RED-SHOULDERED HAWK (*BUTEO LINEATUS*) DISTRIBUTION, PRODUCTIVITY, PARASITE INTENSITY, AND NESTING HABITAT ON MARINETTE COUNTY FOREST IN NORTHEAST WISCONSIN

by

Janet Christine King

A Thesis

Submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

IN

NATURAL RESOURCES

(WILDLIFE)

College of Natural Resources

UNIVERSITY OF WISCONSIN

Stevens Point, Wisconsin

May 2008

APPROVED BY THE GRADUATE COMMITTEE OF:

Dr. Shelli A. Dubay, Graduate Advisor
Assistant Professor of Wildlife Ecology and Management

Dr. Timothy F. Ginnett
Associate Professor of Wildlife Ecology and Management

Dr. Les Werner
Assistant Professor of Forestry

ABSTRACT

Red-shouldered hawks have been listed as threatened in Wisconsin since 1979 and currently the effort to manage the birds and their habitat is reactive. Nest sites often are found during the cruising or marking stage of timber harvesting. If nest sites are known before initiation of timber harvest, foresters can employ a proactive approach to manage red-shouldered hawks.

Marinette County Forest (MCF) encompasses approximately 94,000 ha in northeast Wisconsin and is the 2nd largest county forest in the state. Our objectives were to locate red-shouldered hawk nests on MCF, monitor nest productivity, evaluate blood parasites of nestlings, investigate nest site selection, and compile forest management recommendations for MCF because the state of Wisconsin has no published forest management guidelines for the species.

During the spring of 2006 and 2007, we conducted call-broadcast surveys at 1,121 calling stations along forest roads and trails in MCF. One-hundred twenty one red-shouldered hawk responses were used to locate 41 occupied nesting territories. In 2006, 20 territories were active, 11 (55%) were successful and 28 nestlings successfully reached fledgling age. Productivity in 2006 was 1.4 young per breeding attempt and 2.6 young per successful nest. In 2007, 25 territories were active, 9 (36%) were successful and 20 nestlings successfully reached fledgling age. Productivity in 2007 was 0.8 young per breeding attempt and 2.2 young per successful nest.

Research on red-shouldered hawks in Wisconsin has mainly focused on long-term monitoring of nest productivity and nest-site fidelity. Results suggest that productivity is low in this part of their range, but causes for low productivity have not been determined.

Blood parasites can cause severe anemia or death in nestling raptors, but little is known about blood parasites in red-shouldered hawks and nestlings have not been evaluated for blood parasites. Blood samples were collected from 11 nests in both 2006 and 2007. *Leucocytozoon toddi* was present in 90.5% (38/42) of the nestlings sampled and 100% (n = 22) of the nests had one infected nestling. Intensity of *L. toddi* infection ranged from 2 to 213 infected cells per 2,000 erythrocytes (0.1%-10.7%) and averaged 48.6 ± 58.3 infected cells per 2,000 erythrocytes (2.4 ± 2.9%). Intensity was high when compared to other studies. Prevalence and intensity of *L. toddi* was difficult to relate to nestling mortality because most nestlings were infected, however, *L. toddi* could possibly contribute to low productivity.

To determine nest site selection, we compared habitat variables between active nest sites (n = 34) and stratified random or non-use sites (n = 61). Logistic regression with information-theoretic model selection identified a model with number of tree species and distance to closed wetland as the best-approximating model. Red-shouldered hawk nest locations were negatively associated with distance to closed wetland and positively associated with number of tree species in the plot. Discriminant Function Analysis (DFA) showed similar results as red-shouldered hawk nest site selection was best explained by number of tree species in the plot, distance to closed wetlands, volume of downed woody debris, number of small sawlogs, and distance to streams. Univariate comparisons indicated four of the five aforementioned variables were similar to the DFA model, however, snag trees were considered significant instead of small sawlogs.

As a result, forest management for red-shouldered hawk nest sites should focus on tree richness, closed wetlands, down woody debris, and streams. Forest management recommendations from this study will increase the capacity of managers to locate and plan for continued persistence of this species on MCF.

ACKNOWLEDGEMENTS

This study was made possible by funding from the Marinette County Forestry Committee, with assistance from the Wisconsin Department of Natural Resources, Bureau of Endangered Resources, Aquatic and Terrestrial Resources Inventory (ATRI). I am deeply grateful to my graduate advisor, Shelli Dubay, for her guidance, encouragement, and friendship throughout all stages of my research. She allowed me to spread my wings but managed to keep me grounded. I also thank other members of my committee, Tim Ginnett and Les Werner, whose advice and feedback have been integral to my success. I am also grateful to Jim Woodford for implementing the project and his insightful guidance, field assistance, and trust that I would complete the project. I also thank Aaron Buchholz for his support in implementing the project, guidance, and field assistance.

Furthermore, I thank other faculty and staff of the University of Wisconsin - Stevens Point (UWSP) in the College of Natural Resources (CNR). In particular, I thank Todd Huspeni, Kevin Lawton, Paul Doruska, and Robert Rosenfield for providing additional academic insight. I thank numerous people for providing valuable field, office, or lab assistance, including: Carol Eloranta, John Jacobs, Kendra Sawyer, Heather Brantmeier, Brittany Moe, John Krause, Tony Rinaldi, Jessica Reger, Andrew VanLanen, Aaron McCollough, Heath Dornfeld, Alex Tress, Stephanie Zolkowski, and Marge Gibson. I also thank Don Roppolo, Adam Klein, Les Werner, John Jacobs, Mike Stanonik, Aaron Schauer, and Nick Crawford for climbing nests to obtain red-shouldered hawk nestlings. I also want to thank my colleagues for their assistance, comments, and friendship.

I thank the UWSP Student Research Fund and The Wildlife Society for travel grants that allowed me to attend and present at a national conference and the Wisconsin Society for Ornithology for a grant that assisted me with travel costs in the field. I also thank faculty for selecting me for the Gerhardt Outstanding Graduate Research Assistant Award and the Erik Munson Graduate Scholarship, along with the providers.

Finally, I thank my immediate family, including Charles King, Christine Miller, David Miller, Tammy Reed, Selena Becker, and Kimberly King, for continued support in all aspects of my personal and professional endeavors. Most notably I thank my parents for allowing me to follow my own thoughts and dreams and their unknowing impact of instilling the outdoors early in life. I dedicate this thesis to Josh Brehm, for his love, support, and sharing of his parents.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

PREFACE

The three chapters of this thesis were written using the format of Journal of Wildlife Management, Journal of Wildlife Diseases, and Forest Ecology and Management, respectively. Any duplication, citations, and stylistic variations among chapters are intentional.

CHAPTER I:

BACKROUND INFORMATION ON RED-SHOULDERED HAWKS (*BUTEO LINEATUS*)

Red-shouldered hawks (*Buteo lineatus*) are widespread in the eastern half of the United States and southeastern Canada, but also occur along the west coast of the United States (Crocoll 1994). This medium-sized raptor primarily occupies mature hardwood forests, mixed deciduous-coniferous forests, bottomland hardwood forests, and flooded deciduous swamps (Crocoll 1994). Nationwide, red-shouldered hawk populations appear stable but could be declining in certain areas (Crocoll 1994). These hawks were once considered common or abundant throughout the eastern portion of their range, but destruction and fragmentation of mixed hardwood forests and riparian woodlands has likely resulted in population declines (Henny et al. 1973, Bednarz and Dinsmore 1981, McLeod et al. 2000), with the greatest decline in the north (Crocoll 1994). The red-shouldered hawk is currently listed as a state endangered or threatened species in Iowa, Illinois, Michigan, and Wisconsin, and as a species of special concern in Minnesota, Ohio, and Indiana (Crocoll 1994). The Great Lakes Region of the U.S. Fish and Wildlife Service (USFWS) lists the red-shouldered hawk as a migratory non-game bird of management concern (USFWS 2006).

Data from the North American Breeding Bird Survey (1966-2005) showed that red-shouldered hawk abundance in Wisconsin had the second greatest negative trend of all contributing states (Sauer et al. 2005). Because of this trend, red-shouldered hawks were listed as a Wisconsin threatened species in 1979 (Wisconsin Department of Natural

Resources [WDNR] 1988). Despite its threatened status, the state of Wisconsin has no published forest management guidelines for red-shouldered hawk nesting habitat. The Chequamegon-Nicolet National Forest (CNNF) in Wisconsin developed forestwide guidelines for red-shouldered hawks, however, they are combined with those for northern goshawks (*Accipiter gentilis*) (U.S. Forest Service 2004) despite the need for species specific guidelines (Richardson and Miller 1997). The CNNF designates the red-shouldered hawk as a Regional Forester's Sensitive Species indicating that birds are rare overall but could be locally common in prime habitat (U.S. Forest Service 2004).

Forest dwelling raptors are generally difficult to locate and monitor because they occur at relatively low densities, occupy areas with dense vegetation, have large home ranges, and are secretive (Iverson and Fuller 1991, McLeod and Anderson 1998). Hawk detection can be enhanced by broadcasting taped conspecific or great horned owl (*Bubo virginianus*) calls in possible hawk habitat (Fuller and Mosher 1981, Rosenfield et al. 1988, Kimmel and Yahner 1990, Kennedy and Stahlecker 1993, McLeod and Anderson 1998). In Minnesota, McLeod and Anderson (1998) found that broadcasting conspecific calls early in the morning (0530-1030) and early in the breeding season prior to egg-hatch was effective for detecting red-shouldered hawks. Red-shouldered hawks may respond vocally from a distance, fly in to investigate while vocalizing, fly in and perch silently, or soar overhead. Responses to broadcast calls can be useful both in locating nests and in monitoring population trends over time with repeated, standardized surveys (McLeod and Anderson 1998). Home range for these hawks varies from 108.9 to 339 ha (Crocoll 1994) and nest densities within forests range from 0.1 to 1.0 nests per km^2 (Mosher and Fuller 1996, McLeod and Anderson 1998). J. E. Woodford (WDNR, unpublished data) studied red-shouldered hawks (2002-2006) within an 11,000 ha area on the Menominee Indian Reservation in northeastern Wisconsin and found a nesting density of 0.13 nests per km^2.

Generally, red-shouldered hawks build nests in a main crotch of a deciduous tree or occasionally on a whorl of branches in a coniferous tree, usually ½ the distance to the top of the tree (Palmer 1988). Researchers have suggested that tree structure rather than tree species is important in nest tree selection (Bednarz and Dinsmore 1982, Titus and Mosher 1987). Nest diameter ranges from 45-60 cm and a wide variety of materials such as branches, lichens, moss, leaves, and conifer sprigs are used to construct nests (Bent 1937). Red-shouldered hawks generally nest in taller trees, larger diameter trees, and in stands with taller average canopy height, higher percent canopy closure, and higher basal area than randomly available (Titus and Mosher 1981, Morris and Lemon 1983, Moorman and Chapman 1996, Dykstra et al. 2000, McLeod et al. 2000). In addition, red-shouldered hawks nest near wetlands or other permanent water sources (Bednarz and Dinsmore 1981, Titus and Mosher 1981, Dykstra et al. 2000, 2001, McLeod et al. 2000) potentially because these hawks feed on amphibians during the nesting season (Craighead and Craighead 1956, Bednarz and Dinsmore 1981, Welch 1987). Prey also includes small mammals, birds, and invertebrates (Crocoll 1994). In general, nest sites were negatively associated with treeless upland habitat (Moorman and Chapman 1996) and distance to nearest road or building (Bednarz and Dinsmore 1982, Bosakowski et al. 1992).

In Wisconsin, red-shouldered hawks return to breeding areas in the beginning of March and build or rebuild nests and defend territories throughout March. They lay eggs in mid April and incubate a clutch of 3-4 eggs for about 36 days. Eggs hatch in mid-May and nestlings remain in the nest for about 42 days. The fledgling stage occurs in mid-July when fledged young remain close to the nest for the first 6-15 days while learning to hunt. Young eventually move farther from the nest, but remain in the breeding range of their parents for 45-60 days after fledging (Crocoll 1994, Jacobs and Jacobs 2002) (Appendix A).

Monitoring nests for reproductive success and productivity yields important information about population status and habitat quality and is often used for comparison among years or populations (Steenhof 1987, Dykstra et al. 2000). Reproductive success measures the number of nesting pairs that raise young to the age of fledging in a population, while productivity measures the number of young that reach fledging age (Steenhof 1987). Red-shouldered hawk productivity in eastern North America varies from 1.1 to 2.9 young per active nest (Crocoll 1994). Research in northeastern and central Wisconsin has mainly focused on long-term monitoring of nest productivity and reoccupancy (Jacobs and Jacobs 2002). On the CNNF in northeast Wisconsin, nests monitored from 1992-2007 had 0.8 ± 0.3 young per active nest (J. P. Jacobs, unpublished report), which is lower than 1.6 young per active nest found in central Wisconsin in 2003-2007 (E. A. Jacobs, unpublished report) and over most of eastern North America (Crocoll 1994). Reoccupancy rate (percent of territories occupied the following breeding season) in Wisconsin during 1993-1997 was 66% (Jacobs and Jacobs 2002). Productivity of 0.8 ± 0.4 young per active nest and a nest success rate of 40 ± 18% were reported in Menominee County, Wisconsin from 2002-2007 and considerable variation occurred with year (WDNR, unpublished data). The mean territory reoccupancy rate was 71%, with a low of 60% in 2003 and a high of 84% in 2006 (WDNR, unpublished data).

Many hypotheses have been proposed regarding decreased population trends and low nest productivity for red-shouldered hawks throughout their range, including reduced prey for young (Campbell, 1975), displacement by red-tailed hawks (*Buteo jamaicensis*) because of increased forest openings (Bednarz and Dinsmore 1982, Bryant 1986), fragmentation and loss of riparian woodlands used by red-shouldered hawks during breeding (Bednarz and Dinsmore 1981), and mortality from nest predators such as great horned owls or raccoons (*Procyon lotor*) (Craighead and Craighead 1956). Perhaps abundance declines steadily toward the edge of their geographical range (Mehlman 1997). Blood parasites, which have caused morbidity or mortality in other species of nestling raptors, could contribute to low productivity as well (Remple 1981, Hunter et al. 1997, Smith et al. 1998, Stuht et al. 1999, Raidal and Jaensch 2000). Few studies have evaluated blood parasites of nestling or adult red-shouldered hawks and no study has been reported on nestlings in Wisconsin.

Blood parasites, from the Order Haemosporida, are microscopic, intracellular parasitic protozoa found within blood cells and tissues of their avian hosts (Atkinson 1999). *Haemoproteus* spp. and *Leucocytozoon* spp. are commonly found in birds of prey. *Haemoproteus* spp. are transmitted via hippoboscid flies (*Ornithomyia* spp.) or biting midges (*Culicoides* spp.) and *Leucocytozoon* spp. are transmitted by ornithophilic species of black flies of the genus *Simulium* (Greiner et al. 1975, Remple 2004). Separate infectious and developmental stages occur in the bird host and insect vectors. Infective sporozoites in salivary glands of the insect vector invade host tissue at the site of the bite.

These immediately invade tissues and reproduce as schizonts to produce numerous merozoites. Next, merozoites penetrate red blood cells and mature into infectious gametocytes. The cycle is completed when the gametocytes in the circulating blood cells of the host bird are ingested by another insect. Gametocytes undergo both sexual and asexual reproduction within the insect to produce large numbers of sporozoites. These invade the salivary glands of the insect and are transmitted to a new host bird during the vector's next blood meal (Atkinson 1999).

Infection can be diagnosed by observing stained blood smears and counting the number of parasitized red blood cells (Atkinson 1999). Given that red-shouldered hawks nest near wetlands or surface water to hunt prey (Craighead and Craighead 1956, Bednarz and Dinsmore 1981, Welch 1987), nestlings could be exposed to high insect vector densities that occur in wet sites where insects breed. Moreover, nestling hawks that are unable to fly are confined to nests and unable to avoid these insects (Fallis and Desser 1974).

Haemoprotus spp. and *Leucocytozoon* spp. are commonly considered relatively benign showing little or no pathologic effect. Moreover, many raptor species appear to be well adapted to low numbers of parasites which are kept in check by the immune system (Remple 2004). Resistance to blood parasites may be associated with age, as older birds may have an acquired immunity against the parasite (Shutler et al. 1995, Heidenreich 1997). Occasionally these parasites impact individuals. *Leucocytozoon toddi* was suspected as the cause of severe anemia in a nestling bald eagle (*Haliaeetus leucocephalus*) in Michigan (Stuht et al. 1999). Therefore, infection could contribute to overall health decline in some nestlings. Also, *Leucocytozoon* spp. was believed to cause death in fledgling great horned owls in Canada when food availability was low (Hunter et al. 1997). Overall, blood parasites tend to increase in number in stressed hosts and can be a valuable indicator of underlying disease or severity of a disease process (Bowman 1995). As a result, monitoring blood parasite loads in nestlings could provide information on overall health of nestlings.

Even though red-shouldered hawks are threatened in Wisconsin, no formal state habitat management guidelines exist for timber harvest near red-shouldered hawk nest sites. Currently, the effort to protect the hawks and their habitat is reactive. State and county foresters generally employ their own seasonal restrictions or follow considerations that may be beneficial to the hawks near nest sites (WDNR 2000). Nest sites can be found through opportunistic sighting often during the cruising or marking stage of timber harvest. When nests are found while marking timber, the timber sale must be altered to accommodate for the presence of the nest (A. Buchholz, WDNR, personal communication). If nest sites are known before timber harvests are planned, foresters can employ a proactive approach to manage red-shouldered hawks.

Timber harvest is vital to the economy of many forested regions. Few studies have investigated the effects of forest management practices on red-shouldered hawks (Naylor et al. 2004). In order for harvest practices to be appropriate for both the local economy and hawk management, habitat selection characteristics and effects of timber harvest on red-shouldered hawks must be understood. In central southern Ontario, Bryant (1986) identified land use changes associated with territory abandonment by red-shouldered hawks or the replacement of that species by red-tailed hawks. Incursions by red-tailed hawks were associated with reductions in mean tree density and tree-crown diameter suggesting that selective cutting (removal of the largest, most mature trees) in woodlots may result in displacement of red-shouldered hawks by red-tailed hawks. Red-tailed hawks did not displace red-shouldered hawks in mature forests with high crown closure > 70% and suggested that failure to maintain uncut buffer zones around nest sites may result in nest abandonment. In central Ontario, Naylor et al. (2004) suggested that if well developed harvest guidelines were implemented adjacent to nest sites, characteristics would resemble uncut forests and likely not impact nesting hawks. The guidelines put forth by Naylor et al. (2004) included retaining ≥ 70% tree canopy closure around nests, omitting heavy cutting within 300 m of nests, and retaining ≥ 20 ha of forest dominated by trees ≥ 18 m tall. They recommended that harvest could continue in areas used by red-shouldered hawks as long as precautions were followed around the nest site.

Nest site habitat descriptions have been reported throughout the red-shouldered hawk range (McLeod et al. 2000), but habitat selection has not been evaluated extensively in Wisconsin. In order to identify nest-site selection by adult hawks, investigation of known nest site characteristics must be compared to those available for nesting (use vs. availability). Titus (1984) investigated habitat selection of red-shouldered hawks from 1980-1982 in the Lakewood district of the CNNF in northeastern Wisconsin. Also, J. E. Woodford (WDNR, unpublished data, 2002-2006) investigated habitat use and compared it to habitat availability of red-shouldered hawks in an unfragmented forest in Menominee County, Wisconsin and these data could provide a baseline for other habitat selection studies in similar habitats. J. E. Woodford (WDNR, unpublished data) reported that red-shouldered hawk nests were found near lakes or wetlands and roads or trails. However, many of the trails within the study area receive very little or no traffic during the nesting season. The structural characteristics of the Menominee forest are unique in this region because the forest is relatively homogenous (>99% of the forested area) mature, uneven-aged forest. To create management guidelines for red-shouldered hawks statewide, we need to have a better understanding of statewide abundance, population status, habitat requirements, and potential effects of timber harvest on nesting hawks in sites typical of the rest of the state.

