NORTHERN GOSHAWK ECOLOGY: AN ASSESSMENT OF CURRENT KNOWLEDGE AND INFORMATION NEEDS FOR CONSERVATION AND MANAGEMENT

JOHN R. SQUIRES AND PATRICIA L. KENNEDY

Abstract. The contentious and litigious history associated with managing Northern Goshawks (*Accipiter gentilis*) has focused much research attention toward understanding this species' life history. Results from these studies address many key information needs that are useful to managers and decision makers, but many pressing information needs exist to address key conservation questions. Our goal was to assess the current state of knowledge in light of recent research. We focused on published information, but we also include unpublished studies if necessary to address key information needs. We included key European studies, for areas where there is little information for North American populations. Based on our assessment of current knowledge, we review goshawk conservation and management in terms of threats, ecological relationships; information needs, survey and monitoring, managing in the face of uncertainty, and the increasing demands for science-based management. We conclude by offering our understandings or qualified insights relative to some of the most salient issues confronting goshawk conservation and management.

Key Words: *Accipiter gentilis*, goshawk ecology, goshawk management, Northern Goshawk.

ECOLOGÍA DEL GAVILÁN AZOR: UNA VALORACIÓN DEL CONOCIMIENTO ACTUAL Y DE LAS NECESIDADES DE INFORMACIÓN PARA EL MANEJO Y LA CONSERVACIÓN

Resumen. La contenciosa y discordante historia asociada al manejo del Gavilán Azor *(Accipiter gentilis)* ha enfocado la atención de investigación hacia el entendimiento de la historia de la vida de esta especie. Los resultados de estos estudios dirigen mucha información clave necesaria que es útil para administradores y los tomadores de dediciones, sin embargo, existen muchas necesidades urgentes de información, para dirigir preguntas clave. Nuestro objetivo fue valorar el estado actual del conocimiento sobre investigación reciente. Nos enfocamos en información publicada, pero también incluimos estudios no publicados si era necesario, para dirigir necesidades de información clave. Incluimos estudios Europeos clave, para áreas donde existe poca información para poblaciones de Norte América. Basados en nuestra valoración del conocimiento actual, revisamos la conservación y el manejo del gavilán, en términos de amenazas , relaciones ecológicas, necesidades de información, estudio y monitoreo, incertidumbre en el manejo, y en las crecientes demandas por el manejo basado en la ciencia. Concluimos ofreciendo nuestros conocimientos o ideas relacionadas a algunas de las cuestiones más sobresalientes enfrentadas en la conservación y el manejo del gavilán.

Since the early 1980s, researchers have investigated how forest management impacts Northern Goshawk (*Accipiter gentilis,* hereafter referred to as goshawk) populations (Reynolds et al. 1982, Moore and Henny 1983, Reynolds 1983). Crocker-Bedford's (1990) contention that goshawk populations in the Southwest were dropping precipitously catalyzed state and federal agencies to begin research programs. The goshawk has been proposed for listing several times under the Endangered Species Act (ESA) and its status has been, and still is, the object of considerable litigation (Peck 2000).

Many aspects of goshawk ecology are poorly understood putting decision-makers in the difficult position of having to make important management decisions based on incomplete information. Increasingly, decision-makers are also being asked via the courts and public opinion to define what is defensible information given our limited knowledge and high uncertainty regarding many aspects of goshawk ecology. The primary goal of this paper is two-fold. First, we provide a thorough literature review of goshawk ecology to define our current state of knowledge. Second, based on these understandings, we discuss pressing management issues and information needs. This second goal also includes discussions of data quality standards because they help define defensible information that in turn affects goshawk research and management. We conclude by providing qualified insights which are an attempt to embrace science while

recognizing uncertainty (Ruggiero et al. 2000). Qualified insights are specific statements that are backed by the balance of scientific evidence (Ruggiero and McKelvey 2000); these statements help communicate to land managers and decision makers the critical issues in a distilled format.

