Calculated as the number of fawns added to the population minus the number of deer of all ages dying during a given year. Immigration and emigration are generally assumed to equal one another and are not included in calculations of increment of growth.

Ecological carrying capacity is at the right on this parabola where the population is so large that the increment of growth is zero. Fawns may be born to breeding females in the population, but the number surviving to 6 months of age exactly equals the number of older deer dying. In our example, ecological carrying capacity is reached at 191 females, or 122 deer per square mile. Rarely in nature would you ever expect to see our hypothetical population at exactly 191 females. There will almost always be some fluctuation in any population. A population that is near ecological carrying capacity is likely to be slightly above or below, in any given year. So, we could say that our hypothetical population will average 191 females.

The peak of the parabola represents the largest increment of growth. In our example, this is 64 females added in one year. Remember that at low populations, the number of recruits is limited by the number of breeding females in the population, and, at high populations, recruitment is constrained by the poorer nutritional state of breeding females and survival of fawns to recruitment age. The peak of the parabola is the best possible trade–off between breeding population size and the number of fawns surviving to 6 months of age.



Photo by: Jennifer Woodard

While the general relationship represented by the increment of growth curve is similar in every population, the peak and the ecological carrying capacity are probably different in each population. The difference arises because each environment is unique, and the factors that affect births and deaths in a deer population change from place–to–place.

Suppose our management goal is to hold the population constant at a given abundance. There are 3 basic questions that must be answered:

(1) How many fawns are going to be recruited into the population?

(2) How many adults will be lost from the population through mortality?

(3) How many additional adults will we need to remove from the population to balance recruitment and loss?

Superficially, this calculation is a simple subtraction. For instance, if 50 fawns are recruited and 20 adults die during the year, our population will grow by 30 animals. If we wish to hold the population constant, we must remove 30 deer.

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The problem is that it is nearly impossible to count the number of fawns that survive to recruitment age or the number of adults that die. The trick is to predict the number that we must remove without actually having to make these counts. Knowing dimensions of the increment of growth curve enables us to make this prediction.

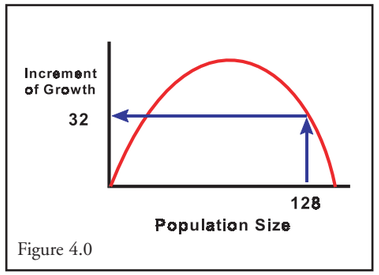


Figure 4.0

Increment of growth curve showing that a population of 128 breeding females will produce 32 female offspring capable of conceiving young the following autumn

The concept is easier to grasp by illustrating it with some numbers. Again, let's use our hypothetical population. Suppose that every year on November 1 we conduct a complete count of the deer population. For simplicity, we can safely ignore males for now. Suppose we count 128 females in our first year. Our increment of growth curve (Figure 4) predicts that a population of 128 breeding females will produce 32 female recruits into the population by November 1 of the next year, bringing the total female population to 160. If we want next year's population to be 128, we will need to ensure that 32 females are removed to balance the growth. If we remove fewer than 32 females, the population will grow. Thus, if our removal effort takes only 22 females, falling short by 10, the population will grow by 10 females.

An interesting characteristic of the increment of growth is that the same removal quota will hold a population constant at either of two levels of abundance. In our example, a population of 160 females will result in an increment of growth of 16. Remember from our earlier discussion of population growth, recruitment in populations of relatively low abundance is limited by the low number of breeding females in the population; at relatively high population abundances, recruitment is limited by the poor nutritional state of females and higher mortality among all deer. This characteristic is important because it means that we can manage a deer population either at a very high level (160 females) or a very low level (16 females) by removing the same number of deer (16) (Figure 5).

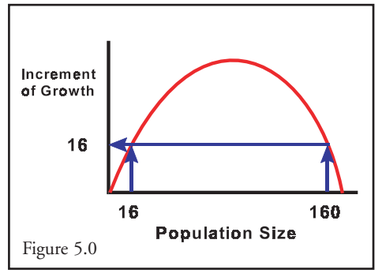


Figure 5.0

Increment of growth curve showing that the same number of deer can be removed (16) at 2 different population levels (16 or 160).

How can we put real numbers on this curve? We use the phrase calibrating the curve to describe the process of putting specific numbers to it. As part of the bait–and–shoot program in Irondequoit, we inspected every deer culled and collected data on physical condition and reproductive status. In addition, we conducted counts of population abundance from a helicopter.

During the first year of the program, the data on reproduction showed that none of the female fawns, and only a few of the yearling females were pregnant. The fact that fawns were not breeding suggested that the population was on the right–hand side of the increment of growth curve.[23] Further, the fact that many yearlings were not breeding suggested that the population was somewhere between 70% and 100% of carrying capacity.

Recruitment – Number of fawns born into a population that survive to sexual maturity. When the intent of management is to control deer abundance, population models often restrict the definition of recruitment to females. This simplification is generally appropriate because control of deer abundance can be achieved by managing just the female segment of the population.

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Photo by: Jennifer Woodard



Photo by: H. Brian Underwood

When deer populations are on the right-hand side of the increment of growth curve fawns, and often yearlings, are not able to reproduce. In Irondequoit, in 1993, the deer population was very close to K so no female fawns or yearlings were reproducing.

Data from four years of culling provided the means for calibrating the increment of growth curve. Remember the three crucial questions: (1) How many recruits? (2) How many deaths? and (3) How many to remove? A little algebra allowed us to estimate increment of growth at several different population densities and to calibrate the curve.

Remember that the number of deer to remove each year must be equal to the increment of growth if the goal is to prevent the population from growing. Increment of growth equals the number of young added by recruitment minus the number of older deer that died.

Accident data provide us with a number for deer dying. We assume that almost all adults that die each year are killed in deer–vehicle accidents, and law enforcement authorities keep good records of these events. Once we know losses to mortality and overall population growth, we can calculate the number of recruits.

All of this is true if annual culling removed exactly the number of deer necessary to hold the population constant. If they remove more deer than necessary, then the combined mortality would exceed the increment of growth. If they remove fewer deer than necessary, then the combined losses would be less than the increment of growth. In either of these two cases, our estimate would be incorrect. Thus, we need to know that they removed exactly the right number.

Helicopter surveys can help answer that question. We know that the total population next year is equal to the population now plus the recruitment of young minus the mortality of adults from vehicle accidents and culling.

Suppose our helicopter counts showed that the total population decreases each year. By coupling the estimate of the population from aerial counts and mortality estimates, we are able to calculate the growth increment. We can then plot a graph of increment of growth against population abundance. By extrapolating this line to the point where it crosses the x–axis (horizontal line) of the graph, we can estimate carrying capacity (Figure 6).

Deer–car collisions are the cause of most suburban deer deaths. Accident data in Irondequoit was provided by the police department and gave biologists a measure of the mortality rates each year.

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Increment of growth adjusted for Irondequoit using population sizes estimated from aerial surveys

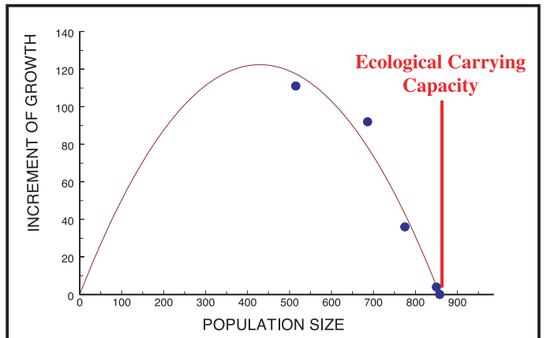


Figure 6.0

Sustained Yield – Often abbreviated as SY. Number of individuals that must be removed from a population each year to hold a population at constant abundance. In population management, SY is the number of adults that must be removed to exactly offset the number of young that are anticipated to reach sexual maturity in a given year.

Suppose our goal is to reduce the population from 600 to 200 females. In Irondequoit, our curve predicts that a population of 600 females will produce approximately 100 female recruits. Note that reducing the population by exactly 100, from 600 to 500, will not move us toward our goal of a population of 200. The population will replace the 100 individuals we removed in the upcoming year. This is the definition of sustained yield (SY) a concept commonly used in regulating hunter harvest in deer populations. Therefore we need to remove more than 100 females.

Notice that as we reduce the population from high abundance, we move higher on the increment of growth curve. Sustained yield for a population of 400 females is 200. By reducing the population over a series of years and monitoring the reproductive status of females removed, we can watch to see when yearlings and fawns begin breeding. When we see pregnant yearlings, we know then that we are making progress in overall population reduction. When we begin to see pregnant fawns, we know that we are near the peak of the increment of growth curve.

Thus, to manage a deer population on the right–hand side of the curve, we need to know either the value for sustained yield, or the true population size. With the curve in place, knowing one of these values will enable us to estimate the other. Pregnancy rates tell us what we need to know in order to judge our success. The risk on the right–hand side of the curve is that we will remove too few individuals in one year and have our work undone by the increased number of recruits.

Once we move to the left–hand side of the curve, the benefits and risks change. To cause a population to move back up the right–hand side of the curve requires increased culling at each step. The benefit of driving a population down the left–hand side of the curve is that it requires fewer individuals be removed each year. The risk is that we no longer have good cues for judging where we are on the curve. Once we get to the left side of the peak, almost all females are breeding. We may misjudge the quota and remove too many females. The ability of the population to compensate is diminished because there are relatively fewer reproducing females and those females produce fewer recruits. A couple of years of misjudgements could take the population far lower than we had intended and recovery may take several years.

In summary, knowing that a deer population grows in response to carrying capacity is fundamental to understanding how to achieve our management goals. Having a calibrated increment of growth curve is an asset to answering the three questions that are crucial to management. Management does not require such a high degree of detail at the outset. We need only know whether we are on the right–hand side of the curve, and pay attention to what is happening to pregnancy rates. Once we move the population to the left–hand side of the curve, more detailed information is required to monitor progress.

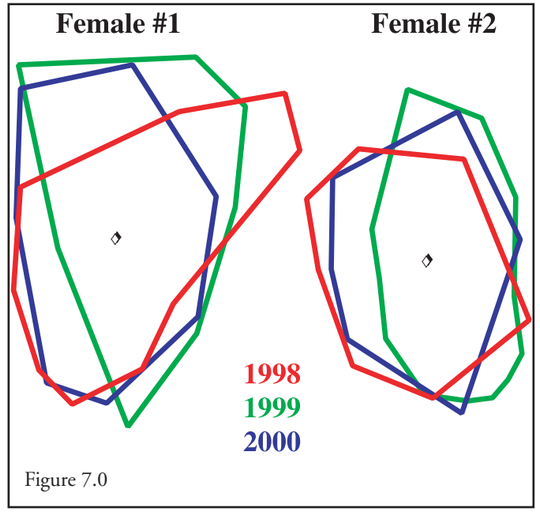
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Of course, the ultimate measure of success is the degree to which our management alleviated the original problem. Are the numbers of car–deer accidents declining? Are landowner complaints declining?

