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AN ECOSYSTEM-BASED CONSERVATION STRATEGY FOR THE NORTHERN GOSHAWK

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Abstract. The Northern Goshawk (*Accipiter gentilis*) is a large forest-dwelling raptor whose viability is in question because of habitat changes resulting from tree cutting, fire exclusion, and livestock grazing. We describe an approach for developing a goshawk habitat conservation strategy, first used in the southwestern US in 1992, that can be applied throughout the range of the species. The strategy described sets of desired habitats based on existing knowledge of the life history and habitats of goshawks, the life histories and habitats of their prey, and the ecology of overstory and understory vegetation in forests occupied by goshawks. These habitats included components such as overstory and understory compositions and structures, snags, logs, woody debris, openings, and size and arrangement of plant aggregations. The strategy incorporated the dynamic nature of forest ecosystems by developing desired landscapes consisting of temporally shifting mosaics of vegetation structural stages that comprised the habitats of goshawks and their prey. This multi-species, ecosystem-based strategy will benefit goshawks because their populations are limited by food and habitat and because the desired landscape will contain goshawk and their prey habitats through time. The approach used in this conservation strategy should be appropriate for other forests occupied by goshawks. However, because the species of prey, and the composition, structure, and dynamics of the vegetation vary among forest types, the approach is likely to result in unique desired habitats and landscapes as well as forest management prescriptions to develop them.

Key Words: *Accipiter gentilis*, conservation strategy, food webs, forest management, habitat, landscapes, prey, structural stage.

UNA ESTRATEGIA DE CONSERVACIÓN PARA EL GAVILÁN AZOR BASADA EN EL ECOSISTEMA

Resumen. El gavilán Azor (*Accipiter gentilis*) es un raptor grande que habita en el bosque, el cual su viabilidad está en duda debido a los cambios del hábitat, los cuales son resultado de la corta de árboles, exclusión del fuego y del pastoreo para ganado. Describimos un enfoque para desarrollar una estrategia de conservación del hábitat del gavilán, utilizada por primera vez en el suroeste de los Estados Unidos en 1992, la cual puede ser utilizada en todo el rango de la especie. La estrategia describió grupos de hábitats deseados, basada en información existente de la historia de la vida y de los hábitats del gavilán, las historias de las vidas de sus presas y la ecología de la vegetación de dosel y sotobosque, en bosques ocupados por gavilanes. Estos hábitats incluyeron componentes tales como, composición y estructura del dosel y sotobosque, árboles muertos en pie, troncos, madera de desecho, aberturas y el tamaño, edad y yuxtaposición de agregaciones de plantas. La estrategia incorporó la dinámica natural de los ecosistemas del bosque, a través del desarrollo de paisajes deseados, que consistían en mosaicos cambiantes temporales de fases estructurales de vegetación, los cuales abarcaban los hábitats del gavilán y sus presas. Esta estrategia basada en el ecosistema, multi-especie, debiese de beneficiar al gavilán, ya que sus poblaciones parecen estar limitadas por el alimento y el hábitat, y porque el paisaje deseado contendrá gavilán y hábitat de su presa en todo momento. El enfoque utilizado en esta estrategia de conservación debería de ser apropiado para otros bosques ocupados por el gavilán .Sin embargo, ya que la presa de la especie, así como la composición y dinámica de la vegetación varía en los tipos de bosque, el enfoque podría resultar en hábitats y paisajes únicos deseados, así como en prescripciones de manejo forestal para desarrollarlos.

Considerable effort has been directed towards developing conservation strategies that protect forest species. Many conservation strategies prompted by recovery goals in the Endangered Species Act are autecological, spatially and temporally limited, and typically use habitat reserve designs (Everett and Lehmkuhl 1996, but see Della Sala et al. 1996, MacCracken 1996, Noss 1996, and Everett and Lehmkuhl 1997 for discussions on the merits of reserves). These strategies often fail to recognize important ecological relationships and linkages that support a species (e.g., food webs) and they often view habitats as static. Although reserves may protect species that are sensitive to human activities, their very design shifts resource extraction pressures to unprotected areas, which may diminish the ecological values of reserves by limiting dispersal (gene flow) of focal species among reserves (Suzuki 2003). Conservation strategies that address all stages of a species' life history, the physical and biological factors that limit its populations, the members of its ecological community, and the spatial and temporal dynamics of the ecosystems it occupies, should be robust to failure. Implementing such strategies in landscapes increases the probability of sustaining whole ecosystems on which a species may depend, and eliminates the difficult tasks of specifying the sizes, numbers, dispersion, and connectivity of reserves or protected areas needed to sustain a species.

Apex predators, because they are often sensitive to changes in their habitats (Belovsky 1987, Melián and Bascompte 2002), are prime candidates for conservation strategies. Population viability of the Northern Goshawk (*Accipiter gentilis*), an apex predator that occurs primarily in forests and woodlands throughout the Holarctic (Squires and Reynolds 1997), is in question because of habitat changes resulting from tree cutting, fire exclusion, and livestock grazing (Herron et al. 1985, Crocker-Bedford 1990, Reynolds et al. 1992, Widén 1997, but see Kennedy 1998). As a result, goshawks have been the object of considerable litigation and the species was considered for listing under the Endangered Species Act (Boyce et al., *this volume*). To protect the habitats of goshawks, conservation strategies were developed for three forest types in the southwestern US in 1992 (Reynolds et al. 1992). These southwestern goshawk conservation strategies (SWGS) accounted for the requisite resources (vegetation structure and food) and ecological relationships (competition, predation, and disease) of goshawks and their prey. Further, because forests change through the dynamic processes of plant establishment, growth, succession, and natural and anthropogenic disturbances, the SWGS identified and incorporated the spatial and temporal scales encompassing these dynamics. The SWGS described sets of desired forest conditions that included habitat components such as tree species composition, structure, landscape pattern, snags, woody debris, tree sizes and densities, and the sizes, ages, and arrangement of tree groups. To account for forest dynamics, the desired forest conditions consisted of temporally shifting mosaics of vegetation structural stages intended to sustain the habitats of both goshawks and their prey in large landscapes for centuries.

The SWGS was incorporated into all USDA Forest Service southwestern national forest management plans in 1996 (USDA Forest Service 1996; Boyce et al., *this volume*). Shortly thereafter, the SWGS was reviewed by animal and forest scientists (Braun et al. 1996, Squires et al. 1998, Long and Smith 2000, Peck 2000, Beier and Maschinski 2003, Andersen et al. 2004). Here we provide an overview of the approach, components, and processes used in the SWGS, particularly those applicable to southwestern ponderosa pine (*Pinus ponderosa*) forests, not only to correct misunderstandings evident in some of the reviews, but to demonstrate how the process can be used to develop similar conservation strategies in other forests. We conclude with a discussion of problems that may hinder tests of the effectiveness of the SWGS for sustaining goshawks and identify some unintended, additional values resulting from implementation of the SWGS.