In 2005, two active red-shouldered hawk nests were found on the Marinette County Forest (MCF), which led to the development of this graduate project. MCF encompasses approximately 94,000 ha in northeast Wisconsin and is the 2nd largest county forest in Wisconsin (Fig. 1.1). The objectives of this study were to: 1) inventory red-shouldered hawks in MCF, 2) determine and describe nest site habitat selection of red-shouldered hawks, 3) determine reproductive success and productivity of nesting red-shouldered hawks, 4) determine the prevalence of blood parasites in nestlings and compare that to nest productivity, and 5) develop forest management recommendations for red-shouldered hawks and provide them to the Marinette County Forestry Committee.

Literature Cited

Atkinson, C. T. 1999. Hemosporidisis. Pages 193-200 *in* Field manual of wildlife diseases: general field procedures and diseases of birds, M. Friend and J. C. Franson (eds.). U.S. Department of Interior, U.S. Geological Survey, Washington, D.C., USA.

Bednarz, J. C., and J. J. Dinsmore. 1981. Status, habitat use, and management of red-shouldered hawks in Iowa. Journal of Wildlife Management 45:236-241.

Bednarz, J. C., and J. J. Dinsmore. 1982. Nest-sites and habitat of red-shouldered and red-tailed hawks in Iowa. Wilson Bulletin 94:31-45.

Bent, A. C. 1937. Life histories of North American birds of prey. U.S. National Museum Bulletin 167, Washington, D.C., USA.

Bosakowski, T., D. G. Smith, and R. Speiser. 1992. Status, nesting density, and macrohabitat selection of red-shouldered hawks in northern New Jersey. Wilson Bulletin 104:434-446.

Bowman, D. D., editor. 1995. Protozoans. Pages 83-111 *in* Georgis' parasitology for veterinarians. Sixth edition, WB Sanders, Philidelphia, PA

Bryant, A. A. 1986. Influence of selective logging on red-shouldered hawks, *Buteo lineatus*, in Waterloo Region, Ontario, 1953-1978. Canadian Field-Naturalist 100:520-525.

Campbell, C. A. 1975. Ecology and reproduction of red-shouldered hawk in the Waterloo region, southern Ontario. Journal of Raptor Research 9:12-17.

Craighead, J. J., and F. C. Craighead, Jr. 1956. Hawks, owls and wildlife. Stackpole Company, Harrisburg, Pennsylvania, USA.

Crocoll, S. T. 1994. Red-shouldered hawk (*Buteo lineatus*). Account 107 i*n* A. Poole and F. Gill, editors. The birds of North America, The Academy of Natural Sciences, Philadelphia, Pennsylvania, and The American Ornithologists' Union, Washington, D.C., USA.

Dykstra, C. R., J. L. Hayes, F. B. Daniel, and M. M. Simon. 2000. Nest site selection and productivity of suburban red-shouldered hawks in southern Ohio. Condor 102:401-408.

Dykstra, C. R., F. B. Daniel, J. L. Hays and M. M. Simon. 2001. Correlation of red-shouldered hawk abundance and macrohabitat characteristics in southern Ohio. Condor 103:652-656.

Fallis, M. A. and S. S. Desser. 1974. On species of *Leucocytozoon*. Advances in Parasitology 12:1-67.

Fuller, M. R. and J. A. Mosher. 1981. Methods of detecting and counting raptors: a review. Studies of Avian Biology 6:235-246.

Greiner, E. C., G. F. Bennett, E. M. White, and R. F. Coombs. 1975. Distribution of the avian hematozoa of North America. Canadian Journal of Zoology 53:1762-1787.

Heidenreich, M. 1997. Birds of prey medicine and management. Blackwell Science Limited, Oxford, UK.

Henny, C. J., F. C. Schmid, E. M. Martin, and L. L. Hood. 1973. Territorial behavior, pesticides, and the population ecology of red-shouldered hawks in central Maryland, 1943-1971. Ecology 54:545-554.

Hunter, D. B., C. Rohner, and D. C. Currie. 1997. Mortality in fledgling great horned owls from black fly hematophaga and Leucocytozoonosis. Journal of Wildlife Diseases 33:486-491.

Iverson, G. C. and M. R. Fuller. 1991. Area-occupied survey technique for nesting woodland raptors. Pages 118-124 *in* B. A. Giron Pendleton, D. L. Krahe, M. N. LeFranc, Jr., K. Titus, J. C. Bednarz, D. E. Anderson, and B. A. Millsap, editors. Proceedings of the Midwest raptor management symposium and workshop. National Wildlife Federation Scientific and Technical Series 15.

Jacobs, J. P., and E. A. Jacobs. 2002. Conservation assessment for red-shouldered hawk

(*Buteo lineatus*): National Forests of north central states. U.S. Department of Agriculture, Forest Service, Eastern Region, Milwaukee, Wisconsin, USA.

Kennedy, P. L. and D. W. Stahlecker. 1993. Responsiveness of nesting northern goshawks to taped broadcasts of 3 conspecific calls. Journal of Wildlife Management 57:249-257.

Kimmel, J. T., and R. H. Yahner. 1990. Response of northern goshawks to taped conspecific and great horned owl calls. Journal of Raptor Research 24:107-112.

McLeod, M. A., and D. E. Andersen. 1998. Red-shouldered hawk broadcast surveys: factors affecting detection of responses and population trends. Journal of Wildlife Management 62:1385-1397.

McLeod, M. A., B. A. Belleman, D. E. Andersen, and G. W. Oehlert. 2000. Red-shouldered hawk nest site selection in north-central Minnesota. Wilson Bulletin 112:203-213.

Mehlman, D. W. 1997. Change in avian abundance across geographic range in response to environmental change. Ecological Applications 7:614-624.

Moorman, C. E., and B. R. Chapman. 1996. Nest-site selection of red-shouldered and red-tailed hawks in a managed forest. Wilson Bulletin 108:357-368.

Morris, M. M. J., and R. E. Lemon. 1983. Characteristics of vegetation and topography near red-shouldered hawk nests in southwestern Québec. Journal of Wildlife Management 47:138-145.

Mosher, J. A., and M. R. Fuller. 1996. Surveying woodland hawks with broadcasts of great-horned owl vocalizations. Wildlife Society Bulletin 24:531-536.

Naylor, B. J., J. A. Barker, and K. J. Szuba. 2004. Effects of forest management practices on red-shouldered hawks in Ontario. The Forestry Chronicle 80:54-60.

Palmer, R. S., editor. 1988. Red-shouldered hawk. Pages 413-429 *in* Handbook of North American birds. Volume 2. Yale University Press, New Haven, Connecticut, USA.

Raidal. S. R. and S. M. Jaensch. 2000. Central nervous disease and blindness in Nankeen kestrels (*Falco cenchroides*) due to novel *Leucocytozoon*-like infection. Avian Pathology 29:51-56.

Remple, J. D. 1981. Avian malaria with comments on other haemosporidia in large falcons. Pages 107-110 *in* Cooper J. E., and A. G. Greenwood, editors. Recent advances in the study of raptor diseases. Chiron Publications, Keighley, West Yorkshire, England.

Remple, J. D. 2004. Intracellular Hematozoa of raptors: a review and update. Journal of Avian Medicine and Surgery 18:75-88.

Richardson, C. T., and C. K. Miller. 1997. Recommendations for protecting raptors from human disturbance: a review. Wildlife Society Bulletin 25:634-638.

Rosenfield, R. N., J. Bielefeldt, and R. K. Anderson. 1988. Effectiveness of broadcast calls for detecting breeding Cooper's hawks. Wildlife Society Bulletin 16:210-212.

Sauer, J. R., J. E. Hines, and J. Fallon. 2005. The North American Breeding Bird Survey, results and analysis 1966-2005. Version 6.2.2006. U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland, USA.

Shutler, D., G. F. Bennett, and M. Adelo. 1995. Sex proportions of Haemoproteus blood parasites and local male competition. Proclamation National Academy of Science 92:6748-6752.

Smith, R. N., S. L. Cain, S. H. Anderson, J. R. Dunk, and E. S. Williams. 1998. Blackfly-induced mortality of nestling red-tailed hawks. The Auk 115:368-375.

Steenhof, K. 1987. Assessing raptor reproductive success and productivity. Pages157-170 *in* B. A. Giron Pendleton, B. A. Milsap, K. W. Cline, and D. M. Bird, editors. Raptor management techniques manual. National Wildlife Federation, Washington, D.C., USA.

Stuht, J. N., W. W. Bowerman, and D. A. Best. 1999. Leucocytozoonosis in nesting bald eagles in Michigan and Minnesota. Journal of Wildlife Diseases 35:608-612.

Titus, K. 1984. Uniformity in relative habitat selection by *Buteo lineatus* and *B. platypterus* in two temperate forest regions. Dissertation. University of Maryland, Catonville, Maryland, USA.

Titus, K., and J. A. Mosher. 1981. Nest-site habitat selected by woodland hawks in the central Appalachians. Auk 98:270-281.

Titus, K. and J. A. Mosher 1987. Selection of nest tree species by red-shouldered and broad-winged hawks in two temperate forest regions. Journal of Field Ornithology 58:274-283.

U.S. Fish and Wildlife Services [USFWS]. 2006. USFWS Great Lakes Basin Ecosystem Team home page. <http://www.fws.gov/midwest/greatlakes/index.html>. Accessed 28 Sept 2006.

U.S. Forest Service [USFS]. 2004. Forest standards and guidelines. *In* Land and resource management plan, R9-CN-FP. United States Department of Agriculture, Forest Service, Chequamegon-Nicolet National Forests, Washington, D.C., USA.

Welch, R. J. 1987. Food habits of the red-shouldered hawk in Wisconsin. Passenger Pigeon 49:81-91.

Wisconsin Department of Natural Resources [WDNR]. 1988. Endangered resources handbook. WDNR Publication 1724.5, Madison, Wisconsin, USA.

Wisconsin Department of Natural Resources [WDNR]. 2000. Threatened and endangered species in forests of Wisconsin. WDNR Publication FR-174, Madison, Wisconsin, USA.

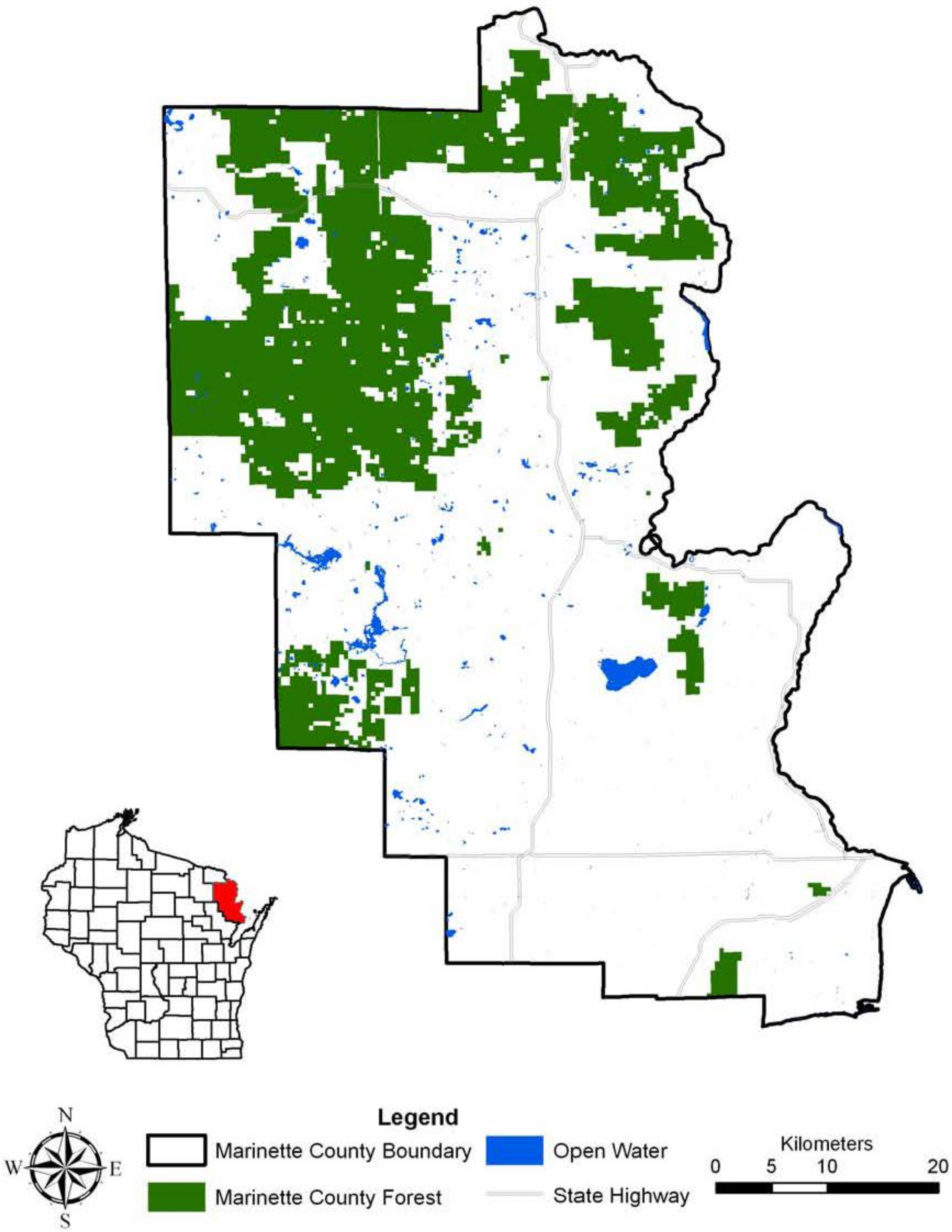

Figure 1.1. Location of Marinette County Forest in Marinette County, Wisconsin, USA.

CHAPTER II:

INTENSITY AND PREVALENCE OF *LEUCOCYTOZOON TODDI* IN NESTLING RED-SHOULDERED HAWKS (*BUTEO LINEATUS*) IN NORTHEAST WISCONSIN (USA)

Abstract: Red-shouldered hawks (*Buteo lineatus*) are threatened in Wisconsin and trends from long-term nest productivity suggest that productivity remains low in the state. Causes for low productivity have not been determined. We investigated prevalence and intensity of blood parasites in red-shouldered hawk nestlings from northeast Wisconsin, USA in June of 2006 and 2007. We evaluated thin blood smears from 42 nestlings in 22 nests and *Leucocytozoon toddi* was present in 90.5% (38/42) of the nestlings evaluated. At least one bird in all nests was infected. Intensity of *L. toddi* infection ranged from 2 to 213 infected cells per 2,000 erythrocytes (0.1%-10.7%) and averaged 48.6 ± 58.3 infected cells per 2,000 erythrocytes (2.4 ± 2.9%). No other blood parasites were identified. *Leucocytozoon* spp. infection has led to severe anemia or mortality in nestlings of other raptor species and could contribute to low productivity for red-shouldered hawks in Wisconsin.

Key words: blood smear, *Buteo lineatus*, intensity, *Leucocytozoon toddi*, nestling, prevalence, red-shouldered hawk, Wisconsin.

Introduction

Red-shouldered hawks (*Buteo lineatus*) have been listed as threatened in Wisconsin (USA) since 1979 (Wisconsin Department of Natural Resources [WDNR], 1988) and past research has mainly focused on long-term monitoring of nest productivity and nest-site fidelity (Jacobs and Jacobs, 2002). Results suggest that productivity is low in this part of their range, but causes for low productivity have not been determined. Red-shouldered hawk productivity in eastern North America varies from 1.1 to 2.9 young per active nest (Crocoll, 1994). On the Chequamegon-Nicolet National Forest in northeast Wisconsin, nests monitored from 1992-2007 had 0.8 ± 0.3 young per active nest (J. P. Jacobs, unpublished report), which is lower than 1.6 young per active nest found in central Wisconsin in 2003-2007 (E. A. Jacobs, unpublished report) and over most of eastern North America (Crocoll, 1994). Productivity of 0.8 ± 0.4 young per active nest was reported in Menominee County in northeast Wisconsin from 2002-2007 but varied considerably with year (WDNR, unpublished data).

Many hypotheses have been proposed regarding decreased population trends and low nest productivity for red-shouldered hawks throughout their range, including reduced prey for young (Campbell, 1975), displacement by red-tailed hawks (*Buteo jamaicensis*) because of forest alteration (Bednarz and Dinsmore, 1982; Bryant, 1986), forest fragmentation and loss of riparian woodlands used by red-shouldered hawks during breeding (Bednarz and Dinsmore, 1981), and mortality from nest predators such as great horned owls (*Bubo virginianus*) or raccoons (*Procyon lotor*) (Craighead and Craighead, 1956). Low productivity could also be a result of decreased abundance toward the edge of their geographical range (Mehlman, 1997). Blood parasites, which have caused severe anemia or mortality in nestlings of other raptor species, could contribute to low productivity as well (Hunter et al., 1997; Smith et al., 1998; Stuht et al., 1999). In Wyoming (USA), Smith et al. (1998) found that red-tailed hawk nestlings died from combined effects of black fly infestations including anemia, early nest departure, and *Leucocytozoon* spp. blood parasite infection. Little is known about blood parasites of red-shouldered hawks and no study has reported information from nestlings.

Hemosporidian parasites, which develop within blood cells of raptors and can cause disease by destroying host cells, are transmitted mainly by blood sucking dipteran arthropods (Bowman, 1995). *Haemoproteus* spp. and *Leucocytozoon* spp. blood parasites are commonly found in birds of prey. *Haemoproteus* spp. are likely transmitted via hippoboscid flies (*Ornithomyia* spp.) or biting midges (*Culicoides* spp.) and *Leucocytozoon* spp. are transmitted by ornithophilic species of black flies of the genus *Simulium*, that require moving water for immature stages (Greiner et al., 1975; Remple, 2004).

Many raptor species appear to be well adapted to low numbers of parasites which are kept in check by the immune system (Remple, 2004). Resistance to blood parasites may be associated with age, as older birds may have an acquired immunity against the parasite (Shutler et al., 1995; Heidenreich, 1997). Overall, blood parasites tend to increase in number in stressed hosts and can be a valuable indicator of underlying disease or severity of a disease process (Remple, 2004). As a result, monitoring blood parasites could provide information on overall health of nestlings. Given that red-shouldered hawks nest near wetlands or surface water (Bednarz and Dinsmore, 1981, 1982; Bosakowski et al., 1992), nestlings could be exposed to high numbers of insect vectors that occur in wet sites. Moreover, nestling hawks are unable to fly and are confined to nests, unable to avoid these insects (Fallis and Dresser, 1974).

Our objectives were to 1) evaluate blood from nestling red-shouldered hawks and determine whether prevalence and intensity of blood parasites could contribute to low nest productivity, and 2) determine if parasite intensity is related to age of nestlings, weight of nestlings, or distance of nests from surface water. We hypothesized that infection would be common because red-shouldered hawks nest near wetlands or surface water. We also hypothesized that nestlings from nest sites closer to surface water would have higher intensities of infection. Lastly, we believed that older nestlings would have lower parasite intensity because of an increased immune response.