DEER BEHAVIOR

Finally, a key to successfully applying management in suburban environments is understanding deer behavior. Specifically, the movement behavior of deer can affect how management can be applied. In many environments, female deer are philopatric, meaning that they remain in the general location of their birth. In the northeastern portion of North America, fewer than 5% of the females disperse from their place of birth.24 The movements of deer during a season comprise their home range. The home range of an individual deer is consistent, and year after year they use the same areas, exhibiting site fidelity, or faithfulness to one or a set of seasonal home ranges (Figure 7).[25] The philopatry and site fidelity result in localized structure of the deer populations allowing the population of deer that are distributed across a large area to be characterized as a set of herds or local populations.26 Each of these local populations may be growing or declining largely independently of adjacent deer. Thus, the deer occupying the Town of Irondequoit may be composed of a set of local populations that reside in portions of the Town. If these local populations are independent, each has the potential of being managed individually to meet the needs and values of the people residing in a specific neighborhood.[27]

With these brief lessons in biology in mind, we can move to the actual field study conducted in Irondequoit.



Example depicting site fidelity, the faithfulness to a home range year after year, of 2 hypothetical adult females. Polygons represent boundaries of the home range, or the area in which a deer regularly inhabits each year.

Figure 7.0

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METHODS

THE FIELD STUDY

To evaluate the potential for use of deer immunocontraception in Irondequoit, we examined 3 general objectives: (1) assess the potential of immunocontraception to control growth of the deer population, (2) estimate the effort required to apply immunocontraception in a suburban environment, and (3) explore the potential for managing local populations of deer independently of one another. Attempting to manage the population in Irondequoit to achieve and maintain a specific level of abundance was beyond the scope of the study.

We approached the field research as five central tasks: (1) estimate the size of the population, (2) characterize physical condition and reproductive rates, (3) predict annual population growth, (4) estimate the amount of effort required to use contraception under field conditions, and (5) estimate size of home ranges, seasonal movements, and dispersal rates of deer among locales within the Town.

ESTIMATE POPULATION SIZE

We estimated deer population size in Irondequoit using helicopter surveys conducted in February of 1995 and 1996, and in March of 1998. The Town was partitioned into 41 blocks, each one square kilometer (0.38 square miles) in size. The small blocks facilitated accuracy of the counts by helping to focus the attention of those doing the counting on a discrete area. (Figure 8).

Time and funds did not permit a count of the deer in every block. Consequently, we conducted what statisticians refer to as a random sample in each of two kinds of habitat.

We classified blocks into different groups, or strata (Figure 9). After studying aerial photographs, each of the blocks was classified into high or low human development. Blocks were classified as high development (Stratum 1) if more than 50% of the area was occupied by houses, roads, or other residential/commercial structures. Blocks with less development were classified as low development (Stratum 2).

Overall, we randomly selected a sample of about 35% the blocks in the Town. Only deer in these selected blocks were counted. We selected more blocks to survey in the low–development stratum than in the

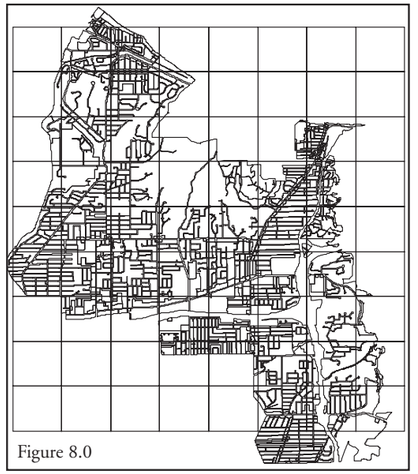


Figure 8.0

The Town of Irondequoit partitioned into 41 1–km2 blocks which were utilized during aerial surveys

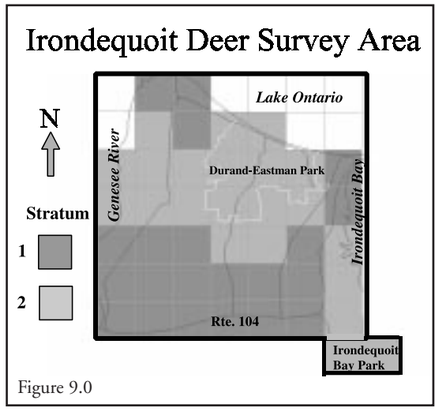


Figure 9.0

The 1 km2 blocks of the Town of Irondequoit were classified as high human development (1) or low development (2) and randomly selected to count deer during the aerial surveys

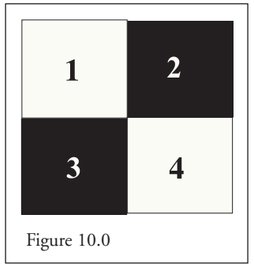


Figure 10.0

To minimize the possibility that deer counted in 1 block were double–counted, deer were only counted in block 1 and 4, and not in adjacent blocks 2 and 3

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high–development stratum because we expected greater variability in numbers of deer in these blocks (i.e., some blocks would contain 2 or 3 deer and other blocks would contain 40 to 50 deer).

To minimize the possibility that deer counted in 1 block would be double–counted if they moved into a neighboring block, we added a constraint to our selection of blocks. Once a block was selected, all adjacent blocks (those sharing a side) were eliminated from the survey; blocks touching corners were acceptable if they were drawn in the sample (Figure 10).

Complete counts of deer in each block were made using a helicopter carrying a pilot, navigator, and two observers. Upon arrival at a survey block, the boundaries were flown to familiarize the crew with landmarks. Flights over blocks were generally made on west–east passes at 100–200 feet above ground level. Additional passes along ravines were made as needed. Deer were counted from the sides and belly of the aircraft, and observers and the navigator communicated sightings of deer to avoid duplicate counts.

We estimated annual population size by averaging the counts from several flights conducted over a two–day time span in each year. We calculated the mean (i.e., average) number of deer in the Town, and the confidence interval (the range of numbers within which we were confident that the true population size would occur). We allowed for a 1–in–10 chance of drawing a sample that was unrepresentative of the population. Finally, we used the aerial sightings to characterize the spatial distribution of deer across the Town (Appendix A). Maps displaying deer population density (average number of deer per unit area) were created for each year aerial surveys were conducted.



Photo by: William Porter

The aerial survey conducted counts of the number of deer seen within each 1 square kilometer block of Irondequoit. Blocks were randomly selected with more low–development surveyed than high–development blocks due to the greater variability in the number of deer seen in low–developed areas.

CHARACTERIZE PHYSICAL CONDITION AND REPRODUCTIVE RATE

To ascertain the nutritional and reproductive state of the Irondequoit deer population, we collected data from deer culled during March, 1993 through 1998. Whole–carcass weights of females were recorded and used as an index of nutritional state. By March, fetuses are large enough to count easily, and we recorded the age and the number of fetuses for each female culled during the bait–and–shoot. Ages of deer were classified into three groups: fawn (< 1 year), yearling (1 to 2 years), and adult (>2 years) based on patterns of eruption of teeth.28 We assumed that the deer removed as part of the bait and shoot were representative of deer throughout the town (Appendix B).

A Bell Jet Ranger helicopter was used to conduct aerial surveys in Irondequoit during winters 1995, 1996, and 1998. The crew of 2 observers counted deer on either side of the helicopter, communicating sightings to avoid duplicated counts.



Photo by: William Porter

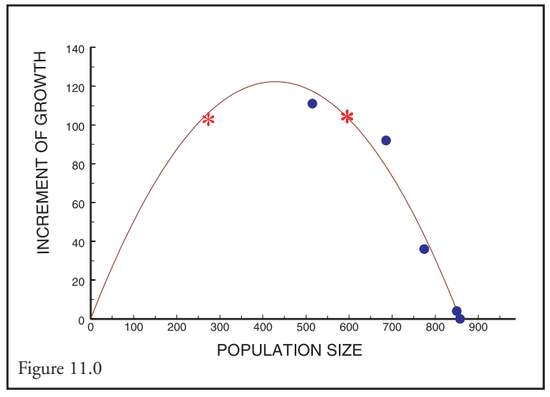


Figure 11.0

Increment of growth curve calibrated to the Irondequoit deer population based on 5 points. The 2 asterisks illustrate that the same number of deer would need to be removed to maintain a stable population size at 260 or 600 deer.a

PREDICT ANNUAL POPULATION GROWTH

As in the example described earlier under Population Management of Deer, we used data from aerial surveys, culling operations, and deer–auto collisions to create an increment of growth curve representative of the Irondequoit deer population. This curve was calibrated using 4 points, each point corresponding to the population in the years 1993–1996. The horizontal (x– axis) position of these points on the graph represented the population size. To determine the population size in 1995 and 1996, we used aerial survey estimates. For 1993 and 1994, we mathematically reconstructed the population size using reproductive rates, and both hunting and non–hunting mortality rates. We assumed that the non–hunting mortality was attributable to deer–automobile collisions and that all collisions were reported. The vertical (y–axis) position of the 4 points on the graph represented the net number of new deer added to the population. Increment of growth was calculated by subtracting the population size in one year from the population size of the previous year.

We calibrated the increment of growth curve to the Irondequoit deer population based on the generalized principles of sustained–yield harvesting and the five points from our data.29 This curve predicts the number of deer that must be removed to maintain a constant abundance of deer at any point across a range of population sizes (Figure 11). The two asterisks on the curve illustrate that the same number of deer (108) would need to be removed to maintain a stable population size at either of two population sizes, one on the left–hand side of the increment of growth curve (260) and the other on the right–hand side (600) population.

We then adapted the increment of growth curve for use in predicting the numbers of females to treat with contraceptives. To make the curve more general, we computed the percentage of females in the population that must be treated to maintain constant abundance across a ranges of population sizes relative to carrying capacity. Because the percentage of breeding females in the population varies with population size relative to carrying capacity, we plotted the percent of breeding females that actually are in the population for comparison. Finally, we created a set of these curves, each depicting a different level of treatment success: 70, 80, 90, 100%.

ESTIMATE EFFORT REQUIRED FOR IMMUNOCONTRACEPTION

Trapping and Handling Deer – The first step in the immunocontraception field study was to capture and tag female deer. Female deer were captured with the use of immobilizing drugs shot from a dart rifle.30 Shots were made to the muscle in the hind leg (gluteal muscle) at distances no greater than 35 yards. Most deer were darted from a pickup truck or a blind at established bait sites. We anesthetized deer using a chemical mixture called Capture–All 5 (made up of 5 parts ketamine hydrochloride to 1 part xylazine hydrochloride).31 Immediately following capture, animals were blindfolded and restrained. Heart–girth and hind–foot measurements, reproductive status, and age class were recorded. Reproductive state was determined as pregnant, lactating, or barren. We determined age class from tooth wear and replacement patterns. Deer were fitted with radio collars32, numbered plastic ear–tags, and metal ear–tags (Appendix C) carrying the words, “Experimental Animal: Do Not Consume.” For most deer, the initial PZP shot was



Photo by: William Porter

Each female deer captured was chemically immobilized using a dart rifle. She was then hobbled and blindfolded while biologists fitted her with plastic ear tags, metal ear tags, and a radiocollar. Reproductive condition, measurements, and age were also obtained, and the initial PZP injection was given to most females at this time.

administered at capture using a hand–held syringe in the gluteal muscle. Either yohimbine hydrochloride or tolazoline hydrochloride was used to reverse the effects of xylazine sedation immediately prior to release.

Measuring Effort – Effort required to capture deer, called capture time, was measured during capture operations conducted during January though July, 1997 and 1998. We recorded the number of hours spent monitoring bait sites and tracking and processing darted deer. Time spent was totaled over all one square kilometer blocks in each of four locales within the town: Flats, Central, Eastern, and Bay (Figure 12). Deer densities for each locale were calculated from aerial surveys and matched with estimates of effort to determine the mathematical relationship between capture effort and deer density. To determine deer densities in each locale, we calculated the mean of all counts made during the thee years (1995, 1996, 1998) for each grid block..

