FLORIDA KEY DEER

Odocoileus virginianus clavium

POPULATION VIABILITY ASSESSMENT

Captive Breeding Specialist Group
Species Survival Commission/IUCN

Prepared by

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Workshop Participants

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(Based upon a population viability analysis
workshop held 2 - 4 May 1990 at
Key West, Florida.)

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FLORIDA KEY DEER

PVA Workshop

SUMMARY

An endangered species or subspecies is (by definition) at risk of extinction. The dominant objective in the recovery of such a species is to reduce its risk of extinction to some acceptable level - as close as possible to the background, "normal" extinction risk all species face. Population viability analysis provides powerful tools to improve the recognition of risk, to rank relative risks, to evaluate the impact of management options on the risk of extinction, and to assist definition of targets for recovery. This workshop was organized to apply these tools to the endangered Florida Key deer.

The Key deer (Odocoileus virginianus clavium) is classified as a distinct subspecies of the white-tailed deer based upon morphological characters, geographical separation from the mainland, and the approximate 4000 years duration (500-600 generations) of this separation. The population probably has never been greater than 600-800 animals but was reduced to a low of 25-80 around 1950, and now is estimated to be currently stable at about 250-300 as a result of protection and management. The distribution of the population has become restricted and partially fragmented by loss of habitat and highways. The maximum population that can be sustained in the present habitat (public and private) with management of habitat quality and establishment of protected land corridors is about 300 animals. If the deer are restricted to currently protected and fragmented habitat (i.e. by fencing), a population of about 150 animals can be supported.

Our stochastic population simulation models used to estimate risks of extinction, average time to extinction, loss of heterozygosity, and population trends utilize information on population size, carrying capacity, sex and age specific reproductive and mortality rates, environmental variation, effects and risks of catastrophes such as hurricanes, and effects of inbreeding. Information and data used to construct the models for the Key deer were assembled in the PVA workshop which included many of the biologists who have worked on the Key deer over the past 25 years. Ranges of values were evaluated to bracket uncertainty in the current demographic parameters and to examine the effects of different scenarios on the probability of extinction. The population projections were made for 100 years.

The scenario that most closely approximated the consensus of the workshop (line 5 of Table 1B) projected, for an initial population of 250, a 74% probability of extinction in 100 years with a mean time to extinction of 67 years and a mean population size of 33 animals for those 26% of populations surviving. Extension of the time period of the

projections to 200 years resulted in 100% probability of extinction. The mean heterozygosity retained was 88%. If the population is managed at 150 animals, the probability of extinction rises to 85% with a mean time to extinction of 62 years. Thus these populations are small enough that random fluctuations can cause extinction. Under conditions of reduced annual mortality the probability of extinction is reduced even in the face of hurricane effects but the population size of 150 animals is at significantly greater risk of extinction than for 250 animals. A population of 250 animals will likely continue to lose heterozygosity but the slower rate may minimize the risks of inbreeding.

It is useful to decide upon the probability or risk of extinction over a specified time period that is considered acceptable. For many endangered species a goal of 5% or less risk of extinction in 100 years has been chosen as a guide for evaluating alternative scenarios and actions for species. This is considered a goal for preservation from extinction. Goals for full recovery of a taxon to allow continuing evolution by selection and adaptation require larger numbers. The results of the simulations of the suggested scenarios for the Key deer indicate the population should be managed at about 250-300 animals in the present range and at a minimum of 400 deer in the historical range to reduce the rate of loss of heterozygosity and to reduce the probaility of extinction from a single catastrophic event. Either an increase in reproductive rates or a decrease in mortality rates (or a combination) to achieve a positive growth rate will be essential in the event of a population reduction by catastrophe. These measures will be required to reduce the risk of extinction to less than 5%. They further indicate that a decline of the population below 200 animals would be a useful signal to establishing a captive population while other management procedures are being developed.

These results support 4 primary recommendations. First is the need to take the actions necessary to protect habitat and manage the Key deer population at 250 animals. Second is the immediate need for adequate current census and demographic information and techniques for annual monitoring of the population with sufficient precision to detect a 10% change in population numbers in one year or 5% per year for 3 years with perhaps 90% confidence. This information is essential for guiding management activities on a continuing basis since the population goals are minimal for preservation of the Key deer and do not allow much margin for error. Third, research is needed to determine if mortality rates, reproductive rates, and the sex ratio can be manipulated by management actions or are density dependent. Finally plans for establishing a captive population if the wild population declines below 200-175 animals should be formulated.

RECOMMENDATIONS and POINTS OF AGREEMENT

1. Habitat Acquisition and Movement Corridors

The highest priority for conservation of the Key Deer is to maintain the largest deer population the present and expanded habitat will sustain, preferably around 400 deer.

a) The most direct approach is to protect existing habitat and maintain or promote its value to the deer.

b) Movement corridors through urban/suburban areas are essential to the goal of maintaining a population of Key deer.

c) Specifically we recommend 2 north-south corridors across US 1, between refuge lands on northern and southern Big Pine Key. They will consist of deer habitat in the corridors, 10' x 100' underpasses at grade level under US 1, fencing of habitat edge parallel to US 1. Vehicles and local traffic will be accommodated by bridges over the underpasses and frontage roads. Cost estimate per corridor: $1 million for an underpass and $2 million for right-of-way and habitat acquisition. This same approach may became necessary on northern Big Pine Key. Other methods that can help reduce road mortality include reduced speed limits, warning signage and public education, and roadside management.

These actions will:

a) Prevent loss of existing habitat and hence reduction of existing deer population.

b) Reduce habitat fragmentation and permit continued movement of deer produced on north Big Pine Key to populate other areas in favorable years.

c) Prevent repair costs, injuries, and deaths to humans from vehicle-deer collisions.

d) Decrease road mortality of deer.

2. There is an urgent and immediate need for a careful census of the current Key deer population including information on their numbers, age and sex structure, fawning rate, sex ratio of fawns, and mortality rates. The cost estimates for the adequate censusing are about $50,000 annually to census Big Pine or $100,000 for all Key deer inhabited areas.

This information is fundamental to formulation of alternative management scenarios, evaluation of the impact of road mortality on the population, and as a basis for continuing monitoring the population trends in the population.

This population study should also serve to develop and validate methods for monitoring the population annually so that upward and downward trends of 5% annually could be detected reliably (90% confidence) within 3 years.

3. Research Needs for Key Deer

A. Population and demographics
   1. Accurate census data
   2. Status of population
   3. Structure of population
   4. Density dependent reproduction
   5. Movements and dispersal especially on outer islands
   6. Relocation impacts
   7. Statistical analysis of road kill data - statistical causes of road mortality using past 20 years of data: e.g. multiple regression of yearly road mortality on population size, age distribution, traffic volume, speed limit, and weather records (temperature and rainfall).
   8. Demographic studies combined with genetic studies of parentage identification (e.g. using DNA fingerprinting) to more accurately estimate ratio of effective population size to actual population size by estimating the distribution (and variation) in reproductive success of males and females.

B. Human/Deer Interaction

   1. Effects of feeding
   2. Effects of ganging
      a) behavior
      b) physiology and disease
      c) social structure
      d) dispersal
      e) fecundity
      f) survivorship
   3. Effects of dogs
      a) predation
      b) harassment effects
   4. People perceptions and attitudes

C. Ecological, environmental, and habitat

1. Impact of deer on habitat (K)
2. Effects of habitat manipulations (on K, use, health) on deer
    - a) prescribed burning, mowing, other manipulations
    - b. supplying water
3. Effects of habitat fragmentation
    - a) effective corridor (safe movement, safe crossings, fences
    - b. interspersion of habitat types
4. Use of remote and outlying islands?
    - a) limiting factors on those keys
    - b) importance to deer
5. Effect of hurricanes and other catastrophes on deer

D. Physiological

1. Baseline data - partly for use in future captive breeding program for conservation (e.g. following a catastrophe)
2. Reproductive output; effect of ganging
3. Evaluation of health
    - a) parasitology
    - b) condition indices
4. Nutritional aspects
    - a) food
    - b) water
    - c) trace elements
5. Salinity tolerances
6. Metabolic requirements
7. Current food study
8. Effects of plant compounds on deer.
9. Use a captive population for morphological, physiological, and growth studies comparing Key deer and various stocks of mainland deer in controlled common (shared) environments such as nutritional regimes. These studies should continue at least 3 generations (with sufficiently large stocks to avoid close inbreeding) to allow for delayed effects of prenatal and postnatal maternal influences. These studies would give a quantitative assessment of the relative contribution of heredity and environment in determining the differences between Key deer and mainland deer, e.g. in fetal sex-ratio, physiology of basal metabolism; salt tolerance in drinking water.

E. Genetic and Taxonomic

1. Taxonomy
    - a) molecular differences
    - b) morphologic differences
    - c) metabolic differences
2. Inbreeding effects - preliminary results on the lack of genetic variability at electrophoretic loci, unusual primary sex ratio (2 males:1 female in fetuses), the high frequency of dental anomalies, and possible slow wound healing when compared to mainland deer, may be indicative of a previous history of severe inbreeding and consequent reduced fitness.
3. Viability of population
4. Variability
    - a) molecular
    - b) genetic
    - c) morphologic
    - d) physiological

Most of these questions could be addressed with a very intensive radio telemetry, mark/observation study designed to answer many of these points simultaneously.

4. Captive Population

Based on evaluation of current data, it is felt that captive breeding of Key deer at this time would not be necessary to recovery of this endangered subspecies of the white-tailed deer. A captive breeding program may become prudent at some future date, however, if the current status of the population changes substantially in a negative manner (decline of 5% per year for 3 years or decline in numbers below 200). However, quantitative data are not available for making such a determination at this time. Therefore, appropriate data should be gathered to develop criteria that would facilitate timely decisions regarding the need, design, and implementation of a captive-breeding program, should such a program ever become a necessary augmentation to the recovery of the Key deer.

The following interrelated criteria may be used for determining future needs for captive breeding of key deer. Data must be provided to quantify each of these criteria, however, before they would be useful as decision criteria.

A captive breeding program should be designed for implementation if:

1. Genetic loss has occurred in the population to an extent that threatens physiological viability (inbreeding depression) of the population.

2. A decline in available habitat occurs such that the number of deer that can be sustained falls below 200. (With a population below 200, the risk of extinction in 100 years will be near 85% and the increased rate of loss of heterozygosity may further increase this risk of extinction.)

3. A dramatic decline in the deer population occurs (numbers fall to or below 200), and/or adverse changes in mortality or reproductive rates occur.

Purposes of a captive breeding program, should they be determined to be necessary, would be:

1. Preservation and management of genetic material representing the population.

2. Production of individuals suitable for augmentation of the wild population and/or population reintroduction, and/or

3. Preservation of a captive population should extreme circumstances result in total loss of the wild population.

4. Captive populations may also serve research needs for management of the species in the wild that can only be pursued under penned conditions, as well as benefit public educational objectives.

Recommendations for information needed to develop quantitative criteria for establishment of a captive population.

1. Genetic research on the population should be completed.

2. A descriptive analysis of all occupied and available key deer habitat should be completed and a habitat monitoring program should be designed and implemented.

3. The demography of the population should be described and appropriate procedures should be designed and implemented to monitor population trends.

4. Data resulting from the research recommended in 1-3 above should be used to develop quantified criteria for future determination of captive breeding needs.

Captive Breeding Specialist Group

Species Survival Commission
IUCN -- The World Conservation Union
U. S. Seal, CBSG Chairman

KEY DEER

Odocoileus viginianus clavium

POPULATION VIABILITY ASSESSMENT AND CONSERVATION PLAN WORKSHOP

Key West, Florida
May 2-4, 1990

Problem:

The Key Deer (Odocoileus virginanus clavium) is endangered and numbers about 300 animals in the wild. Continuing apparent decline of the population with known losses of young and adult animals to road mortality in addition to natural causes, the primary restriction of the population to Big Pine Key, and continuing habitat fragmentation on Big Pine Key put the population at increasing risk of losing genetic variation and vulnerability to demographic extinction. These conditions favor at least continued loss of genetic diversity and at worst extinction in the wild from random environmental events.

Goals:

(1) Prepare a Population Viability Analysis for the Key Deer.

(2) Formulate a quantitative strategy with risk assessments to prevent extinction and achieve the objective of developing viable, self-sustaining populations within the historic range of the animal.

(3) Prepare a report of the analyses and results of the meeting with recommendations.

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Objectives:

(1) Determine numbers of Key Deer and subpopulations required for various probabilities of survival and preservation of genetic diversity for specified periods of time (i.e. 25, 50, 100, 200 years).

(2) Consider habitat and capacity requirements needed to meet objectives of establishing population sizes needed for a 'viable population. Consider how possible interventions in the wild population and its habitat might decrease the mortality rate, increase its rate of growth and decrease its loss of genetic diversity.

(3) Project the potential expansion or decline of Key Deer population numbers under various management regimes.

(4) Outline metapopulation structures that could be used to establish a viable population. Indicate the management structure consequences of this approach.

(5) Formulate and evaluate possible role of captive propagation as a component of the strategy. In particular, consider how captive propagation could (a) accelerate expansion of population, (b) enhance preservation of genetic diversity, (c) protect population gene pool against fluctuations due to environmental vicissitudes in wild, and (d) provide animals for reinforcement of wild populations or establishment of new wild populations.

(6) Explore scenarios for obtaining animals from the wild to establish a captive population and evaluate their effects on the viability of the wild population and the viability of the Key Deer gene pool.

(7) Identify problems and issues that need continuing analysis and research.

(8) Recommend scenarios and a course of action.

(9) Produce a document presenting the results and recommendations of the workshop.

Captive Breeding Specialist Group
Species Survival Commission
IUCN -- The World Conservation Union
U. S. Seal, CBSG Chairman

KEY DEER

Viability Analysis Workshop
2-4 May 1990

AGENDA

1. Introductions and arrangements. (Holle)

   Goals, Workplan, and Assignments for Workshop. (Seal).

Overview of PVA:

2. Demographic, environmental, and catastrophic effects on persistence of small populations.

3. Genetics and persistence of small populations.

4. Species survival planning and collaborative management approaches for small populations.

5. Life history characteristics of wild and captive Key Deer (and other white-tailed deer subspecies) useful for viability analysis and population models. Litter size, age of first reproduction, sex and age specific mortality and fertility, seasonality, generation time, social structure, and dispersal estimates.

Key Deer:

6. Life history characteristics of Key Deer. Reproduction, demography of mortality, food and habitat requirements, social structure, dispersers and dispersal distances.

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7. History of Key Deer population - numbers and distribution. Demography of mortality during past 10 years.

8. Current status of Key Deer in wild. Sex and age structure, distribution, reproduction, habitat availability.

9. Key Deer and other white-tails in captivity. Reproduction and selection in captivity. Suitability for reintroduction.

10. Taxonomy, genetic analyses, heterozygosity, population substructure.

11. Reproductive biology of the Key Deer and need for enhancement through habitat protection and enhancement. Potential need for enhancement through reproductive technology.

12. Interactions with people and impact on genetics and demography.

13. Current and planned land use patterns and impact on subpopulation structure, population sizes, and mortality.

Models and Strategies for the Key Deer:

14. Models of persistence times for the current Key Deer population in the wild.

15. Taxonomic relationships of the Key Deer. How to define boundaries for management of animals from different geographic locations.

16. Genetic and population goals to establish and maintain a viable population. Numbers of founders, effective population sizes, and rates of loss of diversity. Time span?

17. Alternative strategies to achieve a viable population. Role of captive populations. Metapopulation approach to a viable population.

18. Rapid expansion of founder populations.

19. Individual locale recommendations for suggested strategies.

20. Draft document of meeting results. Review of preferred scenarios. Preparation of written report and masterplan. Review, revision, and consensus.

Introduction

An endangered species is (by definition) at risk of extinction. The dominant objective in the recovery of such a species is to reduce its risk of extinction to some acceptable level - as close as possible to the background, "normal" extinction risk all species face.

The concept of risk is used to define the targets for recovery, and is used to define recovery itself. Risk, not surprisingly, is a central issue in endangered species management. Unfortunately, there is ample reason to suppose that we (as humans) are not "naturally" good at risk assessment. Recovery will be more often successful if we could do this better. There is a strong need for tools that would help managers deal with risk. We need to improve estimation of risk, to rank order better the risk due to different potential management options, to improve objectivity in assessing risk, and to add quality control to the process (through internal consistency checks). Among the risks to be evaluated are those of extinction, and loss of genetic diversity.

In the last several years such tools have been developing. The applied science of Conservation Biology has grown into some of the space between Wildlife Management and Population Biology. A set of approaches, loosely known as "Population Viability Analysis" has appeared.

These techniques are already powerful enough to improve recognition of risk, rank relative risks, and evaluate options. They have the further benefit of changing part of the decision making process from unchallengeable internal intuition to explicit (and hence challengeable) quantitative rationales.

In the following sections, Tom Foose, Bob Lacy, and Jon Ballou each describe aspects of Population Viability Analysis (PVA). The text, adapted from that used in other PVAs (Ballou et al. 1989, Lacy et al. 1989), provides an overview of some of the population biology concepts that form the foundation of Population Viability Assessment. Each contributor approaches the subject from their own expertise and experience, so the contributions differ somewhat in perspective and content. There is some overlap, which may help the newcomer by occasionally repeating a point in different language. After these general reviews, a detailed PVA of the Florida Key deer is presented, and recommendations are made for improving the probability of recovery of the taxon.

Interactive Management of Small Wild and Captive Populations (T.J. Foose)

Introduction

Conservation strategies for endangered species must be based on viable populations. While it is necessary, it is no longer sufficient merely to protect endangered species *in situ*. They must also be managed.

The reason management will be necessary is that the populations that can be maintained of many species under the pressures of habitat degradation and unsustainable exploitation will be small, i.e. a few tens to a few hundreds (in some cases, even a few thousands) depending on the species. As such, these populations are endangered by a number of environmental, demographic, and genetic problems that are stochastic in nature and that can cause extinction.

Small populations can be devastated by catastrophe (weather disasters, epidemics, exploitation) as exemplified by the case of the black footed-ferret and the Puerto Rican parrot, or be decimated by less drastic fluctuations in the environment. Demographically, small populations can be disrupted by random fluctuations in survivorship and fertility. Genetically, small populations lose diversity needed for fitness and adaptability.

Minimum Viable Populations

For all of these problems, it is the case that the smaller the population is and the longer the period of time it remains so, the greater these risks will be and the more likely extinction is to occur. As a consequence, conservation strategies for species which are reduced in number, and which most probably will remain that way for a long time, must be based on maintaining certain minimum viable populations (MVP's), i.e. populations large enough to permit long-term persistence despite the genetic, demographic and environmental problems.

There is no single magic number that constitutes an MVP for all species, or for any one species all the time. Rather, an MVP depends on both the genetic and demographic objectives for the program and the biological characteristics of the taxon or population of concern. A further complication is that currently genetic and demographic factors must be considered separately in determining MVP's, although there certainly are interactions between the genetic and demographic factors. Moreover, the scientific models for assessing risks in relation to population size are still in rapid development. Nevertheless, by considering both the genetic and demographic objectives of the program and the biological characteristics pertaining to the population, scientific analyses can suggest ranges of population sizes that will provide calculated protection against the stochastic problems.

Genetic and demographic objectives of importance for MVP

Probability of survival (e.g., 50% or 95%) desired for the population;

Percentage of the genetic diversity to be preserved (90%, 95%, etc.);

Period of time over which the demographic security and genetic diversity are to be sustained (e.g., 50 years, 200 years).

In terms of demographic and environmental problems, for example, the desire may be for 95% probability of survival for 200 years. Models are emerging to predict persistence times for populations of various sizes under these threats. Or in terms of genetic problems, the desire may be to preserve 95% of average heterozygosity for 200 years. Again models are available. However, it is essential to realize that such terms as viability, recovery, self-sustainment, and persistence can be defined only when quantitative genetic and demographic objectives have been established, including the period of time for which the program (and population) is expected to continue.

Biological characteristics of importance for MVP

Generation time: Genetic diversity is lost generation by generation, not year by year. Hence, species with longer generation times will have fewer opportunities to lose genetic diversity within the given period of time selected for the program. As a consequence, to achieve the same genetic objectives, MVP's can be smaller for species with longer generation times. Generation time is qualitatively the average age at which animals produce their offspring; quantitatively, it is a function of the age-specific survivorships and fertilities of the population which will vary naturally and which can be modified by management, e.g. to extend generation time.

The number of founders. A founder is defined as an animal from a source population (the wild for example) that establishes a derivative population (in captivity, for translocation to a new site, or at the inception of a program of intensive management). To be effective, a founder must reproduce and be represented by descendants in the existing population. Technically, to constitute a full founder, an animal should also be unrelated to any other representative of the source population and non-inbred.

Basically, the more founders, the better, i.e. the more representative the sample of the source gene pool and the smaller the MVP required for genetic objectives. There is also a demographic founder effect; the larger the number of founders, the less likely is extinction due to demographic stochasticity. However, for larger vertebrates, there is a point of diminishing returns (Figure 1), at least in genetic terms. Hence a common objective is to obtain 20-30 effective founders to establish a population. If this objective cannot be achieved, then the program must do the best with what is available. If a pregnant female woolly mammoth were discovered wandering the tundra of Alaska, it would certainly be worth trying to develop a recovery plan for the species even though the probability of success would be low. By aspiring to the optima, a program is really improving the probability of success.

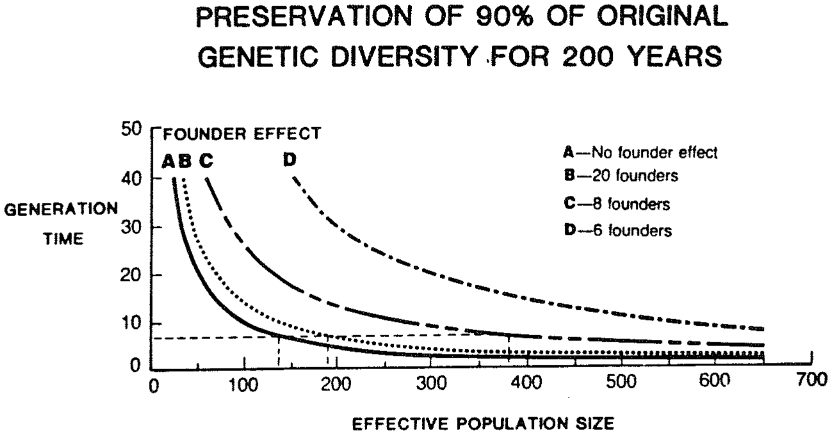


Figure 1. Interaction of number of founders, generation time of the species, and effective population size required for preserving 90% of the starting genetic diversity for 200 years.

Effective Population Size. Another very important consideration is the effective size of the population, designated N_e. N_e is not the same as the census size, N. Rather, N_e is a measure of the way the members of the population are reproducing with one another to transmit genes to the next generation. N_e is usually much less than N. For example in the grizzly bear, N_e/N ratios of about .25 have been estimated (Harris and Allendorf 1989). As a consequence, if the genetic models prescribe an N_e of 500 to achieve some set of genetic objectives, the MVP might have to be 2000.

Growth Rate. The higher the growth rate, the faster a population can recover from small size, thereby outgrowing much of the demographic risk and limiting the amount of genetic diversity lost during the so-called "bottleneck". It is important to distinguish MVP's from bottleneck sizes.

Population viability analysis

The process of deriving MVP's by considering various factors, i.e. sets of objectives and characteristics, is known as Population Viability (sometimes Vulnerability) Analysis (PVA). Deriving applicable results in PVA requires an interactive process between population biologists, managers, and researchers. PVA has been applied to a number of species (e.g., Parker and Smith 1988, Seal et al. 1989, Ballou et al. 1989, Lacy et al. 1989, Lacy and Clark, in press).

As mentioned earlier, PVA modelling often is performed separately with respect to genetic and demographic events. Genetic models indicate it will be necessary to maintain populations of hundreds or thousands to preserve a high percentage of the gene pool for several centuries. Recent models allow simultaneous consideration of demography, environmental uncertainty, and genetic uncertainty.

MVP's to contend with demographic and environmental stochasticity may be even higher than to preserve genetic diversity especially if a high probability of survival for an appreciable period of time is desired. For example, a 95% probability of survival may entail actually maintaining a much larger population whose persistence time is 20 times greater than required for 50% (i.e., average) probability of survival; 90%, 10 times greater. From another perspective, it can be expected that more than 50% of actual populations will become extinct before the calculated mean persistence time elapses.

Species of larger vertebrates will almost certainly need population sizes of several hundreds or perhaps thousands to be viable. In terms of the stochastic problems, more is always better.

Metapopulations and Minimum Areas

MVP's imply minimum critical areas of natural habitat, that will be difficult to obtain in the near future for the Key deer. It may be difficult or impossible to maintain single, contiguous populations of the hundreds required for viability. It is possible that the Key deer has never had a population size more than 700-1000 and that as an island endemic it has always been restricted to essentially a single population. However the posible effects of inbreeding based upon the fawn sex ratio indicates that the population may not have been purged of all deleterious alleles.

However, it is possible for smaller populations and sanctuaries to be viable if they are managed as a single larger population (a metapopulation) whose collective size is equivalent to the MVP (Figure 2). Actually, distributing animals over multiple "subpopulations" will increase the effective size of the total number maintained in terms of the capacity to tolerate the stochastic problems. Any one subpopulation may become extinct or nearly so due to these causes; but through recolonization or reinforcement from other subpopulations, the metapopulation will survive. Metapopulations are evidently frequent in nature with much local extinction and re-colonization of constituent subpopulations occurring.

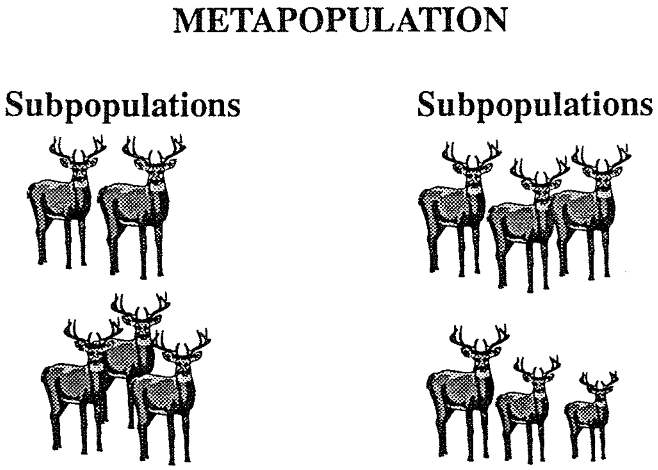
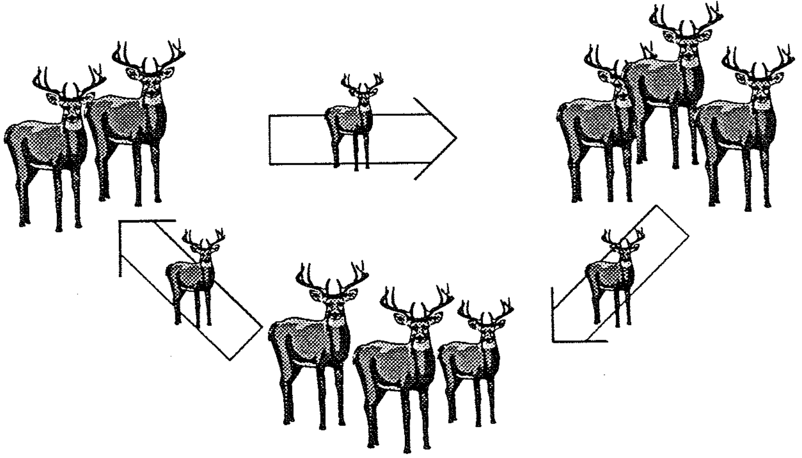


Figure 2. Multiple subpopulations as a basis for management of a metapopulation for survival of a species in the wild.

Unfortunately, as wild populations become fragmented, natural migration for re-colonization may become impossible. Hence, metapopulation management will entail moving animals around to correct genetic and demographic problems (Figure 3). For migration to be effective, the migrants must reproduce in the new area. Hence, in case of managed migration it will be important to monitor the genetic and demographic performance of migrants

Managed migration is merely one example of the kinds of intensive management and protection that will be desirable and necessary for viability of populations in the wild. (MVP's strictly interpreted imply conditions allowing management by benign neglect.) It is possible to reduce the MVP required for some set of objectives, or considered from an alternative perspective, extend the persistence time for a given size population, through management intervention to correct genetic and demographic problems as they are detected. In essence, many of these management measures will increase the N_e of the actual number of animals maintained.



Managed Migration Among Wild Populations

Figure 3. Managed migration among subpopulations to sustain gene flow in a metapopulation.

The Key deer is already subject to intervention: the movements of the population are monitored, the water supply is manipulated, some animals are receiving food from people, movement paths are blocked, and some are acclimated to people. Such interventions are manifestations of the fact that as natural sanctuaries and their resident populations become smaller, they are in effect transforming into megazoos that will require much the same kind of intensive genetic and demographic management as species in captivity.

Captive Propagation

Another way to enhance viability is to reinforce wild populations with captive propagation. More specifically, there are a number of advantages to captive propagation: protection from unsustainable exploitation, e.g. poaching; moderation of environmental vicissitudes for at least part of the population; more genetic management and hence enhance preservation of the gene pool; accelerated expansion of the population to move toward the desired MVP and to provide animals more rapidly for introduction into new areas; and increase in the total number of animals maintained.

It must be emphasized that the purpose of captive propagation is to reinforce, not replace, wild populations. Captive colonies and zoos must serve as reservoirs of genetic and demographic material that can periodically be transfused into natural habitats to re-establish species that have been extirpated or to revitalize populations that have been debilitated by genetic and demographic problems.

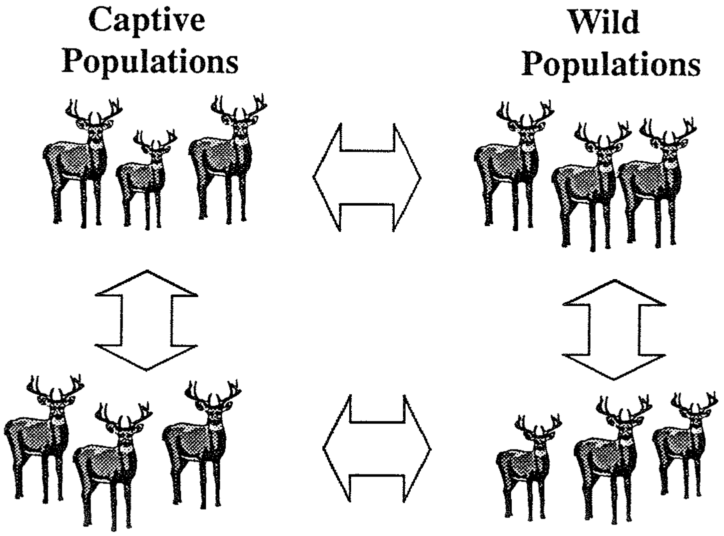


Figure 4. The use of captive populations as part of a metapopulation to expand and protect the gene pool of a species.

The survival of a great and growing number of endangered species will depend on assistance from captive propagation. Indeed, what appears optimal and inevitable are conservation strategies for the species incorporating both captive and wild populations interactively managed for mutual support and survival (Figure 4). The captive population can serve as a vital reservoir of genetic and demographic material; the wild population, if large enough, can continue to subject the species to natural selection. This general strategy has been adopted by the IUCN (the world umbrella conservation organization) which now recommends that captive propagation be invoked anytime a taxon's wild population declines below 1000 (IUCN 1988).

Species Survival Plans

Zoos in many regions of the world are organizing scientifically managed and highly coordinated programs for captive propagation to reinforce natural populations. In North America, these efforts are being developed under the auspices of the AAZPA, in coordination with the IUCN SSC Captive Breeding Specialist Group (CBSG), and are known as the Species Survival Plan (SSP).

Captive propagation can help, but only if the captive populations themselves are based on concepts of viable populations. This will require obtaining as many founders as possible, rapidly expanding the population normally to several hundreds of animals, and managing the population closely genetically and demographically. This is the purpose of SSP Masterplans. Captive programs can also conduct research to facilitate management in the wild as well as in captivity, and for interactions between the two.

A prime examples of such a captive/wild strategy is the combined USFWS Recovery Plan/SSP Masterplan for the red wolf. Much of the captive propagation of red wolves has occurred at a special facility in Washington state, but there is also a growing number of zoos providing captive habitat, especially institutions within the historical range of the red wolf.

Another eminent example of a conservation and recovery strategy incorporating both captive and wild populations is the black-footed ferret. This species now evidently survives only in captivity. Because the decision to establish a captive population was delayed, the situation became so critical that moving all the animals into captivity seemed the only option, circumstances that also applied to the California condor. Another option may have been available if action to establish a captive population had occurred earlier as was done with the Puerto Rican parrot and plain pigeon. Consideration of the survivorship pattern, which exhibited high juvenile mortality for ferrets, as it does for many mammals and birds, suggested that young animals destined to die in the wild might be removed with little or no impact on the population. The AAZPA/SSP and CBSG/SSC/IUCN are involved in these kinds of strategies and programs worldwide.

Population Viability Analysis (R. C. Lacy)

Many wildlife populations that were once large, continuous, and diverse have been reduced to small, fragmented isolates in remaining natural areas, nature preserves, or even zoos. For example, black rhinos once numbered in the 100s of thousands, occupying much of Africa south of the Sahara; now a few thousand survive in a handful of parks and reserves, each supporting a few to at most a few hundred animals. Similarly, the Puerto Rican parrot, the only psittacine native to Puerto Rico, was formerly widespread on the island and numbered perhaps a million birds. By 1972 the species was reduced to just 20 birds (4 in captivity). Intensive efforts since have accomplished a steady recovery to 46 captive and 34 wild birds at the end of 1988. In 1989, the Luquillo forest which is home to both the captive and wild flocks of Puerto Rican parrots was severely damaged by a hurricane. Apparently about half of the wild parrots were killed, most of the traditional nest trees were destroyed, the food supply was decimated, and it is unlikely that a viable population remains in the wild, certainly it will require continuing intensive intervention and management to survive and grow.

When populations become small and isolated from any and all other conspecifics, they face a number of demographic and genetic risks to survival: in particular, chance events such as the occurrence and timing of disease outbreaks, random fluctuations in the sex ratio of offspring, and even the randomness of Mendelian gene transmission can become more important than whether the population has sufficient habitat to persist, is well adapted to that habitat, and has an average birth rate that exceeds the mean death rate. Unfortunately, the genetic and demographic processes that come into play when a population becomes small and isolated feed back on each other to create what has been aptly but depressingly described as an "extinction vortex". The genetic problems of inbreeding depression and lack of adaptability can cause a small population to become even smaller --which in turn worsens the uncertainty of finding a mate and reproducing -- leading to further decline in numbers and thus more inbreeding and loss of genetic diversity. The population spirals down toward extinction at an ever accelerated pace. The size below which a population is likely to get sucked into the extinction vortex has been called the Minimum Viable Population size (or MVP).

The final extinction of a population usually is probabilistic, resulting from one or a few years of bad luck, even if the causes of the original decline were quite deterministic processes such as over-hunting and habitat destruction. Recently, techniques have been developed to permit the systematic examination of many of the demographic and genetic processes that put small, isolated populations at risk. By a combination of analytic and simulation techniques, the probability of a population persisting a specified time into the future can be estimated: a process called Population Viability Analysis (PVA) (Soule 1987). Because we still do not incorporate all factors into the analytic and simulation models (and we do not know how important the factors we ignore may be), the results of PVAs almost certainly underestimate the true probabilities of population extinction.

The value of a PVA comes not from the crude estimates of extinction probability, but rather from identification of the relative importance of the factors that put a population at risk and assessment of the value (in terms of increased probability of population persistence) of various possible management actions. That few species recognized as Endangered have recovered adequately to be delisted and some have gone extinct in spite of protection and recovery efforts attests to the acute risks faced by small populations and to the need for a more intensive, systematic approach to recovery planning utilizing whatever human, analytical, biological, and economic resources are available.

Genetic Processes in Small and Fragmented Populations

Random events dominate genetic and evolutionary change when the size of an interbreeding population is on the order of 10s or 100s (rather than 1000s or more). In the absence of selection, each generation is a random genetic sample of the previous generation. When this sample is small, the frequencies of genetic variants (alleles) can shift markedly from one generation to the next by chance, and variants can be lost entirely from the population -- a process referred to as "genetic drift". Genetic drift is cumulative. There is no tendency for allele frequencies to return to earlier states (though they may do so by chance), and a lost variant cannot be recovered, except by the reintroduction of the variant to the population through mutation or immigration from another population. Mutation is such a rare event (on the order of one in a million for any given gene) that it plays virtually no role in small populations over time scales of human concern (Lacy 1987a). The restoration of variation by immigration is only possible if other populations exist to serve as sources of genetic material.

Genetic drift, being a random process, is also non-adaptive. In populations of less than 100 breeders, drift overwhelms the effects of all but the strongest selection: Adaptive alleles can be lost by drift, with the fixation of deleterious variants (genetic defects) in the population. For example, the prevalence of cryptorchidism (failure of one or both testicles to descend) in Florida panthers (Felis concolor coryi) is probably the result of a strongly deleterious allele that has become common, by chance, in the population; and a kinked tail is probably a mildly deleterious (or at best neutral) trait that has become almost fixed within the Florida panthers. In captive Bali starlings, inbreeding effects are manifest in failure to thrive and increased early mortality.

A concomitant of genetic drift in small populations is inbreeding -- mating between genetic relatives. When numbers of breeding animals become very low, inbreeding becomes inevitable and common. Inbred animals often have a higher rate of birth defects, slower growth, higher mortality, and lower fecundity ("inbreeding depression"). Inbreeding depression has been well documented in laboratory and domesticated stocks (Falconer 1981), zoo populations (Ralls et al. 1979, Ralls and Ballou 1983, Ralls et al. 1988), and a few wild populations.

Inbreeding depression probably results primarily from the expression of rare, deleterious alleles. Most populations contain a number of recessive deleterious alleles (the "genetic load" of the population) whose effects are usually masked because few individuals in a randomly breeding population would receive two copies of (are "homozygous" for) a harmful allele. Because their parents are related and share genes in common, inbred animals have much higher probabilities of being homozygous for rare alleles. If selection were efficient at removing deleterious traits from small populations, progressively inbred populations would become purged of their genetic load and further inbreeding would be of little consequence. Because random drift is so much stronger than selection in very small populations, even decidedly harmful traits can become common (e.g., cryptorchidism in the Florida panther) and inbreeding depression can drive a population to extinction.

The loss of genetic diversity that occurs as variants are lost through genetic drift has other, long-term consequences. As a population becomes increasingly homogeneous, it becomes increasingly susceptible to disease, new predators, changing climate, or any environmental change. Selection cannot favor the more adaptive types when all are identical and none are sufficiently adaptive. Every extinction is, in a sense, the failure of a population to adapt quickly enough to a changing environment.

