Pygmy Shrew (*Sorex hoyi*): A Technical Conservation Assessment

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COVER ILLUSTRATION CREDIT

Cover drawing of the pygmy shrew (*Sorex hoyi*) by S. Scholl (Wyoming Natural Diversity Database - University of Wyoming).

Summary of Key Components for Conservation of Pygmy Shrew

The pygmy shrew (*Sorex hoyi*) occurs as two distinct subspecies in two separate subregions of the USDA Forest Service's Rocky Mountain Region (Region 2): *S. h. montanus* in the mountain forests of northern Colorado and south-central Wyoming, and *S. h. hoyi* in the prairies of eastern South Dakota. This duality was achieved over several millennia. During the Pleistocene/ Holocene transition, pygmy shrews tracked cool and wet conditions northward and upward, eventually positioning the main southern range margin in present day South Dakota and a small relictual population in the Southern Rocky Mountains.

Very few field studies have focused on pygmy shrews, especially in Region 2. Consequently, a lack of reliable information impedes management and conservation of the species. Subspecies *montanus* has been documented at only 17 localities across all Region 2 national forest management units. However, cursory surveys conducted in 2005 failed to document the subspecies at a subset of historically occupied sites. Presence of subspecies *hoyi* has been confirmed at only 12 locations in South Dakota; however, populations of pygmy shrews at these sites are considered contiguous with populations of pygmy shrews in several adjacent states.

Pygmy shrews appear to be habitat and prey specialists, which elevates the degree of conservation concern for the species. Subspecies *montanus* occurs in moist coniferous forest, possibly preferring late-seral stands and the edges between wet and dry forest types. In South Dakota, subspecies *hoyi* has a somewhat wider habitat tolerance, but it still most frequently occurs in wet prairies and wetland margins. The species is completely insectivorous and most commonly eats small arthropods. Like all shrews, pygmy shrews have high-energy requirements and spend most of their extremely short lives (ca. 12 months) searching for food. Co-occurring species of larger shrews can take prey of more variable sizes and thus probably outcompete pygmy shrews in most situations. Pygmy shrews typically are the rarest shrew at any given site, and are restricted to uncommon microhabitats.

Pygmy shrews reproduce only once, at about 10 months of age, which means that populations turn over almost completely within one year and are rather vulnerable to disturbance. In the Rocky Mountains, the most pertinent disturbances are those that convert moist forest to drier and more open types. Such disturbances include timber harvesting, livestock grazing, wildfire, and stand changes wrought by drought and insect outbreaks. In the Great Plains, cultivation agriculture and livestock grazing are likely the most important disturbances. In both regions, it is assumed that roads also degrade pygmy shrew habitat by replacing native vegetation and soils with packed road beds, which may serve as movement barriers. Because of the species' habitat specialization and limited travel capacity, pygmy shrew populations probably are fragmented rather easily.

Existing information can be used to tentatively integrate pygmy shrew conservation with other land uses. However, the highest priority for conservation and management of pygmy shrews should be collecting more data on distribution, abundance, and habitat use. Well-planned and coordinated field inventories, especially for subspecies *montanus*, are strongly recommended.

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INTRODUCTION

Goal

This conservation assessment of the pygmy shrew (*Sorex hoyi*; formerly *Microsorex hoyi*) was produced for the Species Conservation Project being undertaken by the Rocky Mountain Region (Region 2) of the USDA Forest Service (USFS). It addresses the biology, ecology, conservation status, and management of the pygmy shrew throughout its current range, with particular attention given to subtaxa and populations occurring in Region 2. Our goal is to summarize published information, and to provide expert interpretation of that information, for use by USFS personnel in developing conservation strategies and management plans.

Within the five states of Region 2 (i.e., South Dakota, Wyoming, Nebraska, Colorado, Kansas), the pygmy shrew occurs as two distinct subspecies, in two distinct regions: the prairie pygmy shrew (*Sorex hoyi hoyi*) in the prairies and woodlands of eastern South Dakota, and the montane pygmy shrew (*S. h. montanus*) in the mountain forests of south-central Wyoming and northern Colorado (**Figure 1**, **Figure 2**, **Figure 3**). This duality in taxonomy, habitat, and distribution adds complexity to this assessment, and it will be repeatedly addressed to keep readers aware of the two distinct conservation and management contexts.

The species was selected for assessment because of its status as Sensitive in Region 2 (USDA Forest Service 2005a), which is a function of the species' overall rarity and potential sensitivity to disturbances. However, it is *Sorex hoyi montanus* that most clearly occupies USFS units, and the especially small and isolated range of the subspecies likely has produced a unique evolutionary trajectory and elevated the contribution of the subspecies to regional biological diversity. Subspecies *montanus* is the primary reason for the species as a whole receiving Sensitive status and special management attention in Region 2. However, in the interest of completeness, this assessment focuses on both subspecies.

Scope, Uncertainty, and Limitations

As with most shrews, relatively little research has been conducted on the pygmy shrew, particularly regarding populations in Region 2. Therefore, this assessment relies relatively heavily on information collected elsewhere in the species' North American range and, where possible, it attempts to relate this information specifically to aspects of Region 2. Similarly, this assessment draws on information for similar species where deemed appropriate. Information was obtained primarily from peer-reviewed literature, agency reports, and acknowledged shrew experts.

There is uncertainty in all scientific inquiries, and the data described in this assessment are no exception. Thus, where appropriate, this assessment notes the strength of evidence from cited research and provides alternative explanations of observational data and expert inference. Peer-reviewed literature represents the strongest and most rigorous information, and therefore it is used preferentially to draw conclusions regarding the pygmy shrew. Hypotheses and inferences are noted with appropriate qualifications. In some instances, where little or no quantitative research was available to back up specific ideas, expert opinion was obtained independently.

As with all pieces of literature synthesized from disparate data, this assessment has limitations. Because most data presented herein come from specific studies conducted in restricted areas, interpolation and extrapolation of these data must be done with caution. Certain aspects of pygmy shrew biology, ecology, and conservation vary over the geographic extent of the species' range; therefore, the information in this assessment should not be taken as definitive of pygmy shrews in any particular area. Rather, it should be used as a guide to the range of biological parameters and behaviors possible for pygmy shrews, which can then help to direct specific investigations into the status of local populations that, in turn, will inform resource managers in making appropriate decisions.

Web Publication and Peer Review

To make the information in this assessment accessible more rapidly than publication as a book or report, to facilitate its use by USFS personnel, other agencies, and the public, and to make updates and revisions more efficient, this document will be published on the World Wide Web site (http://www.fs.fed.us/r2/projects/scp/assessments/index.shtml) of USFS Region 2. A link to this publication also will be available on the web site of the Wyoming Natural Diversity Database (WYNDD, University of Wyoming; http://uwadmnweb.uwyo.edu/WYNDD).

In keeping with the standards of scientific publication, assessments developed for the Species Conservation Project have been externally peer reviewed prior to their release on the Web. This assessment was reviewed through a process administered by the Society

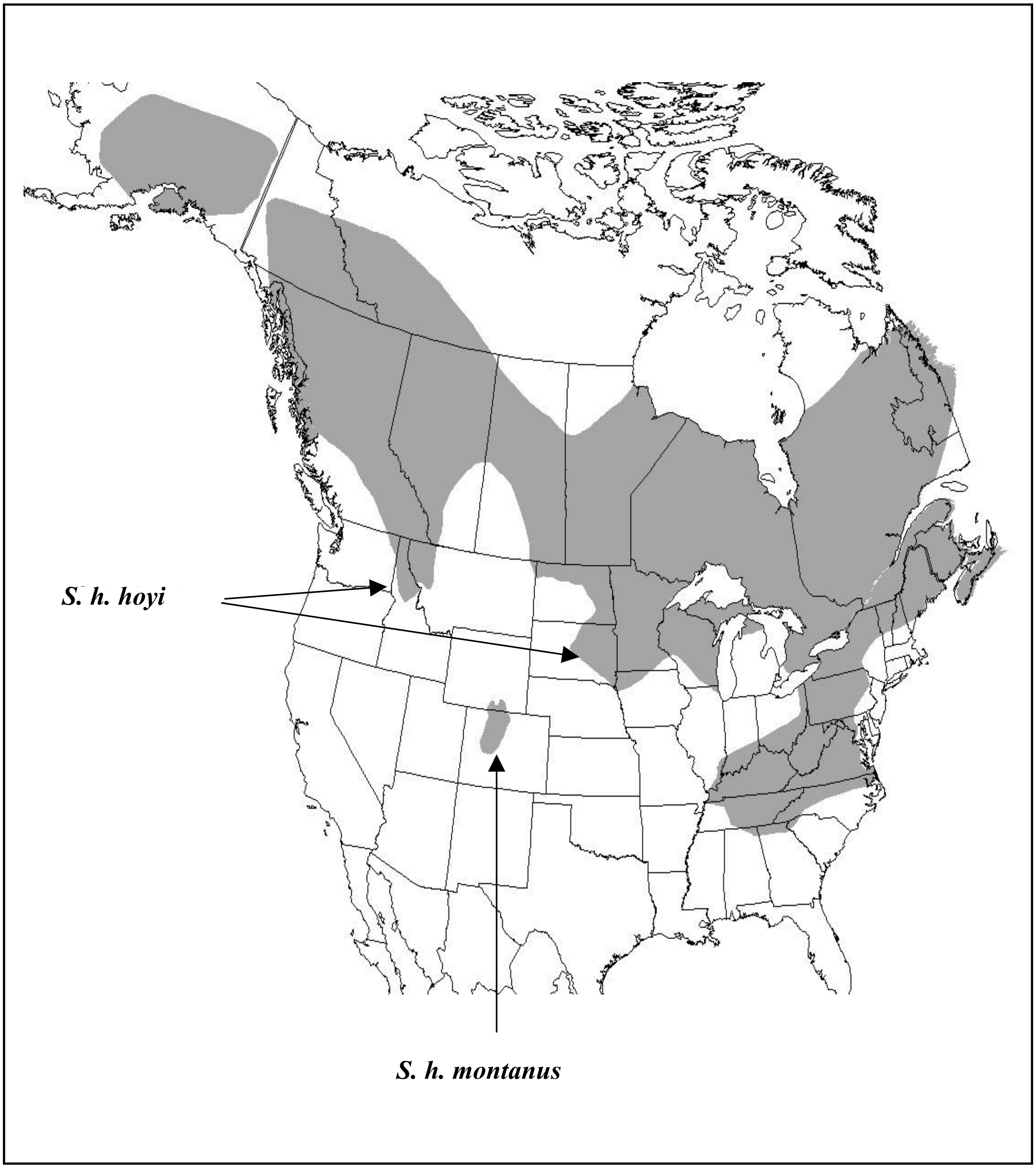

Figure 1. Range of the pygmy shrew (*Sorex hoyi*). Map modified from Patterson et al. (2005) using information from Tims et al. (1989), Laerm et al. (1994), Laerm et al. (1996), Ford et al. (1997), Kirkland and Hart (1999), Cassidy et al. (1997), Bellows et al. (2001), Smith et al. (2002), Idaho Department of Fish and Game (2005), North Dakota Game and Fish Department (2005), USDI Geological Survey National Gap Analysis Program (2005), Wyoming Game and Fish Department (2005b), and Montana Natural Heritage Program (2006).