Effort required for remotely–delivered treatments was measured separately from effort to capture deer. Effort for treatment was measured by recording the number of hours spent monitoring bait sites or approaching deer by vehicle or on foot between the onset of boosting operations and time of delivery of the booster vaccine.

Estimating Effort to *Maintain a Stationary Population* – We created a population model to predict the numbers of females for which contraceptive treatment was required to control deer population growth and to estimate the effort required to achieve this goal. We modeled the population from 1999–2003, considering two scenarios. In the first scenario, effort was limited by budget constraints and, when necessary, contraception was supplemented by culling. We limited effort to approximately 3,100 hours over the four years because this represented the amount of effort we would have been able to invest under our budget. We assumed that all treated deer would need to be captured initially and tagged for identification, would receive the first treatment at capture and a booster shot each year thereafter. Finally, we assumed that all treatments would be administered by a team of at least two people. Efficacy of the PZP vaccine was set at 70% based on field trials from previous research conducted on Fire Island, New York.33

In a second scenario, we estimated the effort associated with contraception alone. No culling would occur and there were no budget constraints. Effort required to maintain a stationary population was compared for all possible abundances using efficacy rates of 70, 80, 90, and 100%. We assumed that all females could be darted and that each female was darted once a year.

Each female captured in Irondequoit was equipped with plastic ear tags and metal tags with the words, "Do not consume," and a radiocollar. Each radiocollar had a unique frequency specific to that female.



Photo by: William Porter

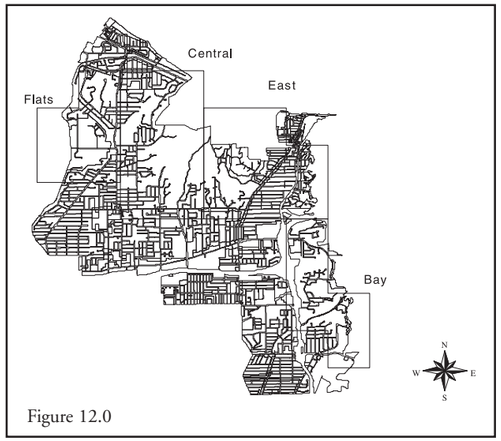


Figure 12.0

Town of Irondequoit delineated as 4 locales: Flats, Central, East, and Bay.

For each scenario, we estimated the reduction in effort resulting from tagging deer with radiocollars. This analysis was designed to address the question: would the added expense of radiocollars be offset by reduced personnel costs associated with improved efficiency of finding individual deer for boosting? To acquire necessary data, we used different strategies for locating deer for treatment in 1997 and 1998. In 1997, we located and treated deer regardless of radiocollars; in 1998, we attempted to treat deer only if radiocollars indicated that targeted deer were near a bait site.

ESTIMATE HOME RANGES, SEASONAL MOVEMENTS AND DISPERSAL RATES

We observed the movement of deer and identified their seasonal home ranges by radio– tracking collared deer in four locales: Flats, East, Central, and Bay. We obtained locations of deer during all times of the day and night by triangulation of radio signals (Figure 13). Data were collected during summer 1997 (1 May – 1 September) through winter 1999–2000 (1 December – 1 April) with the majority of data collected in 1999–2000. At least thirty locations were used to construct a map of the home range of each deer in summer (May1–September 1) and winter (December 1–April 1).34

Site fidelity of each deer was assessed based on the consistency of seasonal home range locations through time. Data for summer home ranges in 1999 and 2000 were examined using the Multiple Response



Photo by: William Porter

Tracking of radiocollared deer was achieved using a directional antenna and specialized receiver. The radiocollars on each deer operated at a unique frequency allowing us to identify them as individuals. Triangulation allowed for the construction of a home range.

Permutation Procedure (MRPP), a statistical technique for comparing similarity of locations between time intervals.[35] Data for years prior to 1999 were insufficient to plot an entire home range for most deer. Therefore, we visually inspected plots of these location data and determined if there was overlap with home range for 1999–2000.

Seasonal movements were examined to identify shifts in home range from summer to winter. We were particularly interested in determining if seasonal shifts caused deer to move from one locale to another.

We defined dispersal as permanent movement of a marked deer from one locale to another, or out of the Town. We radio–tracked females over a 40–month period to determine if females left their home ranges, and, if so, how far they moved.

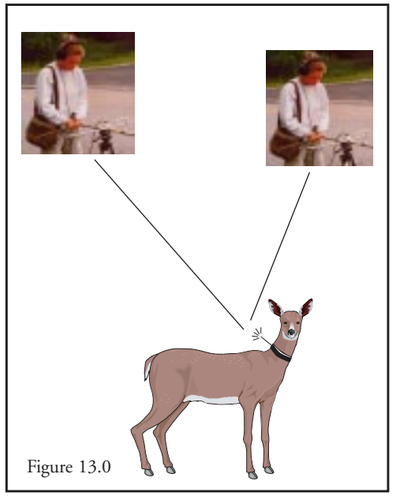


Figure 13.0

Radiocollars emit an electronic signal which biologists can use to measure the direction of the deer from known locations. Ideally, when directional measurements are plotted on a map, the lines intersect as a triangle and the location of the deer at that time is known. A series of these "locations" over time are plotted on the same map and used to calculate the outline of a home range.

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FACTUAL FINDINGS

ESTIMATES OF POPULATION SIZE

The aerial survey estimates showed that the population in 1995, before removals began, was 686 deer. The 90% confidence interval was 520 and 851 deer, indicating that there was only a 1 in 10 chance that true population was outside of this range. Three years into the program, the population had declined to 341 (90% confidence interval, 210 to 539) deer (Tables 1 and 2). This decline corresponded with a decline in deer–vehicle collisions (Table 3). Our assumption that non–hunting losses were due to automobile–deer collisions proved to be questionable because 48% (10 of 21) mortalities of radio–collared deer were due to other causes. Non–hunting causes of mortality included 52% (11 of 21) from automobiles, 24% (5 of 21) accidental losses in the bait–and–shoot culling program, 10% (2 of 21) were killed by predators, 10% (2 of 21) died of unknown causes, and 5% (1 of 21) died of causes related to injury. Our assumption that automobile–deer collisions were reported proved to be reasonable because all instances in which radiocollared deer were killed in collisions were reported.

The 1995 deer density map of Irondequoit indicated that spatial dispersion of deer across the Town was arranged in a broad band from southeast to northwest (Figure 14a). Deer densities in the south–central portion of the study area decreased in 1996 relative to 1995 (Figure 14b). The areas of deer concentration shifted slightly south between 1996 and 1998 (Figure 14c, Appendix D).

Table 1. Annual estimates of the deer population (males and females) and ranges in the Town of Irondequoit, 1995, 1996, and 1998.

Year	Estimate	90% Confidence Interval
1995	686	520–851
1996	485	213–507
1998	341	210–539

Table 2. Estimated deer densities and associated statistics by stratum (high human development [1] and low development [2]) in the Town of Irondequoit, 1995, 1996, and 1998 as calculated by aerial surveys.

Stratum	Year	Mean1 (deer/km2	Standard Deviation1	N2	n3
1	1995	3.97	6.39	21	11
	1996	3.00	5.20	21	3
	1998	1.10	–	21	12
2	1995	31.50	28.16	20	19
	1996	13.50	10.06	22	18
	1998	13.90	–	22	21
Combined	1995	16.73	2.75	41	30
Combined	1996	8.37	–	43	21
Combined	1998	7.9	–	43	33

1 average of 3 independent counts
2 N = total number of blocks in stratum
3 n = total number of blocks sampled in stratum

NUTRITIONAL STATUS AND REPRODUCTIVE RATES

Eight hundred forty–five deer were removed during the bait–and–shoot program from 1993–2000 (Table 4). More than 40% of deer removed each year were breeding females.

Nutritional state of deer improved over the years as evidenced by a significant increase in average whole–carcass weight between 1993 and 1994, and between 1994 and 1995 (Table 5). Reproductive rates for adult, yearling, and fawn females increased over time (Table 6). As population size decreased, reproductive rates for adult female deer increased from 1.4 fawns/female to 2.11 fawns/female.

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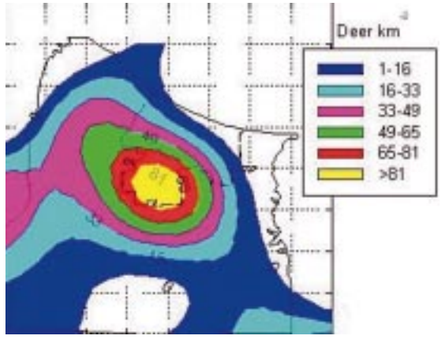


Figure 14a

Deer density map created from 1995 aerial survey.

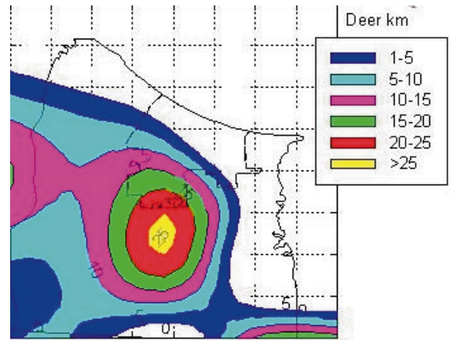


Figure 14b

Deer density map created from 1996 aerial survey.

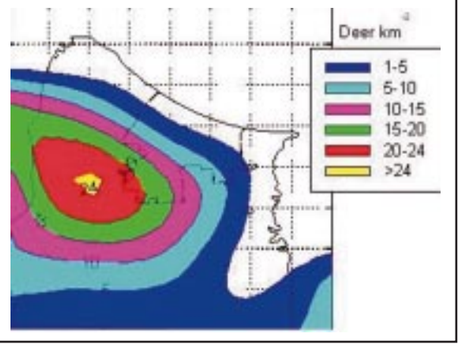


Figure 14c

Deer density map created from 1998 aerial survey.

Table 3. Summary of deer killed by cars in Irondequoit between 1992–1995.

Year	Deer killed
1992	237
1993	206
1994	135
1995	110

Table 4. Numbers of deer (males and females) culled in Irondequoit during bait and shoot operations 1993–2000.

Year	Total
1993	80
1994	160
1995	215
1996	65
1997	120
1998	71
1999	56
2000	77

Table 5. Whole-carcass weights of adult females culled in Irondequoit during bait and shoot operations, 1993–2000.

	Whole–carcass Weight (kg)		
Year	n	Mean	SE
1993	36	45.36	1.32
1994	83	53.30	0.74
1995	113	58.39	0.65
1996	33	57.16	1.24
1997	33	60.18	1.02
1998	19	57.61	1.74
1999	14	57.35	1.66
2000	19	60.97	1.435

Table 6. Reproductive rates (fetuses/female examined) of deer as determined from fetal counts of females removed by bait and shoot culling operations in Irondequoit, 1993–2000.

