Note

Potential Role of Prey in the Recovery of American Martens to Wisconsin

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ABSTRACT The American marten (*Martes americana*), the only state-listed endangered mammal in Wisconsin, has undergone serial reintroductions within the state. Recovery has been slower than anticipated and the limiting factors remain unidentified. The lack of basic knowledge on marten foraging in the Great Lakes Region led us to quantify the diet of martens inhabiting the Chequamegon-Nicolet National Forest (CNNF) in northern Wisconsin using a dual approach of scat and stable isotope analyses. We collected marten scat at winter rest sites within the CNNF from 2000–2011. We identified prey items based on morphological characteristics of indigestible prey remains and calculated percent occurrence for each prey item. We sampled marten hair from museum specimens, and opportunistically from carcasses within the CNNF for isotopic analysis. We collected hair and feather samples from potential prey species in the CNNF in 2010–2013. Our concurrent analyses revealed that shrews and deer were most important to the diet of martens in Wisconsin. These findings contrast with studies conducted elsewhere that report voles as the principle diet items, and shrews as one of the least used prey items. Consequently, such a strong reliance on secondary, less profitable or high-risk prey could be contributing to the delayed recovery of martens in Wisconsin. © 2014 The Wildlife Society.

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Understanding a species' foraging ecology can illuminate patterns of niche partitioning (Kitchen et al. 1999), population dynamics (Flynn and Schumacher 2009), and habitat selection (Coffin et al. 1997). Such information is especially relevant for endangered or rare species because it improves our capacity to implement effective management plans (Gillespie 2013). Martens (*Martes americana*) are small-bodied carnivores that preferentially inhabit structurally complex forests throughout their distributional range (Andruskiw et al. 2007). In many systems, prey availability drives marten vital rates, like fecundity (Flynn and Schumacher 2009) and adult survivorship (Weckwerth and Hawley 1962). As a generalist predator, the diet of martens can vary strongly with resource availability, although they generally consume voles (*Microtus* spp. and *Myodes* spp.) and mice (*Peromyscus* spp.; Buskirk and Ruggiero 1994, Martin 1994).

Historically, martens were distributed across much of the forested regions of Wisconsin but were extirpated from the state in the 1920s as a result of logging, large-scale fires, and

unregulated fur trapping (Jackson 1961). Because of their economic importance as a furbearer and a growing public interest in restoring native wildlife, large-scale reintroduction efforts were initiated by the United States Forest Service and the state of Wisconsin in the 1970s and 1980s to re-establish 2 populations of martens in the Chequamegon-Nicolet National Forest (CNNF)—an eastern and western reintroduction site. To date, multiple reintroductions and augmentations have occurred (Williams et al. 2007); however, recovery has been slow, particularly for the western population, and martens remain Wisconsin's only state-listed endangered mammal.

Recent evidence suggests that adult survivorship of marten, at least within the western side of the CNNF, is sufficiently high for population growth (McCann et al. 2010) and, therefore, prolonged recovery may be the result of low juvenile recruitment. Because the components of recruitment—gestation, lactation, and juvenile development—are each periods of heightened nutritional demands, food limitation or increased risk during foraging could be important mechanisms contributing to slowed population growth and recovery (Powell and Leonard 1983). Nutritional limitation has been shown to affect marten population growth elsewhere (Weckwerth and Hawley 1962, Fryxell

et al. 1999, Flynn and Schumacher 2009). To date, only 1 study has quantified the winter diets of martens within the Great Lakes Region, in the Upper Peninsula of Michigan, which found that martens relied heavily on voles and mice in winter (Hales et al. 2008).

To investigate the diet of a recovering population of American martens in Wisconsin, we used a dual approach of scat and stable isotope (δ^{13}C and δ^{15}N) analyses. By using both approaches, we were able to quantify the diet of martens in Wisconsin and elucidate the contribution of various components to their diet.

