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STATISTICAL METHODS FOR DETERMINING THE SIZE OF FURBEARER
POPULATIONS IN MICHIGAN: RACCOON POPULATION DYNAMICS AND
POPULATION SIZE ESTIMATION USING MARK-RECAPTURE IN THE
ROSE LAKE AREA

By

Gina Lyn Ballard Karasek

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
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ABSTRACT

STATISTICAL METHODS FOR DETERMINING THE SIZE OF FURBEARER POPULATIONS IN MICHIGAN: RACCOON POPULATION DYNAMICS AND POPULATION SIZE ESTIMATION USING MARK-RECAPTURE IN THE ROSE LAKE AREA

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In the Upper Peninsula of Michigan, a modified mark-recapture estimator is used to estimate the black bear population size. Bears are marked through tetracycline laced baiting and recaptured through harvesting. The accuracy of these population estimates has not been assessed. This study proposed to examine the biases associated with this estimator and to develop an alternative method of estimating the black bear population size. A raccoon population was used as a surrogate species in a field study to determine the biases. Population dynamics were examined by monitoring radio-collared animals and a marking and harvest recapture study was conducted to estimate population size of the raccoons. Close scrutiny of the assumptions of the estimator was done using the population dynamics information. In addition, the current methodology used to determine the size of the black bear population was examined for potential biases and recommendations were developed to improve the quality of the estimator.

Similar problems with violation of assumptions were found for both raccoon and black bear. The biggest problem was the violation of the assumption that all individuals in

Gina Lyn Ballard Karasek

all sex and age classes have an equal chance of being marked and harvested. Recommendations to reduce the bias in the black bear estimator were 1) the population estimate for a year should be conducted using only harvest data from the year of marking, 2) the number of marked bear known to die before the harvest should be subtracted from the number of bears marked in the first sample, 3) the estimator may be used only every 3-5 years rather than annually and an index, such as the W-K model developed in this dissertation, could be used in intervening years, and 4) tooth collection from all harvested bears and sex ratios should continue to be recorded annually to provide information on changes in the sex and age structure of the harvested population.

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INTRODUCTION

Many aspects of wildlife management, such as habitat management and regulation of harvests, are dependent upon some type of population size estimate for the species being managed. Many state management agencies use harvest data to help estimate the population size of game species, especially species such as black bear (Ursus americanus), which inhabit large forested areas and are difficult to enumerate through visual counts. In the Upper Peninsula of Michigan, a modified mark-recapture estimator is used for black bear, in which bears are marked through tetracycline laced baiting and recaptured through harvesting. The accuracy of these population estimates has not been assessed.

This study proposed to examine the biases associated with the estimator and to develop an alternative method of estimating black bear population size. To determine the biases, a raccoon (Procyon lotor) population was used as a surrogate species in a field study to examine population dynamics such as reproduction, survival, sex and age structure, and movements. This portion of the study is covered in CHAPTER I. In addition, a marking and harvest recapture study was conducted to estimate population size of the raccoons. Examination of the dynamics of the population allowed close scrutiny of whether the assumptions of the population estimator were being met. The population size

estimator for raccoons and an assessment of the black bear population estimates are found in CHAPTER II.

CHAPTER I. RACCOON POPULATION DYNAMICS IN THE ROSE LAKE AREA

INTRODUCTION

In North America, raccoon numbers began to increase in the 1940's (Stuewer 1943a, Sanderson 1987) after an extended period of low population levels in the 1930's. High population levels have been maintained since then, and the species has increased its range into previously unoccupied areas (Sanderson 1987). Only local population declines have been reported during this time, usually due to diseases, such as rabies and distemper (Mumford and Whitaker 1982), or heavy harvest levels, as in Kentucky (Patterson 1986, Roloff 1990, Norment 1991). However, over its entire range in North America, even without significant management activities, an increased harvest did not result in decreased raccoon population levels mostly because the raccoon is so adaptable (Sanderson 1987). As forested areas decreased in size, raccoons began to occupy grassland and farmland habitats, as well as city areas (Mumford and Whitaker 1982).

Raccoon hunting and coon dog training is a popular sport. Fur harvest and vehicle accidents are the main causes of mortality in raccoons (Sanderson 1987, Glueck et al. 1988, Clark et al. 1989, Hasbrouck et al. 1992). In the United States, the raccoon was second only to muskrat (Ondatra zibethica) in total volume of fur harvested in 1982-1983 (Shieff and Baker 1987).

In the Great Lakes area, harvest densities are reported to be among the highest in the nation, with 1-10 raccoons

harvested per km² (Sanderson 1987). In Michigan, an estimated 646,000 raccoons were harvested by hunters and an additional 216,000 were trapped from 1986-1988 (Reis 1989). However, by 1993 only an estimated 94,190 were harvested by hunters and 45,831 were trapped (Karasek and Moritz 1995).

In the United States from 1982-1983, an estimated average of \$125 annually was spent per raccoon hunter on hunting related items (United States Department of Interior 1985). Using this figure, an estimated total of 3129 raccoon hunters in Michigan (Karasek and Moritz 1995) in 1993 would have contributed \$391,125 to Michigan's economy. The addition of an estimated 2630 trappers in 1993 would have substantially increased that amount. However, annual contributions to the Michigan economy from 1986-1988, when number of raccoon hunters and trappers were much higher (Reis 1989), would have been over \$1 million from hunters alone. Therefore, the drop in number of raccoon hunters and trappers represents a large loss to the Michigan economy. It is possible that the decreased raccoon harvest effort in Michigan can be attributed mainly to a decrease in fur prices in recent years due to anti-fur protests by animal rights organizations.

Without significant harvest levels to help control raccoon populations, this highly adaptable species has increased its numbers in recent years throughout Michigan. As a result, damage and nuisance complaints involving raccoons have become so numerous that MDNR personnel are

unable to effectively deal with them. To encourage people with raccoon problems to control raccoon numbers on their own, Michigan hunting regulations have recently been changed so that "Raccoons may be hunted or trapped on private property by a property owner or designee during the closed season if they are doing or about to do damage on private property. A license is not needed." (Michigan Department of Natural Resources 1994). However, in urban and suburban areas, pest control agencies are generally called in to remove unwanted raccoons from homes because many people are unwilling to kill these animals.

Raccoon habitat is usually described as being forests and wooded areas, especially hardwoods with hollow trees, and especially near water where they travel along drainage ditches, creeks, and rivers (Hartley and Jackson 1961, Mumford and Whitaker 1982). However, the adaptability of this species to a wide variety of habitats is apparent. Besides the typical tree dens and ground burrows, use of barns, crop storage facilities, garages, an abandoned truck trailer, a basement window well, unused heating stoves, chimneys, attics, porch roofs, and a tractor engine compartment have all been reported by the public in the past four years to this researcher as being used by either wintering raccoons or female raccoons with litters.

Damage to buildings or crops by raccoons can occur due to actual destruction by the animals or when wastes are left

behind and accumulate during denning. In addition, people have complained of raccoons raiding garbage and pet feed.

Another consequence of lower harvest levels is the increased risk of diseases and parasites that is associated with a high raccoon population density. In the eastern United States and Canada where raccoon densities have reached high levels, rabies has become a serious health threat to humans and other animals. Oral vaccines have been widely distributed in baits in an attempt to control the spread of rabies by raccoons and other wildlife species (Hanlon et al. 1989, Perry et al. 1989, Bachmann et al. 1990). Although not yet believed to be a problem in Michigan, rabies is reported to be moving through wildlife populations from Ohio to Michigan. It is not known when the disease will reach this state in epidemic levels, but high raccoon numbers will help to spread the disease much more quickly. The spread of rabies through raccoons rather than other wildlife species tends to have much more serious implications for humans because raccoons can occur in high numbers in dense human population centers as well as in rural areas (Perry et al. 1989).

Other diseases and parasites that can be spread through raccoon populations include canine distemper, mange, and parvovirus (Mech et al. 1968, Clark et al. 1989, Hasbrouck et al. 1992). Canine distemper is considered an important factor controlling carnivore populations (Gorham 1966). The spread of this highly contagious and lethal disease by

raccoons could become serious if high raccoon numbers are maintained. Again, because raccoons have adapted their range to include urban centers, the spread of this disease from raccoons to domestic dogs or other canids could result in an epidemic. Parvovirus has similar potential. Although not lethal, mange can be transmitted to humans as well as other animals (B. Johnson, MDNR Wildlife, pers. comm.). Currently, little is known about the status and spread of these diseases through wildlife populations in Michigan, so the implications of a continued increase in raccoon numbers for disease outbreaks can only be hypothesized.

Because of the spread of rabies, many eastern states destroy pest raccoons when they are captured by control agencies rather than move the animals to more suitable habitat (Critter Control 1994). In Michigan, transplanting of pest animals is a viable alternative to euthanasia at present because rabies is not yet known to be a problem. However, Critter Control, a national pest control agency, states that there has been very little research done on relocation of nuisance animals (Critter Control 1994). Therefore, little is known about the survival of translocated pest raccoons or the likelihood that they will continue their nuisance tendencies at their release sites.

Raccoon populations in Michigan were studied extensively from 1939-1941 (Stuewer 1943a). Much research on raccoons has been compiled since then in other states (Dorney 1954, Mech et al. 1968, Urban 1970, Fritzell 1978,

Fritzell et al. 1985, Moore and Kennedy 1985, Clark et al. 1989, Roloff 1990, Norment 1991, Hasbrouck et al. 1992), but little in Michigan (Stuewer 1948; Gysel 1961). Due to differences in climate, harvest pressures, and surrounding habitats, raccoons in other parts of the United States may have very different habitat use patterns and population dynamics than Michigan raccoons. In addition, anti-fur sentiment is unlikely to disappear in the near future, so there is no reason to expect fur prices and thus raccoon harvest levels to increase anytime soon. Therefore, the resulting high population numbers of raccoons in Michigan are expected to continue to cause an increase in both nuisance and disease related problems. A better understanding of the current population dynamics of raccoons in Michigan is needed to provide information for making effective management decisions to deal with these and other potential raccoon-related problems.

In this study I examined movements, survival, and reproduction of raccoons in an unexploited population. This information can be used to assess the current status of and likely future changes in Michigan raccoon populations. In addition, a pilot study was initiated to observe whether transplanted pest raccoons would stay at their release site without causing further nuisance problems.

OBJECTIVES

The specific objectives of this study were as follows.

- 1) In an unexploited population of raccoons to:

- a) describe movements and den use of radio marked animals during the winter denning, breeding and kit-rearing (spring and summer), and fall seasons;
- b) estimate survival of yearling and adult animals throughout the year; and
- c) estimate proportion of females that were lactating.

2) In each of an unexploited and an exploited population of raccoons to:

- a) describe the age structure and sex ratios of the populations;
- b) estimate body weights of animals during spring and fall seasons;
- c) estimate reproductive rates for female raccoons; and
- d) estimate summer and fall mortality due to vehicle accidents.

3) To determine movements and survival of two translocated raccoons from agricultural residences to the Rose Lake Area.

As originally formulated, this study also included an examination of population responses, i.e. movements and sex and age structure, to increased rates of exploitation. However, harvest of raccoons at the Rose Lake Area was negligible during this study. Therefore, these objectives were necessarily modified or omitted during the study period (see CHAPTER II).

All research protocols were reviewed and approved by the All-University Committee on Animal Use and Care.

STUDY AREA

This study was conducted from April 1992 to March 1995 on the Rose Lake Wildlife Research Area. The Rose Lake Wildlife Research Area is located 19.4 km northeast of Lansing, Michigan. The 1446 ha are characterized by moderately rolling topography in farmland, abandoned fields, upland and lowland brush and wooded areas, and open wetlands. The area is divided into seven color-coded sections. This study was conducted in the Orange, Yellow, and Green (west of Upton Road only) areas (Figure 1). The Yellow and Green areas (the Yellow and Green areas are hereafter referred to as the Yellow area) were closed to raccoon hunting and trapping during the 1992-1994 seasons to provide the unexploited area, although the unexploited area was subjected to a trapping harvest by researchers during January-March, 1995. Mud Creek runs north to south through this area and is surrounded by lowland woods and brush with a portion of upland hardwoods. Some marsh areas exist along with a few wildlife habitat patch plantings. The Orange area remained under normal hunting and trapping conditions to provide the exploited population. Throughout the study the hunting season generally began October 1 and continued through January 31, while the trapping season began in mid-October or later and ended January 31. Vermilion Creek runs from the northern portion of this area in a clockwise direction west, south and then east where it exits the area in the southeast. Lowland woods and brush and a large area

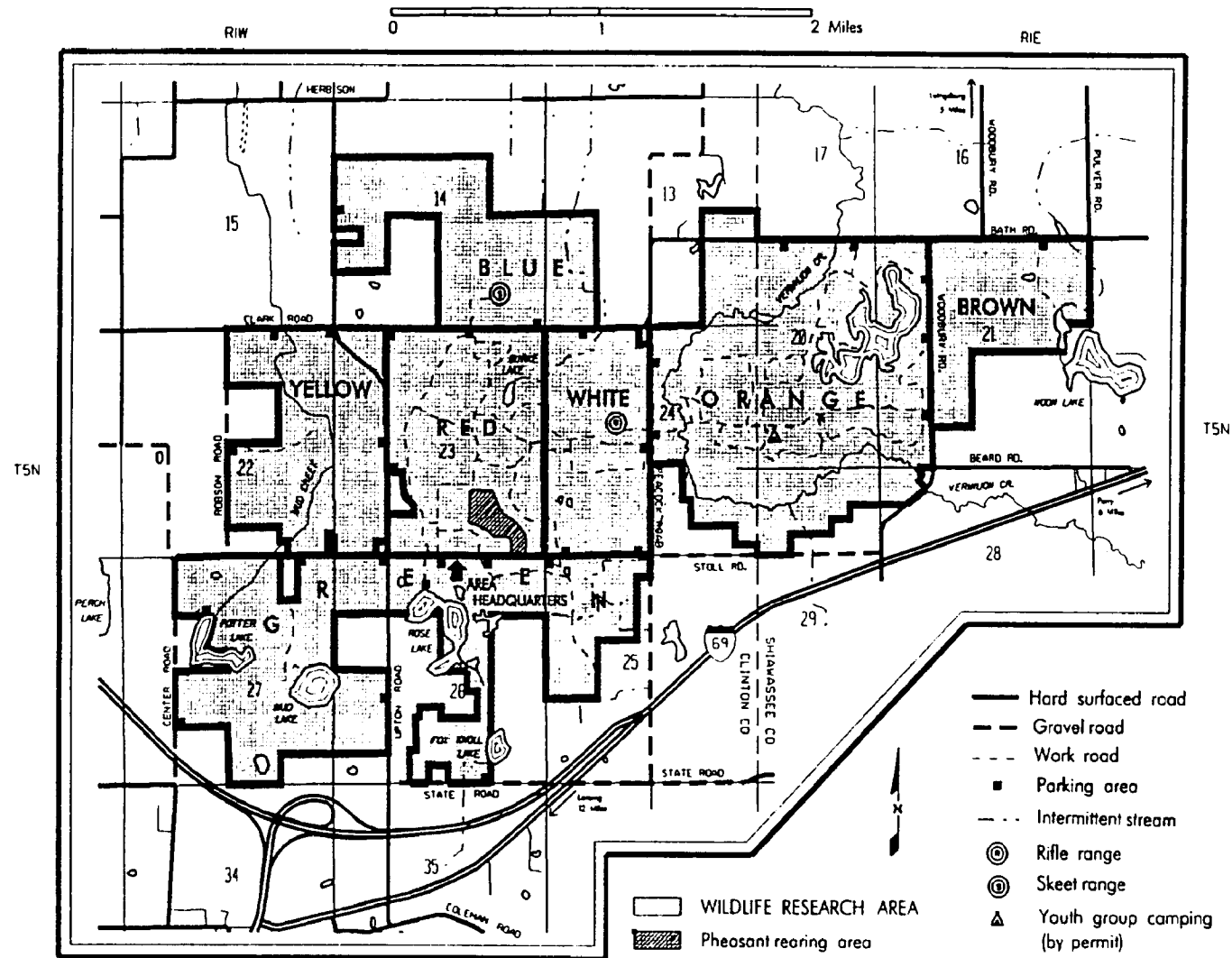


Figure 1. Rose Lake Wildlife Research Area (MDNR 1972).

of upland hardwoods lie along the creek. A large man-made flooding covers the northeastern portion of the area. Several upland brush areas and wildlife habitat patch plantings also exist in the area. The Red and White areas lie between these two areas and served as a buffer zone to decrease the likelihood that raccoons would move from one area to the other.

METHODS

Live trapping and Marking Procedures

Live trapping was done in the spring and fall of each year. Timing and length of trapping sessions within a season were dependent upon weather and availability of field assistants. A summer trapping period was attempted at the end of July, 1992 but was terminated on the third day. Only 1, 1.9 kg kit (young of the year) raccoon was captured. I believe that a raccoon of such small size is still very dependent on its mother, and if it is unable to find her when it is released the next day, it may be unable to survive alone. Based on these initial results, summer trapping was halted. Collapsible wire live traps (Tomahawk Live Trap Co., Tomahawk, Wisconsin) were placed along water avenues in each study area. Throughout the study, canned tuna placed in a small jar was used as bait, although sardines, smelt, and bluegill parts were occasionally used during spring 1992. Initially, fourteen traps were set in the Orange area along Vermilion Creek, while another 14 were

set along Mud Creek in the Yellow area. The number of traps set each night varied throughout each period.

Each captured animal was anesthetized using ketamine hydrochloride (Ketaset, Aveco Co., Inc., Fort Dodge, Iowa) at a rate of 11 mg/kg before being removed from the trap (Seal and Kreeger 1987). Kits were given approximately half that dose due to their small size and the possibility of adverse reactions to the drug. Because the raccoon's eyes remain open while under Ketaset anesthesia, the eyes were shaded from exposure to the sun, and a sterile antibiotic ointment (bacitracin-neomycin-polymyxin veterinary-ophthalmic-ointment, Pharmaderm, Altana, Inc., Melville, New York) was placed into each eye immediately after the animal was removed from the trap.