Essential Information

Information on the life history, ecology, and habitat of the goshawk, the biological and physical factors (food, habitat, predators, competitors, disease, and weather) that potentially limit goshawk populations, the life histories and populations of important goshawk prey species, and the ecology (e.g., composition, structure, pattern, and dynamics) of a forest ecosystem, is essential for developing desired forest conditions in this ecosystem-based conservation strategy.

Goshawk Life History

Goshawks are relatively long-lived, solitary breeders with large home ranges, and that breed in a broad range of forest and woodland types (Squires and Reynolds 1997) where they feed on a variety of birds and mammals (Reynolds and Meslow 1984, Boal and Mannan 1994, Reynolds et al. 1994). Goshawks exhibit high levels of year-to-year fidelity to breeding territories and to mates (Doyle and Smith 1994, Woodbridge and Detrich 1994, Squires and Ruggiero 1995, Reynolds et al. 1994), and often lay eggs in numerous alternate nests within their territories (Reynolds et al. 1992, Woodbridge and Detrich 1994; Reynolds and Joy, *this volume*). Studies have shown that where forests have suitable structures for nests and hunting, and where food is abundant, goshawks are more abundant, breed more often, have heavier body masses, and smaller home ranges (McGowan 1975, Bednarek et al. 1975, Sollien 1979, Lindén and Wikman 1980, Cramp and Simmons 1980, Sulkava et al. 1994, Salafsky 2005; Reynolds et al., *this volume*).

Goshawk Limiting Factors

A fundamental step in developing conservation strategies is to identify the environmental factors that limit a goshawk population's ability to grow. These factors typically affect goshawk birth, death, emigration, and immigration rates. Sources of information for these factors include the published literature, unpublished reports, and expert opinion. Information on factors that may limit goshawk populations is often scarce or absent. In these cases, information on how factors influence other raptor populations may offer indications on how they might influence goshawks. A recent review of the goshawk and other raptor literature identified factors that may limit goshawk populations—the abundance and availability of habitats and foods, the types and abundances of predators and competitors, diseases, and weather (Reynolds et al., *this volume*). The review also showed that in studies of goshawk breeding density and reproduction, the availabilities of nest sites, foods, and suitable foraging sites appeared to be the most common factors affecting goshawk populations, and that predation, competition, disease, and weather would be less likely to affect goshawks negatively if foods and vegetation structures were not limiting (Reynolds et al., *this volume*). For example, when prey are abundant, competition for food might be reduced, food stress would less likely predispose goshawks to disease, weather effects on prey availability might be reduced, and, when high quality nest sites are available, predation at goshawk nests might be reduced (Reynolds et al. 1992). The conservation problem was then to identify and develop the habitats of sufficient quality to support goshawks and their prey populations. The variation among habitats in the composite availabilities of nest sites, foraging sites, foods, escape cover, and abundances of predators and competitors determines habitat quality. The approach used in SWGS assumes that if quality habitats are available in landscapes then the above limiting factors would less likely constrain the growth of goshawk populations.

Goshawk Habitat

North American goshawks nest and hunt in a wide variety of forest and woodland types within their geographic range (Squires and Reynolds 1997). Based on the use of space around goshawk nests by adults and fledglings, the SWGS identified three components of the breeding home range: the nest area (approximately 12 ha), the post-fledging family area (PFA; approximately 170 ha exclusive of nest area) surrounding the nest area, and the foraging area (approximately 2,190 ha exclusive of PFA) surrounding the PFA (Reynolds et al. 1992). We know more about the composition and structure of vegetation in nest areas than in the other areas because of their small size, readily defined boundaries, and the numerous studies that described nest site and nest area vegetation. Forest structure within nest areas provide protected nest, roost, and prey handling sites (Reynolds et al. 1982). Little foraging occurs within nest areas (Schnell 1958) and nest area sizes and shapes can vary by landform, forest setting, and method used to quantify them (Reynolds 1983, Kennedy 1989, Kennedy 1990, Boal et al. 2003). Goshawk nest areas typically have relatively high densities of large trees and high canopy cover, inherent to the forest type and biophysical setting, open understories, and are typically on shallow slopes or in drainages protected by slopes (Squires and Reynolds 1997). While most nest areas are embedded within extensive forests or woodlands, some goshawk individuals and populations nest in small patches of trees within open shrub, tundra, or riparian habitats (Bond 1940, White et al. 1965, Swem and Adams 1992, Younk and Bechard 1994a, b). Despite the disparate species compositions of forests types used by breeding goshawks, the structure of forests within nest areas is surprisingly consistent suggesting that structure is more important than species composition in their choice of nest habitat.

The PFA, defined in the SWGS as the adult female core area including the nest (Kennedy 1989), is used by the adult female for foraging and by her fledglings during the post-fledging dependency period (Reynolds et al. 1992). Because PFAs are larger than nest areas, they typically include a wider diversity of forest conditions—species composition, age classes, openings, and landforms. Because goshawk fledglings spend much of the post-fledging dependency period near the center of a PFA where they may require additional hiding cover from predators, the desired PFA habitat condition is a transition from the denser forests in nest areas to more open foraging habitat in the outer portions (Reynolds et al. 1992).

The foraging area surrounds the PFA and comprises the remainder of the home range of breeding goshawks (Reynolds et al. 1992). The foraging area is used by adult goshawks for hunting, and, like the PFA, should comprise suitably structured foraging habitat and a mix of prey habitats (Reynolds et al. 1992). A number of radio-telemetry studies determined the use of habitats by goshawks (Kenward et al. 1981b, Widén 1985b, Kenward and Widén 1989, Bright-Smith and Mannan 1994, Hargis et al. 1994, Squires and Ruggiero 1995, Beier and Drennan 1997, Good 1998, Drennen and Beier 2003), but their elusive behavior and rapid movements through large home ranges make goshawks difficult to observe and to unequivocally determine whether or not they were actually hunting in the habitats they were detected using. Nonetheless, these studies suggested that breeding goshawks hunted primarily in mature and old forests, but that they also hunted in a variety of other forest age classes, structures, and compositions, and into openings and along forest edges (White et al. 1965, Widén 1989, Bright-Smith and Mannan 1994, Hargis et al. 1994, Younk and Bechard 1994a, b; Bosakowski et al. 1999, Daw and DeStefano 2001). The diversity of habitats used by hunting goshawks often expands during winter when many juveniles and some adults move to lower elevation woodland and shrub communities (Reynolds et al. 1994, Squires and Ruggiero 1995, Stephens 2001, Sonsthagen 2002). Whether these goshawks leave their forest habitats in response to reduced food availability or weather changes is unknown. The year-round diversity of habitat use by goshawks is often reflected in their diets; goshawks eat birds and mammals that occur in mature forests, but frequently eat species whose main habitats are in open forests, along forest edges, and in openings (Reynolds and Meslow 1984, Widén 1989, Boal and Mannan 1994, Daw and DeStefano 2001). Nonetheless, at least within forest situations, goshawks spend much of their time in areas with large trees (Bright-Smith and Mannan 1994, Hargis et al. 1994), areas with high-crown base heights (open understories), allowing goshawks to fly beneath the forest canopy. Older forests also contain abundant tree perches from which goshawks search for prey, and are the prime habitat of many goshawk prey species (Reynolds et al. 1992).