STUDY AREA

We investigated the diet of martens in the CNNF in northern Wisconsin (Fig. 1). This region has a continental climate typified by warm summers, cold winters, and seasonal snow cover. The predominant cover types in our study area include deciduous forest (35.3%), woody wetlands (28.9%), mixed forest (11.7%), evergreen forest (9.4%), and scrubland (5.4%; National Land cover Database, 2011). Over story predominantly consisted of sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*), aspen (*Populus* spp.), basswood (*Tilia americana*), and oaks (*Quercus* spp.). Hardwood stands are interspersed with stands of white pine (*Pinus strobus*), red pine (*Pinus resinosa*), white spruce (*Picea glauca*), hemlock (*Tsuga canadensis*), balsam fir (*Abies balsamea*), and northern white cedar (*Thuja occidentalis*);

understory shrubs include alder (*Alnus* spp.), ironwood (*Ostrya virginiana*), and serviceberry (*Amelanchier* spp.). Potentially relevant food items for martens include red-backed voles (*Myodes gapperi*), deer and white-footed mice (*Peromyscus* spp.), shrews (*Blarina brevicauda*, *Sorex* spp.), red squirrels (*Tamiasciurus hudsonicus*), flying squirrels (*Glaucomys* spp.), snowshoe hares (*Lepus americanus*), white-tailed deer (*Odocoileus virginianus*), ruffed grouse (*Bonasa umbellus*), blackberry (*Rubus* spp.), and strawberry (*Fragaria virginiana*). Potential competitors with martens include coyotes (*Canis latrans*) and fisher (*Martes pennanti*), both of which are relatively common throughout our study area.

METHODS

Scat Collection and Analysis

We collected marten scat samples at rest and trap sites within the CNNF (Fig. 1) during winter months from 2000–2011 ($n = 70$). We located rest sites by backtracking martens or by walking in on resting radio-collared individuals (Dumyahn et al. 2007). Scat samples were stored at $-20°$C, rinsed, filtered through mesh cloth, air dried for 24 hours, and stored in sterile sampling bags until analysis. We examined marten diet through morphological identification of indigestible prey remains (hair, claws, bones, or teeth) recovered from processed scat samples. We analyzed undigested material microscopically and identified prey items according to guard hair coloration, banding patterns, and medulla characteristics
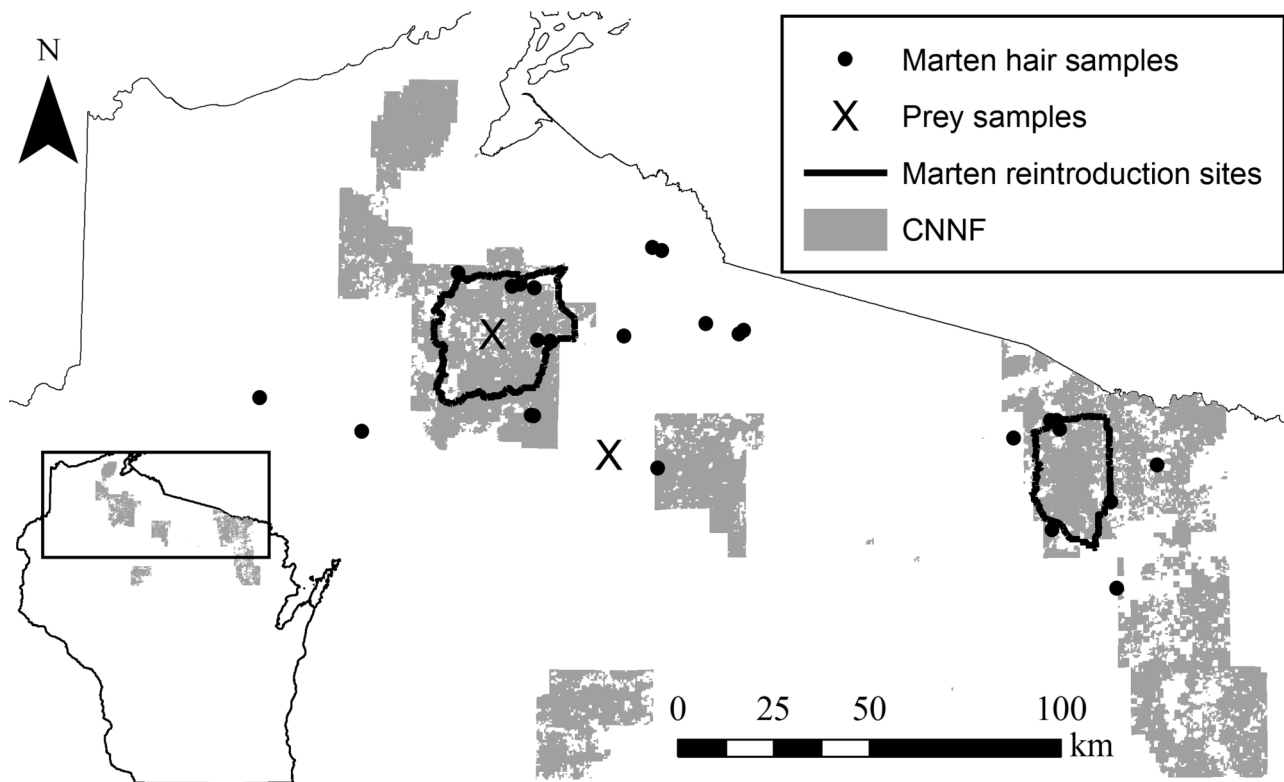
Figure 1. Locations of American marten hair samples (1991–2013) and potential prey items (2010–2013) collected from northern Wisconsin, USA. We also show the Chequamegon-Nicolet National Forest (CNNF) boundaries and the 2 areas of marten reintroduction, the state marten protection areas, for Wisconsin. We obtained marten scat samples ($n = 70$) from in and around the western protection area.