Animals were sexed and marked with a numbered ear tag in each ear (Monel #4; National Band and Tag Co., Newport, Kentucky) and given an intramuscular shot of 100 mg oxytetracycline (Liquamycin LA-200, Pfizer, Animal Health, New York, New York) for additional marking of the teeth. From spring 1993 on, only one ear tag per raccoon was numbered, while the other had 'Contact MSU' and a phone number printed on it.

The first upper premolar was extracted from each captured adult raccoon and frozen for age analysis (Johnston et al. 1987) (see Age Analysis). The first premolar is a single rooted tooth which is fairly easily extracted from a live anesthetized raccoon, and the gums were found to have

healed well in raccoons that were subsequently recaptured. This provided a baseline age structure for each area.

Ear tag numbers of animals that were recaptured during the same year that they were originally marked were recorded and these animals were weighed and released immediately. Nontarget species, mostly opossum (Didelphis virginiana) and woodchuck (Marmota monax), were immediately released with minimal handling.

For the second year, procedures remained the same for initial captures. However, recaptured animals that were originally marked in 1992 were given a second shot of 100 mg of oxytetracycline (to give the animals a second mark) before being weighed and released.

For the third year, trapping procedures remained the same as the first two years, except that no oxytetracycline was administered, and only spring trapping was done. During August 1994, tetracycline-laced baits were dispersed in both areas for consumption by raccoons in an attempt to mark animals that may not have been susceptible to live traps. In the Orange (exploited) area, a 250 mg tetracycline hydrochloride (tetra-HCL) capsule (Aligen, Independent Laboratories, Inc., Jackson, Wyoming) enclosed in bacon bait (approximately 1" diameter) was placed every 200 meters on both sides along Vermilion Creek and approximately 400 meters out from the creek. The tetracycline laced baits were placed similarly in the Yellow (unexploited) area except at every 400 meters along Mud Creek, and 400 meters out. Baits

were checked for consumption and replaced every 3 to 5 days for approximately 3 weeks, for a total of 409 baits in the Orange area and 169 baits in the Yellow area (APPENDIX A). According to tracks at the bait site, forty-two baits were assumed to have been taken by raccoons. Raccoons marked through baiting in the third year were distinguishable from animals marked during the first two years by an absence of ear tags and their age at marking.

Tetracycline has previously been used as a biomarker in raccoons to determine if a certain bait was eaten by an individual animal (Hanlon et al. 1989, Perry et al. 1989, Bachmann et al. 1990, Fletcher et al. 1990). Generally, 100-200 mg tetracycline-HCL has been used per dose (Hanlon et al. 1989, Perry et al. 1989, Bachmann et al. 1990, Fletcher et al. 1990).

Mean weight loss from fall to spring and mean weight gain from spring to fall were estimated on recaptured individuals. A two-sample t-test was used to compare mean weight change from fall to spring between males and females. For both sexes combined, one-tailed paired t-tests were used to see if significant weight loss occurred from fall to spring, or if significant weight gain occurred from spring to fall.

Body weights were compared between lactating and nonlactating females using a two-sample t-test within each spring live trapping season.

Age Analysis

The first upper premolar, a single rooted tooth, was pulled from live anesthetized raccoons during live trapping. All teeth were placed in a freezer for storage until they were processed at the end of the study. The teeth were placed in a decalcifying solution (10% hydrochloride) overnight, then rinsed in water and stored in a refrigerator. The teeth were then placed in a cryostat, and allowed to freeze before slicing into micro-thin cross sections using a single edged knife blade. Approximately 6-10 sections, taken at various distances from the root tip to the middle of each tooth, were placed on a microscope slide with water. Slides were stained and examined under a microscope to count the number of annuli. For raccoons, it was found that one annulus, including a dark portion during slow growth in winter and a light portion during faster growth in summer, was produced per year. However, a few animals showed several somewhat darker lines within the light portion of each annulus, which were suspected to be slower growth periods within the faster growth periods, probably due to stresses such as illness, injury, or reproductive activities. The pulp cavities in raccoon teeth do not grow closed until one year of age or older. Thus it was important for proper age determination to closely examine cross-sections from both the root tip and the middle portions of the teeth to determine where the first year's annulus lies.

For raccoons that were found dead at least one year after their marking, age determination through tooth analysis was verified by comparing the tooth from the raccoon at its initial capture with a tooth from the same raccoon at death. Because the approximate date of tetracycline marking was known for all raccoons in the area, verification was also done by examining the number of annuli that were produced since tetracycline marking.

Radio-collars

The Yellow area (west of Upton Road) were closed to raccoon hunting and trapping for the 1992 through 1994 seasons (through January 1995). This provided an unexploited area to examine population dynamics, with only natural mortality being measured. In this area, basic population demographic information was collected.

During live trapping, a 130g lithium powered radio transmitter collar (Advanced Telemetry Systems, Inc., Isanti, Minnesota) was placed on a raccoon only if the radio-collar was less than 4% of the animal's body weight. This was to ensure minimal stress on the animal from the added weight of the radio. Each radio-collar contained a mortality sensor, which caused the transmitting pulse rate to double if the animal was motionless for 8 hours. Battery life expectancy was 2 years at the normal transmitting pulse rate. A total of 15 raccoons, 7 males and 8 females, were collared. Radio-collared animals were monitored at least weekly during daylight hours to determine movements, den

use, and survival. Monitoring was also done during nighttime hours several times per season in an attempt to locate raccoons for which signals were not received during the day. Nighttime monitoring was conducted during daylight hours, at two hours after sunset, halfway through the night, two hours before sunrise, and again during daylight hours that following day. Total number of relocations was 737. Total number of visual relocations was 195.

Radio locations were marked on a U.S.G.S. topographic map. If the animal was located in a tree, the tree species, diameter at breast height (d.b.h.), and the height of hole or branch where the animal was located were recorded. A two-sample t-test was used to compare mean d.b.h. and mean height between hole den trees and branch den trees. Radio-collar monitoring continued through February, 1995.

Harvest

Because the legal exploitation (hunting and trapping) rate was negligible, the exploitation rate was artificially increased in both areas during early spring 1995, i.e. following the third raccoon season. In January-March 1995, the MDNR Wildlife Division provided an experienced trapper to harvest raccoons from both the unexploited and exploited areas using leghold traps (Nos. 1 and 1 ¹/₂, Woodstream, Inc., Lititz, Pennsylvania). From each harvested animal, sex and ear tag numbers (if marked) were recorded, and a canine tooth was collected. The reproductive tract was also

collected from females to determine reproduction through number of implantations or placental scars (Sanderson 1987).

To examine tetracycline marking, collected undecalcified teeth were cut using a double-bladed diamond saw into a single longitudinal section of approximately 60-150 micrometers (Perry et al. 1989, Fletcher et al. 1990). Sections were examined under ultraviolet light to determine the presence of fluorescing bands (which appear yellow) in the dentin and cementum layers (Johnston and Watt 1981, Johnston et al. 1987, Perry et al. 1989, Fletcher et al. 1990). If a mark was observed, the section was cut in half and one half was decalcified and stained for age analysis. The stained and unstained halves were then aligned on a microscope slide by matching annuli. This allowed determination of age of the raccoon and the year(s) of marking.

Experimental Transplants

Two male raccoons were trapped using Tomahawk live traps at two different sites distant from the study area where raccoons have been known to cause nuisance problems. Each animal was treated as described above in Live trapping and Marking Procedures, except that a tooth was not pulled for aging, and both were fitted with radio-collars as described above in Radio-collars. The raccoons were allowed to recover for 1 to 2 hours from the anesthesia before being released on the study area.

Road Kill Monitoring

In summer and fall of 1993, the boundary roads of the Orange and the Yellow area were driven at least once weekly to monitor the number of raccoons killed by vehicles. The age class and location of the carcass, and road type were recorded for each dead raccoon. The raccoons were placed into age classes as kit or adult, which was determined mainly by body size, but also by tooth size and condition if the head and jaw were intact. Yearlings were placed in the adult age class. Road type was recorded as paved or dirt.

RESULTS

Live trapping

Spring 1992 trapping commenced in late April and continued through the beginning of June (622 trap nights). Twenty-five male (15 adults, 10 yearlings) and 7 female (4 adults, 3 yearlings) raccoons were captured and marked for an initial capture success of 5.1%. Initial capture success is defined as number of 1st time captured raccoons/number of trap nights. A trap night is defined as 1 trap open for 1 night. With 7 recaptures, overall trapping success for this period was 6.3%. Overall trapping success is defined as total number of captures/number of trap nights. Mean weight of adult males was approximately 1.5 kg greater than adult females, while mean weight of yearling males was approximately 1 kg greater than yearling females (Table 1). Additionally, during the trapping period, 18 opossums, 9 woodchucks, 3 domestic cats (Felis catus), and a red

Table 1. Mean weights (in kg) of raccoons at their initial capture on the Rose Lake Wildlife Research Area, 1992-1994.

	Male:			Female:		
	Adult	Yearling	Kit	Adult	Yearling	Kit
Spring 1992						
Mean	5.5	4.4	-	4.1	3.6	-
SD	1.2	0.4	-	0.4	0.5	-
n	15	10	-	4	3	-
Fall 1992						
Mean	6.6	4.1	2.8	6.0	5.7	2.7
SD	2.2	0.0	0.6 ^a	1.0	1.6	0.4
n	2	1	5 ^a	6	3	8
Spring 1993						
Mean	5.3	4.0	-	4.1	3.4	-
SD	1.3	2.2	-	1.1 ^b	2.0	-
n	9	13	-	11 ^b	8	-
Fall 1993						
Mean	-	4.3	3.9	5.8	4.5	3.2
SD	-	0.3	2.6	0.1	0.0	0.0
n	-	4	3	4	1	1
Spring 1994						
Mean	5.9	3.8	-	4.5	3.3	-
SD	0.0	0.5	-	0.3 ^b	0.5	-
n	1	9	-	10 ^b	4	-

^a Includes a 1.9 kg kit captured in summer 1992.

^b Includes an adult female that escaped before being marked.

squirrel (Tamiasciurus hudsonicus) were captured and released.

Summer trapping from July 25-27, 1992 (33 trap nights) in the Orange area resulted in the capture of only 1 male kit raccoon (1.9 kg). A raccoon of such small size may not find its mother by the time it is released the next day and may be unable to survive alone. Therefore, summer trapping was halted. Initial capture success and overall trapping success was 3%. Seven opossum were also captured and released during this period.

Fall 1992 trapping commenced September 11 and continued through October (357 trap nights). Seven male (2 adults, 1 yearling, 4 kits) and 17 female (6 adults, 3 yearlings, 8 kits) raccoons were marked. In addition, one adult escaped before being sexed and marked. Mean weight of adult males was approximately 0.5 kg greater than adult females, while mean weights of kits were similar for both sexes (Table 1). Mean weight of yearling males was similar to that found in spring. Mean weight of yearling females was similar to that of adult females. There were 5 recaptures. Initial capture success was 7%, while overall trapping success was 8.4%. One kit female was recaptured 3 times after her initial capture. At each subsequent recapture, she became more aggressive. It is likely she had not found her mother after being released and was easily captured while trying to forage on her own. Additionally, 2 woodchucks, 19 opossums, 1 skunk (Mephitis

mephitis), and 1 cottontail (Sylvilagus floridanus) were captured and released.

Spring 1993 trapping commenced on March 16 in the Orange area despite a short period of wet, heavy snow and rain. Traps were closed 9 days later due to severe flooding of the area from rain and snow melt. Traps were opened in both areas on April 27, 1993 and continued through June 8, 1993 (385 total trap nights). Twenty-two male (9 adults, 13 yearlings) and 18 female (10 adults, 8 yearlings) raccoons were captured and marked. One adult female and one raccoon of unknown age and sex escaped before being marked. Mean weights were similar to mean weights in spring 1992 for both sex and age classes (Table 1). There were 28 recaptures. Initial capture success was 10.9%, while overall trapping success was 18.2%. Ten raccoons marked in the 1992 trapping periods were recaptured in spring 1993 and given a second shot of 100 mg oxytetracycline. Additionally, 12 opossums were captured and released.

Fall 1993 trapping commenced on October 5 and continued through November 14 (440 trap nights total). Seven male (4 yearlings, 3 kits) and 6 female (4 adults, 1 yearling, 1 kit) raccoons were marked and released. Mean weights of yearlings were similar for both males and females, while mean weight of kit males was approximately 0.7 kg greater than kit females (Table 1). There were 8 recaptures. Initial capture success was 3.2%, while overall trapping success was 5%. Additionally, 20 opossums (2 adults, 18 babies), 2

cottontail rabbits, 2 mink (Mustela vison), and 1 domestic cat were captured and released.

Spring 1994 trapping commenced on May 13 and continued through June 10 (266 trap nights total). Ten male (1 adult, 9 yearlings) and 13 female (9 adults, 4 yearlings) raccoons were marked and released. In addition, 1 adult female escaped before being marked. Mean weights were similar to spring 1992 and spring 1993 for both sex and age classes although adult weights were somewhat greater while yearling weights were somewhat lower than previous years (Table 1). There were 31 recaptures. Initial capture success was 9%, while overall trapping success was 20.7%. In addition, 7 opossums were captured and released.

For all trapping periods combined (2103 trap nights), initial capture success was 6.5%, while overall trapping success was 10.3%.

Mean weight change from fall to spring was -1.6 kg (SD=1.9; n=2) for male raccoons and -1.0 kg (SD=0.9; n=6) for females (Table 2). There was no significant difference between males and females ($t=0.60$; $df=6$; $p>0.50$) so the overall mean weight change of -1.2 kg (SD=1.1; n=8) was used in the paired t-test. A significant weight loss occurred from fall to spring ($t=3.03$; $df=7$; $p=0.0097$). A significant weight gain (mean=2.1 kg; SD=1.25; n=3) occurred from spring to fall ($t=2.91$; $df=2$; $p=.0504$).

Mean percent weight change from fall to spring was

Table 2. Weights (in kg) among seasons for individual raccoons at the Rose Lake Wildlife Research Area, 1992-1994.

Tag	Age ^a	Sex	Spr 1992	Fall 1992	Spr 1993	Fall 1993	Spr 1994
413	3	Male	5.4	7.9	5.0	-	-
401	3	Male	5.2	-	5.0	-	-
415	2	Male	6.4	-	5.0	-	7.0
427	2	Male	6.8	-	6.1	-	-
502 ^b	2	Male	-	-	6.8	-	6.2
425 ^b	2	Male	3.9	-	4.5	-	-
479	Kit	Male	-	3.4	3.2	-	-
508 ^b	10	Female	-	-	5.0	-	5.0
409	3	Female	4.3	-	4.5	-	4.5
477	3	Female	-	-	6.8	-	4.5
505	3	Female	-	-	3.9	-	3.8
510	Adult	Female	-	-	4.4	-	4.0
531	Adult	Female	-	-	-	5.8	4.0
519	Adult	Female	-	-	3.6	-	3.9
445 ^b	Adult	Female	-	5.7	5.0	5.7	-
501	Adult	Female	-	-	3.6	-	3.8
521	Yrl	Female	-	-	3.9	7.0	-
484	Yrl	Female	-	-	1.8	-	3.8
530	Yrl	Female	-	-	-	4.5	4.0
437	Kit	Female	-	2.3	2.7	-	-
451	Kit	Female	-	2.6	0.8	-	3.5
453	Kit	Female	-	-	-	5.8	4.0

^a Age at initial capture.

^b Radio transmitter (130 g) placed on animal at initial capture.

-22.5% (range=-6% to -69%; except for 1 kit female who had a 17% weight gain from her first fall to the following spring). Mean percent weight change from spring to fall was 46.6% (range=14% to 79.5%).

Age Structure and Sex Ratios of the Live Trapped Population

A total of 47 teeth were collected from live trapped animals for age determination. Teeth were not collected from animals that were excessively starved during early spring trapping because the gums were tight and the teeth would easily break off, from captured animals that were pregnant or lactating, appeared ill or had infected gums, or from animals that could be easily classed into kit or yearling age categories. The live trapped population appeared to have a relatively old age structure (see APPENDIX B). When initial age at capture was combined over all three years of trapping, the yearling:adult ratio in the Orange area was 1.62:1 for males and 0.50:1 for females, and the overall male:female ratio was 1.45:1. The kit:adult ratio (excluding 1994 data because trapping was done in spring only) in the Orange area was 0.62:1 for males and 0.50:1 for females. In the Yellow area, the yearling:adult ratio was 1.14:1 for males and 0.69:1 for females, and the overall male:female ratio was 0.97:1. The kit:adult ratio (excluding 1994 data) in the Yellow area was 0:1 for males and 0.29:1 for females.

When both areas were combined, the overall ratio of juveniles (kits and yearlings) to adults was 1.39:1 and the overall ratio of males to females was 1.20:1. Combining the

data from the two different areas in this study should be viewed with caution since the 2 areas appeared to have fairly disparate sex and age ratios. However, no significant difference was found between the two areas when sex and age ratios were compared ($\chi^2=8.59$; $p=0.1266$, $df=5$) (i.e. number of kit females, kit males, yearling females, yearling males, adult females and adult males were compared between the areas).

Radio-collared Animals

In the Yellow area, radio-collars were placed on 3 males (aged 2, 3, and 4 years old) and 2 females (yearling, and 2 years old) in spring 1992 and 4 females (yearling, 3 and 4 years old, and 1 adult of unknown age) in fall 1992. Three males (yearling, 2 and 6 years old) and 2 females (9 years old and 1 adult of unknown age) were collared in spring 1993. A male who had originally been collared in spring 1993 at age 2 was recaptured and re-collared in spring 1994 several months after slipping his original collar. An additional male of unknown age was collared in spring 1994. He is the only collared animal still known to be alive at the end of the study.

Reproduction of Harvested and Live Trapped Females

In spring, 2 of 7, 7 of 23, and 17 of 26 live trapped yearling and adult females were lactating for 1992, 1993, and 1994, respectively. Overall mean body weight of live trapped lactating females was 4.3 kg ($SD=0.46$; $n=26$), while mean body weight of nonlactating females was 3.6 kg

(SD=0.81; n=30). These weights were significantly different ($t=4.48$; $p<0.0001$). When weights were compared within a year, it was found that lactating females had significantly greater body weights than nonlactating females for all three years of live trapping (Table 3). All yearlings in this study were nonlactating and tended to be smaller in size than adults (see Table 1). When yearling weights were removed from the analysis, the overall t-test to compare weights of lactating adults to nonlactating adults was still significant ($t=2.48$; $p=0.0178$).