Materials and Methods

Red-shouldered hawk nests were located in Marinette County Forest (MCF) in northeast Wisconsin (Fig. 1.1; USA; between 45°43'N to 88°22'W and 45°14'N to 87°49'W). The forest is approximately 94,000 ha and is the second largest county forest in Wisconsin. Climate is characterized by long winters and short, cool summers. Annual minimum temperature averages from -14 to -4 C and maximum temperature averages from 15 to 29 C. Annual mean precipitation is 813 mm (Midwestern Regional Climate Center, 2000). Approximately 88% of the MCF is forested (13% forested wetlands), 8% is non-forested wetlands with <1% open water habitats (lakes, streams, and rivers), and 4% is non-forested uplands. Dominant forest types are mixed aspen and aspen (> 50% *Populus* spp.; 43%) and northern hardwoods (sugar maple [*Acer saccharum*], yellow birch [*Betula alleghaniensis*], basswood [*Tilia americana*], and American beech [*Fagus grandiflora*]; 10%) (Marinette County Forest, 2006).

Red-shouldered hawk nests were located throughout MCF during the breeding season of 2006 and 2007 using broadcast survey methods described by McLeod and Anderson (1998). Nests were monitored from early April to early July during both years. To obtain blood for thin blood smears, professional urban foresters climbed trees to access nests between 9-12 June when nestlings were approximately 3 weeks old (Jacobs and Jacobs, 2002). Young were collected and lowered to the ground in a breathable bag. We also aged, weighed, and banded nestlings. We estimated age using an age-feather length regression model (Penak, 1982) and temporal observations (Bent, 1937; Crocoll, 1994). To determine weight, we placed one nestling wrapped in a towel on a balance scale or placed a nestling in a breathable bag and weighed it using a 1000-g spring scale. Bag mass or towel mass was subtracted from total mass to determine body mass of each nestling. Body mass was adjusted by subtracting estimated mass of crop contents (Toyne and Ashford, 1997). Nestlings were banded with #6 lock-on bands using pliers to fold the longer flange of the band over the shorter flange, locking the band in place (Varland et al., 2007). We examined nestlings for insects and external dermatitis by noting lesions, crusting of skin (scabs), feather loss, or deformed feathers.

Blood was obtained by puncturing the brachial vein and collecting blood into a capillary tube or tuberculin syringe (Bennett, 1970). To create thin blood smears, one drop of blood was placed at the base of a microscope slide. The small edge of a second slide was held at a 45º angle over the blood, allowing the blood to spread along the edge. The angled slide was rapidly pushed across the horizontal slide to create the thin blood smear (Krone, 2007). One to four blood smears were prepared for each nestling. Blood smears were air dried immediately and placed in a covered slide box for protection (Bennett, 1970). We attempted to limit our time at the nest to less than one hour.

In the lab, dried blood smears were fixed with absolute methanol for 5 minutes, air dried, and stained using Giemsa's stain following conventional methods. Slides remained in the Giemsa's stain solution for approximately 30 minutes and were removed and placed in buffered water for 45 seconds. Next, slides were rinsed in distilled water and allowed to air dry before being mounted in balsam. To determine prevalence of larger parasites such as *Leucocytozoon* spp., all slides were randomly viewed under 400x for a total of 25 minutes, or until a blood parasite was identified (Dawson and Bortolotti, 1999; Ziman et al., 2004). If no *Leucocytozoon* spp. parasites were found, slides were examined once more. Slides where *Leucocytozoon* spp. was not detected were evaluated for 25 minutes at 1000x for *Haemoproteus* spp. This time frame is considered sufficient to detect low intensity infections (Fedynich et al., 1993). All slides were scanned completely to compensate for changes in blood thickness (Korpimäki et al., 1995).

Intensity of infection was determined by counting the number of parasites contained in 2,000 erythrocytes. At 1000x magnification, we randomly located 40 fields of view and evaluated 50 erythrocytes in each view (Godfrey et al., 1987; Smith et al., 2004). To ensure nonbiased sampling of the blood smear, we generated random X, Y coordinates using the graduated mechanical scale to position our field of view on the microscope (Olympus CH-2, Model: CHT, Tokyo, Japan). Concurrently, we evaluated these fields for smaller parasites such as *Haemoproteus* spp. We evaluated slides from each nestling for 1-2 hours. If we prepared multiple blood smears for a nestling, we divided the 40 fields of view among slides basing our selection on quality of stain and smear. We counted only erythrocytes and parasites that were completely in the field of view and counted across each view from the upper left to lower right. Parasites were identified by comparing size, color, and morphology of our sample to known species found in published literature (Campbell, 1995; Remple, 2004) and in the Parasitology Collection at the University of Wisconsin-Stevens Point, Stevens Point, WI, USA.

Ages determined from nestling measurements were used to calculate hatch date by backdating and determining approximate fledge date using 42 days for the nestling period (Crocoll, 1994; Jacobs and Jacobs, 2002). Steenhof (1987) considered a nest successful if a breeding pair produced one or more young that reached fledgling age and suggested the nestling process must be 80% complete in order to deem a nest successful. From the ground, we visually assessed final productivity in late June and early July by counting young in the nest with binoculars. We noted failure by observing signs of mammal predation (claw marks on the tree, feathers attached to trunk of tree in multiple locations down the tree, gnawing on carcass or feathers), avian predation (crimped feathers, stripped bone, scrapes in bone), or other causes (J. Woodford, WDNR, personal communication). In 2007, a height pole with a video camera attached was used to see inside the nest to confirm failure.

Statistical analyses were performed using SYSTAT Version 11 (Systat Software, Inc., Chicago, IL, 2004). Significance was set at $P = 0.05$. Simple linear regression was used to determine effects of age, weight, and distance to surface water on intensity of blood parasite infection. Analysis of covariance (ANCOVA) was used to test for differences in intensity by age within nests (Zar, 1999).

Results

Blood samples were collected from 11 nest sites in both 2006 and 2007. In 2006, 31 nestlings were banded and blood smears were collected from 18 nestlings. In 2007, 19 nestlings were banded and blood smears were collected from 24 nestlings. Five of the territories sampled in 2006 were considered to be reoccupied by the same red-shouldered hawk nesting pair in 2007 and were sampled again, however, only three of the same nest locations were used in both years. Age of nestlings ranged from 14 to 30 days old.

Leucocytozoon toddi was present in 90.5% (38/42) of the nestlings sampled. Nestlings not infected with *L. toddi* were located in nests where one or more of their siblings were parasitized, therefore 100% (n = 22) of the nests had at least one infected nestling. Intensity of *L. toddi* infection ranged from 2 to 213 infected cells per 2,000 erythrocytes (0.1% - 10.7%) and averaged 48.6 ± 58.3 infected cells per 2,000 erythrocytes (2.4 ± 2.9%) (Table 2.1). No other blood parasites were identified in thin blood smears.

We determined that eight red-shouldered hawk nestlings from 5 different nests died after they were banded and all tested positive for *L. toddi* (Table 2.1). Four nestlings each died in 2006 and 2007. Altogether, four had low intensity of infection, ranging from 2 to 9 parasites per 2,000 erythrocytes and the other four nestlings had higher intensity ranging from 49 to 213 parasites per 2,000 erythrocytes. Causes for morality were difficult to determine but five nestlings showed signs of mammal predation, one appeared to have fallen from the nest for reasons unknown, and the other two died of unknown causes. The four nestlings uninfected with *L. toddi* fledged successfully from the nest.

On average in 2006 and 2007, nest pairs produced 1.1 ± 0.4 young per active nest and 2.4 ± 0.2 young per successful nest (Table 2.2).

We did not find a relationship between intensity of *L. toddi* infection and nestling weight (linear regression, R^2 = 0.03, df = 38, P = 0.28) or distance to streams (linear regression, R^2 = 0.03, df = 40, P = 0.26). We used distance to stream as an independent variable because *L. toddi* was the only parasite detected and is vectored by black flies (*Simulium* spp.) that use moving water for part of their life cycle (Greiner et al., 1975). However, when comparing intensity of *L. toddi* to nestling age, we found a weak relationship. Older nestlings had lower intensities of *L. toddi* infection (linear regression, R^2 = 0.13, df = 40, P = 0.019). However, we did not detect a relationship of age on intensity within nests (ANCOVA, nest: $F_{12,19}$ = 1.7, P = 0.14; age: $F_{1,19}$ = 0.33, P = 0.58).

Skin dermatitis was observed on seven nestlings, characterized by scabbing on the nape and side of the neck, a few growth deformities of primary, secondary, and covert feathers, and loss of feathers.

Discussion

Prevalence and intensity of *L. toddi* was higher in red-shouldered hawk nestlings when compared to several other studies. Stuht et al. (1999) evaluated nestling bald eagles (*Haliaeetus leucocephalus*) in Minnesota and Michigan (USA) for prevalence of blood parasites and used the Ashford scale to determine intensity. This scale assigns birds an intensity of 1 if fewer than 1 parasite is found per 100 high power (400x) fields, an intensity of 2 if 1-10 parasites are found per 100 high power fields, an intensity of 3 if 11-100 parasites are found per 100 high power fields, and finally an intensity of 4 if more than 100 parasites are found per 100 high power fields. Prevalence of *L. toddi* in nestling bald eagles was 67% (14 of 21) during June and July of 1997. Intensity of *L. toddi* was light, 1 to 2 on the Ashford scale. No other parasites were found in nestling bald eagles. *Leucocytozoon toddi* was suspected as the cause of severe anemia in a nestling bald eagle in Michigan.

Boal et al. (1998) evaluated 44 adult and 18 nestling Cooper's hawks (*Accipiter cooperii*) in Arizona (USA) for blood parasites from May to June 1995 and Taft et al. (1994) evaluated 47 adults and 33 nestling Copper's hawks for blood parasites in Wisconsin from June to July in 1991 and 1992. Compared to our study, nestling Cooper's hawks had much lower prevalence of *L. toddi* in both Arizona (5%) and Wisconsin (12%). *Leucocytozoon toddi* was the only parasite present in nestling Copper's hawks in both studies. Adult Cooper's hawks had a higher prevalence of *L. toddi* than nestling Cooper's hawks in both Arizona (9%) and Wisconsin (91%).

Toyne and Ashford (1997) conducted a similar study on nestling northern goshawks (*Accipiter gentilis*) in England. They examined 48 nestlings from 23 nests and found *L. toddi* in nine nestlings (19%) with eight nests (35%) infected. Intensity of infection was relatively low, with six goshawk nestlings having intensity loads of 1 to 2 on the Ashford scale and three nestlings having loads categorized as 3. There was no association between infection and mortality between banding (13-39 d) and fledging because nestlings from both infected and uninfected broods died.

Prevalence of blood parasites in nestling sparrowhawks (*Accipiter nisus*) in Scotland (UK) was lower than our study (Pierce and Marquiss, 1983). Prevalence of *L. toddi* was 26% (20 of 76) in both 1979 and 1980, however, high intensity was observed by counting parasites in 10 random fields under low power (10x). One nestling was reported to average between 343-723 blood parasites per field of view (mean = 510). Although no direct evidence of pathogenicity was observed, it is suggested that *L. toddi* infection may have caused temporary listlessness from anemia and may be a contributing factor in the mortality of raptor nestlings in some areas (Pierce and Marquiss, 1983).

Appleby et al. (1999) reported that all 123 adult tawny owls (*Strix aluco*) in the United Kingdom were infected with *Leucocytozoon ziemanni* in 1994 and 1995, but no nestlings were infected in 1994 (n = 36) and only 16 of 39 (21%) nestlings were infected in 1995. However, *L. ziemanni* intensity in infected nestlings was significantly higher than infected adults. Intensity in tawny owl nestlings averaged 569.8 ± 647.7 parasites per 10,000 cells (mean = 5.7%) and intensity was 6.1 ± 8.7 to 8.5 ± 9.5 parasite per 10,000 cells (0.06% - 0.08%). Tawny owls that suffered declines in food abundance on their territories showed an increase in parasite loads. Hunter et al. (1997) also reported that *Leucocytozoon* spp. was believed to cause the death of fledgling great horned owls in Canada when food availability was low.

High intensity in nestlings may not be surprising given that young birds are immunologically naïve to many pathogens and parasites (Merino and Potti, 1995; Ros et al., 1997). When *Leucocytozoon* spp. produce disease in raptors, it is generally the young or the severely stressed that are affected (Remple, 2004). Smith et al. (1998) found that 11 of 94 (12%) red-tailed hawk nestlings in Wyoming died from the effects of black fly infestations. Of the blood smears taken, 75% were positive for *Leucocytozoon* spp., however, researchers found no evidence that infection led directly to clinical disease. They proposed that death occurred from cumulative harassment by black flies leading to increased energy expenditure and premature nest departure. *Leucocytozoon* spp.

infection likely caused anemia and organ damage, and loss of blood from infestation of blood-sucking flies led to anemia and dehydration. Smith et al. (1998) noted that the presence of black flies and their influence on reproduction are likely undetected during most raptor productivity surveys. Black flies may have caused dermatitis on nestling red-shouldered hawks, but we are unsure of the cause. One black fly was collected from a nestling. Other nestlings could have had dermatitis, but degree of evaluation varied by sampling crew and we limited our time at each nest to decrease disturbance.

We found that younger red-shouldered hawk nestlings had slightly higher intensities of infection when compared to older nestlings. This may be a factor of greater parasitemia in younger nestlings because they are smaller in size (Poulin, 1999) or because as nestlings age, they develop acquired immunity against the parasite (Shutler et al., 1995; Heidenreich, 1997). We did not find a relationship between weight and *L. toddi* infection in nestlings because weight of a bird is not constant and changes with health, availability of prey, and how recently the bird was fed (Dunne, 1987). Also, we did not find a relationship between stream distance and parasite infection, possibly because black fly adults can fly about 15 km from breeding streams (Hahn, 2000) and red-shouldered hawks nest near these sites (Bednarz and Dinsmore, 1981, 1982).

Holmstad et al. (2003) stated that conclusions in any short-term field study in which measurable, negative fitness effects of hematozoa are sought will depend on choice of location, timing, and use of reliable sampling techniques. We think that our timing and sampling techniques were sufficient for detecting blood parasites in nestling red-shouldered hawks. Atkinson and van Riper III (1991) stated that transmission of avian hematozoa in the northern hemisphere occurs mainly during the breeding season when the insect vectors are present and when nestlings and fledglings are exposed. Also, Greiner and Richie (1994) reported that high numbers of parasites may be detected in the blood within four to nine days following infection and parasites can be detected in some nestlings as early as 14 days posthatching (Pierce and Marquiss, 1983). Red-tailed hawk nestlings that suffered from morality ranged from 9 to 43 days old. However, we may have missed nestling mortality that occurred prior to obtaining blood samples.

Red-shouldered hawk nestlings in our study showed high prevalence and intensity of infection. Other studies reported either high intensity or prevalence. Blood parasites entering circulating erythrocytes may impair oxygen-carrying capacity or cause cells to rupture, resulting in host anemia (Kocan and Clark 1966, Maley and Desser 1977). High intensity of infection increases the chance of anemia or other effects of *Leucocytozoon* spp. infection such as dehydration, hemoglobinuria, anorexia, or depression (Campbell, 1995). Infection could contribute to low productivity, but effects were difficult to evaluate because 90.5% of the nestlings were infected with *L. toddi* and only 19% of the nestlings sampled failed to fledge. Nest productivity in 2006 and 2007 (1.4 and 0.8 young per active nest, respectfully) was lower than other studies in eastern North America (1.1 to 2.9 young per active nest), however, other causes of low productivity such as predators, low prey availability, and effects of forest alteration should be considered as well. This is the first known report of *L. toddi* in nestling red-shouldered hawks.

Acknowledgements

We thank Don Roppolo, Adam Klein, Les Werner, John Jacobs, Mike Stanonik, Aaron Schauer, and Nick Crawford for climbing nests. We also thank John Jacobs, Kendra Sawyer, Brittany Moe, and Jessica Reger for measuring, banding, and obtaining blood from nestling red-shouldered hawks. Alan Fedynich, Tim Ginnett, and Les Werner reviewed earlier versions of this manuscript. This study was made possible by funding from the Marinette County Forestry Committee with assistance from the Wisconsin Department of Natural Resources, Bureau of Endangered Resources, Aquatic and Terrestrial Resources Inventory (ATRI). We also want to thank the Biology Department at the University of Wisconsin-Stevens Point for allowing us to work in their lab space.

Literature Cited

APPLEBY, B. M., M. A. ANWAR, AND S. J. PETTY. 1999. Short-term and long-term effects of food supply on parasite burdens in Tawny Owls, *Strix aluco*. Functional Ecology 13: 315-321.

ATKINSON, C. T., AND C. VAN RIPER III. 1991. Pathogenicity and epizootiology of avian haematozoa: Plasmodium, Leucocytozoon and Haemoproteus. *In* Bird-Parasite Interactions, J. E. Loye and M. Zuk (eds.). Oxford University Press, Oxford, pp. 19-48.

BEDNARZ, J. C., AND J. J. DINSMORE. 1981. Status, habitat use, and management of red-shouldered hawks in Iowa. Journal of Wildlife Management 45: 236-241.

----------, AND -----------. 1982. Nest-sites and habitat of red-shouldered and red-tailed hawks in Iowa. Wilson Bulletin 94: 31-45.

BENNETT, G. F. 1970. Simple techniques for making avian blood smears. Canadian Journal of Zoology 48: 585-586.

BENT, A. C. 1937. Life histories of North American birds of prey. U.S. National Museum Bulletin 167, Washington, D.C., USA.

BOAL, C. W., K. S. HUDELSON, R. W. MANNAN, AND T. S. ESTABROOK. 1998. Hematology and hematozoa of adult and nestling Cooper's hawks in Arizona. Journal of Raptor Research 32: 281-285.

BOSAKOWSKI, T., D. G. SMITH, AND R. SPEISER. 1992. Status, nesting density, and macrohabitat selection of red-shouldered hawks in northern New Jersey. Wilson Bulletin104:434-446.

BOWMAN, D. D. (ed.). 1995. Protozoans. *In* Georgis' Parasitology for Veterinarians, 6th edition, W.B. Saunders, Philadelphia, Pennsylvania, pp. 83-111.

BRYANT, A. A. 1986. Influence of selective logging on red-shouldered hawks, *Buteo lineatus*, in Waterloo Region, Ontario, 1953-1978. Canadian Field-Naturalist 100: 520-525.

CAMPBELL, C. A. 1975. Ecology and reproduction of red-shouldered hawk in the Waterloo region, southern Ontario. Journal of Raptor Research 9: 12-17.

CAMPBELL, T. W. 1995. Hematology. *In* Avian medicine: principles and application, B. Ritchie, G. Harrison, and L. Harrison (eds.). Wingers Publishing, Lake Worth, Florida, pp. 176-191.

CRAIGHEAD, J. J., AND F. C. CRAIGHEAD, JR. 1956. Hawks, owls, and wildlife. Stackpole Company, Harrisburg, Pennsylvania, 443 pp.

CROCOLL, S. T. 1994. Red-shouldered hawk (*Buteo lineatus*). Account 107 i*n* A. Poole and F. Gill, editors. The birds of North America, The Academy of Natural Sciences, Philadelphia, Pennsylvania, and The American Ornithologists' Union, Washington, D.C., USA.

DAWSON, R. D., AND G. R. BORTOLOTTI. 1999. Effects of Hematozoan parasites on condition and return rates of American kestrels. Auk 117: 373-380.

DUNNE, P. 1987. Introduction to raptor identification, aging and sexing techniques. *In* Raptor management techniques manual, B. A. Giron Pendleton, B. A. Milsap, K. W. Cline, and D. M. Bird (eds). National Wildlife Federation, Washington, D.C., USA, pp. 13-21.

FALLIS, M. A. AND S. S. DESSER. 1974. On species of *Leucocytozoon*. Advances in Parasitology 12:1-67.