(Moore et al. 1974). We then cross-referenced sample identifications with voucher specimens, identified them to genus, and recorded them as an occurrence of the given prey item. We used the occasionally observed teeth, claws, or bone fragments to aid in identification. We identified birds to the lowest taxonomic level possible through morphological identification of feathers, and noted insects based on the presence of exoskeletons. We also collected a subsample of hair identified as shrews ($n = 2$) and voles ($n = 2$) from scat samples for isotopic analysis to confirm our identification. We calculated the percent occurrence of each food item by dividing the number of scats with that item by the total number of scats. The sum of percent occurrence exceeded 100% because we found more than 1 food item in multiple scats. We standardized frequency with number of scat samples, reported percent occurrence to better distinguish relative importance of prey items (Zabala and Zuberogoitia 2003), and performed a goodness of fit G-test to test for non-random prey selection.

Stable Isotope Collection and Analysis

We obtained marten hair from specimens at the University of Wisconsin Zoology Museum ($n = 10$) that were collected in Wisconsin (Fig. 1) from 1991–2008. We collected additional samples opportunistically from carcasses within the CNNF during the winters of 2005–2013 ($n = 15$). Because hair growth in martens predominantly occurs in the autumn (Pauli et al. 2009), isotopic signatures represent an individual's assimilated diet earlier than scat samples collected in winter. To gather representative isotopic signatures of relevant prey species, we collected potential prey hair and feather samples in the CNNF (Fig. 1) during the spring, summer, and fall seasons of 2010–2013. We baited Sherman live-traps (H.B. Sherman Traps Inc., Tallahassee, FL) with peanut butter and oats to capture small mammalian prey species. We sampled larger prey items, including white-tailed deer and ruffed grouse, opportunistically throughout the CNNF. We sampled and analyzed 9 potential prey species: short-tailed shrews (*B. brevicauda*; $n = 11$), masked shrews (*S. cinereus*; $n = 5$), deer and white-footed mice ($n = 14$), red-backed voles ($n = 8$), red squirrels ($n = 12$), ruffed grouse ($n = 10$), white-tailed deer ($n = 18$), and woodpeckers ($n = 4$). All protocols adhered to the guidelines for the use of mammals in research set forth by the American Society of Mammalogists (Sikes and Gannon 2011) and were approved by the Institutional Animal Care and Use Committee at the University of Wisconsin-Madison (A01486).