	Reproductive Rates			
Year	Yearling + Adult	Adult	Yearling	Fawn
1993	1.33	1.42	1.17	0.00
1994	1.43	1.62	0.85	0.04
1995	1.75	1.82	1.45	0.11
1996	1.85	1.92	1.57	0.08
1997	1.84	1.91	1.69	0.19
1998	2.00	2.11	1.75	0.20
1999	1.93	1.93	1.00	0.13
2000	1.61	1.74	1.44	0.40

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Table 7. Increment of growth as compared to population size of deer in Irondequoit with a K of 858 deer.

Population Size	Increment of Growth
0	0
250	108
515	111
601	108
686	92
775	36
850	4
858	0

Table 8. Generalized sustained yield table for computing numbers of deer to remove to achieve various population goals in Irondequoit.

	Sex– and Age–distribution				Reproductive		N	prop.	Non–removal loss				Total	
	Female		Male		Ratea		fawns	fawns	Female		Male		loss	SY
% K	Adult	Fawn	Adult	Fawn	Adult	Fawn	born	male	Adult	Fawn	Adult	Fawn	N	
10	0.25	0.25	0.25	0.25	2.08	0.50	56	0.50	0.03	0.12	0.06	0.12	11	45
20	0.28	0.24	0.24	0.24	2.07	0.40	115	0.50	0.04	0.21	0.07	0.21	13	82
30	0.31	0.23	0.23	0.23	2.01	0.30	178	0.50	0.05	0.30	0.08	0.30	70	108
40	0.34	0.22	0.22	0.22	1.93	0.21	241	0.50	0.06	0.39	0.09	0.39	120	121
50	0.37	0.21	0.21	0.21	1.89	0.14	311	0.50	0.07	0.47	0.10	0.47	181	130
60	0.40	0.20	0.20	0.20	1.87	0.10	395	0.50	0.08	0.54	0.11	0.54	260	135
70	0.43	0.19	0.19	0.19	1.84	0.10	488	0.50	0.09	0.60	0.15	0.60	358	129
80	0.46	0.18	0.18	0.18	1.73	0.10	563	0.50	0.10	0.66	0.18	0.66	460	103
90	0.50	0.17	0.17	0.17	1.52	0.04	595	0.50	0.11	0.72	0.20	0.72	538	58
100	0.54	0.15	0.15	0.15	1.40	0.00	647	0.50	0.13	0.77	0.24	0.77	638	9

Table 9. Average deer density estimates for each of the 4 locales in Irondequoit, based on aerial surveys, conducted in 1995, 1996, and 1998.

Geographic Locale	Average Deer Density (deer/km2)
Flats	29.9
Central	17.8
East	15.7
Bay	8.4

ANNUAL POPULATION GROWTH

Results showed that the curve characterizing population growth in the Town indicated an ecological carrying capacity (x–intercept) of 858 deer and a maximum increment of growth (peak of the growth parabola) of 124 deer (Figure 11). Presenting the increment of growth as a table (Table 7) shows specific population growth at abundance levels between zero and ecological carrying capacity. Shown are predictions of net growth at 10% intervals of ecological carrying capacity (K). Note that as population size decreases, the proportion of females in the population decreases.

This increment of growth curve, and the associated table provide information necessary to manage the deer population by removal. For example, if the population is composed of about 131 individuals, it is at 10% K (small population size relative to its carrying capacity of 858 deer), and the increment of growth will be 45 deer. This constitutes sustained yield, and consequently, to maintain a stationary population at this size, 45 deer must be removed before the next breeding season (Table 8).

The modified increment of growth curve predicts the percentage of females in the population that must be treated at various population sizes relative to carrying capacity. As the population decreases from ecological carrying capacity, the percentage of breeding females that must be treated with contraceptive generally increases. However, the ability of contraceptives to hold populations at low levels of abundance is limited by interaction of these treatment curves and the percent of breeding females actually in the population. The lower limit depends on treatment efficacy (% success). If efficacy is 80%, the population can be controlled with contraceptives alone at 429 deer, or about 50% of K. If efficacy is 90%, control can be achieved at populations as low as 209 deer, or 24% of K (Figure 15).

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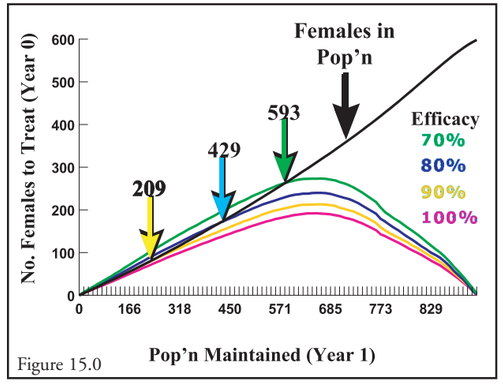


Figure 15.0

Relationship for number of females to treat in the first year and treatment efficacy levels required to maintain a stable population in the second year.

EFFORT REQUIRED FOR IMMUNOCONTRACEPTION

Forty–eight female deer were successfully captured during 1997 and 1998: 34 in the Flats, six in the Central, seven in the Eastern, and one in the Bay locales. Deer were observed moving between locales in only three instances. Twice, individuals returned to the original locale. In the third instance, a deer from the Flats permanently relocated to the Eastern locale. Average deer density estimates for each of the four geographic locales were highest in the Flats, followed by Central, Eastern, and Bay locales (Table 9). Average capture times were 9.8, 12.7, 20.5, and 21.7 hours/capture in the Flats, Central, Eastern, and Bay locale, respectively. Deer density (x) was related to capture time (Y) as an equation with a negative slope (lower deer density requires more capture time, see Figure 16). Statistically, the equation for this relationship is presented as:

$$Y = 30.84 \bullet e(-0.039 \bullet x)$$

The strength of the relationship is described as R2 = 0.79, P = 0.09. To those not familiar with statistical representation, an R2 of 0.99 and P of 0.01 would be nearly ideal. Therefore these values suggest that we have an equation that provides us with good ability to predict effort, given deer density.

We can illustrate the value of this relationship with an example. If we know that the population density is 1 deer per km2, the equation allows us to estimate the time required to dart a deer will be about 29.8 hours. At 50 deer per km2, the effort would be about 4.4 hours. As density increases, effort per deer decreases. Obviously, the time required to dart deer cannot be zero, regardless of how great the density becomes, so the relationship is not a straight line, but rather a curve.

During 1997, 21 of 34 required treatments (61.8%) were delivered during 139.9 hours of effort. During 1998, 30 of 50 required treatments (60%) were delivered during 75.1 hours of effort (Appendix E). The slopes of lines depicting treatment effort (i.e., time) on treatment event for each year were not different, so we combined the data from both years to estimate the relationship. We applied a statistical technique called bootstrapping to generate mathematical relationships that describe how effort increased with each deer we treated.

For collared deer$Y = 0.32 \bullet e(0.062 \bullet x)$

For uncollared deer $Y = 2.62 \bullet e(0.062 \bullet x)$

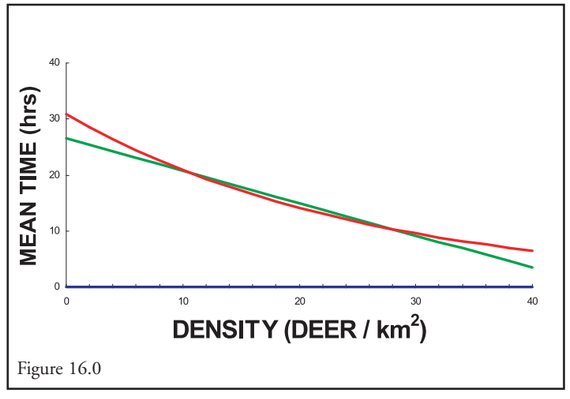


Figure 16.0

Relationship between deer density and average capture time in Irondequoit. Red and green lines indicate exponential and linear regressions generated from data collected in Irondequoit, 1997–1998.

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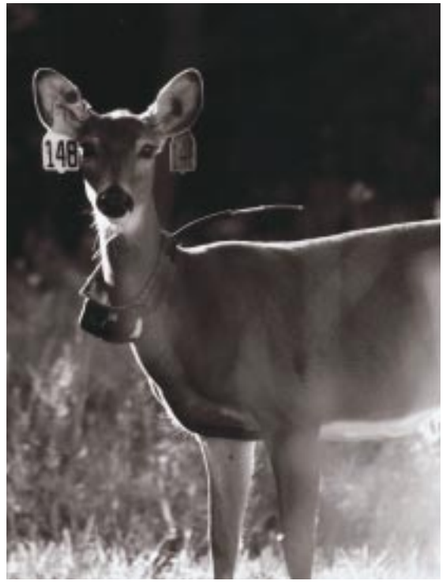


Photo by: Jennifer Woodard

Radiocollars decreased the amount of effort expended to administer treatments to deer in Irondequoit. Radiocollars enabled biologists to determine the general location of deer needing treatment.

In both cases, the time invested per deer in applying treatments increased through the season (Figure 17). However, the amount of effort expended was reduced with radiocollars because they allowed us to find the deer still needing treatment more quickly (Figure 17–lower line).

Scenario #1 – Limited Budget – Immunocontraception and Culling – Given budget constraints and only 3,100 hours of effort, our model estimated that the deer population in the year 2003 would consist of 512 animals, assuming no radiocollar use and an efficacy of 70%. Removal of 129 deer through culling

When a combination of immunocontraception and culling was modeled, the population was controlled at 474 animals with 3,154 hours of effort and removal of only 97 animals. In general, radiocollars improved efficiency by more than 2–fold (Table 10).

Scenario #2 – Unlimited Budget – Immunocontraception Alone – Simulations of population management using immunocontraception alone to maintain zero population growth

Table 10. Effort invested in applying contraceptive treatments to female deer and effects on growth of the population in Irondequoit. Based on computer simulations of applying 70% effective treatments from 1998–2001.

Scenario	Total hrs[a]	Final Pop'n[b]	Decrease in Pop'n[c]	Hrs / Decrease in Pop'n	Removal[d]
Low Effort (No Collars)	3106	512	60	51.76	129
Low Effort (Collars)	3154	474	101	22.85	97
High Effort (No Collars)	7204	488	87	82.81	110
High Effort (Collars)	7333	437	138	53.14	61

[a]capture hours (time spent monitoring bait sites and tracking and processing darted deer) and treatment hours (time spent monitoring bait sites or approaching deer for remote treatment delivery) invested over 4 years

[b]2003 January population size

[c]decrease in final population in reference to unmanaged population

[d]number of deer to remove to maintain stationary population

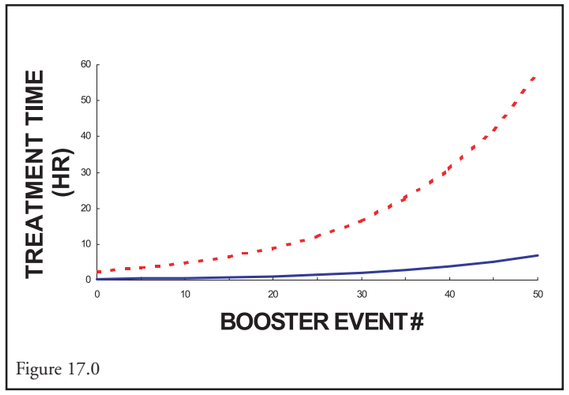


Figure 17.0

Relationship between treatment time to deliver individual contraceptive treatments to female deer and booster event number in Irondequoit using radiocollars (blue line) or without radiocollars (red line).