FEDYNICH, A. M., D. B. PENCE, AND R. D. GODFREY, JR. 1993. Hemosporids (Apicomplexa, Hematozoea, Hemosporida) of anatids from the Southern High Plains of Texas. Journal of the Helminthological Society of Washington 60: 35-38.

GREINER, E. C., G. F. BENNETT, E. M. WHITE, AND R. F. COOMBS. 1975. Distribution of the avian hematozoa of North America. Canadian Journal of Zoology 53: 1762-1787.

-----------, AND B. W. RITCHIE. 1994. Parasites. *In* Avian Medicine, B. W. Ritchie, G. J. Harrison, L. R. Harrison (eds.). Wingers, Lake Worth, Florida, pp. 1007-1029.

GODFREY, R. D., JR., A. M. FEDYNICH, AND D. B. PENCE. 1987. Quantification of hematozoa in blood smears. Journal of Wildlife Diseases 23: 558-565.

HAHN, J. 2000. Black flies. University of Minnesota Extension Service. http://www.extension.umn.edu/yardandgarden/ygbriefs/e601blackflies.html. Accessed 25 March 2008.

HEIDENREICH, M. 1997. Birds of prey medicine and management. Blackwell Science Limited, Oxford, UK.

HOLMSTAD, P. R., A. ANWAR, T. LEZHOVA, AND A. SKORPING. 2003. Standard sampling techniques underestimate prevalence of avian hematozoa in willow ptarmigan. Journal of Wildlife Diseases 39: 354-358.

HUNTER, D. B., C. ROHNER, AND D. C. CURRIE. 1997. Mortality in fledgling great horned owls from black fly hematophaga and Leucocytozoonosis. Journal of Wildlife Diseases 33: 486-491.

JACOBS, J. P., AND E. A. JACOBS. 2002. Conservation assessment for red-shouldered hawk (*Buteo lineatus*): National Forests of north central states. U.S. Department of Agriculture, Forest Service, Eastern Region, Milwaukee, Wisconsin, USA.

KOCAN, R. M., AND D. T. CLARK. 1966. Anemia in ducks infected with *Leucocytozoon simondi*. Journal of Protozoology 13:465-468.

KORPIMÄKI, E., P. TOLONEN, AND G. F. BENNETT. 1995. Blood parasites, sexual selection and reproductive success of European kestrels. Ecoscience 2: 335-343.

KRONE, O. 2007. Endoparasites. *In* Raptor research and management techniques. D. M. Bird and K. L. Bildstein (eds.). Hancock House Publishers, Blaine, Washington, pp.318-328.

MALEY, G. J. M., AND S. S. DESSER. 1977. Anemia in *Leucocytozoon simondi* infections. I. Quantification of anemia, gametocytemia, and osmotic fragility of erythrocytes in naturally infected Pekin ducklings. Canadian Journal of Zoology 55: 355-358.

MARINETTE COUNTY FOREST. 2006. Marinette County Forest Master Plan. <http://www.marinette county.com/forestry_masterplan.htm>. Accessed 21 Oct 2006.

MCLEOD, M. A., AND D. E. ANDERSEN. 1998. Red-shouldered hawk broadcast surveys: factors affecting detection of responses and population trends. Journal of Wildlife Management 62: 1385-1397.

MEHLMAN, D. W. 1997. Change in avian abundance across geographic range in response to environmental change. Ecological Applications 7: 614-624.

MERINO, S., AND J. POTTI. 1995. High prevalence of hematozoa in nestlings of a passerine species, the pied flycatcher (*Ficedula hypoleuca*). Auk 112: 1041-1043.

MIDWESTERN REGIONAL CLIMATE CENTER. 2000. http://mcc.sws.uiuc.edu/. Accessed 24 March 2008.

PENAK, B. L. 1982. Aspects of the nutritional ecology of the red-shouldered hawk (*Buteo lineatus lineatus*) in southwestern Quebec. Thesis, McGill University, Ste-Anne-de-Bellevue, Quebec, Canada.

PIERCE, M. A., AND M. MARQUISS. 1983. Haematozoa of British birds. VII. Haematozoa of raptors in Scotland with a description of *Haemoproteus nissi* sp. nov from the Sparrowhawk (*Accipiter nisus*). Journal of Natural History 17: 813-821.

POULIN. R. 1999. Body size vs. abundance among parasite species: positive relationships? Ecography 22: 240-250.

REMPLE, J. D. 2004. Intracellular Hematozoa of raptors: a review and update. Journal of Avian Medicine and Surgery 18: 75-88.

ROS, A. F. H., T. G. G. GROOTHUIS, AND V. APANIUS. 1997. The relation among gonadal steroids, immunocompetence, body mass, and behavior in young black-headed gulls (*Larus ridibundus*). American Naturalist 150: 201-219.

SHUTLER, D., G. F. BENNETT, AND M. ADELO. 1995. Sex proportions of *Haemoproteus* blood parasites and local male competition. Proclamation National Academy of Science 92:6748-6752.

SMITH, R. N., S. L. CAIN, S. H. ANDERSON, J. R. DUNK, AND E. S. WILLIAMS. 1998. Blackfly-induced mortality of nestling red-tailed hawks. The Auk 115:368-375.

SMITH, R. B., E. C. GREINER, AND B. O. WOLF. 2004. Migratory movement of sharp-shinned hawks (*Accipiter striatus*) captured in New Mexico in relation to prevalence, intensity, and biogeography of avian Hematozoa. Auk 121: 837-846.

STEENHOF, K. 1987. Assessing raptor reproductive success and productivity. *In* Raptor management techniques manual, B. A. Giron Pendleton, B. A. Milsap, K. W. Cline, and D. M. Bird (eds). National Wildlife Federation, Washington, D.C., USA, pp.157-170.

STUHT, J. N., W. W. BOWERMAN, AND D. A. BEST. 1999. Leucocytozoonosis in nesting bald eagles in Michigan and Minnesota. Journal of Wildlife Diseases 35: 608-612.

SYSTAT VERSION 11. 2004. SYSTAT Software, Inc., 225 W Washington St., Suite 425 Chicago, IL 60606 USA.

TAFT, S. J., R. N. ROSENFIELD, AND J. BIELEFELDT. 1994. Avian hematozoa of adult and nestling Cooper's hawks (*Accipiter cooperii*) in Wisconsin. Journal of Helminthological Society of Washington 61: 146-148.

TOYNE, E. P., AND R. W. ASHFORD. 1997. Blood parasites of nestling goshawks. Journal of Raptor Research 31: 81-83.

VARLAND, D. E., J. A. SMALLWOOD, L. S. YOUNG, AND M. N. KOCHERT. 2007. Marking techniques. *In* Raptor research and management techniques. D. M. Bird and K. L. Bildstein (eds.). Hancock House Publishers, Blaine, Washington, pp.221-236.

WISCONSIN DEPARTMENT OF NATURAL RESOURCES. 1988. Endangered resources handbook. Wisconsin Department of Natural Resources Publication 1724.5, Madison, Wisconsin, USA.

ZAR, J. H. 1999. Biostatistical Analysis. Fourth edition. Prentice-Hall, Englewood Cliffs, New Jersey.

ZIMAN, M., A. COLAGROSS-SCHOUTEN, S. GRIFFEY, AND B. STEDMAN. 2004. *Haemoproteus* spp. and *Leucocytozoon* spp. in a captive raptor population. Journal of Wildlife Disease 40: 137-140.

Table 2.1. Intensity of *Leucocytozoon toddi* infection in nestling red-shouldered hawks (*Buteo lineatus*) in Marinette County Forest, Wisconsin, USA, 2006 and 2007.

Year	Nest	Nestling ID[a]	Age (days)	# of *L. toddi*	Weight (g)	Stream (m)	Outcome[b]
2006	1	QN166-136	20	63	409	299	S
	2	XN149a-139	21	9	428	206	F
	2	XN149a-140	24	49	510	206	F
	2	XN149a-141	26	7	591	206	F
	3	YN148-142	17	0	475	338	S
	3	YN148-143	21	7	450	338	S
	3	YN148-144	20	163	422	338	S
	4	XN77-145	19	17	419	164	S
	5	XN156-147	19	2	473	124	S
	6	YN162a-149	28	31	489	272	S
	7	YN150-151	23	5	584	78	S
	7	YN150-152	21	0	464	78	S
	8	YN163-153	21	3	449	79	S
	8	YN163-155	17	70	376	79	S
	9	NY34-156	27	8	596	784	S
	10	AAN159-162	21	14	.	.	S
	10	AAN159-165	16	5	.	.	F
	11	BBN158-166	30	7	540	543	S
2007	12	RN177-181	23	46	570	146	S
	13	EEN155a-191	17	2	397	183	F
	14	YN163-183	21	45	500	79	S
	15	YN150-192	18	166	377	78	S
	15	YN150-193	19	43	397	78	S
	15	YN150-194	20	25	450	78	S
	16	XN149-184	19	134	620	307	S
	16	XN149-185	24	3	520	307	S
	17	BBN158-186	19	0	300	543	S
	17	BBN158-187	24	26	540	543	S
	17	BBN158-188	30	11	460	543	S
	18	BBN152a-195	20	3	449	1371	S
	18	BBN152a-196	24	0	436	1371	S
	19	AAN159a-197	24	13	496	1312	S
	19	AAN159a-198	28	4	533	1312	S
	19	AAN159a-199	30	4	544	1312	S
	20	DN174a-1	20	125	460	650	S
	20	DN174a-189	18	84	420	650	S
	20	DN174a-190	21	175	600	650	S
	20	DN174a-2	14	101	300	650	F
	21	GN197-200	23	14	465	206	S
	21	GN197-3	22	41	458	206	S
	22	NH43-4	22	110	230	366	F
	22	NH43-5	18	213	420	366	F

[a] # represents nest site ID and last three digits of band number (5 nestlings not banded)
[b] S = successful fledged, F = failed

Table 2.2. Productivity of red-shouldered hawks (*Buteo lineatus*) during the 2006 and 2007 breeding season in Marinette County Forest, Wisconsin, USA.

Year	**Occupied Territory**	**Active Nests**	**Successful Nests**	**Young Fledged**	**Young/ Active Nest**	**Success Rate (%)**	**Young/ Successful Nest**
2006	25	20	11	28	1.4	55	2.5
2007	39	25	9	20	0.8	36	2.2

CHAPTER III:

RED-SHOULDERED HAWK (*BUTEO LINEATUS*) DISTRIBUTION, PRODUCTIVITY, NESTING HABITAT, AND HABITAT RECOMMENDATIONS ON MARINETTE COUNTY FOREST IN NORTHEAST WISCONSIN (USA)

Abstract

Red-shouldered hawks (*Buteo lineatus*) have been listed as threatened in Wisconsin since 1979 and currently the effort to manage the birds and their habitat is reactive. When nest sites are found during the cruising or marking stage of timber harvesting, the harvest is altered to accommodate the hawks. If nest sites are known before initiation of timber harvest, foresters can employ a proactive approach to manage red-shouldered hawks. Marinette County Forest (MCF) encompasses approximately 94,000 ha in northeast Wisconsin and is the 2nd largest county forest in the state. Our objectives were to locate red-shouldered hawk nests on MCF, monitor nest productivity, investigate nest site selection, and compile forest management recommendations for MCF because the state of Wisconsin lacks official timber management guidelines for the species. During the spring of 2006 and 2007, we conducted call-broadcast surveys at 1,121 calling stations along forest roads and trails and located 41 occupied nesting territories. In 2006, 20 territories were active and productivity was 1.4 young per breeding attempt. In 2007, 25 territories were active and productivity was 0.8 young per breeding attempt. To determine nest site selection, habitat variables were measured within 0.04 ha plots at active nest sites (n = 34) and at stratified random or non-use sites (n = 61). Logistic regression with information-theoretic model selection identified a model including number of tree species and distance to closed wetland as the best-approximating model. Red-shouldered hawk nest locations were negatively associated with distance to closed wetland and positively associated with number of tree species in the plot. Discriminant Function Analysis (DFA) had similar results because red-shouldered hawk nest selection was best explained by greater number of tree species, closer distance to closed wetlands, greater volume of downed woody debris, decreased number of small sawlogs, and closer distance to streams. Univariate comparisons identified four of the five aforementioned variables in the DFA model as significant however, snag trees were considered significant instead of small sawlogs. Using results of our analysis, we created management recommendations for red-shouldered hawks on MCF. Forest management for red-shouldered hawks nest sites should focus on tree species richness, closed wetlands, down woody debris, and streams. Forest management recommendations from this study will increase the capacity of managers to locate and plan for continued persistence of this species on MCF.

Key Words: broadcast survey, *Buteo lineatus*, forest management, habitat selection, productivity, red-shouldered hawk, Wisconsin.

Introduction

Red-shouldered hawks (*Buteo lineatus*) were once considered common or abundant throughout the eastern portion of their range, but fragmentation and loss of mixed hardwood forests and riparian woodlands has likely resulted in population declines (Henny et al. 1973, Bednarz and Dinsmore 1981, McLeod et al. 2000), with the greatest decline in the north (Crocoll 1994). Data from the North American Breeding Bird Survey (BBS) (1966-2005) showed that red-shouldered hawk abundance in Wisconsin had the second greatest negative trend of all contributing states (Sauer et al. 2005). Because of this trend, red-shouldered hawks were listed as a Wisconsin threatened species in 1979 (Wisconsin Department of Natural Resources [WDNR] 1988).

Despite its threatened status, the state of Wisconsin has no formal forest management guidelines for red-shouldered hawk nest sites. The Chequamegon-Nicolet National Forest (CNNF) in Wisconsin developed forestwide guidelines for red-shouldered hawks, however, they are combined with those for northern goshawks (*Accipiter gentilis*) (U.S. Forest Service 2004) despite the need for species specific guidelines (Richardson and Miller 1997). The CNNF guidelines suggest protecting active and historic nest sites within an area of at least 12 ha surrounding nest site. No harvest should occur within the buffer area and human disturbance will be minimized within the buffer from February 15 to August 1. Also, outside the 12-ha buffer area, managers should not use even-aged management and should maintain at least 80% crown closure with no more than 9 canopy gaps per hectare (up to 12 m diameter). They also suggest closing roads and trails within 100 m of the nest site from February 15 to August 1 and conducting surveys for these species in potential suitable habitat prior to implementing projects. The CNNF considers the red-shouldered hawk as a Regional Forester's Sensitive Species indicating that birds are rare overall but could be locally common in prime habitat (U.S. Forest Service 2004).

Red-shouldered hawks generally nest in taller trees, larger diameter trees, and in stands with taller average canopy height, higher percent canopy closure, and higher basal area than randomly available in habitat selection studies (Titus and Mosher 1981, Morris and Lemon 1983, Moorman and Chapman 1996, Dykstra et al. 2000, McLeod et al. 2000). In addition, red-shouldered hawks select nest sites near wetlands or permanent water sources (Bednarz and Dinsmore 1981, Titus and Mosher 1981, Dykstra et al. 2000, 2001, McLeod et al. 2000) potentially because these hawks feed on amphibians during the nesting season (Craighead and Craighead 1956, Bednarz and Dinsmore 1981, Welch 1987). In general, nest sites are negatively associated with treeless upland habitat (Moorman and Chapman 1996) and distance to nearest road or building (Bednarz and Dinsmore 1982, Bosakowski et al. 1992).

Forest dwelling raptors are generally difficult to locate and monitor because they occur at relatively low densities, occupy areas with dense vegetation, have large home ranges, and are secretive (Iverson and Fuller 1991, McLeod and Anderson 1998). Hawk detection can be enhanced by broadcasting taped conspecific or great horned owl (*Bubo virginianus*) calls in potential hawk habitat (Fuller and Mosher 1981, Rosenfield et al. 1988, Kimmel and Yahner 1990, Kennedy and Stahlecker 1993, McLeod and Anderson 1998). In Minnesota, McLeod and Anderson (1998) found that broadcasting conspecific calls early in the morning (0530-1030) and early in the breeding season prior to egg-hatch was effective for detecting red-shouldered hawks.

Without surveys to enhance detection, the effort to locate and protect the hawks and their habitat is reactive. Nest sites may be found through opportunistic sighting during the cruising or marking stage of timber harvest. When nests are found while marking timber in Wisconsin, the timber sale must be altered to accommodate for the presence of the nest because of their protected status (A. Buchholz, WDNR, personal communication). State and county foresters generally employ seasonal restrictions or follow considerations that may be beneficial to the hawks near nest sites (WDNR 2000). If nest sites are known before timber harvests are planned, foresters can employ a proactive approach to manage red-shouldered hawks. Few studies have investigated the effects of forest management practices on red-shouldered hawks (Naylor et al. 2004). In order for harvesting to be appropriate for both the local economy and hawk management, habitat selection characteristics of red-shouldered hawks must be understood.

Monitoring nests and determining productivity can be valuable in assessing the status of raptor populations. However, caution must be addressed while monitoring raptor nests. Young raptors approaching fledgling age may prematurely fledge the nest if a researcher approaches the nest too closely, however, if nests are visited too early, nest success will be overestimated because researchers may fail to document mortality late in the nesting period (Steenhof 1987). As a result, nests are often monitored a week or so before fledging. Steenhof (1987) considered a nest successful if a breeding pair produced one or more young that reached fledgling age and suggested that at least one nestling must reach 80% of the average age at first flight to deem a nest successful.

Red-shouldered hawk productivity in eastern North America varies from 1.1 to 2.9 young per active nest (Crocoll 1994). On the CNNF in northeast Wisconsin, nests monitored from 1992-2007 had 0.8 ± 0.3 young per active nest (J. P. Jacobs, unpublished report), which is lower than 1.6 young per active nest found in central Wisconsin in 2003-2007 (E. A. Jacobs, unpublished report) and lower than most of eastern North America (Crocoll 1994). Productivity of 0.8 ± 0.4 young per active nest and a nest success rate of $40\% \pm 18\%$ were reported in Menominee County of northeast Wisconsin from 2002-2007, but considerable variation occurred among years (WDNR, unpublished data).

Many hypotheses have been proposed regarding decreased population trends and low nest productivity for red-shouldered hawks throughout their range, including reduced prey for young (Campbell 1975), displacement by red-tailed hawks (*Buteo jamaicensis*) because of increased forest openings (Bednarz and Dinsmore 1982, Bryant 1986), fragmentation and loss of riparian woodlands used by red-shouldered hawks during breeding (Bednarz and Dinsmore 1981), and mortality from nest predators such as great horned owls or raccoons (*Procyon lotor*) (Craighead and Craighead 1956). Low productivity could also be a result of decreased abundance toward the edge of their geographical range (Mehlman 1997).

Marinette County Forest (MCF) encompasses approximately 94,000 ha in northeast Wisconsin and is the 2nd largest county forest in Wisconsin (Fig. 1.1). The Wisconsin Breeding Bird Atlas has not confirmed breeding of red-shouldered hawks in MCF (Cutright et al. 2006), however, three nest sites were reported to the WDNR in 2005. The objectives of this study were to: 1) inventory red-shouldered hawks in MCF using systematic survey techniques, 2) determine reproductive success and productivity of nesting red-shouldered hawks, 3) determine and describe nest site habitat selection of red-shouldered hawks by comparing nest sites to random sites, and 4) develop forest management recommendations for red-shouldered hawks and provide them to the Marinette County Forestry Committee.