We rinsed hair and feather samples $3 \times$ with 2:1 chloroform methanol solution to remove surface oils, homogenized them with scissors, and dried samples for 72 hours at $50°C$ (Pauli et al. 2009). We then weighed samples in duplicate and placed them in tin capsules for $\delta^{13}C$ and $\delta^{15}N$ ratios using a Costech 4010 and Carlo Erba 1110 Elemental Analyzer (Costech, Valencia, CA) attached to a Thermo Finnigan Delta PLUS XP Continuous Flow Isotope Ratio Mass Spectrometer (Thermo Fisher Scientific Inc., Waltham, MA). We provide results as ratios relative to international standards, Vienna-Peedee Belemnite and atmospheric nitrogen, in parts per thousand. We corrected for trophic discrimination using values developed by Roth and Hobson (2000) for red foxes (*Vulpes vulpes*), which were 2.6% for ^{13}C and 3.4% for ^{15}N.

To reduce bias in our isotopic mixing models, we ignored dietary items that would be unavailable during hair growth in autumn (e.g., summer fruits) or those identified as unimportant from our analysis of marten scat (i.e., diet items with ≤ 1 occurrence) and aggregated isotopically indistinct prey items (Hopkins and Ferguson 2012). To determine aggregates, we used a K nearest-neighbor randomization test (Rosing et al. 1998) and identified 4 isotopically distinct (all pairwise $P < 0.05$) and biologically meaningful prey groups: 1) shrews, mice, and squirrels; 2) deer and grouse; 3) voles; and 4) other birds. To estimate the proportional importance of these prey groups to individual martens, we ran 2 sets of Bayesian-based mixing models in the package Stable Isotope Analysis in R V4 (SIAR; Parnell et al. 2010). The first used informative prior probabilities (shrews, mice, and squirrels $= 49\%$, deer and grouse $= 29\%$, voles $= 13\%$, and other birds $= 10\%$) developed from our scat analyses. The second mixing model used uninformative priors to explore the influence of our developed priors on dietary estimates. For both, data are expressed as means of the probability density functions, which correlate a prey group's most probable level of contribution to marten diet (Parnell et al. 2010).

RESULTS

We observed 11 different prey items in 70 marten scat samples (Table 1). Shrews and deer predominated winter diet items and were observed in 39% and 30% of scats, respectively. Other notable diet items included red-backed voles (16%), birds (14%), mice (10%), and red squirrels (10%). Both snowshoe hares and flying squirrels were uncommon prey items (1.4%) in our samples. Our identification of shrews and voles from the subset of identified guard hairs were confirmed isotopically because all fell within ± 1 standard deviation of the mean signature of their appointed species.

Table 1. Percent occurrence for prey items recovered from American marten (*Martes americana*) scat ($n = 70$) collected from the Chequamegon-Nicolet National Forest, Wisconsin, in winter, 2000–2011.

Diet item	Genus	Occurrence (%)
Shrew	*Sorex, Blarina*	38.6
White-tailed deer	*Odocoileus*	30.0
Red-backed vole	*Myodes*	15.7
Other birds	Unknown	11.4
Mouse	*Peromyscus*	10.0
Red squirrel	*Tamiasciurus*	10.0
Ruffed grouse	*Bonasa*	4.3
Weasel	*Mustela*	2.9
Flying squirrel	*Glaucomys*	1.4
Hare	*Lepus*	1.4
Marten	*Martes*	1.4
Insects	Unknown	1.4
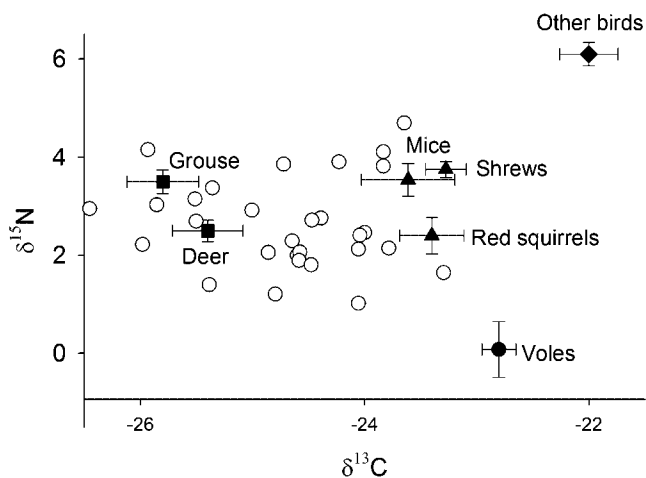
Figure 2. $\delta^{15}N$ or $\delta^{13}C$ signatures of individual American marten (*Martes americana*) hair collected during 1991–2013 (open circles), and prey collected during 2010–2013 (colored symbols; mean ± 1 SE) from Chequamegon-Nicolet National Forest, Wisconsin, USA. Species in the same stable isotope prey group are represented by symbols with the same shape. Marten samples were corrected with trophic discrimination factors of 2.5‰ and 3.5‰ for carbon and nitrogen, respectively.