To avoid the immediate effects of inbreeding and the long-term losses of genetic variability a population must remain large, or at least pass through phases of small numbers ("bottlenecks") in just one or a few generations. Because of the long generation times of the Puerto Rican parrot, the present bottleneck has existed for just one or two generations, and could be exited (successfully, we hope) before another generation passes and further genetic decay occurs. The Florida panther has evidently been in a bottleneck for much of this century, perhaps for tens of generations. The Key deer may have been through several bottlenecks in this century and others during the thousands of years of isolation from the mainland population. Although we cannot predict which genetic variants will be lost from any given population (that is the nature of random drift), we can specify the expected average rate of loss. Figure 5 shows the mean fate of genetic variation in randomly breeding populations of various sizes. The average rate of loss of genetic variance (when measured by heterozygosity, additive variance in quantitative traits, or the binomial variance in allelic frequencies) declines by drift according to:

$$V_g(t) = V_g(0) \times (1 - 1/(2N_e))^t,$$

in which V_g is the genetic variance at generation t, and N_e is the effective population size (see below) or approximately the number of breeders in a randomly breeding population. As shown in Figure 6, the variance in the rate of loss among genes and among different populations is quite large; some populations may (by chance) do considerably better or worse than the averages shown in Figure 5.

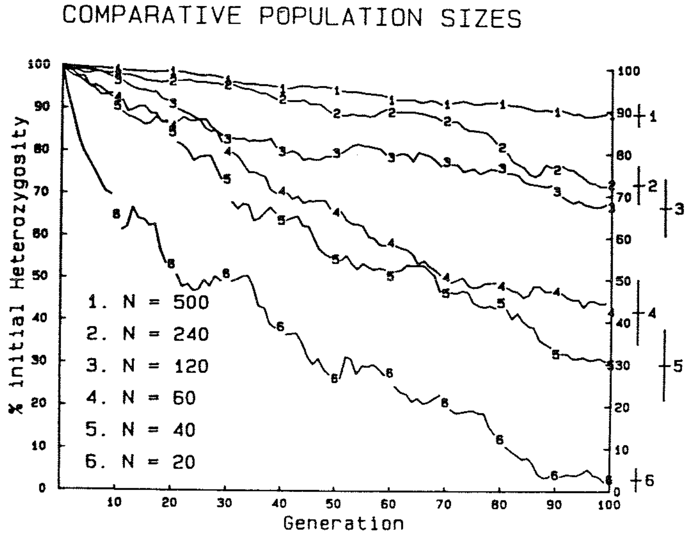


Figure 5. The average losses of genetic variation (measured by heterozygosity or additive genetic variation) due to genetic drift in 25 computer-simulated populations of 20, 50, 100, 250, and 500 randomly breeding individuals. Figure from Lacy 1987a.

The rate of loss of genetic variation considered acceptable for a population of concern depends on the relationship between fitness and genetic variation in the population, the decrease in fitness considered to be acceptable, and the value placed by humans on the conservation of natural variation within wildlife populations. Over the short-term, a 1% decrease in genetic variance (or heterozygosity), which corresponds to a 1% increment in the inbreeding coefficient, has been observed to cause about a 1-2% decrease in aspects of fitness (fecundity, survival) measured in a variety of animal populations (Falconer 1981). Appropriately, domesticated animal breeders usually accept inbreeding of less than 1% per generation as unlikely to cause serious detriment. The relationship between fitness and inbreeding is highly variable among species and even among populations of a species, however. A few highly inbred populations survive and reproduce well (e.g., northern elephant seals, Pere David's deer, European bison), while attempts to inbreed many other populations have resulted in the extinction of most or all inbred lines (Falconer 1981).

Concern over the loss of genetic adaptability has led to a recommendation that management programs for endangered taxa aim for the retention of at least 90% of the genetic variance present in ancestral populations (Foose et al. 1986). The adaptive response of a population to selection is proportional to the genetic variance in the traits selected, so the 90% goal would conserve a population capable of adapting at 90% the rate of the ancestral population. Over a timescale of 100 years or more, for a medium-sized vertebrate with a generation time of 5 years such a goal would imply an average loss of 0.5% of the genetic variation per generation, or a randomly breeding population of about 100 breeding age individuals.

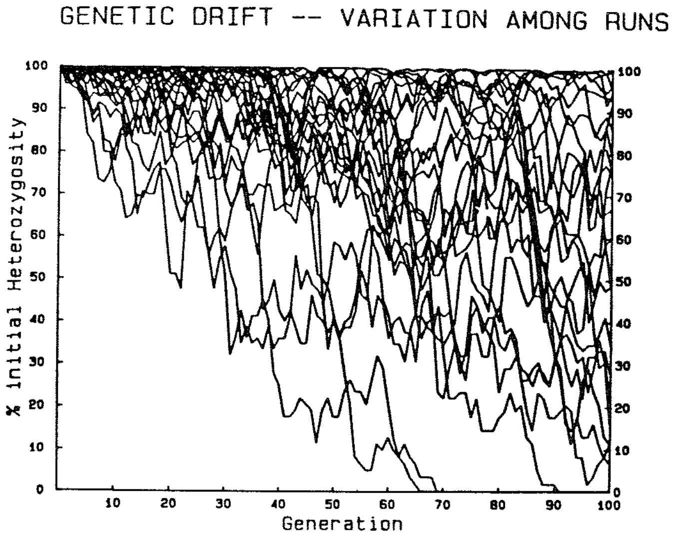
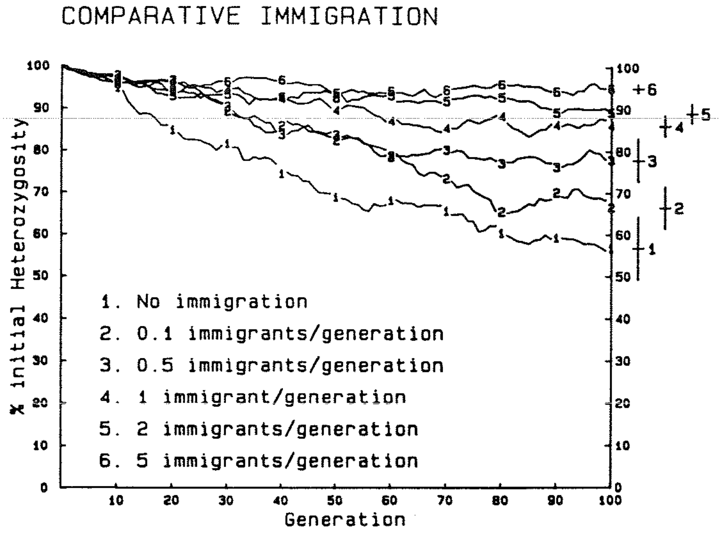


Figure 6. The losses of heterozygosity at a genetic locus in 25 populations of 120 randomly breeding individuals, simulated by computer. Figure from Lacy 1987a.

Most populations, whether natural, reintroduced, or captive, are founded by a small number of individuals, usually many fewer than the ultimate carrying capacity. Genetic drift can be especially rapid during this initial bottleneck (the "founder effect"), as it is whenever a population is at very low size. To minimize the genetic losses from the founder effect, managed populations should be started with 20 to 30 founders, and the population should be expanded to carrying capacity as rapidly as possible (Foose et al. 1986, Lacy 1988, 1989). With twenty reproductive founders, the initial population would contain approximately 97.5% of the genetic variance present in the source population from which the founders came. The rate of further loss would decline from 2.5% per generation as the population increased in numbers. Because of the rapid losses of variability during the founding bottleneck, the ultimate carrying capacity of a managed population may have to be set substantially higher than the 100 breeding individuals given above in order to keep the total genetic losses below 90% (or whatever goal is chosen).

The above equations, graphs, and calculations all assume that the population is breeding randomly. Yet breeding is random in few if any natural populations. The "effective population size" is defined as that size of a randomly breeding population (one in which gamete union is at random) which would lose genetic variation by drift at the same rate as does the population of concern. An unequal sex ratio of breeding animals, greater than random variance in lifetime reproduction, and fluctuating population sizes all cause more rapid loss of variation than would occur in a randomly breeding population, and thus depress the effective population size. If the appropriate variables can be measured, then the impact of each factor on N_e can be calculated from standard population genetic formulae (Crow and Kimura 1970, Lande and Barrowclough 1987). For many vertebrates, breeding is approximately at random among those animals that reach reproductive age and enter the breeding population. To a first approximation, therefore, the effective population size can be estimated as the number of breeders each generation. In managed captive populations (with relatively low mortality rates, and stable numbers), effective population sizes are often 1/4 to 1/2 the census population. In wild populations (in which many animals die before they reach reproductive age), Ne/N probably rarely exceeds this range and often is an order of magnitude less.

The population size required to minimize genetic losses in a medium sized animal, therefore, might be estimated to be on the order of $N_e = 100$, as described above, with $N = 200$ to 400. More precise estimates can and should be determined for any population of management concern from the life history characteristics of the population, the expected losses during the founding bottleneck, the genetic goals of the management plan, and the timescale of management.



COMPARATIVE IMMIGRATION

Figure 7. The effect of immigration from a large source population into a population of 120 breeding individuals. Each line represents the mean heterozygosity of 25 computer-simulated populations (or, equivalently, the mean heterozygosity across 25 non-linked genetic loci in a single population). Standard error bars for the final levels of heterozygosity are given at the right. Figure from Lacy 1987a.

Although the fate of any one small population is likely to be extinction within a moderate number of generations, populations are not necessarily completely isolated from conspecifics. Most species distributions can be described as "metapopulations", consisting of a number of partially isolated populations, within each of which mating is nearly random. Dispersal between populations can slow genetic losses due to drift, can augment numbers following population decline, and ultimately can recolonize habitat vacant after local extinction.

If a very large population exists that can serve as a continued source of genetic material for a small isolate, even very occasional immigration (on the order of 1 per generation) can prevent the isolated subpopulation from losing substantial genetic variation (Figure 7). Often no source population exists of sufficient size to escape the effects of drift, but rather the metapopulation is divided into a number of small isolates with each subjected to considerable stochastic forces. Genetic variability is lost from within each subpopulation, but as different variants are lost by chance from different subpopulations the metapopulation can retain much of the initial genetic variability (Figure 8). Even a little genetic interchange between the subpopulations (on the order of 1 migrant per generation) will maintain variability within each subpopulation, by reintroducing genetic variants that are lost by drift (Figure 9). Because of the effectiveness of even low levels of migration at countering the effects of drift, the absolute isolation of a small population would have a very major impact on its genetic viability (and also, likely, its demographic stability). Population genetic theory makes it clear that no small, totally isolated population is likely to persist for long.

Demographic Processes in Small and Fragmented Populations (J. Ballou)

Extinction rates (persistence times) of populations are determined by the population size, growth rate, susceptibility to demographic challenges (sometimes measured as variation in growth rate), and its spatial distribution. In turn, growth rate, and population's susceptibility to demographic challenges is determined by the population's life history characteristics, and such random factors as the severity of demographic, environmental, genetic, disease and catastrophic events affecting the population.

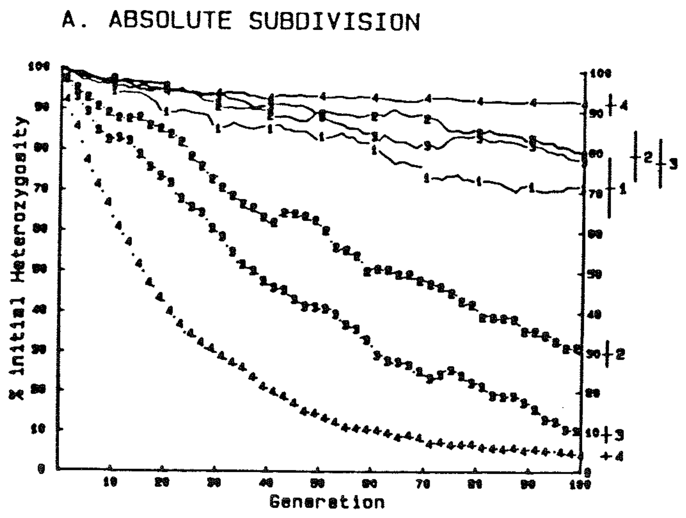

A. ABSOLUTE SUBDIVISION

Figure 8. The effect of division of a population of 120 breeders into 1, 3, 5, or 10 isolated subpopulations. Dotted lines (numbers) indicate the mean within-subpopulation heterozygosities from 25 computer simulations. Lines represent the total gene diversity within the simulated metapopulation. Figure from Lacy 1987a.

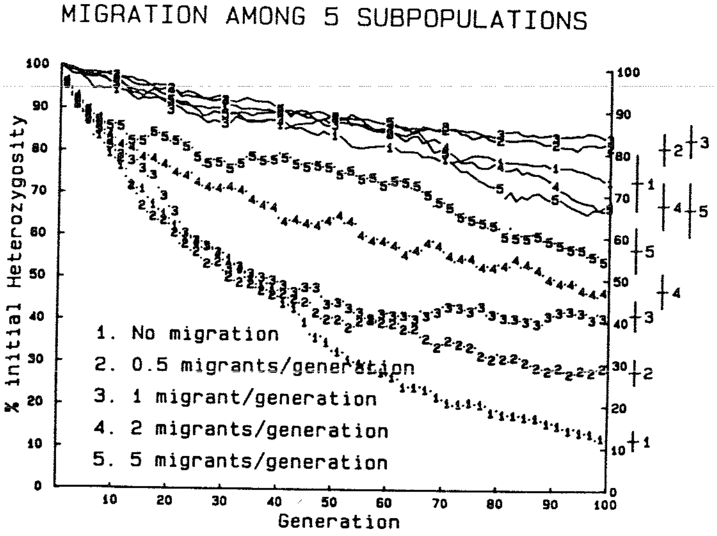


Figure 9. The effect of migration among 5 subpopulations of a population of 120 breeders. Dotted lines (numbers) indicate the mean within-subpopulation heterozygosities from 25 simulations. Lines represent the total gene diversity within the metapopulation. Figure from Lacy 1987a.

Preliminary models are available for estimating persistence times for specific populations providing data are available on the demographic characteristics of the population. These model have been most useful for developing conservation strategies for small populations.

While the mean (expected) persistence time can be roughly estimated, these models show that persistence time is distributed as an approximate exponential distribution. Hence there is a high probability that the population will go extinct well before its calculated mean time. Model results that indicate long mean persistence times are therefore misleading since more than 50% of the time populations will go extinct before the indicated mean time period.

To protect against this, very large populations or a number of different populations will be needed to assure high certainty of population survival for significant periods of time. Furthermore, management decisions need to specify both time frame for management and degree of certainty as specific management goals (e.g. 95% certainty of surviving for 100 years) in order to accurately evaluate available management options and develop Minimum Viable Population Size ranges for populations.

Goals

Goals of single-species conservation programs are, in general, specifically directed towards mitigating the risks of extinction for those species of interest. This is best accomplished by understanding, identifying and redressing those factors that increase the probability of the population going extinct.

Small populations, even if stable in the demographic sense, are particularly susceptible to a discouraging array of challenges that could potentially have a significant impact on their probability of survival (Soule 1987). Among these challenges are Demographic Variation, Environmental Variation, Disease Epidemics, Catastrophes and Inbreeding Depression.

Challenges to Small Populations

Demographic Variation: This is the variation in the population's overall (average) birth and death rates caused by random differences among individuals in the population. The population can experience 'good' or 'bad' years in terms of population growth simply due to random (stochastic) variation at the individual level. This can have consequences for the population's survival. For example, one concern in captive propagation is the possibility that all individuals born into a small population during one generation are of one sex, resulting in the population going extinct. Figure 10 illustrates the probability of this occurring over a 100 generation period in populations of different size. There is a 50% chance of extinction due to biased sex ratio in a population of size 8 sometime during this time period. However, these risks are practically negligible in populations of much larger size. Similar consequences could result from the coincidental but random effects of high death rates or low birth rates.

In general, the effect of any one individual on the overall population's trend is significantly less in large populations than small populations. As a result, Demographic Variation is a minor demographic challenge in all but very small populations.

Environmental Variation: Variation in environmental conditions clearly impact the ability of a population to reproduce and survive. As a result, populations susceptible to environmental variation vary in size more than less susceptible populations, increasing the danger of extinction. For example, reproductive success of the endangered Florida snail kite (Rostrhamus sociabilis) is directly affected by water levels, which determines prey (snail) densities: nesting success rates decrease by 80% during years of low water levels. Snail kite populations, as a result, are extremely unstable (Beissinger 1986).

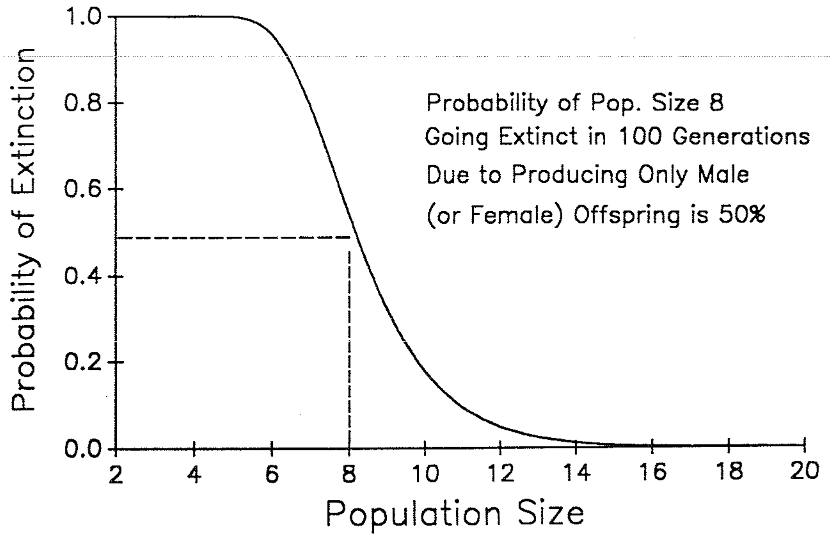


Figure 10. Example of Demographic Variation: Probability of extinction sometime during a 100 generation period due solely to producing only one sex of offspring.

Disease Epidemics: Disease epidemics and catastrophes are similar to other forms of environmental variation in the sense that they are external to the population. However, they are listed separately because we are just beginning to appreciate their role as recurrent but difficult to predict environmental pressures exerted on a population. They can be thought of as relatively rare events that can have devastating consequences on the survival of a large proportion of the population. Less devastating diseases and parasites are a natural accompaniment of all species and populations which may act to decrease reproductive rates and increase mortality rates.

Epidemics can have a direct or indirect effect. For example, in 1985 the sylvatic plague had a severe indirect effect on the last remaining black-footed ferret population by affecting the ferrets prey base, the prairie dog. Later that same year, the direct effect of distemper killed most of the wild population and all of the 6 ferrets that had been brought into captivity (Thorne and Belitsky 1989).

Catastrophes: From a demographic perspective, catastrophes are one-time disasters capable of totally decimating a population. Catastrophic events include natural events (floods, fires, hurricanes) or human induced events (deforestation or other habitat destruction). Large and small populations are susceptible to catastrophic events. Tropical deforestation is the single most devastating 'catastrophe' affecting present rates of species extinction. Estimates of tropical species' extinction rates vary between 20 and 50% by the turn of the century (Lugo 1988).

Inbreeding Depression: In small closed populations, mate choice is soon limited to close relatives, resulting in increased rates of inbreeding. The deleterious effects of inbreeding are well documented in a large variety of taxa. Although inbreeding depression has a genetic mechanism, its effects are demographic. Most data on exotic species come from studies of inbreeding effects on juvenile mortality in captive populations (Ralls, Ballou and Templeton 1988). These studies show an average effect of approximately 10% decrease in juvenile survival with every 10% increase in inbreeding. Data on the effects of inbreeding on reproductive rates in free ranging wild species is limited (lions; Wildt et al. 1987); however, domestic animal sciences recognize that inbreeding effects on reproduction are likely to be more severe than effects on survival. Inbreeding also may reduce disease resistance, and ability to adapt to rapidly changing environments (O'Brien and Evermann 1988).

Interacting Effects: Clearly, demographic challenges do not act independently in small populations. As a small population becomes more inbred, reduced survival and reproduction are likely; the population decreases. Inbreeding rates increase and because the population is smaller and more inbred, it is more susceptible to demographic variation as well as disease and severe environmental variation. Each challenge exacerbates the others resulting in a negative feedback effect (Figure 11). Over time the population becomes increasingly smaller and more susceptible to extinction (Gilpin and Soule 1986).

Susceptibility to Demographic Challenges

Populations differ in their susceptibility to demographic challenges. As mentioned above, population size clearly effects vulnerability. Large populations are relatively unaffected by demographic variation and are less apt to be totally devastated by environmental variation than small populations.

The severity of the demographic challenge is also important. A population in a fairly stable environment is less likely to go extinct than a population in a highly variable environment or an environment vulnerable to catastrophes.

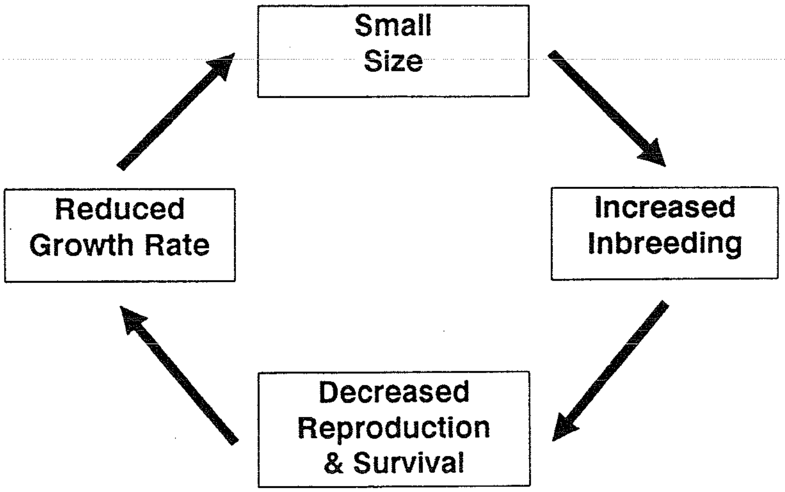


Figure 11. Negative feedback effects of inbreeding on small populations.

A third important factor is a population's potential for recovering from these demographic challenges, in other words, the population's growth rate. A population at carrying capacity experiences normal fluctuation in population size; the degree of fluctuation depending on the severity of demographic challenge. Populations with low growth rates remain small longer than populations with rapid growth potential and therefore are more vulnerable to future size fluctuations.

A fourth important consideration is the population's spatial distribution. A population that is dispersed across several 'metapopulations,' or patches, is significantly less vulnerable to catastrophic extinctions than a same-sized population localized in a single patch. Extinction of one patch among many does not extinguish the entire population and colonization between patches could reconstitute extinct patches (Gilpin 1987).

Populations dispersed over a wide geographic range are also unlikely to experience the same environment over the entire range. While part of a population's range may suffer from extreme environmental stress (or catastrophes), other areas may act as a buffer against such effects.

Estimating Susceptibility with Persistence Time Models

A population's susceptibility to demographic challenges can be measured in terms of the amount of time it takes a population to go extinct. This is often referred to as the persistence time of the population. Ideally, persistence time should be estimated from data on all the variables discussed above. Persistence times are usually estimated from mathematical models that either simulate the population over a period of time (stochastic models) or estimate the population's expected (mean) persistence time (deterministic models).

Unfortunately, methods are not (yet) available to simultaneously consider the effect of all the above variables on persistence time. Usually, persistence times are estimated by considering the effects of only one or two variables. The effects of spatial distribution are the most important; however, they are also the most difficult and consequently are not considered (or only rudimentarily considered) in most persistence time models. These models assume a single, geographically localized population.

Goodman (1987) presents an example of a deterministic persistence time model. This model estimates the mean persistence time of a population given its size, growth rate and its susceptibility to environmental and demographic challenges.

In Goodman's model, susceptibility to demographic challenges is represented by the variance in the population's growth rate. A population that is very susceptible to environmental perturbations will vary drastically in size from year to year, which, in turn, will be reflected as a high variance in the population's growth rate. Goodman's model is:

$$\textbf{Mean Extinction Time} = \sum_{x=1}^{N} \sum_{y=x}^{N} \frac{2}{y(yV - r)} \sum_{z=x}^{Y-1} \frac{zV + r}{zV - r}$$

where: r = exponential annual growth of the population
V = variance in r
N = Maximum (ceiling) population size

The mean persistence times for populations of size 30 and 50 (which bracket recent estimates for the Florida panther population) with low growth potentials (.5% and 2% per year) are shown in Figure 12. These graphs are provided simply to introduce the concept of persistence time models and are not suggested as realistic models of the Key deer population. More realistic models, based on life history data collected from the field, are provided below.

The mean time to extinction is inversely related to the variation in the growth rate: if variance is extremely high, regardless of the population sizes or potential growth rates, the mean persistence time (time to extinction) is approximately 10 years. However, with variances of .2, mean persistence time varies from 42 to 57 years.

To provide perspective on the meaning of variance in r, if the growth rate is distributed as a normal random variable, a variance of .2 would mean that 75% of the growth rates experienced by the population would fall within the range of 50% increase per year and 50% population decline per year.

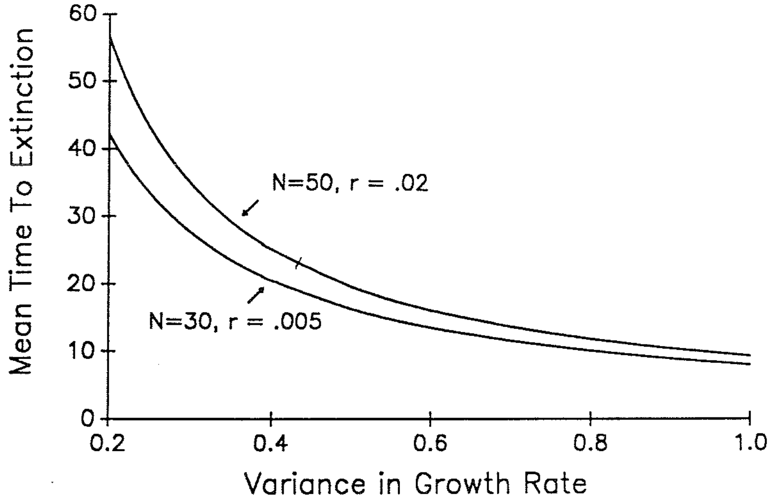


Figure 12. Mean time to extinction (persistence time) for a population of 50 animals with exponential growth rate of .02 (approx. 2% per year) and population of 30 animals with exponential growth rate of .005 (approx. 0.5% per year) under different levels of variation on growth rate. Variation in growth rate is a measure of the population's susceptibility to demographic challenges.

Persistence Time is Exponentially Distributed

An important characteristic of persistence time is that it has an approximately exponential distribution. The models provide the mean, or expected time to extinction; however, there is significant variation around this mean. Many population go extinct well before the mean time; a few go extinct long after.

The exponential distribution of persistence time for a population of 50 individuals with a growth potential of 2% and growth variance of .2 is shown in Figure 13. The mean persistence time is 57 years. However, since the distribution is exponential, there is a high probability that the time to extinction will occur before 57 years. In fact, there is a 33% chance that the time of extinction will be before 25 years.

Given that persistence times are approximately exponentially distributed, times to extinction can be estimated with various degrees of certainty. Again for the same population described in Figure 12, we can estimate the probability of extinction at different time periods (Figure 14). With growth rate variation at .2, mean time to extinction is 57 years; however, there is a 50% chance that the population will survive only to 40 years, only a 75% chance that the population will survive at least to 15 years, and a 95% chance that the population will survive at least to 4 years. In other words, there is a 5% chance that the population will go extinct in 4 years.

The Minimum Viable Population (MVP) Size concept is based on the premise that persistence times can only be defined with reference to degrees of certainty. Ideally, given a population's life history characteristics and management goal (a desired persistence time under a specified degree of certainty, e.g. 95% chance of surviving for 200 years), we could estimate the population size required to achieve the goal. This would be a Minimum Viable Population Size (MVP size) for the program (Shaffer 1981). However, since MVP size is a function of the specific management goals of the population, there is no one "magical" MVP size for any given population in any given circumstance.

Management Implications

The implication of exponentially distributed persistence time is that management strategies can not be based on the mean persistence time if a high degree of certainty is desirable. Although the mean persistence time of the modeled population is 57 years, management strategies should recognize that to be 95% certain that the population survives even 50 years would require a population size whose mean persistence time is 975 years. This would require well over 1000 individuals.

A second implication is that management strategies can only be fully evaluated if both degree of certainty and time frame for management are specified. For example, programs may be evaluated in terms of their potential for assuring a 95% chance of the managed population surviving for 200 years. It is critical that the management decision making process recognize that the process of extinction is a matter of probabilities, as are all its components (environmental and demographic variation, probability of catastrophe, etc.; Shaffer 1987).

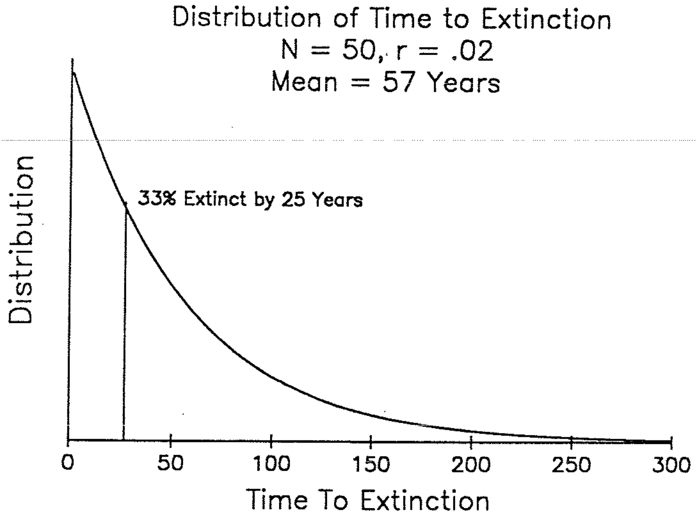


Figure 13. Exponentially distributed time for a population of 50 animals growing at an exponential rate of .02 with a variation in growth rate of 0.2. While the mean (expected) persistence time is 57 years, the exponential characteristic of the distribution shows that there is a high probability of extinction before this period (33% chance by 25 years).

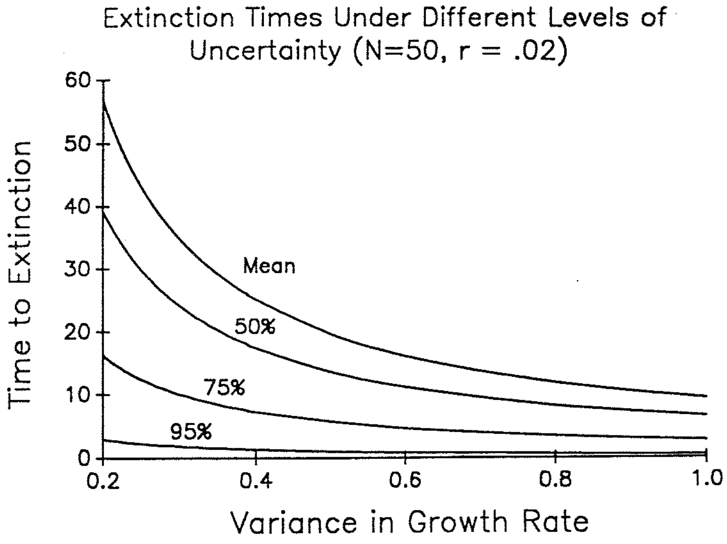


Figure 14. Extinction times under different levels of uncertainty. See text.

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POPULATION BIOLOGY PARAMETERS

Accurate estimates of both means and variances of population parameters are essential to population viability analysis. Extensive field research is therefore a prerequisite to all population modelling and management. The numbers used in this analysis derive mostly from the considerable body of data accumulated through years of devoted research on the Key deer by Dr. W.D. Klimstra and his associates (Hardin 1974; Hardin et al. 1984; Klimstra 1978; Klimstra et al. 1974; Klimstra et al. 1978; Klimstra et al. 1982; Silvy 1975; USFWS 1985; unpublished reports). Additional data, especially on recent trends in the population were provided by the biologists attending the workshop held in Key West, FL (2-4 May 1990). Because uncertainties remain in estimates of population parameters (again, especially for recent years, subsequent to the more intensive studies of the 1960s and 1970s), we also explored the effects on model results of varying some of the less certain estimates.

Current Population Size

The Key deer population is thought to have been reduced to a low of 25-80 animals around 1950, to have recovered to about 350-400 deer by 1974 as a result of the protection afforded the deer by the creation of the Key Deer Refuge and elimination of legal hunting, and then to have declined to about 250-300 deer by 1982 (Klimstra et al 1974; Hardin et al. 1984; Humphrey and Bell 1986). Thus the population grew by about 7% - 12% annually during the 1950s and 1960s, and subsequently declined by about 5% annually in the late 1970s and early 1980s. Lacking recent population estimates, it is uncertain whether the decline has continued since 1984, but the impression of field biologists (in concordance with data on road kills) is that the decline was probably largely halted by recovery efforts undertaken by the refuge. Thus, the workshop participants estimated the current population to be about 250 deer. Although the deer live in a highly fragmented habitat (about 21 islands in the Florida Keys), movements of deer between the islands by swimming have been documented (Hardin et al. 1984, Holle & Wilmers personal observation) and the entire taxon probably responds to genetic and demographic processes as a single population. The population was therefore modelled from a starting point of 250 deer, with an age and sex distribution (determined by life table analysis) approximating that which would develop in a population with the sex ratio at birth and mortality rates observed in the Key deer.

Carrying Capacity

The Key deer population is believed to be at the carrying capacity of its habitat (carrying capacity is naturally variable from year to year as a result of variation in availability of drinking water and vegetation so that the population numbers will also fluctuate. Measured and calculated population sizes are given as ranges or a mean and standard deviation.). Much of the decline in numbers probably resulted from a loss of habitat to development for human habitation. (Road kills, in absolute numbers, were slightly greater in the 1970s than in the 1980s; thus mortality has probably reflected population size, rather than being the primary driving force behind the decline. [There was disagreement at the workshop about whether the road-kill mortality contributed to the decline of the deer population or was removing all or most of the net production.]) Habitat loss continues, but private and public efforts to protect more habitat also continue, and management actions can improve the quality of some existing habitat. Currently protected Key deer habitat is sufficient to support about 150 deer. Management of habitat quality, combined with a cessation of further habitat loss, could result in a long-term carrying capacity of about 300 deer. These numbers define the range of possible carrying capacities likely in the future. Of historical interest (and possible genetic importance), the maximum historical population of Key deer was likely about 600-700, occupying about 19,000 acres of original habitat on all keys within the known historical range of the taxon.

Reproduction

Key deer rarely if ever breed as fawns, about 60% of females breed in their second year (producing progeny when they are about 2 years of age or slightly older), and 95% of older females reproduce each year. Overall, a mean of 88% of females older than 1 year reproduce annually, with 78% of births being singletons and 22% twins (Hardin 1974; Klimstra et al. 1974). No reproductive senescence has been noted in older females; indeed, one female continued breeding throughout a 20-year life span (Klimstra, unpubl. ms.). Males begin breeding in their third year.

Sex Ratio

The sex ratio at birth is strongly skewed toward the production of males. Data on fetuses in road kill does and fawns observed suggest a sex ratio of about 2 males : 1 female at birth (Hardin 1974; Klimstra et al. 1974). The birth sex ratio of white-tailed deer may be affected by inbreeding, population density, and nutrition (Verme and Ozoga 198). Inbreeding, hifg population densities, and a decreased plane of nutrition (caloric intake) can result in an excess of males.

Mortality

Based on a composite life table analysis of marked deer (years 1968-1973), mortality rates (for all causes) were estimated at 35.3% for males and 37.5% for females from 0 to 6 months; 9.4% for males and 7.2% for females from 6 to 12 months (yielding compounded 0 to 12 month mortalities of 41.4% and 42.0%); 32.3% for males and 13.6% for females from 1 year to 2 years of age; 34.8% for males and 8.3% for females from 2 to 3 years; and 39% for males and 15% for females annually beyond year 3 (Silvy 1975). These mortality rates, combined with the reproductive rates reported above, would yield (by life table analysis) an average population growth rate of 2.4%. This population increase is consistent with the observed growth of the population from 1952 to about 1974.

It was noted at the workshop in Key West that the annual mortality of males may have been overestimated (sample sizes were small), and analyses were conducted also with an assumption of 25% annual mortality of males.

Mortality rates may have changed since the above study (1968-1973). In accord with the belief that the population is now approximately stable, additional analyses were conducted with mortality rates 10% greater than above, yielding a population with no average population growth or decline. To examine the consequences of reductions in road fatalities that might be possible with improved management and more intensive enforcement, analyses with 10% lower mortality rates were also examined.

Environmental Variation

Fluctuations in population parameters caused by environmental variation are difficult to assess in the absence of long-term monitoring of a population with consistent methods. Correlations of deer counts with rainfall (Humphrey and Bell 1986) and the observation that deer movements and, therefore, susceptibility to road kill are influenced by availability of fresh water (Klimstra et al. 1974; Drummond 1989) suggest that deer mortality rates are subject to at least moderate environmental variation. Counts of dead deer from 1970 through 1988 fluctuate with a variance that is about 3.4 times the mean number of deaths recorded per year. In a stable population with constant probability of mortality (p), the variation in numbers dying (Np) would be expected to follow a binomial distribution, with variance equal to the mean number dying (Np) times the probability of survival (1 - p). Thus, the variation observed in mortality is about 2.7 times the variation expected from random (demographic) variation in a stable population. Some of that variation in road deaths is likely to be due to changes in the overall population size, so it was assumed for the purposes of population modelling that environmental variation in Key deer mortality is equal to 2.5 times the expected demographic variance (equivalent to a standard deviation of 1.58 times the SD due to demographic stochasticity). This results in annual variation in mortality rates of about ±7% (SD) for first-year mortality, ±6% for annual mortality of adult males, and ±5% for annual mortality of adult females.

No data are available to make similar estimates of environmentally imposed variation in reproduction or in the carrying capacity of the habitat. Lacking such information, modelling was done with an assumption that environmental variation in these aspects of the population biology of the Key deer was also about 2.5-fold greater than the expected variance due to demographic stochasticity (resulting in fluctuations in the percent of adult females breeding of ±4.75%, and in the carrying capacity of ±25 deer).

The above calculations are based on very few data. To explore the effects of a range of possible magnitudes of environmental variation, all analyses were run also with environmental variance factors of 0 (assuming no annual variation in population parameters) and 10 (assuming environmental variation, on a scale of standard deviations, twice as great as described above).