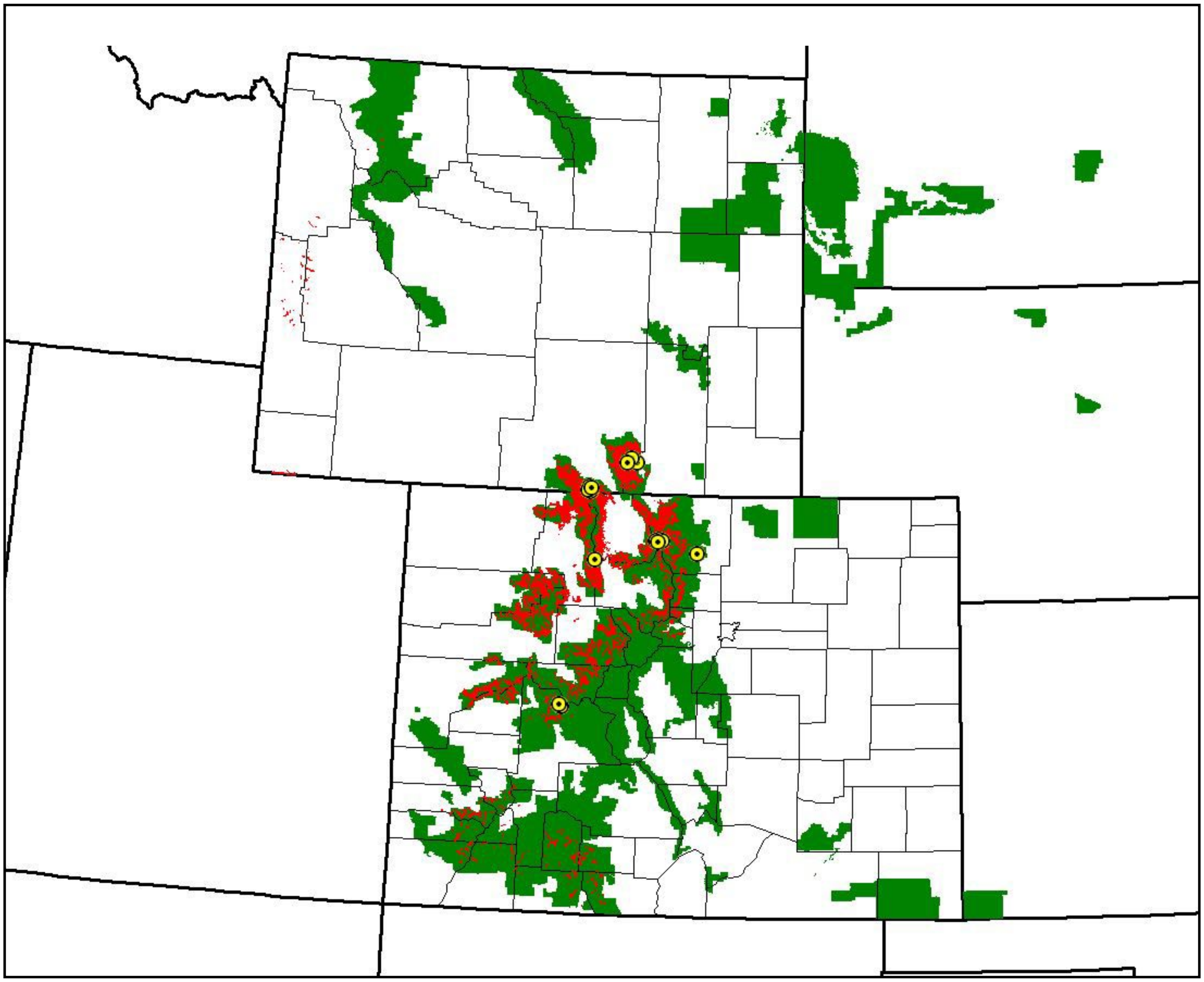

Figure 2. Known and potential distribution of the montane pygmy shrew (*Sorex hoyi montanus*) in USDA Forest Service Region 2. Yellow-and-black dots show points of known occurrence of the subspecies (data on file at the Wyoming Natural Diversity Database – University of Wyoming). Red stippling shows environments statistically most similar to the environments at the points of known occurrence, as modeled by Beauvais and Smith (2005). Green indicates land units managed by USDA Forest Service Region 2.

for Conservation Biology, which chose two recognized experts (on this or related taxa) to provide critical input on the manuscript.

MANAGEMENT STATUS AND NATURAL HISTORY

Management Status

Federal Endangered Species Act

The pygmy shrew currently receives no special status under the U.S. Endangered Species Act, nor has the USDI Fish and Wildlife Service considered it for such status in the past. The isolated, relictual, and potentially unique nature of the montane pygmy shrew may predispose this taxon for future consideration under the Act, possibly as a distinct population segment.

USDA Forest Service

Pygmy shrews occur on National Forest System lands in Regions 1, 6, 7, and 9. To date, however, USFS Region 2 is the only region to designate the full species *Sorex hoyi* as a sensitive species (USDA Forest Service 2005a). Related agency documents (e.g., USDA Forest Service 2005b) refer only to the subspecies *S. h. montanus*, rather than the full species, as sensitive, suggesting that the species' status in Region 2 is due to the *montanus* subspecies.

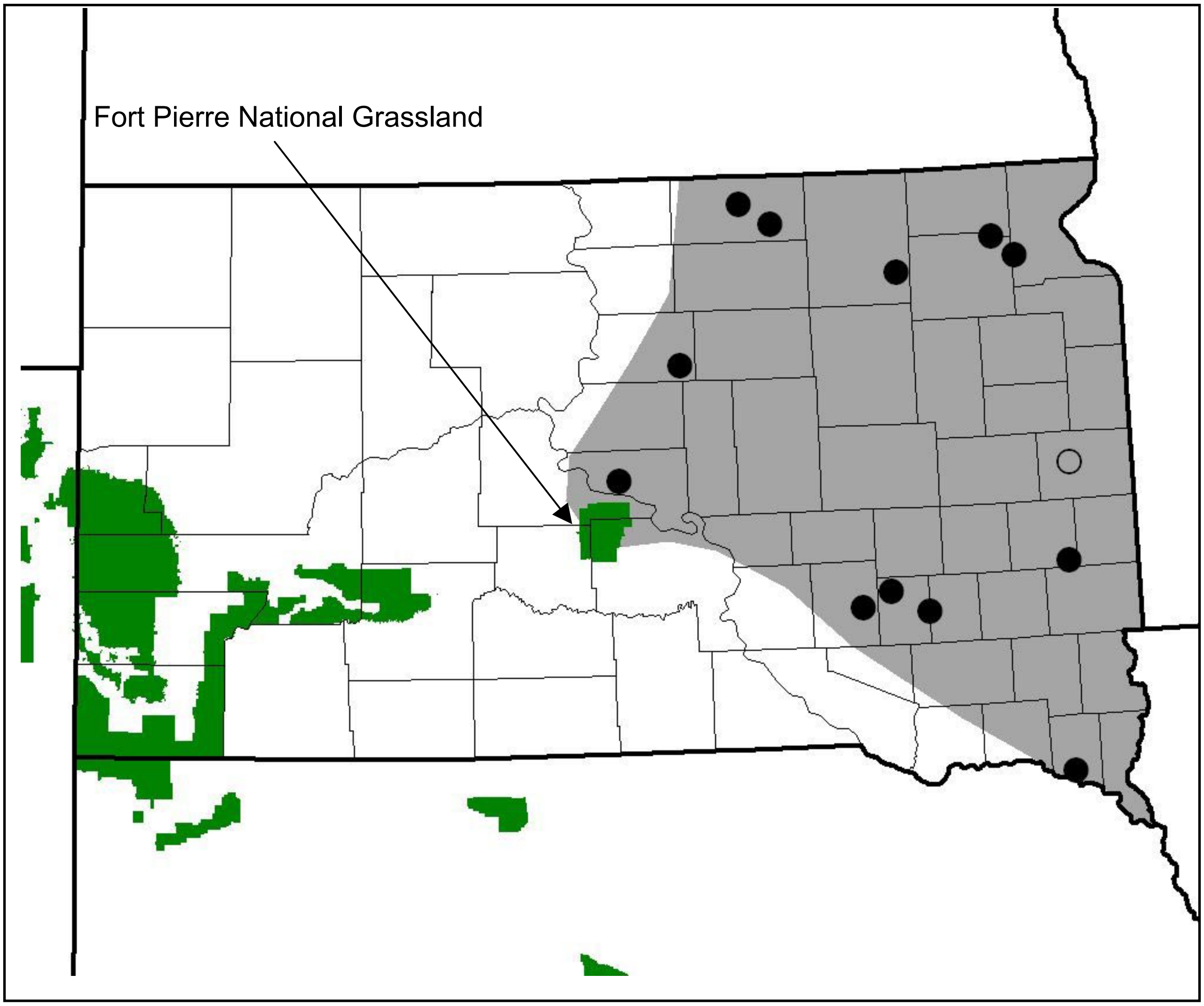

Figure 3. Known and potential range of the prairie pygmy shrew (*Sorex hoyi hoyi*) in USDA Forest Service Region 2. Black dots show points of known occurrence of the subspecies; open dot is a point of suspected occurrence; gray shows the projected range of the subspecies. Green indicates land units managed by USDA Forest Service Region 2. All information adapted from Smith et al. (2002).

Mountain units of the USFS in northern Colorado and south-central Wyoming clearly bear the responsibility for management and conservation of the montane pygmy shrew, as those units comprise essentially all of the known range of this taxon (**Figure 2**). Given that the ranges presented in **Figure 1** and **Figure 2** are based on limited data, the occurrence of the montane pygmy shrew in northern units of Region 2 (e.g., Shoshone National Forest) is possible. Hall (1981) included northwestern Wyoming within the range of this species, but apparently, there was no documentation of the species actually occurring there. Similarly, Brown (1966) predicted potential occurrence of the species all along the main chain of the Rocky Mountains. Although the Fort Pierre National Grassland in central South Dakota is within the presumed range of the prairie pygmy shrew, the presence of this species has not been confirmed on this unit (**Figure 3**).

USDI Bureau of Land Management

No office of the USDI Bureau of Land Management (BLM) has designated the pygmy shrew as "sensitive," "of concern," or any other status conveying special management or conservation attention. Presumably, this is because the montane subspecies primarily occupies boreal forests at higher elevations than most land managed by the BLM in Colorado and Wyoming. Furthermore, the prairie subspecies occupies very little BLM-managed land in Montana, Idaho, or Washington, and essentially no BLM-managed land exists in South Dakota or points east.

State wildlife agencies

The Wyoming Game and Fish Department ranks the pygmy shrew at "2" on their 1 (most imperiled) - 7 (most secure) Native Species Status (NSS) scale, generally indicating that populations are greatly restricted, extirpation is possible, and habitat appears to be restricted but is not undergoing significant loss (Oakleaf et al. 2002, Wyoming Game and Fish Department 2005a). The same agency placed the pygmy shrew on the list of the state's "Species of Greatest Conservation Need" when producing the Wyoming Comprehensive Wildlife Conservation Strategy (Wyoming Game and Fish Department 2005b).

In contrast, neither the Colorado Division of Wildlife nor the South Dakota Game, Fish, and Parks Department confers any special status to the pygmy shrew.

State Natural Heritage Programs

NatureServe (Arlington, Virginia) and the network of state Natural Heritage Programs currently rank the pygmy shrew as G5, indicating that the full species is demonstrably secure from global extinction. The subspecies *montanus* is given the additional rank of T2T3, indicating that the taxon is imperiled or vulnerable, and at moderate risk of global extinction.