Our isotopic analyses complemented those obtained from scat investigation (Fig. 2). For both isotopic mixing models, the shrews, mice, and squirrels grouped along with the deer and grouse, represented the highest mean proportion in marten diet and accounted for a combined 81% of assimilated diet (Table 2). The deer and grouse group was identified as the most consumed prey group in both the uninformed ($\bar{x} = 0.59$) and informed model ($\bar{x} = 0.42$). Voles were the third most important prey group in both mixing models ($\bar{x} = 0.11$ and 0.14), followed by other birds (Table 2).

DISCUSSION

Somewhat surprisingly, we found that martens in Wisconsin did not feed primarily on voles but instead consumed large quantities of deer and shrews. Our isotopic analyses revealed that shrews, mice, and squirrels, in combination with deer and grouse, were the most important diet items for martens in the autumn, constituting the majority of the assimilated diet, whereas voles were a relatively minor nutritional input.

Table 2. Mean proportion of prey groups (95% CI) in the American marten (*Martes americana*) fall diet in northern Wisconsin, 1991–2013, estimated via uninformed and informed isotopic mixing models. Two prey groups, 1) white-tailed deer (*Odocoileus virginianus*) and grouse (*Bonasa umbellus*) and 2) shrews (*Blarina brevicauda* and *Sorex* spp.), mice (*Peromyscus* spp.), and squirrels (*Tamiasciurus hudsonicus*), dominated marten diet. Red-backed voles (*Myodes gapperi*) were the third most important diet group.

	Mean proportion	
Diet groups	Uninformed (95% CI)	Informed (95% CI)
Deer, grouse	0.59 (0.46–0.72)	0.42 (0.32–0.51)
Shrews, mice, squirrels	0.22 (0.06–0.36)	0.39 (0.29–0.38)
Voles	0.11 (0.05–0.17)	0.14 (0.08–0.21)
Other birds	0.08 (0.0–0.20)	0.05 (0.01–0.08)

Our scat examination also demonstrated that shrews and deer were consumed in the greatest frequency, whereas voles remained relatively infrequent. Thus, these 2 methods provided results that were similar but in contrast with reported marten diets across North America, where voles were a central prey item regardless of sampling approach or season (Buskirk and Ruggiero 1994, Martin 1994).

The only other regional studies of marten diet, from Ontario (Thompson and Colgan 1987, 1990) and northern Michigan (Hales et al. 2008), differ from our findings in that voles and mice were overwhelmingly the most important prey items, even during years of vole population declines. It seems unlikely that our observed differences with those studies stemmed from methodological divergences because their estimates were obtained from winter scat (Thompson and Colgan 1987, 1990) and intestinal analyses (Hales et al. 2008). However, Hales et al. (2008) found that 47% of marten intestinal tracts contained deer, but because harvested individuals were baited with deer, these samples were censored from diet analysis because of the difficulty in separating scavenged remains from those consumed at the time of capture. Thus, martens in Wisconsin are likely consuming greater amounts of deer (Thompson and Colgan 1987, 1990) and shrews (Hales et al. 2008). Deer also appear sporadically in the diet of marten populations elsewhere and have been noted as an important supplement to marten populations in Alaska during years of abundant spring carcasses (Ben-David et al. 1997). Our study area possesses very high densities of deer (7–8 deer/km²; Wisconsin Department of Natural Resources 2013). Abundant deer in Wisconsin combined with carcass availability resulting from predation, vehicle collisions, unrecovered hunter-harvest, and winter mortality, likely make deer a readily available food resource for martens throughout the year, but especially in the winter. Conversely, the strong reliance of martens on shrews is unexpected because they are a less profitable diet item and consumed in greater numbers in populations experiencing a decline in primary prey abundance (Weckwerth and Hawley 1962; Thompson and Colgan 1987, 1990).