Methods

Study Area

Climate in MCF is characterized by long winters and short, cool summers. Annual minimum temperatures average from -14 to -4 C and maximum temperatures average from 15 to 29 C. Annual mean precipitation is 813 mm (Midwestern Regional Climate Center 2000). Approximately 88% of the MCF is forested (13% forested wetlands), 8% is non-forested wetlands with <1% open water habitats (lakes, streams, and rivers), and 4% is non-forested uplands (Table 3.1). Dominant forest types are mixed aspen and aspen (>50% *Populus* spp.; 43%) and northern hardwoods (sugar maple [*Acer saccharum*], yellow birch [*Betula alleghaniensis*], basswood [*Tilia americana*], white ash [*Fraxinus americana*], and American beech [*Fagus grandiflora*]; 10%) (Table 3.1) (Marinette County Forest 2006).

Soils in eastern MCF are characterized as calcareous till and outwash, but igneous bedrock is found in the northeast. Central and western sites are dominated by loamy and sandy outwash. Frequent out-crops of bedrock generally occur in the northern half of the county (Marinette County Forest 2006). MCF is encompassed by the Laurentian Mixed Forest province (McNab and Avers 1994) including the subsections of West Green Bay Till Plain, Athelstane Sandy Outwash and Moraines, Green Bay Sandy Lake Plain, and Brule and Point Rivers Drumlinized Ground Moraine. Subsections are divided into several landtype associations including drumlins, barrens, plains, knolls, moraines, and outwash plains (Marinette County Forest 2006).

All of the MCF is open to the public. MCF maintains 360 km of county forest roads in addition to public roads that access the forest, creating easy entry for the public to hunt, fish and recreate. Marinette County has several county parks, beaches, campgrounds, waysides, boat landings, all-terrain vehicle trails, snowmobile trails, and cross country ski trails. Recreation and tourism are ranked as the top business in the county followed by forest industry. Production of forest products is vital to the county's economic well being and revenue from timber sales averages $1.5 million per year (Marinette County Forest 2006).

Locating Red-shouldered Hawk Nest Sites

Broadcast Surveys

During the red-shouldered hawk breeding season in 2006 and 2007, we conducted call-broadcast surveys along forest roads and trails in the MCF to detect and locate hawks. In order to survey the entire forest, half of the stations were completed during 2006 and the other half were completed in 2007. For ease of navigation, townships were used to divide the MCF. Each township was labeled with a letter from north to south, starting with "A" in the northwest corner of the county. Survey stations were mapped 0.80 km apart along county roads, town roads, county forest roads, and county forest trails (Mosher et al. 1990, Iverson and Fuller 1991, McLeod and Anderson 1998). Each survey station was buffered 0.80 km because calls can be broadcasted over this distance and red-shouldered hawks are known to respond from this distance (Mosher et al. 1990, Iverson and Fuller 1991, McLeod and Anderson 1998). The 0.80 km buffer (203 ha area) also covers a majority of the home range size of red-shouldered hawks (109 to 339 ha) (Crocoll 1994). To obtain complete coverage of the MCF, walk-in survey stations were added to areas not covered by the 0.80 km station buffers along roads. Survey stations were numbered according to township. The township lettered "A" had survey stations labeled A1, A2, A3, etc. Township maps were created to show survey stations for navigation using ArcView® (ESRI, Redlands, California, USA) Geographic Information System (GIS) software. We used a Global Positioning System (GPS) unit with station coordinates to navigate from station to station.

To detect red-shouldered hawks at survey stations, broadcast surveys of conspecific calls were used to elicit responses (McLeod and Anderson 1998). During the courtship and incubation periods, adult red-shouldered hawks have the greatest response rate, therefore we surveyed approximately from the end of March to the beginning of May (McLeod and Anderson 1998, see phenology in Appendix A). We surveyed after sunrise when it was light enough for visibility $\geq$ 0.80 km and continued for the next 4 hours. Weather conditions can interfere with detection of hawks, therefore surveys were cancelled if wind speeds were > Beaufort 3 (11-16 km/h), precipitation was constant (more than a light mist), or if visibility was < 1 km (McLeod and Anderson 1998). Conspecific alarm calls were played on a Western Rivers Electronic Game Caller® (Lexington, Tennessee, USA) with a 25-watt amplifier. A hand-held game caller was also used (FoxPro® Model 48B, FoxPro Systems, Lewistown, Pennsylvania, USA) for walk-in survey stations while monitoring time with a stopwatch. To ensure that the speaker of the broadcast caller had an output of 100-110 dB, we tested callers with a Digital Sound Level Meter (RadioShack®, Fort Worth, Texas, USA) in order for broadcasts to carry about 1 km (Kimmel and Yahner 1990, Mosher et al. 1990, McLeod and Anderson 1998). A pre-recorded red-shouldered hawk call was played for 20-sec followed by a 40-sec listening period and this protocol was repeated five additional times for a total of six calling bouts. The speaker was rotated 90º after each 20-sec calling period. Following the broadcast calls, we listened for 4 minutes, resulting in 10 minutes of survey time at each station (Dykstra et al. 2001, McLeod and Anderson 1998). All stations were surveyed at least once during the sampling period.

Survey stations were sampled in succession. At each calling station, we looked and listened in all directions and completed a survey form. When we detected a vocal or visual response, we ceased calling and recorded the azimuth from where the response originated, type of response, and estimated distance to each responding hawk. If multiple responses occurred, information on all responses was recorded. We noted the calling bout (0-6) that was being played at the time of response (zero = a response prior to the start of the survey). We also recorded temperature, wind speed, cloud cover, changes in weather, and responses of other raptor species.

After a red-shouldered hawk response was recorded, we skipped the next 0.80 km survey station to prevent a territorial bird from following the broadcast call from station to station. We returned to the skipped station a different day. A survey station was completely skipped if access was restricted (private property), difficult (too wet an area), or if a nest was found within 0.40 km. Some of the red-shouldered hawk responses were initially too far away to acquire an accurate azimuth; therefore, those survey stations were surveyed once more to determine a more accurate response.

Nest Searches

Nest searches began at survey stations where a response occurred using the azimuth recorded. We walked from the survey station toward the direction of the red-shouldered hawk response for a minimum of 0.80 km, but if time allowed we searched up to 1.61 km. Once the desired distance was reached, we walked parallel to the path traveled but maintained a distance of 25-35 m to cover a wider area (J. E. Woodford, WDNR, unpublished data). We used a GPS unit to track the distance and area traveled. Ideally, we preferred to have 2-3 individuals as a search team, with one observer walking the line from the calling station and the other(s) walking parallel lines 25-35 m apart.

While nest searching, we looked in all directions to examine every tree in view, searching for nests that showed signs of activity in a territory. A territory was defined as an area that contained, or historically contained, one or more nests within the home range of a pair of mated birds (Steenhof 1987). A territory may have an occupied or active nest. To allow for comparison between our study and others, we used consistent productivity definitions from Wisconsin (Jacobs and Jacobs 2002) and Ohio (Dykstra et al. 2000). An occupied nest was defined as a nest that was rebuilt (sticks with freshly broken ends), had fresh green vegetation (evergreen boughs, deciduous leaves) on the nest edge and lining the nest, or had territorial adults present near the nest. An active nest was one containing young, eggs or egg shells, an adult, or had breast feathers present on the nest edge. When we found a nest, we recorded nest activity and marked the location with a GPS and left the area as soon as possible so not to disturb the birds (Appendix B). If we were unable to locate a nest associated with a response, we used a broadcast call again at the same or nearby survey station to determine another response direction. We attempted to find a nest twice from a calling station with a response.

Nestling Measurements and Productivity Monitoring

To follow the 80% of first-flight age criterion for successful nests, we needed to determine the age of red-shouldered hawk nestlings early in the nesting period. Nest trees were climbed between 9-12 June by professional arborists when nestlings were approximately 3 weeks old (Jacobs and Jacobs 2002). Young were collected and lowered to the ground in a breathable bag. We estimated age using an age-feather length regression model (Penak 1982) and temporal observations (i.e., age when feather development occurs on body and behaviors such as raising wings and standing) (Bent 1937, Crocoll 1994). We also weighed and banded nestlings with #6 lock-on bands (Varland et al. 2007). Ages determined from nestling measurements were used to calculate hatch date by backdating and determining approximate fledge date using 42 days for the nestling period (Crocoll 1994, Jacobs and Jacobs 2002). We also identified nesting material and measured nest dimensions.

While monitoring nests and performing final productivity checks, we recorded evidence of nest activity or nest failure (Appendix C). We observed and recorded new greens, down feathers, adults, or young in the nest along with whitewash below the nest which occurs if the young are at least 5 days old (Crocoll 1994). If a nest failed, we noted signs of predation or other causes (J. Woodford, WDNR, personal communication). In 2007, a 15.2 m extension pole with a video camera attached was used to view inside the nest to confirm failure.

Reproductive rate was reported as the number of nestlings per occupied nest, the number of nestlings per active nest, and the number of nestlings per successful nest. Success rate was reported as the percentage of active nests that contained at least one young with at least 80% of the nesting process complete.

Habitat Sampling

After nest sites were located in 2006, we used MCF stand reconnaissance data to determine forest types most frequently used by hawks and to choose random points within the same habitat types. This technique is known as stratified random sampling (Garton et al. 2005). We did not sample random points in the same forest stand of a known nest. Limiting the random sites prevented comparing nest sites to habitats where hawks were unlikely to nest (Moorman and Chapman 1996). Twenty-four nest sites in 2006 had primary or secondary forest stand types of northern hardwood (NH), hemlock hardwood (*Tsuga canadensis* and northern hardwood species; HH), or oak (*Quercus rubra*, *Q. alba*, *Q. velutina*; O) (Table 3.1). Using ArcView® GIS, we queried all primary and secondary forest stand types for NH, HH, or O, resulting in 2,988 stands. To reduce the sample, we deleted all forest stands smaller than the average minimum stand size of the 24 nest sites (21.9 ha ± 0.8 SE). Next, we removed forest stands with known nest sites, resulting in 250 stands. Each random point had a corresponding number (1-250) which was used to reduce our sample size to 100 stratified random sites by generating a random number table (www.random.org). Finally, we selected random points within the defined forest types using the Random Point Generator Extension V1.1. (Garton et al. 2005). Random sites were not sampled if habitat was not reflective of red-shouldered hawk nest sites (i.e., open canopy, current harvesting) (McLeod et al. 2000).

Habitat data were collected within a 0.04 ha circular plot centered on active nest trees and at stratified random locations using methods outlined by James and Shugart (1970) with slight modifications. With exception of nest tree specific variables, we measured the same habitat variables at nest and random plots (Table 3.2). Circular plots with a radius of 11.3 m were marked using flagging and all measurements were taken within the flagged boundary. For all woody species ≥ 2 cm dbh, we identified species and measured dbh using a diameter tape. We also measured the height of all understory woody species ≥ 1.2 m tall and up to 6.0 m high with a height pole. Woody species were divided into size categories in each plot (i.e. seedling, sapling, sawlog; see Table 3.2). Basal area (m^2/ha) was calculated for trees ≥ 10 cm dbh (basal area = 0.005454 × dbh^2) within plots. Using a clinometer (Suunto®, Vantaa, Finland), we measured the height of nest trees and the height of nests within nest plots. Within both nest and random plots, we measured the height of the four tallest canopy trees. To obtain canopy closure, we used a convex spherical densitometer at 3.3, 7.3, 15.3, and 19.3 m distances along a random compass bearing line through the center of each plot. Down woody debris (DWD), defined as all fallen trees or large branches >5 cm in diameter and >1 m in length including stumps, was measured by taking the total length and diameter at the end of each piece of debris along with height and diameter of stumps (Harmon and Sexton 1996). Volume of DWD was calculated using the frustum of a cone formula (Harmon and Sexton 1996). If a piece of DWD extended beyond the plot boundary, measurements were taken at the boundary edge. To measure the presence or absence of understory and ground cover, we used an ocular tube and recorded 10 presence or absence readings at 1 m intervals from plot center in each cardinal direction (James and Shugart 1970).

We measured the distance from nests and random plot centers to roads/trails, streams, lakes/open wetlands, and closed wetlands by pacing if distance was <100 m, otherwise it was estimated with ArcView® GIS software measuring tools from orthophotographs, 7.5 min USGS quadrangle maps, and MCF stand reconnaissance data (Table 3.2). Using MCF stand data, wetlands were divided into closed and open wetlands because adult and juvenile hawks were often observed in closed wetlands (Table 3.3). Wisconsin wetlands include marshes, bogs, floodplain forests, wet meadows and low prairies (WDNR 1995). Measurements at nest plots occurred after a nest failed or after birds fledged.

Analysis

We compared two statistical modeling methods: logistic regression using information-theoretic model selection (Burnham and Anderson 2002) and discriminant function analysis (DFA; McGarigal et al. 2000) to determine the probability of red-shouldered hawk occurrence in relation to habitat variables measured at nest-site and random plots (Table 3.2). We wanted to determine if both methods produced similar results. For all analyses, the dependent variable was the nest (use) or random plot (availability). Logistic regression modeling has been used to model habitat relationships of red-shouldered hawks (McLeod et al. 2000) and has become increasingly popular for modeling wildlife habitat selection (Keating and Cherry 2004). DFA analysis is also frequently used to model species habitat selection (Bergin 1992, Clark and Shutler 1999). Logistic regression and DFA analyses were performed using SAS software (SAS Institute 2001). After model selection, we also used a two sample *t*-test to determine which of the habitat variables differed ($P < 0.05$) between nest and random sites.

Logistic Regression Modeling

Prior to model development, redundant variables were eliminated (Spearman's $r \geq 0.70$) and 19 habitat variables were retained to develop models (Table 3.2). We then specified a set of *a priori*, candidate logistic regression models (Burnham and Anderson 2002) to determine the probability of red-shouldered hawk nest site habitat variables in relation to stratified random habitat variables. We selected variables and developed models based on previously published red-shouldered hawk nest habitat studies and previous field experience with this species. Prior research showed that red-shouldered hawks select taller and larger diameter trees, along with higher basal area and closer distance to streams and wetlands for nest sites. Field experience suggested that an open understory may be of importance along with habitat characteristics that may provide diversity for prey species, such as down woody debris, snag trees, and conifer species.

We specified 17 models: a global model containing all 19 variables and a subset of *a priori* models (Table 3.4). Each model represented a competing hypothesis to explain red-shouldered hawk nesting habitat. We did not consider all possible combinations of variables, as this inflates the number of models beyond which can be reliably analyzed (Burnham and Anderson 2002). Prior to model selection, we tested the fit of the global model using Hosmer-Lemeshow goodness-of-fit test (Hosmer and Lemeshow 2000).

We used Akaike's Information Criterion (AIC; Burnham and Anderson 2002) for model selection. Because the number of occupied and random sites ($n = 95$) was small relative to the number of variables (K) in several models (i.e., $n/K < 40$), we used AIC corrected for small sample size (AIC_c) for model selection (Burnham and Anderson 2002). We used the formulas presented in Burnham and Anderson (2002) to calculate AIC_c from the log-likelihoods (listed in SAS output) for each model. We ranked all candidate models according to their AIC_c values and the best model (i.e., most parsimonious) was the model with the smallest AIC_c value (Burnham and Anderson 2002). Substantial empirical support for models is within 2 units of AIC_{cmin}, although models within 4-7 units may have limited empirical support (Burnham and Anderson

2002). We calculated Akaike weights (w_i) to determine the weight of evidence in favor of each model (Burnham and Anderson 2002). To assess fit of supported models, we calculated Max-rescaled R^2.

Discriminant Function Analysis (DFA)

We used a multivariate DFA to evaluate which habitat variables were most useful for differentiating between red-shouldered hawk nest sites and random locations. Similar to logistic regression analyses, we eliminated redundant variables (Spearman's $r \geq 0.70$) and retained 19 variables (Table 3.2) for analyses. Forward stepwise DFA was used to reduce the number of variables. A full DFA, using the selected variables, was evaluated to determine which variables would contribute most to the discrimination between groups. At each step of the forward stepwise DFA, the variable that minimized the overall Wilks' λ and had a P-value of ≤ 0.05 was entered. We used the model Wilks' λ value to test for statistical significance and determined relative habitat variable importance by examining the magnitude of the standardized canonical correlation coefficients (McGarigal et al. 2000).

Results

Locating Red-shouldered Hawk Nest Sites

In 2006, we completed 512 calling stations from March 25 to May 5 and in 2007 we completed 609 calling stations from March 26 to May 4. Red-shouldered hawk responses were detected at 121 of 1,121 (11%) broadcast survey stations. Several of the responses were possibly from the same adult pair. Nearly all responses were vocal only (59%) or visual and vocal (40%). Other raptor species responding to the broadcast surveys included one sharp-shinned hawk (*Accipiter striatus*), one northern goshawk, two barred owls (*Strix varia*), two Cooper's hawks (*A. cooperii*), two red-tailed hawks, and eight broad-winged hawks (*B. platypterus*).

Thirty-five territories were found through nest searches and 6 were reported by foresters or local researchers during initial stages of the project, for a total of 41 known occupied red-shouldered hawk territories (Figure 3.1). In 20 of 41 (49%) territories, alternative nests were located. All nest searches originated from locations where a red-shouldered hawk response had occurred. Responses were detected in approximately 20 other areas, however, no nest structure was found.

Of the 41 territories, 34 contained an active nest in either 2006 or 2007. The 34 active nests were in the following primary forest types (in decreasing order) (Table 3.1): 16 in mature northern hardwood, 10 in mature mixed aspen, three in mature oak, two in mature white pine (various *Pinus* spp.), one on the edge of mature cedar (various *Thuja* spp.), one on the edge of mature swamp conifer (balsam fir [*Abies balsamea*], cedar, spruce [*Picea* spp.]), and one of the edge of mature swamp hardwood (black ash [*Fraxinus nigra*], red maple [*Acer rubrum*], American elm [*Ulmus* a*mericana*]). Average dbh of all active nest trees was 50.4 ± 12.1 cm. Nests were found (in decreasing order) in red oak (9), paper birch (*Betula papyrifera*; 4), eastern white pine (*P. strobus*; 4), American beech (3), sugar maple (3), big-tooth aspen (*Populus grandidentata*; 2), basswood (2), red maple (2), white ash (2), yellow birch (2), and quaking aspen (*P. tremuloides*; 1). Mean nest height was 14.1 ± 2.2 m and mean nest tree height was 28.6 ± 5.1 m so nests were placed 50.2 ± 7.8% up the distance of the tree.

Nestling Measurements and Productivity Monitoring

Nest measurements were recorded at 24 nests between 2006 and 2007. Mean nest width was 47.5 ± 11.3 cm, nest length was 60.6 ± 14.9 cm, and nest depth was 33.9 ± 8.1 cm. Nest materials used to build and line nests consisted of balsam fir boughs, sugar maple leaves and twigs, northern white cedar (*T. occidentalis*) boughs, aspen leaves and twigs, hemlock boughs, spruce boughs, red oak leaves and twigs, elm leaves, white pine boughs, basswood leaves, ironwood (*Ostrya virginiana*) leaves, paper birch bark strips, shreds of unknown bark, and lichen.

In 2006, we evaluated 13 active nests between 10-12 June. One nest was empty and failure appeared to be from mammal predation. Thirty-one young were measured and banded. Six young from three different nests died between the time they were banded and their fledgling age. One nestling was found dead below a nest for unknown reasons, a nest with three young appeared to have failed from mammal predation, and failure could not be determined for one nest with two young. One additional nest with 3 young was found to be active later in the nesting season and could not be climbed. Nestling ages ranged from 13 to 30 days old, averaging 21 ± 4 days old. In 2007, 12 active nests were evaluated during 9-10 June. One nest was empty and exact cause of failure could not be determined. Twenty-four nestlings were measured and 19 were banded. Four nestlings from three different nests died between the time they were banded and their fledging date. One nest with two young likely failed from mammal predation and cause of failure for the other two nests was unknown. Nestling ages ranged from 14 to 30 days old, averaging 22 ± 4 days old.