Goshawk Prey

Goshawks feed on birds and small mammals (Squires and Reynolds 1997), and the composition of a local goshawk diet depends on the composition of the bird and mammal fauna in a particular forest, the relative abundances and availabilities of the species that goshawks are able to capture, and the dietary preferences of the goshawks. Goshawk diets comprise a limited range of prey sizes (Storer 1966, Snyder and Wiley 1976, Reynolds and Meslow 1984, Bosakowski et al. 1992). The upper prey-size limit appears to be determined by the goshawk's ability to kill with a minimum risk of injury to itself, and the lower size limit is likely determined by a goshawk's ability to capture smaller prey. Small prey are more maneuverable and escape goshawks more readily and return less energy per capture than larger prey (Reynolds 1972, Andersson and Norberg 1981, Temeles 1985). These limits result in goshawk diets composed of robin-to-grouse-sized birds and chipmunk-to-hare-sized mammals (Reynolds et al. 1992).

Goshawks are morphologically and behaviorally suited to hunt in forests. Both their maneuverability for capturing agile prey, provided by short wings and long tail, and their short-perch-short-flight foraging tactic (Kenward 1982), are suited for environments where flight and vision is impaired by tall, dense vegetation (Reynolds et al. 1992). Because of these adaptations it is often assumed that goshawks are limited to old-growth forests and that habitat availability is the main factor limiting goshawk populations. However, even within the forests, goshawk reproduction and survival can be highly variable among years (Reynolds et al. 2005; Keane et al., *this volume*; Reynolds and Joy, *this volume*), and this variation has been associated with inter-annual variations in prey abundance (McGowan 1975, Lindén and Wikman 1980, Doyle and Smith 1994, Selås 1997b, Keane 1999, Salafsky 2004). Furthermore, Widén (1989) reported higher breeding densities in areas richer in foods, and Bednarek et al. (1975) reported extremely high goshawk breeding densities in areas with only 12–15 % of woodland but very rich in food. Widén (1989) suggested that goshawks are more often limited by food than by nesting habitat.

Geographic and Annual Variation in Diets

Goshawk diets differ among forest types, among regions, and both seasonally and annually. Reynolds and Meslow (1984), Kennedy (1991), and Boal and Mannan (1994) reported between 14 and 37 different prey species in goshawk diets in a variety of western American conifer forests, while in eastern American deciduous forests, 23 different prey species were reported (Bosakowski and Smith 1992, Bosakowski et al. 1992). Much of the among-forest and regional differences in diets disappears, however, when prey are grouped at the genus level because prey species are often regionally replaced by congeners. For example, red squirrels (*Tamiasciurus hudsonicus*) in western Oregon are replaced by Douglas squirrels (*Tamiasciurus douglasi*) in eastern Oregon and Nuttall's cottontail (*Sylvilagus nuttalli*) in western North America is replaced by the eastern cottontail (*Sylvilagus floridanus*) in eastern North American (Hall 1981). Due to such replacements, goshawk diets can be generalized to include rabbits, tree squirrels, ground squirrels, woodpeckers, jays, thrushes, doves, pigeons, and grouse. However, goshawks frequently supplement these prey with as many as 20 other incidental bird and mammal species (Schnell 1958, Reynolds and Meslow 1984).

Annual variation in local goshawk diets may stem from annual variation in prey abundances associated with eruptive or inter-annual fluctuations in species such as snowshoe hare (*Lepus americanus*), red squirrel, and grouse (McGowan 1975, Doyle and Smith 1994). Although little winter goshawk diet information is available, diets are likely to vary seasonally due to habitat differences among prey, differential sampling of habitats by foraging goshawks, and the timing of estivation, hibernation, or migration of some prey. The abundance of non-migratory prey (tree squirrels, hares, grouse, and woodpeckers) during winter may affect whether goshawks stay on breeding territories or move to non-forest habitats in winter.

Determining Diets

Because the SWGS approach for developing conservation strategies requires the identification of a suite of important goshawk prey in a focal forest type, we review methods for estimating goshawk diets and a process that can be used to reduce a complete list of prey in a forest type to a reduced list of important prey. Most of our understanding of goshawk diets comes from the breeding period when prey is delivered to nests by adults. Breeding season diets have been estimated with several methods, each with a characteristic bias. A prey-remains method takes advantage of the fact that goshawks regurgitate pellets and pluck feathers and fur from prey in their nest areas (Reynolds and Meslow 1984, Martin 1987). A bias associated with this method is inaccurate counts of individuals or species due to species-specific differences in detectability of remains when they are being collected (Reynolds and Meslow 1984, Bielefeldt et al. 1992). A direct-observation method involves identifying and counting prey delivered to nests from adjacent blinds or with cameras (Schnell 1958, Boal and Mannan 1994, Grønnesby and Nygård 2000). Problems with direct observations are that the number of nests that can be observed is typically limited and difficulty of identifying prey whose diagnostic parts (feathers and fur) have been removed by the goshawks. Schnell (1958) identified 14 prey species from observations at a single nest in California, whereas Reynolds and Meslow (1984) identified 37 different species from prey remains collected at 58 goshawk nests in Oregon. Diet studies that combine these two methods are likely to result in more precise estimates of goshawk diets, but neither method accounts for prey eaten away from nests (Lewis et al. 2004).

What little we know about non-breeding season diets comes mostly from radio-telemetry study of wintering goshawks (Kenward 1979, Widén 1987, Stephens 2001, Drennan and Beier 2003, Tornberg and Colpaert 2001). Diets of goshawks that remain in forests during winter are not likely to differ greatly from the breeding diets, except prey that hibernate or migrate will be missing, and diets of goshawks that move to open habitats are more likely to include non-forest prey. Of course, diets should be determined from an adequate sample of goshawks within a forest type to reduce sampling error (e.g., a goshawk taking aquatic birds from a lake), and should be determined over an adequate number of years to include inter-annual fluctuations in prey species.