Because martens are unable to store large quantities of fat and possess high caloric demands, prey availability is an important driver of population dynamics (Zielinski 2000). Martens require 709 kJ/d in winter, which translates to 126 g of fresh matter daily (Gilbert et al. 2009), or 4–5 voles/day or 6–21 shrews/day depending the type of shrews (*Blarina brevicauda* vs. *Sorex* spp.) consumed. Although adult survivorship within this marten population should be sufficient to maintain a stable or growing population (McCann et al. 2010), reduced consumption of larger-bodied small mammals could decrease energy allocation to support pregnancy, lactation, or juvenile survivorship. Also, the majority of recorded mortalities of adult marten in Wisconsin occurred in the winter months, a time when small-mammal prey is especially scarce (McCann et al. 2010). Our data indicates that martens are also relying on a large portion of their diet with deer, a highly profitable item, though this may come at an increased predation risk.

Deer carcasses in Wisconsin attract multiple larger-bodied competitors, like coyotes, fisher, and raptors, which also heavily rely on this resource (Jennelle et al. 2008), and some of which are species responsible for marten mortality in the state (McCann et al. 2010). In Europe, martens (*M. martes*) perceive enhanced risk at ungulate carcasses (Selva et al. 2005); nutritional demands in winter, coupled with a lack of more profitable prey, have possibly increased martens' tolerance of risk in Wisconsin.

Martens in Wisconsin appear not to be consuming voles, their preferred prey, in high numbers. This could be because voles are simply not abundant in the recovery areas. Recently, Stephens (2012) documented that shrew and mouse captures out-numbered vole captures in every cover type in Wisconsin, except for within conifer swamps. Short-tailed shrews had the highest capture rates of any species in the northern forest sites with notably high numbers near the CNNF reintroduction sites (Stephens 2012). In contrast, red-backed voles were not particularly abundant at any site (Stephens 2012). Previous work has demonstrated the importance of coarse woody debris (CWD) as a determinant of vole abundance (Bowman et al. 2000, Pauli et al. 2006) and marten foraging efficiency (Andruskiw et al. 2007), yet whether CWD could be a limiting feature at and around marten recovery sites is unknown. Further, a regional northward range shift in northern small mammals, including red-backed voles, has recently been observed and attributed to ameliorating winter conditions from climate change (Myers et al. 2009). Thus, the relatively large consumption of alternative prey by recovering marten in Wisconsin could be caused by a declining preferred prey base. Although McCann et al. (2014) found that martens in Wisconsin select for hemlock-cedar stands that border conifer swamps, the habitat with the greatest vole densities, we did not detect a strong signal of vole consumption. Future research should document the abundance and distribution of preferred habitat types in Wisconsin, and explore whether habitat elements, especially sufficient CWD, are present within these sites to support a large prey base of red-backed voles.

MANAGEMENT IMPLICATIONS

The recovery of martens is an important management objective for Wisconsin. Our findings suggest that a novel prey base could be influencing marten foraging ecology, forcing them to consume less profitable (shrews) or higher risk (deer carcasses) diet items. Further research should investigate the availability of important food items to martens in Wisconsin as well as the amount of CWD and how it relates to vole abundance and marten population dynamics in Wisconsin. Management aimed at promoting structural complexity within northern Wisconsin forests, especially related to CWD, should be considered to improve habitat for American martens.

ACKNOWLEDGMENTS

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