Reproductive tracts were collected from all 15 females that were harvested in February-March 1995 (Table 4). Three were yearlings who did not ovulate and were unlikely to breed at all in 1995 because no swelling of the reproductive tract was observed. Of the 12 adults, 10 had both corpora lutea and implanted embryos/fetuses for the 1995 breeding season. Mean number of implantations for these females was 4 (SD=0.9; n=10; range=2-5). Only 4 of these raccoons released a different number of eggs than was successively fertilized and implanted (Table 4). Two released one more egg than was implanted, and the oldest female from the sample released 3 more eggs than were implanted. One raccoon showed the only incidence of identical twins, i.e. released only 3 eggs but had 4 implantations.

Of the 2 adults without implantations for the 1995 season, both were relatively older animals (Table 4). One had 5 corpora lutea in the ovaries (5 eggs had been

Table 3. Mean weights between lactating and nonlactating female raccoons from live trapping in spring 1992-1994 at Rose Lake Wildlife Research Area.

	1992	1993	1994
<u>Lactating</u>			
Mean	4.4 ^a	4.3 ^a	4.3 ^a
SD	0.2	0.7	0.4
n	2	7	17
<u>Nonlactating</u>			
Mean	3.7	3.4	3.7
SD	0.3	1.0	0.5
n	5	16	9
p-value for t-test	0.0335	0.0557	0.0015

^a An F-ratio for homogeneity of variance was done previous to the t-test for each comparison. All F-ratios were nonsignificant at $p = 0.05$. Significantly different (two-sample t-tests) from nonlactating females.

Table 4. Number of implantations or placental scars in the uterus and number of corpora lutea in the ovaries of raccoons harvested at Rose Lake Wildlife Research Area, February-March 1995.

Age	Date	Implantations	Corpora Lutea	Follicles ^a
1	Feb 3	0	0	N/A
1	Feb 23	0	0	N/A
1	Mar 23	0	0	N/A
2	Feb 23	4	4	N/A
4	Feb 23	5	5	N/A
4	Mar 24	4	4	N/A
4	Mar 24	4	5 ^b	N/A
5	Mar 24	4	3 ^c	N/A
6	Feb 23	5	5	N/A
6	Feb 24	5	5	N/A
8	Feb 22	5	6 ^b	N/A
8	Mar 24	2 ^d	3 ^d	several
9	Feb 24	0	5	N/A
11	Feb 23	2	5 ^b	N/A
11	Feb 24	4	4	N/A

^a Eggs about to be released. Only applicable if no corpora lutea are present from the 1995 season.

^b Released more eggs than were implanted.

^c Incidence of identical twinning; i.e. 4 successful implants from only 3 eggs.

^d Scars from the 1994 season. Nothing for 1995.

released), but had no implantations or old (1994 season) placental scars in the uterus. This female had probably just bred, and sufficient time had not elapsed for implantation to occur, or was about to breed. She showed no evidence of successful pregnancy for the 1994 season. The other female had several follicles in each ovary, i.e. eggs were ready to be released. Three corpora lutea from the 1994 season were also observed in the ovaries, as well as 2 placental scars in the uterus from 1994. This female was likely getting ready to breed in the 1995 season, and had 2 successful implantations in the 1994 season.

During monitoring of radio-collared animals, it was found that 1 female (radio 650; 5 years old) used a large well-protected tree den throughout late spring and summer 1993 (APPENDIX C), so it was supposed she had a litter at that time. However, by late summer she began to occasionally frequent a heavily used ground burrow. Because she denned in well-protected places it was not possible to see or hear any kits at any time without disturbing the den, which could have caused additional mortality. In North Dakota, no parous or pregnant female was ever located with another adult or yearling during spring or summer (Fritzell 1978). It is probable then that this female lost her litter by the time she began to share this populated ground burrow, or less likely, that she never had a litter in 1993.

Another radio-collared female (radio 1183; 9 years old) was known to have had kits in spring 1993. She was lactating

when first captured and radio-collared in the middle of May and was then closely monitored for 3 days following her release. The first day following her release she rested in an open topped (3.7 m tall) hollow snag (d.b.h.=70.4 cm) and no kits were present. By the second day, she returned to what is believed to have been her maternal den, a hole at approximately 10.7 m in a basswood (Tilia americana) tree (d.b.h.=55.6 cm) near the hollow snag and stayed there 2 days total. One week later she moved almost 0.5 km north and did not return to the area of her maternal den for the rest of the season. Usually raccoons with litters remain localized at the maternal den until the kits are able to travel. It is believed this female lost her litter.

Another female (radio 550; adult of unknown age) probably lost her litter in spring 1993. She was located at the end of April in a 2.4 m tall snag (d.b.h.=51.1 cm) with an open top and the kits could be heard churring until she pressed her head down upon them at the approach of the researcher. Four days later she was located near the snag in an elm (Ulmus spp.) tree (d.b.h.=47.8 cm) with the entrance hole at the base of the tree. One kit could be heard moving and churring at this time. Eleven days later she was located in a heavily used ground burrow and it is believed she had lost her litter in the meantime.

Only 1 radio-collared female (radio 630; 2 years old) was believed to have successively raised a litter in 1993. At the end of April 1993, she was located in an ash

(Fraxinus spp.) tree (d.b.h.=63.8 cm) with an entrance hole at approximately 6.1 m. Kits could be heard but not seen at this time, but 3 kits could be seen moving around in the den by the end of May. The family used this den for a rest site until the end of June 1993, when kits were probably large enough to move outside the den with their mother.

In 1994, only 1 radio-collared female remained alive (radio 1183; 10 years old). At the end of April 1994, she was located in a basswood tree (d.b.h.=69.6 cm) with 2 entrance holes at approximately 15 and 20 m. She continued to use this den as a rest site through the end of June 1994. It was not possible to see into the den or hear any kits at any time, but it is believed she remained localized in this den for so long because she did have a litter.

Den Use

In spring and summer 1992, the radio-collared animals did not demonstrate fidelity to day rest sites. However, by fall 1992, some individuals were relocated several times in the same tree or ground burrow.

Tree species used as branch rest sites included tamarack (Larix occidentalis), basswood, red pine (Pinus resinosa), red maple (Acer rubrum), red oak (Quercus rubra), and Scots pine (Pinus sylvestris) (APPENDIX C). Tree species used as hole rest sites included apple (Malus spp.), elm, basswood, green ash (Fraxinus pennsylvanica), red maple, silver maple (Acer saccharinum), red oak, and white oak (Quercus alba). Mean height that raccoons were located

in tree holes was significantly lower ($t=2.59$; $p=0.0154$) than mean height that raccoons were located on branches (Table 5). Mean d.b.h. of trees used as hole rest sites was significantly greater ($t=4.18$; $p<0.00025$) than mean d.b.h. of trees used as branch rest sites. Because sample sizes were small, a more conservative approach would have been to use a nonparametric Wilcoxon rank sum test for comparisons. Highly significant differences in mean d.b.h. and height were still found between tree branch rest sites and tree hole rest sites ($p=0.0004$ and $p=0.017$, respectively).

Other day rest sites in winter 1993 include a barn used several times by 1 male, a shed, a basement window well, and under a trailer used by another male. In addition, 4 raccoons were repeatedly located in a ground burrow located beneath a parking area on the west-central edge of the Yellow area (Figure 1).

In the summer of 1992, 2 collared males (radios 500 and 528) were each located in the ground burrow once. In 1993 1 of these males and 3 collared females were relocated in this burrow either together or individually a total of 70 times (radio 500: 42 times; radio 550/1103: 27 times; radio 610: 44 times; radio 650: 8 times). Adult male radio 500 (3 years old) consistently shared this burrow with one or more adult females (one adult of unknown age, one 4 year old, and one 5 year old) 23 times in 1993. In mid-June, radio 550 failed and I was unable to relocate her until she was recaptured during the fall 1993 trapping period. Her collar was

Table 5. Mean diameter at breast height and height of hole or raccoon on a branch of den trees on the Rose Lake Wildlife Research Area, 1992-1994.

	d.b.h. (cm)	Height (m)
<u>Hole</u>		
Mean ^a	69.1 ^b	5.3 ^c
Standard Deviation	20.4	5.5
Sample Size	19	19
<u>Branch</u>		
Mean ^a	38.5	11.1
Standard Deviation	14.9	6.5
Sample Size	10	10

^a If the same tree was used more than once, the measurements were entered into the mean only once. If the same tree was used as both a hole and as a branch rest site, the measurements were entered into the hole mean once and the branch mean once.

^b Significantly greater at $p < 0.00025$ (two-sample t-test) than d.b.h. of tree in which a branch was used.

^c Significantly less at $p = 0.0154$ (two-sample t-test).

replaced (radio 1103) and it is likely she had continued to use this burrow throughout summer 1993, as she used it consistently until her death on January 10, 1994. In 1994, this burrow was used a total of 25 times by 1 or more collared raccoons (females= radio 550/1103: 2 times, radio 610: 15 times, radio 630: 1 time; male= radio 1162: 10 times). Male 500 died at the end of 1993 (see Mortality of Collared Animals and Collar Loss). Three females (radios 630, 610, and 550/1103) died during the first several months of 1994, all after having been located in this ground burrow. One was diagnosed with cardiomyopathy, 1 body was never recovered, and the third died inside of the burrow and was not retrievable. It is suspected that the 2 undiagnosed deaths were due to distemper because both animals were located with or near the raccoon known to have had canine distemper (male 500) and were observed to have symptoms of this disease prior to their death. The male (radio 1162) that had been located in the burrow with these females prior to their death stopped using this burrow in early March, and did not resume using it until late July of the same year. This may have spared him from contact with the distemper virus.

Only 1 other ground burrow was recorded in this study as being used as a day rest site. One male (radio 1162) was found resting in it only once.

Radio-collared raccoons were located 96 times (49% of all locations) in tree rest sites, 93 times (48%) in ground

burrow rest sites, and 6 times (3%) in other rest sites. A total of 68 nighttime locations were recorded.

It appeared that there were 2 different rest site behaviors by radio-collared raccoons on this area. Some raccoons generally used tree hole rest sites throughout the year and occasionally used tree branch rest sites or ground burrows (APPENDIX C; radios 630, 650, 1183, and 1224). Other raccoons preferred ground burrows and used tree sites only occasionally (APPENDIX C; radios 500, 550, 610, and 1162).

Trees used as rest sites were sometimes used as both a hole rest site and a branch rest site by a raccoon at different times (APPENDIX C; radios 630 and 1224 on February 3, 1994). Also, several holes in the same tree were used at different times by a raccoon (APPENDIX C; radio 630 on February 4, 1995). In addition, the same tree was sometimes used by different raccoons on different days (APPENDIX C; January 31 1994, April 5 1994, and September 23, 1994).

Most raccoons preferred to use 1 rest site primarily and used other sites only occasionally. For example, 1 female (radio 650) used the same tree hole 24 out of 27 times she was located in a tree (APPENDIX C) and 24 out of 38 total relocations.

Two adult males consistently denned in tree holes with adult females during winter (APPENDIX C; radios 1162, 630, 1224, and 1183 in January 1994). This has not been documented in other raccoon studies.

Movements of Ear Tagged and Radio-collared Animals

Only 2 collared raccoons left the Yellow area (except see Experimental Transplants). One was an adult male (radio 593) that was killed along the highway (see Mortality of Collared Animals and Collar Loss). The other was a female (radio 570) that moved approximately 312 m east into the Red area where she lost her collar (see Mortality of Collared Animals and Collar Loss). It is possible that she used parts of both the Yellow and Red areas as her normal range and did not truly leave the Yellow area. However, she was never recaptured, so her fate is unknown. Although 1 collared male (radio 1243) often crossed the northern boundary road of the Yellow area to use a day rest site, he was harvested during February 1995 in the Yellow area. Throughout nighttime monitoring, raccoons did not appear to move farther than recorded found during daytime monitoring.

Only 2 instances of ear tagged raccoons leaving the study area were observed and both animals moved north of the Yellow area. One was an ear tagged yearling male that was killed by a landowner just across Clark Road from the Yellow area (see Figure 1). Additionally, 1 ear tagged adult female was killed during the fall 1992 trapping harvest season approximately 0.4 km north of the Yellow area along Mud Creek. All 5 individuals with numbered ear tags in the spring 1995 harvest were killed in the area in which they were originally captured and marked. No marked raccoon was ever observed to move from the Orange area to the Yellow

area or vice-versa. This supported the contention that the White and Red areas were a sufficient buffer zone between the 2 study areas.

In winter during cold temperatures and normal snow conditions, animals remained denned up in ground burrows and den trees (APPENDIX C; January to February 1994), but when temperatures increased temporarily and snow depths decreased, animals made movements to and from their dens presumably to find food. By March, several animals began to leave their primary winter dens for a few days at a time and were subsequently located in several other nearby dens on different days (APPENDIX C). Beginning in March and April, females tended to localize in a specific den tree or burrow, and, unless their litter was lost, remained there until early summer (APPENDIX C; radios 630 and 650 in April 1993, radio 1183 in April 1994). During summer, females with litters began to leave den trees for a day or so at a time, but generally returned to their original den trees at regular intervals. When not at their original dens, these females still used holes in trees as day rest sites (APPENDIX C). Females without litters (either non-breeding or due to litter loss) and males began to use branches in trees as day rest sites in midsummer (APPENDIX C; radios 500 and 610 in July 1993), although some animals used a ground burrow fairly consistently. By fall the collared animals were again using holes in trees and ground burrows

exclusively, probably seeking shelter from the wetter, colder weather (APPENDIX C).

Nighttime monitoring resulted in locations of individuals as they left their den, during movement periods, and/or as they returned to their den in early morning. In general, radio-collared animals did not travel more than 1 km during nighttime movements. At any one nighttime monitoring period, one or more radio-collared raccoons did not leave their den at all that night. Problems with the nighttime monitoring portion of the study included small sample size due to the many other research activities taking place concurrently.

Mortality of Collared Animals and Collar Loss

One 3 year old male (radio 593) was found dead along Highway 69 within a week of his capture in spring 1992, approximately 1.4 km from his release site. One 2 year old female (radio 480) was monitored for 6 months before dying of an unknown cause in November, 1992. Cause of death was not determined.

After being monitored for almost 11 months, a 5 year old male (radio 528) was found dead on March 28, 1993 at the base of a den tree that was currently being occupied by a collared female (radio 650). Cause of death was not determined because the body had been scavenged.

A mortality signal was received from a 2 year old female (radio 570) in March 1993, approximately 5 months after she was collared. Her collar was found intact in a

basswood den tree that she or another animal was currently using. The female had apparently lost so much weight over winter that the collar had slipped over her head. She was never recaptured, so her fate is unknown.

As stated previously in Den Use, 1 collar (radio 550) failed in summer 1993, but this female was re-collared (radio 1103) in fall 1993 and was monitored until her death in January 1994. In addition, an adult female (radio 593 refurbished) collared in spring 1993 disappeared within a week of her capture and was subsequently located with a mortality signal in a residential area several kilometers from Rose Lake. The next day no signal was detected anywhere within the area, and it is believed the collar was destroyed. The raccoon may have been found dead and the collar kept as a souvenir but then destroyed when the person realized it could be located.

Radio 500 died outside of a ground burrow on December 31, 1993 from canine distemper. He had been monitored for almost 19 months. Radios 550/1103, 1203, 630, and 610 all died during the first few months of 1994 (January 10, February 18, February 19, and March 22, respectively), after having been monitored for 16, 9, 21, and 18 months, respectively. One was diagnosed with cardiomyopathy (radio 630), two animals were never recovered (radios 1202 and 610), and the third died inside of the same ground burrow and was not retrievable (radio 550/1103). It is suspected that the 3 undiagnosed deaths were due to distemper. These 3

raccoons were located with or near the raccoon known to have canine distemper, and were subsequently observed to have symptoms prior to their death.

One female (radio 650) is suspected to have suffered collar failure. She was monitored for over 18 months then no signal was ever received again after March 24, 1994. She was never recaptured so her fate is unknown. One male (radio 1162) was killed on a road on February 3, 1995 after being monitored for 21 months.

One male (radio 1224) was monitored from May 11, 1993 until it slipped its collar in March 1994. This raccoon was subsequently recaptured in May 1994 and was re-collared (radio 1243). His movements were again monitored until he and 1 female (radio 1183), who was collared on May 14, 1993, were killed on February 23, 1995 in the experimental harvest.

Only 1 collared male raccoon (radio 1122) was known to be alive at the conclusion of the study (except see Experimental Transplants). He was originally collared on May 13, 1994.

In summary, eight of the 15 radio-collared animals in this study were known to have died, and another 4 were suspected to have died. One remained alive at the conclusion of the radio-collar monitoring portion of the study. Two animals slipped their collar off during winter weight loss, but 1 of these was later re-collared. Two animals suffered

collar failure, but 1 was later re-collared. Thus two animals had unknown fates.

Estimated mortality rate of collared animals was 33% (3 out of 9 animals collared in or alive at the beginning of 1992) for 1992, 60% (6 of 10) for 1993, and 75% (3 of 4) for 1994.

Harvest

The MDNR trapping in January-March 1995 resulted in a total harvest of 29 raccoons from both Orange and Yellow areas.

Experimental Transplants

Male #1 was captured on September 19, 1994 from a tree farm south of Williamston, Michigan. He weighed approximately 5.3 kg. Male #2 was captured on October 14, 1994 from a barn used to store hay just southeast of Laingsburg, Michigan. He weighed approximately 8.5 kg. Both animals were released at the Rose Lake Wildlife Research area near Mud Creek in a mature forested area, approximately 26 km northwest and 7.4 km southwest from their capture sites, respectively.

Male #1 was relocated in the release area 2 days after being released. Faint signals were received from the area for several months following his release, but no exact location could be determined. No signals were ever received from this animal after November 29, 1994, so his fate is unknown. It is most likely this raccoon dispersed from the area.

Male #2 was relocated at night on the same day he was transplanted, and faint signals were received from the area for about 1 week thereafter, but again, no exact locations could be determined. He was reported harvested during the 1994 hunting season by a raccoon hunter near Elsie, Michigan, approximately 33.4 km northeast of its release site and approximately 28.3 km north of its capture site.