To complement these global measures, state Natural Heritage Programs provide subnational (S) ranks that which indicate the probability of extirpation from each state, using the same 1 (highest probability) - 5 (lowest probability) scale. WYNDD ranks pygmy shrews at S1, or critically imperiled, and the South Dakota and Colorado Natural Heritage Programs each rank the species at S2, imperiled. WYNDD additionally applies a "Wyoming Contribution Rank" of "Very High" to pygmy shrews, indicating that Wyoming populations of *Sorex hoyi montanus* contribute greatly to the range-wide persistence of the subspecies (Keinath and Beauvais 2003).

Existing Regulatory Mechanisms, Management Plans, and Conservation Strategies

No state or federal regulations specifically pertain to the pygmy shrew. However, because this species is officially recognized as part of the native fauna of each of the three states (South Dakota, Wyoming, and Colorado) in which it occurs in Region 2, it receives legal protection from intentional take under the nongame statutes of each state. For South Dakota, this includes state statute chapters under Title 41 and 34A; for Wyoming, chapters 33 and 52 of the Wyoming Game and Fish Commission Regulations; for Colorado, chapters 10 and 13 of the regulations of the Wildlife Commission of Colorado. Certain federal laws (e.g., Lacey Act), which generally apply to many forms of wildlife, also cover pygmy shrews. However, since pygmy shrews are not subjected to widespread or frequent intentional killing, transport, or trade, such general laws provide essentially no conservation guidance or effect, nor do they inform management to any meaningful degree.

As discussed, the State of Wyoming considers the pygmy shrew as a conservation target within the state's recently completed Comprehensive Wildlife Conservation Strategy (Wyoming Game and Fish Department 2005b). This strategy states explicitly that the species was designated as such largely because of poor documentation of its distribution, abundance, trends, and conservation status. By including pygmy shrews in this strategy, the Wyoming Game and Fish Department now can acquire federal funds to study and assist in the management of the species or its habitats. No action yet has been taken to this end, and it is assumed that pygmy shrews will be considered a medium priority, at best, among all taxa identified in this plan. Neither Colorado nor South Dakota identified this species as a target within their respective Comprehensive Wildlife Conservation Strategies.

It is reasonable to assume that pygmy shrews have not been, are not now, and probably will not be impacted by management actions applied directly to the species (e.g., intentional killing, captive propagation and reintroduction, population monitoring). Instead, they are most affected by management actions that affect their habitat. Furthermore, given the distribution of the montane subspecies in Region 2 (**Figure 2**), it is reasonable to assume that the most relevant management actions will be under the direction of USFS units in northern Colorado and south-central Wyoming. Thus, USFS standards and guidelines, such as those pertaining to late-seral forest, wildlife, biological diversity, and riparian environments, are the primary instruments by which this species is managed. Pygmy shrews have the added advantage of USFS Sensitive Species status in Region 2, which brings their habitat needs more to the forefront in analysis and planning of ground-disturbing projects.

Given the distribution of the prairie pygmy shrew in South Dakota (**Figure 3**), management actions affecting habitat are mostly under the direction of private landowners and their associated agencies and organizations (e.g., South Dakota Department of Agriculture, Watershed Advisory Groups, Conservation Districts, Weed and Pest Districts).

Biology and Ecology

Taxonomy and description

Taxonomy

Pygmy shrews long have been distinguished from other shrews by their extremely small third and fifth upper unicuspids (**Figure 4**; Diersing 1980). This character was once thought unique enough to define a separate genus, *Microsorex*, and for much of the 20th century the species was referred to as *M. hoyi* (e.g., Long 1972, Hall 1981). However, there is a rather long history of debate over the validity of *Microsorex* as a full genus. Diersing (1980) established it as a subgenus only, and identified all North American pygmy shrews as *Sorex hoyi*. Electrophoretic analyses by George (1988; and also later by Driskell and Feldhammer 2003) further downgraded the uniqueness of *Microsorex*, retained the basic species-level arrangement of *Sorex* including *S. hoyi*, and estimated that *S. hoyi* first appeared during the early Pleistocene. Later genetic analyses by Demboski and Cook (2003) indicated no major changes to the species-level arrangement of *Sorex*, but their work did not explicitly include *S. hoyi*.

A recent re-assessment of dental characters revealed that in *Sorex hoyi*, the posterior end of the first lower incisor reliably extends to beneath the first lower molar (**Figure 5**), whereas it never does in similar and co-occurring shrews (Carraway 1995). This character is a valuable species identification tool since it can be applied to specimens with worn teeth.

Most researchers now recognize five or six subspecies of *Sorex hoyi*, with the only significant controversy regarding the status of some far northern populations that have no bearing on Region 2. The subspecies *S. h. montanus* (first described as *Microsorex hoyi montanus* by Brown [1966]) is recognized and well-defined by both its small size and extreme geographic isolation in northern Colorado and south-central Wyoming (e.g., Long 1972, 1974, 1999, Diersing 1980; **Figure 2**). It is most similar in size to *S. h. winnemana* in the southern Appalachian Mountains. It is widely accepted that *S. h. montanus* represents a Pleistocene relict (see Beauvais 2000 and Range section below).

The subspecies *Sorex hoyi hoyi* is regarded as the most widespread subspecies, encompassing populations in eastern South Dakota, northern Idaho, and northwestern Montana (**Figure 1**, **Figure 2**, **Figure 3**). Long (1974) may have been the latest to recognize *S. hoyi* in Idaho and Montana as *S. h. washingtoni*. These populations were subsumed into *S. h. hoyi* by Diersing (1980), and *washingtoni* is not recognized as a unique form today.

Description

The pygmy shrew is clearly at the extreme small end of mammalian body size; adults generally weigh only 3 to 8 g, and are only 60 to 110 mm in total length. These dimensions are comparable to those of the dwarf shrew (*Sorex nanus*). Only one North American mammalian species is smaller, the recently discovered Alaskan tiny shrew (*S. yukonicus*; Dokuchaev 1997). The Etruscan, or white-toothed, pygmy shrew (*Suncus etruscus*) from the Mediterranean region also is smaller. Like all *Sorex*, *S. hoyi* has reduced eyes and ears, and a notably long and flexible snout. Because *Sorex* is the only genus of shrew in the montane, boreal, and alpine zones of the Rocky Mountains, these characters are adequate to identify specimens to genus there. In South Dakota, however, specimens of *Sorex* may be confused at the genus level with *Blarina* (short-tailed shrews) and *Cryptotis* (least shrews), but most members of the latter two genera are noticeably larger.

Sorex in Region 2 are uniformly brownish or grayish above and whitish below, with the relatively blackish (and large) water shrew (*S. palustris*) a notable exception. Identifying specimens to species requires close examination of the teeth. All *Sorex* in the region have five upper unicuspids, but in the pygmy shrew, the third and fifth upper unicuspids are so small they are almost invisible in lateral view, even under a dissecting scope (**Figure 4**). This configuration is typically enough to identify a specimen to *S. hoyi*; secondary characters include adult total length 62 to 106 mm, tail 21 to 39 mm, and hind foot 8 to 12 mm (Clark and Stromberg 1987). The teeth of field-caught shrews, especially older individuals, are often extremely worn, making it difficult to assess relative tooth size and visibility. In such instances, the secondary characters play a more prominent, but less definitive, role in identification. More importantly, the character identified by Carraway

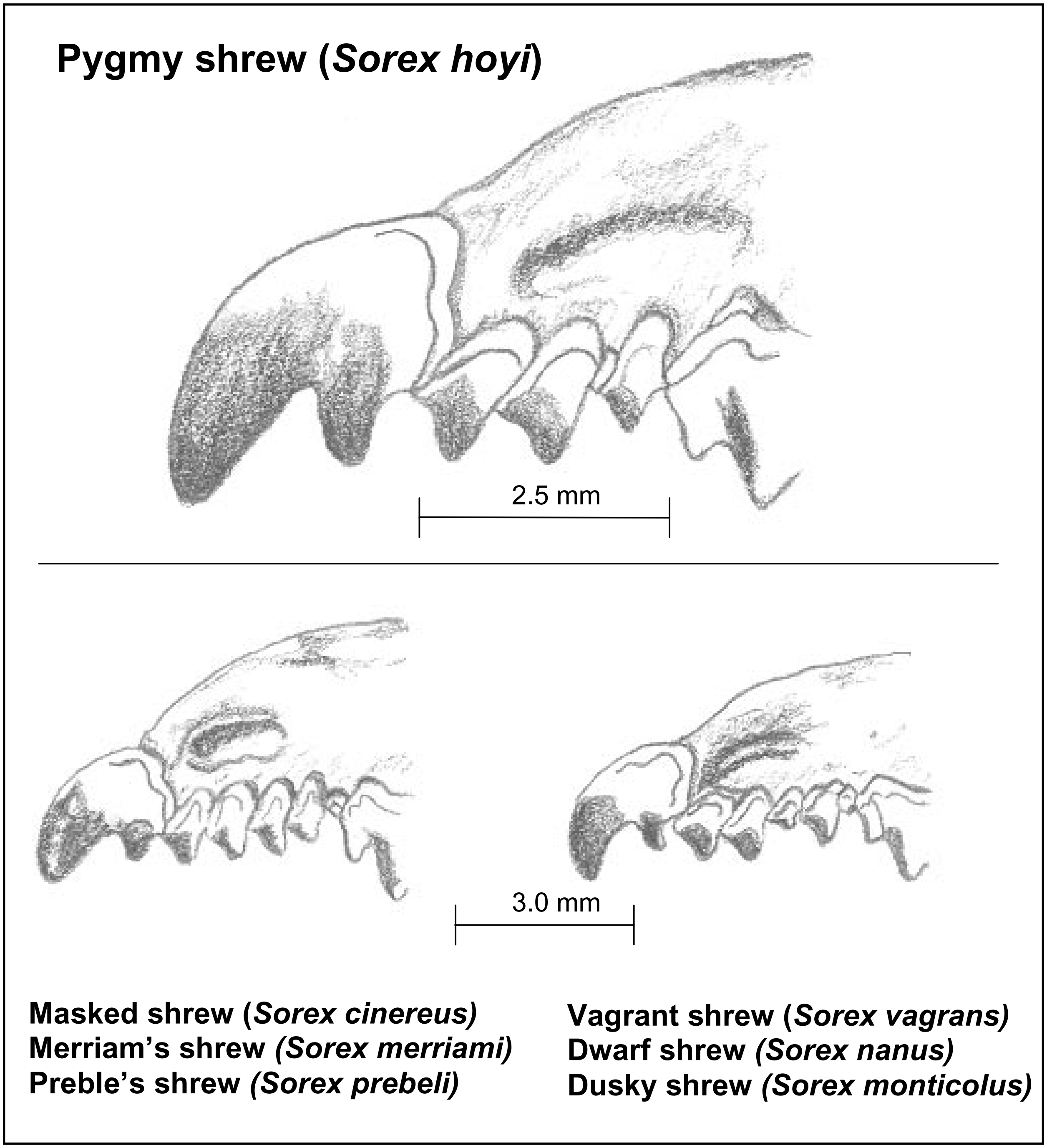

Figure 4. Lateral views of the upper tooth rows of some shrews occurring in USDA Forest Service Region 2. Note that all have five unicuspids, but unicuspid 3 and 5 are almost invisible, in lateral view, in the pygmy shrew. Pygmy shrew enlarged for emphasis; refer to scale bars. Redrawn by R. Smith (Wyoming Natural Diversity Database – University of Wyoming) from Clark and Stromberg (1987).