Suites of Important Prey

Reducing a complete list of goshawk prey in a forest to a subset of important goshawk prey may be necessary because some species are taken only incidentally and their inclusion might dilute the forest habitats needed by more commonly captured prey. Goshawk diets are rarely dominated by a few species. In California, six of a total 14 prey species contributed about 80% of the numbers of prey in the diet of a single goshawk pair (Schnell 1958), 18 of 37 species contributed 85% of prey in a large sample of Oregon nests (Reynolds and Meslow 1984), and 11 of 18 species contributed 67% of prey in Arizona (Boal and Mannan 1994). Also, rarely does a single prey species contribute more than 30% of total numbers of prey in a diet; in fact, most prey species contributes less than 5% of the total. If a threshold for identifying a suite of important prey was chosen to include all species contributing more than 2% of individuals in a goshawk diet, then the suite would include eight prey species (57% of total species) in Schnell's (1958) California study, 18 species (49%) in Reynolds and Meslow's (1984) Oregon study, and 11 species (61%) in Boal and Mannan's (1994) Arizona study.

However, because larger prey contribute more food biomass to the energy budget of goshawks, they can be more important than small prey even when small prey are eaten more often. Using the above 2% threshold in Table 1 excludes three large species—Belding's ground squirrel (*Citellus beldingi*), mountain cottontail (*Sylvilagus nuttalli*), Ruffed Grouse (*Bonasa umbellus*)—that perhaps should be included in a suite of important prey because of their body mass. In Table 1, thresholds lower than two individuals per species may include too many incidental prey. Alternatively, including too

Table 1. An example for identifying a suite of important goshawk prey, including the numbers and percent frequency of individuals by species, and a frequency and biomass ranking of each species in diets of breeding goshawks in Oregon (29 species, 227 individuals; Reynolds and Meslow 1984).

Species	Number [a]	Percent	Frequency rank	Biomass[b] rank
Steller's Jay (*Cyanocitta stelleri*)	29	12.8	1	4
Snowshoe hare (*Lepus americanus*)	24	10.6	2	1
American Robin (*Turdus migratorius*)	20	8.8	3	12
Golden-mantled ground squirrel (*Citellus lateralis*)	17	7.4	4	5
Northern flying squirrel (*Glaucomys sabrinus*)	15	6.6	5	7
Northern Flicker (*Colaptes auratus*)	15	6.6	5	10
Douglas' squirrel (*Tamiasciurus douglasi*)	13	5.7	7	6
Mountain Quail (*Oreortyx pictus*)	10	4.4	8	8
Mourning Dove (*Zenaida macroura*)	7	3.1	9	16
Chipmunk spp. (*Eutamias* spp.)	7	3.1	9	17
Blue Grouse (*Dendragapus obscurus*)	5	2.2	11	2
Gray squirrel (*Sciurus grisesus*)	5	2.2	11	3
Gray Jay (*Perisoreus canadensis*)	5	2.2	11	19
----------------------Greater than four individuals/species threshold [c]-----------------------				
Belding's ground squirrel (*Citellus beldingi*)	4	1.8	14	15
Varied Thrush (*Ixoreus naevius*)	4	1.8	14	20
--------------------Greater than three individuals/species threshold [c]-----------------------				
Mountain cottontail rabbit (*Sylvilagus nuttalli*)	3	1.3	16	11
Townsend's chipmunk (*Eutamias townsendii*)	3	1.3	16	23
----------------------Greater than two individuals/species threshold [c]----------------------				
Mallard (*Anas platyrhynchos*)	2	0.9	18	9
Ruffed Grouse (*Bonasa umbellus*)	2	0.9	18	14
Townsend's ground squirrel (*Citellus townsendii*)	2	0.9	18	24
European Starling (*Sturnus vulgaris*)	2	0.9	18	27
Hairy Woodpecker (*Picoides villosus*)	2	0.9	18	30
Williamson's Sapsucker (*Sphyrapicus thyroideus*)	2	0.9	18	32
Western Tanager (*Piranga ludoviciana*)	2	0.9	18	34
Finch spp. (*Carpodacus* spp.)	2	0.9	18	36
Dark-eyed Junco (*Junco hyemalis*)	2	0.9	18	39
Great horned Owl (*Bubo virginianus*)	1	0.4	27	13
Cooper's Hawk (*Accipiter cooperi*)	1	0.4	27	18
Bushy-tailed woodrat (*Neotoma cinerea*)	1	0.4	27	21
Pileated Woodpecker (*Dryocopus pileatus*)	1	0.4	27	22
Woodrat spp. (*Neotoma* spp.)	1	0.4	27	25
Dusty-footed woodrat (*Neotoma fuscipes*)	1	0.4	27	26
Black-billed Magpie (*Pica pica*)	1	0.4	27	28
Western Screech-Owl (*Otus kennicottii*)	1	0.4	27	29
Lewis' Woodpecker (*Melanerpes lewis*)	1	0.4	27	31
Red-winged Blackbird (*Agelaius phoeniceus*)	1	0.4	27	33
Red-naped Sapsucker (*Sphyrapicus nuchalis*)	1	0.4	27	35
Black-headed Grosbeak (*Pheucticus melanocephalus*)	1	0.4	27	37
Least chipmunk (*Eutamias minimus*)	1	0.4	27	38

[a] After Reynolds and Meslow (1984).

[b] Biomass = number of individuals of a species in diet x mass of the species determined from the literature and museum collections (Baldwin and Kendeigh 1938, Hartman 1955, Collins and Bradley 1971, Dunning 1984, Reynolds and Meslow 1984, Bosakowski and Smith 1992) .

[c] Thresholds define three possible suites of important prey, with minimums of 4, 3, and 2 individuals per species. If the threshold of 4 individuals per species were used, the suite would contain 15 important prey, with some contributing as little as 1.8 % of items.

few species may result in an insufficiently diverse and abundant food resource to sustain goshawks through poor food years. Other information, such as a comparison of the abundance of a marginally important prey species in unmanaged forests to its abundance and frequency in goshawk diets in managed forests, may help decide on whether or not to include marginal species in the suite of important prey. Finally, we pointed out that the diversity of habitats provided for the suite of 14 prey species in southwestern forests also provided habitats for many incidental prey species as well as non-prey species (Reynolds et al. 1992).