Road Kill Monitoring

Approximately 8 km of dirt roads and 12 km of paved roads were monitored weekly from July 5 to November 14, 1993. No raccoons were found dead along dirt roads. Fourteen raccoons, 9 kits and 5 adults, were found dead along paved roads (Table 6).

DISCUSSION

Live trapping

Overall, the initial capture success of 6.5% and overall trapping success of 10.3% was high compared to studies in other areas. This suggests a relatively dense population of raccoons as other studies have reported overall trapping success of 0.4-6.5% in Kentucky where raccoon population densities were reported to be low (Patterson 1986, Roloff 1990, Norment 1991).

Previously in Michigan, Stuewer (1943a) found similar body weights for adult males and females and yearling females in spring, but reported weights of yearling males slightly less than those recorded for this study. In the fall season, Stuewer (1943a) found body weights

Table 6. Adult and kit raccoon deaths due to vehicle accidents along 20 km of roads at the Rose Lake Wildlife Research Area from July 5 to November 14, 1993.

Date	Age Class	Road Type	Location/Area ^a
Jul 5	kit	paved	Clark Road/Orange
Jul 5	adult	paved	Bath Road/Orange
Jul 10	adult	paved	Woodbury Road/Orange
Jul 12	kit	paved	Clark Road/Yellow
Jul 12	kit	paved	Clark Road/White
Jul 12	adult	paved	Upton Road/Yellow
Jul 17	kit	paved	Upton Road/Yellow
Jul 19	adult	paved	Clark Road/Red
Aug 24	adult	paved	Peacock Road/Orange
Sep 14	kit	paved	Woodbury Road/Orange
Sep 16	kit	paved	Woodbury Road/Orange
Oct 14	kit	paved	Upton Road/Yellow
Oct 14	kit	paved	Clark Road/Red-White
Oct 22	kit	paved	Woodbury/Orange

^a Road name and color-coded area of Rose Lake Wildlife Research Area that road borders (see Figure 1).

approximately 1 kg greater for adult males and females than found in this study. He reported weights of yearling males and females 1.5-2 kg greater than for this study. However, because he did not report any standard deviations, no statistical analyses could be run to see if the mean weights that he found were significantly different than mean weights in this study.

In Tennessee, adult males tended to weigh approximately 1 kg greater than adult females (Moore and Kennedy 1985). In Michigan, Stuewer (1943a) found that adult males weighed approximately 1.5 kg more than adult females in spring, but only 0.5 kg more in the fall. Similar results were found in this study.

A significant weight loss from fall to spring and a significant weight gain from spring to fall was found during live trapping sessions. These results support the idea that raccoons starve throughout winter during a semi-hibernation lifestyle, then gain considerable weight throughout the rest of the year to make up for winter loss. However, sample sizes of recaptured individuals were extremely small and inferences to the entire population should be made carefully. If animals that lost significant weight through winter were more likely to be captured while foraging heavily during spring trapping than animals that did not have significant weight loss, the spring recapture sample may be biased towards starved animals. This bias may extend into the fall recapture sample such that animals who were

significantly starved when captured in the spring may then show a greater weight gain by fall than the average individual in the population. These potential biases should be taken into consideration when viewing these data. The timing and length of the fall and spring live trapping seasons were so variable that the actual total weight loss of an individual may have been greater or less than was estimated depending on whether the animal was captured early or late in the season.

In Minnesota (Mech et al. 1968) and Tennessee (Moore and Kennedy 1985), raccoons of all age classes lost approximately 50% of their body weight during winter dormancy from late November through late March. Stuewer (1943a) suggested that raccoons at their minimum weight in winter may weigh 50% less than their normal weight, but did not report data on individuals to support his idea. In this study, mean percent weight loss was not as extreme, although 1 individual lost 69.2% of its fall body weight.

Age Structure and Sex Ratios of the Live Trapped Population

In an unhunted population in Minnesota (Mech et al. 1968), the ratios of yearlings:adults and of males:females of both age classes were 1:1. In Kentucky, the ratio of juveniles:adults was 0.44:1 and 0.67:1, while the ratio of males:females was 1.16:1 and 1.5:1, respectively (Roloff 1990, Norment 1991). In Tennessee, the ratio of juveniles:adults was 0.85:1 and the ratio of males:females was 1.12:1 (Moore and Kennedy 1985). Caughley (1974) states

that generally in mammals the ratio of juveniles:adults should be 2:1 in a stable population. This suggests that the above studies had populations that were probably declining and of low productivity. It also suggests similar conclusions for the Rose Lake Area raccoons where the overall ratio of juveniles to adults was 1.39:1, although I suspect that this area currently has a high raccoon population.

Sex ratios favoring males were found in Tennessee, Virginia, Ohio, and Kentucky (Urban 1970, Sonenshine and Winslow 1972, Moore and Kennedy 1985, Roloff 1990, Norment 1991). Sex ratios favoring females in litters were found in Michigan (Stuewer 1943a), but in this study, sex ratios tended to favor males. Kits in the Rose Lake area were not sampled until fall live trapping so a greater survival of male kits may occur from the time they are born resulting in a greater proportion of males in the overall population. No reasons for this differential survival were found for yearlings or adults in this study however, as both sexes appeared to be equally vulnerable to leg hold trapping harvest and natural mortality factors (see Mortality of Collared Animals and Collar Loss and CHAPTER II). However, a possible differential survival of male and female kits may occur between birth and their first fall. A mechanism which would cause such a difference is not known.

Possible differences in vulnerability to different capture or harvest techniques by sex and age classes may

exist. In addition, differences in sample sizes and time of sampling may have occurred between this study and those cited previously. These differences could account for some of the disparity of reported sex and age ratios.

Reproduction of Harvested and Live Trapped Females

In this study, lactating females were found to have a significantly greater mean body weight than nonlactating females even when the analysis was run on adults only. In Illinois and Missouri there was no difference in mean body weight between reproductive and nonreproductive adult females, but these raccoons were collected during November-January (Fritzell et al. 1985), while data on the Rose Lake raccoons were collected during spring.

Mean number of implantations in this study was similar to litter size reported previously for Michigan (Stuewer 1943b: mean=4; SD=1.25; n=10), and appeared slightly larger than mean litter sizes reported in Illinois, Missouri, and Iowa (Sanderson 1984, Fritzell et al. 1985, Clark et al. 1989).

No yearlings in this study were found to be pregnant or lactating from the live trapped sample (n=17) or the harvested sample (n=3). This does not agree with a previous Michigan study which reported 27 of 28 yearlings had mated, 15 of which were subsequently found to be lactating or with litters, and 1 was found to be pregnant (Stuewer 1943b). Thus 59% of yearlings were estimated to reproduce in that study. In Iowa, Missouri, and Illinois, similar results were

found (Fritzell et al. 1985, Clark et al. 1989), but only 9% of yearlings were found to have litters in North Dakota (Fritzell 1978).

From the observations of the 2 radio-collared females who appeared to have successfully raised a litter, raccoons at Rose Lake gave birth to their litters at approximately the end of April and the maternal den was used for approximately 2 months until the family left at the end of June. This estimate is within the range presented by Stuewer (1943b) for Michigan raccoons. In Illinois, mean birth date of litters was mid-April (Sanderson 1987). For maternal dens, both of these females used holes in trees at relatively great heights. This apparent preference for tree dens during kit rearing may be to decrease the risk of predation from ground dwelling animals. In Michigan, Stuewer (1943b) found that most raccoon litters were born in tree dens, and ground dens were used only when hollow trees were scarce. For 1993, 25% of litters survived until they left the den. Similar results were found in Minnesota (Mech et al. 1968) where 2 of 7 litters were found to survive until winter.

Den Use

In this study an adult male often shared a ground burrow with 1 or more adult females. However, because there were many entrances, it is possible that this burrow had multiple compartments and thus the animals may not have been in direct contact with one another, although the spread of

canine distemper among raccoons using this burrow is evidence to the contrary. In other studies, adult males have not been known to den with adult females (Fritzell 1978, Norment 1991).

This burrow appeared to originally be a woodchuck den that raccoons occupied. To examine the inside of the burrow it would have been necessary to dig it up and destroy it. This burrow appeared to be an important habitat component for many raccoons on this study area, since such a high proportion of radio-collared animals (7 out of 15) which were captured at different places throughout the Yellow area all used this den somewhat consistently. Therefore, the den was left undisturbed. Ground burrows have the advantage of having more consistent internal temperatures as outside weather changes, due to the insulating value of soil. In addition, the inside of the burrow would remain much drier than tree dens in inclement weather and provide safety from predators. Except for 1 other burrow used once by a male, this was the only ground burrow that was positively identified as being used by radio-collared raccoons in this study. However, radio signals do not transmit very well from subterranean sites. If an animal used a burrow that was not near a site where the researcher stopped to listen for signals, the signal was unlikely to be received and attempts to locate that animal may have been unsuccessful. Thus other ground burrows may have been used on this study area, but were not located.

Previously in Michigan (Stuewer 1948), it was found that raccoons will use ground dens but they prefer tree dens if available. Similar results were found in Missouri, where raccoons occasionally used ground burrows but tree dens were far more important (Bennitt and Nagel 1937). However, other studies have reported extensive use of ground burrows as den sites. In Wisconsin (Dorney 1954) where few tree dens were available, 90% of raccoon dens were in ground burrows, and the author felt that tree dens were not a limiting factor to the raccoon population in that area. In Ohio, Butterfield (1954) also concluded that tree dens were not needed if ground dens were available. He found that all raccoons in 1 study site used ground dens even though there were many suitable den trees available. He also observed a raccoon fighting with a woodchuck outside of a series of ground holes in the side of a hill. Later, 9 separate individuals were tracked to this same set of holes after they were captured and released throughout different parts of the study area. Previously at Rose Lake and other areas in south-central Michigan, Gysel (1961) found that raccoons were most numerous in forest stands with the largest number of suitably sized tree cavities, but in the stands where ground burrows were most numerous, raccoon numbers were also high.

In the Rose Lake area, raccoons seemed to use both tree dens and ground burrows equally. Some individuals appeared to prefer ground dens throughout the year. In mild weather

it was found that raccoons in this area also used tree branches as rest sites. This concurs with reported use by raccoons of tree branches for sunning themselves in warm weather in Indiana (Mumford and Whitaker 1982).

Movements of Ear Tagged and Radio-collared Animals

In North Dakota and Tennessee, it was found that most yearlings disperse from their birth area (Fritzell 1978, Moore and Kennedy 1985), but in Michigan, only some yearlings, especially males, were reported to disperse (Stuewer 1943a). Only 1 yearling, a female, was radio-collared in this study, and she never left her original capture area, but she may have dispersed prior to her original capture.

Mortality of Collared Animals and Collar Loss

Canine distemper affects the central nervous system and so causes disorientation, loss of fear of humans, and convulsions, as well as upper respiratory infections (runny nose and eyes) and pneumonia (T. Cooley, MDNR Wildlife Division, pers. comm.). Canine distemper has been cited as a significant factor controlling raccoon populations (Gorham 1966). In Indiana, 24 of 32 sick raccoons were diagnosed with canine distemper in 1956 (Mumford and Whitaker 1982). In local areas where raccoon populations become dense, canine distemper may act as a controlling mechanism of population size. This is a possible scenario for the Rose Lake area in 1993-1994. Besides the collared animal deaths, many dead nonmarked raccoons were observed laying on the

ground throughout the study area during the 1993-1994 winter radio-collar monitoring sessions. Canine distemper was a potential factor in the deaths, but post-mortems were not conducted on nonmarked raccoons. Starvation was apparent upon ocular examination of many of these dead raccoons. Only one ear tagged raccoon was diagnosed with canine distemper at death (see Movements of Ear Tagged and Radio-collared Animals).

At the Rose Lake Area, the estimated annual mortality rate of collared raccoons ranged from 33% to 75%. In Missouri, it was found that adult mortality was 56% (Sanderson 1951). Stuewer (1943a) stated that, other than hunting and trapping, there were no significant factors causing mortality in raccoons in Michigan. He reported that only 2 were killed by automobile accidents, only 1 unhealthy appearing animal was ever observed, and no dead, entire animal was ever found in the field during several years of study. This led him to believe that raccoons are an exceptionally healthy species, and he suggested that there were no longer any important predators of raccoons. This study found very different results than his, such as several deaths due to distemper, and a large proportion of loss of litters due possibly to predation, starvation, or other factors. However, only ear tags and toe clipping were used to track raccoons by Stuewer, and deaths of these animals may easily go unnoticed, whereas this study also used radio-

collars with mortality sensors, so that the death of an animal was obvious.

Experimental Transplants

It has been shown that raccoons in this area tend to use ground burrows as den sites rather than tree hollows, especially during extreme hot and cold weather (see Den Use). If the 2 transplanted raccoons were using ground burrows, at most only faint signals could be received from the radio-collars when these animals were denned up underground. Strong signals can only be received when the animals are above ground during nightly movements. However, several nightly excursions by the researcher did not result in finding any stronger signals. Thus, it is most likely that both raccoons left the study area after being released.

A positive result is that if these animals had been using a barn or garage in this area as rest sites, strong signals would have been received, so these transplanted raccoons did not appear to become pests at their release site.

Kaufman (1982) found that raccoons transplanted into unfamiliar areas showed no evidence of being able to return to their original capture site, and often wandered long distances in random directions. However, of 456 raccoons transplanted from Texas to Indiana, most recoveries of dead animals were less than 5 km from their release sites (Mumford and Whitaker 1982). In this study, both raccoons

appeared to have dispersed much farther from the area where they were released.

The 2 transplants (both males) were a pilot study with an extremely low sample size and there are no replicated transplants from the same area. A similar study at a much larger scale including females must be done to reach strong conclusions about the movements and nuisance tendencies of transplanted raccoons. In addition, a screening for parasites and diseases in the transplanted raccoons before release, after release during a recapture, or at death, could help determine the likelihood of spread of parasites and diseases from or to translocated raccoons.

Road Kill Monitoring

It is unlikely that raccoons make the distinction to choose to cross paved roads more than dirt roads. Thus, the finding that no raccoons were killed on dirt roads is more likely due to the fact that vehicles tend to travel faster on paved roads than on dirt roads. Therefore drivers are not as easily able to stop or avoid an animal that is in the road.

No ear tagged raccoons were found dead along these roads during this monitoring period. In addition, no ear tagged raccoons and only 1 radio-collared raccoon (except see radio 593 in Mortality of Collared Animals and Collar Loss) was ever found dead along these roads during the entire study.

Although only 1 marked raccoon was killed by a vehicle in this study, many raccoons were found in a 4 month period on the perimeter of the study area, approximately 0.7 raccoons per kilometer during that time. In addition to these, many more raccoons, including 1 radio-collared male, were found killed on roads all around the study area. In contrast, during 3 years, Stuewer (1943a) found only 2 raccoons killed by vehicles within a 48 km radius of his study area in Michigan. In Indiana, a range of 0.007 raccoons/kilometer/year to 0.01 raccoons/kilometer/year were found to have been killed by vehicles on roads throughout the state (Mumford and Whitaker 1982). They also found that in early fall, the number of road kills reached a peak. At the Rose Lake Area, it appeared that more raccoons were killed by vehicles in mid to late summer, possibly coinciding with increased movements of mothers with their litters during this time.

CONCLUSIONS AND RECOMMENDATIONS

Raccoons were studied from 2 areas at the Rose Lake Wildlife Research Area from 1992-1995. The primary objectives were to determine movements, den use, survival, and reproduction. During the study it was found that exploitation rates of raccoons in this area were low, and population levels as suggested by live trapping results, nuisance complaints, and number of road kills were relatively high. In addition, the age structure of these populations appeared to be relatively old. Although a large

number of live trapped animals were under 5 years of age, relatively few kits or yearlings were live trapped compared to adults. This suggests high population levels, and perhaps a decreasing population level in the future as animals in older age classes die but are not totally replaced by animals in younger ones. Differences in vulnerability to live trapping may have helped produce these results. A localized canine distemper outbreak midway through the study may have also helped to control this population.

Although according to female reproductive tract examinations, reproductive efforts appeared to be within normal ranges reported for raccoons, a low number of kits to adults were live trapped in this area during fall. This may signify a high mortality of kits between birth and their first fall. This is corroborated with some evidence from observed litter loss and road kills. As stated previously, this may suggest somewhat saturated habitat from high population levels at present.

Den use in this area did not agree with a study previously done in Michigan which found that raccoons use ground burrows only when tree dens were scarce (Stuewer 1948). An extensive ground burrow was used almost 50% of the time by radio-collared animals in this study, however, that may be an underestimate. Radio signals were received by some animals only during nightly movements which suggests that they were using unidentified ground burrows as rest sites during the day.

Movements of ear tagged and radio-collared animals suggested that the 2 areas studied were separate populations as no animal was ever observed to move from 1 area to the other. Very few observed movements of marked animals out of each study area boundary also suggests that these were relatively closed populations.

Using combined estimates from this study of sex and age ratios, reproductive success, and survival, a 10 year population projection was constructed for Rose Lake Area raccoons (APPENDIX D). A hypothetical initial population size of 300 yearlings and adults was used and initial population sizes of yearlings and adults were calculated using estimates of sex and age ratios from the Rose Lake raccoons. The number of kits produced each year was calculated as $((\text{estimated proportion of females who breed}=0.83) * (\text{mean litter size}=4.2) * (\text{proportion of litters that survive until fall}=0.4))$. Survival for yearlings and adult males and females was calculated from estimates of radio-collared animals survival during the first year of the study (0.67). An 80% survival was used for kits from fall to 1 year of age. For each year of the projection calculations of survival from the previous year's population was done, then adult female raccoons reproduced to provide the current year's kits. That is, 80% of previous year's kits survived to become yearlings in the current year, 67% of last year's yearlings survived to become the current year's adults, of which 46% became adult males and 54% became adult females,

and then the number of adult females in the current year produced the current year's number of kits (calculated from the previously stated formula). The projection using the above estimates resulted in an increasing population from 428 in year 1 to 686 in year 10. If the Rose Lake raccoon population dynamics are indicative of raccoon populations throughout Michigan, then raccoon populations should be increasing fairly rapidly throughout the state. Although the Rose Lake population is estimated to be high at present, it does not appear to be increasing as rapidly as the projection predicts. The reported harvest at Rose Lake was negligible, but as stated previously, there may be more exploitation in this area than is reported. In addition, there may be more car accidents or disease factors, such as distemper, that are controlling the population increase. Raccoons killed on roads were checked for ear tags throughout the entire study and the number of marked raccoons killed was negligible (2 marked raccoons total). But deaths due to distemper may not be as apparent as road kills. Several distemper deaths in the Rose Lake Area were recorded in 1994. In addition, several property owners along the area's border reported raccoons with distemper like symptoms in their yard and concerns over disease spread to pets or threats by sick raccoons to humans were raised. Perhaps the population has reached a size where disease levels have already begun to increase.