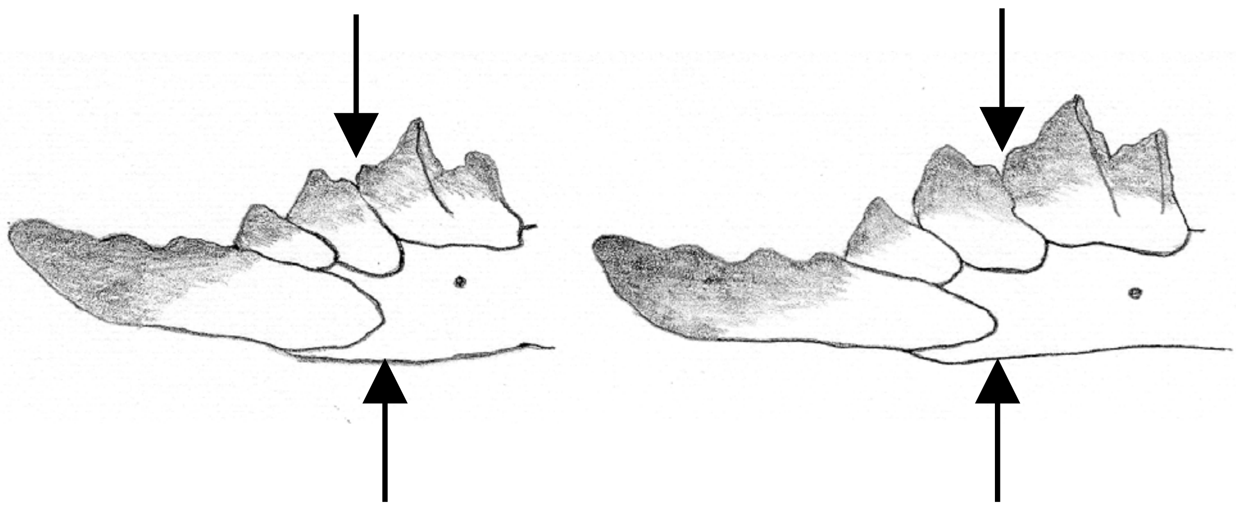

Figure 5. Labial view of the lower tooth row of two shrews occurring in USDA Forest Service Region 2. Arrows indicate the posterior extension of the first lower incisor under the first lower molar in the pygmy shrew, but not in the dusky shrew. Redrawn by R. Smith (Wyoming Natural Diversity Database – University of Wyoming) from Carraway (1995).

(1995) can be applied to all *Sorex* specimens, including those with worn teeth, to distinguish *S. hoyi*; in the pygmy shrew, the posterior end of the first lower incisor reliably extends to beneath the first lower molar (**Figure 5**), whereas it does not in similar and co-occurring species.

Currently within Region 2, pygmy shrew specimens can be reliably assigned to subspecies based solely on location of capture (**Figure 2**, **Figure 3**). If specimens are ever captured from the Central Rocky Mountains in northern Wyoming (as predicted by Brown [1966] and Hall [1981]), their subspecific affiliation would not be immediately apparent since this area is between the known distribution of the montane subspecies to the south and the prairie subspecies to the north.

Male and female pygmy shrews apparently do not differ substantially in outward appearance (Long 1972, Diersing 1980). Diersing (1980) described noticeable changes in the position of the first upper incisor with age (probably from the combined effects of growth and wear), which may be useful in aging field caught specimens. Long (1972) noted that summer-caught pygmy shrews appear more reddish brown above and grayish below, whereas winter-caught animals are more grayish above and white below.

Distribution

The main body of the distribution of pygmy shrews extends from Alaska and western British Columbia through central and southern Canada, the Great Lakes region, and New England to Nova Scotia and coastal Maine (**Figure 1**). The range of the species dips south generally along the Appalachian Mountains, Eastern Coastal Plain, and Cumberland Plateau to northern Georgia and Alabama. Another southern extension follows the Rocky Mountains southward into northern Idaho and northwestern Montana, with an isolated center of occurrence in the Southern Rocky Mountains of northern Colorado and south-central Wyoming (*Sorex hoyi montanus*; **Figure 2**). This mountain isolate is thought to be a remnant of a once larger distribution in the region; during the late Pleistocene, populations of pygmy shrews were widespread through the central and southern United States, but during Holocene warming, they were forced to track cool and wet conditions northward in latitude, and upward in elevation. Eventually, the southern isolate became separated by relatively dry and warm lowlands from the northern populations (see Beauvais 2000).

The range of the pygmy shrew is matched quite well by that of the wood frog (*Rana sylvatica*), another vertebrate with a main distribution located north of isolated mountain populations in the northern Southern Rocky Mountains and southern Appalachian region. The coincidence between the two species commonly is remarked upon in the literature (e.g., Pettus and Leichleitner 1963, Armstrong 1972).

Hall (1981) mapped pygmy shrews extending into the Central Rocky Mountains of northwestern Wyoming, and into the Southern Rocky Mountains in northern New Mexico, but he did not document the species as actually occurring in either place. Similarly, Brown (1966) suggested the possible occurrence of the species throughout most of the Rocky Mountains. Environments in northwestern Wyoming are generally similar to areas occupied by pygmy shrews in northern Montana and southern Wyoming. Distribution modeling of montane pygmy shrews by Beauvais and Smith (2005) indicated only a small amount of suitable environment for the subspecies in northern Wyoming (**Figure 2**). However, their work was an extrapolation of the environments at points of known occurrence within the known range of the subspecies and thus was deliberately biased towards the Southern Rocky Mountains. It is reasonable to assume that like most shrews, the pygmy shrew has not been adequately surveyed in the Central Rocky Mountains, thus its occurrence there remains a possibility. In this context, it should be noted that DeMott and Lindzey (1975) extended the range of the montane subspecies 100 miles to the south, to Gothic, Colorado, with a single, small-scale, mammal survey. Also, one 10-year study of small mammals in a single drainage added an entirely new mountain range, the Sierra Madre Mountains in Wyoming, to the known range of the subspecies (Pearson and Ruggiero 2001). Targeted surveys conducted over about 12 years in the eastern United States greatly expanded the known range of *Sorex hoyi winnemana*, eventually revealing that populations of this subspecies, once regarded as isolated in the southern Appalachians, actually were probably contiguous with populations in New England (Tims et al. 1989, Laerm et al. 1994, Laerm et al. 1996, Ford et al. 1997, Kirkland and Hart 1999, Bellows et al. 2001).

The distribution of the prairie pygmy shrew in South Dakota is known only coarsely. **Figure 3** suggests that the species may be restricted to the eastern half of the state (generally east of the Missouri River). Inspection of interpolated climate data (DAYMET U.S. Data center; www.daymet.org) indicates that eastern South Dakota is noticeably wetter and cooler than the rest of the state (excluding the Black Hills). Mullican (1992) speculated that such differences might confine this subspecies to the eastern portion of the state. Environmental maps produced by Smith et al. (2002) supported this idea, as they suggested qualitative differences between the natural landscapes of eastern and western South Dakota. Although the range boundary as currently mapped may approximate the true distributional limit of the subspecies, more field inventories are needed here as well. A 1956 capture of the prairie pygmy shrew in extreme southeastern South Dakota (Mullican 1992) raised the potential for occurrence in extreme northeastern Nebraska (**Figure 3**).

Abundance and population trend

Very little is known about pygmy shrew abundance or trends, especially in Region 2 where field studies of the species have been rare. It is generally accepted that pygmy shrews are most abundant in boreal latitudes, and less abundant in southern portions of their range (Long 1999). When several species of *Sorex* occur sympatrically, it is typical for the pygmy shrew to be the most narrowly distributed and least abundant species (Spencer and Pettus 1966, Brown 1967, Wrigley et al. 1979). As discussed in more detail later, it is thought that this results from their extremely small body size, which places them at a general competitive disadvantage. Larger shrews can exploit a wider range of prey, and they are presumably more dominant in aggressive interactions, allowing them to occupy many microhabitats. In contrast, pygmy shrews are relegated to a smaller set of microhabitats unusually rich in smaller invertebrates, where small shrews have a feeding advantage.

The montane pygmy shrew was documented only recently. The first pygmy shrew captured in the Rocky Mountains south of Montana was captured in 1961 in northern Colorado (Pettus and Leichleitner 1963), followed by others from the same location from 1961 to 1964 (Spencer and Pettus 1966) and south-central Wyoming in 1963 and 1964 (Brown 1966). Brown (1966) was the first to describe these specimens as a unique subspecies. Since then there have been few studies of the subspecies, some of which merely document opportunistic captures due to trapping for other small mammals (e.g., Vaughan 1969, Armstrong 1972, DeMott and Lindzey 1975).

Beauvais and Smith (2005) compiled as many documented capture locations for montane pygmy shrews as possible to use as input to their distribution modeling efforts. This resulted in a list of fewer than 100 specimens captured at 71 point locations. However, many of these point locations are tightly clustered because trapping surveys were conducted over small areas. Collapsing capture sites within 1600m of each other into one effective location resulted in only 17 unique sites known to have been occupied by montane pygmy shrews. Furthermore, the subspecies has been documented at only seven of these sites in the past 20 years, with six of those falling in a single drainage on the Sierra Madre Mountains of Wyoming (Beauvais and Smith 2005).

WYNDD conducted cursory surveys for montane pygmy shrews in Wyoming, including some sites of historic occupation, in summer 2005, but failed to capture the subspecies (G. Beauvais, unpublished data). Given all information summarized in this section, there is clearly not enough data with which to estimate reliable trends.

A similar situation exists for prairie pygmy shrews in South Dakota. Although known to occupy the state for a comparatively long time (first capture in 1928; Jackson 1928), the subspecies is not well studied there. Mullican (1992) compiled four confirmed and one questionable capture locations in South Dakota in 1992. The South Dakota Gap Analysis Project, completed ten years later, compiled only eight additional confirmed locations (**Figure 3**; Smith et al. 2002). Again, this is not an adequate dataset with which to estimate trends in this area reliably.

Spencer and Pettus (1966) noted that abundances of montane pygmy shrews peaked in August on their Colorado study site, primarily due to a pulse of summer reproduction (see also Huggard and Klenner 1997). This also may lead to broader local distributions in late summer, as surplus individuals disperse from "full" optimal sites into adjacent, suboptimal environments (Long 1972). Given the results of Hawes (1977) for vagrant shrews (*Sorex vagrans*) and dusky shrews (*S. monticolus*), it may be adult (ca. 1-year old) animals that are relegated to suboptimal environments, while young-of-the-year occupy and defend higher quality sites. It is assumed that late-summer populations begin to decrease by late September (as observed by Spencer and Pettus 1966) as weather worsens, prey availability drops, and 1-year old individuals begin to succumb to the many mortality vectors that beset shrews at the natural limit of their life span. Because of heavy overwinter mortality, populations likely are at their low-points in late spring-early summer (ca. April - June), before reproduction.

Activity

Like all shrews, pygmy shrews are active all day long and year-round, leading rather frenetic lives of near-constant searching, foraging, and movement. Prince (1940) remarked that a captive pygmy shrew was "continually active, its movements rapid, with many sudden stops and starts. [D]id not appear to have any set period for sleeping. Observations made on a number of occasions during the night, revealed it to be just as active as during the day. During the ten days of captivity it was observed sleeping on only one occasion, in mid-afternoon." Observations of another captive by Buckner (1964) were similar: continuous activity at all times, especially at night, with short start-and-stop bursts of motion. Additional observations from these authors indicated that pygmy shrews are very able climbers and jumpers, can climb vertical walls and dangle vertically by their hind limbs, and appear to rely heavily on smell for navigation. Winter activity is assumed to occur primarily in the subnivean space, with only occasional surface forays.