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Table 11. Number of deer to capture and treat in year t and associated capture effort required to achieve zero population change in year t+1 over a range of population sizes and treatment efficacy in Irondequoit, NY.

% K	Final Pop'n	Deer to capture & treat				Capture hours			
year		Efficacy				Efficacy			
t	t+1	70%	80%	90%	100%	70%	80%	90%	100%
10	131	56	48	43	39	N/Aa	N/Aa	N/Aa	1,102
20	254	112	99	87	79	N/Aa	N/Aa	2,306	2,086
30	365	165	144	128	115	N/Aa	N/Aa	3,130	2,821
40	464	213	187	165	149	N/Aa	4,217	3,738	3,378
50	559	255	223	198	178	N/Aa	4,654	4,139	3,714
60	650	273	240	213	191	5,285	4,638	4,116	3,698
70	730	250	219	194	176	4,468	3,922	3,473	3,141
80	789	183	160	142	128	3,027	2,644	2,352	2,115
90	830	112	98	88	79	1,720	1,499	1,346	1,209
100	867	17	15	14	12	241	209	193	177

[a]Number to capture and treat exceeds number of females in the population.

showed that the potential for holding the population stationary was dependent on treatment efficacy and the proportion of breeding females in the population. The total time required to capture enough females to achieve zero population change was estimated by multiplying the number of deer to treat by capture time per deer.

In Irondequoit, the effort required to capture enough females for treatment to achieve zero population change, assuming 100% efficacy, was highest (3,714 hours) when the goal was to maintain a population of 559 animals (Table 11); effort decreased at lower and higher abundances. For example, assume that the desired abundance was 365 deer in the Town. If we could achieve a treatment efficacy of 100%, then we would need to treat 115 females. This would require an investment of 2,821 hours. If the desired abundance was 789 deer, then we would treat 128 females and would need 2,115 hours. Our investment results in a constant population of deer and requires that we make the same investment each year, on a continuing basis.

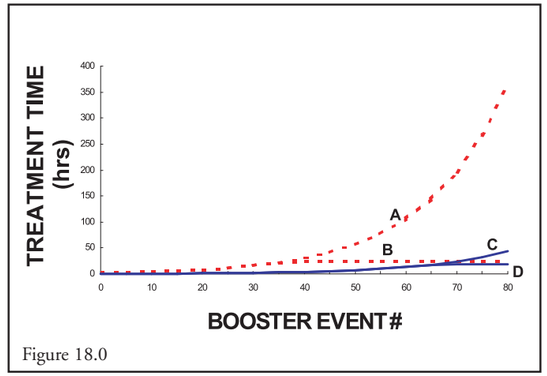


Figure 18.0

Relationship between treatment time and booster event number in Irondequoit. A = uncollared deer, exponential increasing effort; B = uncollared deer, assuming no additional effort per deer; C = collared deer, exponential increasing effort; D = collared deer, assuming no additional effort per year.

There are three key observations to make in this table. First, notice that while the number of females that we must treat is a little higher (128 females as compared to 115) the effort is lower (2,115 hours as compared to 2,821). This apparent contradiction reflects the greater ease in finding and darting deer at higher population densities. Second, notice that as efficacy of our treatment decreases from 100% to 90% the investment we must make increases. At a desired population of 365 deer, the investment increases from 2,821 to 3,130. Finally, notice that if efficacy is only 80%, we cannot hold a population at 365 deer because there are not enough females in the population. To be certain that 144 females are successfully treated, we need to treat 180 females (180 females treated times 80% efficacy is 144 females successfully treated). The population does not include 180 females. If it contains only 150 females and we treat every one, we will have 24 females producing young (150 females times 80% efficacy is 120 females successfully treated, which is 24 short of our necessary 144 females).

When using radiocollars for finding deer to administer the booster treatment, total effort required to achieve zero population change was calculated by substituting the booster event number (i.e., the first deer treated with a booster shot is event 1) into

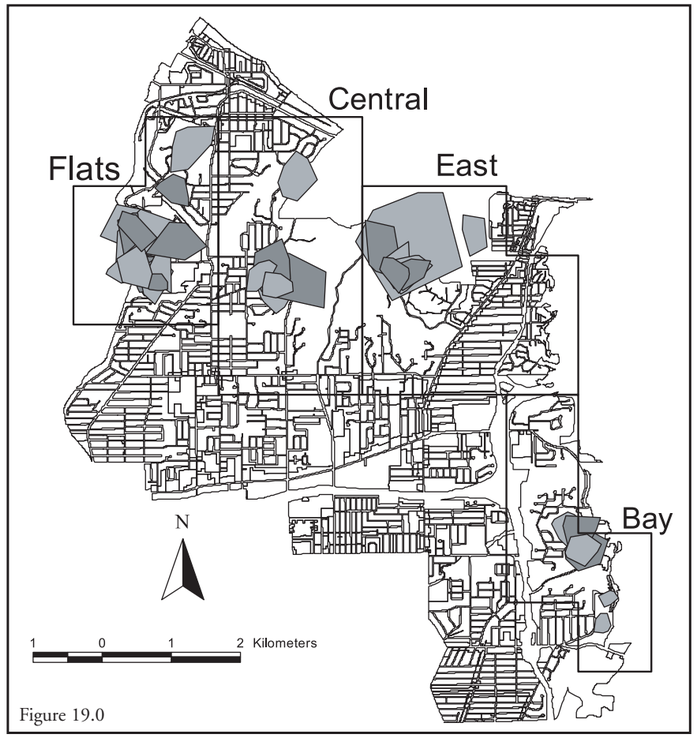


Figure 19.0

Home ranges for all radiocollared deer during summer, 1999, in Irondequoit.

equation 3. Assuming that boosting effort per radiocollared deer is not larger than the maximum effort we observed in Irondequoit, then 8 hours/treatment are required for event number 66 and beyond (Figure 18).

Effort required to treat enough females to achieve zero population change in Irondequoit is highest at a population of 650, ranging from 4,032 hours for treatments of 70% efficacy to 2,557 hours for treatments of 100% efficacy (Table 12). Effort is lowest in very large populations. These are the minimum estimates of expected investment because the extrapolation of the effort curve is most likely to continue upward.

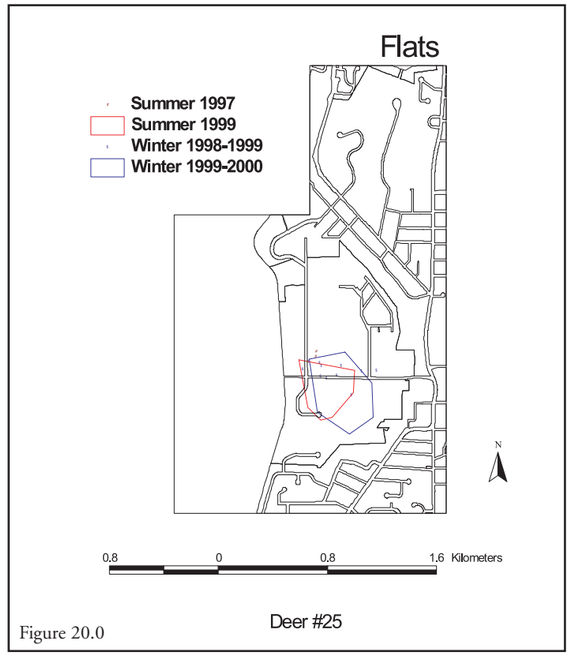


Figure 20.0

Seasonal home ranges and relocations of female radiocollared deer during summer and winter 1997–2000.

Table 12. Effort required in year t with and without radiocollars in order to achieve zero population change in year t+1 over a range of deer population sizes and treatment efficacy in Irondequoit, NY.

% K	Final Pop'n	With radiocollars				Without radiocollars			
year		Efficacy				Efficacy			
t	t+1	70%	80%	90%	100%	70%	80%	90%	100%
10	131	56	48	43	39	N/Aa	N/Aa	N/Aa	1,102
20	254	112	99	87	79	N/Aa	N/Aa	2,306	2,086
30	365	165	144	128	115	N/Aa	N/Aa	3,130	2,821
40	464	213	187	165	149	N/Aa	4,217	3,738	3,378
50	559	255	223	198	178	N/Aa	4,654	4,139	3,714
60	650	273	240	213	191	5,285	4,638	4,116	3,698
70	730	250	219	194	176	4,468	3,922	3,473	3,141
80	789	183	160	142	128	3,027	2,644	2,352	2,115
90	830	112	98	88	79	1,720	1,499	1,346	1,209
100	867	17	15	14	12	241	209	193	177

[a]Number to capture and treat exceeds number of females in the population.

30 of the 31 females tracked during 1999–2000 had home ranges that overlapped from summer to winter. This high degree of site fidelity and limited seasonal movements makes deer in suburban environments optimal for management on a localized scale.



Photo by: Jennifer Woodard

ESTIMATE HOME RANGE AND SEASONAL MOVEMENT

Limited observation of movements of deer during summers of 1997 and 1998 resulted in data for 12 and 17 females, respectively. An average of 2 relocations per deer were recorded in summer 1997 and an average of 4 relocations per deer were recorded in summer 1998. Twenty–three females were monitored by radio–telemetry in winter 1998–99 with an average of 7 relocations per deer. In summer 1999, 35 females were monitored and 32 relocations were obtained on average per deer (Figure 19). In winter 1999–2000, 32 females were monitored with an average of 24 relocations per deer. The average size of the summer home range in 1999 was 53.5 acres, ranging from 10 to 313.5 acres. The average winter home range was 56 acres, ranging from 13.2 to 173.7 acres.

Site Fidelity – We found no difference in locations of seasonal home ranges between 1999 and 2000. Comparison of summer and winter 1999–2000 home ranges plotted with relocations from 1997–1999 seasons showed high site fidelity for all deer. Most relocations fell within the most current home range boundaries. Those few exceptions were located just outside the home range outline. However, all of the relocations were distributed in the same locale of the town.

Seasonal Movements – Fourteen females (43.8%) did not exhibit significant seasonal movements between summer 1999 and winter 1999–2000. Of the 18 (56.3%) females that made significant movements, only 1 (3.1%) had completely non–overlapping summer and winter ranges (Figure 20). Average distances between the centers of summer and winter home ranges were all short. The average distance between centers for the Flats, Central, East, and Bay locales were 0.68, 0.31, 0.28 and 0.07 miles, respectively. There was no interchange of any deer between locales during both seasons. In winter 1999–2000, 1 female frequently crossed Irondequoit Bay when it was frozen. However, both of her ranges were located within the Bay locale of the Town.

Dispersal – The average dispersal rate for females approximately 14% per year (Table 13). Over the 3 years in which we had radiocollars on females, a total of 11 females dispersed. Three of 4 females moved from the Flats to other locales within the Town and were killed. Only 1 female moved from one locale to another and remained there permanently. Seven females moved permanently out of the Town of Irondequoit.

Table 13. Dispersal rates of deer in Irondequoit, NY, 1997–1999. Yearling females were considered adults in June of each year analyzed.