If raccoons throughout Michigan have similar population dynamics, an increase in disease levels throughout the state is probably imminent. The potential spread of rabies from Ohio to Michigan and north throughout the state may become reality much quicker than if raccoon populations are lower. It is recommended that the MDNR take action to promote furbearer harvest to better control raccoon populations in Michigan for the purpose of both better controlling disease transmission throughout the state and alleviating some of the nuisance problems many people are presently experiencing. Suggestions to promote furbearer harvest include designating one day per year a ``Free Furbearer Harvest Day'' such that any person is allowed to hunt or trap furbearers without a license for that day. This is similar to the Free Fishing Day that currently exists. Such a program should help encourage participation in furbearer harvest by people who do not currently hunt or trap furbearers. More educational programs concerning the benefits of harvest of furbearer species and the implications of a high population density of species such as raccoons for disease and nuisance problems should also be provided for the public. Another idea is to provide a sort of bounty on raccoon pelts that will add to the current fur prices. A portion of the funds could be collected through a nominal increase in fur harvester license fees. This ``bounty'' could be used during years that harvest is expected to be lower than is needed to control raccoon

numbers. Recommendations for future raccoon research are study of population dynamics of harvested versus nonharvested raccoon populations on a larger scale throughout Michigan. Large nonharvested raccoon populations can be found in urban areas. Many nuisance complaints come from these areas. Another study should examine disease levels and transmission of diseases from and throughout raccoon populations on a state-wide scale. Results from the above stated research ideas could help determine if 1) Rose Lake raccoons are indicative of the entire state, 2) if disease levels and threats to humans or domestic animals are high, and 3) if higher harvest levels may help reduce disease and nuisance levels in Michigan.

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CHAPTER II. STATISTICAL METHODS FOR DETERMINING THE SIZE OF FURBEARER POPULATIONS IN MICHIGAN: POPULATION SIZE ESTIMATION FOR RACCOONS IN THE ROSE LAKE AREA AND FOR BLACK BEAR IN THE UPPER PENINSULA

INTRODUCTION

Population size is often difficult to estimate on large or reclusive mammals, especially in a forested habitat, such as Michigan. An unbiased estimator is difficult to develop due to biases in probabilities associated with marking and recapturing, violation of assumptions of equal catchability of all individuals in the population and of a closed population (i.e. no births, deaths, immigrations, or emigrations). For example, raccoons are fairly easy to live trap. However, because they often become trap-happy or trap-shy, a simple mark-recapture study is not appropriate to estimate population size. A more suitable alternative may be a modified mark-recapture, in which animals are live trapped and ear tagged as the marking portion of the study and harvest returns are then used as the recapture portion. Such use of a different capture technique for marking than for recapturing should eliminate the problem of trap-happiness (or -shyness).

An alternative marking method to ear tags is the use of tetracycline-hydrochloride (tetra-HCL) as a biomarker. Baits laced with tetra-HCL, which when consumed orally leave a fluorescent deposit in teeth and bones, can be dispersed throughout an area for the marking procedure. A canine tooth from harvested animals can be extracted and sectioned to

determine whether or not each animal was marked. The number of baits eaten, and number of harvested animals with and without tetra-HCL deposits can be used in a Chapman estimator (Krebs 1989) to estimate population size. This is currently being done by the Wildlife Division of the Michigan Department of Natural Resources (MDNR) to estimate the size of the black bear population in Michigan. To date, no assessment of the accuracy of these estimates has been made.

Baits are placed on a grid throughout the entire Upper Peninsula of Michigan at least 1 month prior to the harvest, and then to estimate the number of marked bears, the bait sites must be revisited to check whether or not the bait was eaten by a bear. This method is a very time-intensive effort. Hunters are required to bring harvested bears in for extraction of a premolar tooth that will be checked for tetracycline marking. Tooth analysis reveals the age of the bear and the year(s) in which tetracycline bait was consumed by the bear.

At this time, biases are likely to exist in the MDNR estimator because of the methodology used. A greater proportion of bears in adult age classes tend to eat the bait and be marked than young bears, yet the harvest ("recapture") consists of a greater proportion of young bears than adults. This may cause a bias in the population estimate.

A population estimator which would not require tetracycline baiting may be more practical for field personnel who may already have time restrictions. An alternative to mark-recapture is a catch-per-unit-effort model (Laake 1992) which uses hunter or trapper effort and the age structure of the harvested population.

An exploited population of raccoons was studied to examine the methods and biases associated with mark-recapture and catch-per-unit-effort population size estimators. In addition, the current MDNR methodology used to determine the size of the black bear population in Michigan was examined for potential biases and recommendations were developed to improve the quality of the estimator.

OBJECTIVES

- 1) In an exploited population of raccoons to:
 - a) estimate population size through
 - i. ear tagging and harvest mark-recapture, and
 - ii. tetra-HCL laced bait and harvest mark-recapture,
 - b) determine biases associated with the population size estimators, and
 - c) estimate population response to an increased rate of exploitation. Because substantial harvest occurred only in the final year of the study, this objective may be addressed in a follow up study being conducted in fall 1995, but will not be addressed here.

2) For Michigan black bear to:

- a) estimate population size through
 - i. tetra-HCL laced bait and harvest mark-recapture, and
 - ii. a catch per effort model based on hunter harvest and effort data (Laake 1992), and
- b) determine biases associated with these population size estimators.

STUDY AREA

The study area is described in CHAPTER I.

METHODS

Raccoon Marking Procedures

Methods were the same as in CHAPTER I (see Live Trapping and Marking Procedures and Age Analysis).

Raccoon Harvest

The Orange area remained under normal hunting and trapping conditions to provide an exploited area for this study. This area was used to examine mark-recapture population estimation strategies. The number of marked animals that showed up in the fall harvest were recorded and the population size estimated with a Chapman estimator (Krebs 1989). I originally planned to use harvest effort and age distribution of the harvest in a catch-per-unit-effort (CPUE) model (Laake 1992) as an alternative to estimate population size of Rose Lake raccoons, but was unable to do so because the model requires multiple harvest seasons. Natural exploitation rates of the Rose Lake raccoons were

found to be low, and a substantial harvest on the population was accomplished only in the final year of the study. The Yellow area was closed to hunting and trapping of raccoons throughout the study (see CHAPTER I).

Because the legal exploitation (hunting and trapping) rate was negligible, the exploitation rate was artificially increased in both areas during early spring 1995, i.e. following the third study season. In February-March 1995, the MDNR Wildlife Division provided an experienced trapper to harvest raccoons from both the unexploited and exploited areas using leghold traps (Nos. 1 and 1 ¹/₂, Woodstream, Inc., Lititz, Pennsylvania). From each harvested animal, sex and ear tag numbers (if marked) were recorded, and a canine tooth was collected.

To examine tetracycline marking, collected undecalcified teeth were cut using a double-bladed diamond saw into a single longitudinal section of approximately 60-150 micrometers (Perry et al. 1989, Fletcher et al. 1990). Sections were examined under ultraviolet light to determine the presence of fluorescing bands (which appear yellow) in the dentin and cementum layers (Johnston and Watt 1981, Johnston et al. 1987, Perry et al. 1989, Fletcher et al. 1990). If a mark was observed, the section was cut in half and one half was decalcified and stained for age analysis. The stained and unstained halves were then aligned on a microscope slide by matching annuli. This allowed estimation of the age of the raccoon and the year(s) of marking.

Information on the age structure of the marked animals was compared to the age structure of the harvested animals using chi-square analysis to see if they were disproportionate as in the black bears.

Raccoon Population Estimates

A Chapman estimator (Krebs 1989) was used on the ear tag and tetracycline marking and harvest recapture to estimate raccoon population size in the Orange area, the Yellow area, and both areas combined. The formula was:

$$\hat{N} = \frac{[(\text{number marked in 1st sample})+1]*[(\text{number in 2nd sample})+1]}{[(\text{number marked in 2nd sample})+1]} - 1 \quad \{2.1\}$$

Ninety-five percent binomial confidence intervals (Krebs 1989) were constructed around the estimates. Corrected estimates for each were then made using estimated ear tag loss and multiple tetracycline marking rates. The population estimate using ear tag data was for the 1992 population, while the estimate using the tetracycline data was for the 1994 population.

The assumptions of this population estimator are:

- 1) For all individuals in all sex and age classes, there must be an equal chance of:
 - a) being marked through live trapping or tetracycline baiting, and
 - b) being harvested.
- 2) For tetracycline baiting:

a) each bait can be consumed by only 1 raccoon and baits taken by raccoons can be distinguished from baits taken by other species, and

b) each raccoon consumes only 1 bait.

3) Ear tags are not lost, and all raccoons that consume bait have permanent visible tetracycline marks.

4) No background level of tetracycline exists in the population.

5) Deaths and/or emigrations from the population occur at equal rates among marked and nonmarked raccoons.

6) There is no immigration into the population.

Current Methodology to Estimate Black Bear Population Size

Annually from 1989 to 1993, approximately 600 baits containing tetracycline-hydrochloride (500 mg tetracycline-HCL capsules enclosed in approximately 0.5 kg bacon) were suspended in trees on an 8 km² grid throughout the Upper Peninsula of Michigan during June, July, or August (Visser, MDNR unpubl. data). Tetracycline dose per bait was 2000 mg in 1989, 2500 mg in 1990-1991, and 4500 in 1992-1993. Baits were checked for consumption after 2 weeks and baits that were not eaten were removed. Claw marks on tree trunks were used to determine whether it was a bear or another species which had consumed the bait (Garshelis and Visser, unpubl. data).

The bear harvest occurred in September and October of each year. Bear hunters were required to submit a first upper premolar from each harvested bear. Each tooth was

examined for tetracycline marks (see METHODS Raccoon Harvest).

The number of baits taken by bears in a year was assumed to be the number of bears marked in the first sample (although corrected for double marks; i.e. bears which took more than 1 bait). The number of teeth examined from that year's harvest was considered to be the number of bears in the 2nd sample. The number of teeth with a tetracycline mark from the year for which the population estimate was being made was used as the number of marked bears in the 2nd sample. These data were used in a Chapman estimator to estimate the population size for that year (Krebs 1989). Population estimates excluded the cubs of the year because it was assumed they rarely take baits, and their claw marks on trees weren't distinguishable from other mammalian carnivores.

The assumptions of this population estimator are:

1) For all individuals in all sex and age classes, there must be an equal chance of:

- a) consuming tetracycline laced bait, and
- b) being harvested.

(i.e. both marking and harvesting is a random sample from the same population).

- 2) Each bait can be consumed by only 1 bear.
- 3) Each bear consumes only 1 bait.

- 4) All bears that consume bait become marked; i.e. the tetracycline is deposited into the teeth, and the mark is detectable.
- 5) No background level of tetracycline exists in the population.
- 6) Deaths and/or emigrations from the population occur at equal rates among marked and nonmarked individuals.
- 7) There is no immigration into the population; i.e. there is no addition of nonmarked individuals into the population.

If Assumptions 3, 4, and 7 are violated, the population estimate will be an over-estimate of the true population size. If Assumptions 2 and 5 are violated, the population estimate will be an under-estimate of the true population size. If Assumptions 1 and 6 are violated, the resulting estimate will be either an under- or over-estimate of the true population size depending on which way the assumption is violated. For example, if the death rate of marked animals is greater than that of nonmarked animals, the estimator will yield an over-estimate of the true population size.

In subsequent years, bears marked in previous years showed up in the harvest. These data were added to the original data for each year to update the population estimate, but the number of nonmarked bears was adjusted to eliminate bears too young to have been alive during the original year of marking. For example, to update the 1989 population estimate by adding in data from the 1990 harvest,

only teeth from bears 2 years and older were included in the estimate, and the number of bears younger than 2 years old was subtracted from the number in the 2nd sample. To add in data from the 1991 harvest, only data from bears 3 years and older were used to update the 1989 estimate, and only data from bears 2 years and older were used to update the 1990 estimate. This eliminated the problem of having to assume that there were no birth additions to the population over successive years, but Assumption 7 still had to be met.

This methodology was used for a hypothetical population of 7000 individuals with random marking and harvesting to demonstrate how the estimator should work if Assumption 1 is met. To simulate random marking and harvesting, the proportion of individuals in each age class of the initial population is the proportion used for marking and harvesting in each age class.

Catch-per-unit-effort Estimator

The number of bears harvested in each sex and age class, and the estimated number of hunters and number of hunter-days were used in PROGRAM HARVEST, a catch-per-unit-effort model (Laake 1992), to estimate black bear population size in Michigan. Some of the assumptions for this model are:

- 1) A discernible relationship exists between harvest and effort.
- 2) Accurate measurements of the number of animals harvested in each sex and age category are made.

- 3) Accurate measurements of harvest effort are made.
- 4) A large proportion of the population is harvested each year.

An Alternative Estimator

An alternative population estimator (Winterstein-Karasek) was developed which incorporates the number of double marked individuals in the harvest. Tetracycline-laced baits would be placed throughout the area each year, but the baits would not need to be counted or re-checked for consumption. This model relies on the number of marks for each individual harvested bear in the 2 marking periods prior to death (APPENDIX E). It also uses the probabilities of an individual bear taking a tetracycline bait and of an individual bear being killed in the harvest.

RESULTS AND DISCUSSION

Raccoon Marking

A total of 114 raccoons were marked with Monel #4 ear tags (see CHAPTER I RESULTS Live Trapping).

During live trapping, it was found that 4 raccoons lost 1 ear tag (Monel #4) each, while 2 raccoons lost both ear tags from 131 total individuals. Additionally, in spring 1992, a different type of ear tag, than Monel #4, was placed on the first 21 raccoons who were captured. These ear tags did not appear strong enough for retention by raccoons, because animals with holes in their ears but no tags were subsequently recaptured. It is believed that all 21 raccoons lost these tags. Four of those who lost the first ear tag

type in spring 1992 were retagged with Monel #4 tags and 1 was radio-collared when recaptured. The ears of some recaptures were too torn or infected from the first tags to be retagged. For purposes of the Chapman population estimator, identifying individual animals is not necessary, only whether an animal was marked or not. Therefore, ear tag loss was considered to be the loss of both ear tags, not the loss of only 1. From these data it is estimated that ear tag loss was 1.7% for Monel #4 tags (i.e. 2 out of 116 raccoons with Monel #4 tags lost all evidence of ear tagging), and 16.8% when both tag types were included.

Raccoon Harvest

The only tagged animal that was reported harvested for the 1992 season was an adult female that was trapped north of the Rose Lake Area along Mud Creek. Signs were placed at all parking areas around the Orange area explaining the importance of reporting ear tags and provided a phone number. In addition, several local hunters and trappers were contacted but reported no tagged kills.

During the 1993 harvest, no tagged kills were reported. Our artificial increase of the natural exploitation rate commenced in the 1994 season. A local hunter attempted to increase the harvest of raccoons in the Orange area but killed only 6, of which 4 had ear tags. There were rumors that although many local hunters reported little to no harvest, there was actually substantial hunting harvest occurring in the Rose Lake Area. A local fur trapping supply

company, which is visited by many local racoon harvesters, estimated 60 raccoons had been killed in the Rose Lake Area in fall 1994. Additionally, although the Yellow area was officially closed to raccoon hunting and trapping in 1992-1994, 4 skinned raccoon carcasses (2 male, 2 female) were found in a parking lot on the northern edge of the Yellow area. It is possible that hunters were unwilling to admit how many raccoons were harvested either due to fear of stricter harvest regulations in the future, or because some poaching had been occurring.

The MDNR trapping in January-March 1995 resulted in a total harvest of 29 raccoons from both the Orange and Yellow areas (Table 7) from 307 trap nights. Ten of the 29 harvested raccoons had tetracycline rings in their canine tooth, and of those 9 had previously been live trapped, of which 8 received tetracycline injections (Table 8). The other 1 was originally captured in 1994, the year in which no tetracycline injections were given because tetracycline laced baits were distributed. Five of the 9 who had been live trapped had also eaten tetracycline bait. Only 1 raccoon received its mark from the tetracycline bait only, even though it was 4 years old and so was alive during all live trapping seasons. Of the nine animals who had been live trapped, 7 still had ear tags. Two of the ear tagged animals had MSU ear tags only, i.e. they had lost the numbered ear tag, so it was not possible to identify which individuals these 2 were. The 2 other raccoons with tetracycline

Table 7. Raccoon leghold trapping success over 3 trapping periods in spring 1995 at the Rose Lake Area Wildlife Research Area.

Trapping Period	<u>Orange Area</u>		<u>Yellow Area</u>		<u>Overall</u>		
	Nights ^a	Raccoons ^a	Nights	Raccoons	Nights	Raccoons	Percent Success
Feb 1-2	41	2	0	-	41	2	4.9
Feb 20-23	78	11	63	7	141	18	12.8
Mar 20-23	40	6	85	3	125	9	7.2
Total	159	19	148	10	307	29	
Percent Success	11.9		6.8		9.5		

^a Nights = number of trap nights. A trap night is defined as 1 trap open for 1 night.
Raccoons= number of raccoons harvested.

Table 8. Sex, age structure, and marks of 29 raccoons harvested in spring 1995 at the Rose Lake Wildlife Research Area.