Movement patterns

Shrews do not migrate or become nomadic in the classic sense, but it may be difficult to recognize such movements in such a small animal with such limited movement abilities. A pygmy shrew moving 50m across a small draw may constitute a "migration" equivalent to a big game herd moving several kilometers. Individual vagrant and dusky shrews (especially males) increase movements and home range sizes during the breeding season. Although this has been casually described as "nomadism," it should be noted that it involves an average increase in home range size of only about 2,500 m^2 (Hawes 1977). From the perspective of a land manager working on the scale of kilometers, pygmy shrews are effectively non-migratory and inhabit static home ranges that shift only in response to drastic environmental changes.

Given the observations of captive animals by Prince (1940) and Buckner (1964), and the natural history and physiology of shrews in general, it is reasonable to assume that pygmy shrew movements are directed primarily to foraging during most of the year, and switch to locating mates during the breeding season (see also Hawes 1977). Movements of females are assumed to be restricted by the need to care for newborns until they achieve independence, about four weeks after birth.

Of probably most interest and meaning to managers are dispersal movements that connect population segments. However, there is essentially no published information on shrew dispersal patterns and characteristics. Therefore, until such information becomes available, assessments of population connectivity necessarily are reduced to assessments of the connectivity of suitable and preferred habitats, as outlined in the following section.

Habitat

General descriptions of pygmy shrew habitat (e.g., Whitaker and French 1984, Long 1999) suggest a rather wide environmental tolerance. However, such species-level summaries obscure the habitat associations of particular subspecies. In this case, the montane subspecies in particular, but also the prairie subspecies, appears rather specialized to particular environments within their respective ranges.

A careful reading of even species-level habitat summaries (Prince 1940; Long 1972, 1974, 1999; Whitaker and French 1984; McShea et al. 2003) reveals a regular association between pygmy shrews and moist environments, especially for *Sorex hoyi montanus*, *S. h. winnemana*, and other populations along the southern margin of the range, including southern populations of *S. h. hoyi*. This is consistent with the widely accepted idea that shrews generally are restricted to moist habitats (e.g., Pruitt 1953, Getz 1961, Wrigley et al. 1979), and it is consistent with Demboski and Cook's (2003) conclusion that whereas Canadian *Sorex* generally inhabit more xeric environments, southern forms occur more often in mesic ones. Habitat descriptions for southern prairie pygmy shrews commonly list bogs, marshes, wet prairies, and the forested margins of lakes and streams as suitable, and likely optimal. Associations with wetlands and other moist landcover types are assumed to arise from the osmoregulatory challenges posed by dry southern uplands (poor osmoregulatory ability is a hallmark of almost all shrews; see discussion and citations in Getz [1961]), and the higher biomass of invertebrate prey produced in wet sites (McCay and Storm 1997, Matlack et al. 2002 and citations therein). In general, significant associations between shrews and specific landcover types probably are based on the presence of moist microhabitats within those types (Pruitt 1953, Getz 1961, Wrigley et al. 1979, MacCracken et al. 1985).

Landscape context

Although the literature addressing habitat use by montane pygmy shrews is decidedly sparse, it does present a consistent theme of "wet conifer forest" as the primary occupied landscape. In the Southern Rocky Mountains, all known capture sites are in upper montane or subalpine landscapes dominated by conifer forest and dense stream networks that interact with various bogs, marshes, and other wetlands (Pettus and Leichleitner 1963, Spencer and Pettus 1966, Brown 1966, Brown 1967, Vaughan 1969, Armstrong 1972, Long 1972, DeMott and Lindzey 1975, Pearson and Ruggiero 2001).

Subspecies *montanus* may prefer mosaics of wetlands and dry upland forest, rather than the wet types alone. Most existing studies of the subspecies remark on the interdigitation of wet and dry forest, best expressed by Spencer and Pettus (1966): "[the] surplus of captures at sites intermediate between marsh and forest type, suggests that in this area it requires both types in close proximity, perhaps, preferably interspersed." Pettus and Leichleitner (1963), Brown (1967), and DeMott and Lindzey (1975) also supported the idea of interspersed upland and wetland boreal forest as an optimum landscape for the subspecies. Long (1972) reported apparent avoidance of the center of a swamp within a woodland. Similarly, DeMott and Lindzey (1975) failed to capture montane pygmy shrews in either marsh or dry meadow, but rather found them on the margins of each. Given this limited information, it is reasonable to hypothesize that this subspecies is attracted to the edges between wet and dry forest.

The forest theme is weaker for prairie pygmy shrews in South Dakota, but the subspecies still appears restricted to wet or mesic landscapes. The summary by Long (1972) suggested that pygmy shrews throughout the Midwest occupy wet prairies, moist forest and woodland, and true wetlands. The capture site from Mullican (1992) in southeastern South Dakota was on the border of a slough dominated by narrow-leaved cattail (*Typha angustifolia*). Smith et al. (2002) clearly favored wetlands, wet prairie, and mesic woodlands in their definition of suitable habitat for South Dakota pygmy shrews; of the 12 landcover classes they listed as suitable, only two ("Vegetated Badlands" and "Ponderosa Pine Forest") were not true wetlands or generally mesic in character.

Stand-scale

Most montane pygmy shrews have been captured in stands of Engelmann spruce (*Picea engelmannii*) or mixed Engelmann spruce/ subalpine fir (*Abies lasiocarpa*) (Brown 1966, Brown 1967, DeMott and Lindzey 1975, Pearson and Ruggiero 2001). Fewer captures have been reported in stands of aspen (*Populus tremuloides*), streamside willows (*Salix* sp.) (DeMott and Lindzey 1975), *Sphagnum*- and sedge-dominated bogs (Pettus and Leichleitner 1963, Brown 1966), and subalpine meadows (Vaughan 1969). In almost all situations where the subspecies has been captured in a non-forest cover type, those types have been small patches enclosed by coniferous forest and in close proximity to streams or wetlands.

"Stand" is a poorly defined, and hence less usable, term when applied to the mixture of prairie, woodland, and agriculture in the Midwest. "Patch," or perhaps the even more vague "cover type," may be more apt. In this context, it appears that prairie pygmy shrews in South Dakota and surrounding prairie states are reliably found within and next to wet cover types such as sloughs, bogs, and irrigated agricultural fields (Long 1972, Mullican 1992, Smith et al. 2002). There are essentially no data relating pygmy shrew abundance, reproduction, or survival to structural or floristic variation within these cover types.

Microhabitats

Pearson and Ruggiero (2001) reported an apparent, but statistically insignificant, preference by montane pygmy shrews for late-seral stands of spruce and fir. Such stands commonly are cooler and more moist than early seral stands, and they tend to contain more fallen logs and stumps. These and other forms of coarse-woody debris appear to be important to shrews in general (e.g., McCay and Komoroski 2004), and to pygmy shrews in other parts of its range (e.g., Bellows et al. 2001, Bunnell et al. 2002). Long (1972) and DeMott and Lindzey (1975) noted much coarse-woody debris at sites supporting the montane subspecies. In the Rocky Mountains, shrews presumably use logs and stumps as cover from predators and weather, as moist "refugia" that retain water when the surrounding forest floor dries out, and as foraging sites that produce abundant and diverse invertebrate prey. Pygmy shrews commonly burrow under logs and stumps as well, forming protected den sites in which to rest, give birth, and rear young (Long 1999). High quality dens may be very important to pygmy shrews, as indicated by the large amount of energy devoted to den construction and maintenance (Prince 1940, McDevitt and Andrews 1994).

Heavy accumulations of surface litter may contribute similarly to cover, moisture, and prey production. The occurrence of shrews elsewhere in the Rocky Mountains has positively correlated with litter cover (MacCracken et al. 1985). Likewise, tall and dense vegetation, especially understory (ca. <1m) vegetation, increases physical cover, humidity, and invertebrate production, which in turn can increase probability of occurrence and abundance of shrews (MacCracken et al. 1985).

In general, moist sites produce more invertebrates than drier ones, and increased prey availability and quality (invertebrates from moist sites are soft-bodied and have high water contents, both qualities preferred by shrews) may explain why shrew occurrence and abundance are consistently higher in moist microhabitats (McCay and Storm 1997, Matlack et al. 2002). Wallwork (1970 as cited in Hawes 1977) suggested that acidic soils support more small arthropods and fewer large arthropods. Hawes (1977) interpreted this to mean that acidic soils are high-quality habitat for shrews, such as the dusky shrew, that are specialized towards smaller prey. Given that pygmy shrews also specialize towards small invertebrates (see Food habits), it is reasonable to hypothesize a similar situation: mesic forests and wetlands on acidic soils may favor this species by producing more small arthropod prey, possibly increasing the shrew's reproductive output and survival and allowing it to outcompete sympatric shrews. This is especially relevant given new data suggesting that acidic peatlands are more abundant and widespread on the Medicine Bow- Routt National Forest than previously assumed (WYNDD, unpublished data).

The degree to which pygmy shrews use subterranean spaces and passages is unknown. Feldhammer et al. (1993) hypothesized that pygmy shrews spend much of the summer below ground in burrows dug by other mammals, as a way to partition space (thus minimize competition) with larger shrews.

Seasonal changes in habitat use

Pygmy shrews appear to track wet conditions throughout the year. Long (1972) noted that sites occupied in spring, generally under wet conditions, may not support pygmy shrews in August, under dry conditions. It is assumed that such tracking is very local in nature; that is, individual pygmy shrews move on the order of tens-of-meters to maintain proximity to wet soils and vegetation. It is unlikely that individuals undertake regular seasonal movements across basin divides.

Complicating this local seasonal movement is the fact that pygmy shrew abundances peak in August, which, as discussed earlier, may lead to surplus individuals occupying sub-optimal dry habitats adjacent to more optimal wet sites at that time of year (Spencer and Pettus 1966, Long 1972, Huggard and Klenner 1997). In addition, some *Sorex* shrews increase movements and home range sizes substantially during the breeding season (Hawes 1977), suggesting that they may be found in a wider range of environments during this period.

Area requirements

There are no direct estimates of pygmy shrew area requirements in the literature. Individuals are assumed to inhabit home ranges close in size to those inhabited by other *Sorex* shrews, with the British Columbia study by Hawes (1977) probably presenting the most relevant information. Nonbreeding home ranges of British Columbian vagrant shrews averaged 1,039 m^2 (range = 510 - 1,986), and those of dusky shrews averaged 1,227 m^2 (range = 338-1,951). Home ranges in the breeding season for the same group of animals were substantially larger (vagrant shrews mean = 3,258 m^2, range = 732 - 5,261; dusky shrews mean = 4,020 m^2, range = 605 - 4,425), indicating wider movements at this time of year. Additionally, although male and female home ranges were roughly equal in size during the non-breeding season, male breeding home ranges were over twice as large as those of females, for each species.

In California, home ranges of vagrant shrews averaged 372 m^2 (Ingles 1961); in England, home ranges of common shrews (*Sorex araneus*) averaged 2,800 m^2 (Buckner 1969).

Food and feeding habits

Diet

By virtue of their small body size, pygmy shrews are restricted to small prey, even relative to other shrews (Whitaker and French 1984). Thus, invertebrates predominate in the diet; small vertebrates like mice and voles may not be taken, at least as live prey, to the same degree as recorded for other *Sorex*.