We visually conducted final productivity evaluations in late June and early July by viewing young in the nest using binoculars. All young were counted. We monitored 25 occupied red-shouldered hawk territories in 2006 and 39 in 2007 (Table 2.2). On average, red-shouldered hawks produced 1.1 ± 0.4 young per active nest and 2.4 ± 0.2 young per successful nest in 2006 and 2007.

Five of the active territories sampled in 2006 were considered to be reoccupied by the same red-shouldered hawk nesting pair in 2007 and were sampled again. However, only two active nest locations were the same between years. Number of young in the nest varied from one to four in 2006 and 2007.

Habitat Sampling

We measured habitat data at 34 nest and 61 random plots (Fig. 3.2). In 2006 and 2007, we measured habitat variables at all active nest sites. Eight of the active nests in 2007 appeared to be within the same territories as active nests in 2006. Habitat data from multiple nest sites within the same territory could bias our results, therefore, we randomly chose a single nest site to represent each breeding territory. Using the two sample *t*-test, habitat variables that differed between nest and random plots were distance to closed wetland, number of tree species, distance to stream, volume of down woody debris, and number of snag trees (Table 3.5).

Logistic Regression Modeling

Of 17 logistic regression models explaining nest site selection of red-shouldered hawks, one model containing number of tree species and distance to closed wetland was selected as the best-approximating model (Table 3.4). Red-shouldered hawk nest locations were negatively associated with distance to the nearest closed wetland and positively associated with number of tree species (Table 3.6). The Akaike weight (w_i) for the best approximating model containing number of tree species and distance to closed wetland was 0.81 (Table 3.4). Akaike weight can be interpreted as a probability that the current model is the best-approximating model among those considered (Burnham and Anderson 2002). The Hosmer-Lemeshow test indicated that the global model fit the data ($\chi^2_8 = 5.79$, $P = 0.67$).

The second best model included only number of tree species ($\Delta AIC_c = 4.73$; Table 3.4) and received limited empirical support (i.e., within 4-7 ΔAIC_c units of AIC_{cmin}). This model also showed that red-shouldered hawk nest locations were positively associated with number of tree species (Table 3.6). Weight of evidence ($w_{\text{best model}}/w_{\text{second-best model}}$) in favor of the best model with number of tree species and distance to closed wetland was about 10 times greater than that of the model with number of tree species (Table 3.4), indicating little uncertainty in selection of the best candidate model (Burnham and Anderson 2002). Two additional models received limited empirical support, "distance to closed wetland" and "large tree and closed wetland". The remaining 13 models received essentially no empirical support ($\Delta AIC_c \geq 10.57$, $w_i = 0.00$; Table 3.4).

Discriminant Function Analysis

The stepwise DFA model was statistically significant (Wilks $\lambda = 0.716$, $F_{5, 89} = 7.07$, $P < 0.001$) and included five habitat variables (in order of importance): number of tree species, distance to closed wetland, volume of down woody debris, number of small sawlogs, and distance to stream (Fig. 3.3). These variables had standardized correlation coefficients of -0.496, 0.490, -0.578, 0.439, and 0.399, respectively. An examination of discriminant scores (Fig. 3.3) indicated that red-shouldered hawk nest selection was best explained by the greater number of tree species, closer distance to closed wetlands, greater volume of downed woody debris, fewer small sawlogs, and closer distance to streams. The DFA model produced an overall classification accuracy of 76.5% for nest plots and 70.5% for random plots.

Discussion

Systematic surveys using broadcast calling methodology proved highly successful for locating red-shouldered hawk nest sites on the MCF. Prior to this study, very few documented breeding reports for red-shouldered hawks existed within MCF (Cutright et al. 2006). Standard BBS methods may be of limited use to detect this secretive forest species because methodology does not elicit a territorial response during early stages of the nesting period. It has also been suggested that the red-shouldered hawk population is too low and localized in Wisconsin to be adequately monitored by BBS methods (Robbins et al. 1996).

Our study is the first in Wisconsin to systematically survey an entire large forest to locate red-shouldered hawk nest sites. The broadcast survey technique (McLeod and Anderson 1998) used in our research could be applied to other areas in Wisconsin to determine red-shouldered hawk and other raptor occupancies along with relative abundances (Mosher et al. 1990, McLeod and Anderson 1998).

We detected red-shouldered hawks from approximately 20 other areas in MCF where no occupied nests were found, indicating additional hawk nests in the area. To find nest locations, land managers could use our broadcast survey and nest search methods, and develop a search image using nest tree characteristics measured on MCF, such as average dimension of nests, distance up the tree, and dbh of nest tree. Red-shouldered hawks usually build nests in a main crotch of a deciduous tree ½ the distance to the top of the tree (Palmer 1988), which is consistent with our results (Fig. 3.4). Nests were built in 11 tree species, with most nests in red oak (26%). However, researchers have suggested that tree structure rather than tree species is important in nest tree selection (Bednarz and Dinsmore 1982, Titus and Mosher 1987), and our observations agree with this claim. Several studies have also shown that red-shouldered hawks select nest trees with larger dbh than randomly available (Bednarz and Dinsmore 1982 [63.0 ± 12.7 cm], Titus and Mosher 1987 [>40cm], McLeod et al. 2000 [43.6 ± 8.6 cm]). Our study did not compare nest tree dbh to dbh of random trees, however, our mean nest tree diameter (50.4 ± 12.1 cm) is consistent with these studies.

Productivity of red-shouldered hawks on MCF was comparable to other long-term studies in Wisconsin. Overall, productivity in Wisconsin is low when compared to results in the eastern United States (Crocoll 1994). Causes for low productivity have not been determined. In 2006, 55% of the nests in MCF were successful and in 2007 36% of the nests were successful. Within the Great Lakes Region, nest success averages about 55% (Jacobs and Jacobs 2002). Maintaining suitable habitat near each nest site is critical because only approximately half of the red-shouldered hawk nests successfully produce young each year and hawks use these sites for multiple years (Crocoll 1994).

Twenty-nine percent of nest sites were located within mature mixed aspen forest type. Mixed aspen and aspen stands comprise 43% (40,420 ha) of MCF forested area. Forty-seven percent of nest sites were found in mature northern hardwood forest type, which comprises 10% (9,400 ha) of MCF forested area, suggesting strong selection for northern hardwood forests. McLeod et al. (2000) found that 90% (18 of 20) of the red-shouldered hawks in one site in Minnesota nested in mature northern hardwood stands. At a second site, 100% (n = 39) of the nests were located in mature upland hardwood stands (McLeod et al. 2000). Also, all red-shouldered hawk nest sites on Menominee County, Wisconsin were found in northern hardwood and hemlock-hardwood forest types (J. Woodford, WDNR, unpublished report).

Logistic regression models identified that red-shouldered hawks select nest sites near closed wetlands and with increased tree species richness. The DFA model was similar in that number of tree species and distance to closed wetland were the most important habitat variables identified followed by volume of downed woody debris, number of small sawlogs, and distance to streams. The univariate comparison indicated that five habitat variables differed between nest and random sites. Four of the five variables were similar to the DFA model, however, snag trees were considered significant instead of small sawlogs.

To our knowledge, this is the first red-shouldered hawk nest site selection study to identify tree species richness and down woody debris as important in selection. Retaining tree species richness within MCF stands will provide perching, nesting, and foraging opportunities for wildlife (Boardman and Yahner 1999) and may result in greater wildlife species diversity. Down woody debris also explained red-shouldered hawk nest selection. Many wildlife species, especially amphibians and small mammals, use coarse woody debris for cover, denning, nesting, and foraging (Maser et al. 1979). Large snags with cavities are also used by many wildlife species for similar reasons (Yahner et al. 2005). Over time, snag trees will add to coarse woody debris in the forest.

Red-shouldered hawks consume small mammals, birds, herpetofauna, and invertebrates (Crocoll 1994) and therefore, down woody debris and large snags could increase their prey base. These habitat characteristics could be particularly important if prey are limiting.

Distances to closed wetlands and streams were also important variables in nest site selection. Nest site association with distance to wetlands or permanent water sources has been described previously (Titus and Mosher 1981, Bosakowski et al. 1992, McLeod et al. 2000), but these studies did not differentiate between closed and open wetlands. Titus and Mosher (1981) measured distance of nest sites to water, Bosakowski et al. (1992) measured distance to streams, lakes, and wetlands, and McLeod et al. (2000) measured distance to permanent surface water. We differentiated wetlands because adult and juvenile hawks were observed often in closed wetlands and MCF stand reconnaissance data allowed us to differentiate between the two types (Table 3.3). Wetlands with adjacent forest cover may provide red-shouldered hawks with ideal foraging areas for amphibians, which are an important food source during the nesting period (Craighead and Craighead 1956, Bednarz and Dinsmore 1981, Welch 1987). Riparian zones are also important to a rich diversity of flora and fauna (Naiman and Dechamps 1997).

Our research will directly aid MCF staff in forest management activities by providing red-shouldered hawk nest site locations. Knowledge of nest locations will save time and money when foresters initiate harvest and mark timber stands allowing for proactive management. MCF staff can use location data for several years, since a pair of red-shouldered hawks use a nest territory for multiple years (Crocoll 1994).

Reoccupancy rate (percent of territories occupied the following breeding season) in central and northeast Wisconsin during 1993-1997 was 66% (Jacobs and Jacobs 2002) and on Menominee County in northeast Wisconsin during 2002-2006 was 71% (WDNR, unpublished data). Most importantly, knowledge of nest locations can provide a visual understanding of nest characteristics and habitat selected by red-shouldered hawks for MCF staff. Local foresters and wildlife biologists can use this knowledge to narrow their search for red-shouldered hawk nests on the property they manage.

I expect that this research will be a significant contribution toward future conservation and management of red-shouldered hawks in Wisconsin because little has been reported on habitat selection of this threatened species, and this information may help standardize state management guidelines. Also, the protocol used to detect red-shouldered hawks can be used throughout the state to identify occupied nest sites, providing for a possible method to estimate population abundance of this species. Foresters and wildlife biologists can use these management guidelines to improve forest habitat for red-shouldered hawks with the ultimate goal of delisting the species.

Management Implications

We found that tree species richness was important for nest site selection by red-shouldered hawks. Thus, management emphasis on tree species richness should improve red-shouldered hawk nesting habitat. As an example, within the northern hardwood cover type we recommend maintaining the five major tree species if possible (sugar maple, beech, basswood, white ash, and yellow birch) as well as associated species such as red maple, red oak, hemlock, white pine, and balsam fir (WDNR 2006). The conifer component is important for forest stand management at nest sites because it adds tree species richness, provides nest trees for red-shouldered hawks (conifers were used on occasion), and provides material for lining nests. Management activities that lead to species homogenization should be avoided.

Closed wetlands and streams were also important for red-shouldered hawk nest sites and are likely critical in foraging success. Land managers should follow best management practices for water quality to decrease impact near nest sites (WDNR 1995).

Managers should also maintain natural volumes of down woody debris within forest stands, with potential to increase volume of debris when possible. Loggers should avoid damaging downed logs and leave cull material, especially hollow logs, in the woods. This study and others have documented importance of large diameter woody debris (e.g., large logs, snags, and root mounds) for forest wildlife species. This can be accomplished by retaining older and larger diameter trees through longer stand rotations that will eventually increase average snag tree diameter and volume of course woody debris. Retaining older trees will also provide larger diameter trees that red-shouldered hawks require for nest trees. Structure of the nest tree is important, and therefore retention of large trees with forking (crotches) is an important consideration.

We recommend that human disturbance (including road construction and logging) be minimized from March through July 15 during the red-shouldered hawk nesting season. We also recommend conducting surveys for red-shouldered hawks prior to implementing projects within potential habitat areas.

These recommendations have the potential to improve forest habitat for red-shouldered hawks on MCF and elsewhere in Wisconsin. Our suggestions mimic many of the wildlife management considerations currently used for northern hardwood management in Wisconsin (WDNR 2006). Even though our focus has been on recommendations for red-shouldered hawks, these recommendations will greatly improve habitat for other forest wildlife species as well.

Acknowledgements

This study was made possible by funding from the Marinette County Forestry Committee, with assistance from the Wisconsin Department of Natural Resources, Bureau of Endangered Resources, Aquatic and Terrestrial Resources Inventory (ATRI). Special thanks go to individuals that assisted with broadcast surveys and nest searches including: Jim Woodford, Carol Eloranta, Tony Rinaldi, John Krause, Aaron Buchholz, and Aaron McCollough. A complete inventory of the MCF would not have been possible without their help. Field technicians, Kendra Sawyer, Heather Brantmeier, and Brittany Moe were essential in measuring vegetation within nest and random plots. We thank Don Roppolo, Adam Klein, Les Werner, John Jacobs, Mike Stanonik, Aaron Schauer, and Nick Crawford for climbing nests and assisting with measurements on the ground. We also thank Jessica Reger for assistance in the field and entering data.

References

Bednarz, J. C., and J. J. Dinsmore. 1981. Status, habitat use, and management of red-shouldered hawks in Iowa. Journal of Wildlife Management 45:236-241.

Bednarz, J. C., and J. J. Dinsmore. 1982. Nest-sites and habitat of red-shouldered and red-tailed hawks in Iowa. Wilson Bulletin 94:31-45.

Bent, A. C. 1937. Life histories of North American birds of prey. U.S. National Museum Bulletin 167, Washington, D.C., USA.

Bergin, T. M. 1992. Habitat selection by the western kingbird in western Nebraska: A hierarchical analysis. The Condor 94:903-911.

Boardman, L. A., and R. H. Yahner. 1999. Wildlife community structure and composition in managed forested stands of central Pennsylvania. Northern Journal of Applied Forestry 16:1-7.

Bosakowski, T., D. G. Smith, and R. Speiser. 1992. Status, nesting density, and macrohabitat selection of red-shouldered hawks in northern New Jersey. Wilson Bulletin 104:434-446.

Bryant, A. A. 1986. Influence of selective logging on red-shouldered hawks, *Buteo lineatus*, in Waterloo Region, Ontario, 1953-1978. Canadian Field-Naturalist 100:520-525.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and inference: a practical information-theoretic approach. Second edition. Springer-Verlag, New York, New York, USA.

Campbell, C. A. 1975. Ecology and reproduction of red-shouldered hawk in the Waterloo region, southern Ontario. Journal of Raptor Research 9:12-17.

Clark, R. G., and D. Shutler. 1999. Avian habitat selection: pattern from process in nest-site use by ducks? Ecology 80:272-287.

Craighead, J. J., and F. C. Craighead, Jr. 1956. Hawks, owls and wildlife. Stackpole Company, Harrisburg, Pennsylvania, USA.

Crocoll, S. T. 1994. Red-shouldered hawk (*Buteo lineatus*). Account 107 i*n* A. Poole and F. Gill, editors. The birds of North America, The Academy of Natural

Sciences, Philadelphia, Pennsylvania, and The American Ornithologists' Union, Washington, D.C., USA.

Cutright, N. J., B. R. Harriman, and R. W. Howe, editors. 2006. Atlas of the breeding birds of Wisconsin. The Wisconsin Society for Ornithology, Inc., Waukesha, Wisconsin, USA.

Dykstra, C. R., J. L. Hayes, F. B. Daniel, and M. M. Simon. 2000. Nest site selection and productivity of suburban red-shouldered hawks in southern Ohio. Condor 102:401-408.

Dykstra, C. R., F. B. Daniel, J. L. Hays and M. M. Simon. 2001. Correlation of red-shouldered hawk abundance and macrohabitat characteristics in southern Ohio. Condor 103:652-656.

Fuller, M. R. and J. A. Mosher. 1981. Methods of detecting and counting raptors: a review. Studies of Avian Biology 6:235-246.

Garton, E. O., J. T. Ratti, and J. H. Giudice. 2005. Research and experimental design. Pages 43-71 *in* C. E. Braun, editor. Techniques for Wildlife Investigations and Management. Sixth edition. The Wildlife Society, Bethesda, Maryland, USA.

Harmon, M. E., and J. Sexton. 1996. Guidelines for measurements of woody detritus in forest ecosystems. Publication Number 20. U.S. LTER Network Office, University of Washington, Seattle, Washington, USA.

Henny, C. J., F. C. Schmid, E. M. Martin, and L. L. Hood. 1973. Territorial behavior, pesticides, and the population ecology of red-shouldered hawks in central Maryland, 1943-1971. Ecology 54:545-554.

Hosmer, D. W., and S. Lemeshow. 2000. Applied logistic regression. Second edition.

John Wiley and Sons, Inc., New York, USA.

Iverson, G. C., and M. R. Fuller. 1991. Area-occupied survey technique for nesting woodland raptors. Pages 118-124 *in* B. A. Giron Pendleton, D. L. Krahe, M. N. LeFranc, Jr., K. Titus, J. C. Bednarz, D. E. Anderson, and B. A. Millsap, editors. Proceedings of the Midwest raptor management symposium and workshop. National Wildlife Federation Scientific and Technical Series 15.

Jacobs, J. P., and E. A. Jacobs. 2002. Conservation assessment for red-shouldered hawk (*Buteo lineatus*): National Forests of north central states. U.S. Department of Agriculture, Forest Service, Eastern Region, Milwaukee, Wisconsin, USA.

James, F. C, and H. H. Shugart. 1970. A quantitative method of habitat description. Audubon Field Notes 24:727-736.

Keating, K. A., and S. Cherry. 2004. Use and interpretation of logistic regression in habitat-selection studies. Journal of Wildlife Management 68:774-789.

Kennedy, P. L. and D. W. Stahlecker. 1993. Responsiveness of nesting northern goshawks to taped broadcasts of 3 conspecific calls. Journal of Wildlife Management 57:249-257.

Kimmel, J. T., and R. H. Yahner. 1990. Response of northern goshawks to taped conspecific and great horned owl calls. Journal of Raptor Research 24:107-112.

Marinette County Forest. 2006. Marinette County Forest Master Plan. <http://www.marinette county.com/forestry_masterplan.htm>. Accessed 21 Oct 2006.

Maser, C., R. G. Anderson, K. Cromack, Jr., J. T. Williams, and R. E. Martin. 1979. Dead and down wood material. Pages 78-95 *in* J. W. Thomas, editor. Wildlife habitats in managed forests - the Blue Mountains of Oregon and Washington. U.S. Department of Agriculture, Forest Service, Handbook 553.

McGarigal, K., S. Cushman, and S. Stafford. 2000. Multivariate statistics for wildlife and ecology research. Springer-Verlag, New York, New York, USA.

McLeod, M. A., and D. E. Andersen. 1998. Red-shouldered hawk broadcast surveys: factors affecting detection of responses and population trends. Journal of Wildlife Management 62:1385-1397.

McLeod, M. A., B. A. Belleman, D. E. Andersen, and G. W. Oehlert. 2000. Red-shouldered hawk nest site selection in north-central Minnesota. Wilson Bulletin 112:203-213.

McNab, W. H., and P. V. Avers. 1994. Ecological subregions of the United States. <http://www.fs.fed.us/land/pubs/ecoregions/index.html>. Accessed 20 Oct 2006.

Mehlman, D. W. 1997. Change in avian abundance across geographic range in response to environmental change. Ecological Applications 7:614-624.

Midwestern Regional Climate Center. 2000. http://mcc.sws.uiuc.edu/. Accessed 24 March 2008.

Moorman, C. E., and B. R. Chapman. 1996. Nest-site selection of red-shouldered and red-tailed hawks in a managed forest. Wilson Bulletin 108:357-368.

Morris, M. M. J., and R. E. Lemon. 1983. Characteristics of vegetation and topography near red-shouldered hawk nests in southwestern Québec. Journal of Wildlife Management 47:138-145.