Prey Habitats

After identifying a suite of important prey, the distributions, life histories, abundances, and habitats of the prey can be assessed in the literature and by expert opinion (Reynolds et al. 1992). Much information on the ecology and habitats of a variety of goshawk prey is available in Reynolds et al. (1992) and Drennan et al. (*this volume*). Often, information on the ecologies, habitat relations, and foods of prey species within a certain forest type is limited. In these cases, information from the same or a similar forest type in adjacent regions could be used. Limitations of these kinds of data include: (1) incomplete information on a species' life histories, population ecologies, and how these vary among forest types, (2) uncertainty about relationships between a species' demography and habitat conditions, (3) difficulties distinguishing a species' habitat use from its habitat preference, and (4) the appropriateness of using studies designed to investigate other questions (Morin 1981, VanHorne 1983, White and Garrott 1990).

Forest Habitat Elements of Prey

Once the life histories, habitats, and foods of important prey are assessed, a list of forest habitat elements (FHE), including items such as vegetation structural stages, size of openings, edges, understory and overstory compositions and structures, woody debris, snags, nesting and feeding substrates, and interspersion of forest age classes, for each prey species can be developed. This process can be facilitated with matrices that display the frequencies of the relative importance of FHEs for each prey species (Table 6 in Reynolds et al. 1992). An overall relative importance of FHEs for the suite of prey can be estimated by summing the levels of importance of each FHE across species (Table 6 in Reynolds et al. 1992). Such assessments for the suite of goshawk prey in southwestern forests resulted in an understanding of the importance of sustaining large amounts of mid-aged to old forests dispersed at a fine scale within landscapes (Reynolds et al. 1992, Long and Smith 2000).

Forest Ecology

Forests, and by extension forest habitats, are dynamic ecosystems that undergo change through plant growth and succession and periodic natural and anthropogenic disturbances such as wind, fire, insects, and vegetation management. Each of these factors changes the composition, structure, and pattern of plant communities, which in turn have short- and long-term effects on wildlife habitats. Thus, describing and managing forest habitats for plants and animals in the goshawk food web requires an understanding of forest dynamics as well as the habitat relationships of the plants and animals. Here we identify sources of essential information on how to develop and sustain desired forest conditions through management, how to identify limits or constraints on such variables as maximum tree sizes and longevity, sizes of plant aggregations and tree densities, and the species composition, structure, and landscape pattern of desired landscapes. Some important processes that occur during forest development include plant establishment, development, senescence, competitive exclusion, biomass accumulation, canopy gap initiation, understory re-initiation, maturation, decadence development, and mortality (Franklin et al. 2002). Each of these processes, which typically vary among forest types, is often integrated into potential vegetation classifications. Moreover, these classifications provide estimates of forest productivity, vegetation development rates, plant occurrence and position (e.g., canopy layer), life form (e.g., grass, forb, or shrub), their roles in plant succession (e.g., early, mid-, or late seral), and include physical and biological components such as climate, soil, geology, and vegetation (Daubenmire and Daubenmire 1968, Cooper et al. 1991, Hann et al. 1997). These classification systems can also be integrated with known fire relations (Bradley et al. 1992, Agee 1993, Hann et al. 1997, Graham et al. 1999b, Kaufmann et al. 2000) and are compatible with efforts for defining and mapping fire regime condition classes for forests (Schmidt et al. 2002). Sources of data on current forest conditions include Forest Inventory and Analysis and Geospatial Analysis Processes (USGS National Gap Analysis Program 1995, O'Brien 2002).

Synthesis of Components

Once information on goshawks, their prey, and forest ecology is assembled, it is synthesized into desired habitat that benefits the goshawk and all its important prey (Fig. 1). The SWGS used a vegetation structural stage (VSS) classification to describe forest development. VSS is an integrative approach that combines vegetation growth and maturation into generalized descriptions of forest conditions from young to old vegetation complexes (Thomas et al. 1979, Verner and Boss 1980, Oliver and Larson 1990, Reynolds et al. 1992, Franklin et al. 2002). The FHEs were incorporated with VSS into generalized landscapes that included abundant and dispersed large tree components (large live trees, large snags, and large logs), groups (<0.2 ha in ponderosa pine) of trees with interlocking crowns, small openings around tree groups with a well developed grass/forb/shrub vegetation (Fig. 2), and a high level of interspersion (intermixing) of all VSS, each a small group of trees (Reynolds et al. 1992, Long and Smith 2000; Fig. 2). In ponderosa pine, groups of trees with interlocking crowns allow the tassel-eared squirrel (*Sciurus aberti*) and red squirrel (*Tamiasciurus hudsonicus*) to move among tree crowns, a critical habitat element especially around their nests (Reynolds et al. 1992, Dodd et al. 2003). Because mycorrhizal fungi are an important food for squirrels, and because the fungi are more abundant in mid-aged forests, an interspersion of mature and old VSS groups with mid-aged VSS groups benefits squirrels. Small (Fig. 1) openings containing grasses, forbs, and shrubs around tree groups are habitat for prey such as rabbits, ground squirrels, and grouse that require openings for feeding or brood rearing. These openings should remain treeless because they are often occupied by roots of the grouped trees (Pearson 1950), facilitating nutrient uptake and vigorous tree growth. Openings, because they are occupied by important prey, offer hunting opportunities for goshawks (Reynolds et al. 1992). For southwestern forests, the three older VSS were the most important habitats for the suite of prey, followed by openings.