Pygmy shrews primarily eat small arthropods. In New Brunswick, Whitaker and French (1984) established that larval insects (mainly Lepidoptera, followed by Diptera, Coleoptera, and Tipulidae) made up the bulk of the diet (68 percent of pygmy shrew stomach volume), followed by adult insects (mainly Coleoptera, followed by Carabidae, Lepidoptera, and Hemiptera; 22 percent), and spiders (10 percent). Shrews, including pygmy shrews, are regarded as major predators of forest sawflies (e.g., *Pristiphora erichsonii*) in northern forests. Shrew predation on cocoons may be enough to keep sawfly numbers below pest levels, especially when considered in combination with bird predation on adult sawflies (Buckner 1964).

Grasshoppers (Orthoptera) are taken when available (e.g., Buckner 1964), and they may be more important to the prairie pygmy shrews of eastern South Dakota than to the montane pygmy shrews of northern Colorado and south-central Wyoming. Captive pygmy shrews ate only the internal organs of grasshoppers, and discarded the exoskeletons, whereas they ate larvae and small adult insects in their entirety (Prince 1940).

Buckner (1964) conducted limited food preference trials with captive pygmy shrews and in one instance found that they avoided ants almost entirely. However, Ryan (1986) found ants prevalent in the diet of free-ranging pygmy shrews in Michigan. Thus, results of food trials may not apply well to field situations, and there may be wide geographic variation in diet. It is assumed that under wild conditions all shrews, including pygmy shrews, will take any prey item in the correct size range in a rather opportunistic fashion.

Pygmy shrews occasionally eat vertebrate carrion (Long 1999). When provided with freshly killed shrews, mice, and voles, captive pygmy shrews typically began by breaking into the skull to eat the brains or opening the abdominal cavity to eat the viscera, then proceeded to eat other soft tissue. In one instance, a pygmy shrew left a shrew carcass to feed on grasshoppers, and returned to the carcass only after finishing the insects, suggesting a preference for invertebrates over vertebrate carrion (Prince 1940).

It appears that pygmy shrews eat only very limited amounts of vegetation (e.g., seeds, berries; Long 1999). Prince (1940) observed no consumption of green grass by captive pygmy shrews; however, this was in the context of much animal food being offered as well. Haveman (1973) reported small amounts of *Sphagnum* moss in the stomachs of Michigan pygmy shrews.

Shrews probably obtain most of their water through food ingestion, and it appears that prey items with high water content are crucial to positive rates of survival and reproduction (Matlack et al. 2002 and citations therein). Captive pygmy shrews approached water dishes, but they did not drink (Prince 1940).

Foraging

By all accounts, all *Sorex* are voracious and "vicious" (Prince 1940) eaters, having very high energy requirements. Buckner (1964) estimated that a single captive pygmy shrew required about 98 sawfly eonymphs per day (i.e., about 150 percent of shrew body weight in eonymphs per day). For free-ranging shrews, energy requirements are higher, and food availability is lower, in winter than in summer (Hawes 1977). Captive pygmy shrews will waste and hoard prey items under situations of abundance, with rates of wasting and hoarding proportional to the amount of surplus food (Buckner 1964). It is assumed that free-ranging animals do the same.

Coarse food preferences (e.g., larval insects vs. adults, moist items vs. dry items) may dictate which microhabitats are searched by foraging pygmy shrews, and perhaps also which prey items are killed, eaten, or hoarded first when prey are especially abundant. However, foraging behavior is assumed to be driven primarily by finding prey in the appropriate size range rather than in any specific taxonomic category (Butterfield et al. 1981, Yalden 1981, Whitaker and French 1984, Ryan 1986). Finding the correctly sized food items, frequently and in abundance, is central to the life history of most *Sorex*, and winter is clearly when food is most limiting (e.g., Hawes 1977).

Breeding biology

Breeding phenology

Based on the age and breeding condition of the very few field-caught specimens of montane pygmy shrews, it appears that breeding occurs primarily in July, with young born late July to mid August (Brown 1966, Spencer and Pettus 1966, Long 1972). Spencer and Pettus (1966) remarked that the breeding cycle for this subspecies may be about three weeks earlier than that of sympatric shrews, but this is based on limited data. McCay et al. (1998) found pygmy shrew parturition in the Appalachians occurring about 26 days earlier than that of sympatric shrews, and they interpreted this as a strategy for minimizing competition. Feldhammer et al. (1993) reached similar conclusions for pygmy shrews in their Appalachian study area. The breeding cycle of prairie pygmy shrews in the Midwest appears to be similarly timed, but likewise, it is based on a limited dataset. Long (1972) placed breeding in July and most births in August. It is assumed that the breeding season is somewhat longer in the milder climates of the Midwest compared to the harsher subalpine zone of the Southern Rocky Mountains.

Breeding behavior

Hawes (1977) established that individual vagrant shrews and dusky shrews dramatically increase movements and home range sizes during the breeding season, with males doing so to a higher degree than females. This is assumed to result from extended searches for mates, and reasonably can be assumed to hold for other shrews including pygmy shrews.

There are essentially no data on parental care, movement and dispersal of young, or susceptibility to disturbance during breeding season specific to pygmy shrews. It is assumed that they have the same general characteristics in these regards as other *Sorex*: namely, young are born in protected, vegetation-lined nests. Prior to independence, young may follow their mothers on short forays in "caravans" in which they hold on to one another. Young achieve independence three to five weeks after birth (Nowak 1991).

Fecundity and survivorship

Litter sizes of three to seven have been recorded for pygmy shrews (Long 1974, DeMott and Lindsey 1975), and these are similar to litters produced by other *Sorex*. Generally, it is assumed that the species produces only one litter per year, and that litters are generally larger in more northern populations and smaller in southern groups, including *S. hoyi montanus* and presumably *S. h. hoyi* in South Dakota (Long 1974). Free-ranging *Sorex* rarely live through two winters. Mortality is assumed to be highest during winter, under conditions of increased food and temperature stress.

Population demography and spatial characteristics

There are essentially no data concerning sex ratios, age structures, recruitment rates, or other demographic parameters of pygmy shrew populations. Based on information from other *Sorex* populations, and the basic life history of *S. hoyi*, it is reasonable to assume that summer populations are composed mostly of individuals that were born during the previous August, will breed during July and August, and die the following winter (Huggard and Klenner 1997). Thus, populations probably turnover almost completely within a year, and only a very few individuals survive a second winter or breed twice in their lifetimes. This has some substantial management implications: disturbances that preclude or reduce breeding in a single season can substantially reduce the persistence of a given population segment, as few individuals will survive to a second breeding.

At the regional scale, the pygmy shrew is organized into two clear spatial groups: *Sorex hoyi montanus* in the mountains of northern Colorado and south-central Wyoming, and *S. h. hoyi* in eastern South Dakota. Each group appears to be on a separate evolutionary trajectory, with most conservation concern centering on the small, geographically isolated, and presumably more genetically impoverished *S. h. montanus*. In contrast, pygmy shrews in South Dakota appear to represent the periphery of a much larger and more contiguous regional population.

Given the subspecies' apparent preference for moist conifer forest (and possibly for the edges between dry upland and moist lowland conifer forest; see Habitat), local distributions of montane pygmy shrews probably match local distributions of these habitats. Where such habitats are rare and fragmented, it can be reasonably assumed that populations of this subspecies are analogously small and fragmented. In such situations, pygmy shrew populations may operate with some metapopulation-like dynamics; small and isolated patches of moist forest may occasionally support pygmy shrews, then become unoccupied, only to be re-colonized later. Large and well-connected patches of moist forest may serve as population "sources" that remain consistently occupied, even under generally poor conditions, and supply dispersing animals to re-colonize satellite patches. Forested stream corridors likely are the primary links between major centers of occurrence (e.g., large forested bogs, large stands of moist late-seral forest), suggesting that managers should consider minimizing disturbances in such corridors and maintaining sufficient corridor width to prevent excessive drying of the forest floor.

The same dynamics may apply generally to the local distribution of prairie pygmy shrews in eastern South Dakota. However, this subspecies appears to have a wider environmental tolerance than its mountain cousin does, and mesic cover types appear to be more broadly distributed in this part of the Great Plains. Thus, while wetlands and stream corridors still may hold the majority of pygmy shrews in South Dakota, it is reasonable to assume more occupation of and movement through upland types and less restriction to stream networks.

Hawes (1977) established that young-of-the year vagrant and dusky shrews defended exclusive territories against members of their own generation, both intra- and interspecifically, starting at independence and continuing through the winter until the start of the breeding season. Territoriality decreased with the onset of breeding, as individuals of both sexes started ranging longer distances in search of mates. The interpretation was that territories are defended primarily to guarantee adequate food to survive the winter and the following spring, allowing shrews to enter the breeding season in good condition. This explains why territories apparently were not defended against members of the parental generation; most such animals will die in autumn or winter, and thus do not represent significant future food competitors. It also explains why members of the parental generation apparently did not defend territories; since very few 1-year-old animals survive to a second breeding season, there has been little selective pressure for animals of this age to defend territories.

The degree to which this system applies to pygmy shrews is unknown. However, the dual priorities (i.e., food in the non-breeding season, mates in the breeding season) probably generally apply to all *Sorex*. It is assumed that pygmy shrews manage these priorities through a spacing system that includes at least some seasonal territoriality.

Community ecology

Predation

The small size of pygmy shrews makes them vulnerable to a wide variety of vertebrate predators, including owls and diurnal raptors as well as a variety of canids, felids, mustelids, and even larger shrews. The predator assemblage affecting any given pygmy shrew population is probably safely assumed to be a cross-section of the local predator fauna. Therefore, whereas montane pygmy shrews probably suffer very little predation from snakes because few snakes inhabit the subspecies' range, prairie pygmy shrews in eastern South Dakota may be routinely taken by gopher snakes (*Pituophis catenifer*) and possibly western rattlesnakes (*Crotalus viridis viridis*). Predation is generally assumed a minor control on pygmy shrew populations, but this is based on few data.

Shrews, including pygmy shrews, are recognized as important predators of forest sawflies in northern forests (Buckner 1964). Shrew predation on larval sawflies, combined with bird predation on adults, may maintain sawfly populations below pest levels in most circumstances.

Interspecific interactions

Sorex shrews are well-known for forming assemblages of several sympatric species, which immediately raises the question of how they partition resources to minimize competition. Kirkland and Van Deusen (1979) established that it is especially important for species with high energy requirements, like shrews, to reduce competition, and it appears that *Sorex* shrews do so primarily by exploiting different prey bases (Whitaker and French 1984). Specialization to prey of specific sizes and hardnesses is evident in the distinct dental characters of different *Sorex* species (Carraway and Verts 1994), and in the changes that teeth and jaws undergo as shrews age (Carraway et al. 1996, Verts et al. 1999).

When the pygmy shrew co-occurs with other shrews, typically it is the most narrowly distributed and least-abundant species in the assemblage (Spencer and Pettus 1966, Brown 1967, Wrigley et al. 1979, Whitaker and French 1984). Larger shrews can take prey across a wider size range, and they are presumably more dominant in shrew-shrew aggressive interactions; thus, larger shrews tend to be relatively general in distribution and can achieve relatively high abundances (Churchfield 1991, Fox and Kirkland 1992). Smaller shrews, like pygmy and dwarf shrews, gain a competitive advantage only in specific microhabitats where smaller invertebrates are more abundant than larger invertebrates, thus allowing small-bodied shrews to feed relatively efficiently (Getz 1961). It is likely that patterns of habitat use and local distribution of pygmy shrews primarily are functions of this need to locate concentrations of small invertebrates and to avoid competition with larger sympatric shrews.

Parasites and disease

There is very little information regarding parasites and diseases in pygmy shrews, and none appears relevant to management of the species in Region 2. In general, pathogens are assumed to be of only minor importance to most shrew populations.