Mosher, J. A., M. R. Fuller, and M. Kopeny. 1990. Surveying woodland raptors by broadcast of conspecific vocalizations. Journal of Field Ornithology 61:453-461.

Naiman, R. J., and H. Dechamps. 1997. The ecology of interfaces: riparian zones. Annual Review of Ecology and Systematics 28:621-658.

Naylor, B. J., J. A. Barker, and K. J. Szuba. 2004. Effects of forest management practices on red-shouldered hawks in Ontario. The Forestry Chronicle 80:54-60.

Palmer, R. S., editor. 1988. Red-shouldered hawk. Pages 413-429 *in* Handbook of North American birds. Volume 2. Yale University Press, New Haven, Connecticut, USA.

Penak, B. L. 1982. Aspects of the nutritional ecology of the red-shouldered hawk (*Buteo lineatus lineatus*) in southwestern Quebec. Thesis, McGill University, Ste-Anne-de-Bellevue, Quebec, Canada.

Richardson, C. T., and C. K. Miller. 1997. Recommendations for protecting raptors from human disturbance: a review. Wildlife Society Bulletin 25:634-638.

Robbins, S. D., D. W. Sample, P. W. Rasmussen, and M. J. Mossman. 1996. The breeding bird survey in Wisconsin: 1966-1991. Passenger Pigeon 58:81-179.

Rosenfield, R. N., J. Bielefeldt, and R. K. Anderson. 1988. Effectiveness of broadcast calls for detecting breeding Cooper's hawks. Wildlife Society Bulletin 16:210-212.

SAS Instiutute. 2001. SAS/STAT Software, Version 8.2. SAS Institute Inc., Cary, North Carolina.

Sauer, J. R., J. E. Hines, and J. Fallon. 2005. The North American Breeding Bird Survey, results and analysis 1966-2005. Version 6.2.2006. U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland, USA.

Steenhof, K. 1987. Assessing raptor reproductive success and productivity. Pages157-

170 *in* B. A. Giron Pendleton, B. A. Milsap, K. W. Cline, and D. M. Bird, editors. Raptor management techniques manual. National Wildlife Federation, Washington, D.C., USA.

Titus, K., and J. A. Mosher. 1981. Nest-site habitat selected by woodland hawks in the central Appalachians. Auk 98:270-281.

Titus, K. and J. A. Mosher 1987. Selection of nest tree species by red-shouldered and broad-winged hawks in two temperate forest regions. Journal of Field Ornithology 58:274-283.

U.S. Forest Service [USFS]. 2004. Forest standards and guidelines. *In* Land and resource management plan, R9-CN-FP. United States Department of Agriculture, Forest Service, Chequamegon-Nicolet National Forests, Washington, D.C., USA.

Varland, D. E., J. A. Smallwood, L. S. Young, and M. N. Kochert. 2007. Marking techniques. *In* Raptor research and management techniques. D. M. Bird and K. L. Bildstein (eds.). Hancock House Publishers, Blaine, Washington, pp.221-236.

Welch, R. J. 1987. Food habits of the red-shouldered hawk in Wisconsin. Passenger Pigeon 49:81-91.

Wisconsin Department of Natural Resources [WDNR]. 1988. Endangered resources handbook. Wisconsin Department of Natural Resources Publication 1724.5, Madison, Wisconsin, USA.

Wisconsin Department of Natural Resources [WDNR]. 1995. Wisconsin's Forestry Best Management Practices for Water Quality. Wisconsin Department of Natural Resources Publication FR-093, Madison, Wisconsin, USA.

Wisconsin Department of Natural Resources [WDNR]. 2000. Threatened and endangered species in forests of Wisconsin. Wisconsin Department of Natural Resources Publication FR-174, Madison, Wisconsin, USA.

Wisconsin Department of Natural Resources [WDNR]. 2006. Chapter 40: Northern hardwood cover type in Silviculture and Forest Aesthetics Handbook. Wisconsin Department of Natural Resources Publication HB2431-5, Madison, Wisconsin, USA.

Yahner, R. H., C. G. Mahan, and A. D. Rodewald. 2005. Managing forestlands for wildlife. Pages 898-919 in C. E. Braun, editor. Techniques for wildlife investigations and management. Sixth edition. The Wildlife Society, Bethesda, Maryland, USA.

Table 3.1. Cover types, descriptions, and associated percentages of Marinette County Forest (94,000 ha) in northeast Wisconsin, USA, 2006 and 2007. Descriptions are from the Wisconsin Department of Natural Resources Manual Code 8625.5 on Mapping Symbols and Terms. Marinette County Forest in Wisconsin follows the same cover/forest type descriptions (continued on next page).

Code	Type	Description	%
	Forested		
A	Aspen	More than 50 percent aspen.	43.488
NH	Northern Hardwoods	More than 50 percent northern hardwood species: sugar maple, yellow birch, basswood, rock elm, beech, etc.	10.334
PR	Red Pine	More than 50 percent pine with red pine outweighing white pine and jack pine.	5.820
SH	Swamp Hardwoods	More than 50 percent swamp hardwood species: black ash, red maple, American elm, etc.	5.551
O	Oak	Dominated by red oak, white oak, or black oak; in association with other hardwoods.	5.126
PJ	Jack Pine	More than 50 percent pine with jack pine outweighing red pine and white pine.	3.981
C	White Cedar	More than 50 percent swamp conifers with white cedar outweighing other species.	2.922
OX	Scrub Oak	More than 50 percent stocked by various species of oak which, in this type, will produce only fuelwood and cellulose materials.	2.489
SC	Swamp Conifer	Swamp type with mixed species including predominantly balsam fir, cedar, and spruce; in association with red maple and a variety of other hardwoods.	2.489
SB	Black Spruce	More than 50 percent swamp conifers with black spruce outweighing other species.	1.419
FS	Fir-Spruce	Swamp border or upland types with mixed species, including predominantly balsam fir and spruce; with white pine, white cedar, red maple, aspen, etc.	1.376
PW	White Pine	More than 50 percent pine with white pine outweighing red pine and jack pine.	0.797
BW	White Birch	More than 50 percent white birch.	0.688
HH	Hemlock-Hardwoods	More than 50 percent hemlock in association with northern hardwood species.	0.458
MR	Red Maple	More than 50 percent red maple.	0.418
T	Tamarack	More than 50 percent swamp conifers with tamarack outweighing other species.	0.190
BH	Bottomland Hardwoods	Bottomland hardwoods dominated by silver maple, river birch, elm, cottonwood, etc.	0.097
		Total	88

	Non-forested Wetland		
LB	Lowland Brush	The "LB" symbol will be used for lowland brush on forest lands less than 10% stocked with tree species.	4.306
LBA	Lowland Brush Alder	More than 50% alder.	2.013
K	Marsh	The "K" symbol should be used for grass or high water table areas.	0.673
KEV	Emergent Vegetation Marsh	Coarse emergent marsh vegetation such as cattails, river bulrush, tall sedges, etc.	0.249
KG	Lowland Grass Marsh	Ground cover consisting of more than 50% of true grasses such as canary grass, bluejoint, redtop, cordgrass, big bluestem, fire stemmed sedges, etc.	0.205
SXSB	Noncomm. Wetland Black Spruce	More than 50% black spruce.	0.042
KB	Muskeg - Bog Marsh	Bog such as sphagnum moss, cotton grass, leatherleaf, cranberry, Labrador tea, etc.	0.041
KH	Lowland Herbaceous Veg. Marsh	Ground cover consisting of more than 50% of herbaceous vegetation, such as lowland asters, stinging nettle, wild sunflowers, etc.	0.011
SX	Noncommercial Forested Wetland	The "SX" symbol will be used for spruce, tamarack or cedar forested wetlands in which trees will not produce standard pulpwood in 100 years.	0.003
LBW	Lowland Brush Willow	More than 50% shrub willow.	0.002
L	Water	Lakes, ponds and flowages in excess of 40 acres in area, or rivers in excess of _ mile in width.	0.040
LM	Minor-Lake	Water under 40 acres in area, excluding rivers less than _ mile in width.	0.315
LMS	Minor-Stream	Minor - stream LMS Streams less than _ mile in width.	0.138
		Total	8
	Non-forested Upland		
UB	Upland Brush	Upland sites less than 10% stocked with tree species but having 50% or more of the area stocked with taller growing, persistent shrubs.	1.343
ROW	Right-of-Ways*	Rights-of-way ROW Improved roads, railroads or right-of-way for gas, power or telephone lines.	1.191
Z	Rock Outcrops and Sand Dunes	Rock outcrops including rocky beaches more than 1 acre in extent. Sand dunes including sand beaches, more than 1 acre in extent.	0.852
GG	Grass	Ground cover predominately true grasses such as brome, quack, blue grass, timothy, big and little bluestem, Indian grass, etc.	0.370
GH	Herbaceous Vegetation	Ground cover predominately herbaceous vegetation species such as bracken fern, sweet clover, giant ragweed, stinging nettle, goldenrod, etc.	0.216
GLS	Low Growing Shrubs	Ground cover predominately low growing woody plants such as blueberry, raspberry, etc.	0.202
G	Grass	The "G" symbol will be used for upland grass, sweet fern, bracken fern, etc., including abandoned fields less than 10% stocked with tree species.	0.094
I	Developed Use	The "I" symbol should be used for general developed uses.	0.033
ICG	Campground	Areas designated for either family camping (tent and trailer), group tent camping or indoor group camps.	0.007
IP	Picnic Area	Maintained day use areas containing picnic tables, toilets, etc., for picnickers.	0.004
IA	Parking Area	An area which is used for parking in conjunction with a recreational facility such as a beach, picnic area, observation tower, public hunting area, etc.	0.003
		Total	4
*contains unknown amount of wetland acreage			

Table 3.2. Habitat variables used for modeling habitat relationships of red-shouldered hawk (*Buteo lineatus*) nest sites within 0.04 ha nest and random plots in the Marinette County Forest, Wisconsin, USA, 2006 and 2007.

Variable	Unit	Abbreviation	Additional Description
Distance to road[a]	m	ROAD	Distance from plot center to nearest road (4WD track, gravel, paved, or useable trail)
Distance to stream[a]	m	STREAM	Distance from plot center to nearest stream
Distance to open wetland[a,b]	m	OPWET	Distance from plot center to nearest lake or open wetland
Distance to closed wetland[a,b]	m	CLWET	Distance from plot center to closed wetland
Canopy height	m	CANHT	Average canopy height of the 4 tallest trees in the plot measured with a clinometer
Canopy density	%	CANDEN	Average % of closed canopy measured at 4 stations in the plots with a spherical densitometer
Basal area	m^2/ha	BA	Basal area for stems ≥ 10 cm dbh in the plot
Basal area from conifer species	%	BACO	% basal area from conifer species in the plot
Average dbh	cm	AVDBH	Average dbh for all trees in the plot ≥ 10 cm
Short-live seedlings	#	SLS	Number of stems < 3.0 cm dbh and 1.2 to 3.0 m tall and stems 1.2 to 3.0 m tall
Tall-live seedlings	#	TLS	Number of stems < 3.0 cm dbh and > 3.0 m tall and stems > 3.0 m tall
Saplings	#	SAP	Number of stems 3.0 to 12.9 cm dbh
Pole size timber*	#	POLES	Number of hardwood (13.0 to 27.9 cm dbh) and softwood stems (13.0 to 22.9 cm dbh)
Small sawlogs	#	SMSAW	Number of hardwood (28.0 to 37.9 cm dbh) and softwood stems (23.0 to 37.9 cm dbh)
Large sawlogs	#	LASAW	Number of stems ≥ 38 cm dbh in the plot
Snag trees	#	SNAGTR	Number of snags trees ≥ 13 cm dbh in the plot
Number of tree species	#	SP	Number of different tree species ≥ 10 cm dbh in the plot
Total shrubs per hectare*	#	SHRUB	Total number of shrubs per hectare (shrubs per 0.04 ha plot × 25 plots = 1 hectare)
Total trees per hectare*	#	TREE	Total number of trees per hectare (trees per 0.04 ha plot × 25 plots = 1 hectare)
Ground cover	%	GRCOVER	Presence/absence readings at 1 m intervals from plot center in each cardinal direction using ocular tube
Understory cover	%	UNCOVER	Presence/absence readings at 1 m intervals from plot center in each cardinal direction using ocular tube
Down woody debris	m^3/ha	DWD	Total volume of down woody debris in the plot

[a] Distance was paced if < 100 m; otherwise it was estimated from orthophotographs, 7.5 min USGS quadrangle maps, or shapefile delineating forest types from Marinette County Forest, WI, USA using GIS.

[b] Open and closed wetland cover types are categorized and described in Table 3.3.

* indicates variable was not used in logistic regression or discriminant function modeling because of high redundancy (Spearman's r ≥ 0.70).

Table 3.3. Description of forest types used to categorize open and closed wetlands in Marinette County Forest, Wisconsin, USA, 2006 and 2007. Descriptions are from the Wisconsin Department of Natural Resources Manual Code 8625.5 on Mapping Symbols and Terms. Marinette County Forest in Wisconsin follows the same cover/forest type descriptions.

Code	Type	Description
	Lake/Open Wetlands	
K	Marsh	The "K" symbol should be used for grass or high water table areas.
KB	Muskeg - Bog Marsh	Bog such as sphagnum moss, cotton grass, leatherleaf, cranberry, Labrador tea, etc.
KEV	Emergent Vegetation Marsh	Coarse emergent marsh vegetation such as cattails, river bulrush, tall sedges, etc.
KG	Lowland Grass Marsh	Ground cover consisting of more than 50% of true grasses such as canary grass, bluejoint, redtop, cordgrass, big bluestem, fire stemmed sedges, etc.
KH	Lowland Herbaceous Vegetation Marsh	Ground cover consisting of more than 50% of herbaceous vegetation, such as lowland asters, stinging nettle, wild sunflowers, etc.
LB	Lowland Brush	The "LB" symbol will be used for lowland brush on forest lands less than 10% stocked with tree species.
LBA	Lowland Brush Alder	More than 50% alder.
LBW	Lowland Brush Willow	More than 50% shrub willow.
L	Water	Lakes, ponds and flowages in excess of 40 acres in area, or rivers in excess of _ mile in width.
LM	Minor-Lake	Water under 40 acres in area, excluding rivers less than _ mile in width.
	Closed Wetlands	
SB	Black Spruce	More than 50 percent swamp conifers with black spruce outweighing other species.
BH	Bottomland Hardwoods	Bottomland hardwoods dominated by silver maple, river birch, elm, cottonwood, etc.
SC	Swamp Conifer	Swamp type with mixed species including predominantly balsam fir, cedar, and spruce; in association with red maple and a variety of other hardwoods.
SH	Swamp Hardwoods	More than 50 percent swamp hardwood species: black ash, red maple, American elm, etc.
T	Tamarack	More than 50 percent swamp conifers with tamarack outweighing other species.
C	White Cedar	More than 50 percent swamp conifers with white cedar outweighing other species.
SX	Noncommercial Forested Wetland	Spruce, tamarack or cedar forested wetlands in which trees will not produce standard pulpwood in 100 years.
SXSB	" " Black Spruce	More than 50% black spruce.

Table 3.4. Logistic regression models explaining influence of habitat attributes (0.04 ha plots) on nest site selection of red-shouldered hawks (*Buteo lineatus*) in Marinette County Forest, WI, USA, 2006 and 2007. Model rankings were based on Akaike's Information Criterion corrected for small sample size (AIC_c).

Model[a]	K[b]	AIC_c [c]	ΔAIC_c [d]	w_i [e]
Number of tree species and distance to closed wetland {SP, CLWET}	3	111.59	0.00	0.81
Number of tree species {SP}	2	116.32	4.73	0.08
Distance to closed wetland {CLWET}	2	116.90	5.30	0.06
Large tree and closed wetland {LASAW, CLWET}	3	117.54	5.95	0.04
Distance to stream {STREAM}	2	122.17	10.57	0.00
Down woody debris {DWD}	2	123.08	11.48	0.00
Snag tree {SNAGTR}	2	123.17	11.58	0.00
Conifer tree density {BACO}	2	125.68	14.08	0.00
Sawlogs {SMSAW, LASAW}	3	125.80	14.21	0.00
Distance to open wetland {OPWET}	2	126.31	14.72	0.00
Tree density {BA}	2	127.33	15.73	0.00
Distance to road {ROAD}	2	127.72	16.12	0.00
Canopy density {CANDEN}	2	128.04	16.45	0.00
Ground cover {GRCOVER, UNCOVER}	3	128.70	17.11	0.00
Large trees {AVDBH, CANHT}	3	129.13	17.54	0.00
Seedlings and saplings {SLS, TLS, SAP}	4	130.94	19.35	0.00
Global {CANHT, CANDEN, GRCOVER, UNCOVER, DWD, SLS, TLS, SAP, SMSAW, LASAW, SNAGTR, SP, BA, BACO, AVDBH, ROAD, STREAM, OPWET, CLWET}	20	135.46	23.86	0.00

[a] Abbreviations in parentheses correspond to model parameters in Table 3.1.

[b] Number of estimable parameters in approximating model.

[c] Akaike's Information Criterion corrected for small sample size.

[d] Difference in value between AIC_c of the current model versus the best-approximating model (AIC_{cmin}).

[e] Akaike weight. Probability that the current model (w_i) is the best-approximating model among those considered.

Table 3.5. Sample means ($\bar{x}$) and standard deviations (SD) for variables measured or derived at 0.04 ha red-shouldered hawk (*Buteo lineatus*) nest plots (n = 34) and random plots (n = 61), Marinette County Forest, Wisconsin, USA, 2006 and 2007. An asterisk (*) indicates that data from nest sites differed significantly from data at random sites (two sample t-tests, $P < 0.05$).

Description	Nest Plots $\bar{x}$	Nest Plots ± SD	Random Plots $\bar{x}$	Random Plots ± SD	*P* -value
Distance to road (m)	103.8	92.6	114.4	83.8	0.572
Distance to stream (m)	440.9	416.8	644.8	391.2	0.023*
Distance to open wetland (m)	406.7	230.8	479.5	281.5	0.202
Distance to closed wetland (m)	182.0	162.2	357.5	314.6	0.001*
Canopy height (m)	26.7	4.2	26.0	3.4	0.360
Canopy density (% closed)	86.1	4.9	86.0	4.0	0.927
Basal area (m^2/ha)	30.5	9.2	28.9	8.4	0.399
Basal area from conifer species (%)	13.9	24.5	7.1	17.4	0.118
Average dbh for all trees in plot (cm)	23.8	4.0	23.0	3.6	0.343
Short-live seedlings	62.7	60.8	64.1	64.3	0.915
Tall-live seedlings	12.3	18.4	13.4	15.2	0.752
Saplings	29.0	21.8	25.3	13.4	0.313
Pole size timber	13.4	6.0	14.4	6.0	0.435
Small sawlogs	3.4	2.4	4.3	2.5	0.078
Large sawlogs	2.7	1.9	2.1	2.0	0.182
Snag trees	1.7	1.6	1.0	1.3	0.036*
Number of tree species	5.5	1.9	4.3	1.4	0.002*
Total shrubs per hectare	2599.3	2032.6	2571.7	1683.5	0.944
Total trees per hectare	486.0	141.6	520.9	150.9	0.273
Ground cover (%)	54.9	20.7	54.0	19.9	0.826
Understory cover (%)	31.7	19.6	26.7	19.0	0.226
Down woody debris (m^3/ha)	43.6	24.3	33.1	19.8	0.036*

Table 3.6. Parameter estimates (β) and standard errors (SE) from logistic regression best-approximating models used to explain influence of habitat attributes on nest site selection of red-shouldered hawks (*Buteo lineatus*) in Marinette County Forest, WI, USA, 2006 and 2007.