Date	Sex	Age	Ear Tags	Tetracycline Marks ^a
<u>Orange Area:</u>				
Feb 22	M	1	None	-
Feb 24	M	1	None	-
Feb 23	M	2	None	-
Feb 24	M	2	None	-
Mar 23	M	2	None	-
Feb 3	M	3	None	-
Mar 23	M	3	None	-
Feb 23	M	4	None	+92,+93
Mar 21	M	4	None	+94(2 baits or more)
Feb 22	M	5	Tags 415/416	+92,+93,+94
Feb 24	M	5	None	+92,+94(2 baits)
Feb 3	F	1	None	-
Feb 23	F	1	None	-
Feb 23	F	4	None	-
Mar 24	F	4	Tag 531	+93
Mar 24	F	5	None	-
Mar 24	F	8	None	-
Feb 24	F	9	None	-
Feb 24	F	11	None	-
<u>Yellow Area:</u>				
Mar 23	M	1	None	-
Feb 23	M	2	None	-
Feb 23	M	4	Tag 502/Radio 1243	+93,+94(3 baits or more)
Mar 23	F	1	None	-
Feb 23	F	2	None	-
Mar 24	F	4	MSU Tag	+93
Feb 23	F	6	Tags 477/478	+92,+94
Feb 24	F	6	MSU Tag	+94
Feb 22	F	8	None	-
Feb 23	F	11	Tag 508/Radio 1183	+93

a - = no tetracycline ring in tooth; +92 = tetracycline ring from 1992 live trapping injection; +93 = tetracycline ring from 1993 live trapping injection; +94 = tetracycline ring from 1994 baiting (there were no injections in 1994). Raccoons which took more than 1 bait during 1994 are noted.

injections no longer had any evidence that they were ear tagged. One ear tagged raccoon had been tagged in 1993, but a 1992 tetracycline mark was also found in its tooth sample. This animal must have been originally captured in 1992, but lost all evidence of tagging prior to its 1993 capture.

Although this is a small sample size, it is estimated that 10% of the population were not susceptible to live trapping; i.e. 1 in 10 tetracycline marked raccoons was never live trapped. However, if harvested animals which were old enough to have been live trapped during spring 1992 to spring 1994 (i.e. at least 2 years of age), but were never captured are considered, approximately 14 of 23, or 61%, were not susceptible to live trapping. Only 1 raccoon who was old enough to have been live trapped, but wasn't, picked up the bait.

From the harvest, 3 of 9 originally ear tagged animals lost both ear tags (including the 1 who had lost its 1992 tags, but retained its 1993 tags), 2 lost one ear tag each, and 5 retained both tags. Ear tag loss from harvested animals is estimated to be 30%.

When observed ear tag loss from both live trapping and the harvest are combined, total ear tag loss is estimated to be 4.3% for Monel #4 tags (i.e. 5 raccoons lost both tags from 116 raccoon taggings) and 19% for both tag types together.

No significant difference was found in age structure between the Orange and Yellow areas either over all years

($\chi^2=10.26$; $p=0.2473$; $df=8$) or within a year ($p>0.30$). A significant difference in age structure was found between marked and harvested raccoons ($\chi^2=36.22$; $p<0.0001$; $df=8$) when ages by year from yearlings to age 11 was compared. Marked raccoons had a younger age distribution than harvested raccoons. Ninety-two percent of marked raccoons were aged 1 year to 3 years, while only 45% of harvested raccoons were in those age classes. This analysis used ages of marked animals that were exactly aged through tooth examination (90 marked raccoons total). When ages were compared using only yearling and adult age classes (115 marked raccoons total), a significant difference in age structure between marked and harvested animals was still found ($\chi^2=7.41$; $p=0.0065$; $df=1$). Forty-nine percent of marked raccoons were in the yearling age class, while only 21% of harvested raccoons were yearlings.

Raccoon Population Estimates

Low sample sizes caused population estimates to have very large confidence intervals (Table 9). For both ear tagging and tetracycline baiting data, population estimates for the Yellow area had much narrower confidence intervals than the Orange area. In addition, the estimate seemed to be more accurate. Although true population size is not known, each area was comprised of approximately 2.6 km², so the estimates of 38 to 65 raccoons for the Yellow area seem more likely than the estimates of 64 to 303 for the Orange area.

Table 9. Chapman population estimates of the Rose Lake Wildlife Research Area raccoons for 1992 using ear tags and for 1994 using tetracycline marks.

	<u>Uncorrected</u>		<u>Corrected^a</u>	
	Estimate	C.I. ^b	Estimate	C.I. ^b
<u>1992:</u>				
Orange Area ^c	303	(138,5699)	290	(132,5458)
Yellow Area ^c	65	(47,168)	62	(45,161)
Both Areas ^c	299	(188,832)	286	(180,797)
(1994 hunt) ^d	84	(63,276)	81	(60,265)
<u>1994:</u>				
Orange Area ^c	104	(53,699)	64	(32,432)
Yellow Area ^c	62	(34,382)	38	(21,236)
Both Areas ^c	183	(107,572)	111	(65,348)

^a 1992 estimates were corrected for estimated ear tag loss. 1994 estimates were corrected for multiple tetracycline marks.

^b Binomial confidence intervals.

^c Recaptures were from the spring 1995 trapping harvest.

^d Recaptures were from the fall 1994 hunting harvest.

Violation of some assumptions may have caused some bias in the population estimates. Assumption 1, that individuals of all sex and age classes have an equal chance of being marked and harvested, was violated to some extent. First, as stated previously, there was a significant difference in age structure of marked animals versus harvested animals. Secondly, in live trapping sessions, adult and yearling males were more likely to be captured in spring than in fall, yearling females were more likely to be captured in the fall than in spring, while adult females were captured in both spring and fall (see CHAPTER I). But throughout the year, the sex and age classes appeared to even out so that all individuals may have had an equal chance to be marked (see APPENDIX B), although the true sex and age structure of the raccoons in this area was not known. Lastly, males and females were captured equally in the spring 1995 harvest, and all ages appeared to be represented in the harvest (Table 8) although again, the true sex and age structure of these raccoons is not known.

It is unlikely that Assumption 2a, that each bait was consumed by only 1 animal, was violated. The baits contained only 1 tetracycline capsule each, and were only approximately 2.5 cm in diameter. It is likely that a bait of this size was consumed completely by 1 raccoon, and not shared among a group. In addition, most raccoons, except females with kits, travel alone. Assumption 2b, that each raccoon consumed only 1 bait, was violated. In the spring

1995 harvest, of the 6 raccoons who had been marked through baiting, 2 took at least 2 baits, and 1 took at least 3 baits. Thus, half of the raccoons marked through baiting were estimated to have taken multiple baits. So many baits were placed throughout the study areas in the attempt to mark as many raccoons as possible that a foraging raccoon may have come upon several baits in 1 night. In addition, baits were checked and replaced several times throughout a 3 week period which allowed consumption of multiple baits over the time period at the same locations. The estimated number of multiple baits taken may have been higher because some cementum growth must occur between tetracycline deposits for multiple rings to be observed. If a raccoon took more than 1 bait in the same night, the tetracycline deposit may appear as only 1 ring. When the population estimates were corrected for multiple marks, there was a 39% change in the estimate (Table 9).

Another problem with the baiting was that baits were placed on the ground where practically any terrestrial animal species had access to it. In addition, there were often no tracks at the baiting site, so that it was impossible to tell whether a raccoon or another species had consumed it. This possibly caused a bias in the estimate of the number of marked animals in the population. It was not possible to estimate this bias.

Assumption 3, that all marks are permanent and detectable, was known to be violated to some extent. Some

ear tags were lost, but because tetracycline injections were given at the same time ears were tagged, it was possible to check harvested animals for possible tag loss. When the population estimates were corrected for estimated tag loss, there was not much change (Table 9), again leading to the conclusion that the assumption was not violated to a great extent. All injected tetracycline marks and most bait marks were very visible. However, 1 bait mark was very thin and barely visible. Some bait marks may have been missed if animals did not grow enough after consuming the bait to deposit enough tetracycline into the cementum. Again, it was not possible to estimate this bias.

It is not known whether Assumption 4, that there was no background level of tetracycline in the population, was violated. However, there does not appear to be high background levels of tetracycline in other wildlife populations in Michigan (see RESULTS AND DISCUSSION Current Methodology to Estimate Black Bear Population Size).

Assumption 5, that deaths and emigration from the population occur at equal rates among marked and nonmarked raccoons, was probably not violated to any great extent either (see CHAPTER I).

Finally, Assumption 6, that there was no immigration into the population, may have been violated, but it is not known to what extent. Sixty-one percent of the harvested animals which were old enough to have been live trapped were never captured or marked. This could mean that they were

either not susceptible to live trapping, not susceptible to baiting, or had immigrated into the population between the August 1994 baiting and the spring 1995 harvest. It is not known which of these scenarios is true for those 14 animals.

Violations of Assumptions 2 and 3, that multiple baits may have been consumed by the same raccoon but not detected and that some bait marks may not have been dark enough to be detected at all, would result in an over-estimate of the true population size. Violations of Assumption 1 and an assumption that the number of marked animals in the population is known, would result in either an over- or under-estimate depending on which way the assumptions were violated. For example, if some baits were taken by raccoons but no tracks were left at the baiting site, the number of marked raccoons in the population would have been underestimated and thus the population estimate would have been an under-estimate of the true population size.

Current Methodology to Estimate Black Bear Population Size

The population estimates of the black bear in Michigan's Upper Peninsula varied considerably from year to year (Table 10). When harvest data collected in subsequent years was added to the harvest data of the original year of marking, the population estimate increased as each new year's data were added (except the 1990 population estimates; see Table 10). For the 1989 population estimate this is a 167% increase from the estimate using the 1989 harvest data to the 1994 harvest data updated estimate. The

Table 10. Population size estimates of the black bear population in the Upper Peninsula of Michigan from 1989 to 1993 using a Chapman estimator (Visser, MDNR, unpubl. data).^a

Estimate Year	Number Marked ^b	Harvest Year	Number of Bears Harvested ^{c,d}	Marks in Harvest ^d	Population Estimate
1989	88	1989	934	19	4160
		1990	352	4	4772
		1991	424	4	5438
		1992	369	1	6382
		1993	244	2	6671
		1994	170	1	6935
1990	196	1990	469	12	7121
		1991	636	19	6808
		1992	511	12	7239
		1993	320	7	7481
		1994	225	4	7743
1991	175	1991	811	29	4763
		1992	756	25	5017
		1993	499	3	6271
		1994	337	4	6823
1992	237	1992	887	35	5870
		1993	677	20	6650
		1994	450	8	7492
1993	246	1993	949	42	5456
		1994	765	18	6943

^a The estimate is updated by accumulating the data from each subsequent year's harvest.

^b The number marked is adjusted for the estimate of multiple baits picked up by one bear within a year.

^c The number of bears harvested is adjusted by subtracting the number of bears which were too young to have been alive during the baiting year.

^d The number of bears harvested and the number of marks in the harvest include bears killed by means other than the legal harvest.

reason this difference is so large is that during the 1989 harvest 22% of the animals with 1989 marks showed up in the harvest, but in subsequent years <5% of the animals with 1989 marks were harvested each year, although the total number of bears harvested, i.e. number of bears in the 2nd sample, did not decrease by as much. Logically, as the ratio of number of marks in the 2nd sample to the total number of bears in the 2nd sample decreases, the population estimate will increase. Similar, but less dramatic decreases in this ratio in subsequent years' harvests occurred in the 1990-1993 estimates.

If all the assumptions for the Chapman estimator were met, the addition of data from subsequent harvests should result in similar estimated population sizes regardless of how many times the estimate is updated by adding new data (Table 11). The Chapman estimator does result in a slightly increasing population size estimate as sample size increases because this model tends to under-estimate at small sample sizes, however, the Lincoln-Petersen estimates remain the same over time. Because the MDNR updated estimates do not remain the same, but show a dramatically increasing trend that results in nearly double the population size estimate as new samples are added over a 5 year period, one or more of the assumptions for the Chapman estimator must be significantly violated for Michigan black bear.

Violation of the assumptions of the Chapman estimator may help explain why an over- or under-estimate may occur in

Table 11. Population estimates (for Year 1) of a hypothetical population of 7000 individuals if marking and harvesting are random. Estimates are updated over time by accumulating data from each successive year's harvest.

Year	Age	<u>In Population</u>		<u>In Harvest</u>		Chapman ^b	L-P ^b
		Mark	No Mark	Mark	No Mark		
1	1	50	1700	10	340		
	2	40	1360	8	272		
	3	36	1224	7	245		
	4	24	816	5	163		
	5	20	680	4	136		
	6	14	476	3	95		
	7	10	340	2	68		
	8+	6	204	1	41		
	Total	200	6800	40	1360		
						6867	7000
2	1	N/A ^a					
	2	40	1360	8	272		
	3	32	1088	7	245		
	4	29	979	5	163		
	5	19	653	4	136		
	6	16	544	3	95		
	7	11	381	2	68		
	8+	8	272	1	41		
	Total	155	5277	30	1020		
						6938	7000
3	1	N/A ^a					
	2	N/A ^a					
	3	32	1088	7	245		
	4	25	843	5	163		
	5	24	816	4	136		
	6	15	517	3	95		
	7	13	449	2	68		
	8+	9	313	1	41		
	Total	118	4026	22	748		
						6961	7000

^a Individuals in these age classes were not yet born during marking in Time 1.

^b Chapman= see {2.1}; L-P = Lincoln-Petersen = ((initial number marked)*(number harvested)/(number marked in harvest)). Accumulation occurs as follows in the example for Harvest Year 3:

$$L-P = ((200)*((40+1360)+(30+1020)+(22+748)))/(40+30+22))$$

the population estimates. For example, if some bears consumed more than 1 bait, and/or some bears did not retain tetracycline deposits in their teeth, and/or there was significant net immigration of nonmarked bears into the population, then the population estimate would be an over-estimate of the true population size. However, this bias would remain consistent over all years that the estimate was updated, unless the assumptions were violated differently from year to year to account for an increased over-estimate as each years' data were added. There was no evidence to support this idea.

Known violations of the 7 assumptions were as follows. For Assumption 1, that all individuals in the population have an equal chance of being marked, and all individuals in the population have an equal chance of being harvested, there were several violations reported (Visser, MDNR unpubl. data). Marking in bears 8 years of age or older appeared to be low, possibly due to thinner cementum deposits in the teeth of older bears. In addition, males had a greater marking rate than females (Visser, MDNR unpubl. data), and males 1 year old and 8 years and older had a lower marking rate than males 2-7 years old. Females that were 8 years of age or older also showed a lower marking rate compared to other sex and age classes, but when tetracycline doses per bait were increased in 1992-1993, the rate of marking of these bears increased.

Because there is not an independent estimate of marks in the population, i.e. the information on the marking rates comes from the harvest sample, the estimated marking rates by sex and age classes may be inaccurate, especially if the harvest was skewed towards one or more age and/or sex classes.

The bear harvest consisted of a greater proportion of males than females, and a greater proportion of young animals than older ones (Figure 2). The true sex and age structure of the population is not known. However, because the sex and age structure of the marked population differed from the harvested population, either the marking or the harvest portion of the study (or possibly both) must have been nonrandom.

Assumption 2, that each bait can be consumed by only 1 bear, was probably met since bears are solitary foragers, and only sows with cubs travel in groups. There is a slight chance that a sow could have pulled the bait down from the tree and fed on it with her cubs. If the tetracycline capsules within the bait were separately consumed by >1 bear in the group, then the number of bears in the population that were marked may have been under-estimated. All cubs are excluded from the analysis so family groups sharing 1 tetracycline bait would not cause an under-estimate of the number of marked bears. In addition, a sow is unlikely to travel far when foraging with cubs, so the chance of them encountering a bait may not be as great.

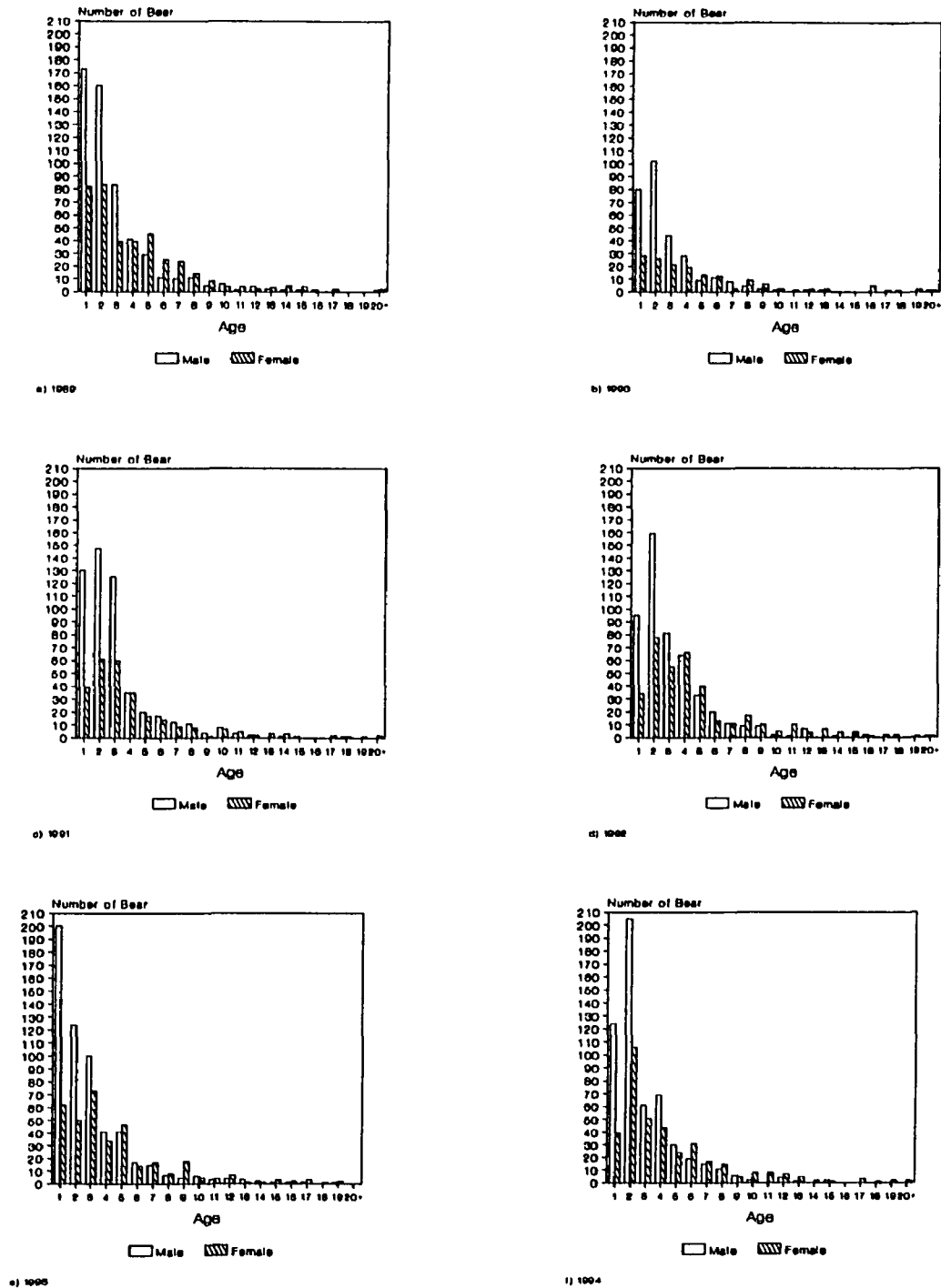


Figure 2. Sex and age structure of the black bear harvest in the Upper Peninsula of Michigan from 1989 to 1994.