Year	Adult Females (%)	Yearling Females (%)	Pooled Average (%)
1997	10.0 (2 of 20)	0.0 (0 of 10)	5.0
1998	6.3 (2 of 32)	18.0 (2 of 11)	12.2
1999	8.5 (4 of 47)	25.0 (1 of 4)	16.8
Average of all Years	8.3	14.3	

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INTERPRETATION OF FINDINGS

Every indication was that the deer population in Irondequoit in the early 1990's was nearing it's ecological carrying capacity. Prior to the first bait–and–shoot program, the population was showing signs of intense competition for resources. Female weights and reproductive rates indicated that the population was on the right–hand side of the increment of growth curve. Whether or not the population was too high is not for us to say. Decisions to undertake bait–and– shoot suggest that there was the political will to reduce the population. However, implicit in this decision was an understanding that contraception would be seriously considered for maintaining the population over many years.

To evaluate the potential of immunocontraception as a population management technique we need an understanding of the factors affecting the effort required to achieve a population–level effect. At the heart of the findings in this study are 2 important concepts underlying effort: encounter rate and efficacy. Any variation in these factors has a strong impact on effort. Further, estimating the total effort that must be invested each year is complicated by the fact that the number of deer to treat is related to population density in a non–linear fashion.[9,36] This makes doing contraceptive management seem daunting. The take–home message is that the calculation of effort is not as simple as multiplying an average hours per deer invested in the first few deer treated, times the number of deer you want to treat, times the cost per hour.

EFFORT AS AFFECTED BY ENCOUNTER RATE

Population Density – Central to the investment of effort in contraception are the factors affecting encounter rate. First we consider the abundance of the deer population, or more precisely, population density. Assume for a moment that approachability and access are unimportant. We can most easily understand the relationship between density and the effort to dart females if we think about the metaphor we've heard often: finding needles in a haystack. If we have a haystack containing many needles, the amount of time we will spend finding those needles is relatively small. However, if there are few needles in the haystack, we will invest much more time finding them. Deer are like needles and the community is the haystack.

The work in Irondequoit is the first to quantitatively describe the relationship between capture effort and deer density using dart rifles, though other similar analyses appear in the literature.[37,38] The exact form of the relationship is likely to vary from one community to another. However, the relationship is likely to be curvilinear because deer at low densities will be difficult to encounter, and effort at high densities cannot be zero.

Approachability – There is a tendency to believe that population density is the principal factor driving cost. However, the importance of behavior becomes obvious as soon at the first 10 deer are treated. Darting deer in a park or suburban environment looks easy because we can often go out nearly any time of day and see a few females feeding along curbsides and in backyards. Often we can get so close that we are amazed. But perceptions are often deceptive. Experience dictates that some deer will be less frequently seen and more difficult to approach than others.[39] Indeed, in Irondequoit, some of the deer that we radiocollared were never seen again, by us or anyone else. We knew these deer were alive and present in the community only because of the radiocollar.

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Photo by: Jennifer Woodard

The challenge to contraception for managing suburban deer is approachability. Some deer are easily approached and would require little effort to contracept. Other deer may not allow people to approach within the necessary distance to administer contraceptives.

In treating deer with contraceptives, those individuals that are seen frequently, respond readily to bait, or are easily approached will be treated first. These individuals will require little investment. As more deer are treated, those that remain will comprise a pool of animals whose behavior makes them increasingly difficult to approach. We measured effort in our darting with an intent of quantifying the relationship between effort, and approachability. The first few females were easy because we darted almost any female deer we saw standing in a yard; the last few were much more time consuming.

At low densities, density and approachability are likely to interact. This will be especially true if the population has been reduced by culling because those deer remaining will be among the most wary.

Access – Suitable areas for darting may be limited by lack of cooperation of landowners or legal statute. For instance, darting deer in county parks other than Durand–Eastman was not possible because of existing firearms laws. Access is also limited by thick vegetation or terrain that makes darting impractical, or by safety considerations associated with playgrounds or high– traffic route; others have encountered similar problems.[40]

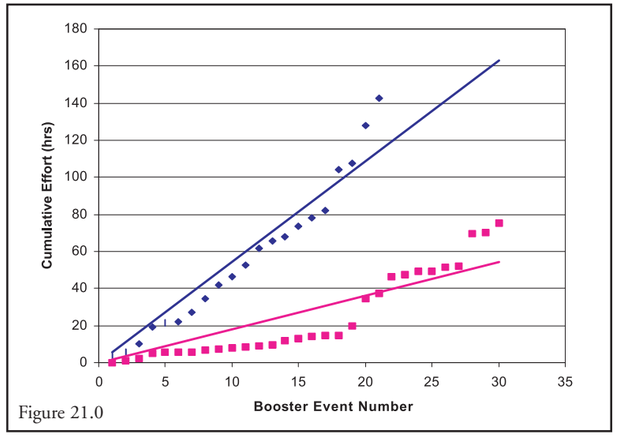


Figure 21.0

Relationship between cumulative effort and booster event number. Blue line represents 1997 data and pink line is 1998 data

Some females are easy to dart because they are seen in habitats where biologists have clear and easy shots (a). Other females may be within close range but are not accessible to dart because of the thick vegetation or proximity to homes and people (b).

Photo by: William Porter





Photo by: Jennifer Woodard

Many areas of Irondequoit are characterized by habitat that is more similar to rural, forested landscapes. Because of that, effort was limited even when deer were visible.

In Irondequoit, neighborhoods with large open fields and relative seclusion from traffic enabled us to capture more deer and boost a higher percentage of these animals. The Flats was one of the best areas. Areas where the vegetation was more similar to that of rural, forested landscapes reduced effective darting opportunities. In areas where streets and houses were in close proximity, our efforts were limited to the point that even when deer were visible, few could be darted.

To be more realistic, we add approachability. Now the graph that best represents the relationship is effort on the vertical axis and treatment event number on the horizontal axis (Figure 21). Treatment number 1 represents the treatment of the first deer; number 2, the treatment of the second deer, and so on. Effort is just what it says: the effort to treat the first deer, then the effort to treat the second deer, and so on. The vertical rise with each treatment event reflects the differences in approachability. If approachability were not a factor, then the line would be flat.

Remember that the deer that are most easily approached are treated first. As the easy deer are completed, approaching deer becomes increasingly difficult. The vertical rise increases. We draw a smooth curve through this stair–step pattern so that we can estimate the cumulative effort statistically. The mathematical form of the statistical equation is exponential because the curve increases at an accelerating rate. While an exponential equation sounds a little intimidating, we are all familiar with it in other aspects of life. For instance, compound interest on savings accounts follows an exponential form.

There are actually a series of exponential curves that characterize approachability at different densities. For instance, at high densities, we have lots of easy deer to treat, so the curve accelerates slowly. At low densities, few deer are visible and easily approached. Consequently, we are forced to begin working with the more difficult individuals early in the treatment program.

The role of access is similar to density. When access is high and deer densities are high, the curve is shallow. However, if access is restricted, the curve will become steeper, even at the same densities. This is because there will be fewer easy deer available for treatment. Of course, the people doing the darting will quickly conclude that the easy deer are standing only in places that are not accessible.

INFLUENCE OF EFFICACY

When we apply immunocontraceptive drugs to free–ranging deer, the remote injection brings a host of challenges. Darts must hit a large muscle (the rump of a deer) with enough energy to cause a small charge contained within the dart to detonate and inject the drug. However, the energy of the dart must not be so great that it causes serious injury to the deer. There is obviously a fine line here and charging the rifle correctly requires skill.

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Assuming the dart is delivered appropriately and the injection occurs, the next concern is that the full dose is injected. The rush of liquid being pushed through the hypodermic needle can sometimes propel the dart out of the animal, spraying the dose on to the fur where it does no good. After the dose is injected, the dart must fall out so that the biologist can retrieve it. To accomplish this, the darts have a small metal barb or dab of gelatin that holds them in the muscle for a few moments. Again, there is a fine line associated with getting the dart to stay in just long enough.

The challenge in the field is being certain that each dart delivers its dose when it hits the deer. Deer often jump when the dart hits. In pens, people can watch from several angles to be sure that the drug was completely injected. In the field, a short jump may result in the deer turning away, or being obscured by vegetation at the moment of injection. The biologists can retrieve the dart to be certain that the charge detonated, but sometimes cannot be certain that the drug was injected completely into the muscle. An option is to dart the same female again, just to be sure, but if there are many females to treat in a short time period, the biologist may not have that luxury. So, we are left with some uncertainty about efficacy. How does that affect the cost of the program?

To answer this question, we draw on the concept of the increment of growth. Remember that the increment of growth shows the number of deer added to the population across a range of population densities from 0 – 100% K. The traditional increment of growth predicts the number of deer to remove to hold a population constant. The peak of the contraception curve will be higher than that of the traditional recruitment curve, even if efficacy is 100%, because we know that the number of females that we must treat is greater than the number culled to achieve the same effect.

Suppose efficacy is only 80%. To hold our population at 600 deer, we need to ensure that 234 females will be successfully treated. At 80% efficacy, if we dart 234 females, our treatment will be successful in only187 of those individuals. One way of dealing with this problem is to dart enough females so that when we account for the treatment failures, we still have 234 females successfully treated. Compensating for the failures requires that we treat 292 females (292 females * 0.8 efficacy = 234 successfully treated females). When we draw the curve for 80% efficacy, it's peak will be still higher.

A difficulty arises because in some populations there are not enough females available to treat to make up for treatment failures. Suppose we have a population of 115 females and we need to treat 100 of them to maintain zero growth. If efficacy is 100%, there is no problem. We treat 100 out of the 115. However, if efficacy is 80%, we need to treat 125 females to ensure success in 100 (125 females * 0.8 efficacy = 100 successfully treated females). Unfortunately, the population contains only 115 females. The best we can do is treat every female and settle for success in treatments of 92 (115 deer * 0.8 efficacy = 92 successfully treated deer). The population will grow because at least 23 females will produce young, 8 more than we can allow.

Does this situation really occur in natural populations? Yes. As population densities change from 0 to 100% K, the proportion of breeding females changes.[27] At low densities, the population is composed of approximately equal proportions of young females, breeding females, young males and adult males, each about 25%. As the density increases, a shift occurs and at 70%K, breeding females comprise 55% of the population. When competition for food and other resources increases, the least able to survive are the young.[23] Mortality rates for males are higher than for females at all ages, so the population becomes skewed toward females.

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Mortality for female fawns is higher than for 2 or 3 year old females, so the population becomes skewed toward breeding females.

The problem occurs at lower densities. As we reduce a population downward from K, we must treat an increasing proportion of the total population. Furthermore, we must treat an increasing proportion of the females. We reach a maximum for proportion of total deer at the peak of the curve, about 50% K, but not the maximum for proportion of females. As we drive the population still lower, we begin treating a lower proportion of the total population, but a still higher proportion of the breeding females. This is because we are not producing any mortality in the population, and most females are breeding. The number of breeding females we must treat at lower densities grows smaller, but the proportion grows larger.

In Irondequoit, our studies show that with an efficacy of 100%, we can hold the population at any level between 0 and 100% K. If, however, the population is reduced to 25%K, and the efficacy is 90%, we are forced to treat every breeding female in the population to compensate for the 10% failure rate. Below that 25%K, there are not enough females in the population to allow compensation. The implication is that management to maintain a population below 25%K with 90% efficacy is not possible[10]. If efficacy is only 70%, compensation for failed treatments means that the lowest population achievable is 69% K (Figure 22).

Wherever the proportion of females existing in the population is greater than the proportion to treat, management by contraception is theoretically possible. Where the proportion of females crosses the contraception line and drops below the proportion to treat, management by contraception is not possible without further improvements in efficacy.