Model	β	SE	R^{2a}
Number of tree species and distance to closed wetland			0.244
Constant	-1.813	0.882	
Number of tree species	0.404	0.158	
Distance to closed wetland	-0.001	0.000	
Number of tree species			0.159
Constant	-2.859	0.775	
Number of tree species	0.473	0.152	
Distance to closed wetland			0.152
Constant	0.300	0.354	
Distance to closed wetland	-0.001	0.000	
Large tree and closed wetland			0.171
Constant	-0.042	0.452	
Number of large sawlogs	0.143	0.119	
Distance to closed wetland	-0.001	0.000	

[a] Max-rescaled R^2

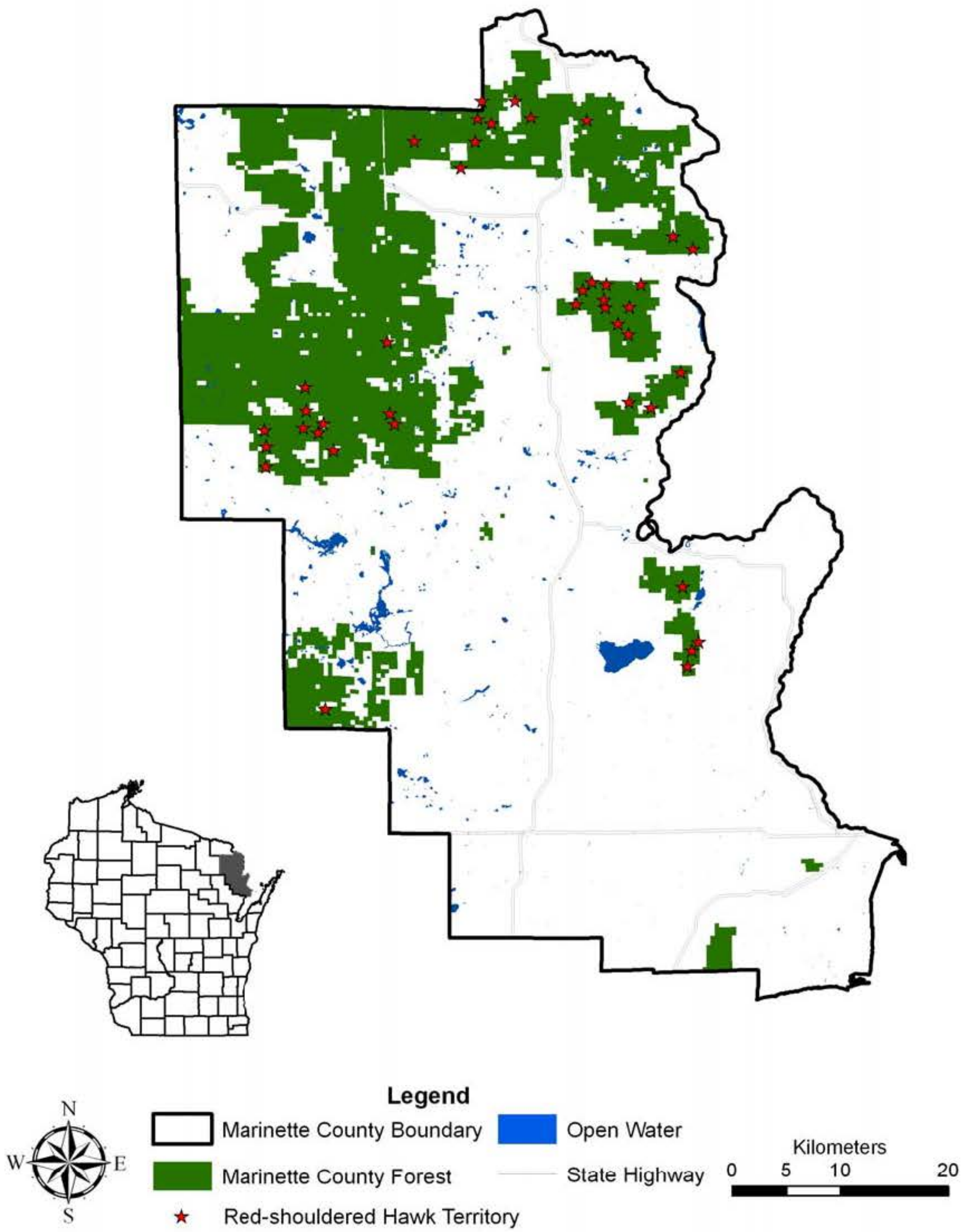

Figure 3.1. Location of red-shouldered hawk (*Buteo lineatus*) occupied territories (n = 41) on Marinette County Forest in northeast Wisconsin, USA, 2006 and 2007.

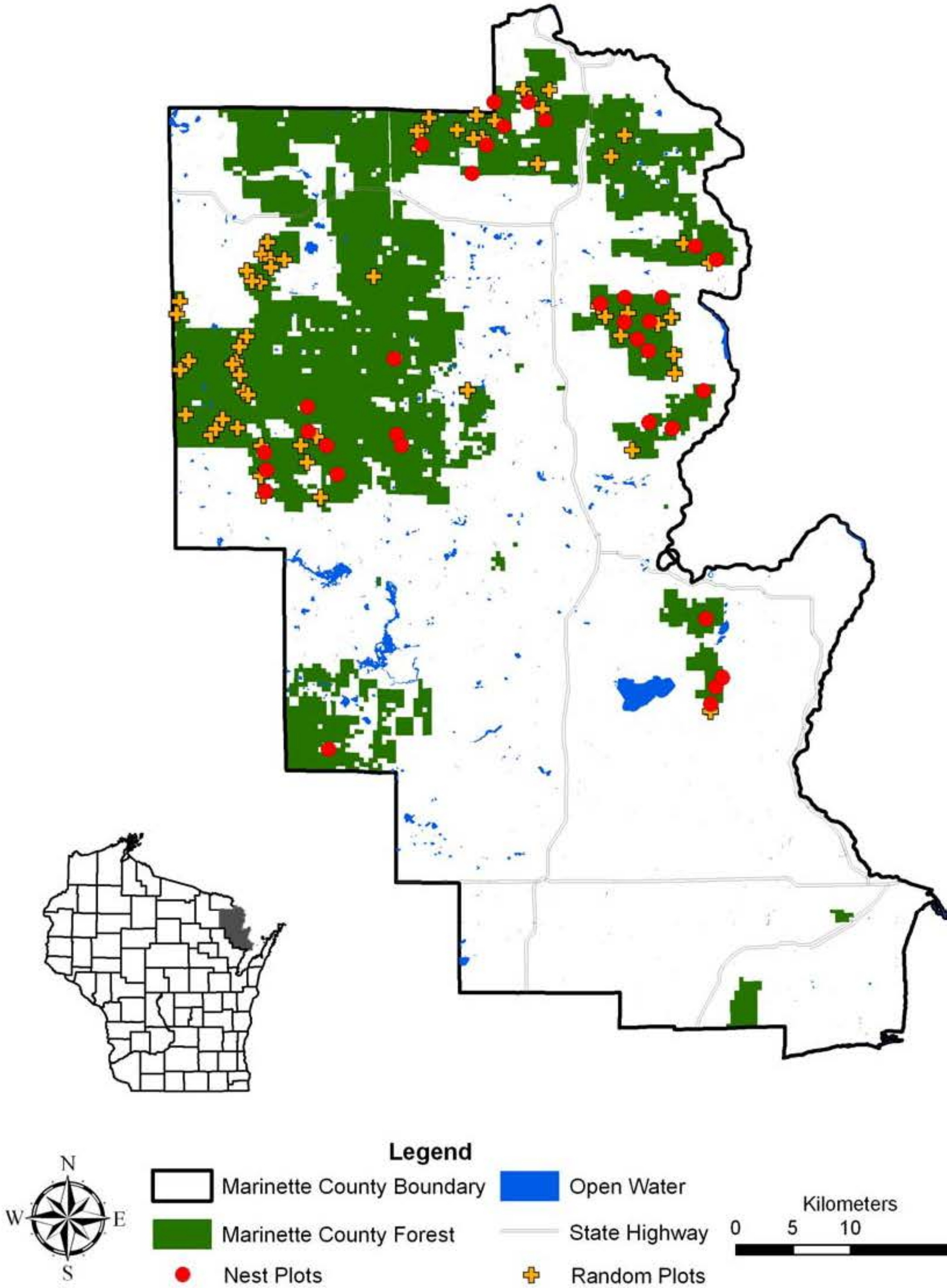

Figure 3.2. Location of nest plots (n = 34) and stratified random plots (n = 61) used to collect habitat variables for analysis of nest site selection of red-shouldered hawks (*Buteo lineatus*) on Marinette County Forest, WI, USA, 2006 and 2007.

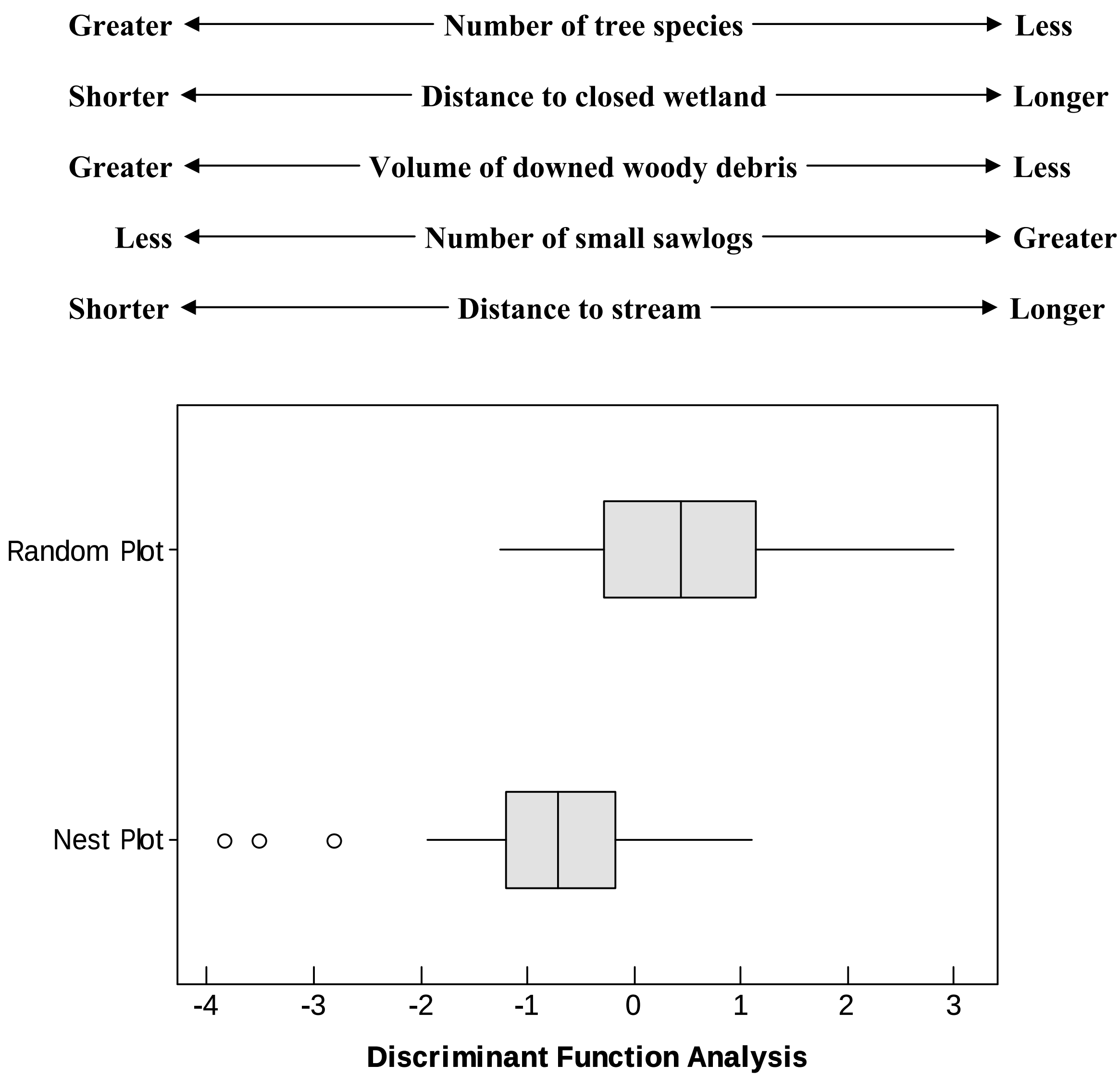

Figure 3.3. Discriminant function scores used to explain nest site selection (nest vs. random plot) of red-shouldered hawks in Marinette County Forest of Wisconsin, USA, 2006 and 2007. Variables above box plot are listed in the order of importance. The vertical line represents the mean, bar left and right of the mean is 1 S.E., horizontal line represents the range of values, and circles represent outliers (between 1.5 and 3 times the interquartile range).

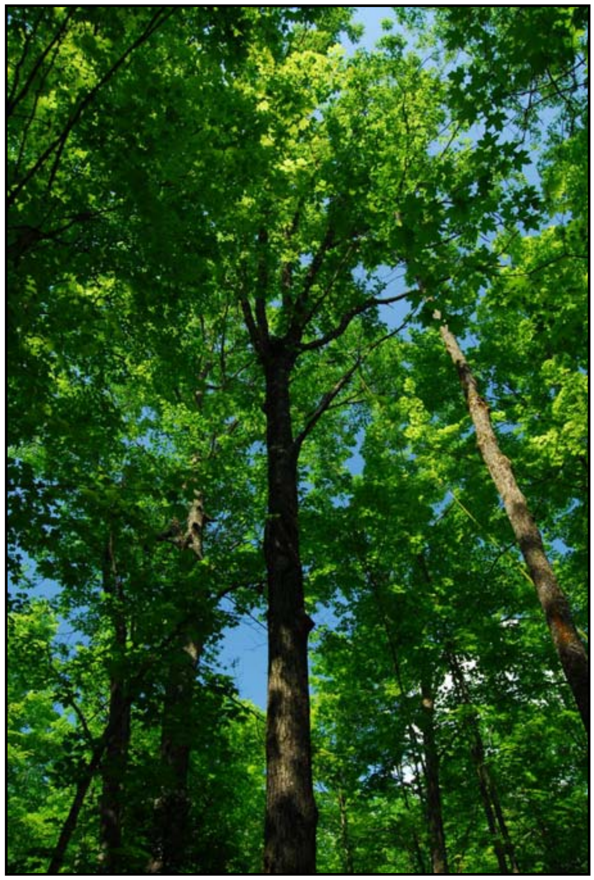

Fig. 3.4. Photographs of red-shouldered hawk (*Buteo lineatus*) nests showing position of nest in tree (main fork) and tree structure on Marinette County Forest in northeast Wisconsin, USA, 2006 and 2007.

Appendix A. Red-shouldered hawk breeding phenology for northeast Wisconsin.

Information from Conservation and Assessment for Red-shouldered Hawks, USDA Forest Service Eastern Region (Jacobs and Jacobs 2002).

<u>RSHA Return to Nest Site</u>

- Approximately March 7th
- By the end of March, fresh evergreens sprigs "greens" and new sticks may be added to the nest. Fresh broken ends of new sticks and old sticks may be visible (seen with binoculars).

<u>RSHA Incubation Begins</u>

- April 15th (ranges from March 29th – May 6th)
- Down feathers may be visible on the nest, adults may be observed flying from the nest, and greens should be visible in the nest (seen with binoculars).
- Incubation lasts 36 days.

<u>RSHA Egg Hatch</u>

- May 20th (ranges from May 4th – June 10th)
- Young defecate over the nest by day 5, therefore, "whitewash" seen on the ground can be used as an indication that eggs have hatched. Young may be visible in the nest.
- Nesting period lasts 42 days.

<u>RSHA Young Fledge from Nest</u>

- June 30th (ranges from June 13th – July 22nd)
- Fledged young remain close to nest for the first 6-15 days while learning to hunt.
- Young remain in the breeding range of their parents for an approximate total of 45-60 days after fledging.

Appendix B. Nest validation form formatted after WDNR forest raptor form.

Red-shouldered Hawk Nest Validation Form

Marinette County (version 04/06)

Date (month/day): ____________ **Site ID:** ____________________________________
Nearest Road Name: _______________________________ **Tree Tag #:** ____________
Observer(s) (F. Last): ____
Weather (circle):
Sunny Partly Cloudy Mostly Cloudy
Cloudy Rain Snow
Beaufort Wind Scale (see form):
Wind: <1 1-3 4-6 7-10 11-16 17-21 22-27
Temperature: _______**°F**
Reason for Visit (circle):
Survey Station Response Reported Nest Annual Check
Location:
GPS Coordinates: ___________________**N,** ___________________**W** (Lat/Long - decimal degree or degree-minute-second)
Town, Range, Section (¼ and/or ¼, ¼):___________________________________

Nest Tree:
Species: _________________ **General Nest Description:** ____________________ ____ (which fork, percent distance up the tree (2/3, 3/4), estimated height of nest)
Nest Condition (circle one): Excellent Good Fair Poor
Nest Diameter: __________ **Nest Depth:** __________ **Nest Tree DBH:** __________

Habitat and Topography
Estimated Distance to Nearest Road/Trail: _____________ **Direction:** ___________
Description of Terrain: ________________________ (e.g. flat, hilly, rolling, moraines)
Nest Site Aspect: __________ (degrees) **Canopy Density:** High Medium Low
Presence of Hemlock w/i 100m: Yes No **Hemlock Density:** High Medium Low
Tree Species Composition within Nest Tree Area (greatest to least): _____________
____
Scale of Conifer Coverage within 100m of Nest Tree (circle):
None Little Medium Heavy Complete Dominant Species: __________
Understory Density (circle):
Dense Moderate Sparse None Dominant Species: __________
Distance to Nearest Aspen Stand: ______________________

Activity Evidence (adult and/or young observed, sign of territory activity: rebuilt nest (new sticks with fresh broken ends), white wash, evergreens present, down): ____________________
____
____

Driving Directions and Access to Nest Site: ____
____
____
Other Information (near timber thinning, marked for harvest, climbing access, etc.):
____
____

Appendix C. Monitoring form formatted after WDNR forest raptor form.

Red-shouldered Hawk Monitoring Form

Marinette County (version 04/06)

Date (month/day): ____________ **Site ID:** ________________________________
Nearest Road Name: ______________________________ **Tree Tag #:** ____________
Observer(s) (F. Last): ____

Weather (circle):

Sunny   Partly Cloudy   Mostly Cloudy
Cloudy   Rain   Snow

Beaufort Wind Scale (see form):

Wind: <1 1-3 4-6 7-10 11-16 17-21 22-27

Temperature: _______°F

Monitoring Stage (check one):

- □ Incubation (April to mid May)
- □ Occupied/Active Nest (mid May to mid June)
- □ Fledgling (mid June to mid July)

Activity Evidence (check all that apply):

- □ Incubating Adult
- □ # of Adults __________ (circle all that apply):
  Auditory Visual Auditory and Visual Soaring Flyby Perch
- □ Evergreens
  What kind? _____________________
- □ Sticks w/fresh broken ends
- □ Down
- □ Whitewash
- □ # of Eggs seen __________
- □ # of Young seen or heard __________
- □ Prey Remains
  Collected – Yes No If yes, what kind? _____________________
- □ Adult Feather
  Collected – Yes No If yes, what kind? _____________________

Activity Evidence Comments: ____
____

Signs of Predation (circle):

Mammalian:

Claw marks on tree Crushed egg shells Gnawing on carcass/feathers
Down along trunk of tree (drag mark)

Avian:

Crimped feathers Stripped bone Beak bite nips Scrapes in bones

Other:

Other Species Observed: ____

Additional Comments: ____