Catastrophes

The Key deer (the present population has a limited distribution, therefore the entire subspecies is at risk) are likely extremely vulnerable to hurricanes. A major hurricane striking directly at Big Pine Key would produce a tidal surge that would wash over most or all of Key deer habitat. Clearly many deer would die immediately (especially fawns), and fresh water sources may be contaminated with salt water for some time after the passing of the storm. The major hurricane season also corresponds to the breeding season, so it is likely that a hurricane would cause some loss of breeding. The Keys lie in a region that experiences a hurricane once every seven years on average, although major hurricanes (e.g., the size of hurricane Hugo in 1989) strike any given area about three times a century.

Lacking data on the effects of past hurricanes, several levels of hurricane impact were modelled. In the most severe scenario (believed to be the most likely scenario by many workshop participants), it was assumed that a moderate storm would occur with 5% probability, would kill 20% of the deer and would cause a 10% decrease in reproduction for the year; while a major hurricane would occur with 3% probability, kill 50% of the deer and reduce breeding by 20%. In a second scenario, the same effects were assumed, but major hurricanes were modelled as occurring only once per 100 years on average. In the third scenario, hurricanes were assumed to affect reproduction strongly and survival only moderately: 5% probability of a moderate storm killing 10% and reducing breeding by 20%, 3% probability of severe storm killing 20% and reducing breeding by 50%. Finally, populations were modelled with the assumption that no catastrophes could impact the population.

It was noted at the workshop that the Key deer may be vulnerable to other catastrophes. In particular, an African tick carrying a Rickettsia disease vector has been reported from islands in the Caribbean. The disease was found to kill all 7 white-tailed deer that were experimentally inoculated. The probability of this or other disease outbreaks could not be estimated and was not incorporated into the analyses.

Genetic Variation and Inbreeding Depression

When populations become small, inbreeding becomes likely or even inevitable. Abundant data exist to show that inbreeding causes decreased reproduction and decreased survival in most mammals, although the severity of this "inbreeding depression" apparently differs considerably among species and even among populations within a species. Fitness of white-tailed deer at Savannah River, SC, has been shown in studies by M.H. Smith and associates to be correlated with heterozygosity (i.e., negatively correlated with inbreeding), but no studies have been conducted to test the response of Key deer to inbreeding. Because Key deer underwent a bottleneck during the 1940s and early 1950s, and because the taxon has never been abundant and widespread, natural selection acting during past episodes of inbreeding may have removed some of the genes that would cause inbreeding depression (the "genetic load" of the population), and the Key deer may now be partly adapted to low genetic variation and moderate inbreeding. It might also be noted, however, that the observed low rate of twinning and male-biased sex ratio at birth are effects that have been noted in other mammalian species as responses to inbreeding. Whether these aspects of the population biology, both strongly depressing population productivity, are environmentally or genetically caused has not been investigated.

To model the population dynamics of the Key deer, we simplistically assumed that the present population has a genetic load of one lethal recessive gene per individual. This would result in inbreeding depression about one-third as severe as the median of 40 mammalian taxa surveyed by Ralls et al. (1988), and would allow for continued reduction of the genetic load by the greater mortality inbred animals through the generations of the simulated population.

Time Period for Population Projection

No taxon will persist forever (although evolutionary descendant taxa may do so) and, until massive alteration of the global environment by humans began a few centuries ago, the mean life span of taxa was probably on the order of a million years. Implicitly or explicitly, every conservation plan must identify a period of time through which recovery efforts are designed to assure survival of the taxon. Due to the virtual certainty that global warming will lead to sea level rises over the next 50 to 100 years, protection of the Key deer in its present habitat will be of limited duration. The maximum elevation on Big Pine Key, the primary habitat of the deer, is about 3 meters, and much of Key deer habitat is less than 1 m above present sea level. Therefore, population viability analysis of the Key deer utilized population projections for 100 years.

POPULATION VIABILITY RESULTS

Standard life table analysis of the above estimates of birth and death rates in the Key deer population yield an expected mean population growth rate of 2.4% (lambda = 1.024), with a mean generation time (approximately the mean age of breeding adults) of 7.7 years. Yet the population declined subsequent to the field studies that produced those estimates, and workshop participants felt that it was prudent to examine also mortality rates that would lead to a population with no average growth. With a 10% increase in mortality of each age class, the population would experience no net growth or decline (lambda = 1.0), with a generation time of 7.1 years. Even greater mortality rates are possible (the population be still be in decline), yielding negative lambdas and lower generation times.

Stochastic Simulation of Population Extinction

Life table analyses yield average long-term projections of population growth (or decline), but do not reveal the fluctuations in population size that would result from randomness and variability in demographic processes. To examine the probabilities of population persistence under various scenarios, we used a computer program (VORTEX), written by one of us (RCL) in the C programming language. Many of the algorithms in VORTEX were taken from a simulation program, SPGPC, written in BASIC by James W. Grier of North Dakota State University (Grier 1980a, 1980b, Grier and Barclay 1988). Grier makes his program freely available to anyone with a use for it, and we similarly will provide the source code and compiled versions (for use on microcomputers using the MS-DOS operating system) of VORTEX to anyone who has a use for it.

VORTEX models population processes as discrete, sequential events, with probabilistic outcomes determined by a pseudo-random number generator. VORTEX simulates birth and death processes and the transmission of genes through the generations by generating random numbers to determine whether each animal lives or dies, whether each adult female produces broods of size 0, or 1, or 2, or 3, or 4, or 5 during each year, and which of the two alleles at a genetic locus are transmitted from each parent to each offspring. Mortality and reproduction probabilities are assumed to be the same for each sex, and fecundity is assumed to be independent of age (after an animal reaches reproductive age). Mortality rates are specified for each pre-reproductive age class and for reproductive-age animals. The mating system can be specified to be either monogamous or polygynous. In either case, the user can specify that only a subset of the adult male population is in the breeding pool (the remainder being excluded perhaps by social factors).

Each simulation is started with a specified number of males and females of each pre-reproductive age class, and a specified number of male and females of breeding age. Each animal in the initial population is assigned two unique alleles at some hypothetical genetic locus, and the user specifies the severity of inbreeding depression (expressed in the model as a loss of viability in inbred animals). The computer program simulates and tracks the fate of each population, and outputs summary statistics on the probability of population extinction over specified time intervals, the mean time to extinction of those simulated populations that went extinct, the mean size of populations not yet extinct, and the levels of genetic variation remaining in any extant populations.

A population carrying capacity is imposed by truncation of each age class if the population size after breeding exceeds the specified carrying capacity. The program allows the user to model trends in the carrying capacity, as a geometric increases or decreases across a specified numbers of years.

Each year in the simulation, the number of animals surviving, as well as the number reproducing, would be expected to follow binomial distributions with means equal to the specified probabilities. Environmental variation in reproduction, survival and the carrying capacity can be incorporated into the model by increasing the binomial variances in these parameters by an amount specified by the user. These variances are functions of the starting population size, so the effect of doubling the variance in survival, for example, depends on the initial population size (smaller N yields larger binomial variance).

VORTEX can model catastrophes, the extreme of environmental variation, as events that occur with some specified probability and reduce survival and reproduction for one year. A catastrophe is determined to occur if a randomly generated number between 0 and 1 is less than the probability of occurrence (i.e., a binomial process is simulated). If a catastrophe occurs, the probability of breeding is multiplied by a severity factor that is drawn from a binomial distribution with mean equal to the severity specified by the user. Similarly, the probability of surviving each age class is multiplied by a severity factor that is drawn from a binomial distribution with mean equal to the severity specified by the user.

VORTEX also allows the user to supplement or harvest the population for any number of years in each simulation. The numbers of immigrants and removals are specified by age and sex.

Overall, the computer program simulates many of the complex levels of stochasticity that can affect a population. Because it is a detailed model of population dynamics, often it is not practical to examine all possible factors and all interactions that may affect a population. It is therefore incumbent upon the user to specify those parameters that can be estimated reasonably, to leave out of the model those that are believed not to have a substantial impact on the population of interest, and to explore a range of possible values for parameters that are potentially important but very imprecisely known.

VORTEX is, however, a simplified model of the dynamics of real populations. Some of its artificialities are the independence of environmental variation in birth and death rates (except during catastrophes), and the lack of density dependence of birth and death rates except when the population exceeds the carrying capacity. The first of these simplifications will likely lead to underestimates of extinction rates, because the various risks to a population occur independently in the model and are therefore distributed more evenly over time than may be the case in most natural populations. The lack of density dependence may cause underestimation or overestimation of extinction, depending on whether the population responds positively (increased breeding and reduced mortality) when numbers are low, as might be expected if intra-specific competition or aggression were common, or negatively, as might occur in social species or if mates are difficult to find.

VORTEX continues to evolve, but earlier versions of the simulation program (under the name of SIMPOP) have aided population viability analyses of the Puerto Rican parrot (Lacy et al. 1989), the eastern barred bandicoot population (Lacy and Clark, in press) in Victoria, Australia, the Sumatran rhinoceros, and the black rhino populations in nature preserves in Kenya (Lacy 1987b). The simulation program was used for an earlier Population Viability Analysis of the Florida panther (Ballou et al. 1989). The work presented here is a refinement and extension of that earlier effort. We are indebted to the biologists who reviewed the earlier PVA for pointing out some errors in estimation of parameters and for their many suggestions for improvements.

A sample input and output for VORTEX is given as an appendix to this report.

Simulation Results

Of the simulations analyzed, the scenario that most closely approximates the consensus of the workshop as to the current status of the Key deer is that on line 5 of Table 1B (mortality increased by 10% relative to 1973 rates to yield a population with no average growth in non-catastrophe years, carrying capacity of 250, moderate environmental variation, strong impact on survival by severe hurricanes). In that scenario, the simulation projects a low probability of population persistence over 100 years and a small ultimate population size in the cases of population survival. Without a positive growth rate, the deer would not recover from catastrophic decline following a hurricane, nor even from a series of years with poorer than average reproduction and survival. Even in the absence of any catastrophic hurricanes or disease, the population may not be fully secure if births only match deaths (lines 4, 8, and 12 of Table 1B). The population of 250 is small enough that random fluctuations can cause extinction, and its designation as an Endangered Species by the US Fish and Wildlife Service seems appropriate.

If mortality rates still approximate those of the early 1970s (Tables 1A and 1D), or if mortality rates would return to those levels following any decline below the carrying capacity of the habitat, then the population may have a considerably greater probability of persistence. If major hurricanes do impact the population strongly (e.g., line 5 of Tables 1A and 1D), then the population faces approximately 25% probability of extinction; if hurricanes are less devastating, then the population may be relatively secure. A strong impact of hurricanes on mortality is more damaging than an impact on reproduction (compare scenarios with catastrophe type B to those with type C), as would be expected for a moderately long-lived species that can breed in subsequent years even if reproduction is limited during a single season.

If environmental variation is large (e.g., percent of breeding females varying according to 88% ± 9.5% SD, adult female mortality 15% ± 10.1%, as in scenarios with EV factors of 10), then just moderate effects of hurricanes would put the Key deer at substantial risk of extinction, and some risk remains even in the absence of hurricanes and under 1973 levels of mortality (lines 10 and 11, Table 1A). The impact of environmental variation is much greater if the carrying capacity of the habitat declines (lines 22 and 23).

The loss of genetic variation (inbreeding) can hasten the extinction of small populations. In the simulated deer populations, however, extinctions do not seem to be fundamentally genetic in cause. Extinctions occurred in some scenarios that had mean losses of less than 5% genetic variation, a rate of inbreeding that would not have reduced population growth substantially (e.g., most lines of Table 1C). Yet genetic variation did decline with declining population size (see scenarios with K = 150), often resulting in accumulated losses of 20% or more over 100 years, and the effects of inbreeding in those cases would have accelerated the population declines and increased the probabilities of extinction.

If habitat that is presently unprotected continues to be developed, leaving the deer with only the protected habitat capable of supporting about 150 deer, the prospects for the taxon deteriorate substantially. At that lower carrying capacity, the population would appear to be stable only if there is minimal environmental variation, minimal probability of a damaging hurricane, and sufficiently low mortality to achieve a positive population growth (compare lines in the middle third of Tables 1A - 1D). Considering the proportion of the population that is breeding adults and the bias in sex ratio, it is likely that a population of 150 deer has a genetically effective population size below the 50 animals that have been recommended (based on the consequences of inbreeding) as a minimum number for short-term viability (Franklin 1980). Populations below that size are often unstable both genetically (losses of 10% to 30% genetic variation in the simulations) and demographically.

If losses of habitat cease and habitat improvement leads to an increase in the carrying capacity to 300 deer, the probability of population persistence increases very marginally over the comparable scenarios with carrying capacities of 250 (compare top third of each table to bottom third). Because of past development and loss of habitat (original population estimated to have been 600 to 700), there is little scope for increase in the carrying capacity. Within the range of feasible capacities (up to 300), the Key deer population remains at high risk if hurricanes (or disease) have potentially strong impacts on the population (catastrophe scenario A: 50% mortality from a major storm) or if the population lacks a mean positive growth rate (Table 1B). The Recovery Plan (USFWS 1985) recognizes a continued risk to the Key deer population in stating that it will probably never be possible to delist the taxon. Although management to improve habitat quality may not be able to improve prospects much above what they are at present, clearly such efforts may be necessary in order to counter habitat losses and keep carrying capacity at or near 250.

Despite the pessimistic outlook of much of the preceding discussion, it is not certain that the Key deer population lacks the stability and resilience to persist through the next century, nor that achievable management actions could not greatly reduce any risk that presently exists. Some plausible scenarios, with low environmental variation, minimal impact of hurricanes, and mortality rates no greater than measured in the 1970s, resulted in low probabilities of extinction in the models, with population numbers remaining near carrying capacity. Given the uncertainties that remain in our knowledge of the reproductive biology (e.g., the cause of the sex ratio bias, the potential for a positive response in breeding if densities were low), of the sources and magnitude of mortality (higher or lower than in the 1970s, density dependence, effects of droughts, susceptibility to diseases and hurricanes), and of the current population numbers and trends (declining or stable), it can only be stated that the Key deer population **may** require intensive management to prevent extinction. (Extinction probabilities estimated for various scenarios ranged from 0 to 95%.) It is clear, however, that management actions that retain or even increase habitat while reducing mortality would make the population much less vulnerable to the demographic, environmental, and catastrophic variation that will be difficult or impossible to prevent (see Table 1C).

Finally, it must also be recognized that population biology parameters of the Key deer may be density-dependent, with birth and death probabilities responding to changes in population numbers. The simulation used incorporates density dependence only in that a (variable) carrying capacity was imposed. When the population exceeded the carrying capacity, additional mortality was imposed to bring the population down to the carrying capacity. If Key deer increase reproduction, or if mortality rates decline, when numbers are below carrying capacity, then the population may be less vulnerable than represented by the results of the simulation modelling. If reproduction decreases when the population is at very low density because some female deer do not encounter mates, then the population may be more vulnerable than believed. There are presently no data on density-dependent responses in reproduction or mortality by the deer population.

Table 1. Results from 1,000 simulations of the Key deer population under various scenarios of carrying capacity (K), environmental variation in reproductive rates and mortality (EV), and the frequency and impact of hurricanes (catastrophes). Given for each set of parameters are the mean annual population growth rate (lambda), calculated from the life table; the percent of 1,000 simulations that went extinct within 100 years (P[E]); the mean time to extinction in years of those simulated populations that went extinct (T[E]); the percent of the initial expected heterozygosity (gene diversity) remaining at 100 years in those populations still extant (%HET); and the mean population size at 100 years of extant populations (N).

Four scenarios of hurricanes were examined:

A = 5% probability of 10% loss of reproduction, 20% mortality
3% probability of 20% loss of reproduction, 50% mortality
B = 5% probability of 10% loss of reproduction, 20% mortality
1% probability of 20% loss of reproduction, 50% mortality
C = 5% probability of 20% loss of reproduction, 10% mortality
1% probability of 50% loss of reproduction, 20% mortality
0 = no catastrophes

Mortality rates were as estimated from the Key deer population (for females: 42% first year mortality, 14% second year mortality, and 15% annual mortality of breeding age adults; for males: 41% first year mortality, 32% second year mortality, 35% third year mortality, and 39% annual mortality of breeding age adults), with modification in Tables 1A - 1C as follows:

(A) No modification of mortality rates
(B) Mortality rates increased by 10% to model scenarios with zero population growth (lambda = 1.00) in the absence of hurricanes
(C) Mortality rates reduced by 10%
(D) Adult male mortality set at 25% annually

Reproductive rates, sex ratio at birth (2:1), initial population size (250), and effect of inbreeding same for all runs, as described in text.

Table 1A.

	INPUT PARAMETERS			SIMULATION RESULTS			
K	EV	Catastrophes	lambda	P[E]	T[E]	%HET	N
250	0	A	1.00	24	76	84	92
		B	1.01	3	84	90	149
		C	1.02	0	--	93	213
		0	1.02	0	--	94	243
	2.5	A	1.00	30	74	84	90
		B	1.01	4	81	89	140
		C	1.02	<1	97	92	181
		0	1.00	0	--	93	214
	10	A	1.00	46	69	79	63
		B	1.01	17	74	84	91
		C	1.02	4	88	87	117
		0	1.02	1	85	90	146
150	0	A	1.00	40	71	79	57
		B	1.01	13	77	84	83
		C	1.02	1	91	89	118
		0	1.02	0	--	90	141
	2.5	A	1.00	44	69	77	55
		B	1.01	16	74	82	76
		C	1.02	3	84	86	96
		0	1.02	0	--	88	116
	10	A	1.00	74	59	71	44
		B	1.01	44	66	73	46
		C	1.02	27	74	77	54
		0	1.02	15	75	80	64
300	0	A	1.00	21	75	86	109
		B	1.01	3	82	91	189
		C	1.02	0	--	94	264
		0	1.02	0	--	95	294
	2.5	A	1.00	25	75	85	107
		B	1.01	4	78	90	163
		C	1.02	0	--	93	230
		0	1.02	0	--	94	264
	10	A	1.00	41	72	82	81
		B	1.01	11	78	86	115
		C	1.02	2	84	90	154
		0	1.02	0	--	92	190

Table 1B.

	INPUT PARAMETERS			SIMULATION RESULTS			
K	EV	Catastrophes	lambda	P[E]	T[E]	%HET	N
250	0	A	.97	75	68	85	29
		B	.98	39	78	90	47
		C	.99	10	88	93	70
		0	1.00	<1	96	96	133
	2.5	A	.97	74	67	88	33
		B	.98	45	77	88	51
		C	.99	17	85	93	64
		0	1.00	2	87	95	115
	10	A	.97	86	61	81	34
		B	.98	65	70	84	40
		C	.99	42	75	88	52
		0	1.00	23	80	90	72
150	0	A	.97	85	62	78	26
		B	.98	61	72	83	34
		C	.99	34	82	88	43
		0	1.00	7	88	92	70
	2.5	A	.97	87	60	80	30
		B	.98	65	69	81	33
		C	.99	45	77	86	42
		0	1.00	16	83	90	61
	10	A	.97	95	50	68	21
		B	.98	84	58	74	29
		C	.99	73	65	79	34
		0	1.00	55	66	82	41
300	0	A	.97	73	68	85	33
		B	.98	37	80	90	47
		C	.99	10	86	94	74
		0	1.00	<1	98	97	159
	2.5	A	.97	72	69	87	35
		B	.98	37	76	89	55
		C	.99	10	83	93	79
		0	1.00	1	90	96	149
	10	A	.97	81	62	84	34
		B	.98	58	71	87	49
		C	.99	33	79	91	60
		0	1.00	12	82	93	87

Table 1C.

INPUT PARAMETERS			SIMULATION RESULTS				
K	EV	Catastrophes	lambda	P[E]	T[E]	%HET	N
250	0	A	1.02	4	77	95	159
		B	1.03	<1	65	97	214
		C	1.04	0	--	97	241
		0	1.05	0	--	97	249
	2.5	A	1.02	6	75	95	154
		B	1.03	<1	87	96	203
		C	1.04	0	--	97	224
		0	1.05	0	--	97	231
	10	A	1.02	13	72	92	116
		B	1.03	2	78	95	149
		C	1.04	<1	73	96	176
		0	1.05	<1	66	96	188
150	0	A	1.02	11	71	91	94
		B	1.03	<1	75	94	124
		C	1.04	0	--	95	124
		0	1.05	0	--	95	148
	2.5	A	1.02	11	74	91	84
		B	1.03	1	73	93	110
		C	1.04	0	--	94	125
		0	1.05	0	--	94	132
	10	A	1.02	39	66	85	57
		B	1.03	15	66	90	70
		C		1.04	5	67	92 82
		0	1.05	2	64	92	92
300	0	A	1.02	4	77	96	198
		B	1.03	0	--	97	259
		C	1.04	0	--	98	292
		0	1.05	0	--	98	299
	2.5	A	1.02	4	69	95	186
		B	1.03	<1	75	97	246
		C	1.04	0	--	97	271
		0	1.05	0	--	97	281
	10	A	1.02	10	73	94	140
		B	1.03	1	71	96	193
		C	1.04	0	--	97	220
		0	1.05	0	--	97	235

Table 1D.

	INPUT PARAMETERS			SIMULATION RESULTS			
K	EV	Catastrophes	lambda	P[E]	T[E]	%HET	N
250	0	A	1.00	23	74	84	88
		B	1.01	3	84	90	152
		C	1.02	0	--	93	215
		0	1.02	0	--	94	244
	2.5	A	1.00	24	75	83	87
		B	1.01	4	78	90	138
		C	1.02	0	--	93	187
		0	1.02	0	--	93	214
	10	A	1.00	41	71	79	59
		B	1.01	15	78	85	88
		C	1.02	3	79	88	119
		0	1.02	1	80	90	146
150	0	A	1.00	38	72	78	54
		B	1.01	9	76	85	84
		C	1.02	<1	96	89	117
		0	1.02	0	--	91	140
	2.5	A	1.00	38	72	78	51
		B	1.01	15	77	82	71
		C	1.02	1	82	87	94
		0	1.02	<1	81	89	115
	10	A	1.00	62	61	70	37
		B	1.01	36	70	75	48
		C		1.02	23	70	78 55
		0	1.02	12	69	81	64
300	0	A	1.00	20	77	86	98
		B	1.01	2	77	92	188
		C	1.02	0	--	95	263
		0	1.02	0	--	95	294
	2.5	A	1.00	19	75	86	105
		B	1.01	3	81	91	166
		C	1.02	0	--	94	234
		0	1.02	0	--	94	263
	10	A	1.00	35	75	81	73
		B	1.01	8	78	87	116
		C	1.02	1	79	91	158
		0	1.02	<1	77	92	193

APPENDIX

Sample input session with VORTEX computer simulation of population viability, corresponding to line 5, Table 1A

User responses in **bold**.

```
Welcome to VORTEX.
Written by R.C. Lacy, Chicago Zoological Park
Version 5.0, April 1990

Input file name? (CR for keyboard)
deer5.in
Output file name? (S for screen)
deer5.out
How many times do you want the simulation repeated?  1000

Do you want to incorporate inbreeding depression?  y
Do you want a general HETEROSIS model (specify H) or a
    RECESSIVE LETHALS model (specify L)?  L
At what age do females normally begin breeding?  2
At what age do males normally begin breeding?  3
What is the sex ratio (proportion males) at birth?  .66667
What is the maximum number of young per litter?  2
In an average year ...
  what percent of adult females produce 0 young?  12
  what percent of adult females produce 1 young?  68.64
  what percent of adult females produce 2 young?  19.36
Monogamous (M) or polygamous (P) breeding?  p
Are all adult males in the breeding pool
     and equally likely to sire offspring? (Y or N)  y

What is the percent mortality of females between ages 0 to 1?  42.0
What is the percent mortality of females between ages 1 to 2?  13.6
What is the annual percent mortality of adult females (age > 2)?  15.0
What is the percent mortality of males between ages 0 to 1?  41.38
What is the percent mortality of males between ages 1 to 2?  32.3
What is the percent mortality of males between ages 2 to 3?  34.8
What is the annual percent mortality of adult males (age > 3)?  39.0
What is the population carrying capacity?  250
Is there a trend projected in the carrying capacity? (Y or N)  n
```

```
Enter levels of environmental stochasticity as
  factors to be applied to the indicated variances.
  If you have no idea, guess one of the following:
    0 = no year-to-year variation
    1 = minimal year-to-year variation
   10 = moderate year-to-year variation
  100 = much year-to-year variation

    Reproductive rates: Binomial variance for breeding success x ?  2.5
    Mortality rates: Binomial variance x ?  2.5
    Carrying capacity: Poisson variance x ?  2.5

Enter the probability of catastrophe type I (as a percent):  5
Enter the severity of type I catastrophes as a mean multiplicative effect
  (to which will be applied a binomial variance).
Note: 0 = total catastrophe, 1 = no effect.

    Severity with respect to reproduction?  .9
    Severity with respect to survival?  .8

Enter the probability of catastrophe type II (as a percent):  3
Enter the severity of type II catastrophes as a mean multiplicative effect
  (to which will be applied a binomial variance).
Note: 0 = total catastrophe, 1 = no effect.

    Severity with respect to reproduction?  .8
    Severity with respect to survival?  .5
How many years do you want the simulation to run?  100
At what time interval do you want extinction reports?  10
How many females of age 1 are in the initial population? 20
How many adult females (age > 2) are in the initial population?  117
How many males of age 1 are in the initial population?  40
How many males of age 2 are in the initial population?  27
How many adult males (age > 3) are in the initial population?  46
For how many years do you want to harvest/supplement the population?  0
```

[computer's response during running of the program ...]

```
Run 1
        Final population size     204
        Expected heterozygosity  0.9093
        Observed heterozygosity  0.9167
        Number of alleles         20
        Effective no. alleles   11.03
```

```
Run 2
        Final population size    8
        Expected heterozygosity  0.6953
        Observed heterozygosity  1.0000
        Number of alleles        4
        Effective no. alleles    3.28

Run 3
        Final population size    74
        Expected heterozygosity  0.5832
        Observed heterozygosity  0.6622
        Number of alleles        3
        Effective no. alleles    2.40

Run 4
         Population did not survive.  Extinction at year 80.
...
```

Sample output from VORTEX (with above input parameters)

```
VORTEX -- simulation of genetic and demographic stochasticity

deer5.in     Input parameters:
  RECESSIVE LETHALS model of inbreeding depression

  Polygamous breeding
  First age of reproduction for females: 2   for males: 3
  Sex ratio at birth (proportion males): 0.6667

  In an average year ...
    12.00 percent of adult females produce litters of size 0
    68.64 percent of adult females produce litters of size 1
    19.36 percent of adult females produce litters of size 2

   42.00 percent mortality of females between ages 0 and 1
   13.60 percent mortality of females between ages 1 and 2
   15.00 percent annual mortality of adult females (age > 2)

   41.38 percent mortality of males between ages 0 and 1
   32.30 percent mortality of males between ages 1 and 2
   34.80 percent mortality of males between ages 2 and 3
   39.00 percent annual mortality of adult males (age > 3)
```

```
 Carrying capacity of 250

Environmental stochasticity:

  Reproductive success binomial variance x  2.500
     88.00 percent females produce litters
       binomial SD =   3.00 percent
       SD in annual RS due to environmental variance =   4.75 percent

  Mortality binomial variance x  2.500
     42.00 female mortality from age 0 to 1
       binomial SD =   4.41 percent
       SD in female mortality due to environmental variance =   6.98 percent

     13.60 female mortality from age 1 to 2
       binomial SD =   3.07 percent
       SD in female mortality due to environmental variance =   4.85 percent

     15.00 female mortality from age 2 to 3
       binomial SD =   3.19 percent
       SD in female mortality due to environmental variance =   5.05 percent

     41.38 male mortality from age 0 to 1
        binomial SD =   4.41 percent
        SD in male mortality due to environmental variance =   6.97 percent
     32.30 male mortality from age 1 to 2
        binomial SD =   4.18 percent
        SD in male mortality due to environmental variance =   6.61 percent
     34.80 male mortality from age 2 to 3
        binomial SD =   4.26 percent
        SD in male mortality due to environmental variance =   6.74 percent
     39.00 male mortality from age 3 to 4
        binomial SD =   4.36 percent
        SD in male mortality due to environmental variance =   6.90 percent

  Carrying capacity poisson variance x  2.500
    mean K = 250
      Poisson SD =  15.81
      SD in K due to environmental variance =  25.00

 Frequency of type I catastrophes:  5.000 percent
   with  0.900 mean ( 0.028 SD) multiplicative effect on reproduction
    and  0.800 mean ( 0.025 SD) multiplicative effect on survival
```

```
  Frequency of type II catastrophes:  3.000 percent
    with  0.800 mean ( 0.037 SD) multiplicative effect on reproduction
     and  0.500 mean ( 0.032 SD) multiplicative effect on survival

  Population simulated for 100 years, 1000 runs
  Initial population size:
    20 females 1 years old
    117 female adults (age > 2)
    40 males 1 years old
    27 males 2 years old
    46 male adults (age > 3)

Deterministic population growth rate (based on females):
     r =       -0.002
     lambda =  0.998
     R0 =        0.986
     Generation time =   6.85

Stable age distribution of females:  Age class   Proportion
                                       0 to  1      0.228
                                       1 to  2      0.129
                                       2 to  3      0.109
                                       3 to  4      0.091
                                       4 to  5      0.075
                                       5 to  6      0.063
                                       6 to  7      0.052
                                       7 to  8      0.043
                                       8 to  9      0.036
                                       9 to 10       0.030
                                      10 to 11       0.025
                                      11 to 12       0.021
                                      12 to 13       0.017
                                      13 to 14       0.014
                                      14 to 15       0.012
                                      15 to 16       0.010
                                      16 to 17       0.008
```

```
Year 10
        N[Extinctions] =     0, P[E] = 0.0000
        N[Survivals] =    1000, P[S] = 1.0000
        Population size =             184.50 (   1.75 SE,    55.49 SD)
        Expected heterozygosity =      0.9870 ( 0.0002 SE,  0.0057 SD)
        Observed heterozygosity =      0.9984 ( 0.0001 SE,  0.0036 SD)
        Number of extant alleles =    126.92 (   0.94 SE,   29.65 SD)
        Effective number of alleles =  83.99 (   0.61 SE,   19.23 SD)

Year 20
        N[Extinctions] =     2, P[E] = 0.0020
        N[Survivals] =     998, P[S] = 0.9980
        Population size =             158.75 (   2.12 SE,    66.92 SD)
        Expected heterozygosity =      0.9730 ( 0.0005 SE,  0.0162 SD)
        Observed heterozygosity =      0.9945 ( 0.0003 SE,  0.0101 SD)
        Number of extant alleles =     70.29 (   0.70 SE,   22.10 SD)
        Effective number of alleles =  43.51 (   0.42 SE,   13.26 SD)

Year 30
        N[Extinctions] =     8, P[E] = 0.0080
        N[Survivals] =     992, P[S] = 0.9920
        Population size =             138.72 (   2.28 SE,    71.82 SD)
        Expected heterozygosity =      0.9557 ( 0.0010 SE,  0.0307 SD)
        Observed heterozygosity =      0.9871 ( 0.0007 SE,  0.0231 SD)
        Number of extant alleles =     46.51 (   0.55 SE,   17.44 SD)
        Effective number of alleles =  28.35 (   0.33 SE,   10.25 SD)

Year 40
        N[Extinctions] =    19, P[E] = 0.0190
        N[Survivals] =     981, P[S] = 0.9810
        Population size =             124.52 (   2.30 SE,    72.18 SD)
        Expected heterozygosity =      0.9355 ( 0.0016 SE,  0.0508 SD)
        Observed heterozygosity =      0.9784 ( 0.0012 SE,  0.0391 SD)
        Number of extant alleles =     33.84 (   0.45 SE,   14.00 SD)
        Effective number of alleles =  20.56 (   0.26 SE,    8.21 SD)

Year 50
        N[Extinctions] =    50, P[E] = 0.0500
        N[Survivals] =     950, P[S] = 0.9500
        Population size =             116.32 (   2.36 SE,    72.84 SD)
        Expected heterozygosity =      0.9181 ( 0.0019 SE,  0.0599 SD)
        Observed heterozygosity =      0.9701 ( 0.0016 SE,  0.0496 SD)
        Number of extant alleles =     26.43 (   0.37 SE,   11.51 SD)
        Effective number of alleles =  16.20 (   0.22 SE,    6.82 SD)
```

```
Year 60
        N[Extinctions] =   79, P[E] = 0.0790
        N[Survivals] =    921, P[S] = 0.9210
        Population size =            104.45 (   2.34 SE,    70.90 SD)
        Expected heterozygosity =     0.8989 ( 0.0025 SE,  0.0760 SD)
        Observed heterozygosity =     0.9585 ( 0.0025 SE,  0.0747 SD)
        Number of extant alleles =    21.31 (   0.32 SE,     9.71 SD)
        Effective number of alleles = 13.19 (   0.19 SE,     5.80 SD)

Year 70
        N[Extinctions] =  117, P[E] = 0.1170
        N[Survivals] =    883, P[S] = 0.8830
        Population size =             98.32 (   2.43 SE,    72.30 SD)
        Expected heterozygosity =     0.8797 ( 0.0031 SE,  0.0918 SD)
        Observed heterozygosity =     0.9464 ( 0.0032 SE,  0.0957 SD)
        Number of extant alleles =    17.89 (   0.29 SE,     8.50 SD)
        Effective number of alleles = 11.25 (   0.17 SE,     5.15 SD)

Year 80
        N[Extinctions] =  168, P[E] = 0.1680
        N[Survivals] =    832, P[S] = 0.8320
        Population size =             95.30 (   2.52 SE,    72.60 SD)
        Expected heterozygosity =     0.8620 ( 0.0034 SE,  0.0980 SD)
        Observed heterozygosity =     0.9346 ( 0.0036 SE,  0.1051 SD)
        Number of extant alleles =    15.39 (   0.26 SE,     7.51 SD)
        Effective number of alleles =  9.80 (   0.16 SE,     4.65 SD)

Year 90
        N[Extinctions] =  227, P[E] = 0.2270
        N[Survivals] =    773, P[S] = 0.7730
        Population size =             91.86 (   2.55 SE,    70.82 SD)
        Expected heterozygosity =     0.8466 ( 0.0036 SE,  0.1010 SD)
        Observed heterozygosity =     0.9244 ( 0.0040 SE,  0.1099 SD)
        Number of extant alleles =    13.62 (   0.24 SE,     6.73 SD)
        Effective number of alleles =  8.78 (   0.15 SE,     4.21 SD)

Year 100
        N[Extinctions] =  301, P[E] = 0.3010
        N[Survivals] =    699, P[S] = 0.6990
        Population size =             89.68 (   2.64 SE,    69.87 SD)
        Expected heterozygosity =     0.8375 ( 0.0039 SE,  0.1044 SD)
        Observed heterozygosity =     0.9107 ( 0.0048 SE,  0.1277 SD)
        Number of extant alleles =    12.46 (   0.23 SE,     5.99 SD)
        Effective number of alleles =  8.11 (   0.14 SE,     3.79 SD)
```

```
In 1000 simulations of 100 years:
  301 populations went extinct and 699 survived.
This gives a probability of extinction of 0.3010 (0.0145 SE),
  or a probability of success of          0.6990 (0.0145 SE).

Mean time to extinction was  73.61 years (  1.14 SE,  19.71 SD).
Mean final population for successful cases was   89.68 ( 2.64 SE, 69.87 SD). Prior to carrying
capacity truncation, mean lambda was 1.000 (0.00 SE,0.126 SD)
Final expected heterozygosity was      0.8375 ( 0.0039 SE,  0.1044 SD)
Final observed heterozygosity was      0.9107 ( 0.0048 SE,  0.1277 SD)
Final number of alleles was           12.46 (   0.23 SE,    5.99 SD)
Final effective number of alleles was    8.11 (   0.14 SE,    3.79 SD)
*************************************************************************
```

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KEY DEER PVA WORKSHOP

Key West, FL

MINUTES

2 May 1990:

Meeting opened at 8:20 with a welcome by Deborah Holle.

Deborah introduced Dr. Seal, who asked everyone to introduce themselves.

SEAL: Ground rules, objectives: to bring together the biology, conservation issues, management options.

Essential that ideas and comments be submitted to CBSG at this meeting, in written form, to assure accuracy and completeness. Minutes to be distributed on a daily basis for approval. Will break into groups to make points of agreement and recommendations to be reviewed and agreed upon while at meeting.
Attempt to have completed document, reviewed as a series of drafts, by the end of the meeting to be used for final document to be distributed asap, in about 1 month.

SEAL: Slide presentation on population viability analyses and overview of CBSG work.

LACY: Slide presentation on genetic and demographic population analyses and modelling.

> Group attempted to fill in answers for PVA modelling.
> Population high estimate: 600+ at peak, perhaps 250-300 now.
> Key West 8 sq. miles
> Big Pine Key = biggest key, 6000 acres

FOLK: Deer separated for 4000 years from mainland keys.

HUMPHREY: Controversy over that hypothesis, but is probably correct (data are very strong). Older hypothesis is gradual rise of water.

SEAL: Using 4000 year hypothesis. Any molecular studies comparing Key deer population and mainland deer population?

SILVY: Very homogenous in the Keys. Work on allozymes shows little variation. Not unusual for deer populations though; comparable to deer in Texas. Expects study results in about 1 year.

LANDE: Small size--any studies?

FOLK: Comparing skull sizes of Key deer and mainland deer. Study results forthcoming.

SEAL: Any manipulations regarding size?

SILVY: Captive key deer on refuge. Don't remember any weight differences; faster antler growth.

HOLLE: Example of "Bubbles" wasn't a bigger deer. Corn-fed key deer don't exhibit size difference.

SEAL: Requests anecdotal information sources be listed and CBSG be given a copy. Experimentally need 3 generations to determine if genetic or environmental influences.

(SALISBURY - added later: Relationship of body size to island environmental constraints. Joh Ldorosa at New York Zoological Island, St. Catherine's Island, indicated that western white-tails were introduced to St. Catherine's several generations ago and that the current island deer are now smaller and lighter than the founder stock. Check with NYZS to determine when introduction was made and origin of founder stock. Mean size/weight differences between founder population and island population (over several generations) could then be extrapolated.)

ZIEGLER: 2, 1 male and 1 female, Key deer at Crandon Park Zoo. No reproduction. No data on them or other pairs.

HOLLE: 1 Discovery Park animal, lived about 20 years.

SMITH: Population work on Everglades deer appears to be same sizes as Key deer.

HOLLE: Klimstra presentation showed rounded heads on Key deer; longer, narrower head of most white-tails.

FOLK: 3 significant differences in Key deer skull measurements.

SMITH: What is source of these deer?

FOLK: Several populations from hunter kills in southern FL.

SMITH: Wants to examine those skulls.

HUMPHREY: Comment -- taxonomic studies can have fatal error by failing to sample population over entire range; error results from distorted subset of data.

SILVY: Samples from over large range -- from Keys to Alaska. Very difficult in past to obtain permits to test effect of nutrition on Key deer.

HOLLE: 1967: Key deer listed as endangered.

SEAL: Historical population size of Key deer?

HUMPHREY: 1500, a guess.