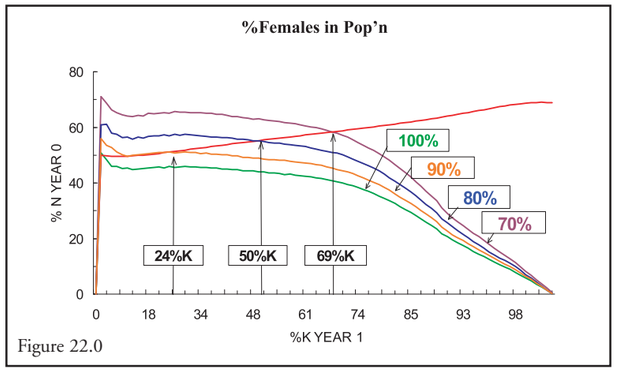


Figure 22.0

Female deer (expressed as %N) to capture and treat with PZP in year 0 to maintain a stable population at a variety of %K in year 1 in Irondequoit. The red line is the percentage of females in the population. The proportion of females that need to be contracepted was determined for treatments of 100, 90, 80, and 70% efficacy.

Whether near–100% efficacy can be achieved under field conditions is debatable. Clinical trials show that nearly 100% efficacy can be achieved under ideal conditions so a high efficacy is possible.[41] In application, a complete injection of the drug is sometimes difficult to judge under field conditions. Even if a darting team is motivated and efficient, its members are still likely to be liberal in their judgement of successful injection. Thus, assuming that each deer is darted once, <100% efficacy appears realistic for application of immunocontraception to free– ranging deer populations.[33] We chose 70% efficacy as a place to start, but expect efficacy will improve through time and with experience of field crews and developments in technology. Efficacy of 90% is probably as good as can be expected under field conditions. This means that the lower limit for management of zero population growth is 25% K. The Citizen Task Force recommended a goal of 20 deer per square mile of quality habitat. This goal is probably near the limit of 25% of K.



Photo by: Jennifer Woodard

Dispersal rates of females in Irondequoit were about 14%. Most of the female dispersers moved to the west, across the Genesee River. One female dispersed from the Flats to the East locale and remained there permanently.

NEIGHBORHOOD MANAGEMENT

Does this mean that contraception will be too expensive to apply? No. We need to find ways to apply it more intelligently. We need to find ways to optimize three factors: maximize encounter rates, maximize efficacy and minimize the number of difficult females to treat.

What if we didn't have to manage all the deer in a park or community, but just those deer that were causing a local problem? Could we remove just those deer in a portion of the community? Could we control a deer population at a lower density in 1 neighborhood while leaving those in surrounding neighborhoods at a higher densities? Would deer in the surrounding neighborhoods move into the area of lower density to take advantage of less competition for food resources? If we could, then some of the alternatives for controlling deer might be more socially and financially acceptable.

The prospect of localized management of deer populations is dependent on movement behavior of deer.[24] Most people tend to think that deer behave in a manner similar to the diffusion of gas molecules. When a gas is released into a volume, the molecules move about until an equilibrium density is established. Thus, when deer perceive that an area has a lower density, they move in to fill it until there is an approximately equal density across the landscape. The behavioral research on fidelity and philopatry suggests otherwise, predicting that deer will not move to fill an area of lower population density, even if it is nearby.[21,25] Areas of habitat that are unoccupied by deer will be filled by dispersal of female deer away from their natal area. Observations in deer populations throughout the northeastern US suggest about 6% of females disperse, and dispersal occurs mostly in females between 1 and 2 years old.[24]

In Irondequoit, the females we radio–tagged showed fidelity to their summer home ranges. We did not document philopatry in Irondequoit because to do so requires that females be tagged within days of birth. However, most of the deer we tagged were captured at less than 1 year of age, and therefore were probably in the home range where they were born. Dispersal of these females was similar to that observed in other areas.

The home range fidelity and philopatry suggest that a reduction in the deer in a neighborhood of several square miles in size might result in a lower population density that would persist for some time.[27] The persistence of the effect depends on the number of females left in the targeted area. Our research in the Adirondacks showed that live–trap and removal of about 90% of all the females from an area of 1/2 square mile created a near void in the population for at least 2 years. Some deer moved through the void area, but few lived there during the summer or winter.

If not all the females are removed from a neighborhood, then the population will regrow quickly. Suppose the population was at ecological carrying capacity at 25 deer. If we reduced the population to 2 females, we could expect the population to recover completely within 6 years. Population models show that a



Photo by: William Porter

Localized management targets individual neighborhoods within a town. In Irondeuqoit, female deer do not move between neighborhoods and thus can be managed as smaller sub–groups.

population reduced by 50% will recover in as little as 2 years, depending on where we begin on the increment of growth curve.

One approach might be to couple a reduction in the population with application of contraception. Costs of the contraception would be lower because there would be fewer female deer to be treated, and because neighborhoods with appropriate access to deer and safe darting conditions could be selected.

The concept of localized management also has important implications to resolving conflicts over the various approaches to controlling deer populations. Home ranges of deer in Irondequoit averaged a little more than 50 acres, about 1/10 the size of home range sizes of deer in many rural environments. Management efforts could be focused on an area as small as 1 or 2 square miles. This means that it should be possible to control deer populations in 1 neighborhood with contraception, apply bowhunting in another neighborhood to reduce the population, and leave the deer alone in a third neighborhood, all within the same community.

However, the implications of movement behavior also have an effect on the extent of a management action. Removal of deer from Durand–Eastman Park as part of the bait–and–shoot program has

little impact on the numbers of deer in the Flats because deer seldom move back and forth between these areas. Consequently, we need to recognize that management actions in 1 neighborhood are not likely to resolve problems over large portions of the Town.

The characteristics of the various neighborhoods may influence which management technique is applied. For instance, contraception is best suited to areas with the following qualities:

1. Few restrictions to property access by those doing darting.
2. Few roads carrying heavy traffic or playgrounds that would present safety concerns.
3. Large open spaces where deer can be darted.
4. Few areas of dense vegetation or rugged topography where deer can hide.

Many areas of Irondequoit may be suited to contraception management, depending on the geographic scale at which population control is desired. The Flats area proved to be the most efficient area for our work because it met these criteria. We had nearly complete access from supportive residents, the streets were



Photo by: Jennifer Woodard

The application of contraceptive treatments in Irondequoit would increase success through the use of adaptive management. The process of adaptive management reaches a consensus on what form of management the community deems acceptable, acquires information to assess each management alternative, identifies risks associated with the most suitable alternative, and carries out the alternative as an experiment with the goal of reducing risks.

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residential and quiet, and there were large backyards of flat topography. Deer in this area were not affected by the bait–and–shoot program in Durand– Eastman Park, so were easily approached. Bowhunting began in the Flats during our study, but the effects were limited because few deer were removed. The only drawback to the area was its proximity to dense vegetation along the river.

Contraceptive treatment in other neighborhoods is possible. Among the best sites are County parks. Firearms laws would need to be amended to allow darting with rifles. Within the other neighborhoods, areas with a few large backyards, a park or a cemetery would be good candidates. The key question is, what is the smallest area on which population control can be achieved? The answer to this question is unknown and will require experimentation.

The Town has frequently stated that it wishes to take a multifaceted approach to deer management. Localized management offers a novel means for accomplishing this goal. A single technique such as contraception, or bowhunting may not be efficient or acceptable across the entire community. At the smaller scale of the neighborhood, there is greater potential to find a single technique that will work and that has the political support to be sustained.

We recommend application of contraceptive treatments through a process of adaptive management. Adaptive management is a 4–step process that includes (1) reaching a concensus on community values and setting boundaries on acceptable management alternatives, (2) acquiring information necessary to make preliminary assessments of each alternative, (3) explicitly identifying uncertainties and risks associated with the preferred alternative, and (4) implementing the alternative in an experimental context with an intent of reducing the uncertainties and risks through rapid learning.

The Town has moved through a long series of consensus–building activities. While government officials are in the best position to make judgements, there appears to be general agreement that the deer population needs to be managed and that immunocontraception should be part of a multifaceted to management. Our study lays the foundation for assessing management alternatives by providing information about the biology of deer and about the factors that are critical to estimating costs of immunocontraception. Specifically, we now know much about deer densities, physical condition and movement behavior of deer. We have preliminary measurements of effort required to administer vaccine via dart rifle, and determined the limits to biological feasibility of the technique.

Our findings suggest that three important uncertainties limit a comprehensive assessment of the feasibility of controlling growth in the deer population in Irondequoit:

1. the ability to achieve efficacy rates of greater than 90% under field conditions.
2. the changes to expect in encounter rates as both people and deer learn about darting.
3. the potential to control local populations apart from surrounding populations.

The next step in the development of this technique should be a full–scale test of a contraceptive program to control population growth over a period of at least 5 to 10 years. We recommend that such a test be conducted in an experimental fashion with an intent of gaining more information pertaining to the uncertainties. The goal of an experimental application of contraceptive management should be to learn to more effectively assess the benefits and costs of this technique.

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Photo by: Jennifer Woodard

The data collected in Irondequoit have revealed 3 key uncertainties that limit the feasibility of using contraceptives to control der population growth. First, the ability to achieve treatment efficacy rates <90%, second, the differences in encounter rates as people and deer become more accustomed to darting, and third, the possibility of controlling local deer populations separate from surrounding populations.

ACKNOWLEDGMENTS

We gratefully acknowledge the residents of the Town of Irondequoit who allowed us access to their property and reported sightings of marked deer. Without their support, this project would not have been possible.

We were assisted by a group of excellent field biologists: Dawn Gorham, Doug Little, and Daniel Bogan served as assistants during field work to collect data on darting and movement behavior. Dr. Dale Garner of the Iowa Department of Natural Resources assisted with aerial surveys. James Eckler and John Hauber of the Department of Environmental Conservation helped us collect data from deer removed during bait–and–shoot operations.

The project was a joint effort that included biologists from the College of Agriculture and Life Sciences at Cornell University, the New York State Department of Environmental Conservation, and the College of Environmental Science and Forestry in Syracuse. Dr. Milo Richmond, Leader of the Biological Resources Division Cooperative Research Unit, and Dr. Paul Curtis, Professor of Wildlife cooperated closely throughout the project, and directed the companion work at Seneca Army Depot. Drs. Barbara Knuth and Bruce Lauber of the Human Dimensions Research Unit in the College of Agriculture and Life Sciences at Cornell University directed the sociological surveys of the Town. The Department of Environmental Conservation provided administrative oversight and field assistance, and we gratefully acknowledge Dr. George Mattfeld, John O'Pezio, David Odell, John Hauber, and James Eckler.

The Humane Society of the United States provided the PZP vaccine/Adjuvant and we operated under their license. We appreciate the fine efforts of Dr. Allen Rutberg.

The residents and public servants in Monroe County and the Town of Irondequoit deserve tremendous thanks. James Mulley enabled us to move through the County system with ease. Town Supervisors Suzanne Masters, William Dillon and David Schantz worked long hours to ensure a cooperative spirit existed throughout the Town. Robert Brown, Maryann Haas and Sandy Baker served as a sounding board to our ideas and a link to the community. Sgt. Dunn provided great assistance during the course of the research.