Conservation and Management of The Pygmy Shrew in Region 2

Biological Conservation Status in Region 2

Current distribution and abundance

As currently understood, the montane subspecies of the pygmy shrew is known from only a small and isolated area of northern Colorado and south-central Wyoming. It is relatively specialized within that range, occupying high-elevation, mesic coniferous forest with possible preference for late-seral stands and possibly the edges between wet, lowland forest and dry, upland forest. Even within these habitats, it appears to be a relatively rare member of the local fauna. The known distribution of this subspecies strongly suggests that its fate will be determined by management of national forests within Region 2, with managers in the Medicine Bow- Routt and Arapahoe- Roosevelt national forests bearing most responsibility.

In contrast, the prairie subspecies of the pygmy shrew in South Dakota is at the periphery of an otherwise large and contiguous center of occurrence. This subspecies appears similarly rare and restricted to moist habitats relative to other shrews. Region 2 management units currently are not known to support this subspecies; future field inventories may reveal presence on the Fort Pierre National Grassland.

Trends

The relictual nature of the montane pygmy shrew suggests that its range has contracted over the past several millennia. Furthermore, given accepted scenarios of global climate change, it is reasonable to assume that this range contraction will continue over the next several decades, if not centuries. The range of the prairie pygmy shrew in the Great Plains probably is best described as having "shifted," rather than contracted, on a millennial scale, and it may be forecasted to shift further north with anticipated climate change.

On more management-relevant scales of time (i.e., years, decades) and space (i.e., hectares), clearly there are not enough existing data with which to directly estimate trends in distribution or abundance of pygmy shrews in Region 2. It may be possible to estimate provisional trends based on apparent habitat usage, with the obvious qualification that patterns of habitat use are assumed from rather meager data. Within its range, the montane pygmy shrew is assumed to have declined in both distribution and abundance in areas that have undergone extensive timber harvesting (especially clearcutting) and stand-replacing fires, as these processes generally convert mesic forest to rather dry and open cover types. Persistent livestock grazing likely has also reduced the quality of pygmy shrew habitat in many areas, possibly eliminating the species from some, by reducing understory vegetation and compacting soils (Grant et al. 1982). Pygmy shrew habitat probably has been especially reduced where such processes have affected late-seral stands of timber, forested wetlands, and forested stream courses. In this context, it should be noted that pygmy shrew responses to timber harvesting, fires, and grazing in wetter regions such as British Columbia (e.g., Huggard and Klenner 1997) and Maine (e.g., Monthey and Soutiere 1985) might not apply to the drier forests in Region 2. Other processes, such as the creation of road networks, which have replaced moist forest floor with dry and compacted road beds and increased air circulation (thus evaporation) in forest stands, also may have contributed to a general decline in the distribution and abundance of montane pygmy shrews.

Paralleling this forest situation in the West, the distribution and quality of habitat for prairie pygmy shrews in eastern South Dakota also are assumed to have declined as a result of agricultural development. Draining, filling, and plowing of wet meadows and other mesic cover types, along with persistent livestock grazing in remaining native vegetation types, likely have reduced and fragmented habitat for pygmy shrews throughout this region.

Intrinsic vulnerability

As discussed earlier, pygmy shrews in Region 2 are both habitat specialists and prey specialists, which increases their vulnerability to a wide range of possible disturbances. Additionally, pygmy shrews have an extremely limited capacity for travel, as is expected for a terrestrial mammal with an adult weight of only 5 g. Thus, not only are patches of suitable habitat naturally rare and fragmented, pygmy shrews cannot move long distances to access such patches. Ground-disturbing actions that may appear minor to larger species (and to human resource managers), such as road beds, patch cuts, powerline corridors, or plowed fields, may represent significant barriers to pygmy shrews. It is likely that the combination of habitat specialization, prey specialization, and reduced movement capabilities predisposes pygmy shrew populations to fragmentation.

Furthermore, pygmy shrews have an effective life span of only one year, with the majority of individuals reproducing only once in their lifetimes at about 10 months of age. Thus, any disturbance that precludes or reduces reproduction in even a single season could imperil the persistence of the affected population segment. Most pygmy shrews will die before a second breeding attempt, and pygmy shrew populations likely do not contain any pools of "surplus" individuals that can buffer the loss of breeders.

Pygmy shrews in Colorado and Wyoming further may be challenged by reduced genetic variability arising from founder effect during their isolation, and allele fixation from genetic drift following their isolation (Beauvais 2000). There are no data regarding genetics of the montane pygmy shrew; the issue is raised here only as a possibility that bears further investigation. It is reasonable to assume, however, that the isolation of pygmy shrews in this region has produced a unique and irreplaceable form of the species. Whereas prairie pygmy shrews in eastern South Dakota can be considered "replaceable" by populations in several neighboring states, the montane pygmy shrew is endemic to a rather small region and represents a qualitatively unique component of regional biological diversity. This raises the conservation value of the taxon, whether or not it is also challenged by reduced genetic variability.

Extrinsic threats

Natural impacts and stochastic events

The paucity of data on pygmy shrews makes any discussion of threats, either natural or anthropogenic, rather speculative. The current literature on conservation biology makes it clear, however, that small and isolated populations are more vulnerable to stochastic events than are larger and more connected populations. In this broad sense, disturbances affecting pygmy shrew populations and habitat are of more concern for the montane subspecies than for the prairie subspecies.

Natural processes that alter or convert mesic forest to more open and drier cover types, such as wildfire, blowdowns, drought, and insect infestation, likely reduce and fragment habitat for montane pygmy shrews. Wildfire and drought-related cover changes also may affect prairie pygmy shrew habitat in South Dakota.

Unusually early (or even late) freezes and snowfall may affect pygmy shrews by reducing the abundance of invertebrate prey. Given the species' apparent affinity for swamps, bogs, and wet meadows, it is interesting to speculate on the effects of annual flooding and snowmelt. Local distribution of pygmy shrews probably shifts somewhat in response to spring flooding; it is possible that especially heavy spring flooding forces pygmy shrews into suboptimal environments where they are more vulnerable to predators, are forced to compete more with larger shrews, and have a less-abundant prey base. Such effects may be countered, however, by spring flooding that converts otherwise dry cover types to wetter states that are more suitable for pygmy shrews.

Anthropogenic impacts

People are assumed to affect pygmy shrews almost exclusively through habitat alteration. Alterations that are most pervasive and probably have the most negative impact on pygmy shrews are timber harvesting (especially clearcutting) and livestock grazing in Colorado and Wyoming, and cultivation agriculture and livestock grazing in South Dakota. Clearcutting initially converts mesic forest to dry and open grassland, which regenerates to a forested state only very slowly in the Southern Rocky Mountains. Furthermore, stands regenerating after clearcutting typically contain little coarse-woody debris, as most large trees that eventually form coarse-woody debris are removed during the harvest. As discussed earlier, coarse-woody debris may be important to pygmy shrews for several reasons. Stands bordering clearcuts are dried by increased sunlight and wind, which likely reduces their ability to support pygmy shrews. Harvest methods other than clearcutting produce several of the same effects, but to a lesser degree.

Large swaths of eastern South Dakota have been, and continue to be, converted from native prairie and woodland to annual crops. Many of the wetter native habitat types (e.g., wet meadows, lowland woodlands, riparian grasslands) are assumed to have supported pygmy shrews in the past. Regular disturbance of croplands (e.g., plowing, seeding, harvesting) is assumed to preclude pygmy shrews from occupying, or at least building effective populations in, such cover types. In contrast to timber harvesting within the range of the montane pygmy shrew, which occurs almost exclusively on Region 2 national forest land, cultivation within the range of the prairie pygmy shrew in South Dakota occurs almost exclusively on private lands. Thus, if the prairie subspecies occupies national forest units (which has not yet been shown), such units may represent "refuges" for the subspecies.

Livestock grazing is known to affect small mammals in general, and shrews in particular, by reducing the height and density of understory vegetation and compacting soil surfaces (Grant et al. 1982, Zwartjes et al. 2005). Short and sparse understories on compacted soils produce few invertebrates, and rather low surface humidities, relative to dense, ungrazed understories (Whitaker et al. 1983).

Roads probably have the next biggest anthropogenic impact on pygmy shrews, affecting both subspecies. Roads generate a well-known suite of ecological impacts in almost all environments (Trombulak and Frissell 2000), including the Rocky Mountains and the Great Plains. Pygmy shrews probably avoid crossing most roads, as roads generally are much drier and more open than surrounding vegetation. Roads also can dry adjacent vegetation and soils by increasing air flow, dustfall, and incident sunlight.

Other anthropogenic impacts probably are less pervasive than those discussed previously. It seems reasonable to conclude that reservoir construction has eliminated some habitat for both subspecies. The draining of wetlands, which may have accompanied agricultural development in some parts of South Dakota, also may have locally reduced pygmy shrew habitat. Wetland contamination by mine runoff may have had the same impact in portions of the Southern Rocky Mountains. Insect control through pesticides may reduce the prey base for pygmy shrews; it is assumed that this is a greater problem in the agricultural landscapes of South Dakota than in the forests of Colorado and Wyoming.

When considering anthropogenic impacts, it is important to recall the earlier discussion of how easily pygmy shrew populations can be fragmented because of the species' habitat and prey specialization and reduced travel capacity. The effect of a given anthropogenic disturbance on a pygmy shrew population will be determined largely by the position of that disturbance relative to the distribution of the local population. For example, a clearcut placed on the edge of a large patch of suitable pygmy shrew habitat can be assumed to reduce the population more or less proportional to the size of the cut. However, the same clearcut placed on a narrow corridor of suitable habitat that connects two subpopulations may isolate those subpopulations, and substantially endanger both of them in their entirety.

Management of the Pygmy Shrew in Region 2

Conservation elements

The basic life history of the pygmy shrew is so poorly known that priority should be placed on acquiring basic data on distribution, abundance, and patterns of habitat use. Only after such data are collected and synthesized can resource managers confidently integrate pygmy shrew conservation with other land uses. Existing data should be used to the same ends in only a provisional manner.

1. **Provisional principles.** The following recommendations should be considered subject to change given the results of subsequent Conservation Elements. Based on existing knowledge of the montane pygmy shrew, resource managers in the Medicine Bow-Routt, Arapahoe- Roosevelt, White River, and Grand Mesa-Gunnison-Uncompahgre national forests can consider moist conifer forest, including forested swamps and bogs and late-seral stands of spruce and/or fir, as high quality habitat. Additionally, forested stream corridors can be considered as linkages that connect subpopulations across the landscape. Maps of such habitats will aid in placing ground-disturbing activities (especially timber harvesting and road construction) in areas that minimize impacts on montane pygmy shrews. Similarly, resource managers in the Fort Pierre National Grassland can consider mesic cover types, including wet meadows and the borders of true wetlands, as potentially occupied by prairie pygmy shrews.

2. **Distribution inventory.** Field inventories are needed to more confidently determine the distribution of montane pygmy shrews in Colorado and south-central Wyoming. Importantly, this includes confirmation that pygmy shrews still occur at some historic capture sites in the core of the subspecies' suspected range on the Medicine Bow-Routt and Arapahoe-Roosevelt national forests. It also includes new inventories on the White River and Grand Mesa-Gunnison-Uncompahgre national forests. Presence on the former unit has yet to be confirmed, and presence on the latter is known only through a single historic capture (**Figure 2**). For prairie pygmy shrews, inventories should be conducted on the Fort Pierre National Grassland. If the subspecies is confirmed there, inventories should be considered on the Buffalo Gap National Grassland and Samuel R. McElvie National Forest as well. Inventories aimed at resolving the actual distribution of pygmy shrews should focus on environments known to be occupied by the species. Projects that seek to determine habitat preferences, which necessitate field effort in all environments within a study area, are of lower priority in the short term. It seems reasonable to commit limited inventory resources to delineation of actual distribution first, and only later consider habitat preference analyses - see Conservation Element 4.