BIG PINE: 6000 acres 80% of 400 animals.
30 acres per deer.
KEY WEST: Had pines.
LITTLE PINE: 600 acres.
TORCH KEYS: Have some deer.
NO NAME KEY: 1200 acres.

SILVY: Early development probably increased population of deer. Filling of flats increased habitat for deer. Guess of 600 deer.

WILMERS: Habitat not consistent over Key deer range; Big Pine & No Name Key best habitats. Other locations marginal habitat so lower carrying capacity.

SEAL: Useful number of 600-1000 deer as historical population.
Population before protected less than 50-100. 10-15 years, or 3 generations, have since passed.

SILVY: Residents' reports--population low about 1951.

WATSON studied deer in 1954. Privately established protected lands. Refuge established in 1957.

LACY: 1984 cited pop. as 200-300 deer. this still used as current pop. figure. No more recent population estimates. If population continued pre-1984 downward trend, 200-300 may be overestimate.

HOLLE: Talked with Klimstra about this. He felt this number remaining stable.

SMITH: 62:48 male:female ratio.

HUMPHREY: Nova demonstrated not fair to compare portions of islands. Analysis from 1977-84 counts, 5% annual decline. 3, 5, 7,= regression figures. Road mortalities analysis results concur.

HOLLE: After 1984, refuge management efforts may have counterbalanced that decline.

WILMERS: On deer censuses, 92% of deer to 63% Port Pine Heights population.
2 other censuses have resulted in very small sample sizes.

SILVY: 3 consecutive nights of population studying resulted in highly variable numbers. Hence, had students study deer for a season. Resulted in greater variability, so were seeing seasonal variabilities.

Port Pine Heights population concentrated in backyard of one deer-feeding resident.

WILMERS: 1975- Key Deer Refuge had high staff turnover, variations in training, change of route. 3 of 4 highest deer counts since 1980 in last 4 years.

SEAL: Need working group to determine pop. estimates & other factors. 1984 population decline could be occurring without detection based on census information.

HUMPHREY: Indexed census figure. 5% decline based on flawed data, on deer on northern end. Concurs that such a gradual decline would be difficult to detect. SILVY's point that habitat loss has continued, so probable continued decline in numbers. Predicts best censuses are estimated numbers from seasoned Key deer observers.

WILMERS: Feeding of deer greatly impacts carrying capacity.

MARCUS: New bridges resulted in increased residential development and a larger impact by more visitors; disproportionate habitat loss:human traffic.

ZEIGLER: Most census are active -- what about passive censuses such as track counts, plus creating the possibility of creating track fields along roadways?

HARDIN: Track counts tried mid-late 60;s, also pellet counts. Because of substrate, both methods unreliable.

WILMERS: How feasible is population study on area as large as Big Pine Key? Funds and refuges are limited in resources.

FOLK: Not reasonable to do census on such large area with limited personnel.

WILMERS: Data base is weak; hesitancy to use in models.

SEAL: Accept the limitations that data are weak, don't let that limit discussions of possibilities.

HARDIN: Increased human populations have impacted deer movements and habitat usages in last 15 years; difficult to standardize census.

LOGAN: Helicopter census a possibility?

WILMERS: Limited by residents, daylight hours, $400/hour. Requires a correction factor relating helicopter census to real numbers of deer present.

HARDIN: Earlier, during mosquito spraying, Key deer ran for cover when aircraft flew overhead.

SMITH: Radio-collared animals with follow-up might result in better numbers.

WILMERS: Need cooperative census, for refuge unable to fund such a census. Capture of 6 Key deer took considerable efforts.

SEAL: Don't limit options yet by existing funds and already used methods.

HUMPHREY: Capture and radio-collar 30 animals. Question of permits.

SMITH: Need real estimates with confidence limits.

WILMERS: Mark-recapture limited in time.

SILVY: Needed to mark 50% of animals to get reliable estimates
(both radioed and capture/mark animals.)

LANDE: Deer movement patterns? Are they territorial?

SILVY: Not territorial, but have home ranges. Females have ranges, males seasonally. Movements over 3 miles recorded (males). See mark:remark animals in ratio true to population. Assumption is of equal chances to see marked animals in different locations.

Used road census data in ..... for estimates on Big Pine Island.??

SILVY: 50% found best % of population to mark for mark/recapture studies.

SEAL: Will break into groups to work through data and methods to determine the actual data and its limitations.

Consensus Derived Life History Characteristics:
Females: No fawns reproducing (1 yr. olds)
2 yr olds (60% bred based on road kill data) (HARDIN)

88% of adult females reproductively active (2 yrs and older)

95% of adult females "   "   (older than 2 yrs)
(based on road kill data)

Probably no reproductive senescence based on example of 20 yr old known breeder.

Litter size: 78% singles

22% twins 1969-1974 (HARDIN) of all age class pregnant does. (based on road kill data)

SEAL: Worthwhile to break into age classes.

HUMPHREY: During data collection period Key deer may have been at carrying capacity and experienced no harvest.

WILMERS: Fawn survey (1989) documented 44 individual fawns, including 7 pairs of twins.

FOLK: Not coincidence; road kill data supports.

Does show density dependence.

SILVY: Maybe Key deer always at carrying capacity.

WILMERS: Doe:buck ratios. High number of does:bucks based on census data. At least 4:1.

SMITH: Differential use of habitat by sex.

SILVY: Fetuses: 2.0 males:1 female.
Fawns: 2.4 males:1 female. Sample size:?

LOGAN: Appears that reproductive level of mainland deer populations stable. Survival & recruitment rates are source of variation due to low, & highly fluctuating carrying capacity.

SMITH: Everglades deer breeding strategy selects for litter of 1.

Adult sex ratio:? 60:40 male:female (based on road kills) (WILMERS)

Road kill data and fawn data representative of population?

HARDIN: Yes, for females. 0.5 males:1 female killed (from road kills)

SILVY: Need to look at census methodology. Differential visibility of sexes seasonally.

LACY: Inconsistency between birth sex ratios or mortalities.
1.5 males:1 female death ratio. So, is male death ratio underestimated? Either more males or more male deaths.

SMITH: Uses peak rut to determine sex ratios. Adult males and females only associate during breeding season.

SILVY: 2,394 adult males:7,819 adult females or 0.31 males:1 female is ratio of total observed adult males:adult females from 1968-72.

LANDE: Verme paper. Is sex ratio unusual? Yes.

SEAL: Verme's paper: Effects of energy on sex ratio?

Richter's? paper. 1982 or 83?

SMITH: Has not seen ratios of 2:1 in Everglades deer.

LOGAN: In utero sex ratios do not reflect sex ratios of adults. Sex ratio in road kills more a reflection of differential sex mortality.

SEAL: Need this discussion to look at data and test it. Some of group now explaining data away to become comfortable with it.

LANDE: Fetal sex ratios should be unbiased.

LOGAN: Not representative of population sex ratio because road kill data biases.

VERME paper may refer to sex ratio of fawns at different age classes of females.

LANDE: Sex ratio stops at ....

HARDIN: Males more precocious and likely to be killed. Attempting to obtain data from any and all sources.

WILMERS: Refuge has road kill data. Will attempt to obtain data overnight.

2 May 1990 (Afternoon session):

LACY: Any males excluded from breeding?

HARDIN: Yearling males are excluded from breeding during peak. They participate in limited breeding at end of breeding season. Most dominant available males have breeding access.

WILMERS: Comment from Klimstra.........

SILVY: September: first month of breeding. Births: April & May.
SMITH: Skewed access to breeding by males.

FOLK: Port Pine Heights has females that are resident; probably bred by very small number of males and habitat is edge habitat.

WILMERS: Road kill information--much from Frank Drummond.
Pie graph p.3. Data from 1968-1988. US Highway 1 divides Big Pine Key and is major access to keys. Key Deer Blvd.=site of 2nd most road kills;bisects Key Deer Refuge.

Table 5 Key deer road kills on US 1 by month; May, June, & July, and Oct. & Nov. = highest road kill months. Dispersal of juveniles in May, perhaps June.

1986-89 data. 1986-89: 17 road kills on 0.3 stretch of US 1 (26.6-29.9 mile markers).
Previously had 5 kills (1980-85); road usage changes.
Major hotspot: pointed out on map.

Possible changes to account for increased road kill mortality for 29.6-29.9 mile marker; looked at data by month and by time of day. Number of bucks and does comparable.
Younger animals dying; during daylight hours.
Losing a lot of bucks in February. 1980-86 only 5 bucks died on US 1.

Temporal trends (p.41)
0600-0900 & 1800-2100--highest # road kills. Believe that artificial feeding entices deer across roads.

Feeding issues: credibility: need to enforce key-wide, public relations, education, enforcement.

Another hotspot of road kills (32.8-32.9 mile marker): traditional crossing; grassy median on curve with poor visibility. Also, dispersal in narrow area may force their use of road.

Actions taken to prevent road kills: reduced speed limit, highly visible highway patrol, roadside vegetation cut back. Other options: fencing, overpasses.

Highest road kill year was in 1971 (64 deaths).

NETTLES: Suggests mounting permanent radar transmitter before 1 curve at US 1. Better signage.

HUMPHREY: Habituation to traffic devices. Fuzz busters might work, self-induced.

STUART: Too many rental cars without radar detectors to be effective.

WILMERS: Road kill mortality underestimated. Methods to find road kills:
1. vulture gatherings at carcasses.
2. reports by local agencies, citizens.

Drowning, dogs, etc. all other sources of mortality.

HARDIN: 18% of marked fawns drowned. Ditches flush with tides; carcasses washed away, thus under-reported. Also expensive to survey.

HOLLE: Poaching: 4 found in last 4 years; easily poached. Can entice with food.

WILMERS: Has found hunters' blinds on 2 of the keys. Key deer remarkably free of parasites & diseases.
Schulte et al.: published paper on this.

NETTLES: The SCWDS has assisted the NKDR staff by conducting necropsies on road-kill deer and lab tests. Key deer generally rated good general physical condition. Haemonchus contortus, large stomach worm, present in subclinical levels. Of known importance in deer at levels of 30 worms/lb. Fawns much more susceptible especially when nutrition is poor. Large numbers of lungworms, Dictyocaulus viviparous, also present in low numbers. A few animals have had antibodies to either epizootic hemorrhagic disease or bluetongue virus. The documentation of antibodies, not disease, is probably not a problem because antibody positive deer in other southern Florida areas have not had die-offs. In overview, current data do not show parasite or disease problems of major significance.

Need to monitor physical conditions and body fat: if good then indication that not overpopulated.

LANDE: Role of deer in tick life cycles?

NETTLES: Deer presence probably enhances tick population. There was 1 case of human Lyme disease on Big Pine Key.

MARCUS: Many lice present on 1 road kill specimen. Will obtain specimen for i.d.

WILMERS: All body fat indices indicate well-fed animals.
Nova and Jim did last good fawn study. Last year had community involved resulting in

highest fawn counts. 44 fawns. Took steps to exclude repeat sightings. April: fawning season; July not included because more fawn movement. One evening driving fawn census route: 11 fawns, highest ever observed on formal census.

SILVY: Observation ratios -- February: does concentrate in groups; juveniles leave mothers; much more visible.

20% mortality between parturition and 6 months of age.

0-6mo	35.3%	males	17 (sample size)
	37.5%	females	8
6-12mo	9.4%	males	32
	7.2%	females	14
1yr	32.3%	males	31
	13.6%	females	22
2yr	34.8%	males	23
	8.3%	females	24
3yr	25.0%	males	12
	10.7%	females	28
4yr	42,9%	males	7
	5.0%	females	20
5yr	25.0%	males	4
	5.9%	females	17
6yr	0.0%	males	2
	30.8%	females	13
7yr	100.0%	males	3
	28.6%	females	7
8yr	---	males	0
	66.7%	females	3
9yr	---	males	0
	---	females	0

110 marked deer composite life table based on 1968-73, total mortality. Note: aging deer is inexact.

NETTLES: Heartwater disease is caused by a rickettsial organism that is spread from animal to animal by ticks. The tick vector Amblyomma variegatum is found on 19 islands in the Caribbean but heartwater only known on 4 of these islands. Experimental studies have shown that heartwater is fatal to deer. The native ticks in FL experimentally shown to carry the disease. Cattle, sheep and goats susceptible.

FOLK: Alligators and sharks other mortality sources. Drought: concentration of deer on Big Pine Key.

PACE: Development has increased water availability.

FOLK: 60-70 % of Key deer on Big Pine Key.

MARCUS: Pigs another source of mortality only Little Pine Key.

LANDE: Enough data to do multiple regression on numerous factors affecting mortality.

HUMPHREY: Drought reflected in the mortality data.

FOLK: Refuge can provide rainfall report.

SEAL: Chance for circulation between fragments of population?

HARDIN: Movement of males and females on bridges and swimming. Key deer on Cudjoe & Torch Keys. Effectively 1 population.

HUMPHREY: Question about genetic mixing and suitability of models.

HOLLE: 1 female had moved from Sugarloaf to Cudjoe.

SILVY: Doe from Big Pine to Porpoise Key. Would swim about 0.8 mile in 24 hour period to nourish fawn.

SMITH: Would a male breed a doe on more than 1 island?
Consensus: yes.

FOLK: 95% of animals on the following keys: Big Pine complex, No Name, Little Pine complex, and the Torches.

SEAL: Is Key deer habitat likely to increase?

MARCUS: Controlled burning is a management tool now used to manipulate habitat.

HOLLE: Can enhance habitat. 2500 acres on Big Pine including The Nature Conservancy land. Could get 500 more acres possibly.

HUMPHREY: May increase 3-5 fold the available funds for habitat acquisition.

SEAL: How much land is a possibility to add?

HOLLE: 2000 acres maximum could be added. Have purchased land on Cudjoe and keys. Could possibly look at Knockemdown key.

SEAL: Land acquired would serve to protect population and to allow population management.

LACY: Is estimate of 31% habitat loss if all scheduled development occurs accurate?

SEAL: Range of values for carrying capacity estimate?

HUMPHREY: Fire a management policy not used much in past.

HOLLE: 6000 acres.

FOLK: 6000 acres, planimetry.

HUMPHREY: Opportunity for a 2nd pop. On Cudjoe, upper and lower Sugarloaf and maybe Knockemdown Keys.

FOLK: Water and dogs are limiting factors. Water being added. Could add 2000 acres total on Sugarloaf, 300 acres pine and hummock. Cudjoe Key could add 1000 acres, if burned.

WILMERS: Data agrees with high dog usage of water holes on Sugarloaf Key.

MARCUS: 7900 acres owned by Key Deer Refuge.

SEAL: So habitat could be doubled.

LACY: Protected habitat doubled, but not all of it useable habitat.

FOLK: If habitat types are known can estimate carrying capacity.

LOGAN: Estimates of 30 acres needed per deer, then need 9000 acres to support a population of 300 as estimated. Discrepancy.

HOLLE: This past year experimentally bulldozed ferns and other growth, now mowing to create more grassy areas to keep animals off the roads.

WILMERS: Not all subdivisions attract Key deer equally.

SEAL: What are suggested population goals?

HUMPHREY: Manage for 100 years. In 60 years 1 meter rise in sea level projected. Argument focuses on when and how much the sea level will rise, not if it will happen. Options: abandon FL keys and the Key deer or hedge the bets that this projection is wrong?

LANDE: Projected sea level rise in 200 years?

NETTLES: Generation time of Key deer, 5 year?
LACY: Mean age of mothers producing offspring. Will calculate.

SEAL: 100 years will allow for about 20 generations.

HUMPHREY: In 20 years it's thought the data will much more reliably predict if the sea level will rise.

Average water levels will not be critical extremes will be critical, such as storm levels.

HOLLE: Comment about El Nino.

SEAL: Any data on effect of hurricanes on Key deer?

SILVY: Lower islands went under. Tidal surges were 6.5 feet.

HOLLE: Sun, moon and earth were all in alignment. Caused high tides; not even storm conditions.

LACY: Need to determine % target for population survivability for 100 years. Example: 50% chance of surviving for 10 years.

SILVY: Actual populations do not match the models -- example whooping crane.

HUMPHREY: Suggests 95% survival target.

SEAL/LACY: Need to also define targeted number of individuals in population.

HUMPHREY: 250 animals for both populations. The possible available habitat suggests this population level.

SEAL: If 250 total population has effective population size of 100, then 10% loss of genetic material would occur.

LANDE: Assuming no mutation seems likely that although population went through bottleneck 6-8 generations ago, most of genetic variability not lost; population probably went through a number of bottlenecks.

If Key deer quite homozygous (as discussed earlier) then diversity probably not lost recently. Populations on the order of several thousand necessary to insure highly heterozygous population. Probably never case with Key deer. Basis of decision must be from genetic loss standpoint.

With pedigree can measure degree of heterozygosity of morphological characters lost. Long-term, indefinite genetic maintenance requires numbers of about 250-300.
Polymorphic versus polygenic traits explanation.

SILVY: What about out-breeding depression in zoo?

LACY: Knows of no data that illustrate this.

LANDE: Inbreeding depression is in short term.
Population target can be lower if planning for 100 years, relatively short period of time.
Higher numbers of animals needed if want to maintain this population indefinitely.

HUMPHREY: Carrying capacity of available habitat will be reduced. If money is available to buy habitat, are the targeted goals adequate?

LOGAN: Need to estimate available acreage and use. Calculate the number of deer that acreage can support. Demographic values and hard data recommended to make management decisions such as buying land.

SEAL: Population goal targets to useful to plug into models and to generate discussion.

Suggests groups meet tonight to discuss fundamental issues and produce written documents, will continue tomorrow.

Issues:
1. Population estimate. (Hardin and Humphrey)
2. (Logan)
3. Catastrophic loss. Mortality loss or reproductive loss?
Consensus to model a class 5 hurricane every 50 years with 50-75% mortality.
4. Disease
5. Mark 50 deer.
6. Genetic studies: summarize studies and timetable.

3 May 90:

LANDE: 2:1 fetal sex ratios highly unusual.

SILVY: Road kill Female Reproductive Data

AGE	#PG/ #KILLED	#LACTATING	#SINGLES/SEX	#TWINS/SEX

fawns	0				
1 yr	0				
2 yr	7/12	2	6	4m/2unk	1 pr. f/f
3 yr	7/9	2	6	2m/2f/2unk	1 pr. f/f
4 yr	2/4	2	1	1m	1 pr. m/m
5 yr	3/5	2	3	1m/2f	0
6 yr	0/1	1	-	-	-
7 yr	0/1	1	-	-	-

Discussion of VERME paper and nutritional stress and sex ratios.

HARDIN: 2.4 males:1 female fawn data (99 samples from capture data) 1968-73.

LANDE: Evolutionarily advantageous for unbiased sex ratio.

HOLLE: Have collected blood samples from road kills.

SILVY: 119 deer 1969-197? radio-tagged for habitat study
probably of being found in given habitat
1 deer/42 acres open areas
1/17 hammock
1/35 buttonwood
1/32 mangrove
1/28 hardwood
1/23 pine

213/deer Big Pine in 1971. Deer on 21 keys, 19,600 acres; most liberal estimate -- could support 653 deer if all habitat on these keys as good as that on Big Pine Key. Most likely estimate 300 animals.

Habitat loss to development was of important habitat, hammock and pineland areas on Big Pine Key.

LOGAN: Captive breeding not an action to be implemented at this time although it may play a role in the future given that specific criteria, which have not yet been identified, are met. Key deer do not appear to be experiencing known inbreeding, low numbers, or genetic concerns of FL panthers. Captive breeding could serve several management functions of benefit to the wild population should such needs be determined necessary. The data that will be necessary for determining the need for captive breeding are not currently available. Therefore, efforts should be implemented to gather necessary genetic, demographic, and habitat data to establish action and decision levels for captive breeding.

SILVY: Involved in captive breeding of prairie chickens at Fossil Rim to save genetic material in event of loss. Difference with Key deer: captive breeding techniques known.

Placing animals in zoo would reduce habitat preservation efforts.

LOGAN: 2 public reactions are:
1) with captive breeding it is no longer necessary to restrict land use and
2) the resource agencies have given up.
The public typically perceives captive breeding as a replacement for all other recovery efforts rather than an augmentation.

SILVY: Land owner viewpoint: lots designated as not-for-building, no taxes assessed. However had owner can't build and/or sell for over his original cost. Upsets landowner.

LANDE: Captive breeding as insurance policy. Highest source of mortality=road kills, density independent. The more density independent factors the more vulnerable to catastrophe. Need to keep currently representative samples of animals or genetic material at hand.

SILVY: Deer mortality by road kill is density dependent. As population increases yearlings particularly exhibit more movement when searching for home range.

LOGAN: Density of deer and road kills related. Road design and management of the road corridor can lessen road kills.
Enforcement of reduced speed limits, broadened shoulders, reduction of deer attractants, addition of wildlife crossings are all road management options.

HARDIN: Data supports that drought increases deer density on Big Pine Key resulting in higher road mortality, illustrating density dependence.

REINER: Few biological reasons habitat cannot support the deer population. Sociological issue.

WILMERS: Supports that it is sociological issue.

HUMPHREY: Clear top priority = habitat. Risks modest thereafter. Hedge bets with .... Assess adequacy of current population & population goals. Translocation recommended; will possibly need augmentation, preferable from wild population, not captive. Possible translocation site: Big Island. Disadvantages: cost, water, outside of historical range. USFWS has record of treating subspecies as species.

SEAL: USFWS considering issue and attempting to have symposium to resolve issue.

HUMPHREY: Revises estimate to buy habitat from $50 million to $30 million.

BENTZIEN: Population reduction to ?? deer is action threshold. Maladaptive selection may occur in population.

ROCKWELL: Eager to see models for better evaluation of current population. Allowing captive managers lead time would increase the amount of captive space available to be utilized for support of the wild population. If captive managers are brought in at the "eleventh hour" it will be more difficult to obtain the amount of space required within the needed time parameters.

REINER: Modelling will help define decision point for captive pops. Should be iterative process.

SEAL: In response, can freeze sperm.

HOLLE: Heartwater threat to Key deer: slow progression of disease. Time would allow capture and movement of deer.

ZEIGLER: Regulations exist for ability of Miami MetroZoo to take in Key deer. Miami MetroZoo not interested in Key deer exhibits at this time; will aid with injured deer. Losses are not only immediate in event of catastrophe, but 4-6 days later losses will again increase due to other factors -- water, food, etc. Zoos need time to gear up to house animals so their response time will also slow aid; the condition of animals will increase losses of transferred animals due to stress. Immediacy of solutions serious.

HUMPHREY: Failure to acquire land, Key Deer Refuge not adequate.

WILMERS: Dawson's paper in Condor illustrates catastrophic loss.

SALISBURY: Population has gone through 1 bottleneck. Benefit of captivity is education. Higher numbers of attendance at zoos than all national sporting events combined.

ZEIGLER: Key deer is regional issue, not same interest FL-wide. Public education support would enhance Key deer efforts. Zoos can play a role immediately to aid in state-wide recognition.

FLEMMING: Catastrophic plan in existence at Key Deer Refuge?

HOLLE: No.

REINERS: Criteria for action: the current pop. conditions synthesized in the model.

HUMPHREY: Model heterozygosity.

SEAL: Value of captive pop.to better experimentally test physiological issues surfaced.

LOGAN: Variables to trigger implementation of captive breeding must be developed and quantified. Captive populations may be useful to research specific questions, but I do not know of any important questions that could not be examined in the wild population.

WILMERS: Klimstra seeking funding for study ganging issue in unnatural setting; important to study those reproduction mechanisms.

SMITH: Identify problems that cannot be tested in wild.

HUMPHREY: Demographic problem: unusual pop. growth. Study re-population of Sugarloaf Key, includes recruitment.

LANDE: Need for nutritional study on differences between Key deer and mainland pop.

SEAL: HARDIN lead group on censusing, habitat and carrying capacity.
LOGAN lead action-trigger criteria.
LANDE lead research questions

LACY: Modelling data clarification. Consistent birth/mortality data. also consistent. Pop. growth rates unknown now. Consistent w/data, not interpretation, high juvenile mortality not consistent with mortality data for 1-2yr deer.

WILMERS: Key deer mortality by age and sex, for 210 road-killed deer and 42 deaths due to miscellaneous cause from 1985-89.

	ROADKILLS				MISCELLANEOUS DEATHS					
AGE	BUCKS		DOES		BUCKS		DOES		TOTAL	%
<1	29	12%	12	5%	4	2%	3	1%	48	19
1-2	48	19	17	7	5	2	3	1	73	29
2-3	36	14	20	8	6	2	4	2	66	26
3-4	12	5	15	6	5	2	2	1	34	14
4-5	8	3	4	2	2	1	0	-	14	6
5-6	4	2	1	-	1	-	1	-	7	3
6-7	1	-	1	-	0	-	1	-	3	1
7-8	0	-	0	-	1	-	1	-	2	1
8+	1	-	1	-	1	-	2	-	5	2
TOTALS:	139			71		25		17	252	

LACY: Road kills in younger age classes due to either vulnerability or more deer in those age classes. Examining % deer expected killed by age class to actual number killed, indicates that 3-4 age class most vulnerable.

Afternoon session

Presentation of Reports

LOGAN: Role of captive breeding in Key deer. While it may play a role later, not appropriate at this time. Need criteria for implementing captive breeding.
Reasons for captive breeding:
- preservation of genetic material
- augmentation of wild population or re-introduction
- preservation of representation of genetic material in event of loss of wild pop.
- research
- education

Need the following criteria to have complete information which would prompt action:
genetic analysis-if problems, need for research study:

(1) quantification & description of habitat; event of habitat decline would trigger action

(2) demography: status & trends

Need figures to describe; need convincing data.

WOOD'S SUMMARY

SEAL: Useful for Key deer to be reclassified from endangered to critical.

LANDE: Research to Address Using Captive Key Deer

Benefits of basic research for management.
Specifics:

1. Baseline studies for any future breeding program, before information is necessary.
   - breeding
   - breeding w/other deer
   - sex ratio
   - twinning rate
   - dental anomalies indicative of inbreeding?
   - slow rate of wound healing
   - crosses between Key deer and Swamp deer, and Swamp deer and mainland deer to quantitate inbreeding depression. Increase in fitness in Key/Swamp hybrids compared to Swamp/mainland hybrids. Could consider addition of genetic material from other pops.
   - Nutrition

Educational aspect could be incorporated.

Research Issues for Wild Population

Behavioral studies example: road crossings demography, traffic factors: speed limit, etc.

habitat management, example: burning plant compositions, species abundance
island composition difference
movement between islands
genetic differences between animals using different islands

HARDIN: Census problems & techniques

Three population estimates important: on Big Pine, on immediately adjacent islands, on outlying keys. Road access from no roads to many (Big Pine Key).

Optimal Censusing (no limited constraints)

Big Pine Key & adjacent islands (use roads and firebreaks)
Mark 50 deer & observe weekly to estimate populations.
Use consistent route and personnel.
Telemetry to monitor shifts in animals.
Fawn surveys be maintained or intensified.

Outer islands:

Monitor at freshwater sites, at least monthly, count deer observed,; use remote sensing devices, cameras, to identify deer visiting sites and to monitor trend data.

Minimum Censusing:

1-2 times annually: consecutive night surveys, 4-5 nights/week driving of standard census routes, choose consistent time(s) each year, choose optimal time to obtain sex ratios trends. Gives trend data, not absolute numbers.

Constraints:

Costs of trapping, equipment, personnel.
Demands on Refuge personnel.

Suggestions:

Contract out, use grad students, use volunteers.
Marked and captured animal censuses every 5 years. In between, trend studies.

Costs:

$50,000 annual cost estimate to census Big Pine.
$100,000 for all Key deer inhabited areas.

SMITH: Everglades: $100,000 annually to track 40-45 animals tracked every 4-5 days by helicopter.

LOGAN: Comment concerning objections to suggestions for cross-breeding.

BENTZIEN: Permits legally unobtainable from USFWS for cross-breeding.

HUMPHREY: Plant composition study completed already by U. of FL.

SEAL: Experimental studies to obtain genetic information is relatively new methodology.

SILVY: Small sample size with deer very different than sample sizes of Drosophila and mice.

LACY: Modelling results.

SILVY: Habitat Carrying Capacity Report (deer/acre)

1 deer/42 acres	open-developed
1/17	hammock
1/35	buttonwood
1/32	mangrove
1/28	hardwood
1/23	pineland

Overall density Big Pine Key 1 deer/30 acres (200 total)
Harlow & Jones (1965) 1 deer/34 pine-oak uplands
21 keys 19,601 acres IF habitat as good as Big Pine (i.e. 1 deer/30 acres) would support 653 deer maximum. Key West at about 2500 acres would have only supported 83 deer IF habitat was as good as Big Pine Key.
Current habitat can support no more than 300 deer total. Had estimate of 250 for Big Pine, estimated 100 on other areas (SILVY's original studies). Currently at or near carrying capacity on protected lands.

NETTLES: Effect of artificial feeding on Key deer should be included.

LACY: If charged public minimal amount, to view Key deer, optimal census method could be funded.

SEAL: Research on captive populations

3 issues recurrent topics that could be tested with captive pop.:

1. Reproductive rate--low rate of twining
2. Sex ratio--
3. Morphology and growth rates

Results would have management implications.

SILVY: Key deer sex ratios and reproductive rates comparable to published data on FL deer and other states and Canada.

SEAL: Baseline data allow multiple testing. No data showing basis for sex bias.

LANDE: Metabolic studies would require more extensive use of controls. Basic research proposed could use wild deer population as control.

LACY: If sex ratios, reproductive rates are invariant & genetically based has affects on rebounding capabilities and therefore management implications.
Hurricane Contingency Plan for Key Deer

Note: Assume decision to have captive population already made. probability of Key deer surviving 1 catastrophic event has been determined at this meeting. If probability of extinction is high, based on population modelling results, some deer will already be in captivity. If probability is low, they won't be in captivity.

HOLLE: USFWS Hurricane and Catastrophe Planning

Due to USFWS policy, Refuge staff will be evacuated before hurricane hits. If for some reason they are on site the Regional office will send in help to make sure the staff has food & housing.

Aerial survey of the Refuge will be make ASAP to assess damage. Greater probability of seeing live deer the sooner a survey is done. Also assess habitat damage using aerial photographs and video. If deer already in captivity, decision will have to be make to capture all surviving deer, some number of surviving, or none to augment the captive population. I none in captivity a decision will be made to take some into captivity at some future date (not immediately) to protect from a second catastrophic event.

Transport personnel and needed equipment to Refuge. Highest priorities at the Refuge may be to assist human population with catastrophe.

Designate a public affairs person for news releases. Be prepared to house injured and displaced deer.

NETTLES: Recent Disease and Parasite Data on Key Deer.

Work conducted cooperatively between National Key Deer Refuge (NKDR) personnel and the Southeastern Cooperation Wildlife Disease Study (SCWDS).

Since 1986, abomasal parasites counts and serum antibody profiles have been conducted on 38 and 31 Key deer, respectively. Abomasal parasites have almost totally been limited to subclinical burdens of the large stomach worm Haemonchus contortus. Prevalence of infection is 87%. Average worm burdens have been 145 worms/deer which is considered below a pathogenic level. Nevertheless, this parasite can be of serious consequence to deer, particularly juveniles, at level of 30 worms/pound of body weight. Other helminths identified in low numbers in individual animals include the medium stomach worm, Apteragia sp. (1 deer, 20 worms), the large lungworm, Dictyocaulus viviparous (1 deer, 4 worms) and Trichuris sp (1 deer, 1 worm).

Of the deer examined, the necropsy was done by SCWDS staff on only 5 animals. The rest of the arrivals were necropsied by NKDR staff. Serum analyses on 31 serums have revealed antibodies to blue tongue virus & epizootic hemorrhagic disease virus in 2 and 3 deer, respectively. Serologic activity has not been detected for brucellosis, parainfluenza virus 3, IBR and BVD. Two deer had low titers against Leptospira interrogans serovar grippotyphosa.

Arthropod parasites found on deer have been identified as chewing lice Tricholipueris sp. and black-legged ticks, Ixodes scapularis. Both ectoparasites occur as low-level infestations on animals at a low prevalence.

The overall conclusions by SCWDS at this time are as follows:

1. subclinical parasitism is present below levels sufficient to warrant concern for herd health at the present time;

2. the presence of large stomach worms is reason to be concerned if the population increases markedly and the nutritional plane declines;

3. the serologic data indicate presence of hemorrhagic disease viruses; however the likelihood with mortality at this latitude is low;

4. the physical condition ratings and general appearance of the deer (lack of lesions) indicate that the deer population is healthy and viable; and

5. continued monitoring of deer health parameters is necessary to be able to detect changes in the deer herd.

LANDE:

I. Research topics that can (best or only) be addressed using a captive population.

Rationale:
Basic research on the biology of endangered species does not necessarily have immediate application in management practices. However, in general, with a broad base of fundamental knowledge on the ecology, demography and genetics, the better the management can ultimately be.

Specific Research:

1. Baseline studies for use in future captive breeding program for conservation (e.g. following a catastrophe) to anticipate any special problems encountered in captive propagation of Key deer.

2. Morphological, physiological, and growth studies comparing Key deer and various stocks of mainland deer in controlled common (shared) environments such as nutritional regimes. These studies should continue at least 3 generations (with sufficiently large stocks to avoid close inbreeding) to allow for delayed effects of prenatal and postnatal maternal influences. These studies would give a quantitative assessment of the relative contribution of heredity and environment in determining the differences between Key deer and mainland deer, e.g. in fetal sex-ratio, physiology of basal metabolism; salt tolerance in drinking water.

3. Hybridization studies to investigate possible inbreeding depression in Key deer and the genetic mechanisms underlying hereditary differences between Key and mainland deer.

A. Preliminary results on the lack of genetic variability at electrophoretic loci, unusual primary sex ratio (2 males:1 female in fetuses), the high frequency of dental anomalies, and possible slow wound healing when compared to mainland deer, may be indicative of a previous history of severe inbreeding and consequent reduced fitness. Such possible inbreeding depression could be measured by crossing Key deer with various stocks of mainland deer, with control crosses among mainland stocks. Measurements of increases in fitness components, such as growth, reproduction and early survival, in the F1 hybrids relative to the pure stocks would reveal whether the Key deer is experiencing inbreeding depression in these components of fitness. However, some components of fitness, e.g. adult survival in nature, would be difficult or impossible to measure in captivity.

B. The same F1 hybrids if mated among themselves within each cross, to produce an F2 generation, could be used to analyze the genetic mechanisms underlying the unusual fetal sex ratio, high frequency of dental anomalies and the twinning rate (22% in Key deer, versus 0% in Everglades swamp deer).

II. Public Education

A research herd could also contribute greatly to public education, if properly located, e.g. at a major zoo.

III. Additional research on wild population of Key deer.

1. Deer behavior, e.g. road crossing hotspots, possible deterrents, use of underpass or overpass.

2. Statistical causes of road mortality using past 20 years of data: e.g. multiple regression of yearly road mortality on population size, age distribution, traffic volume, speed limit, and weather records (temperature and rainfall).

3. Population structure: dispersal and possible genetic differentiation between subpopulations.

4. General ecosystem studies in relation to management practices, especially controlled burns. The plant community, its species composition, and response to deer browsing, fire and other management practices, and hurricanes, need further study.

5. Demographic studies combined with genetic studies of parentage identification (e.g. using DNA fingerprinting) to more accurately estimate ratio of effective population size to actual population size by estimating the distribution (and variation) in reproductive success of males and females.

4 May 1990:

SEAL: Comments on captive breeding.

PACE: Hurricane hitting would possibly reason for developing captive breeding program.

LACY: Models could be have few lines written to include determination of reaching crisis point -- some critical low threshold.

SEAL: Probabilistic determination is method to choose critically defined level.

SMITH: Numbers used in the modelling are approximate; doesn't want to base establishment of captive breeding program on uncertain approximations. What is harm in establishing captive breeding now when removal of 20 would not jeopardize pop.

SALISBURY: Lowry Park has resources infrastructure to maintain a Key deer exhibit. Would propose cooperative effort with FWS. FWS would capture animals. Lowry Park would provide educational program.
Environmental Education at Lowry Park Zoo: Between 19988-1990 the Lowry Park Zoo has trained 1600 teachers in environmental education. Two teacher per grade level (K-7) attend curriculum writing workshops. Grades 3-5 have a yearly building curriculum on Florida ecosystems, development and species endangerment. In upper grades more global environment concerns are taught. The schools cover a 7 county area. From March 1989-90,

42,000 students visited the zoo on structured school excursions and covered environmental topics. These zoo-based environmental education/conservation programs are written in accordance with the State of FL's science objectives as identified for school children.

Our new zoo's 8 acre $8 million FL biome is the largest zoo comitment to date on FLORIDA SPECIES, ECOSYSTEMS, EDUCATION, and effects of human development of habitat. In this project, we are working with state and federal agencies on:

1. Red wolf
2. FL panther
3. Manatees

BENTZIEN: Option of frozen genetic materials?

SEAL: 60 species with programs underway. None have yet, except for mice embryos, reached application stage. The plan is for continued development. To develop such a program for new species like Key deer would require 3-5 years.

HOLLE: If captive breeding program implemented would propose first to capture some of .... animals; habituated to humans, perhaps less desirable genetically.

SEAL: Important that choices don't jeopardize habitat acquisition.

FLEMMING: Panthers issue -- public views captive breeding as giving up. Under permit restrictions can't take endangered species for display; must be for research and enhancement of species.

FRANK: Threat of hurricane good ground for public education.

SEAL: Details of options to discuss at later meeting. Now, broader discussion of options appropriate.

LACY: Explanation of "Results of preliminary simulations"

REINER: If hurricanes have devastating result, more knowledge of hurricanes would help define critical levels for action.

SMITH: Feels storms probably have beneficial effect on this deer population.

HUMPHREY: Used deterministic Leslie matrix to model 1970 Key deer date; current levels of pop. within realm of modelling results.

SILVY: Modelled Key deer pop. data from 1974 backwards, included hurricanes; model fit historical data.

Don't have to model density dependent effects.

SILVY: Deer in captivity would breed to excess; what then?

SALISBURY: Employ active breeding management to control pop; example: contraceptive implants.

FOLK: Research Needs for Key Deer

Population and demographics

1. Accurate census data
2. Status of population
3. Structure of population
4. Density dependent reproduction
5. Movements and dispersal especially on outer islands
6. Relocation impacts
7. Statistical analysis of road kill data

Ecological, environmental, and habitat

1. Impact of deer on habitat (K)
2. Effects of habitat manipulations (on K, use, health) on deer
    a. prescribed burning, mowing, other manipulations
    b. supplying water
3. Effects of habitat fragmentation
    a. Effective corridor (safe movement, safe crossings, fences
    b. Interspersion of habitat types
4. Use of remote and outlying islands?
    a. Limiting factors on those keys
    b. importance to deer
5. Effect of hurricanes and other catastrophes on deer

Physiological

1. Baseline data
2. Reproductive output; effect of ganging
3. Evaluation of health
    a. Parasitology

    - b. Condition indices
- 4. Nutritional aspects
    - a. food
    - b. water
    - c. trace elements
- 5. Salinity tolerances
- 6. Metabolic requirements
- 7. Current food study
- 8. Effects of plant compounds on deer.