Assumption 3, that each bear consumes only one bait, was violated. An estimated 1.5% of marked bears showed a double mark (Visser, MDNR unpubl. data), but rates may have possibly been even higher. Tetracycline doses were so high that consumption of >1 bait within the 2 week baiting period was not easily detected because the highly fluorescent rings may not have been separated by enough cementum to discern separate marks within the same year.

Assumption 4, that all bears that consume bait become marked, and all marks are detectable and permanent, was probably violated, but it is not known to what extent. In Minnesota, it was found that 5% of marks in teeth were so faint that they might have been missed if sections of the rib bone had not been checked first for marks (Garshelis, MN DNR unpubl. data). In addition, it was suspected that older bears do not lay down enough cementum, because of slower growth rates, to deposit enough tetracycline for marks to be visible.

Violation of Assumption 5, that no background level of tetracycline exists in the population, appeared to be negligible. Only 3 teeth out of 4815 that were examined from 1989-1994 contained tetracycline marks that were deposited prior to 1989.

Assumption 6, that deaths and emigration from the population occur at equal rates among marked and nonmarked individuals, was also not likely violated. There is little movement of bears across the Michigan-Wisconsin state

border, and an examination of teeth from bears killed in neighboring Wisconsin counties yielded tetracycline marks in only 1% of the bears (MDNR unpubl. data). Movements of ear tagged and radio-collared bears also support the idea that emigration is probably negligible (MDNR unpubl. data). In addition, a mechanism which would cause differential emigration or survival rates in marked bears versus nonmarked bears is not known, since the tetracycline marking should not affect mobility or survival. There is also little evidence to suggest that Assumption 7, that there is no immigration into the population, was violated significantly.

It appears that only Assumptions 1, 3, and 4 were violated to a great extent. Assumptions 3 and 4 were partially corrected for when possible. As stated previously, violation of 3 and 4 would result in an over-estimate of the true population size, but these biases would be consistent over all years that the population estimate was updated. This does not explain why population estimates for each year of marking tended to increase with the addition of subsequent years' harvest samples.

The violation of Assumption 1 may be the significant factor in explaining these trends. It has been suggested that the population estimate from the year of marking was an under-estimate and that accumulating the harvest samples from subsequent years made the estimate more accurate (Garshelis and Visser, unpubl. data). The mechanism causing the under-estimate was suspected to be that bears attracted

to the tetracycline baits were positively reinforced to search out baits in the immediate future. Therefore these bears were more likely to be harvested in the year that they were marked. This would have resulted in a greater proportion of marked bears to be in the first harvest after marking, but the learned attraction to baits from the positive reinforcement would wane after the first year's harvest. This would mean that the ratio of the number of marked bears in the 2nd sample to the total number of bears in the 2nd sample would be higher than actually occurred in the population. Thus, the population estimate using the first harvest sample after marking would have been an underestimate. As the attraction waned in subsequent years, the proportion of the number of marked bears in the 2nd sample to the total number of bears in the 2nd sample would have decreased to the true population ratio of marked to nonmarked bears. However, this scenario is not very likely because there was no significant difference between marking rates of Michigan bears killed by hunters using hounds (or other nonbaiting methods) versus bait (Garshelis and Visser, unpubl. data). Another explanation that was suggested to explain why the ratio of the number of marked bears in the 2nd sample to the total number of bears in the 2nd sample would be higher in the first harvest after marking, was that bears which are more mobile are more likely to encounter baits and be marked, and to be tracked and killed (Garshelis and Visser, unpubl. data). Again, such a bias would be

consistent over all years of harvest sampling and although it would produce an under-estimate of the true population size, it would not explain the increasing trend of the population estimate as subsequent years' harvest samples were added.

I suggest that the current methodology actually causes the ratio of the number of marked bears in the 2nd sample to the total number of bears in the 2nd sample to be lower in the first harvest after marking than in the true population, not higher. The MDNR uses data from all reported bear deaths in the Chapman estimator, including nonlegal harvest and nonharvest mortalities such as poaching, road kills, nuisance bears, etc. Some of these deaths occurred prior to the baiting session for that year (Visser, MDNR unpubl. data), so that these animals necessarily were nonmarked, because they were not alive long enough to be marked that year. This would cause a bias in the estimate by assuming that these animals had the chance to be marked and so the ratio of the number of marked animals in the 2nd sample to the number of nonmarked animals would be an under-estimate. This would result in an over-estimate of the true population size for the first harvest after marking.

From the number of marks within age classes in the harvests, it was estimated that a greater proportion of bears aged 2-7 years were marked than bears aged 1 and 8 years or older (Table 12). It was also estimated that a greater proportion of bears aged 1 to 3 were harvested than

Table 12. The number of tetracycline marked and nonmarked black bears in the 1989 legal harvest in the Upper Peninsula of Michigan (excluding Drummond Island).

Age	Males		Females	
	Marked	Nonmarked	Marked	Nonmarked
1	2	171	2	82
2	3	157	2	81
3	5	78	1	39
4	2	39	0	38
5	0	29	0	45
6	1	10	0	25
7	0	10	0	24
8	1	11	0	14
9	0	5	0	8
10	0	6	0	4
11	0	1	0	4
12	0	4	0	2
13	0	2	0	3
14	0	1	0	5
15	0	1	0	4
16	0	1	0	0
17	0	0	0	2
18	0	0	0	0
19	0	0	0	0
20+	0	1	0	2

older bears (Figure 2). The proportion of bears within a certain age class that were marked was determined during the year of marking, and each subsequent year, each marked animal became 1 year older (Figure 3). However, the proportion of bears within a certain age class that were harvested remained constant each year, i.e. the 1-3 year old age classes were always about 75% of the harvest. As a result, in subsequent years the marked animals became older and less vulnerable to harvest, whereas the majority of the harvest occurred in the 1-3 year old age class. For example, in 1989, 75% of the marks in the harvest occurred in 1-3 year old bears (Table 12). In the 1990 and 1991 harvests, only 50% of the 1989 marks occurred in the 1-3 year old age class. In 1992, there were no 1989 marks in the harvest. In the 1993 harvest, only a 6 year old bear had a 1989 mark. In 1994, two 1989 marks were in the harvest, and both bears were in older age classes, i.e. 8 and 15 years old. Similar results were found for all other years of population estimates.

This disproportion between the age of marked animals and the age of harvested animals would result in a lower ratio of the number of marked bears in the 2nd sample to the total number of bears in the 2nd sample than there was in the true population. This ratio would have become lower in each successive year as marked animals became older and older and thus less vulnerable to harvest. As a result, as each subsequent years' harvest data were added into the

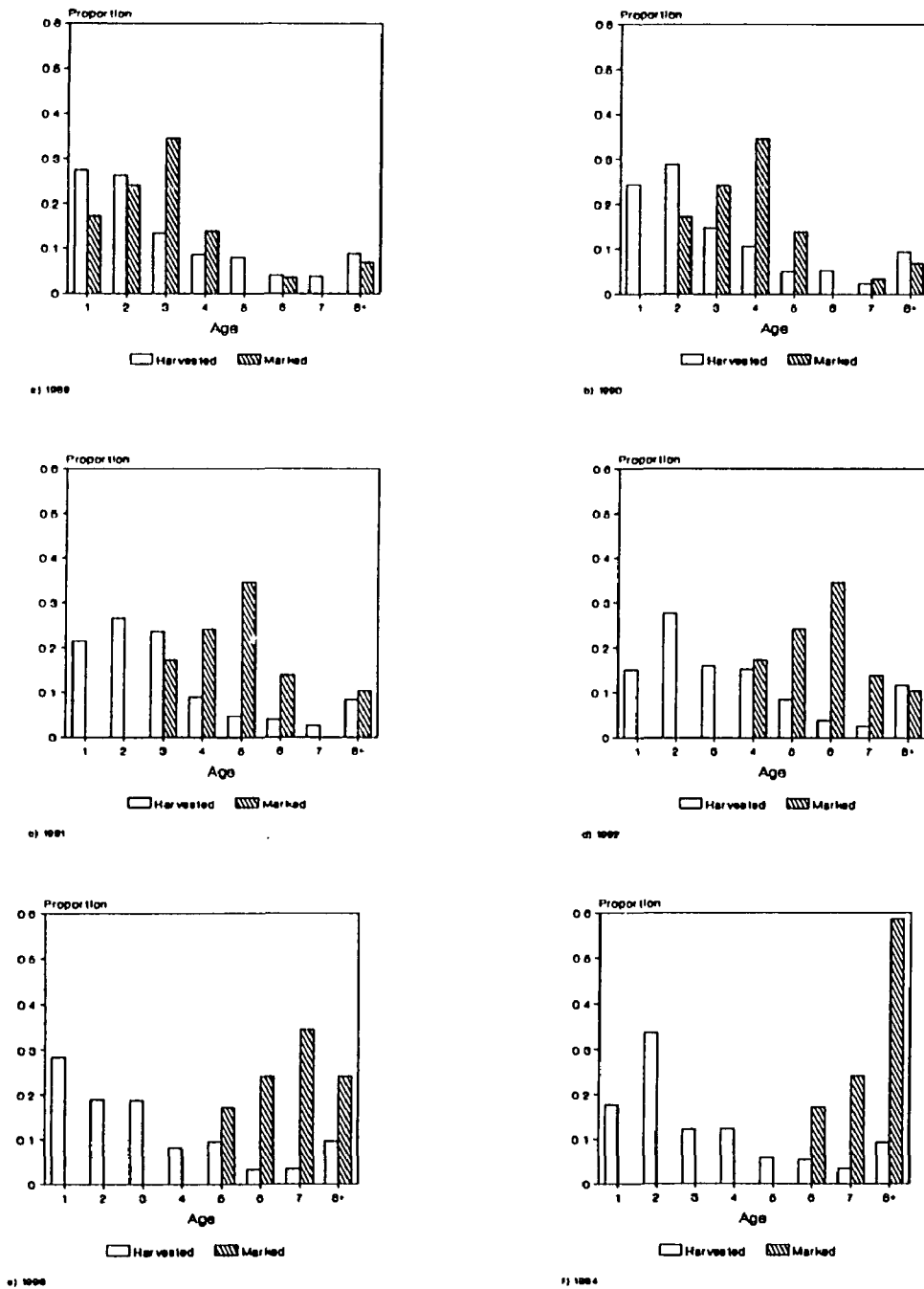


Figure 3. Proportion of the Michigan Upper Peninsula black bear harvest in each sex and age class from 1989-1994, and the proportion of tetracycline marked bears in each sex and age class in the 1989 harvest (made to be one year older each year for 1990-1994).

sample to update the population estimate for a certain year, the population estimate would show an increasing trend such as was exhibited by the MDNR's updated population estimates.

Catch-per-unit-effort Estimator

The catch-per-unit-effort (CPUE) population estimator developed by Laake (1992) may have future applications for estimating the size of the Michigan black bear population, but cannot be used at this time. The relationship between harvest and effort did not appear to be consistent enough (Figure 4) within the short time frame in which the MDNR had data that included both hunter effort and age structure of the harvest (1990-1994). Another potential problem was the change to a restricted permit hunting system in 1990 from the unrestricted hunting system in previous years. The number of hunters and hunter-days was reduced by approximately two-thirds that of unrestricted hunts (Figure 4). With a larger data set of restricted hunts (i.e. since 1990), there is no reason statistically that the CPUE estimator cannot be used in the future, unless there is absolutely no relationship between effort and harvest of Michigan black bear. However, from 1990-1994, the range of the number of hunters that were allowed permits was narrow (Figure 4a). Ideally the effort should vary over a range in which high effort is at least 200% above low effort (Laake 1992). Without a wider range of the number of hunters that results in a wider range of number of bears harvested, this

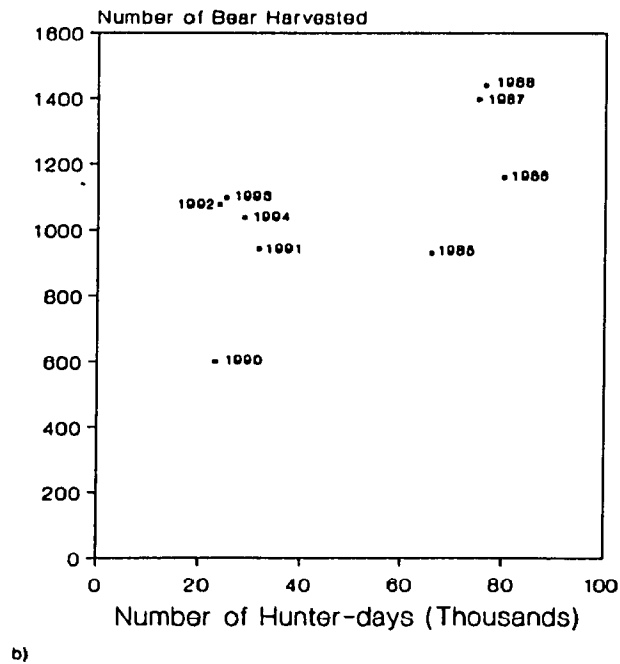
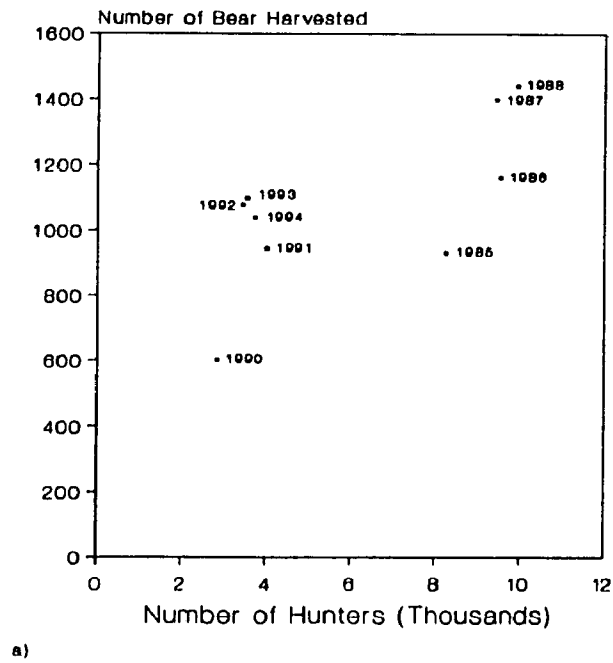


Figure 4. Hunter effort and number of bears harvested in Michigan's Upper Peninsula from 1985-1994 (except 1989).

estimator will not work because the relationship between effort and harvest becomes obscured.

An Alternative Estimator

The black bear harvest data from 1989-1994 was summarized in terms of tetracycline marks from the 2 marking periods prior to harvest (Table 13). The number of bears that showed double marks in back to back years was very low compared to the number of bears with a single mark from either year or no marks. Such a low probability of being marked 2 years in a row causes the Winterstein-Karasek model (W-K model) to fall apart so that the full model is not useful as a population estimator. However, Part I of the model (APPENDIX E) can be used as an alternative population estimator as follows. In Year 1, the tetracycline baits are placed throughout the area and the number of baits taken by bears counted, as is currently done. The number of Year 1 marks in the Year 1 harvest is then used with the number of baits taken by bears in the Chapman estimator to estimate population size for Year 1. M , the probability of an individual bear in the population receiving a mark in Year 1 [$M = (\text{number of marked bear in the population}) / (\text{population size})$] is estimated from the harvest data by assuming that the proportion of marked bears in the harvest is equal to the proportion of marked bears in the population. H , the probability of an individual bear being harvested in Year 1 can be estimated using the Chapman estimate of population size (N_{chap}) as follows.

Table 13. Number of bears in the harvest containing tetracycline marks from the 2 years prior to harvest.

Harvest	Marking Periods	++ ^a	+-	-+	--
1990	1989,1990	0	4	12	321
1991	1990,1991	1	16	25	574
1992	1991,1992	2	22	26	685
1993	1992,1993	3	15	30	615
1994	1993,1994	0	19	1	736

^a + indicates tetracycline mark is present; - indicates no mark: ++ = marked both years; +- = marked the first year but not the second; -+ = marked the second year but not the first; -- = not marked either year.

$$H=n_1/N_{\text{chap}}; \quad \{2.2\}$$

where n_1 =number of bear harvested in Year 1.

These estimates can then be used in Part I of the W-K model to estimate population size as follows.

$$m_1=N_{WK1}M_1H_1 \quad \{2.3\}$$

where m_1 =number of marked bears in the Year 1 harvest, N_{WK1} =estimated population size for Year 1 using the W-K model, M_1 =probability of receiving a mark in Year 1, and H_1 =probability of being harvested in Year 1.

Equation {2.3} can be rearranged to:

$$N_{WK1}=m_1/(M_1H_1) \quad \{2.3a\}$$

For the Year 1 population estimate, $N_{WK}=N_{\text{chap}}$. For Years 2-5, baits are placed throughout the area each year, but a count of baits consumed by bears is not needed. However, baiting effort must remain consistent over the 5 year period so that an increase in the number of marks is directly related to an increase in the number of bears in the population, not to an increase in the number of baits available to bears. Each year the tooth collection from harvested bears is required to determine m . The assumption that M and H are constant from Year 1 through Year 5 must be made. This assumption appears to be met for the Michigan black bear data, as M ranges from 0.02-0.04 in 1989-1993 (see Table 10). Each year, m is used in the W-K model to estimate population size. For Year 1: $N_{WK1}=(m_1/(M_1H_1))$; for Year 2: $N_{WK2}=(m_2/(M_1H_1))$; for Year 3: $N_{WK3}=(m_3/(M_1H_1))$; for Year 4: $N_{WK4}=(m_4/(M_1H_1))$; and for Year 5: $N_{WK5}=(m_5/(M_1H_1))$.