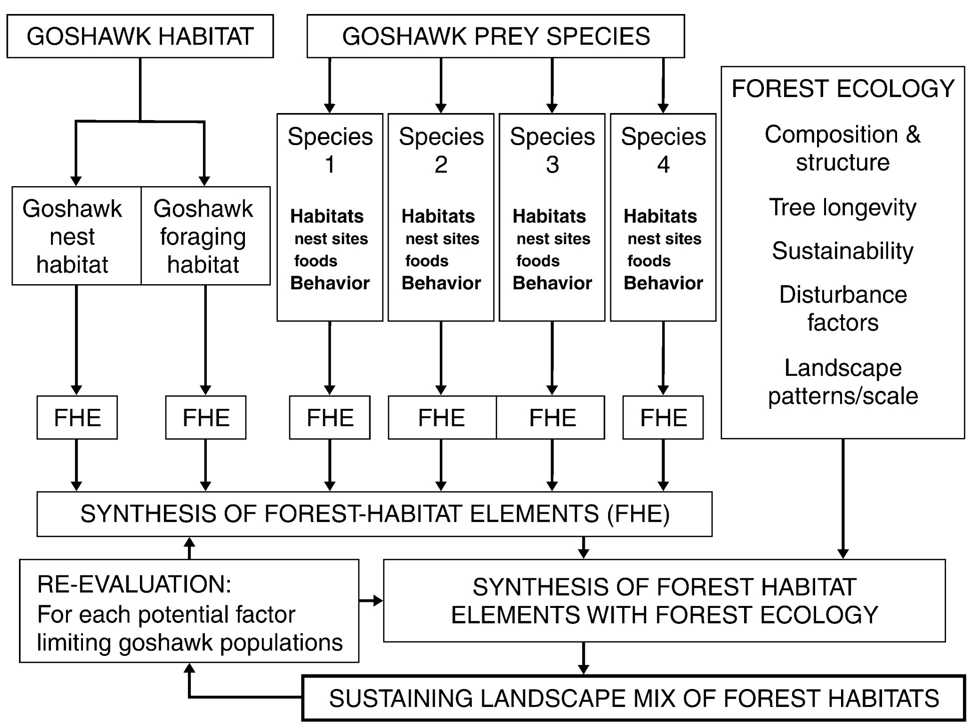

FIGURE 1. Essential components and two levels of synthesis of goshawk habitats, prey habitats, and the composition, structure, and pattern of forests used to identify mixes of desired habitats in the southwestern goshawk conservation strategy (Reynolds et al. 1992).

FIGURE 2. The desired groups of trees with interlocking crowns surrounded by openings in southwestern ponderosa pine forests.

Forest Setting

An integration of information on the autecology and synecology of forest vegetation is essential for developing and sustaining goshawk and prey habitats (Fig. 1). A wealth of information on forest development can provide guidance for the development of the desired habitats. This information includes, but is not limited to, vegetation classifications, forest vegetation simulations, fire histories, natural-area descriptions, and wild-land, fuel-management strategies (Haig et al. 1941, Pearson 1950, Daubenmire and Daubenmire 1968, White 1985, Fulé et al. 1997, Reinhardt and Crookston 2003, Graham et al. 2004). Such information is used to fine tune the desired goshawk and prey habitats in a particular forest type to increase the likelihood that both can be attained and sustained.

Sustaining the desired landscape mix of goshawk and prey habitats requires the incorporation of the spatial and temporal dynamics of forest vegetation. Vegetation dynamics, including the establishment, development, senescence, and its composition, structure, and pattern, can be estimated and modeled (Oliver and Larson 1990, Reynolds et al. 1992, Franklin et al. 2002, Reinhardt and Crookston 2003). For example, sustaining the maximum amount of mature and old VSS in southwestern forests for goshawks and their prey was best achieved with about 10% of landscape in VSS 1 (grass-forb-shrub), 10% in VSS 2 (seedling-sapling), 20% in VSS 3 (young forest), 20% in VSS 4 (mid-aged forest), 20% in VSS 5 (mature forest), and 20% in VSS 6 (old forest) (Reynolds et al. 1992). These proportions reflect forest development from cohort establishment through canopy closure to old forests. However, classification systems that depict forest development over 1,000 yr tend to display greater proportions of a forest in the mature and old classes than classification systems depicting forest development through periods <300 yr. For example, Franklin et al. (2002) showed over 70% of the forest occurring in structural stages greater than 800 yr, as did Spies and Franklin (1996). Integrating a VSS distribution with goshawk habitats (nest area, PFA, foraging area) and tree-group metrics favoring the suite of southwestern prey, resulted in desired landscapes comprised of shifting mosaics of VSS through time and space (Reynolds et al. 1992, Long and Smith 2000).

Probably because of plant and animal adaptations to the natural compositions, structures, and patterns, the desired conditions developed in the SWGS approximated the composition, structure, and landscape pattern existing in southwestern forests before fundamental changes in natural disturbance regimes (Pearson 1950, White 1985, Fulé et al. 1997, Long and Smith 2000) (Fig. 2). Of course, it is important that the plant and animal habitat relations used to develop ecosystem-based conservation strategies be internally consistent as well as consistent with current knowledge (Guldin et al. 2003).

Implementation of the Goshawk Strategy

Once the desired compositions, structures, and mixes of goshawk and prey habitats are described, management actions can be developed and implemented through appropriate planning processes. The SWGS recommended that goshawk breeding habitat be partitioned into nest areas, PFAs, and foraging areas, and because the movements of breeding goshawks are energetically limited to some finite space around their nests, that these home range components be approximately centered on the nest. Goshawk conservation strategies can be implemented at a variety of spatial scales depending on management objectives. For example, implementation at the goshawk home range scale is appropriate for developing and protecting habitats in known territories. If the intent is to provide habitat for undiscovered goshawks or for an expansion of a goshawk population, the scale must be larger, e.g., a national forest or ecoregion (Reynolds et al. 1992, Graham et al. 1999b). Implementing the strategy in entire landscapes accommodates seasonal, annual, and geographic variation in goshawk home range sizes (Hargis et al. 1994, Boal et al. 2003), and eliminates the need to specify the number, their juxtaposition, and connectivity of breeding territories to sustain goshawk populations.

Specific management actions and the intensity that they are applied should be contingent on the differences between the existing conditions and the desired conditions. If differences are great (e.g., no old-forest structure), centuries may be needed to develop the desired conditions. For example, >200 yr are required to develop old-forest structure in southwestern ponderosa pine forests (Reynolds et al. 1992), and >1,200 yr are required to develop all of the structural stages found in northwestern Douglas-fir forests (Franklin et al. 2002). The capability of forests to produce the desired conditions can vary among sites depending on factors such as soils, slope, exposure, elevation (Daubenmire and Daubenmire 1968, Wykoff and Monserud 1988, Basset et al. 1994). Thus, differing growth potentials require that site-specific desired conditions be matched to a site's capabilities. Not all sites within a landscape can, nor should they have, the same exact conditions.

The Kaibab National Forest in Arizona began implementing the SWGS in ponderosa pine forests in 1993. Figure 3 displays one such implementation (right portion of photo) adjacent to 12–16 ha seed-tree cuts (center, lower left), a forest treatment in which a few trees are retained as seed sources, and a natural area (top center) that had recent low-intensity surface fires and little tree cutting. Note the similarities in the aggregation of ponderosa pine trees and surrounding openings in the implementation area and the natural area. A lesson learned from multiple implementations is to avoid removing trees from within groups (especially in mid-aged, mature, and old VSS). Thinning groups often eliminates the interlocking of tree crowns, critical habitat for tree squirrels (Dodd et al. 2003). Rather, when tree cutting is needed to create or sustain the desired conditions, an entire group of trees should be regenerated as opposed to thinning within a group. The desired within-group structures in both mature and old VSS could be developed with appropriate forest treatments (e.g., thinning or prescribed fire) in the younger age classes (e.g., seedling-sapling, young forests, and mid-aged forests; Reynolds et al. 1992).