Human/Deer Interaction

1. Effects of feeding
2. Effects of ganging
    - a. behavior
    - b. physiology -- stress effects
    - c. social structure
3. Effects of dogs
    - a. predation
    - b. harassment effects
4. People perceptions and attitudes

Genetic and Taxonomic

1. Taxonomy
    - a. molecular differences
    - b. morphologic differences
    - c. metabolic differences
2. Inbreeding effects
3. Viability of population
4. Variability
    - a. molecular
    - b. genetic
    - c. morphologic
    - d. physiological

Most of these questions could be addressed with a very intensive radio telemetry, mark/observation study designed to answer many of these points simultaneously.

SEAL: Incorporation of many questions with thoughtful research proposals; overwhelming list if viewed as separate studies.

HUMPHREY: Movement corridors: 3 reasons

1. genetic flow and population mixing as argument probably not defensible.
2. demographic
3. reducing or preventing road mortalities.

LANDE: Effects of buying land along road?

HUMPHREY: In cities, areas of high human population lack of corridors, roads become corridor. Useful also when working with DOT for over- and underpasses.

WILMERS: Has had history of working with this issue; agrees that this issue has become genetic. Buying the land provides for the option if pop. becomes divided.

REINERS: Approaches question of fragmentation of habitat; habitat less valuable as access is limited or cut off.

NETTLES: Corridor would reduce mortality, with effect on genetics in the long run.

HUMPHREY: Underpass costs: $100,000 each. 10 feet high, width variable as long as not too narrow.

HOLLE: Underpass costs will probably require separately appropriated funds.

LANDE: Movement of road a possibility.

SILVY: What happens to models if road kills eliminated from mortality? Population would skyrocket because virtually no controls on growth since most mortality by road kills. Disease would more likely become pop. growth factor.

NETTLES: Advantage of controls as hunting as population control; have ability to change parameters as need dictates.

SEAL: Population at carrying capacity; road kills pop. control factor.

SILVY: Road kill mortality is density dependent.

FLEMMING: Road traffic increasing on all roads; corridors would only affect US 1.

SILVY: $15,000/mile cost for fencing. Fencing all Refuge area would reduce pop.

WILMERS: Example of browse line at Munson Island. Agrees that mortality protecting habitat. Other controlling mechanisms will enter.

HOLLE: Wouldn't animals disperse to unoccupied islands?

SILVY: Other factors why those islands not occupied. Records of deer swimming from Big Pine to ....in periods of high density.

SMITH: Don't know if road kills compensatory mechanism. Data based on temperate species. Don't think pop. would explode; other density factors will intervene.

HUMPHREY: Unless no corridors, pop. implosion. If corridors, pop. explosion will occur.

LANDE: Road kill mortality and pop. density. If density dependent, affects pop. Easier to get below carrying capacity when any level.

SILVY: Faulty argument. Fence deer in, no road kill mortality; density control factors will intervene.

SEAL: Good, increasingly sophisticated arguments.

LANDE: Can't compare changing road mortality to fencing situation.

SILVY: High densities causing deer to disperse to the south and becoming road kills. Fencing would prevent movement to south.

HUMPHREY: Range effect.

LANDE: If pop. doubled would road kills double?

SILVY: No.

HOLLE: Animals in residential areas increasing & animals increasing.

SILVY: All production in northern part, little in south. Dispersing from production center.

HOLLE: Road mortality has been relatively constant in last 20 years. Could afford to lose that pop. because of less restrictions on habitat. Can't afford that loss now.

LACY: Two weeks of computer running time for computer simulations.

SALISBURY:

Significance of Captive Key Deer Herd in Florida.

1. Increase genetic variability and numerical status of total population.

2. Create a second population less vulnerable to natural catastrophe.

3. Use captive herd to conduct scientific inquiries related to wild population management.
    a. Establish growth, reproductive, dietary, and medical standards.
    b. Review relationship of basal rate and thermal conductance to environmental adaption in non-invasive experiments in conjunction with U. of FL.
    c. Establish baseline captive management protocols necessary for future captive breeding and possible crisis management.
    d. Test and access captive founders for inbreeding depression.

4. A further function of captive herd relates to environmental education of 1/2 to 3/4 million zoo visitors per annum and about 50.000 school children, as part of a zoo-based environmental education program active in 7 activities and including 1600 teachers to date in grades K-7.

HUMPHREY: Corridor Plan

The highest priority of this plan is to maintain the largest deer population the habitat will sustain. The most direct approach is to protect existing habitat and maintain or promote its value to the deer. Movement corridors through urban/suburban areas are essential to the goal of maintaining a population of zoo deer.
Recommend 2 north-south corridors across US 1, between refuge lands on northern and southern Big Pine Key. Will consist of deer habitat in the corridors, 10' x 100' underpasses at grade level under US 1, fencing of habitat edge parallel to US 1. Vehicles and local traffic will be accommodated by bridges over the underpasses and frontage roads. Cost estimate per corridor: $1 million for an underpass and $2 million for right-of-way and habitat acquisition.

Will accomplish:
1. Prevent loss of existing habitat and hence reduction of existing deer population.

2. Permit continued movement of deer produced on north Big Pine Key to populate other areas in favorable years.

3. Prevent repair costs, injuries, and deaths to humans from vehicle-deer collisions.

4. Decrease road mortality of deer.

This same approach may became necessary on northern Big Pine Key.

MEETING CLOSED AT 1500.

Chapter 19

FLORIDA KEYS

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ENVIRONMENT

Key deer, smallest of the North American white-tailed deer, occupy islands south of Miami, Florida, from Little Pine Key to Sugarloaf Key (Figure 83). Big Pine Key, the historic center of the population, is 3.3 kilometers (2.0 miles) wide and 13.3 kilometers (8.3 miles) long, and includes about 2,400 hectares (6,000 acres) of land. The maximum elevation is 3 meters (10 feet). The distance from Big Pine to adjacent islands ranges from 0.1 to 6.4 kilometers (0.06–4.0 miles). These islands range in size from about 8 to 1,200 hectares (20–2,965 acres), and show evidence of Key deer activity.

The Florida Keys have two types of surface rock, as a result of two Pleistocene age formations (Hoffmeister and Multer 1968). Most of the lower Keys are composed of exposed oölitic Miami Limestone. This formation has a laminated crust broken into plates in many places by tree roots. Key Largo Limestone, an elevated coral-reef rock, comprises most of the upper Keys (Hoffmeister and Multer 1968). Much of Big Pine Key is oölitic in nature; only the southeast point is Key Largo Limestone. Soils vary from a blue-gray marl to a black peaty muck (Dickson 1955). From 61 to 76 centimeters (24–30 inches) of humus-rich soils occur in older hammocks and buttonwood parks, while pinewoods have little or no soil.

Vegetation of the Florida Keys is of West Indian origin (Stern and Brizicky 1957). Plants with high salt tolerance, such as red mangrove, occur at the fringe of islands and in low-lying areas. Plants with low salt tolerance, such as hammock and pineland vegetation, occur only at higher elevations. Much of the vegetation on Big Pine and adjacent islands reflects the heavy influence of fires, farming and land clearing by early residents. In the absence of fire, plant succession is from pinelands to hammocks.

Dickson (1955) recognized nine plant communities on Big Pine Key: pineland; hammock; southeast point hammock; regrowth burned pineland; land previously cultivated; grass prairie; transition zones; open scrub-type mangrove/prairie; and beach dune communities. Yaw (1966) considered only mangrove thicket, open scrub, button-mangrove park, open-mixed hardwood, hammock and pinewoods. Silvy (1975) combined the open scrub and button-mangrove park, but recognized open developed areas as an additional type. Dense red mangrove thickets that fringed many islands have been replaced by residential developments following canal dredging which yielded marl for filling these low areas.

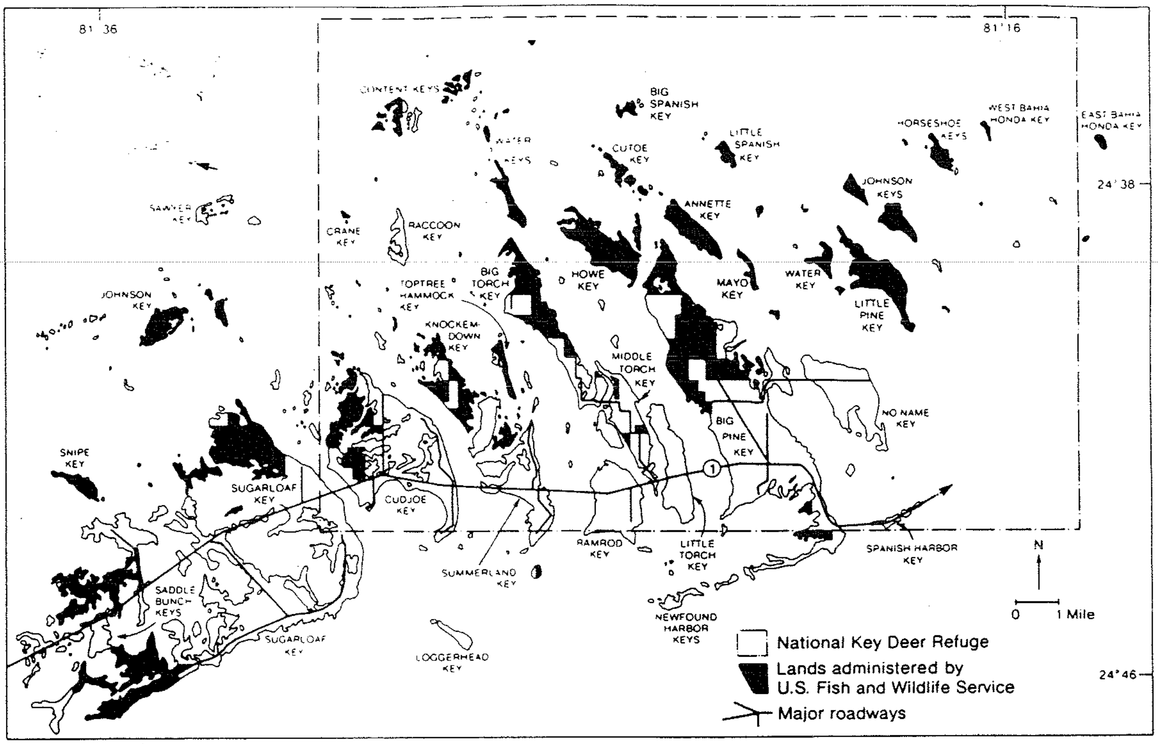
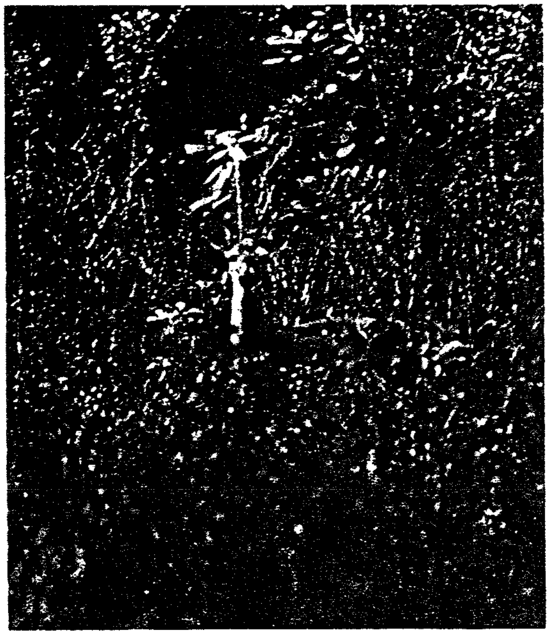
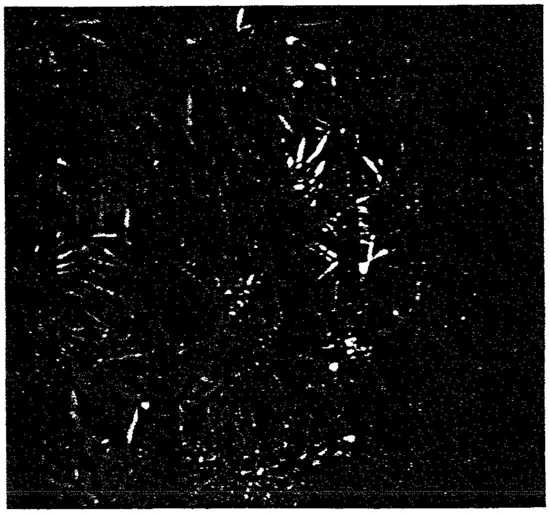


Figure 83. Islands of the Florida Keys within the range of Key deer.



Stands of white indigo berry and saffron plum are excellent sources of food for Key deer. They are extensively utilized on Big Pine Key where these plants invaded areas when agricultural practices ceased in the late 1930s and early 1940s. *Photo courtesy of the Southern Illinois Cooperative Wildlife Research Laboratory.*



Stands of slash pine are limited to a few Keys; the largest of such acreage occurs on Big Pine Key. These stands are important because they afford Key deer a variety of useful plant foods. Also, their many depressions with palmetto provide shelter for fawns, and the extensive and widely-dispersed silver and Key thatch palms serve as both food and cover. The highest populations of Key deer are associated with Keys with pine stands that, when subject to controlled burns, yield significant increases in high-quality deer foods. *Photo courtesy of the Southern Illinois University Cooperative Wildlife Research Laboratory.*

The mean maximum temperature is 27.8 degrees Celsius (82 degrees Fahrenheit). Mean monthly highs range from 24.1 to 31.5 degrees Celsius (75.4–88.7 degrees Fahrenheit) and lows from 18.4 to 25.6 degrees Celsius (65.1–78.1 degrees Fahrenheit). Annual rainfall varies among the islands, but is approximately 102 centimeters (40 inches) at Key West (Dickson 1955). The monthly average from December to March is 4.47 centimeters (1.76 inches).

Land use varies from intensive commercial and residential development along U.S. Highway 1 (Big Pine, Little Torch, Ramrod, West Summerland, Cudjoe and Sugarloaf), to moderate development on Keys with secondary country roads (No Name, Middle Torch and Big Torch), to little or no development on remote islands accessible only by water (Little Pine and Johnson). Approximately 424 hectares (1,050 acres) or 17.6 percent of Big Pine Key were in housing subdivisions in 1969, with 96 kilometers (60 miles) of roads, 27 kilometers (17 miles) of firelanes, more than 160 kilometers (100 miles) of mosquito ditches, and 29 kilometers (18 miles) of canals (Klimstra et al. 1974). During the period 1968–1973, 46 hectares (114 acres) of land were cleared annually, in contrast to 32 hectares (80 acres) each year during the period 1979–1982. Similar rates of development occurred on several other islands within the Key deer range.

Clearings in subdivisions and along roadways have increased diversity, created areas of abundant browse adjacent to cover and temporarily increased localized carrying capacity for the deer. However, completion of developments generally results in a sudden loss of habitat. The accompanying increase in human activity and traffic can be presumed to increase the risk of deer accidents on highways—a continuing major source of mortality, as is an increase in poaching and losses to predation by dogs.

WHITETAIL POPULATION

Earliest mention of the Key deer is found in the memoirs of Escalante Fontaneda (1575), a Spaniard who was held captive by Indians. Later references suggest that deer were abundant as far as Key West, and were used as food by residents and crews from passing ships (Romans 1775, Mathews 1908, Maynard 1987, de Pourtales 1877).

Unfortunately, the published record provides little reliable information on population levels and distribution of this deer in the lower Keys. However, one can presume that where there were mature forested lands—which seemingly was the case for much of the Keys except the marl prairie, scrub mangrove and mangrove border portions of at least the larger land masses—carrying capacity for deer probably was low, especially so for such a diminutive animal. Storms, in particular hurricanes, probably released segments of this dominating vegetation, creating successional stages that improved food availability. With the development of human populations in the mid- to late-1800s (and associated farming activities), clearing and harvest of the wooded areas surely enhanced habitat, and the response was an increase in deer numbers. This evolved people/deer setting surely resulted in Key deer being viewed as a pest, and also encouraged expanded use of it for food. The intensity of this interaction probably began in the late 1800s and the very early 1900s, reaching annihilation levels by the early 1930s. The banning of hunting in 1939 by the Florida legislature was ineffective, as there was little if any effort at enforcement. Hunting continued, with dogs used and Keys burned to drive deer into the open for easy harvesting. Although various factors—especially the 1934 Ding Darling cartoon captioned "The Last of the 'Toy' Deer of the Florida Keys"—contributed to this ban on hunting, residents of the Keys resisted or ignored all efforts to relieve the plight of the Key deer. Hence, by the 1950s it was suggested that the population was as low as 25 deer, but this likely was a poor if not highly erroneous estimation. Official action occurred around 1950, when an effort was made to introduce legislation to establish a Key Deer National Wildlife Refuge. Also during that year a protection plan was developed by the Boone and Crockett Club. And in 1951, Jack C. Watson, who had devoted nearly 25 years of his life to the deer, was employed and endowed with both state and federal enforcement authority. That same year Florida established a Federal Aid Project and hired John Dickson to study the Key deer. These initial actions, largely from private interests and groups encouraged by C. R. "Pink" Gutermuth, yielded the foundation and dollars for land acquisition, leasing, and legislation to establish protection of the Key deer and its shrinking habitat.

Shortly after assuming office as chief of the U.S. Bureau of Biological Survey (predecessor of the U.S. Fish and Wildlife Service), cartoonist and conservationist Jay N. "Ding" Darling made an extensive search of the nation's wetlands with an eye toward establishing refuges, principally for the benefit of waterfowl. Cruising in a commercial fishing launch past mangrove thickets of the Florida Keys in 1934, Darling observed an uninhabited islet charred and still smouldering from the effects of a recent fire. He learned that the devastation was caused by Cuban fishermen who frequently visited the Keys to obtain meat. They commonly set fire to island vegetation to drive deer into the water where the animals were shot or clubbed. Stunned and horrified at the callous lawlessness of the activity and the wanton destruction that resulted, Ding then and there drew a caricature of the incident. Entitled "The Last of the 'Toy' Deer of the Florida Keys," the cartoon ". . . played an important part in whipping up support for a bill calling for a federal Key deer refuge" (Lendt 1979:130, *see also* Trefethen 1975). *Photo courtesy of the Jay N. Darling Collection, Special Collections Department, University of Iowa Libraries.*

In 1957 a 2,400-hectare (5,930-acre) Key deer refuge was established, including parcels of land on islands between Cudjoe and Little Pine Key, through efforts of the Boone and Crockett Club, Wildlife Management Institute, North American Wildlife Foundation and U.S. Fish and Wildlife Service. The Key deer was placed on the federal list of endangered species on March 11, 1967. However, Florida identifies it as threatened (Hendry et al. 1982).

In 1974 there were an estimated 200 to 250 deer on Big Pine Key and evidence of 100 to 150 deer on 22 other islands (Klimstra et al. 1974). Although there is some consensus to the effect that population stability occurs at these levels, our appraisal of 1982 suggests that a decline has occurred. However, in the absence of current research data, such a decline cannot be documented.

A study made from 1968 to 1973 revealed an apparent increase in the adult component of the population and a decrease in fawns, suggesting a low rate of increment (Hardin 1974). Male fetuses outnumbered females 1.75:1.00, and newborn male fawns outnumbered females 2:1. Older fawns were captured at a rate of 2.7 males to 1.0 female. The continuation of such statistics in the population must be presumed to be biologically negative.

The body size (weight and height) of Key deer is extremely variable, suggesting a genetic impact that yields subpopulations in the evolution of island inhabitants. The maxima in Key deer measurements show a very limited overlap with those of deer of the Florida Everglades; generally, Key deer measurements tend to be less. Barbour and Allen (1922) believed the Key deer to be a legitimate subspecies and the smallest white-tailed deer in the United States. Dickson (1955) shared this opinion, and our findings yield considerable data that strongly support the morphological distinctiveness of the race *clavium* in contrast to *osceola* and *virginianus* of the Florida mainland.

At birth Key deer fawns weigh 1 to 2 kilograms (2.2–4.5 pounds), with a mean of 1.7 kilograms (3.8 pounds). Males attain 40.3 percent of average maximum total weight during the first 12 months; in the same period, females attain 33.3 percent of average maximum total weight. The average weight of males is 19.1 kilograms (42.5 pounds) at one year, 26.9 kilograms (59.7 pounds) at two years and 35.9 kilograms (79.8 pounds) for all three years or older. Does show average weights of 16.7 kilograms (37.0 pounds) at one year, 24.7 kilograms (54.9 pounds) at two years and 28.4 kilograms (63.2 pounds) for all three years or older; maximum weight is reached at four to five years, whereas bucks continue weight gain until impacted by old age problems. Height at the shoulder for animals more than two years ranged from 43.18 to 82.55 centimeters (17–32.5 inches)—with a mean of 62.54 centimeters (26.98 inches)—for bucks, and 31.75 to 74.95 centimeters (12.5–29.5 inches)—with a mean of 64.87 centimeters (25.54 inches)—for does.

Based on weights of animals, fat deposits, and the absence of parasites and diseases, it appeared that Key deer were in good condition. However, they had a low rate of reproduction. Based on examination of 35 carcasses of does two years old or older, 31 were reproductively active, 19 had single fawns, 7 had twins and 5 were lactating, indicating at least 1 fawn. Only three two-year-old does bred as yearlings. Our studies during September 1969 through December 1972 suggested that 71 percent of 117 marked does of reproductive age had fawns. The data indicate a 20-percent mortality between preparturition and four to six months of age.

The physical stature of Key deer is distinctively small, but maxima overlap those of whitetails of the Florida Everglades. Generally, legs of Key deer are shorter, and the body and head are "blockier." Adult shoulder height averages 68 centimeters (26.8 inches), with a range of 32 to 83 centimeters (12.6–32.7 inches). *Photo courtesy of the Southern Illinois University Cooperative Wildlife Research Laboratory.*

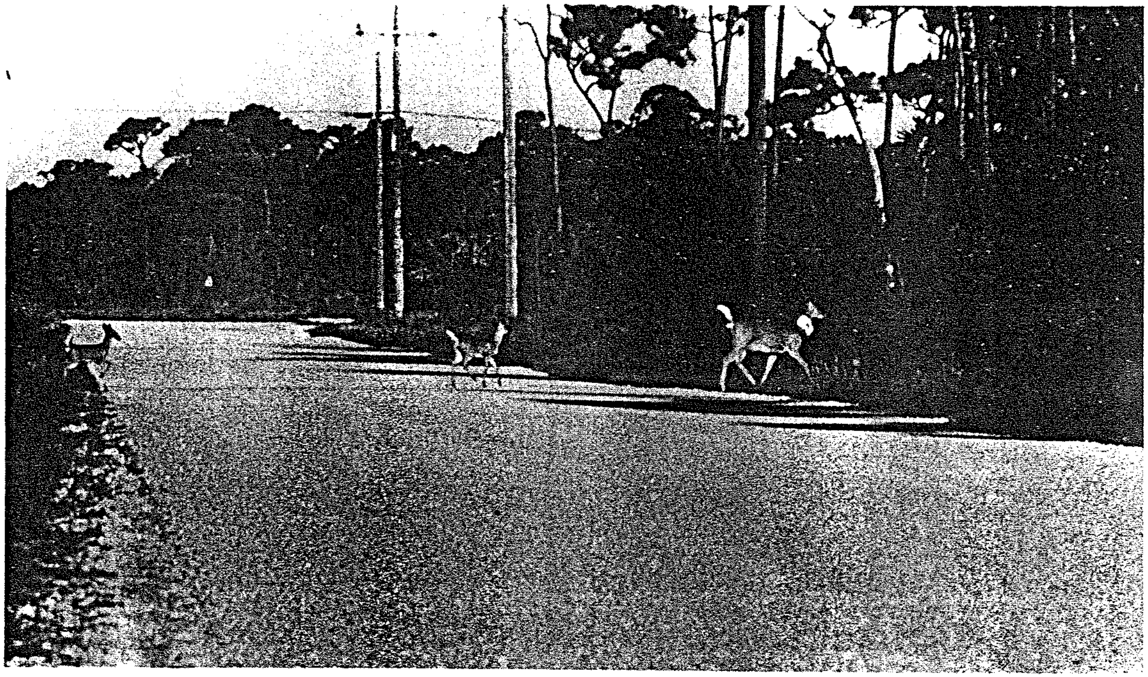
There is substantial mortality of Key deer even though there is no legal hunting, nor any natural terrestrial predators. It is thought that the rate of loss from year to year probably is quite variable, fluctuating sharply in response to drought, violent storms, seasonal patterns of human activity and deer behavior. From 1968 through 1973, 304 deaths were recorded on 10 different islands. A computer simulation using mortality and natality data gathered during that period suggested a net increase of 8 percent in the population per year, as expected if the level was 50 animals in 1949 and had increased to 350 by mid-1970s (Silvy 1975). From 1968 through 1980, highway mortalities show annual variation from 36 to 74 and have totalled 627 animals, with 85 to 90 percent occurring on Big Pine Key. During the period 1968–1973, traffic losses represented 76 percent of all recorded mortality. Since that time, however, there have been very significant increases in the free-running dog population and the probability of poaching.

Drought may have contributed to mortality by causing deer to shift to areas where they were more vulnerable to automobiles. Six skeletons were found near dry waterholes on outer islands during the severe drought of 1970 and 1971. Others may have drowned while swimming between Keys in the shark-infested channels, many of which have hazardous currents.

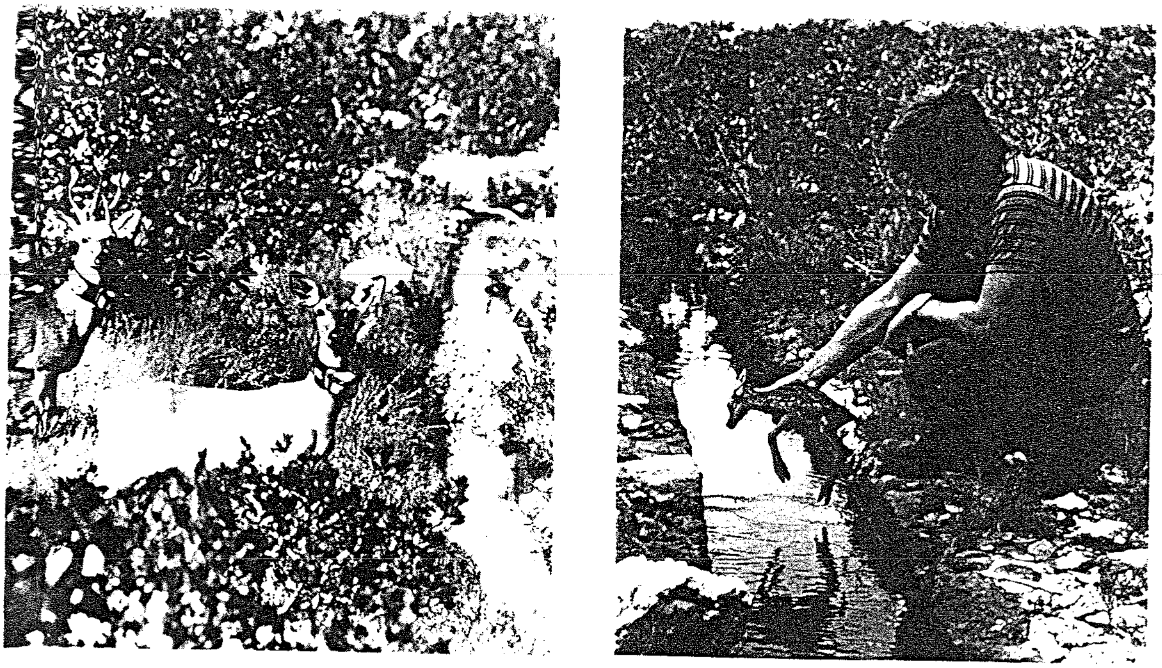
Big Pine Key has more than 161 kilometers (100 miles) of ditches connecting basins of standing water to the saltwater of Florida Bay, and these are a major cause of fawn mortality. From 1970 to 1973, 6 of 33 marked newborn fawns and 5 unmarked fawns drowned in these ditches. Many of the ditches flush daily with the tides, and fawns falling into them cannot escape and are likely to be carried into the Bay.

Key deer utilize a wide variety of plants and habitat types. Virtually no plant species is immune to deer use at one time or another. Red mangrove, black mangrove, apes-earring, Indian mulberry, Florida silverpalm, brittle thatch palm and pencilflower are some of the most heavily eaten species (Dooley 1974). New growth of browse and herbaceous species are heavily grazed after fire; grazing declines sharply six to nine months after fire.

The availability of early succession plants for limited periods and the movements and feeding of deer are influenced by land-use activities such as mosquito ditching, clearing, roadway and right-of-way management, subdivision development and fire trails.



The greatest cause of recorded mortality among Key deer is collision with vehicles on U.S. Highway 1 and state roads on several Keys (*See* Figure 83). Annual losses vary considerably and do not appear to mirror speculated deer population levels or traffic patterns. *Photo courtesy of the Southern Illinois University Cooperative Wildlife Research Laboratory.*



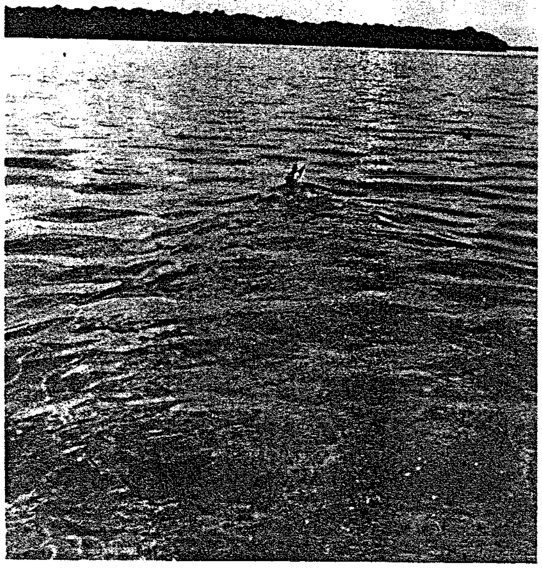
Mortality of Key deer fawns drowning in mosquito ditches on Big Pine Key—which has more than 161 kilometers (100 miles) of such ditches—is believed to be significant when fawns are less than two to three weeks old. At this age, the fawns cannot jump the 35–40-centimeter (14–16-inch) wide, steep-sided, water-filled ditches, and once having fallen in, are unable to escape. The same is true for an occasional adult. *Photos courtesy of the Southern Illinois University Cooperative Wildlife Research Laboratory.*

The several types of palms on Big Pine and Little Pine Keys provide an important source of food for Key deer; flower stalks, fruits and new frond shoots are heavily used. Such a food source as provided by silver and Key thatch palms becomes unavailable as the palms increase in height; only the palmetto remains continuously available. *Photo courtesy of the Southern Illinois University Cooperative Wildlife Research Laboratory.*

Red, white and black mangroves constitute major portions of deer habitat in the Florida Keys and, in some cases, cover entire islands. They are valuable sources of food and cover for Key deer. Fruits of white and black mangroves are especially important food of the deer, as are leaves, fruit and flowers of red mangroves; their nutritional levels are roughly equivalent to that of alfalfa. *Photo courtesy of the Southern Illinois University Cooperative Wildlife Research Laboratory.*

SPECIAL PROBLEMS AND CONSTRAINTS

Availability of fresh water for drinking does not appear to be a primary limiting factor for deer on Big Pine Key, but it may limit year-round utilization of the outer Keys. After an extremely dry winter in 1971, two deer skeletons on Howe Key and one on Big Johnson Key were found near dry or saline waterholes, indicating that the deer were victims of drought. During this same period, a radio-tagged doe with a fawn on Porpoise Key—an island lacking fresh water—made daily trips to Big Pine Key where she watered and fed. Immediately after the rains, she remained on Porpoise Key. On Big Pine Key, many deer shifted to areas having fresh water during the drought. Even where water is available, it may exceed the 1.5 percent salt-tolerance level that appears to be critical for livestock (Pierce 1957, 1959, Weeth and Haverland 1961).



The phenomenon of Key deer swimming between islands has been recorded on many occasions and is believed to be important in the distribution of deer among the lower Florida Keys. This adult doe was captured swimming between Big Pine and Porpoise Keys. She was radio-collared and subsequently recorded as swimming a roundtrip every 24 hours to accommodate a fawn on Porpoise Key, while feeding and probably obtaining fresh water on Big Pine Key. *Photo courtesy of the Southern Illinois University Cooperative Wildlife Research Laboratory.*

In certain areas, browse and selected plant species are "pressured," but there is no evidence that current food quantity and quality are limiting factors. The mean energy value of 25 plants important in the diet of Key deer was 4,534 calories per gram (Klimstra et al. 1974). This is equivalent in energy to various commercial animal feeds.

As previously indicated, there are no native terrestrial predators of the Key deer. Dogs and alligators have been seen feeding on deer, but this probably represents scavenging. However, there has been a significant increase in recent years of free-roaming dogs, and kills of deer by dogs are being reported.

There is no evidence of disease-related mortality, although some deer have fibromas growing on their skin. Key deer are relatively free of ectoparasites except ticks, mosquitoes and deer flies. At times, deer will move to open areas or to shallow water in mangroves in order to escape mosquitoes. Three genera of nematodes, one trematode and a protozoan have been recorded in fecal samples of Key deer, but there was no indication that these intestinal parasites produced pathogenic effects (Schulte et al. 1976).

There is little adverse interaction between Key deer and other native fauna, except perhaps the raccoon, which may compete for fruits and water.

As a result of policy of the U.S. Fish and Wildlife Service concerning endangered species, the Florida Key Deer Recovery Plan was developed and approved in 1980 (Klimstra et al. 1980). Only limited segments of recommendations are being implemented due to budgetary constraints. Emphasized in the Recovery Plan are matters that reflect administration, land acquisition, management, monitoring, education and experimentation in research. It was noted that, administratively, there should be enforced prohibitions to protect habitat and the deer population; inviolate areas need be designated and appropriately identified; and there should be control of visitor access and reduced speed limits and posting of warning signs. Land acquisition is of urgency so as to secure quality habitat before further development occurs and to consolidate public holdings to reduce people-related problems. The management objectives included the employment of an experienced biologist who could continuously examine and interpret monitoring data and adjust management as required.

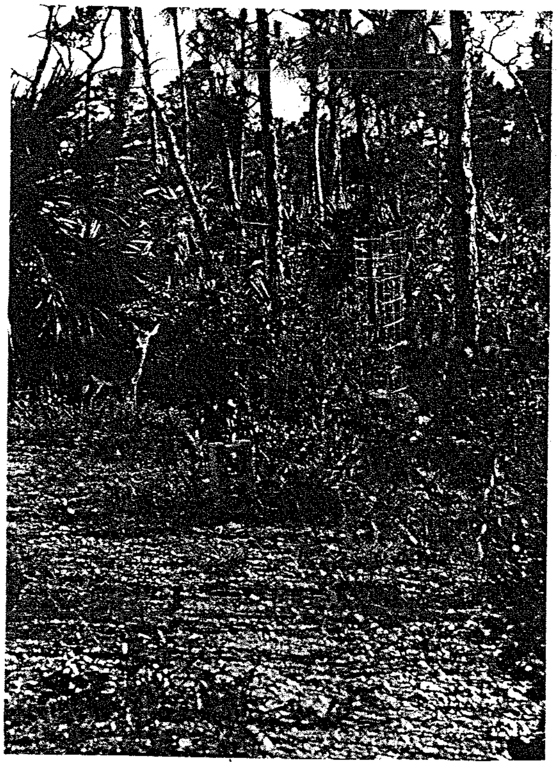
Also, it was strongly recommended that deer be removed and translocated selectively, especially when and where problems occur, to restock appropriate, currently unpopulated Keys; to clean out, develop and maintain freshwater basins; to develop and maintain fire trails; to prescribe burn to ensure continuity of the pine/palm habitats; and to fill mosquito ditches on lands under jurisdiction of the Key Deer National Wildlife Refuge. To accommodate continuity of important biological data gathering, a monitoring program was recommended. It would include regular road censuses, continued routine inspection of outer islands for evidence of deer utilization, continuous monitoring of freshwater supplies, autopsy of all mortalities, development of vegetational exclosures and evaluation of deer impact on important food supplies, continuation of marking animals to develop and maintain a cohort of marked known-aged animals, and monitoring the patterns of highway crossing by deer. An educational program was recommended to develop and provide informational materials to residents and tourists, to build and staff a visitors' center, and to hire an information specialist who could provide advice and expertise.

Because the Key deer has been researched for such a short period of time and because of rather distinctive problems associated with this insular subspecies, it is appropriate that there be continuing experimentation and research in an effort to respond better to requirements for the protection of this unique animal and its habitat. Suggestions include fencing around the Port Pine Heights subdivision in an effort to restrict people/deer interactions, manipulating the habitat of the Little Pine Key complex to ensure its capability to support possibly the last really isolated population, and conducting a variety of additional studies on the natural history and population dynamics of the Key deer population. Since this deer is a product of evolution in an island setting, and because it probably still is not completely genetically isolated from those animals on the mainland from which it originated, every effort must be made to ensure its integrity. It is likely that only those deer semi-isolated on outlying Keys may still be subjected to the pressures of natural selection characteristic of the Keys. This process must be optimized, and under no circumstances must Key deer maintained in zoological gardens be considered as a reserve for restocking Key deer ranges either now or in the future.