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We especially wish to thank Maryann Haas. In every large effort, there is one person working behind the scenes who makes the difference. She was that person. She brought the idea of a field test of immunocontraception to life in Irondequoit through endless meetings and telephone calls. She then made the project a success by introducing us to key people in the community and teaching us grassroots politics.

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APPENDIX A.

ESTIMATES OF ABUNDANCE OF DEER IN IRONDEQUOIT BASED ON AERIAL SURVEYS.

There is consensus among wildlife biologists that aerial methods are superior to ground– based methods for determining abundance and location of deer. The quality of aerial counts is heavily dependent on the ability of observers to detect deer. Observer experience, vegetation, and topographic features affect detection, and hence, quality of counts. In northern latitudes, aerial counts for surveying populations of deer are best conducted during winter months when deciduous trees and shrubs are leafless and the ground is covered by snow – conditions ensuring optimal detection of deer.

The aerial survey conducted in 1995, 1996 and 1998. Surveys for 1995 were conducted from 11–13 February under ideal conditions. Surveys for 1996 were flown on 20 February under marginal conditions, but information from the first year's count and population demography were used to correct the estimate for missed deer. Weather conditions were not suitable for a survey in 1997, so an estimate of abundance is not available. In 1998, surveys were flown on 24–25 March under fair to good conditions.

SURVEY AREA

The area of survey is defined by Lake Ontario to the north, Route 104 to the south, the Genesee River on the west and Irondequoit Bay on the east, including Irondequoit Bay Park. This area is approximately 43 square kilometers (km^2) or 17 square miles (mi^2) in size and lies approximately 6 km (4 miles) to the north of the city of Rochester, NY. The topography is characterized by a north–facing plateau eroded by several creeks, producing a ridge and valley relief, particularly near the lake shore and along the river and bay. Drainage is predominantly to the north; however, due to a relatively small change in elevation, approximately 49 m (160 ft) across the survey area, some streams drain to the east into Irondequoit Bay and west into the Genesee River. Dominant vegetation throughout the area is mature deciduous forest with scattered conifer plantations.

Much of the plateau supports intensive commercial and residential development. The steeper terrain is largely undeveloped. Durand Eastman Park comprises about 5 km^2 (2 mi^2) in the north central portion of the survey area. The southern portion of the Durand Eastman Park is composed of wooded ravines. To the north are lowland grassy areas, a golf course, and several lakes. Kings Highway bisects the park. Route 104 and Interstate 590, in the southern and eastern portions of the survey area, respectively, are major traffic thoroughfares serving the city of Rochester, NY.

METHODS

We designed a grid–based sampling system specifically for Irondequoit and used a helicopter in our counts of deer. The survey area was divided into 43 1 km^2 blocks using the Universal Transverse Mercator (UTM) projection system overlaid onto a United States Geological Survey, 7.5 minute quadrangle map. To facilitate navigation, individual blocks were photocopied from Department of Transportation maps. These maps show all relevant roads, buildings and other important landmarks in a large format. Complete counts of deer were made in selected blocks using a Bell Jet Ranger helicopter (Aviation Services, Barneveld, NY) carrying a pilot, navigator, and two observers. Upon arrival at a survey block, the boundaries were flown to familiarize the crew with land marks. Flights over blocks were generally made on north–south passes at 100–200 ft above ground level. Additional passes along ravines were made when necessary to ensure thorough coverage of the block. Deer were counted from the sides and belly of the aircraft, and observers and navigator communicated sightings of deer to avoid duplicate counts.

The survey area was classified into two strata with the aid of a composite aerial photo (Fig. 1). Survey blocks were classified into the high–development stratum (Stratum 1) if more than 50% of the area was occupied by houses, roads or other residential/commercial structures. Survey blocks with less development were classified into the low–development stratum (Stratum 2).

We selected a subset of all survey blocks covering the Town to estimate abundance. Our goal was to fly as many blocks as needed to obtain a population estimate for the Town. Because we expected greater variability in numbers of deer, we allocated more survey effort in Stratum 2 than in Stratum 1. Data from previous years indicated a 5:2 or 6:1 allocation of survey blocks (Stratum 2: Stratum 1) to optimize precision of the population estimate.

To minimize the possibility that deer counted in one block would be double–counted if they moved into a neighboring block, we constrained the random selection of blocks to only those not sharing a common boundary (i.e., selected survey blocks could only touch at the corners). Finally, we used standard statistical procedures for stratified random sampling to estimate the deer population from the counts in individual survey blocks. This analysis yields a range of deer density within which we were 90% confident that the true population size would occur.

The statistical design used to estimate abundance was a stratified random sample

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without replacement and replication. We initially allocated our sampling effort without preliminary estimates of strata means and standard deviations, but with the expectation that more deer would be observed in blocks with the least amount of development. Hence, the variance in this stratum was expected to be highest. Using allocation proportional to the standard deviations of the strata (Neyman type) and guesses for stratum means (CV = 100%), we formulated several sampling plans by computer simulation based on differing numbers of blocks that could be sampled on any given occasion (the sampling intensity). Each sampling intensity was based on an assumed, but unknown, cost (time) associated with navigating the helicopter through an average block. This cost ultimately determined our ability to replicate the survey. Blocks were chosen at random with constraints. These constraints set an upper limit to the sampling intensity at about 30%, or 14 of 43 blocks.

A stratified mean density was computed for each survey using standard formulas. We approximated the effective number of degrees of freedom to account for possible differences among stratum variances. Each point estimate derived from separate counts was used to compute an overall mean density and number for the survey area using formulas for replicated counts when appropriate. Instead of individual sample unit counts, the observations in these calculations were the stratified mean densities of each replicate. We also incorporated the finite population correction factors into our estimates of the standard error to account for the fact that we sampled a large proportion of each stratum at any given survey.

A smoothed representation of variation in town–wide deer density was created by computer modeling using the aerial survey data. We created a composite map of deer distribution by combining the results of each of the surveys. For blocks sampled more than once, density was represented by the average count. Maps displaying contours of deer density (deer/km^2) were generated by interpolating and smoothing the observed counts among survey blocks. A gradient from cool to warm colors was used to indicate density variation over the town in each year.

FINDINGS

The estimate of total population size for the Town of Irondequoit this year is 341 deer (Table 1). Statistical confidence limits were within 57% of the mean town–wide estimate, and suggest that the true population size falls within the range of 210 to 539 deer. We counted substantially more deer in Stratum 2 (10x) than in Stratum 1.

$$\textit{Stratified Mean} = \bar{y}_{st} = \frac{1}{N}\sum_{i=1}^{L} N_i \bar{y}_i = \frac{1}{N}\left[N_1 \bar{y}_1 + N_2 \bar{y}_2 + \ldots + N_L \bar{y}_L\right]$$

$$\textit{Total} = T = N \bar{y}_{st}$$

$$\textit{Variance of Mean} = s^2_{\bar{y}_{st}} = \frac{1}{N^2}\sum_{i=1}^{L} N^2_i s^2_{\bar{y}_i} = \frac{1}{N^2}\left[N^2_1 s^2_{\bar{y}_1} + N^2_2 s^2_{\bar{y}_2} + \ldots + N^2_L s^2_{\bar{y}_L}\right]$$

$$\textit{Standard Error of Mean} = s_{\bar{y}_{st}} = \sqrt{\frac{1}{N^2}\sum_{i=1}^{L} N^2_i s^2_{\bar{y}_i}}$$

$$\textit{Standard Error of Total} = s_T = N s_{\bar{y}_{st}}$$

$$\textit{Effective Degrees of Freedom} = n_c = \frac{(\sum_{i=1}^{L} g_i s^2_i)^2}{\sum_{i=1}^{L} \frac{g^2_i s^4_i}{n_i - 1}} = \frac{\left[g_1 s^2_1 + g_2 s^2_2 + \ldots + g_L s^2_L\right]^2}{\frac{g^2_1 s^4_1}{n_1 - 1} + \frac{g^2_2 s^4_2}{n_2 - 1} + \ldots + \frac{g^2_L s^4_L}{n_L - 1}}$$

where:

L = *number of strata*

N_i = *number of sampling units in stratum i*

n_i = *number of sampling units selected in stratum i*

s^2_i = *estimated variance for stratum i*

$s^2_{\bar{y}_i}$ = *estimated variance of stratum mean i*

$\bar{y}_i$ = *estimated mean of stratum i*

$$g_i = \frac{N_i(N_i - n_i)}{n_i}$$

Formulas for estimating a stratified mean density and associated statistics for deer in the Town of Irondequoit, 1996.

The general distribution of deer across the Town is a broad band of highest density stretching from southeast to northwest (Figs. 2–4). The greatest concentrations of deer are found in two areas of the town: (1) the area west of Culver Road and north of Titus Avenue, just south of Durand Eastman Park, and (2) the area locally described as the Flats. Few deer were observed in the heavily developed areas south of East Ridge Road to Route 104, and in the northeastern portions of Durand Eastman Park. Compared to previous years, areas of deer concentration near Durand Eastman Park have shifted south, toward Titus Avenue.

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INTERPRETATION

Three aerial surveys showed the Irondequoit deer population was estimated at 686 deer in 1995, 485[1] deer in 1996, and 341 deer in 1998 (Table 1). No estimate was formulated over the winter of 1997, so trends in the data for the three estimates actually span four years.

Although 1998 data suggest a lower deer density compared to 1996, statistically speaking, these counts are not different. Confidence interval coverage around this year's estimate (143 – 539 deer) is influenced by an unusually large count (210 deer) during the first flight. The higher count during the first flight can be attributed directly to counts in two particular survey blocks, which were not counted during subsequent flights. The wide confidence interval reflects the variation between estimates of abundance derived from the first flight and those generated from the other two flights. In fact, the lower confidence limit (143 deer) is lower than total number of deer counted during the first flight. Therefore, the minimum number of deer in the Town is at least 210.

Table 1. Estimated white–tailed deer density and associated statistics by stratum and year, Town of Irondequoit, New York.

Stratum Description	Year	N[b]	n[c]	Density (deer / km^2)	Total Deer	Confidence Intervals
High Development (Stratum 1)	1995	21	11	4.0[d]		
	1996	21	3	3.0		
	1998	21	12	1.1[d]		
Low Development (Stratum 2)	1995	20	19	31.5[d]		
	1996	22	18	13.5		
	1998	22	21	13.9[d]		
Total Survey Area	1995	41	30	16.7[d]	686	520–851
	1996	43	21	8.4	485[a]	213–507
	1998	43	33	7.9[d]	341	143–539

[a] adjusted upward by approximately 6 deer per Stratum 2 survey block
[b] N = total number of blocks in stratum
[c] n = total number of blocks sampled in stratum
[d] average of 3 independent point estimates

Figure 1. Map of the white–tailed deer survey area encompassing Irondequoit, New York, March 1998. Shaded areas represent stratum designations.

Figure 2. Interpolated contour map of white–tailed deer density (deer/km^2) sampled from aerial surveys over the town of Irondequoit, New York, March, 1998.

Figure 3. Interpolated contour map of white–tailed deer density (deer/km^2) sampled from aerial surveys over the town of Irondequoit, New York, February, 1996.

Figure 4. Interpolated contour map of white–tailed deer density (deer/km^2) sampled from aerial surveys over the town of Irondequoit, New York, February, 1995.

Appendix B. Physical data for deer removed from Irondequoit in the bait–and– shoot program.

[1] This number represents an estimate adjusted for deer missed in the aerial survey.