3. **Distribution mapping and databasing.** All inventory locations should be mapped to within at least 100m of their actual location. These locations, plus all other relevant information including trapping results (e.g., species collected, number of individuals) and, especially, habitat descriptions and measurements, should be stored in a format suitable for display and manipulation within a geographic information system (GIS). Even inventories that fail to collect pygmy shrews should be mapped and databased in this manner, as information suggesting absence (negative points) is often as valuable as information indicating presence (positive points). Importantly, all known positive (e.g., Brown 1967) and negative (e.g., cursory surveys for shrews conducted by WYNDD, summer 2005) points from previous surveys should be included in this dataset, to form a comprehensive picture of known distribution. These data can directly inform managers, and be used to update distribution models (e.g., Beauvais and Smith 2005) to predict occurrence in unsurveyed portions of Region 2. Ideally, all mammal specimens collected should be deposited in accredited lending museums; at the very least, all *Sorex*, and especially all suspected *S. hoyi*, should be treated in this manner.

4. **Habitat usage analysis and mapping.** Once the actual distribution of the pygmy shrew within Region 2 is known with more confidence (see Conservation Element 2), resource managers would be well-served

by field sampling projects designed to yield information on habitat preferences. Of primary concern is ensuring that sampling effort is distributed across all major habitat types within a given area, with the amount of sampling in any given type at least proportional to the area of that type. Data from such an effort then can be analyzed in terms of occupied types vs. unoccupied types to provide general indices of preference. Such information can then be used to produce more detailed maps that distinguish between occupied environments (i.e., all environments known to be occupied by pygmy shrews, whether preferred or not) and preferred environments (i.e., all environments with positive preference indices).

5. **Monitoring of distribution and abundance.** After the above Conservation Elements are addressed, it seems reasonable to institute a program that monitors distribution and abundance of the pygmy shrew on broad scales. Within the range of each subspecies, it is recommended that standardized inventories (i.e., same methods, sampling effort, timing) be conducted in several locations known to be occupied, plus nearby environments not known to be occupied but suspected to be suitable. Careful selection of these locations, with attention to spatial independence, geographic breadth, and range of cover types and other environmental qualities, will ensure that resulting data can be interpreted in terms of trends in abundance and distribution.

Tools and practices

Inventory and monitoring - field collection

It is generally recognized that shrews, especially small shrews, are best trapped in the field with pitfall traps (Brown 1967, Smallwood and Smith 2001). Other techniques, such as snap-traps and tracking tubes (e.g., Glennon et al. 2002, Nams and Gillis 2003), either commonly fail to capture small shrews or to produce data that cannot be reliably assigned to species. Positive identification of *Sorex* species requires detailed examination of teeth in most instances, and certainly with *S. hoyi* (refer to **Figure 4** and **Figure 5**), so lethal collection methods are necessary.

An inexpensive, efficient, and effective method for determining presence in a given landscape is to collect and examine owl pellets for the presence of pygmy shrew mandibles. Given that basic distribution is the primary information gap for this species in Region 2 (see Conservation Element 1), this technique could be extremely valuable in quickly generating new points of species occurrence across the region. Owl pellet examination and pitfall trapping each have the advantage of sampling multiple shrew species simultaneously, so collections targeting any one species will generate data on others as well. Emphasis on this multi-species "efficiency" may help those lobbying for support for pygmy shrew studies. Collecting owl pellets to acquire mandibles requires incorporating expertise in locating owl feeding and resting perches near likely pygmy shrew habitat.

Pitfall traps of many different sizes and shapes are successful at capturing shrews. It appears that almost any smooth-sided container, at least 15 cm deep and buried with the rim flush to the ground surface, is adequate. One traditional design is a large container (e.g., 5-gallon plastic bucket) filled with ca. 8 cm of alcohol topped with ca. 2 cm of mineral oil. A wide lid, braced ca. 5 cm above the ground surface, is placed over the bucket to prevent rain and debris from entering while still allowing small mammals to enter. Such traps are left unattended for several weeks, with trapped mammals preserved by the alcohol (which is prevented from evaporating by the mineral oil). Clearly, this design is intensive in both labor and materials, and it is vulnerable to disturbance by larger mammals. Smaller and simpler pitfalls (e.g., uncovered coffee cans with drainage holes, plastic beverage cups) are less expensive, can be transported more easily and in greater numbers, and can be set up rather quickly; however, they require more frequent checking to collect specimens.

There is much variability in the arrangement of pitfall traps at a particular trapping site. Typical arrangements place one to four pitfall traps at nodes in a grid, or sometimes at intervals along transects. Such regular trap placement may be more appropriate for habitat preference studies or monitoring projects. Advice on trap placement and configuration for such projects can be found in Smallwood and Smith (2001) and Kirkland and Sheppard (1994). Inventories intended to establish presence at a site, and thus better delineate actual distribution, may be better served by more subjective trap placements determined by experienced shrew trappers. There appears to be no general consensus on the use of drift fences (sheets of plastic or other material that extend outward along the ground from the edge of a pitfall, intended to guide more animals into the trap) or bait (when used, typically a blood- or meat-based paste) to increase trapping success. The extra material and labor associated with drift fences and baits may increase the rate of capture/trap, but also decrease the number of traps able to be employed in a given study. Baits have the added disadvantages of potentially attracting larger mammals that can disturb traps, and potentially confusing patterns of habitat use by attracting shrews from adjacent habitats.

Shrews are more difficult to trap in the field than are other small mammals, and there are often substantial differences in the trapping successes of novice and experienced field crews. Prior experience appears important to many aspects of trapping, including the selection of trapping sites, fine-scale trap placement, and grooming of the ground surface near set traps. Pitfall trapping should be performed under the direction of an experienced shrew trapper whenever possible.

Inventory and monitoring - sampling design; spatial and temporal considerations

Establishing the true regional distribution of pygmy shrews requires sampling in unoccupied sites that are generally similar in environment to occupied sites: i.e., forested wetlands and late-seral stands of spruce and fir on the White River and Grand Mesa-Gunnison-Uncompahgre national forests for the montane subspecies; wet meadows and wetland borders on the Fort Pierre National Grassland for the prairie subspecies. In addition, the montane subspecies should probably be re-confirmed as occurring at some historically occupied sites on the Medicine Bow-Routt and Arapahoe-Roosevelt national forests, and sampling for the prairie subspecies on Buffalo Gap National Grassland and Samuel R. McElvie National Forest may be warranted if the subspecies is confirmed on Fort Pierre National Grassland. Selection of specific sampling locations can be informed by distribution modeling exercises such as Beauvais and Smith (2005; see also **Figure 2**), and by careful inspection of other sites of known occurrence to develop an appropriate habitat search image.

Trapping to determine habitat preferences involves trapping across a representative sample of major habitat types within a given area, with sampling effort in each type at least proportional to the area of that type, and then analyzing results in a use/availability framework. A complete outline of such analyses is beyond the scope of this assessment; readers should consult Manly et al. (1993) for more details. Trapping intended to monitor distribution and abundance involves repeated trapping cycles, using standardized techniques, at a consistent subset of occupied sites and also at nearby sites that are suitable but assumed to be unoccupied at the start of the project. Readers are again encouraged to consult the primary literature for more information on the structuring of monitoring studies.

Field biologists need to pay close attention to the timing of shrew inventories. Pygmy shrews appear to be so rare that a relatively high amount of sampling effort is needed to detect their presence, let alone generate enough captures to estimate abundance. Therefore, it makes sense to conduct distribution inventories during the annual population high, after young-of-the-year have achieved independence but before autumn weather begins to increase mortality. The limited amount of information collected to-date suggests that this period generally encompasses the month of August (Brown 1966, Spencer and Pettus 1966, Long 1972; see also Huggard and Klenner 1997). However, trapping to determine habitat preferences may be best conducted at other times because some individuals may be forced into non-typical environments when population density is high, which might mask patterns of habitat use. Clearly, researchers conducting long-term monitoring need to ensure that trapping cycles are timed similarly from year to year to generate comparable data.

Inventory and monitoring - sampling effort

Existing studies provide only broad guidance as to the sampling effort (number of pitfall-nights) required to detect pygmy shrews at any given trapping site. Published capture rates (standardized here to number of individuals captured per 100 pitfall-nights) for montane pygmy shrews in suitable habitat include 0.1 (Spencer and Pettus 1966, Pearson and Ruggiero 2001), 0.7, and 3.0 (Brown 1967). Capture rates for prairie pygmy shrews in the upper Midwest fall in about the same range, with 0.5 (Mullican 1992) and 0.8 (Ryan 1986) being typical values. An assumed conservative rate of 0.1 individuals captured per 100 pitfall nights suggests that a bare minimum of 1000 pitfall-nights would be needed to detect the presence of pygmy shrews at any given site. This is a substantial amount of field effort, especially considering the relatively large number of sites that would need to be trapped to confidently outline regional distribution and habitat preferences, and the additional per-site effort that would be needed to generate enough captures with which to reliably estimate trends in distribution and abundance. Assuming a more liberal capture rate of 0.5 individuals captured per 100 pitfall nights suggests a minimum of 200 pitfall-nights to detect pygmy shrew presence, which is still formidable but within the realm of possibility. Thus, before committing to full-scale field inventories, managers may consider conducting smaller-scale pilot studies, possibly in historically occupied sites with high likelihoods of being currently occupied, to more precisely establish expected capture rates and study design parameters for future pygmy shrew inventories in Region 2.

The above discussion emphasizes the importance of three points raised previously: (1) experienced trappers often have higher capture success rates than novices, thus should be employed when possible; (2) pygmy shrew inventories conducted during the period of highest annual numbers (August) have a higher likelihood of capturing individuals than those conducted at other times; and (3) collection of shrew mandibles from owl pellets may be a more efficient manner of determining the presence of this species than pitfall trapping. See Smallwood and Smith (2001) for a more complete understanding of factors that affect trapping success for shrews.

Data management, accessibility, and mapping

Data from field inventories, habitat use studies, and monitoring projects can inform managers only to the extent that they are presented in easily accessible and usable formats. Although such data have been, and continue to be, presented in text and tables, it is clear that spatially explicit formats more efficiently and effectively integrate field results into management and planning. The recent development of desktop GIS and relational database technologies has resulted in several platforms that are ideal for storing, managing, and distributing mapped wildlife data; prime examples are the USFS Fauna data system now being implemented throughout Region 2, and the Biotics data system employed at state Natural Heritage Programs. Each quickly generates maps of rare species and habitat information, and there is a history of cooperation between USFS and state Natural Heritage Programs that should allow for open data exchange and synthesis. Results of pygmy shrew field inventories and monitoring should be entered into and accessible through such systems for maximum utility, with careful attention to the entry of historical data (e.g., Pettus and Leichleitner 1963) and negative field results alongside current and future positive results.

Information Needs

Pygmy shrews are so poorly known that most information needs are addressed above as Conservation Elements. After these needs are fulfilled managers and researchers can focus on important, but less urgent, issues such as:

- ❖ quantifying the genetic uniqueness of the montane pygmy shrew
- ❖ correlating soil type, especially soil acidity, with availability of small invertebrates and habitat quality
- ❖ establishing a precise breeding phenology
- ❖ measuring dispersal distances
- ❖ determining spacing characteristics and territoriality.

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