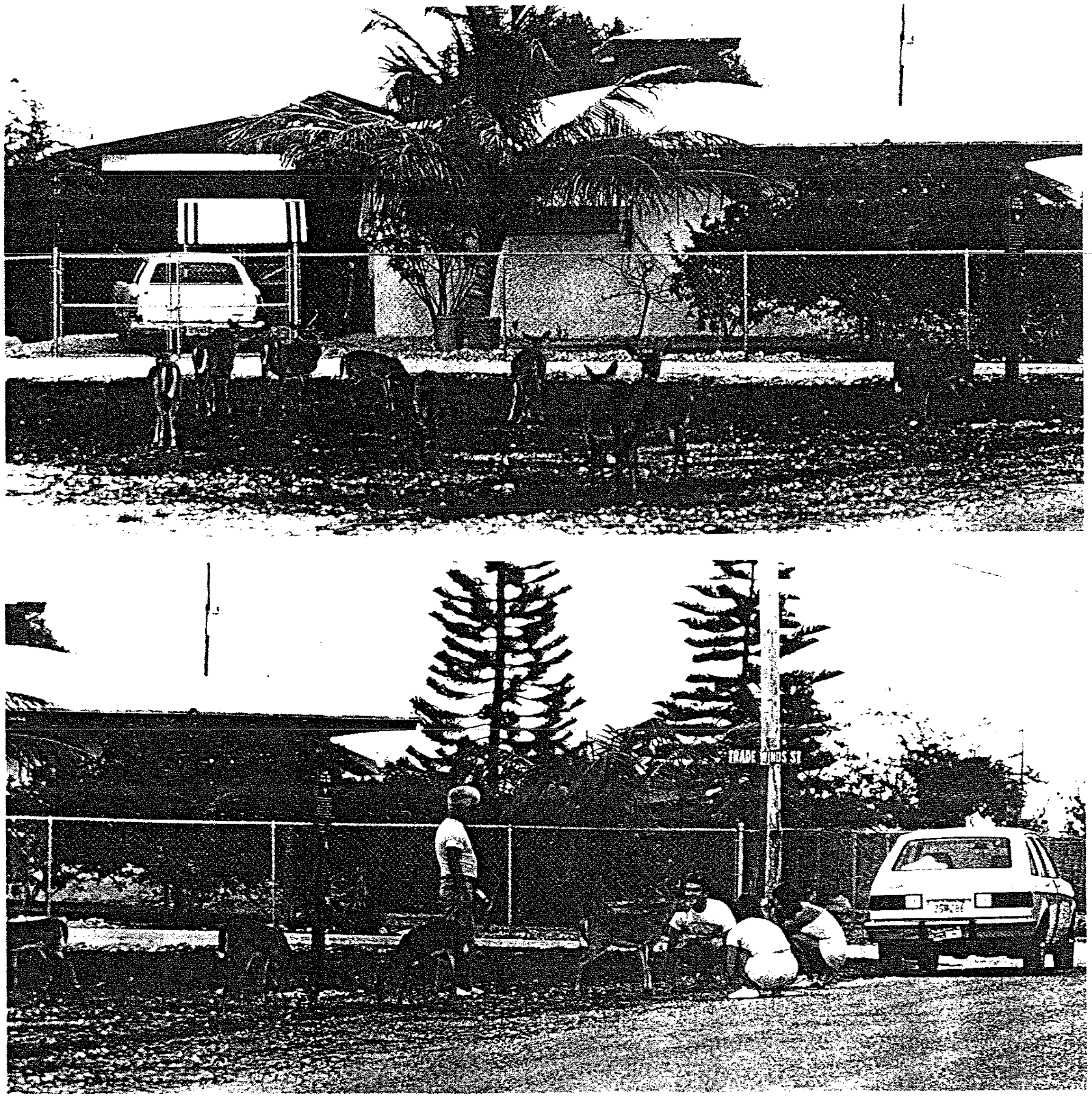
OUTLOOK

The greatest obstacle to Key deer is human use of land for residential and commercial enterprises. And since the number of tourists and the resident human population are likely to increase, the deer and their habitat undoubtedly will decrease except in specific areas set aside for them. Also, the negative impact of increased dog harassment and probable kills and human feeding of the deer cannot be overemphasized.

Key deer have been a food source, an oddity of nature and a tourist attraction. In the past, most residents strongly supported the creation and maintenance of a refuge to protect the deer. But in recent years, attitudes have changed. Many now view the deer as a nuisance because they feed on cultivated and ornamental plants,



Damage by Key deer feeding on shrubbery and citrus trees in backyards is extensive on Big Pine Key and requires either complete fencing of yards or isolation of selected shrubs with cylinders of wire for protection. *Photo courtesy of the Southern Illinois University Cooperative Wildlife Research Laboratory.*



Since 1976, an increasing problem for Key deer is people befriending the deer on Big Pine and No Name Keys. Besides tourists offering food to the wildlife, some permanent residents have enticed large numbers of deer to front and backyards by providing feed. Recent Florida legislation to make feeding deer a misdemeanor may aid in reducing this problem. *Photos courtesy of the Southern Illinois University Cooperative Wildlife Research Laboratory.*

cause property loss as a result of collisions with vehicles and present a hazard to human life on heavily traveled roadways. As Key deer become associated more closely with people due to expanded development, there will be decreasing interest in saving the deer. Also, the public tends to resist restrictions on private land or access areas to accommodate deer.

There is no room for complacency regarding this diminutive subspecies of white-tailed deer. Its future clearly is threatened by human activity. Management steps must be taken to (1) provide optimum habitat on refuge lands, (2) acquire quality Keys (such as No Name), (3) continue study of Key deer population levels, mortality and habitat utilization, and (4) accommodate the deer more appropriately on private land. Without question, there must be concern that the predicted increase in competition for land use (Smith et al. 1970) likely will reduce the Key deer population, possibly to its precarious status of the 1950s.

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THE KEY DEER POPULATION IS DECLINING[1]

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Intense hunting pressure and changes in habitat reduced the once-abundant Florida Key deer (*Odocoileus virginianus clavium*) to historic lows of about 26 in 1945 (U.S. Fish and Wildl. Serv. 1985), 57 in 1952 (Allen 1952), and 25–80 in 1951–1952 (Dickson 1955). Responses to this problem were a ban on hunting (seldom enforced) by the State of Florida in 1939, establishment of the National Key Deer Wildlife Refuge (NKDWR) in 1957, desig-

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nation as an endangered species in 1967, and protection under the Endangered Species Act in 1973. With hunting eliminated and some habitat preserved, the population grew to an estimated 350–400 individuals by 1974 (Silvy 1975, Klimstra et al. 1978).

Subsequent qualitative judgment (Hardin et al. 1984) indicated a reduction to 250–300 animals by 1982, attributed to habitat loss and mortality associated with rapid urban and suburban development of the Lower Keys (U.S. Fish and Wildl. Serv. 1985). This possible decline raises the question of whether the existing conservation program is adequate. An immediate need is corroboration of the population trend. The purpose of this paper was to evaluate counts along transects by NKDWR staff to discern whether a decline has occurred.

METHODS

Spotlight counts were conducted once a month along road transects on Big Pine and No Name keys from July 1968 through 1984. The counts on Big Pine from 1968 to 1972 were made by Silvy (1975), beginning at 2230 hours, along 16 km of roads on and adjoining NKDWR. Both Hardin (1974) and Silvy (1975) made procedural suggestions based on their experience. No counts were made from 1973 to 1975. More extensive transect routes were established by NKDWR staff in 1976, covering representative roads throughout each island. In 1980 the routes were shortened. The 56-km Big Pine route was reduced to 32 km, and the 5-km No Name route was reduced to 3 km. After the routes were shortened, counts were begun at 2000 or 2100 hours and typically spanned 3 hours. Silvy (1975) concluded that all-island and NKDWR counts should not be compared, because the latter yielded higher counts. Therefore, trend analysis was appropriate only for data from 1976 to 1984.

Data on deer mortality were recorded continuously during the study in association with research, management, and law-enforcement activities. Dead animals were located by direct sightings, reports from citizens, or observation of turkey vultures (*Cathartes aura*). Deaths from miscellaneous causes (dogs, poaching, drowning, unknown) were not easily detected, but probably most animals killed on roads were detected, because their locations coincided with the travels of NKDWR staff and because flocks of vultures were highly visible.

Data on total annual rainfall were recorded by NKDWR staff on Big Pine Key. Rainfall is clinal in the Florida Keys, averaging 1,270 mm/year on Key Biscayne and 890 mm/year on Key West (Thomas 1974). Rainfall on Big Pine Key varies seasonally, averaging from 25 to 50 mm/month from December to March, 100 to 125 mm from May to June, and 150 to 175 mm in September.

Counts were expressed as average number of animals/1.61 km and averaged for each calendar year. Because the major procedural changes in 1976 set sample size at 9 years, all statistical tests were interpreted as significant at beta = 0.2. The purpose of this liberal criterion was to avoid making a Type II error under the null hypothesis of no population trend. We preferred to accept the alternate hypothesis that a trend existed rather than recommend no action when conservation would be appropriate.

Statistical analysis was done with the Statistical Analysis System (SAS Inst. Inc. 1982*a,b*) and facilities of the Northeast Regional Data Center on the University of Florida campus. Simple linear regression (PROC REG) was used to describe variation among counts and to test the hypothesis that rainfall affected counts. The hypothesis that population trends occurred was tested with multiple regression treating years and rainfall as covariables. Because our study was done on large islands with permanent water supplies, counts and number of animals killed along roads should covary with rainfall. During drought only the large islands retain lenses of fresh rainwater over the saline groundwater. In response, Key deer (1) swim from small, outlying islands to large, developed ones, (2) move from the periphery of a large island towards its center, and (3) enlarge their home ranges; deer disperse again when droughts cease (Allen 1952, Dickson 1955, Jacobson 1974, Silvy 1975).

We examined the multiple regressions for autocorrelation with the Durbin-Watson *d*-statistic because of the risk that successive values might be correlated. If autocorrelation is present, the test is biased toward the null hypothesis of no trend.

Regression results and limited applicability of the Durbin-Watson *d*-statistic led us to test the trend hypothesis with econometric methods, which avoid the autocorrelation problem. We used first-order time-series analysis (the random-walk model, PROC AUTOREG with NLAG = 1) and with exponential smoothing (PROC FORECAST, specifying a linear trend). A random-walk model assumes that the present is the best predictor of the future, and it predicts each count solely from the previous count, by randomly changing the sign and amount of change. Forecasting extrapolates into the future rather than testing hypotheses, so it makes no significance tests.

RESULTS AND DISCUSSION

Both Big Pine and No Name keys supply water year-round to Key deer (Dickson 1955). Deer counts on Big Pine (B) and No Name

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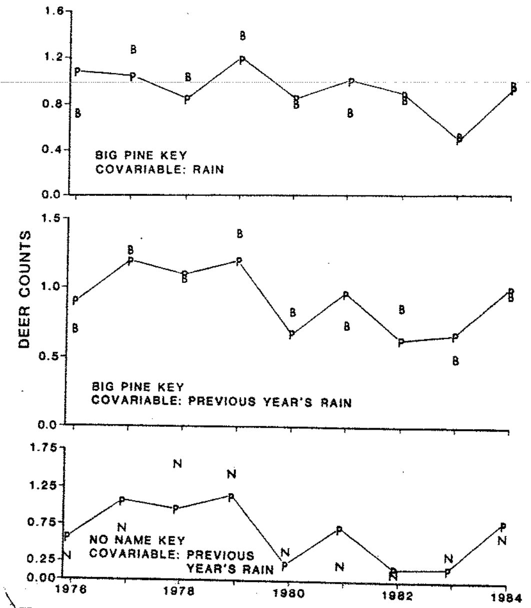

Fig. 1. Trend in counts (deer/1.61 km), accounting for the effect of rainfall. Actual counts are shown as B for Big Pine Key and N for No Name Key. Predicted values (P) were calculated by simple linear regression.

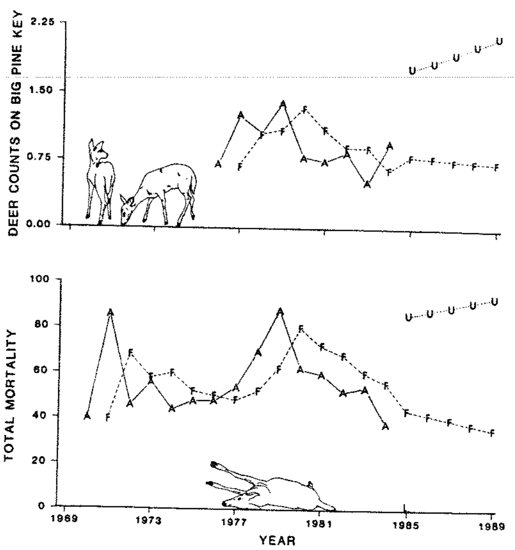

Fig. 2. Average annual counts (deer/1.61 km) on Big Pine Key and total deaths/year, showing actual values (A), forecasted values (F), and 95% confidence limits (U and L for 1985–1989 only).

(N) keys were correlated (B = 0.69 + 0.38N, $r^2 = 0.52$, $F = 7.60$, $P = 0.028$). This result is consistent with the hypothesis that the hydroperiods of their freshwater lenses have similar effects on deer.

Deer counts on the 2 islands differed ($t = 2.37$, $P = 0.045$), with counts on No Name being lower and more variable (0.62 ± 0.54) ($\bar{x}$ ± SD) than on Big Pine (0.92 ± 0.28). Causes of this difference could include a longer average detectability distance of deer on Big Pine, a higher carrying capacity on Big Pine resulting from either (1) higher forage quality or (2) more area or access points supplying freshwater (as stated by Dickson [1955]), or a lower mortality rate on Big Pine. Only the last possibility is inconsistent with available data. No Name Key was extensively cleared by bulldozer in the early 1960s and now is dominated by dense, successional hardwood forest. Where undeveloped, Big Pine Key is a mosaic of pine (*Pinus elliottii*) savanna and tropical hardwood forest (mature and successional). These differences in vegetation result in better visibility and more diverse forage on Big Pine Key.

Deer mortality was correlated with deer counts, considering data pooled from both islands (total mortality, $r^2 = 0.29$, $F = 4.16$, $P = 0.069$; road mortality, $r^2 = 0.20$ $F = 2.55$, $P = 0.141$). This result is consistent with the hypothesis that movement of deer causes concurrent changes in density and mortality.

The effect of rainfall on Big Pine Key for both the current year and the previous year was evaluated with 2 regression analyses. Deer counts declined slightly during 1976 to 1984 (Fig. 1). They were negatively affected by current-year rainfall (Big Pine counts, B = 98.26 − 0.0487Year − 0.0081Rain, $R^2 = 0.48$, $F = 2.74$, $P = 0.143$; No Name counts, $P > 0.2$). Deer counts were positively affected by previous-year rainfall (Big Pine counts, B = 141.19 − 0.0714Year + 0.0103Rain, $R^2 = 0.64$, $F = 5.36$, $P = 0.046$; No Name counts, N = 246.76 − 0.1253Year + 0.0176Rain, $R^2 = 0.53$, $F = 3.40$, $P = 0.103$). Partial correlation values and probability of a greater value of t for

Year for these 3 regressions are, respectively: $r^2 = 0.29$ and $P = 0.292$; $r^2 = 0.52$ and $P = 0.042$; $r^2 = 0.421$ and $P = 0.082$. These analyses indicate that deer densities on the large islands increased during dry years and decreased 1 year later; Jacobson (1974) made the same deduction from a different set of data. Coefficients of first-order autocorrelation (based on the d-statistic, $n = 9$) for the 3 significant regressions were, successively, 0.03, −0.46, and 0.04. Because published tables of significant d-values begin at $n = 15$, these coefficients cannot be interpreted, but caution directs re-evaluation of the apparent trend with econometric methods. No trend appeared in mortality variables.

Random-walk predictions of deer counts provided a fair fit to actual changes in counts (Big Pine counts, $B = 100.76 - 0.0504\text{Year}$, $r^2 = 0.30$, t-ratio $= 0.81$, approximate $P = 0.159$ compared with $B = 79.46 - 0.0397\text{Year}$ calculated by ordinary least squares; No Name counts, $P > 0.2$). These results confirmed the negative trend of the counts. That the current count is more important than previous ones in predicting the future is consistent with the iterative nature of demographic processes.

Validation of the random-walk model led us to use an exponential discount rate of 30% in the forecasting algorithm to project trends >1 year into the future. Forecasts (Fig. 2) showed that both deer counts on Big Pine Key and total mortality should decrease ($m = -0.0120$ and -2.1787, respectively)—similar rates relative to their respective scales. The slope of forecasted counts was similar to but slightly less negative than results of the other analytical methods, suggesting an even higher discount rate as realistic. The combination of rates for counts and deaths leads to a prediction of population decline.

MANAGEMENT IMPLICATIONS

Based on 1969–1973 rates of land-clearing for development on Big Pine Key, Silvy (1975) predicted loss by 1992 of all remaining habitat not already dedicated to conservation. He concluded that the Key deer population inevitably would decrease. Although the rate of development has slowed somewhat since Silvy's study (Hardin et al. 1984), every test of the data on Key deer counts confirms the judgment that the population has declined recently. This fact mandates rapid implementation of the newly revised recovery plan. Additionally, optimal refuge design should be studied, because the NKDWR is fragmented by developing suburbs and may be ineffective as presently configured.

Significance levels used for these tests were lower than desirable, because of low resolution of the count data. An emergency exists when an endangered species is declining, so a better monitoring method should be devised, tested, and implemented. The method should (1) reduce variance by restricting counts to seasons when deer behavior stabilizes the conditions of observation, (2) provide estimates of variance by subdividing the travel route into sections, (3) determine how many repeated runs along transects are needed to produce the desired level of precision, and (4) use the line transect method of Burnham et al. (1980) to calculate density from count data. However, the original counting procedure should overlap the new one for a few years to assure continuity in monitoring the population.

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USE OF REPLICATE COUNTS TO IMPROVE INDICES OF TRENDS IN MANATEE ABUNDANCE

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Direct counts of animal populations usually encounter the problem that not all individuals are observable during a given census (Caughley 1979, Eberhardt et al. 1979). The proportion of animals missed varies greatly among species (Caughley 1974) and within surveys of the same species, depending on many variables associated with census procedures (Caughley et al. 1976).

Replicate surveys have been used to evalu-

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Endangered

KEY DEER

Odocoileus virginianus clavium Barbour and G. M. Allen, 1922

Family Cervidae

Order Artiodactyla

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RR #5 Box 343
Flamingo Lane
Big Pine Key, FL 33043

TAXONOMY: Although Hal of priority to employ Dama for all new world deer, Opinion 581 of the International Commission on Zoological Nomenclature (Bulletin of Zoological Nomenclature 1960) rejected Dama/Zimmerman 1780, making Odocoileus/Rafinesque 1832 available. Because there is uncertainty as to distribution of O. v. osceola and O. v. seminolus (Layne 1974), precise relationship of O. v. clavium to these southern Florida races is uncertain, although Key deer undoubtedly originated from mainland stock. Barbour and G. M. Allen (1922) considered clavium a distinct race based on length of row of molariform teeth whereas Klimstra et al. (1980) suggested Key deer show distinction beyond race level. Analyses of skull dimensions suggest several that distinguish Key deer (Maffei et al. 1988). Current study of skulls and genetics of Florida deer and of genetics of Key deer may resolve these questions.

DESCRIPTION: As documented by Barbour and G. M. Allen (1922) and substantiated by Dickson (1955) and Klimstra et al. (1974), the Key deer is on the average smaller than other eastern races of white-tails. Data recorded since 1967 suggest much variation in weight, with the average approximately 36 kg for adult males and 29 kg for females. However, maxima for both sexes are about 58 kg and 50 kg, respectively, suggesting overlap with races of the Florida mainland. At birth, spotted fawns average 1.5 kg. Maximum growth of females occurs at 4-5 years, whereas that of males tends to continue at least through 8 years. This deer appears stockier than other races due to proportionately shorter legs; shoulder height of adults ranges from 64 to 76 cm. Readily apparent is a wider skull, especially obvious in males; ratios that compare interorbital and palate widths vs length of skull distinguish clavium from other races (Maffei et al. 1988).

Coat color, which varies from a melanistic reddish-brown to a grizzled near-gray, can be seen any season; however, the latter often seem to be older animals. The rather obvious blackish facial mask in most fawns becomes more intensified in adults (Figure 1). Data accumulated from 1968 through 1973 suggest typical antler development is spike at 2 years, fork at 3 years, 6 points at 4 years and 8 points at 5 years. However, more recent documentation suggests much variation to this pattern, with appearance of several with small 6-point racks at 2 and 3 years of age. This may reflect interesting biological aspects associated with population dynamics of a population seemingly stabilized at 350-400 animals during the 1970s (Klimstra et al. 1978, 1980, 1982) and then declining to 250-300 animals during the 1980s (Hardin, et al. 1984, Klimstra 1985, U. S. Fish and Wildlife Service 1985).

POPULATION SIZE AND TREND: According to Dickson (1955) there may have been as few as 25-80 animals in 1951; cause of its near demise is believed to be hunting (DePourtales 1877). Until the early 1970s, recruitment appeared to exceed mortalities as the population grew. By about 1973-74 the herd seemed to be stable at 350-400 (Klimstra et al. 1974, 1978, 1982) of which

65-70% were on Big Pine Key (Klimstra, et al. 1974). Although population levels of 600 to 1,000 have been indicated (Layne 1974, Leposky 1973, Weiner 1985, Woodard 1980), verification is not possible. By the early 1980s the numbers had declined by 100 to the current estimated population of 250-300 (Hardin et al. 1984, Klimstra 1985).

DISTRIBUTION AND HISTORY OF DISTRIBUTION: Key deer, restricted to the Lower Keys, once ranged from Key West to Duck Key (Barbour and Allen 1922); considering the 9.8 kilometers of open water between Key Vaca and keys to the west there may be question about Boot, Grassy, Duck and Vaca keys. During 1951-52, Dickson (1955) recorded sign on only 11 keys. Klimstra et al. (1974) established that Key deer probably use most keys from Boca Chica to the Johnsons. However, sign of use indicates transient and/or seasonal occurrence for many islands except for Big Johnson, Little Pine, No Name, Big Pine, Big Torch, Middle Torch, Little Torch, Cudjoe, Howe, Sugarloaf, Knockemdown, and Summerland, where there is reasonable access to freshwater. During the dry season the range is constrained due to fewer locations of acceptable water; hence, deer populations of keys with freshwater may show an increase during winter (Jacobson 1974). The majority of the deer occur within the boundary of the National Key Deer Refuge.

GEOGRAPHICAL STATUS: The Key deer became endemic to the lower Florida Keys following rise in ocean level with the retreat of the Wisconsin glacier (Hoffmeister and Multer 1968). The inundation of the land mass contiguous with the mainland created Florida Bay, isolating terrestrial fauna and subjecting them to constraints and influences of island conditions. Once believed an occupant of Duck Key to Key West (Barbour and Allen 1922), the Key deer is now recorded on 26 islands located between Spanish Harbor Bridge and Boca Chica (Klimstra et al. 1974, Klimstra, Unpubl. data). Permanent residence is restricted by access to fresh water and diverse habitat, especially the pine-palm community. Regular seasonal use and occasional transient use of selected keys is accomplished by swimming across open water. The 9.8 kilometers of open water to the south and west of Key Vaca appears a viable barrier except for truly unusual circumstances.

HABITAT REQUIREMENTS AND HABITAT TREND: Based on character of Big Pine Key, which supports 65-70% of all the Key deer, diversity of habitat and size are important; but top priority is available fresh water. According to Silvy (1975), pinelands and hardwoods are used most often; open-developed and mangrove areas show somewhat lesser use. Although hammock and buttonwood communities are of some importance, their use is related to special needs of a daily or seasonal nature. Sites burned, recently cleared, and sparsely developed are especially attractive (Klimstra et. al 1974 and Klimstra 1986), providing new, more succulent early-successional vegetation foods as well as escape from mosquitoes due to more pronounced wind. Habitat manipulation affects patterns of deer movement, enhances food supply, and increases area of use.

That fresh water is essential is shown by deer movements to keys with permanent supplies during the low rainfall normally occurring October through April (Jacobson 1974, Klimstra et al. 1974). As a result, many keys have only temporary or transient deer use even though other habitat qualities may be minimally adequate. Although these temporary uses seem associated with periods of higher rainfall, dispersal or accelerated movement occurs in conjunction with breeding and fawning seasons (Hardin 1974, Silvy 1975).

The importance of pinelands is obvious from deer occupancy (Silvy 1975); however, reasons are not so clear. Because the pine/palm habitat depends on fire (Dickson 1955, Alexander and Dickson 1972, Klukas 1973), a greater diversity and availability of quality deer food and cover are presumed a consequence. And, where there has not been fire for an extended period the density of the understory, largely palms, precludes adequate food and desirable cover (Klimstra 1986). Although such keys afford diversity and fresh water, deer use is low; hence, habitat manipulation tactics as recommended by Klimstra et al. (1974, 1980) are appropriate.

Based on range of activities recorded for sex and age classes (Silvy 1975), adequate space is an obvious need; but, quality habitat and its diversity and water may be the most important. Keys with elevations less than 3 to 4 feet above sea level contribute only seasonally; hence, use by deer is temporary/transitory.

Although the diet of Key deer is diverse as reflected by 164 plant foods identified in 129 samples from road mortalities, 28 plant species yielded 75% of the total volume (Dooley 1975). Woody plant browse and fruits combined yielded 67%; palm fruits, flowers, and spathe 14%; and forbs 13%. Use of browse was greatest during December-March and fruits and flowers during April-November, a reflection of seasonal availability. In energy value, plant foods available to deer ranged from 1,985 to 5,940 cal/g; for those known to be prominent in their diet, the mean was 4,534 cal/g. (Morthland 1972). Analysis of 216 available plant foods (Widowski 1977) generally exhibited high ash and calcium, high ca:P ratios, and low phosphorus in comparison to needs of white-tailed deer; the latter may contribute to low herd productivity. Thatch palm (*Thrinax microcarpa*) ranked fifth in dietary importance value (Dooley 1975) and contained 5,174 cal/g, but yielded the lowest predicted *in vivo* digestibility of the deer's staple foods (Donvito 1979).

VULNERABILITY OF SPECIES AND HABITAT: The Key deer is especially vulnerable to habitat loss due to commercial land use to serve tourists and local residents, and to subdivision development (Klimstra 1985). Although the current rate and extent of habitat and space loss to development on Big Pine Key is somewhat less than the predicted 46 ha per year during 1969-1978, most, if not all, private holdings could be developed early in the 21st century. This would result in a resident population of 6,800 plus 4,000 seasonal residents (Klimstra et al. 1974, Klimstra 1985, Sedway Cooke Associates 1989). Big Pine Key is especially significant as it provides for 65-70% of the deer population because of its size, extent of public-owned lands, and quality of habitat. Although other keys subject to development have less high-quality habitat, have fewer deer, and are of smaller size, human impact is a factor as most are used by deer at least seasonally.

A major factor in suitability of habitats, is not only quality as reflected in food and cover needs, but especially fresh water. Because rainfall is the principal source, its availability is dependent upon annual occurrence in depressions that capture surface waters and in the oolitic limestone. Further, its persistence is dependent upon elevation, intrusion of salt/brackish waters through the subsurface oolitic limestone (either due to normal rise and fall of tides and/or dredged canals into interior of

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given keys), and to presence as well as the volume of freshwater lenses (i.e., Big Pine Key). Hence, developments and wells have an obvious impact on occurrence of fresh water and, in turn, time and level of deer use of otherwise suitable habitats. As a result, total usable area increases and decreases with the rainy season (May-October) followed by the dry season (November-April).

Associated with human impacts is the deer's vulnerability to a variety of mortalities (Klimstra 1985). The heavy traffic on state, county, and subdivision roads results in approximately 80% of all annual deer loss (an average per year for 1968-88 of about 44), largely on U. S. Route 1 across the southern portion of Big Pine Key. The 160 kilometers of mosquito ditches represent a problem, especially to fawns; Hardin (1974) documented an 18% loss of marked fawns in mosquito ditches. Although hunting has been banned since 1939, poaching continues; especially vulnerable are those animals in close association with people, readily enticed by feeding or baiting. With increasing human populations is a marked rise in the "guard" dog population, of which many are free-running. Documented deer mortality has increased both from direct dog attacks and from pursuit onto roads or into water where auto accidents or drowning occurs. There has been little documentation to suggest parasites and diseases a problem in Key deer. Schulte et al. (1976) found a variety of intestinal parasites, but recorded no evidence of pathogenic effects. Of the most prevalent and potentially dangerous deer diseases in southern U. S. (Newson 1984), Key deer are known to carry antibodies for epizootic hemorrhagic disease and blue tongue indicating exposure. The potential for "exotic" diseases and parasites rises with increasing number and variety of domestic animals associated with increased human residency and activity. Also, the attraction of maintained right-of-ways and subdivisions increases the perception that Key deer are a nuisance because of damage to landscape plantings and auto accidents. Many residents have resorted to fencing, which in turn reduces habitat and space available.

The Key deer is a victim of its own reproductive biology. Twining is not common, precocial breeding is clearly exceptional, and contribution by yearlings is infrequently documented (Hardin 1974, Klimstra et al. 1974, Hardin et al. 1984). This low level of reproductive output seemed necessary for an island population with a rather stable life-style, especially in the absence of large terrestrial predators. Verme (1969) believed male-biased sex ratios such as documented 1968-1973 for Key deer was evidence of a reduced rate of population increase.

CAUSES OF THREAT: Although originally lack of protection and hunting reduced the population to 25-80 animals (Dickson 1955), the recent and current threat is a combination of extensive deer mortality and habitat loss resulting from development to serve an ever-increasing number of residents and tourists. Associated with developmental factors, both direct and indirect losses of deer occur from auto accidents, poaching, free-running dogs, mosquito ditches, and feeding. Deer losses from 1980 through 1988 due to auto accidents include 388 animals; an additional 95 animals were lost due to other factors. For a herd estimated at 250-300 and with naturally low annual productivity, annual losses have approached or exceeded a given year's recruitment--hence the population decline of $\geq$ 100 animals since 1979.

RESPONSES TO HABITAT MODIFICATION: The response of Key deer to habitat modification is well documented (Klimstra et al. 1974, 1980, 1982; Klimstra 1986, Hardin et al. 1984). Following disturbance such as subdivision development, road building, mosquito ditching, and clearing there was extensive deer use/activity. Initially this was due to attraction to openings ("breaks" in cover) and edge created, and subsequently due to the early successional stages of revegetation. Many plant species were of high priority in their daily, seasonal, and annual diets. The response to burning, whether planned or unplanned, was immediate, before all smoke and/or smoldering had ceased (Silvy 1975, Klimstra 1986). Especially attractive are subdivisions and right-of-ways that are maintained by frequent mowing in early successional stages with palatable grasses and forbes. Cleared strips, whether firelane, roadway, or mosquito ditch, also serve as travel lanes through heavy cover.

Pine/palm communities considered important in providing habitat of Key deer, are a consequence of fire and can be perpetuated in high-quality condition only through periodic burning (Alexander and Dickson 1972, Carlson 1989, Klukas 1973, Wade et al. 1980, Klimstra 1986, Schomer and Drew 1982). The advancement to hardwood hammock conditions in openings (i.e., grassy areas) can be effectively retarded or reduced by fire (Alexander and Dickson 1970). The food supply for deer is dramatically enhanced in these communities as a consequence, resulting in greatly increased deer use/activity.

Deer depredation is a serious, long-standing problem in subdivisions; few plants used in landscaping are not browsed. Hence, there is extensive fencing or individual plant isolation by wire cylinders. Some residents consider the deer a nuisance and an expense to be endured.

Developments to enhance available fresh water have included removing accumulated debris from selected water holes, enlargement and deepening natural depressions, and use of a plastic "guzzler"; some deer response on Big Munson, Howe, Sugarloaf, Water, and Johnson keys has been documented. Subdivision and road construction have changed terrain resulting in fresh water being surface-pocketed in a large area formerly influenced by tidal or subsurface intrusion of saline water on Big Pine Key. Also, mosquito ditches in former freshwater sites (i.e., solution basins) of hardwood hammock communities on Big Pine Key, now blocked off, greatly enhance permanency and distribution of available fresh water. During the lengthy drought of 1970 an obvious deer response to these man-created supplies was documented during routine censuses (Jacobson 1974), suggesting significant movement of deer from other parts of Big Pine and probably adjacent keys.

DEMOGRAPHIC CHARACTERISTICS: Breeding begins in September, peaks in October, and declines through November and December; occurrence of a spotted fawn in any month suggests occasional exceptions (Hardin 1974, Hardin et al. 1984). Parturition is primarily from mid-March through mid-May following a 204-day gestation. Females 2 years and older contribute a major portion of annual recruitment; precocial and yearling breeding appear minimal at best. Twining is infrequent and rarely recorded among surviving newborn. Males less than 3 years of age seldom have full rack development and rarely participate in breeding; exceptions may occur late in breeding season when dominant adult males are less aggressive.

There is a minimum of 20% mortality through the first 6 months of life (Hardin 1974). A 50% survival of males through 1.5 years has been recorded; none have been documented after 8 years. In contrast, 50% of

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females reach 2.5 years; most do not survive beyond 9 years. However, a female marked March 1968 was known to have survived 20 years and another at least 19 years; both were believed to have produced a fawn until year of death. During 1968-1973, sex ratio of fetuses was 1.75 males to 1.00 females whereas for fawns it was 2.0 to 1.0, respectively. Such a high ratio of males to females (Verme 1969) is associated with relatively low recruitment and self-imposed constraint on reproduction.

KEY BEHAVIORS: Loose matriarchal groups consisting of an adult female with one or two generations of offspring is the norm (Hardin 1974, Hardin et al. 1976), but generally they are rather solitary as individual animals, beginning with the wandering fawns at 3-4 months in age. Bucks occur in groups during the nonbreeding season, especially following antler loss and until loss of velvet; occasionally adult males in velvet are in a gang of several females. Since 1973 mixed groups, largely more than one adult female and offspring, have been observed in subdivisions at almost any time (Klimstra 1985). This is in response to attention given by individual residents who present water and domestic foods. Evidenced are small groups of deer using open areas of subdivisions from dusk to dawn for feeding, bedding, and escaping insects, especially during summer and early fall. Generally, normal deer habitat use reflects daytime in hardwood hammock and buttonwood communities with lesser use of clumps of palms, stands of palmetto in depressions, and isolated stands of understory hardwoods within pinelands.

A given animal or group has well-defined patterns of activity and location; they are creatures of habit (Klimstra et al. 1974). Well-established trails and areas of bedding are evident in some areas.

Repeated use of certain sites to cross roads results in "hot spots" for automobile accidents.

Key deer readily swim from island to island; this occurs most when sources of fresh water are limited and dispersal associated with the breeding season. Patterns of home-range use and dispersal are very similar to that of other whitetails (Hardin 1974, Silvy 1975).

CONSERVATION MEASURES TAKEN: As a result of local concern and the 1934 cartoon by "Ding" Darling, the Florida Legislature banned hunting of the deer in 1939 (Ryden 1978). The studies of Dickson (1955) during 1951-52; the hiring of Jack C. Watson, Sr., as warden with funds from the Boone and Crockett Club in 1951; the contributions and donations of private individuals; and the unrelenting efforts of representatives of members of the U. S. Congress, the Boone and Crockett Club, Wildlife Management Institute, National Audubon Society, North American Wildlife Federation, and U. S. Fish and Wildlife Service provided the initiative for establishment of the National Key Deer Refuge in 1957 (Ryden 1978). As a result of donation and purchase the Refuge now includes about 3,000 hectares. Beginning in 1964 U. S. Fish and Wildlife Service personnel initiated study of deer habitat-use and attempted to monitor population levels (Stieglitz 1964, 1967; Yaw 1965, 1966). The Key deer was placed on the federal endangered species list in 1967 with full protection under the Endangered Species Act in 1973, and was documented among endangered biota of Florida in 1978 (Klimstra 1978), although listed as threatened by Hendry et al. (1982). In December 1967 an intensive 6-year research effort was begun (Klimstra et al. 1974), resulting in previously unknown data regarding the biology of the deer, its habitat use, current and anticipated

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critical problems, and recommendation for several management initiatives. Subsequently, a Recovery Plan was produced (Klimstra, et al. 1980, U. S. Fish and Wildlife Service 1985) with extensive recommendations for action by state and federal interests. Key issues included habitat acquisition, protection, and maintenance; deer protection; monitoring of deer condition, population, and habitat; experimenting with habitat manipulation; educating the public; and conducting additional studies of natural history and population dynamics.

Because automobile accidents contribute 75-80% of known mortality, an effort was made to reduce such loss; initially this was through use of deer crossing signs and reflectors. Subsequently, U. S. 1 was posted at a maximum speed of 45 mph and all other roads were reduced from 45 to 30 mph. Since 1957 annual road losses have ranged from 14 to 64, and during 1968-1988 it varied little, averaging around 44. This suggests these techniques have not been adequate.

With increasing human population there has been increase in dog harassment of deer resulting in several efforts to control through capture and public education. Through extensive collaboration of private, state and federal interests, a dog pound on Big Pine Key and appropriate personnel has become a reality.

Efforts to acquire land through gift/purchase have been underway since the establishment of the Refuge in 1957. Only in the last few years has the effort focused on those habitats deemed essential to Key deer needs. There has been continuous monitoring of the population (numbers, location, sex and age) since 1968 (Humphrey and Bell 1985, Klimstra, et al. 1974, Silvy 1975) through emphasis on road censuses (largely on Big Pine Key). Additionally, there has been generalized evaluation of condition of deer through examination of mortalities, including analysis of selected tissue samples by the Southeast Deer Disease Study Group.

Beginning in 1969, controlled burning activities were begun on Big Pine Key. This effort was expanded in 1978 and most recently has been extended to other keys. Burning has yielded important values in perpetuating deer habitat quality (Alexander and Dickson 1970, 1972; Carlson 1989; Klimstra 1986). Additionally, disturbed areas resulting from development such as roadways, subdivisions, and mosquito ditching yielded increased diversity valuable to deer. Water supply has been enhanced by removing accumulated sediment in selected sites on several keys and establishment of plastic guzzlers on two.

Filling selected segments of mosquito ditches to reduce fawn loss has been approved and implemented. Through additional staff, the Refuge has increased patrols to reduce harassment by dogs and possible poaching. Public education has been stepped up regarding people-related problems, especially feeding. Although the Florida Legislature made feeding the deer a misdemeanor and provided for a $500 fine, deer feeding continues because no convictions have been obtained.

The recent emphasis by various organizations and agencies regarding land use in the Lower Keys has significant importance to Key deer. Support for selected land acquisition, regulation of commercial and road developments, dog control, and protection of critical habitat and the deer are noteworthy. Also, the development of Monroe County's Comprehensive Land Use Plan and its implementation will have far-reaching effects; hopefully, its ecological integrity will not be diluted by political processes.

CONSERVATION MEASURES PROPOSED: Of primary importance is the full implementation of the Recovery Plan (Klimstra et al. 1980, U. S. Fish and Wildlife Service 1985). Priority should be given to recommended acquisitions not yet in public ownership with immediate attention placed on selected areas on Big Pine and Big Torch keys and all of No Name Key. No Name Key is of highest quality, reflecting outstanding habitat diversity, permanent fresh water, and a strong deer population. Its complete acquisition would maximize public control and restrict public access. In all acquisitions, every effort should be made to reduce private inholdings that hinder effective application of habitat management, contribute to undesirable people-deer interactions, and constrain effective monitoring of deer. Major emphasis should be on preservation of wetlands, especially those on Big Pine Key south of Watson Boulevard. Also, effective growth management and land use planning for the Lower Florida Keys must be expedited.

Habitat management must be aggressively pursued with a workable controlled burning plan that will enhance food supply, diversity, and edge (Klimstra 1986, Carlson 1989). Pine/palm communities and open grasslands must be targeted to maintain their continuity. Fresh water supplies must be enhanced through protection of wetlands, insuring permanency of strategically located sites, installation of guzzlers, and possibly replenishing water on selected keys during extreme drought.