In Year 6, the Chapman estimator is used again to re-evaluate M and H , so the number of baits consumed by bears must be counted in Year 6. M and H are then re-estimated using Year 6 data. M_6 and H_6 are assumed to be constant from Year 6 through Year 10, and the procedures to estimate population size from Years 2-5 are used for Years 7-10.

For example, in 1989, $m_{89}=19$, $n_{89}=928$ and the number of baits taken by bear = 88 (only data from the legal harvest are used). Thus, $N_{chap89}=4134$, $M_{89}=(m_{89}/n_{89})=0.020474$, and $H_{89}=(n_{89}/N_{chap89})=0.224480$. Then $m_{90}=12$, $m_{91}=29$, $m_{92}=33$, and $m_{93}=42$. Thus, $N_{WK89}=4134$, $N_{WK90}=2611$, $N_{WK91}=6310$, $N_{WK92}=7180$, and $N_{WK93}=9138$. Although these intervening estimates (Years 2-5) are actual population estimates, they may be more effectively used as an index to the true population size, and only every 5th year estimate, in which the full mark-recapture Chapman estimator is conducted, can be used as an actual population estimate. The above estimates show dramatic increases and decreases in the bear population, but a change in baiting effort and procedures over the 5 year period may have caused such a result. If there is concern that M and H are not constant over a 5 year interval, then the Chapman can be conducted on a shorter interval, such as every 3rd year.

CONCLUSIONS AND RECOMMENDATIONS

Similar problems with violation of assumptions of the Chapman population estimator were found for both raccoons and black bear. The biggest problem, and probably the most

difficult to remedy, is the violation of the assumption that all individuals in all sex and age classes in the population have an equal chance of being marked and of being harvested, i.e. that the marking and the harvest are both random samples of the same population. It is very difficult to estimate these biases in the field and correct for them, especially in a population as large as the Upper Peninsula black bear.

It was originally planned that the raccoon population would serve as a surrogate species for the black bear in which the marking and harvesting parameters could be controlled and manipulated to test biases in several population estimators. The harvest in the Rose Lake Area was negligible throughout the study, so these objectives were not fully met. However, examination of data from both the raccoon and black bear marking and harvest resulted in several recommendations for reducing bias in the use of the Chapman estimator for the black bear population in the Upper Peninsula of Michigan.

First, the population estimate for a year should be conducted using only harvest data from the year of marking. The MDNR used the final population estimate arrived at after updating for each year, i.e. the estimate for 1989, 1990, 1991, 1992, and 1993 populations were concluded to be 6935, 7743, 6823, 7492, and 6943, respectively (see Table 10). Estimates should not be updated this way by adding subsequent year's harvest returns. As stated previously, the

increasing trend of the updated population estimates for a year was caused by the increasing age of the marked population over the years, while harvest proportions in each age class remain similar over the years. When only harvest data from the year of marking is used, the population estimates for 1989, 1990, 1991, 1992, and 1993 are 4160, 7121, 4763, 5870, and 5456, respectively (Table 10). These estimates are substantially lower than what the MDNR traditionally reports. If this population estimate is an under-estimate of the true population size, it is at least a consistent bias for each year's estimate. When subsequent year's harvest data is added into the estimator for a year, it is not known whether the estimate continues to be an under-estimate or becomes an over-estimate. Thus, it is recommended that data be used from the first year's harvest after baiting only. In addition, the data used in the Chapman estimator should be only those deaths known to occur at least 1 month (P. Friedrich, MDNR Wildlife, pers. comm.) after the baiting session for that year. This will ensure that all bears in the sample are alive to have the chance to be marked that year, and are given time after baits are consumed for cementum growth to occur so that tetracycline deposits are visible. Also, before the data are used in the Chapman estimator, the number of marked animals known to die before the harvest (from nonharvest causes) should be subtracted from the number of bears marked in the first sample. This will adjust the number of marked bears existing

in the true population to those that actually have the chance to be harvested. Obviously a bear which is killed before the harvest begins cannot possibly be killed in the harvest, i.e. there is one less marked bear in the population than originally estimated. So, the number must be adjusted for known deaths of marked bears, or the population estimate will be an over-estimate of the true population size.

Another suggestion is that the Chapman estimator can be conducted only every 3-5 years, rather than annually. This should give a reasonable estimate of the population size if the previous recommendations for use of data in the estimator are followed. The W-K model could be used in intervening years as an index and any significant increase or decrease in the index could be further investigated by conducting the Chapman estimator again the following year if deemed necessary. This could save money for the MDNR and time for field personnel. It is recommended that the tooth collection from all harvested bears should be done every year. The sex and age structure of the harvested animals is useful information for the MDNR to examine changes in the population structure of the black bear.

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LITERATURE CITED

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APPENDICES

APPENDIX A. Number and fate of tetracycline hydrochloride laced baits distributed in the Rose Lake Wildlife Research Area, August, 1994.

Yellow Area:

<u>Dates:</u>	<u>8/8-9</u>	<u>8/12</u>	<u>8/15</u>	<u>8/18</u>	<u>8/22</u>	<u>8/25</u>
Distributed	29	28	28	28	28	28
Not taken	5	0	2	2	3	a
Raccoon	8	0	7	2	5	a
Nontarget ^b	16	28	19	24	20	a

Orange Area:

<u>Dates:</u>	<u>8/6-7</u>	<u>8/10</u>	<u>8/12-13</u>	<u>8/15</u>	<u>8/18</u>	<u>8/22</u>
Distributed	41	41	40	38	41	39
Not taken	6	5	5	4	3	a
Raccoon	13	5	0	2	0	a
Nontarget ^b	22	31	35	32	38	a

^a Baits were not checked after the final distribution date.

^b Taken by either nontarget or unidentified species.

APPENDIX B. Age structure of the live trapped population
(first captures only) of raccoons at the Rose Lake Wildlife
Research Area from 1992-1994.

Age	Male			Female		
	1992	1993	1994	1992	1993	1994
<u>Yellow Area:</u>						
kit	0	0	0 ^a	4	0	0 ^a
1	3	0	0	4	0	0
2	5	1	0	2	1	0
3	3	0	0	2	1	0
4	1	0	0	1	0	0
5	1	0	0	0	0	0
6	0	1	0	0	0	0
7	0	0	0	0	0	0
8	0	0	0	0	0	0
9	0	0	0	0	1	0
yrl ^b	1	9	3	0	4	3
adult ^b	0	1	1	1	5	2
<u>Orange Area:</u>						
kit	5	3	0 ^a	4	1	0 ^a
1	7	0	0	1	0	0
2	4	1	0	1	1	0
3	1	1	0	2	0	0
4	0	0	0	0	0	0
5	1	0	0	0	0	0
6	0	0	0	1	0	0
yrl ^b	0	8	6	1	5	1

(APPENDIX B cont'd).

	<u>Male</u>			<u>Female</u>		
Age	1992	1993	1994	1992	1993	1994
adult ^b	1	4	0	0	5	6

^a No kits could be captured in 1994 because trapping was done in spring only.

^b Age determination on these individuals was not done through tooth analysis

APPENDIX C. Description of tree rest sites used by raccoons on the Rose Lake Wildlife Research Area, 1992-1994.

Date	Radio	d.b.h. ^a	Species	Part of Tree ^b	Height ^c
<u>1992</u>					
27 May	528	29.2	tamarack	branch	10.7
28 May	630	35.1	red oak	branch	15.2
1 Jun	528	36.3	red pine	branch	8.5
9 Jun	630	47.8	red maple	branch	5.3
19 Jun	500	96.3	white oak	d	
25 Jun	630	34.3	red oak	branch	18.3
22 Nov	630	66.0	green ash	d	
29 Nov	650	120.7	white oak	hole	2.4
29 Nov	630	(same as 22 Nov)			
<u>1993</u>					
6 Mar	650	53.1	dead oak	hole	1.4
7 Mar	650	104.6	apple	hole	0.0; 2.1
28 Mar	650	(same as 29 Nov 1992)			
4 Apr	630	51.3	silver maple	hole	10.7
6 Apr	650	(same as 29 Nov 1992)			
18 Apr	571 ^e	74.4	basswood ^f	hole	4.6
23 Apr	550	51.1	dead snag	hole/open top	2.4
23 Apr	630	63.8	ash	hole	6.1
27 Apr	550	47.8	elm	hole	0.0
27 Apr	630	(same as 23 Apr)			
8 May	650	(same as 29 Nov 1992)			
8 May	630	(same as 23 Apr)			
15 May	650	(same as 29 Nov 1992)			

(APPENDIX C cont'd).

Date	Radio	d.b.h. ^a	Species	Part of Tree ^b	Height ^c
15 May	630	(same as 23 Apr)			
15 May	1183	70.4	snag white oak	hole/open top	3.7
16 May	1183	55.6	basswood	hole	10.7
17 May	1183	(same as 16 May)			
25 May	630	(same as 23 Apr)			
25 May	650	(same as 29 Nov 1992)			
26 May	630	(same as 23 Apr)			
26 May	650	(same as 29 Nov 1992)			
26 May	1183	55.9	basswood	hole	4.6
11 Jun	650	66.0	ash log	hole	0.0
15 Jun	650	(same as 29 Nov 1992)			
18 Jun	630	(same as 23 Apr)			
22 Jun	630	(same as 23 Apr)			
24 Jun	650	(same as 29 Nov 1992)			
30 Jun	650	(same as 29 Nov 1992)			
6 Jul	610	48.5	ash	hole	0.0
16 Jul	500	31.2	scotch pine	branch	5.8
21 Jul	610	34.0	scotch pine	branch	5.5
21 Jul	650	52.1	red maple	hole	0.0
30 Sep	630	(same as 23 Apr)			
30 Sep	1183	93.0	silver maple	hole	0.0
18 Dec	650	(same as 29 Nov 1992)			
21 Dec	650	(same as 29 Nov 1992)			
<u>1994</u>					
11 Jan	630	84.9	white oak	hole	15.2

(APPENDIX C cont'd).

Date	Radio	d.b.h. ^a	Species	Part of Tree ^b	Height ^c
11 Jan	1162	(with 630)			
11 Jan	1183	84.8	oak spp.	hole	12.2
11 Jan	1224	69.6	basswood	hole	15.2
13 Jan	650	(same as 29 Nov 1992)			
17 Jan	630	(same as 11 Jan)			
17 Jan	1162	(with 630; same as 11 Jan)			
17 Jan	650	(same as 29 Nov 1992)			
17 Jan	1183	(same as 11 Jan)			
17 Jan	1224	(same as 11 Jan)			
18 Jan	630	(same as 11 Jan)			
18 Jan	1162	(with 630; same as 11 Jan)			
18 Jan	1183	(same as 11 Jan)			
18 Jan	1224	(same as 11 Jan)			
20 Jan	630	(same as 11 Jan)			
20 Jan	1162	(with 630; same as 11 Jan)			
20 Jan	650	(same as 29 Nov 1992)			
20 Jan	1183	(same as 11 Jan)			
20 Jan	1224	(same as 11 Jan)			
26 Jan	630	(same as 11 Jan)			
26 Jan	650	(same as 29 Nov 1992)			
26 Jan	1183	(same as 11 Jan)			
26 Jan	1224	(with 1183)			
28 Jan	630	(same as 11 Jan)			
28 Jan	650	(same as 29 Nov 1992)			
28 Jan	1183	(same as 11 Jan)			

(APPENDIX C cont'd).

Date	Radio	d.b.h. ^a	Species	Part of Tree ^b	Height ^c
28 Jan	1224	(with 1183; same as 26 Jan)			
31 Jan	630	(same tree used by 1183 on 16 May 1993)			
31 Jan	1183	(same tree used by 1224 on 11 Jan)			
3 Feb	630	(same as 31 Jan, but) branch			19.2
3 Feb	650	(same as 29 Nov 1992)			
3 Feb	1224	(same as 11 Jan, but) branch			19.8
4 Feb	630	(same as 31 Jan, but) hole			20.4
4 Feb	650	(same as 29 Nov 1992)			
9 Feb	650	(same as 29 Nov 1992)			
9 Feb	1183	(same as 31 Jan)			
18 Feb	650	(same as 29 Nov 1992)			
19 Feb	650	(same as 29 Nov 1992)			
4 Mar	1224	65.5	unknown	hole	10.7
12 Mar	650	(same as 29 Nov 1992)			
24 Mar	650	(same as 29 Nov 1992)			
1 Apr	nonmarked	15.2	unknown	branch	3.0
5 Apr	1183	(same as 650 on 29 Nov 1992)			
28 Apr	1183	(same as 31 Jan)			
10 May	1183	(same as 31 Jan)			
18 May	1183	(same as 31 Jan)			
3 June	1183	(same as 31 Jan)			
10 June	1183	(same as 31 Jan)			
17 June	1183	(same as 31 Jan)			
28 June	1183	(same as 31 Jan)			
23 Sep	1243 ^g	(same as 630 on 11 Jan)			

(APPENDIX C cont'd).

Date	Radio	d.b.h. ^a	Species	Part of Tree ^b	Height ^c
12 Oct	1183	(same as 31 Jan)			

^a Diameter in centimeters either at breast height for standing trees or at hole height for fallen logs.

^b Either in hole or on branch.

^c Height in meters of hole or raccoon on branch.

^d Information not available.

^e Collar had slipped off of the animal.

^f Entire tree was hollow; raccoon was in one fork that had fallen over so that tip touched ground; d.b.h. measurement is at hole height.

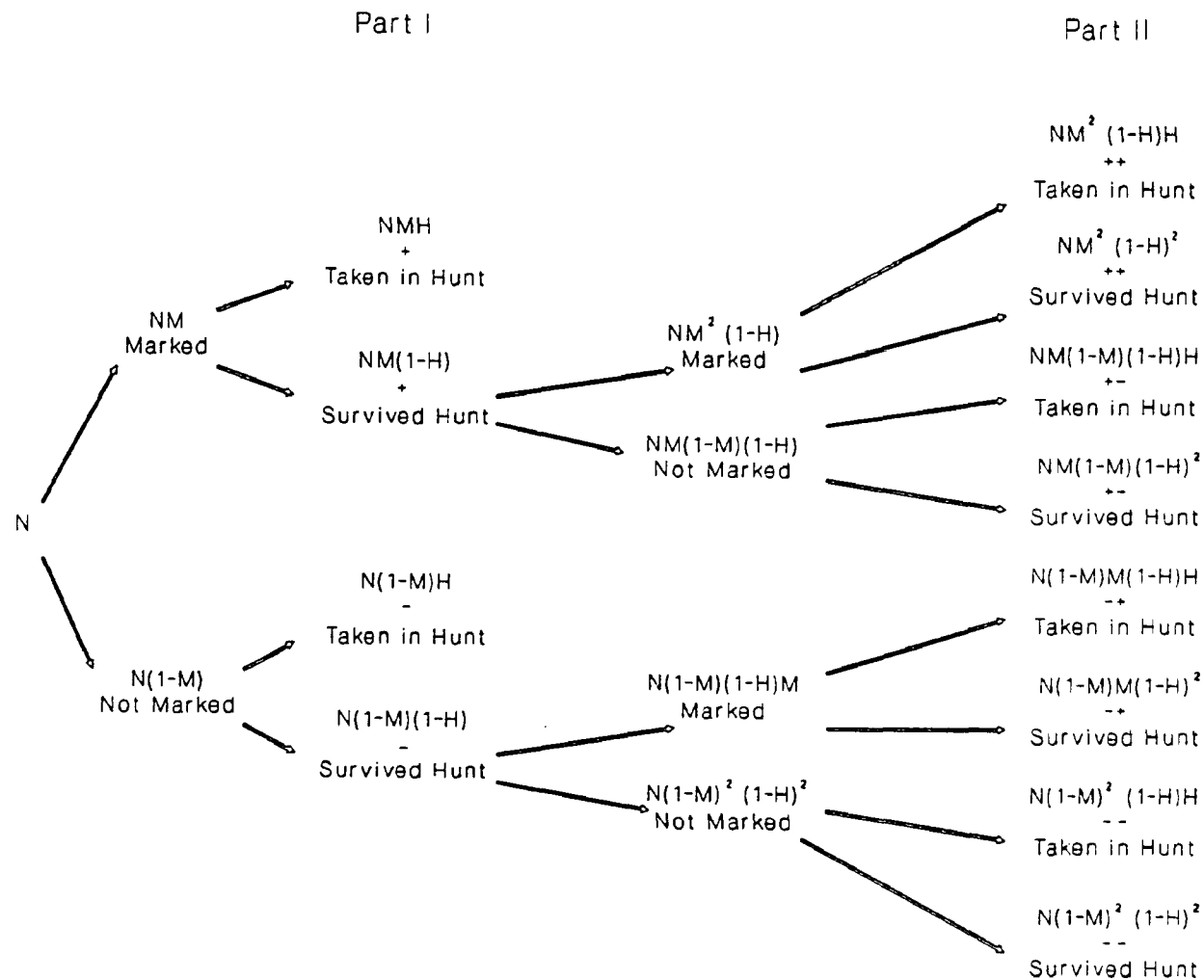
^g Recollared as 1243; same raccoon which was previously collared as 1224.

APPENDIX D. Ten year projection of population size changes of a hypothetical raccoon population using estimates^a of sex and age ratios, reproductive rates, and survival from the Rose Lake Area study.

Age	Initial	Time 1	Time 2	Time 3	Time 4	Time 5	Time 6	Time 7	Time 8	Time 9	Time 10
kit	-	128	151	153	163	171	181	190	200	211	222
yearling	129	129	103	121	122	131	137	145	152	160	169
adult male	79	79	93	94	100	105	110	116	122	129	136
adult female	92	92	108	110	117	123	130	136	144	151	159
Total	300	428	455	477	503	530	558	587	619	652	686

^a reproductive success=1.39; survival=0.67 for adults and yearlings; survival=0.80 for kits from fall to spring.

APPENDIX E. Population size estimator model developed by Winterstein and Karasek.



N=population size
M=probability of being marked
H=probability of being killed in hunt
++marked; --not marked;