Evaluation of Implementation

Squires et al. (1998) suggested that the SWGS be tested before large scale implementation. Testing is needed to determine if management actions successfully moved existing forest conditions toward the desired conditions and if the actions had the desired effects on goshawks and their prey. One such test is to compare goshawk reproduction and survival in forests that are in or near the desired conditions to those in contrasting forests (paired-landscape approach). Such comparisons, however, could be confounded by ecological differences (e.g., soil types) in the areas being compared. Another approach is to monitor the effects of implementation on the same sample of goshawk territories before and after treatment design. However, depending on the degree of difference between existing and desired forest conditions, and because annual forest treatments are typically small relative to goshawk home ranges, achieving the desired conditions on a study sample of goshawk home ranges could take decades. Of course, interim monitoring and evaluating the effectiveness of implementation on moving the existing forest conditions toward the desired conditions

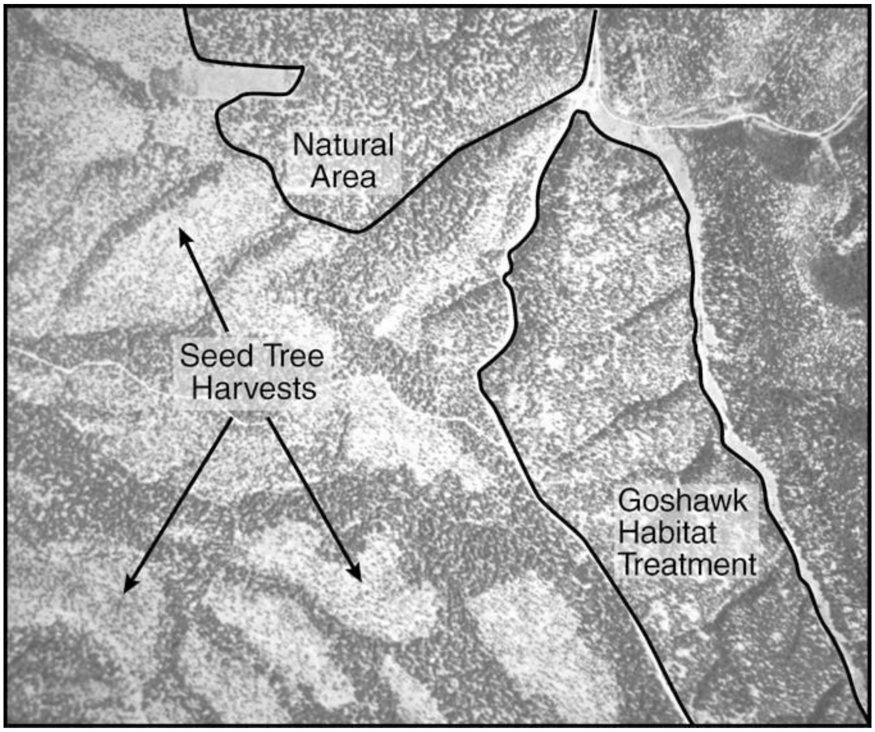

FIGURE 3. Aerial photo showing a 1994 implementation of the southwestern goshawk conservation strategy (Reynolds et al. 1992) adjacent to seed tree harvests and a natural area in ponderosa pine forest in Arizona.

and on increasing the abundance of goshawk prey species should be undertaken. Such monitoring (versus a testing program focused on goshawks) could be achieved at greatly reduced costs because much smaller areas would be needed. Whatever approach is taken, a sound experimental design is required to evaluate implementation. Some potential problems in assessing the effectiveness of implementation are the needs for replications, risks of incorrectly assigning causal inferences due to ecological complexity and interactions within an ecosystem framework, and risks of spatial and temporal autocorrelations within the data (Mellina and Hinch 1995). Considerable economic costs would also be associated with testing the SWGS in sufficiently large landscapes. Because of these difficulties, combined with the improved likelihood that the broad-based ecosystem approach of the SWGS will successfully sustain goshawks, and because implementation initiates the restoration of management-altered forest habitats and ecosystems, we suggest that immediate implementation in broad landscapes is a better option than the long wait for experimental tests of the SWGS's effectiveness. During implementation, however, we advocate monitoring programs that track the habitats and populations of goshawk and their prey, not necessarily within a testing framework, but as integral parts of an adaptive management program (McDonnell et al. 1997, Murry and Marmorek 2003). The SWGS was based on the habitat relationships of many plants and animals, an understanding of the autecology and synecology of the forest vegetation, and on knowledge of vegetation treatments to create the desired forest conditions. Do we know that this approach is appropriate or that the desired conditions are correct and sustainable (Long and Smith 2000)? Some degree of uncertainty exists regarding these questions; however, we do know that past management fundamentally altered forest ecosystems and that active management in many cases is needed to restore the ecosystems.

Added Benefits of Implementation

Reynolds et al. (1992) identified a number of added benefits from implementing the SWGS. A main benefit is restoration of forest ecosystems. Implementing of the SWGS benefits many plants and animals of southwestern forests by restoring tree densities, structures, and patterns similar to