The dog control plan being finalized must be effectively implemented. Auto speed constraints must be established on U.S. 1 across all of Big Pine Key and there must be greater enforcement, including all state and feeder roads. Right-of-ways must be assessed for reduction of attraction to deer and for enhancement of deer-driver visibility. The serious problem of deer interacting with residents and tourists must be significantly reduced. Aggressive public education must be mounted and maintained to enlighten the permanent and temporary residents and tourists regarding the Key deer, its requirements, and the negative impacts of treating them as pets.

Monitoring and research must be continued to understand the future status of the deer. This includes road-censusing, age and sex-ratio analyses, documentation of mortalities, habitat evaluation and deer use, health of the deer based on mortalities, analysis of level of deer use of public and private lands in the Lower Keys, and evaluation of the various deer and people management practices implemented.

ACKNOWLEDGEMENTS: The contributions of Jack C. Watson, Sr. (deceased), the first manager of the National Key Deer Refuge, were invaluable in establishing and conducting research during 1967-1973. Many past and current staff of the Refuge aided importantly: refuge managers Donald Kosin and Deborah Holle; wildlife biologists Steven Klett, Bonnie Bell and Thomas Wilmers; and Chester Eldard, Jack Watson, Jr., Lois Robinson, Valeen Silvy, and William Swicker. The baseline data contributed by John D. Dickson, III, Taylor R. Alexander, Edward D. Yaw, Stephen C. Johnson, and Walter O. Stieglitz provided important foundation for the Key deer studies. Financial support was contributed by the U.S. Fish and Wildlife Service, National Geographic Society, North American Wildlife Foundation, National Wildlife Federation, Cooperative Wildlife Research Laboratory of Southern Illinois University, and W. D. Klimstra Distinguished Professor Fund. Scores of graduate students at Southern Illinois University, participated in the field research: James W. Hardin, Nova J. Silvy, Bruce N. Jacobson, Todd R. Eberhardt, and Allan L. Dooley. Others studied materials

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KEY or TOY DEER RARE

Odocoileus virginianus clavium Barbour and Allen, 1922

Order ARTIODACTYLA Family CERVIDAE

SUMMARY Restricted to islands off the lower Florida Keys, U.S.A. where in 1979 the population was estimated at 300-400, possibly up to 600, and stable, having increased from near extinction in the 1950s. Most now occur in the 1764 ha National Key Deer Wildlife Refuge established in 1954 on Big Pine Key which includes most of the suitable remaining habitat. Principal cause of decline was loss of habitat but most mortality is now through roadkills. Management consists mainly of protection and controlled burning of habitat. In 1980 a Recovery Plan was approved by the U.S. Fish and Wildlife Service. The deer seems to be at the carrying capacity of its available habitat and provided it receives continual protection, its future seems secure.

DISTRIBUTION Florida, USA. Once inhabited islands from Key West to Key Vaca in the lower Florida Keys, but now restricted to islands in the vicinity of Big Pine Key, Monroe Co. Florida. The western boundary is Sugarloaf Key, the eastern the Little Pine - Johnson Key complex (5). Within this area deer are resident only on Keys with permanent freshwater: Big Pine, Big Torch, Cudjoe, Howe, Little Pine, Little Torch, Middle Torch, No Name, Sugarloaf and Summerland Keys, but are also found on at least ten other islands during the wet season (7).

POPULATION In 1979 estimated at 350-400 and appears relatively stable due to high mortality, low reproductive rate, and a large proportion of male fawns (5,7,11). The 1980 official estimate for the National Key Deer Wildlife Refuge was 600 deer but this may be revised downward as monthly census data are analysed (7). Big Pine Key is estimated to hold about two-thirds of the total population (5,7). Three population concentrations can be discerned and there is probably little exchange of animals between them (5). Although the population has apparently stablized, the relatively low numbers and limited range continue to make this an animal of concern. The Recovery Plan aims to maintain a stablized population as opposed to increasing it (8). Numbers began to increase around 1950 in response to protection from hunting and disturbance. The estimated total in 1955 was 25-80 (2,5,7).

HABITAT AND ECOLOGY The ecology and behaviour of the Key deer has been extensively studied (3,4,5,7). Five habitat types have been noted in descending order of preference: pinelands, hardwood hammock, buttonwood - scrub mangrove, mangrove swamp, and developed areas. Habitat selection varies with season, time of day, and age and sex of the individual (6,7). Pinelands, recent clearings, roadsides, grassy areas and hardwood hammocks are used for feeding while hammocks and Red Mangrove act as daytime retreats (5). Red Mangrove (*Rhizophora mangle*) also constitutes an important food source, with 63 per cent occurrence in pellet analysis (2,7). Food plant utilization changes seasonally, probably reflecting availability and nutritional needs and virtually no plant species is immune from deer use at one time or another (6,7,8). The deer are strongly attracted to newly burned areas, and will feed extensively on new woody and herbaceous growth for up to 6-9 months (8). A fresh water supply is essential (10) although there is a limited tolerance for salt (11). Adult females form loose matriarchal groups with one or two generations of offspring, while bucks feed and bed together only in the non-breeding season (5). Adult males maintain ranges of about 120 ha., adult females of about 52 ha. (5). Most breeding occurs in

September and October with fawns born in April/May. Reproductive rate is low (av. 1.08 fawns per adult doe annually) (7). Male fawns outnumber females, but differential mortality leads to adult females outnumbering males by 2.38 to 1. Longevity records are 8 years for males and 9 years for females and few males breed at less than three years of age (6,7,11).

THREATS TO SURVIVAL Loss of habitat to development was the primary reason for the original population decline and continues to be a major threat. Big Pine Key, the main stronghold for deer, had 37 per cent of it cleared for development by 1973 (an average of 46 ha per year between 1969 and 1973) (6,7). Most mortality on Big Pine Key is now caused by roadkills which comprised 76 per cent of known mortalities between 1968-73 (8). Another significant factor is the drowning of fawns in drainage ditches. Overhunting with dogs and jacklights was probably an important factor in the 1940s and 1950s and poaching was reported as still rather frequent in 1974 (7).

CONSERVATION MEASURES TAKEN Afforded full legal protection in the U.S.A (5,7). The National Key Deer Wildlife Refuge was established in 1954, and by 1980 comprised 1764 ha of which 300 ha were leased; it includes most of the suitable remaining deer habitat. Management consists mainly of protection and some controlled burning (5,7). In 1980 the United States Fish and Wildlife Service approved a Key Deer Recovery Plan (8). The animal has been the subject of a study by Southern Illinois University since 1967 (3,4,6,10).

CONSERVATION MEASURES PROPOSED Klimstra recommends: continued protection from illegal hunting, and of the refuge lands from development and major changes; acquisition of additional deer habitat, especially on Big Pine, No Name and Cudjoe Keys; use of controlled burning to maintain pinewoods; maintenance of existing fresh water holes on refuge lands; possible fencing of islands where refuge lands and privately owned housing subdivisions adjoin; and continued research on all aspects of the deers' biology (5). The Key Deer Recovery Plan additionally recommends: restriction of dogs from refuge lands; lower speed limits; the posting of deer warning signs; fencing of highways except at trail crossing points; and increased public awareness (8).

CAPTIVE BREEDING According to the Recovery Plan, because the Key Deer are the product of a unique selective system (a restrictive insular environment with no natural predators), management should involve the retention of those natural selection factors that influenced their evolution and thus under no circumstances should a captive, zoo-bred herd be used for re-stocking purposes (8).

REMARKS For description of animal see (1). In recent years it has been noted that Key Deer appear to be growing to a larger size, perhaps due to improved nutrition. The taxonomic status of the animal has been questioned and is now under investigation by Klimstra and others (7). The full species has a very wide distribution in North America being resident in practically every state in the U.S.A. except Alaska, and possibly Utah. Northwards its range extends into southern Canada and southwards it occurs through Mexico and Central America into the northern half of South America. At present at least 38 subspecies are recognised, of these two are listed in the Red Data Book, the above mentioned taxon and the Columbian White-tailed Deer O. v. leucurus (9). Dr. W.D. Klimstra, Director of the Cooperative Wildlife Research Laboratory, Southern Illinois University, kindly assisted with the compilation of this data sheet.

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SPECIAL REPORT: KEY DEER ACCESSIBILITY TO ALL OF BIG PINE KEY

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INTRODUCTION

This report was prepared in response to questions raised concerning carrying capacity, deer use, and the continued viability of Key deer on Big Pine Key. Much of the report is based on previous (especially from 1968-1973) and current (1987 to present) Key deer research efforts by the staff of the Cooperative Wildlife Research Laboratory (CWRL), Southern Illinois University at Carbondale.

This report addresses questions concerning Big Pine Key as a "whole" and as three separate major regions. One region lies north of Watson Boulevard (including all of Tropical Bay Estates and the adjoining peninsula); another is that south of Watson Boulevard and north of U.S. Highway 1; and, the third includes all area south of U.S. 1. Because of their isolation and current enticements to "hold" a core of animals it is appropriate to view the Newfound Harbor Keys a small but important fourth region.

Somewhat indirectly, inference is made to contrast carrying capacity of refuge and private-owned lands. Carrying capacity, as used here, emphasizes a maximum deer population that may be supported without long-term damage to vegetation (Boyd et al. 1986). The foundation of estimates is based upon the long-accepted assumption that habitat attributes may be used to predict the abundance of a wildlife species (Cooperrider et al. 1986).

CARRYING CAPACITY

Methods

Current habitat composition on Big Pine Key was determined by planimetry of overlay-maps on aerial (1:9600) photographs. Up-to-date, recently ground-truthed habitat maps were available from current CWRL studies. The amount of each habitat type (open-developed areas, hammock, hardwood, pineland, scrub mangrove-buttonwood, and mangrove forest) was divided by its respective potential deer density (from Silvy 1975) to give number of deer per habitat type. Numbers of deer for each habitat within an area were summed to give an overall "crude" carrying capacity (without deterioration of plant communities). This carrying capacity estimate reflected only habitat availability; further refinements in carrying capacity estimates were made for problems associated with fencing, home range size, dispersal, and food and water availability. Human/deer interactions and genetics were reviewed.

Four maps were prepared to graphically depict the dramatic increases in development along U.S. Highway 1 between 1963 and 1989. Developed areas were drawn on acetate sheets placed over aerial photographs. The most recent overlay map includes fences and was ground-truthed November - December 1989. In addition, two overlay maps were prepared to show road development along U.S. 1 during 1966 to 1989. A map was prepared from ongoing CWRL research showing existing nontidal wetlands from Watson Boulevard to south of U.S. 1. Sites varied from permanent waterholes to seasonally flooded basins and wet pine flatwoods.

Data were collected to approximate numbers and locations of residential lots enclosed by fences on Big Pine Key. Residential areas were driven and lots enclosed by fence were marked on a base map. The goal of this survey was to provide estimates of the area enclosed by fences, their locations, and how fencing increased since the early 1970's. Due to difficulties of access, visibility, determination of lot locations, and time constraints, the results are incomplete and must be viewed as conservative estimates.

Habitat Composition

Deer home ranges overlap parts of major vegetational areas (habitats) (McCullough 1984). Key deer use all habitat types for feeding and other general purposes, but each habitat also serves special needs of the deer. Open-developed habitats consist of areas where the native vegetation has been removed or largely disturbed; they are important areas for feeding, loafing and escaping insect pests. Hammocks are hardwood forests with high canopies, open understories, and an accumulation of organic soil material; these are important for bedding and birthing. The low, shrubby, dense vegetation of hardwood habitat provides important escape cover, some food supply, and bedding areas. Pinelands, existing at higher elevations, provide important drinkable water and are also important escape, feeding, and birthing areas. Scrub-mangrove buttonwood habitats, for purposes of this report, include currently identified areas (CWRL unpubl. data) of salt marsh, scrub mangrove, prairie, buttonwood transition wetlands, and most nontidal wetlands. Buttonwood habitats contain critical sources of drinking water and bedding, loafing, and feeding areas. Finally, mangrove forests are important for loafing, bedding, and feeding.

Openings created by periodic dozing (e.g. bracken area of Watson's Hammock) or prescribed burning (as practiced on other refuge lands) provide important loafing and feeding areas. Clearing and burning improve forage availability and quality, and allow management of various successional stages desirable for deer and other wildlife.

Based on diversity of habitat, type and distribution of plant communities, deer activities and numbers, and protection, most of Big Pine Key north of Watson Boulevard provides the best quality and distribution of habitat types of the three regions (Fig. 1). The density of people is about 0.7/ac (compared to densities of 1.9/ac for the middle region and 0.3/ac for the south region). With few exceptions, people are concentrated in subdivisions. Dispersed intrusion of people into prime deer habitat is therefore less than in other regions of the island. All habitat types are present (Table 1); 1,134.4 ha (2,801.1 ac), excluding tidal ponds, suggest a capability to support 90 - 100 deer.

The region between Watson Boulevard and U.S. 1 is about half the size (602.1 ha, 1,486.7 ac) of that north of Watson (Fig. 1), and the density of people (1.9/ac) is the highest of the three regions of Big Pine Key. Compared to other regions, it contains the highest proportion of open-developed habitat to total area (Table 1). However, most development is on the periphery (coastal subdivisions); roads fragment the area, but selected high quality habitats including strategically located freshwater wetlands are still present. Based on habitat composition the area has a potential for approximately 45 - 55 deer.

The southern region contains the lowest density of people (0.3/ac) of the three major regions. Selected quality habitats, though present (Table 1), are distributed in a manner that generally requires most deer to travel extensively to pursue daily, seasonal, and annual needs (Fig. 1). Based on habitat characteristics the 531.9 ha (1,313.4 ac) have the potential for 35 - 45 deer.

All habitat types except pineland occur in very limited and dispersed sites in the Newfound Harbor Keys chain (Table 1). The five islands (Little Palm (Munson), Big Munson, Hopkins, Cooks, and the Big Pine mangrove island) probably represent a minimal contribution (4 - 6) to the overall carrying capacity of Big Pine Key. Evidence of habitat deterioration, in the form of a browse line, has been present in all upland areas of Big Munson probably since the late 1970's. The habitat problem reflects concentrations of deer (12 - 15) that would not be present without non-natural enticements. As noted during 1968 - 1975, deer use of the Newfound Harbor Keys was transient and coincided with periods when drinkable water was available. Because these animals are artificially concentrated more or less as an isolated group, they provide questionable contribution to the future of the Key deer. The commercialization of Little Palm and human habitation of Cook Island, both adjacent to Big Munson, must be viewed as problems.

Commercial development and fencing are extensive and most visible along U.S. 1; changes since the 1960's are shown in Figs. 2 - 5. Fig. 6 portrays the increase in roads along U.S. 1 since the 1960's.

Fences

Subdivisions north of Watson Boulevard now reflect about five times more fenced lots than in the early 1970's. Of today's dwellings, about 43% have fences; approximately 19 ha (47 ac) have been enclosed and are unavailable to Key deer.

Over half of the dwelling units on Big Pine Key occur between Watson Boulevard and U.S. 1. About twice as many lots are fenced now compared to the early 1970's, but lot size must be considered. Fenced lots in the early 1970's were small and concentrated in Sands Subdivision. Since then there has been a dramatic increase in the fencing of large lots (1 ac or more), especially east of Key Deer Boulevard and west of Whispering Pines subdivision (Fig. 7). It should be noted that not all fences here are associated with dwellings. Large areas of high quality upland habitat have been enclosed, and deer movements in some areas have been disrupted to the point where they must travel through a "checker-board" maze. Canals block north-south deer movements on both sides of the island (Fig. 7); hence, in conjunction with fences, a bottleneck is formed. Strategically located high quality habitats must be preserved in a manner that will minimize the inevitably increasing problems due to fragmentation. Approximately 37% of the occupied dwellings between Watson Boulevard and U.S. 1 are fenced. Fences enclose about 74 ha (183 ac) of residential and commercial (mainly along U.S. 1) property. Most of this habitat consists of pineland; at 23 acres/deer density (Silvy 1975), adjustments to carrying capacity result in an estimate of 40 - 50 deer.

South of U.S. 1 there are about 16 times more fenced residential lots than in the early 1970's; some 31% of today's dwellings have fences. Approximately 18 ha (44.5 ac) are fenced and unavailable to deer.

About 111 ha (274 ac) are fenced on Big Pine Key. Although "loss" of this 5% of the island may seem minimal, consideration must be given to other problems associated with fencing. Fenced areas fragment habitats and interfere with the deer's ability to pursue life requisites. The location of fenced areas and how they fragment habitats will determine the degree of interference. High concentrations of fenced and developed areas such as along U.S. 1 (Fig. 5) and east of Key Deer Boulevard (Fig. 7) disrupt normal deer behavior, constrain access to permanent water and feeding sites, and reduce deer numbers and use. Intrusion by people and automobiles further complicates the problem and constrains the deer.

Disruption of deer movement is a serious consequence of fencing. Key deer have evolved in a very limited insular environment; any restriction of their freedom of movement between habitat types and the associated space, cover, food and water supplies compounds negative factors recognized for small space and isolation, especially as related to abilities for adaptation to "new" experiences through natural selection processes. The response of the deer individually (physical, physiological, and behavioral) and as a population (size and distribution) will tax wildlife managers' ability to detect changes. More importantly, when such occur, it will be "too late to address". Such problems can and must be addressed <u>before</u> the deer show drastic responses to the stress of restriction.

Carrying capacity of Big Pine Key as a whole (not including the Newfound Harbor Keys), adjusted for habitat loss due to fencing, is estimated at 165 - 195 deer. Further adjustments (reductions) in carrying capacity are described in the next two subsections. These adjustments only apply to the three regions of the island under the theoretical setting of the island having complete barriers between regions.

Home Range and Dispersal

Key deer home ranges tend to be linearly-shaped (Silvy 1975, Drummond 1989). Linearity in home range allows maximal use of resources with minimal movement (Marchington and Hirth 1984). Home ranges overlap the divisions (Watson Boulevard, U.S. 1) between major regions of Big Pine Key. Drummond (1989) described the necessity for deer to cross U.S. 1 for meeting seasonal needs of space, cover, food, and water.

Key deer home ranges are dynamic, especially when comparing between summer and the breeding season for adult male deer (e.g. Figs. 8 and 9). Clearly, because of the size of these home ranges in proportion to the area of the island, any barriers to deer movement will adversely affect the behavior of rutting bucks. This can be anticipated to result in the unacceptable consequence of decreased genetic variability.

Studies since 1968 indicate that Key deer on various occasions and on annual/seasonal bases have used all available space on Big Pine Key (Silvy 1975, CWRL unpubl. data). Areas with less dense deer populations, such as south of U.S. 1, are important for deer that disperse from the more densely populated central and northern portions of the island.

If barriers to deer movement were present between the three regions of the island, carrying capacity estimates for each area would be less in order to account for associated problems of restrictions in space and resources. As a minimum a 20% reduction in the estimate for north of Watson Boulevard is realistic, resulting in a carrying capacity of 72 - 80 deer. Significantly larger reductions (30%) can be expected in carrying capacities in the other two regions because of habitat limitations. Each is about half the size of the north region and limited in various habitat characters essential for Key deer. Adjusted estimates for the middle and south regions, respectively, are 31 - 35 deer and 24 - 31 deer.

Food and Water

Currently, there is no evidence that food quantity and quality, or availability of drinking water are limiting factors for Key deer when Big Pine Key is considered as a single, undivided unit of deer habitat and accessible space (Hardin et al. 1984). However, home ranges of deer overlap U.S. 1 because of the differences in habitat needs and use north and south of the highway (Drummond 1989). Preventing deer from crossing U.S. 1, along with the development of habitats adjacent to U.S. 1, will displace deer and ultimately result in lower carrying capacities both north and south of the highway. To maximize use of Big Pine plant communities, home ranges of some deer must span U.S. 1 to meet daily, seasonal and annual needs for food and water. Geographical distribution and timing of the fruiting season of important Key deer food affect seasonal deer distribution. Black mangrove (Avicennia germinans) was the second highest in importance value in a ranking of 115 Key deer foods (Dooley 1975). Drummond (1989) recognized the abundance of black mangrove south of U.S. 1, and suggested it may serve as an important food source and attractant to deer during fall. Seasonality of Key deer food selection was established by Klimstra et al. (1974) and Klimstra and Dooley (1990).

Key deer need a variety of foods for meeting nutritional requirements, and management practices should <u>increase</u> plant diversity (Widowski 1977). Barriers to deer movement such as those proposed that would prevent deer from ready access to vegetation on either side of U.S. 1, will effectively <u>decrease</u> plant diversity and availability of important deer food and cover. Limiting the Key deer's access to a diverse diet will result in nutrient deficiencies, thereby reducing the health and vigor of the herd. Key deer must not be denied access to selected foods because of the potential for nutritional "barricades" for island species (Widowski 1977, Donvito 1979, Klimstra and Dooley 1990).

Data establish that carrying capacities of the three regions of Big Pine Key are also seasonal with respect to drinking water availability (CWRL unpubl. data). Fig. 10 illustrates the extent of nontidal wetlands (including drinkable water for Key deer, salinity < 15 parts per thousand) from Watson Boulevard to the north edge of Coupon Bight. Permanent sources of drinking water for deer are concentrated in the area south of Watson Boulevard.

South of U.S. 1 permanent sources of drinking water are largely limited to the upland area south of the intersection of U.S. 1 and Key Deer Boulevard and the pinewoods west of this intersection. Most sites have been or are being altered by human intrusion; many have been or are being subjected to waste disposal and miscellaneous filling. The wetlands exhibit elevated salinities during the dry season. Hence, limited sources and distribution of drinking water in the dry season, as contrasted with that available north of U.S. 1 (Fig. 10), require many deer in this region to cross U.S. 1 to meet water needs (Drummond 1989). It has been established that during periods of drought there is substantial northward movement of deer (Klimstra et al. 1974).

Availability of drinking water between Watson Boulevard and U.S. 1 has similarity to that north of Watson Boulevard, but with several important differences. Wetlands here have been much more impacted by filling for roads and development and they exhibit higher average salinities during the dry season. Much of this area is considered a discharge area due to its lower elevation and location between the two major lenses of Big Pine Key. Several sloughs traversing the island have been impounded and mosquito ditch excavation has created numerous permanent water sources. Wetlands in this central part of Big Pine Key must be considered essential drinking water sources for deer (especially those south of U.S. 1) on a daily and/or seasonal basis.

It appears that drinking water sources may be available to deer in the Newfound Harbor Keys. Only Big Munson Island has naturally occurring freshwater wetlands, but these are dry during periods of drought. The extent of people influence is not clear but is known to occur.

The area north of Watson Boulevard, the "core" area of Big Pine Key and the deer population, provides the greatest year-round availability of fresh drinking water. During drought conditions refuge lands within this area would provide the greatest abundance of drinking water sites in the entire Key deer range. However, even here constraints and population stress occur as the large north end segment of Big Pine Key and the adjacent Howe Key lack adequate permanent drinking water during drought.

Genetics

Under best of conditions Big Pine Key as a contiguous, unrestricted unit may provide for 165 - 195 deer; however, fragmenting into three separate regions effectively decreases this carrying capacity and may result in habitat depredation. Depending on level and degree of development, people interaction, etc., the number of deer could be reduced by 20 - 30%. In other words, the sum of carrying capacities of the parts (regions of Big Pine Key separated by barriers) clearly will not equal the carrying capacity of the whole (Big Pine Key without barriers). Any reduction in carrying capacity and in turn herd decrease is biologically unacceptable. Further, splitting the herd into different subpopulations will increase inbreeding and decrease genetic variability of a dangerously small population. Big Pine Key north of Watson Boulevard, other than its small size compared to the entire island, has some potential for "self-sufficiency". Both of the regions south of Watson Boulevard, due to constraints in year-round availability of food, water, and space, along with complications due to increasing habitat fragmentation and deer/people interaction, are questionable as to the ability to independently support individual herds of Key deer. At best, these herds would be dangerously small.

Clearly, a total herd of 300 already fragmented throughout its range is at a critical level with questionable recovery powers when subjected to extensive annual losses. There can be no comfort in small numbers and the rise to 350 - 400 from 25 - 80 deer during 1950 - 1975 offers no assurance for the future. That growth increment occurred when human population was small, development was barely underway, and intensive protection was in place. More importantly, the genetic integrity may have already been negatively affected during the low population level of the 1950's. Big Pine Key is the "population hub"; as it goes so goes the Key deer herd. We must not lose the core population in terms of size as well as its inherent genetic diversity.

Human/Deer Interactions

Human-related loss (primarily roadkills) is responsible for a majority of known Key deer mortality; and, in conjunction with habitat loss, is preventing recovery of Key deer numbers (Actions required to insure the viability of Key deer on Big Pine Key, Draft report, 4 April 1989, prepared by a committee of biologists). Drummond (1989) provided recommendations for minimizing deer-car accidents.

Other human/deer interaction problems, though important, may not be as striking as the roadkill problem, and certainly are more difficult to quantify. Enormous growth in human population and the associated land use changes have affected deer activities, movements, behaviors, and habitat uses. Increasing densities and activities of human residents and tourists on Big Pine Key, and the subsequent increase in human/deer interactions will be detrimental to the Key deer population. Harassment by dogs and the feeding/watering by humans are important problems to be recognized (Hardin et al. 1982) and resolved. The many problems involved with feeding/watering of Key deer, and the associated formation of "gangs", have been previously summarized (Actions required to insure the viability of Key deer on Big Pine Key, Draft report, 4 April 1989, prepared by a committee of biologists).

Gangs present a special problem when comparing an area's estimated carrying capacity and its actual population. Populations in area with gangs may be "artificially" higher than what carrying capacities would predict based on "natural" densities. An unnatural concentration of deer may create a void in surrounding habitats, which gets "filled in" with deer from outside the area, resulting in a greater number of deer than originally present. Ganging in the Newfound Harbor Keys has resulted in habitat degradation and an unnatural, isolated "satellite" subpopulation. Ganging is a well-known problem in the Port Pine Heights subdivision. As the human population of Big Pine Key increases, there will be increasing dangers of more deer becoming "pets". If measures are not taken now, as suggested earlier for the deer movement problem, it may be too late. Actions must be taken to prevent the deer from becoming merely pets, with Big Pine Key as their "zoo". Laws minimizing people/deer interaction, especially the feeding/watering of deer, must be enforced. Management practices (e.g., forest openings, burning, etc.) must be implemented to lure deer away from developed areas.

The human population of Big Pine Key is the fastest growing of the lower Keys (Sedway Cooke Associates et al. 1989). With additional human development of the fragile environment, limited space, and a small population of Key deer, the problems associated with human/deer interaction will intensify.

Development of a corridor concept must recognize the manner in which deer and people will be interactive. Even 1-ac lots will create problem settings unless plans accommodate minimizing contact of people with deer. The minimal fencing concept should be maintained to keep deer out of yards around houses, to address deer depredation of landscape plantings, and to control dogs.

CURRENT DEER DISTRIBUTION, NUMBERS, AND MOVEMENTS

Methods

Morning deer surveys were conducted for estimating relative deer use of the three regions of Big Pine Key. Six 33.9-km (21.2-mi) surveys were driven 31 October - 5 November 1989. Two observers (including the driver; the same people for each day) searched from their sides of the vehicle for deer. The earliest starting time was when deer could be clearly identified (0610); the latest starting time was 0700. Vehicle speed was usually ≤ 24 km/h (15 mph); the route took from 1.25 to 1.45 hrs. The survey route included Key Deer Boulevard, Newfound Harbor Road, U.S. Highway 1, Long Beach Road, Wilder Road, Avenue B, and Watson Boulevard from Avenue B to Key Deer Boulevard. Subdivisions were not driven in order to avoid biases associated with deer concentrations there.

Extensive records of deer sign at nontidal wetlands throughout Big Pine Key have been kept since December 1987 as part of an ongoing study by the CWRL. These records were used when addressing deer distribution.

Estimates of current deer numbers and distribution were also aided by field notes of CWRL staff taken during Key deer capture efforts in the southern half of Big Pine Key March - August 1988. Radio telemetry of collared deer and concurrent incidental deer observations from March 1988 to the present also provided insight.

Quantity, quality, and distribution of current habitat types were considered in conjunction with the above information to derive estimates of Key deer numbers and distribution south of U.S. 1. Estimate of deer numbers on the Newfound Harbor Keys is based on observations from visits during radio-tracking and freshwater monitoring.

Deer Distribution

The regional distribution of 53 deer sightings during the early morning surveys was similar to the theoretical distribution of deer based on carrying capacity estimates (Table 2). A larger proportion of deer observed to estimated deer present in the region north of Watson Boulevard may have been due to 1) greater density of deer in that region, 2) greater visibility of deer in relatively open pineland and grassy field (Port Pine Heights) habitats, and 3) an increased presence of deer near roads due to deer being less fearful of humans in and near the Port Pine Heights subdivision. Deer sign at nontidal wetlands throughout Big Pine Key also indicates that deer, at one time or another, are distributed over the entire island.

Deer sign at nontidal wetlands shows that deer use all available space south of U.S. 1. Nontidal wetlands are concentrated in three areas: the south end of Newfound Harbor Boulevard, south of the intersection of U.S. 1 and Key Deer Boulevard, and Cactus Hammock. Along with availability of drinkable water, these areas contain relatively high quality upland plant communities; deer activity is concentrated there. However, there is extensive documented movement of deer between these 3 areas and to the north of U.S. 1 to meet daily, seasonal, and annual needs.

Until recent years when they have been attracted and held by enticements, deer in the Newfound Harbor Keys were fewer in number and present on only a seasonal basis when drinkable water was available. These deer were part of an "ebb and flow" of natural deer movement with and across Big Pine Key.

Deer Numbers

Because of daily, seasonal, and annual movements, it must be understood that the number of deer in a defined area (e.g. south of U.S. 1) is a dynamic concept. Even if it were possible to count every single animal in an area, because of deer movement, one would have to report a range of deer numbers during a specified time unit rather than an "absolute" single number. In consideration of the above, two estimates of numbers of deer south of U.S. 1 are presented. When male Key deer are traveling during the rut, and black mangrove fruits and drinking water are available, an estimated 35 - 45 deer utilize the region south of U.S. 1. This time frame corresponds roughly with September through December. During other times of the year, a speculated 20% decrease in numbers results in a range of 28 - 36 deer. An additional 10 - 15 deer reside in the Newfound Harbor Keys. With the current small Key deer population, the importance of 35 - 45 deer south of U.S. 1 (and an additional 10 - 15 in the Newfound Harbor Keys) cannot be overstated. In the best interests of ensuring the survival of Key deer, safe passage of deer to and from the region south of U.S. 1 must be accommodated.

Deer Movements

It is the nature of Key deer to make extensive movements at various times and for different reasons. Of 119 radio-collared Key deer on Big Pine Key, 90% made long trips out of their "home" range (Silvy 1975).

The longest recorded movement was 11.2 km (7 mi); within a 24-hour period a yearling male traveled over 6.4 km (4 mi). Reasons why Key deer travel:

1. It is normal for deer to travel to obtain daily nutritional needs including fresh drinking water. Especially during drought, many Key deer on the southern half of the island are required to make trips northward to more permanent freshwater sites (Klimstra et al. 1974, Drummond 1989).
2. Deer will travel to obtain food, especially to reach preferred, seasonally available foods (e.g. black mangrove fruits in autumn, palm fruits in summer, etc.) (Dooley 1975).
3. Male deer make trips to all parts of Big Pine Key during the rut (Silvy 1975).
4. Yearling males disperse from their areas of birth; all yearling males (n = 7) radio-tracked by Silvy (1975) dispersed.
5. Pregnant does tend to move to preferred habitats to give birth (Silvy 1975).
6. Adult does are dominant over other deer during fawning and drive others out of their range (Hardin 1974).
7. Deer are known to disperse from certain "core" areas of Big Pine Key with higher quality habitats, and subsequent higher deer densities (Drummond 1989). Refuge lands north of Watson Boulevard, as well as to a lesser degree the entire island, serve as reproductive core areas from which the surrounding islands within the Key deer range are naturally "stocked" (Actions required to insure the viability of Key deer on Big Pine Key, Draft report, 4 April 1989, prepared by a

committee of biologists). A healthy herd on Big Pine Key, reproducing at a level which exceeds annual loss, serves as the "hub" yielding "pioneers" for outlying areas which lack that necessary to be self-sustaining. Some of these deer are transients and/or temporary occupants when carrying capacity is low or habitat inadequate on a year-round basis.

8. There is evidence of tradition in home range use (Marchinton and Hirth 1984) and travel routes used by deer. Key deer are creatures of habit as evidenced by deer trails that, through generations of use, have worn deep into the marl.

9. Because development is creating patch-type habitats, deer must move more to accommodate daily and seasonal needs (Klimstra et al. 1974). Development, through the removal of native vegetation, building, and fencing, essentially displaces deer from where they formerly occurred. These human-created habitat disturbances cause deer to be more "exposed" to a variety of vicissitudes that often result in mortalities as well as undesirable human interactions.

Measures must be taken to ensure that Key deer will have freedom of movement and access to all areas of Big Pine Key, including land south of U.S. 1.

RECOMMENDATIONS

Reevaluation of Key deer data assembled during 1968 - 1973, in-depth review of appropriate literature, consideration of events related to people-generated habitat changes, service needs and travel during the past decade, and recent and current studies serve as the foundation for recommending that:

1. Corridors must be established to permit safe deer crossing of U.S. 1. Findings from roadkill analyses (esp. Drummond 1989) must be the basis for planning habitat acquisition. Management and/or protection of lands both north and south of U.S. 1 as continuous corridors must be of highest priority. Therefore, acquisition and/or protection of lands east of Key Deer Boulevard and Wilder Road is of immediate concern. The immediate protection of all remaining undeveloped land bordering directly on U.S. 1 (Fig. 5) would help insure that safe deer crossing areas can be established; securing all such areas now would provide important flexibility in future planning of corridors. All wetland habitats subject to protection from development by the Federal Clean Water Act, the Endangered Species Act, and the Monroe County Land Use Plan must be included when planning corridors. Criteria for selection of corridor lands must also include minimizing of deer/people interactions. Important existing deer movement areas, as evidenced by deer trails and sign, should be considered when locating corridors. It is <u>essential</u> that there be opportunity for movement of deer in a north and south direction that includes south of

U.S. 1, between U.S. 1 and Watson Boulevard, and northward on Big Pine Key.

2. Fencing large tracts (developed or otherwise) within the corridors should be discouraged, if not prohibited. However, fencing small areas around homesites for protecting landscape plantings, for keeping pets from direct contact with deer, and for restricting the human urge to feed and/or pet the deer should be encouraged. Remaining habitats should remain "native" and as natural as possible.

3. Permanent and seasonal drinking water sources must receive special attention for deer as well as other fish and wildlife. Innovative tactics/arrangements must be employed to ensure access by deer, particularly south of Watson Boulevard and south of U.S. 1. A wide distribution of water holes should be maintained to allow for efficient access to drinking water by deer in natural areas.

4. Any new roads and/or upgrading to create new or extensively-used alternative travel routes, especially parallel to U.S. 1, must be restrained. A possible exception is immediately adjacent to U.S. 1 <u>provided</u> safe crossing for deer is ensured and all habitat loss is deemed acceptable. Road and right-of-way maintenance and traffic flow patterns must reflect that considered in the best interest of the deer.

SUMMARY

The summary is designed to briefly address questions presented in a memorandum (8 September 1989) from the refuge manager of the National Key Deer Refuge (Appendix A). The text of the report should be consulted for details of supportive information regarding particular issues.

Carrying capacity, as used here, refers to the maximum number of Key deer that a given area can support without long-term damage to vegetation. Habitat composition and distribution, deer density estimates, home range size, dispersal, food and water availability, genetic aspects, human/deer interactions, and development and fencing of habitats were considered while deriving estimates of carrying capacity. Big Pine Key as a contiguous, unrestricted unit may support 165 - 195 Key deer (90 - 100 deer for the area north of Watson Boulevard, 40 - 50 between Watson Boulevard and U.S. Highway 1, and 35 - 45 for the region south of U.S. 1). Based on previous and current studies, Key deer, at one time or another, use all available habitats and space on Big Pine Key. Key deer make extensive movements out of their home ranges, at various times and for at least nine reasons (see Deer Movements section).

Question 1) from memorandum: What will happen if the deer herd is fragmented into north and south herds?

Barriers to deer movement such as extensive fences or intensive development will effectively decrease the carrying capacity, and in turn, the population of Key deer. The sum of carrying capacities of the parts (regions of Big Pine Key separated by barriers) clearly will not equal the carrying capacity of the whole (Big Pine Key without barriers). Further, splitting the herd will increase inbreeding and decrease genetic variability. There is no question that splitting the herd will jeopardize the survival of the Key deer.

Question 2) from memorandum: How many deer are there south of U.S. 1 and how important are they to the total population or survival of the Key deer? How important is it to maintain deer south of U.S. 1?

For much of the year, an estimated 35 - 45 deer utilize the area south of U.S. 1. Another 10 - 15 deer reside on the Newfound Harbor Keys. This number of deer is clearly a vital and necessary proportion of an already dangerously small herd. Isolating the lands south of U.S. 1 will, in essence, decrease the already limited land area of Big Pine Key by close to one-fourth. Perhaps more importantly, a barrier at U.S. 1 will reduce the availability and diversity of Key deer food plants (e.g., black mangrove south of U.S. 1) thereby presenting a "nutritional barricade". Access to critical drinking water sites would also be disrupted. The region south of U.S. 1 provides important space for deer dispersing from more northerly portions of the island.

Question 3) from memorandum: Do we need corridors to provide for interchange of deer north and south of U.S. 1? If we don't acquire the corridors what will happen to the deer south of Watson Blvd. and south of U.S. 1?

Corridors are a must. It is <u>essential</u> that deer have opportunities for movement including across U.S. 1, south of U.S. 1, between U.S. 1 and Watson Boulevard, and north of Watson Boulevard. If barriers prevent deer movement, the regions south of Watson Boulevard, due to constraints in year-round availability of food, water, and space, along with complications due to increasing habitat fragmentation and deer/people interaction, cannot be expected to independently support herds of Key deer. Without corridors, the three regions of Big Pine Key would become "islands" unto themselves. The resulting isolated deer populations would be unlikely to make significant contributions to the viability of the Key deer. Findings from roadkill analyses, habitat fragmentation by fences and roads, human/deer interactions, habitat quality and quantity, and location of critical nontidal wetlands must be considered when addressing the corridor concept.

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Table 1. Habitat (plant community) composition in acres (with proportions of totals) of Big Pine Key, by major region. Tidal ponds are not included.

Habitat	Region			
	North of Watson Blvd.	Watson Blvd. to U.S. 1	South of U.S. 1	Newfound Harbor Keys
Open-developed	525.4 (18.7)	512.0 (34.4)	266.5 (20.3)	3.8 (1.7)
Hammock	44.8 (1.6)	0.0 (0.0)	31.8 (2.4)	26.7 (12.2)
Hardwood	206.3 (7.4)	16.5 (1.1)	159.7 (12.1)	5.7 (2.6)
Pineland	987.2 (35.2)	679.4 (45.7)	88.8 (6.8)	0.0 (0.0)
Scrub-mangrove buttonwood	811.5 (29.0)	262.5 (17.7)	539.9 (41.1)	18.3 (8.4)
Mangrove forest	225.9 (8.1)	16.3 (1.1)	226.7 (17.3)	164.1 (75.1)
Totals	2801.1 (100)	1486.7 (100)	1313.4 (100)	218.6 (100)

Table 2. Deer observed during six morning surveys (with proportion of totals) and estimated numbers of deer in three regions of Big Pine Key.