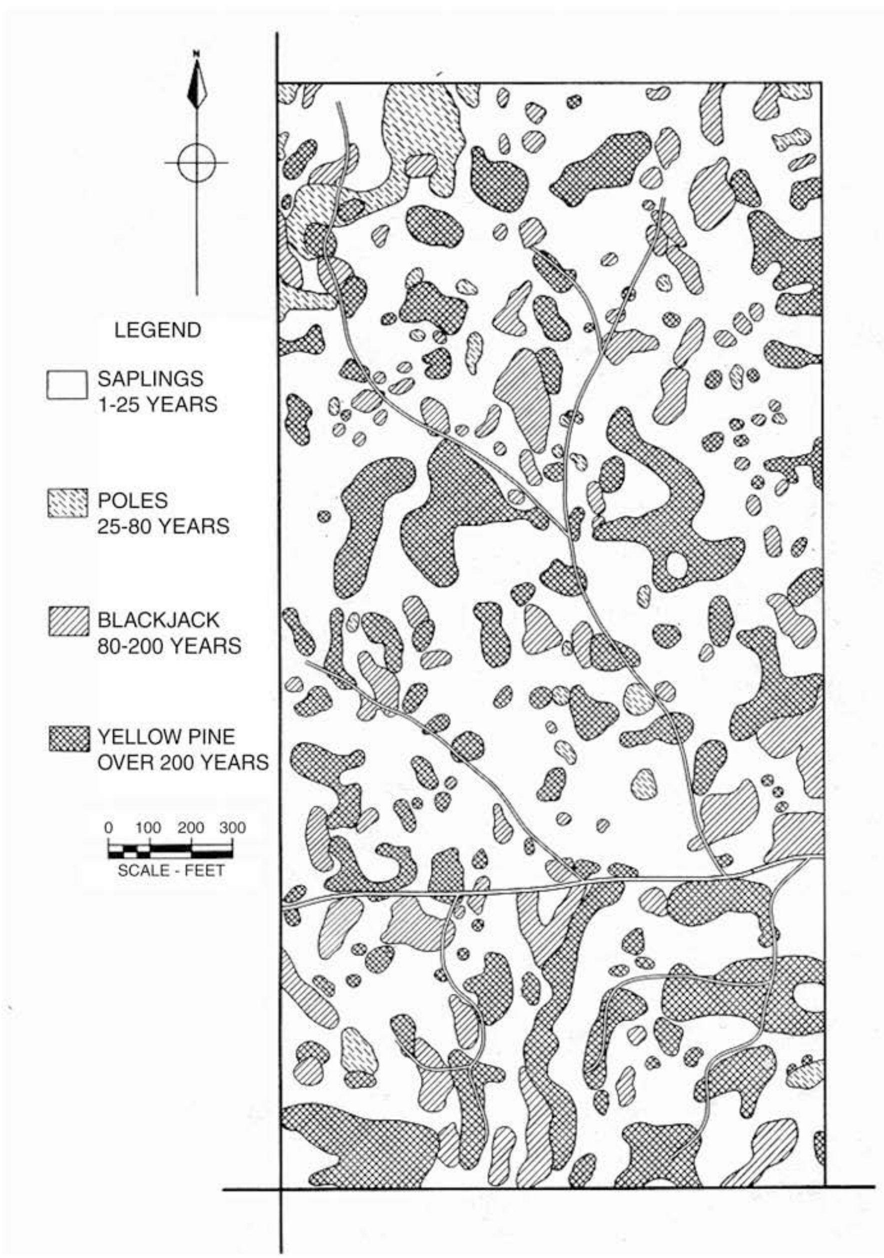

FIGURE 4. Historical mix of groups of different aged ponderosa pine trees on the Fort Valley Experimental Forest, Flagstaff, Arizona (from Pearson 1950, White 1985). This and other information (see text) provided references for supporting the desired sizes and mix of vegetation structural stages that could likely be sustained in southwestern ponderosa pine forests (Reynolds et al. 1992).

those occurring pre-settlement (circa 1850; Fig. 4). Throughout much of interior of western North America, tree densities in dry conifer forests have greatly increased since the initiation of fire exclusion in the early 1900s (Cooper 1960, Weaver 1961, Covington and Moore 1994b, Graham et al. 2004). In pre-settlement times, frequent surface fires maintained open forest conditions by cleaning the forest floor and killing small trees (Weaver 1943, Graham et al. 2004). In addition, timber harvests and associated treatments tended to homogenize forest composition, structure, and pattern (Nyland 2002).

Thus, forests have become increasingly dense and less diverse. These changes increased inter-plant competition for moisture and nutrients, resulting in decreased tree vigor, increased tree disease and insect epidemics, and increased frequency of lethal wildfires (Weaver 1943, Fellin 1979, Williams and Marsden 1982, Anderson et al. 1987, Swetnam and Lynch 1989, Covington and Moore 1994b, Graham 2003, Graham et al. 2004).

The desired forest conditions described in the SWGS resembled the historical conditions of southwestern ponderosa pine forests described by Pearson (1950) and White (1985). These similarities suggest that implementing the SWGS would move forests towards restoration of pre-settlement conditions (Long and Smith 2000). For example, the SWGS restores old structures—large live trees, snags and logs—maintains groups of trees with interlocking crowns, promotes the grass-forb-shrub layer, and minimizes the risk of lethal wildfires by reducing surface and ladder fuels (Reynolds et al. 1992, Graham 2003, Graham et al. 2004). In addition, by favoring lower stand densities, the strategy reduces the likelihood of disease and insect epidemics (Schmid and Mata 1992, Harvey et al. 1999). These conditions also are similar to those suggested as being desirable in the Healthy Forests Initiative and Healthy Forests Restoration Act (USDA Forest Service 2004).

The SWGS has been described as single-species management (Beier and Maschinski 2003). However, the SWGS is a multi-species strategy because it included the habitats and ecological relationships of many plant and animals in the goshawk food web (Reynolds et al. 1992, Long and Smith 2000). Thus, the SWGS shifts the focus from single-species and stand-level management to vegetation management for food webs in large landscapes (Reynolds et al. 1992, Long and Smith 2000). The SWGS utilized the concept of desired forest conditions. Advantages of this concept include the recognition that long time periods may be required to attain the desired conditions, allows variable management actions depending on existing conditions, calls attention to native disturbance regimes and how these operated at multiple temporal and spatial scales, and focuses on resources that are left after treatment rather than on what resources are removed (Reynolds et al. 1992, Haynes et al. 1996, Graham et al. 1999b, Franklin et al. 2002).

SUMMARY

The strategy for conserving goshawks in the southwestern US described desired forest landscapes intended to sustain the habitats of both goshawks and their prey (Reynolds et al. 1992). The approach and procedures developed in this conservation strategy are readily adapted to other locations and forests. However, the specific desired conditions for other forests are likely to be different because the kinds of prey available as well as the composition, structure, pattern, and dynamics of the vegetation often differs among forests. The approach we present identifies goshawk nest and feeding habitats and nest and feeding habitats of important goshawk prey in particular forest types (Fig. 1). Goshawk habitats were summarized in the SWGS, as were the habitats and life histories of 14 important goshawk prey species. Moreover, we described a procedure for reducing a full list of species eaten by goshawks to a manageable suite of important prey. The information assembled for the goshawk and its prey should be integrated with the ecological dynamics of the vegetation in a focal forest type and we provided suggestions as to how this integration can be accomplished (Fig. 1). Depending on the current forest conditions—we provide suggestions on how they can be determined—management actions may be as simple as doing nothing to actively managing forests to develop and maintain goshawk and prey habitats. While we believe that the approach used in the SWGS for identifying and developing desired habitats for goshawks is sound, economically feasible, and, due to its diversity of components, robust to failure to sustain goshawks, we also realize that forest management is fraught with uncertainties and that managing goshawk and prey habitats is a long-term proposition. What is needed is an in-depth analysis of implementation projects as they come on line to make preliminary judgments about what works, what does not, and how success should be measured.

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