Region	Numbers Observed During Surveys	Estimated Numbers of Deer[a]	Proportion Observed/Estimated
North of Watson Blvd.	34 (64)	95 (53)	0.36
Watson Blvd. to U.S. 1	10 (19)	45 (25)	0.22
South of U.S. 1	9 (17)	40 (22)	0.23
Totals	53 (100)	180 (100)	

[a] Midpoints of carrying capacity ranges (see report)

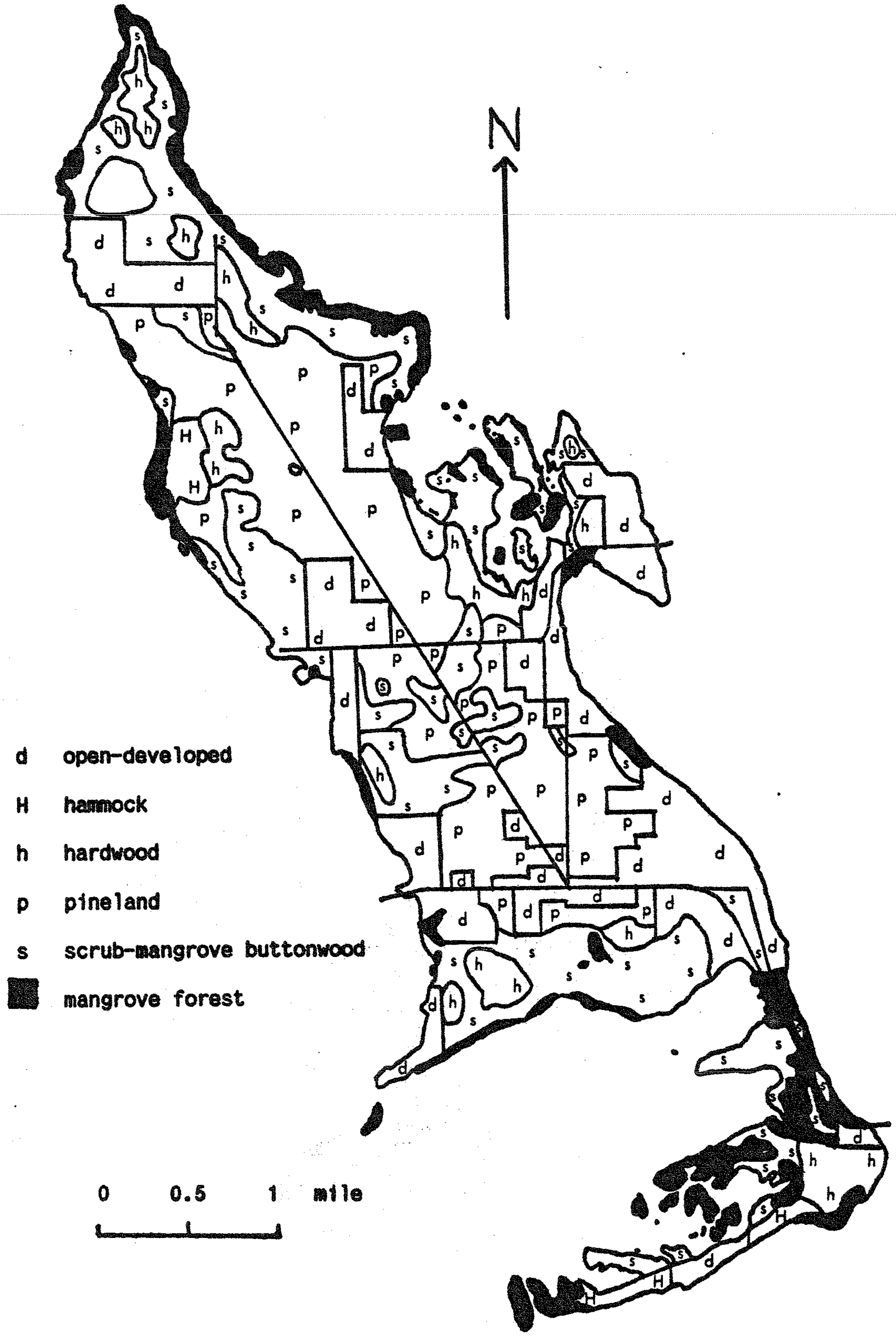

Fig. 1. Generalized habitat composition map of Big Pine Key.

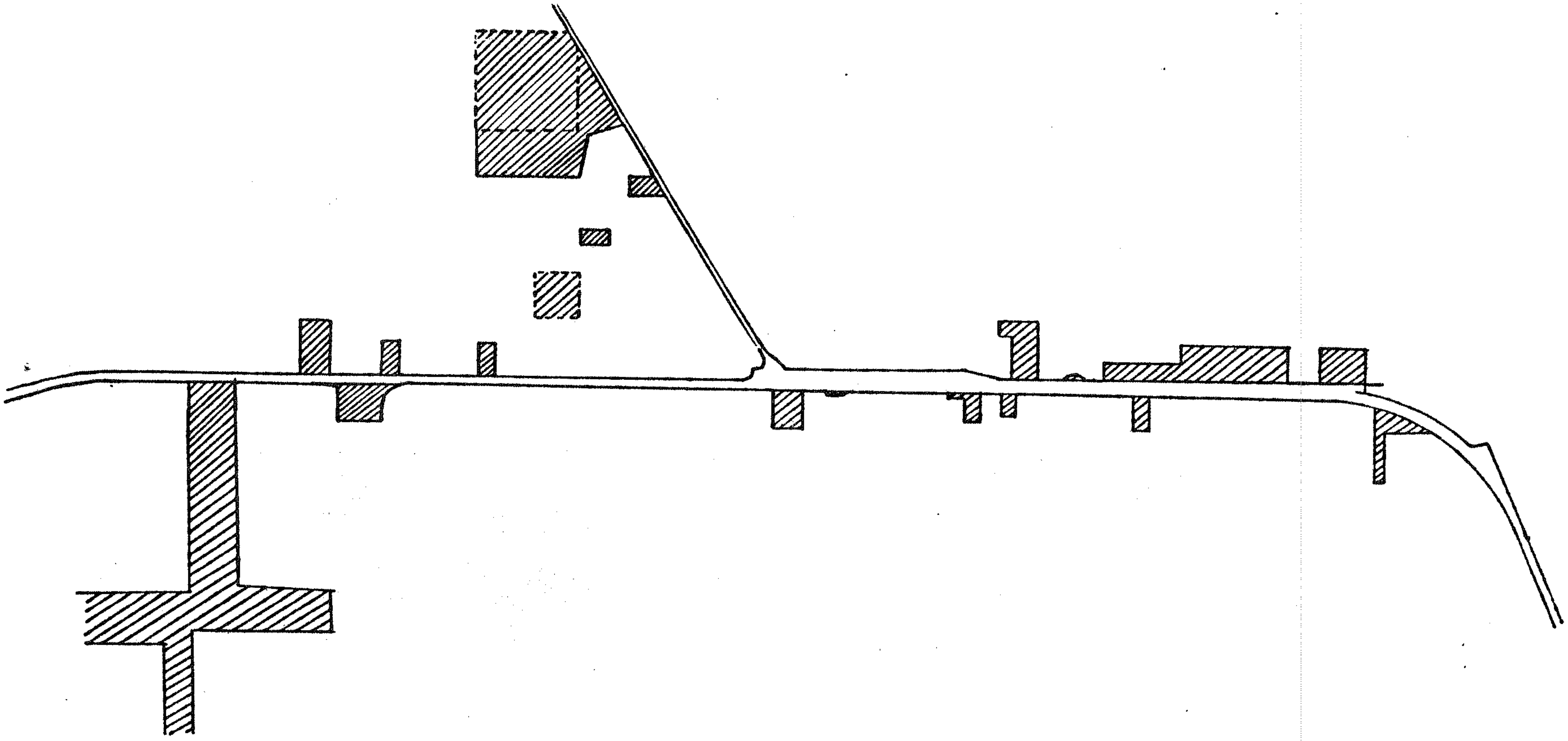

Fig. 2. Developed and cleared areas along U.S. 1 in 1963. Wilder Road had not yet been constructed. Locations are approximate.

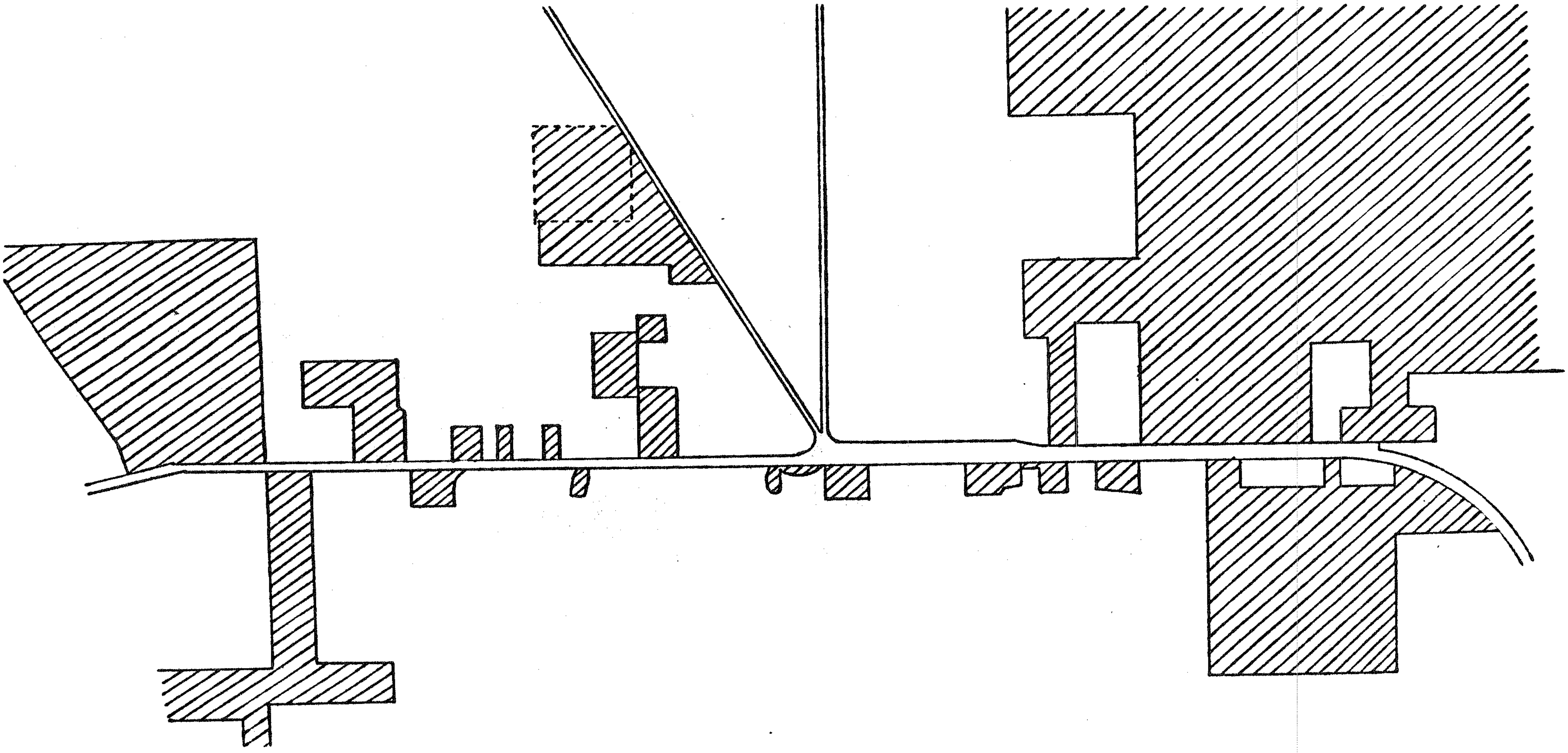

Fig. 3. Developed and cleared areas along U.S. 1 in 1971. Locations are approximate.

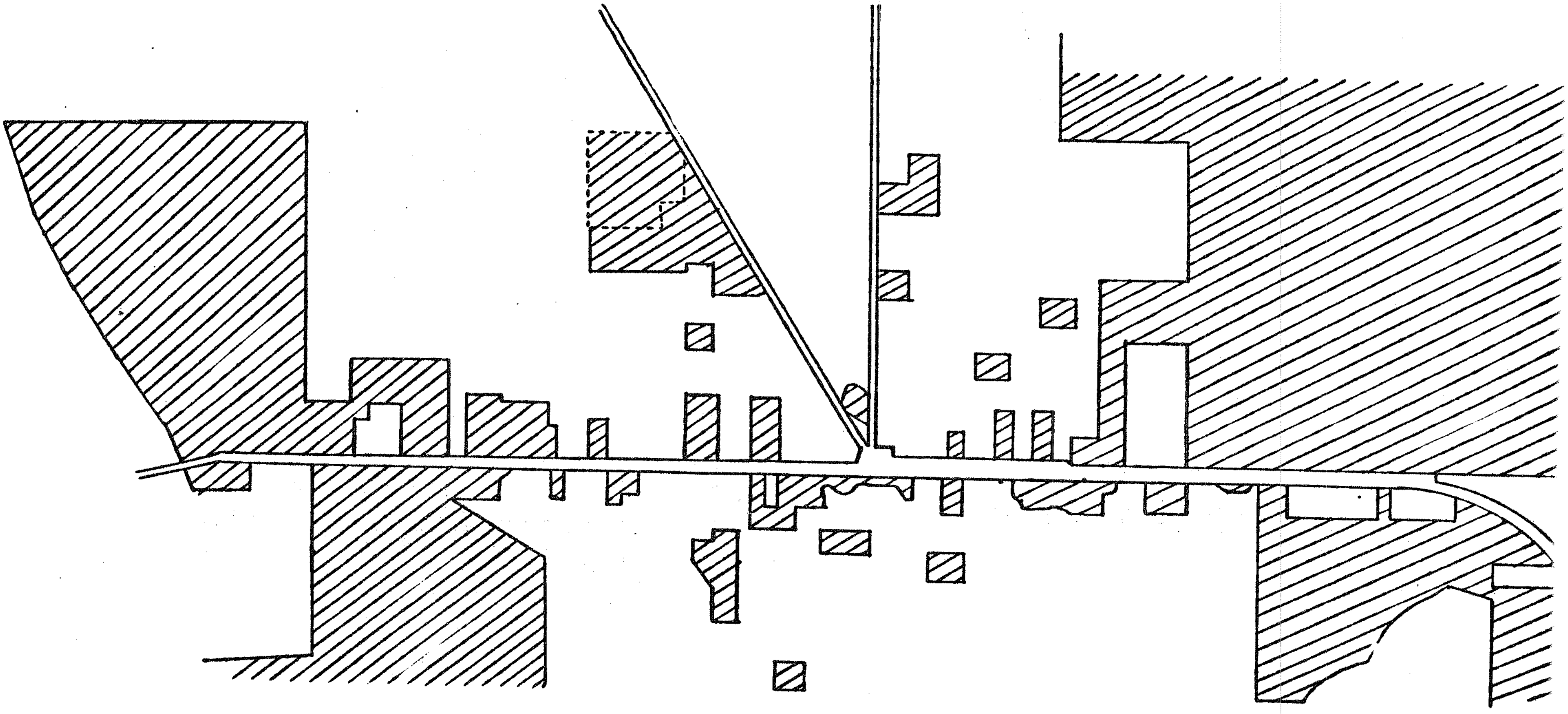

Fig. 4. Developed and cleared areas along U.S. 1 in 1981. Locations are approximate.

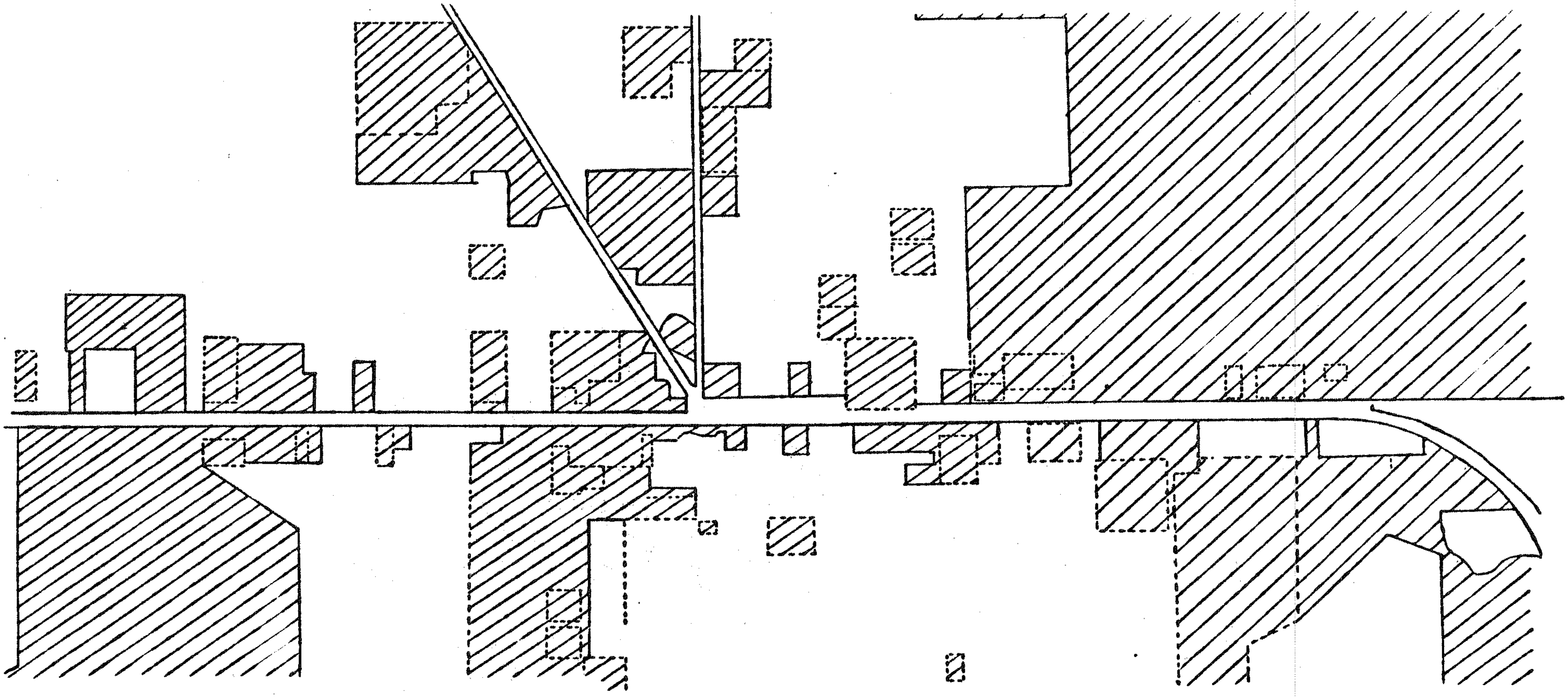

Fig. 5. Developed and cleared areas along U.S. 1 in 1989. Fences are denoted by dashed lines. Locations are approximate.

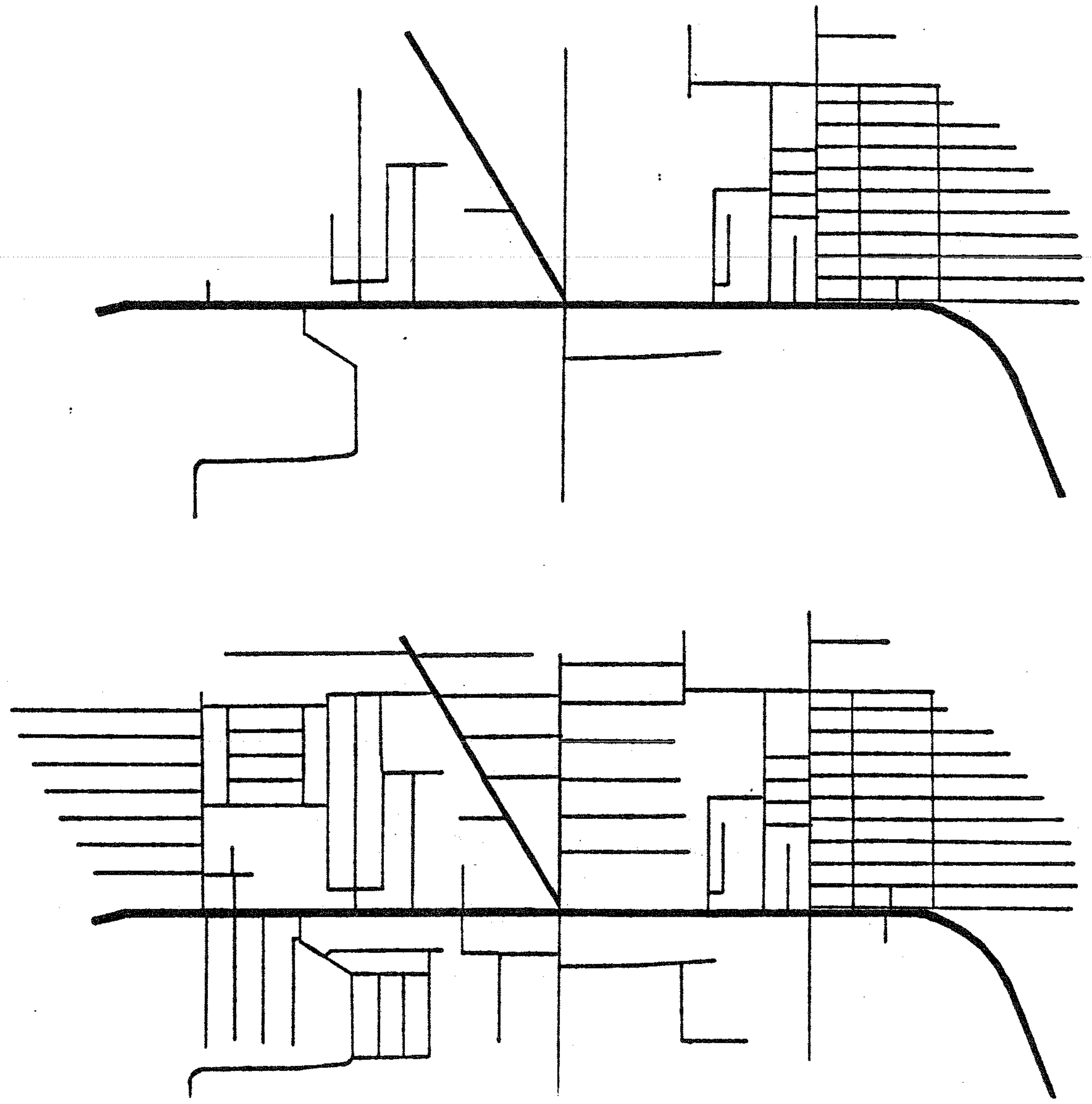

Fig. 6. Roads along U.S. 1 in 1966 (top) and 1989 (bottom). Locations are approximate.

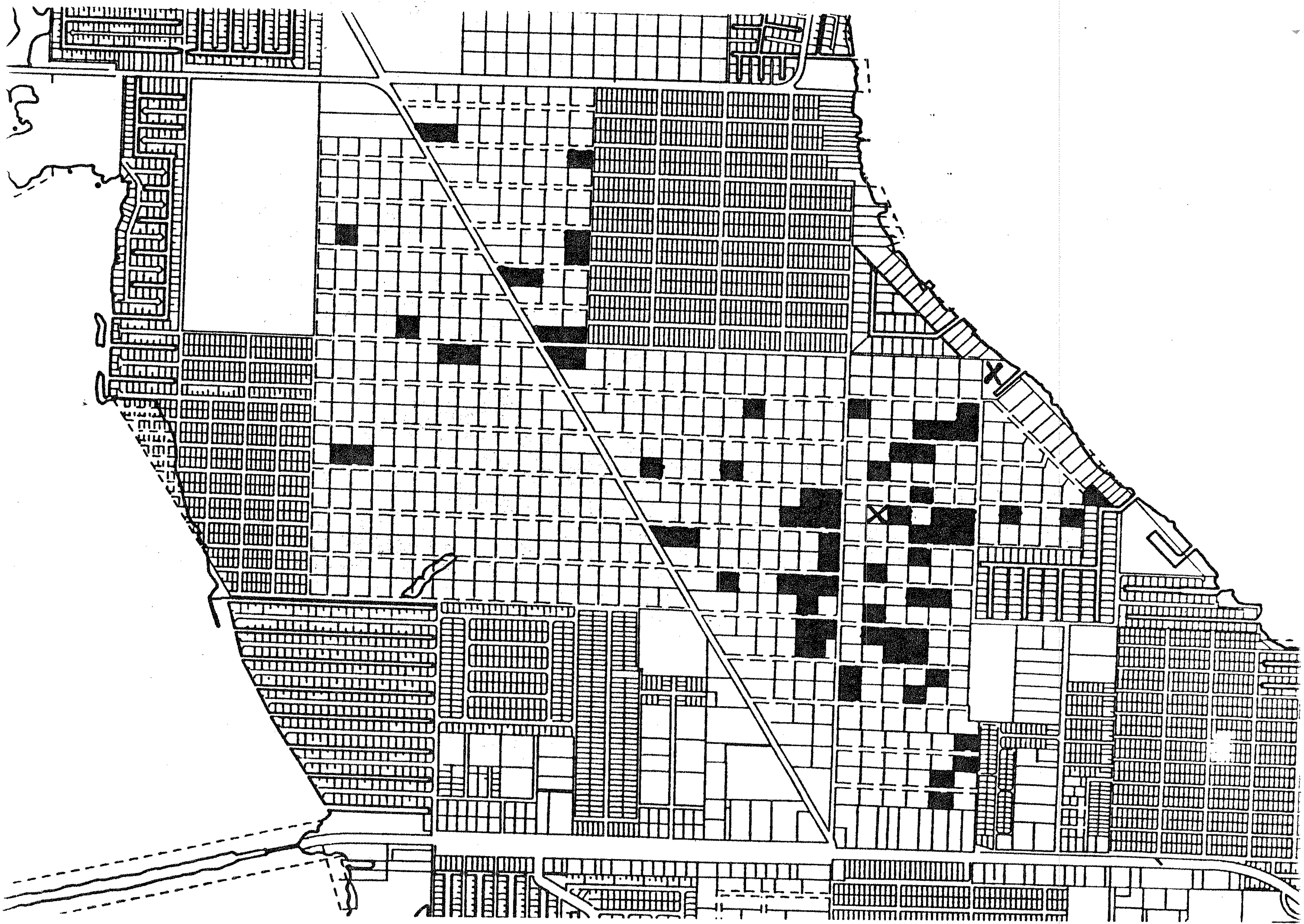

Fig. 7. Concentration of fenced lots between Watson Boulevard and the U.S. 1 commercial district on Big Pine Key. Lots marked with x's were fenced in the early 1970's. Shaded lots represent fenced area since that time. Locations are approximate.

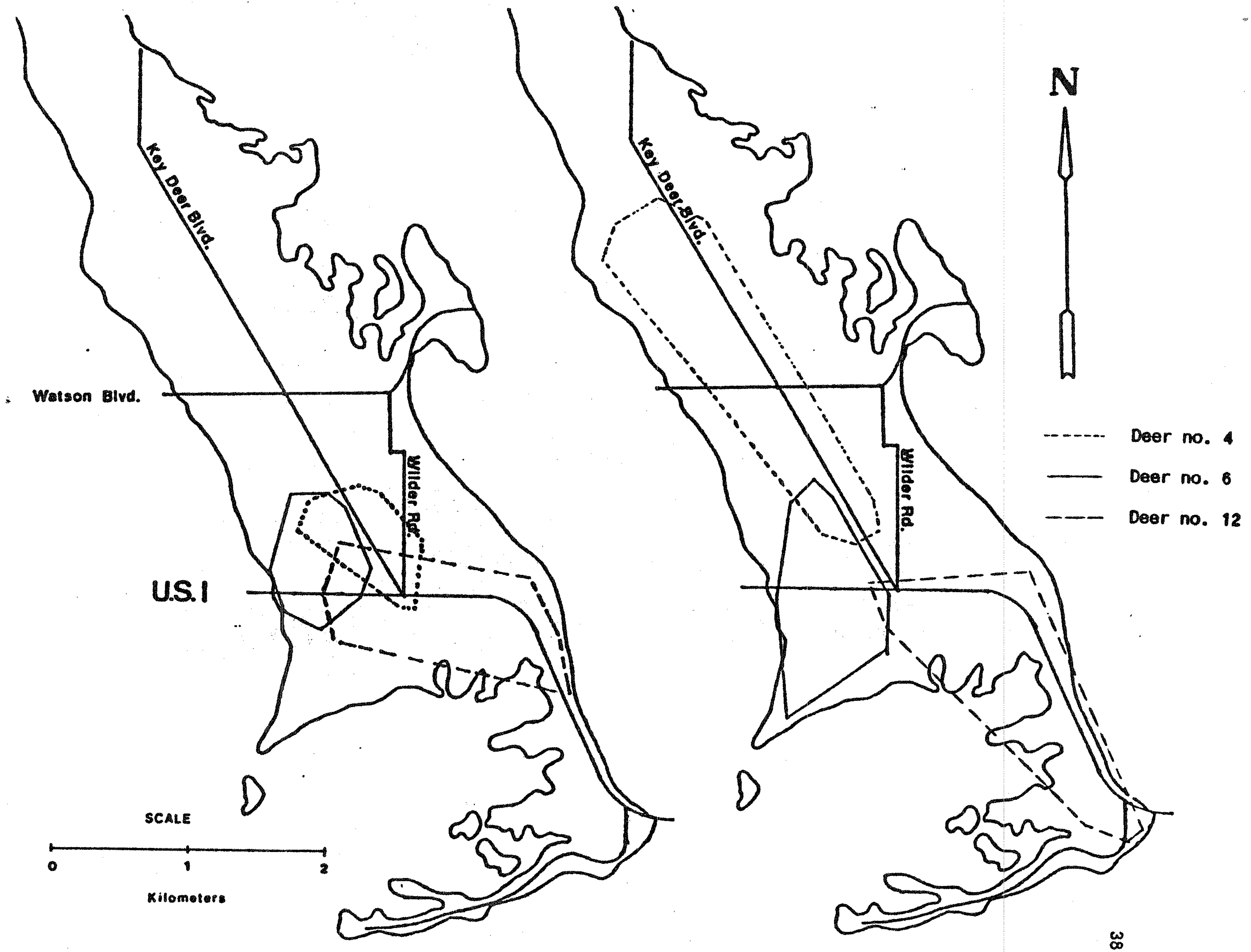

Fig. 8. Summer (left) and breeding season (right) home ranges of 3 adult male Key deer. (After Drummond 1989.)

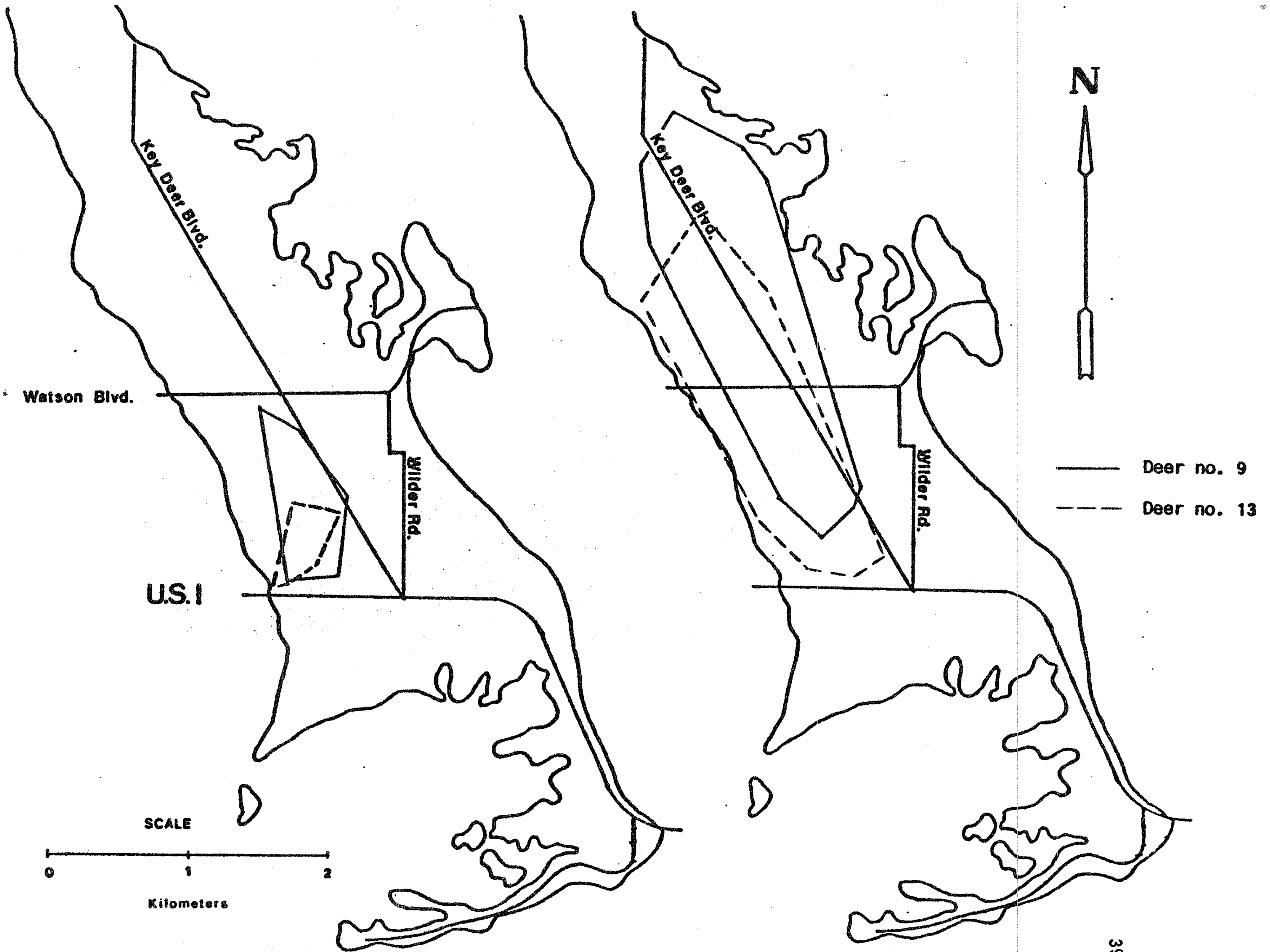

Fig. 9. Summer (left) and breeding season (right) home ranges of 2 adult male Key deer. (After Drummond 1989.)

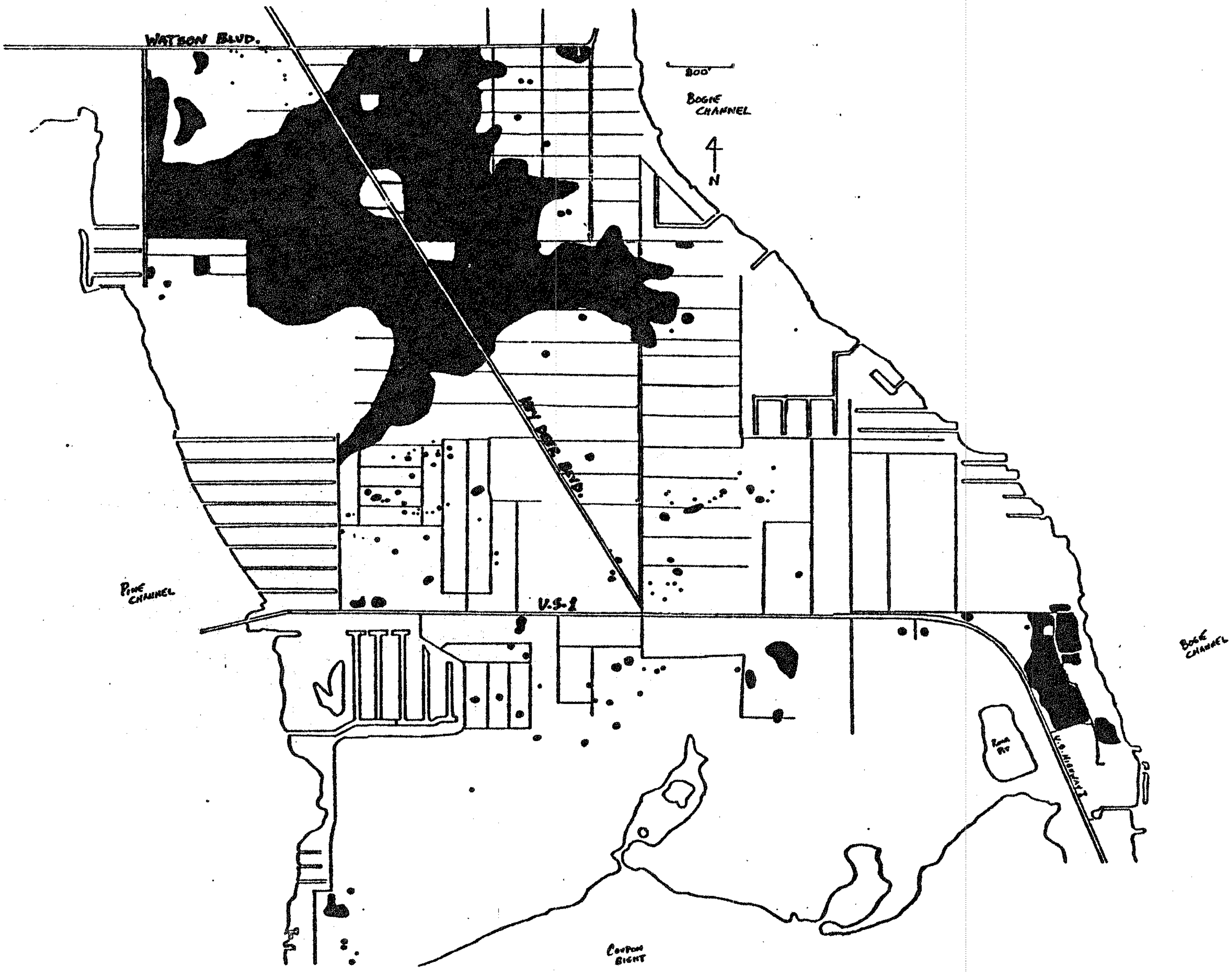

Fig. 10. Shaded areas represent seasonal and permanent freshwater and nontidal wetlands mapped to date (12/89) south of Watson Boulevard on Big Pine Key. Residential fill areas scattered in the large area of wetlands and wet pine flatwoods immediately south of Watson Boulevard are not shown. Locations are approximate.