To describe our current state of knowledge, we drew primarily from the recent reviews of Squires and Reynolds (1997) and Kennedy (2003) and updated these reviews with new information. Not all publications on goshawks were referenced in this assessment, nor were all published material considered equally reliable. Literature that was not included does not mean these studies were inferior scientifically. Rather, the results were not directly relevant to our assessing the current state of knowledge relative to management and conservation. We preferentially referenced peer-reviewed literature because this is the accepted standard in science. Non-refereed publications or reports were regarded with greater skepticism, but were included if these papers addressed important information gaps not reported in published literature. Moreover, we recognize that researchers in Europe have many important insights regarding this species, but we do not know how well these understandings can be generalized to North American populations. Thus, we included European publications that were particularly relevant to important information gaps, but we did not exhaustively review studies outside North America. Further, we downplayed certain topics that are important, but were either too extensive to cover in this paper or were better addressed in a different format. For example, we did not rigorously discuss the ecology of individual prey species nor did we discuss the forest ecology associated with the many habitat types used by goshawk. We minimized our discussions of distribution and systematics because this was reviewed in Squires and Reynolds (1997) and little new published information is available on this topic. We also did not discuss field identification due to the many excellent field guides that provide a better format (Wheeler and Clark 1995, Wheeler 2003). Finally, in reporting the current state of knowledge, we could not conduct a comprehensive meta-analysis of goshawk literature nor did we conduct new analyses aimed at addressing conservation concerns. For example, we did not examine current federal land management plans to discern the direction of forest management relative to goshawks, nor did we analyze geographic information systems (GIS) and other spatial data to assess habitat trends like changes in the abundance and spatial arrangement of mature forests. Thus, we only discuss key conservation issues and information needs based on the current state of knowledge and our collective experience researching goshawks.

DISTRIBUTION AND SYSTEMATICS

SUBSPECIES IN NORTH AMERICA

Approximately 8–12 subspecies of goshawks exist worldwide depending on the taxonomic source (Brown and Amadon 1968, del Hoyo et al. 1994, Squires and Reynolds 1997). Although some authorities recognize three subspecies in North America (Johnsgard 1990), the American Ornithologists' Union (1998) recognizes only two—*A. g. atricapillus* and *A. g. laingi*. *A. g. atricapillus* breeds throughout Alaska, Canada, and the mountains of the western and eastern US. *A. g. laingi*, breeds on Queen Charlotte and Vancouver Islands (Taverner 1940, Johnson 1989), possibly extending north to Baranof Island in southeast Alaska or Prince William Sound in south-central Alaska (Webster 1988, Iverson et al. 1996, Cooper and Stevens 2000). A third subspecies, *A. g. apache*, is not recognized by the AOU as a legitimate subspecies, but its putative distribution is from southern Arizona south to Jalisco in the mountains of Mexico (van Rossem 1938). The USDI Fish and Wildlife Service (USFWS) (USDI Fish and Wildlife Service 1998a) considers the validity of this subspecies to be unresolved; *A. g. apache* is recognized by some scientists (Snyder and Snyder 1991, Whaley and White 1994). The Eurasian subspecies (*A. g. gentilis*) is larger in size and body weight than any of the North American subspecies (del Hoyo et al. 1994).

NORTH AMERICAN BREEDING DISTRIBUTION

In North America, *A. g. atricapillus* breeds from boreal forests of north-central Alaska to Newfoundland and south to western and southwestern montane forests in the US, and locally in the mountains of northwestern and western Mexico (Fig. 1). In central to eastern North America, goshawks breed in the western Great Lakes region and eastward to Pennsylvania, central New York, northwestern Connecticut, and locally south in montane habitats at least to West Virginia and possibly eastern Tennessee and western North Carolina (Brown and Amadon 1968, Squires and Reynolds 1997, USDI Fish and Wildlife Service 1998a). Factors that limit the southern extent of the goshawk range are unknown (Kennedy 1997).
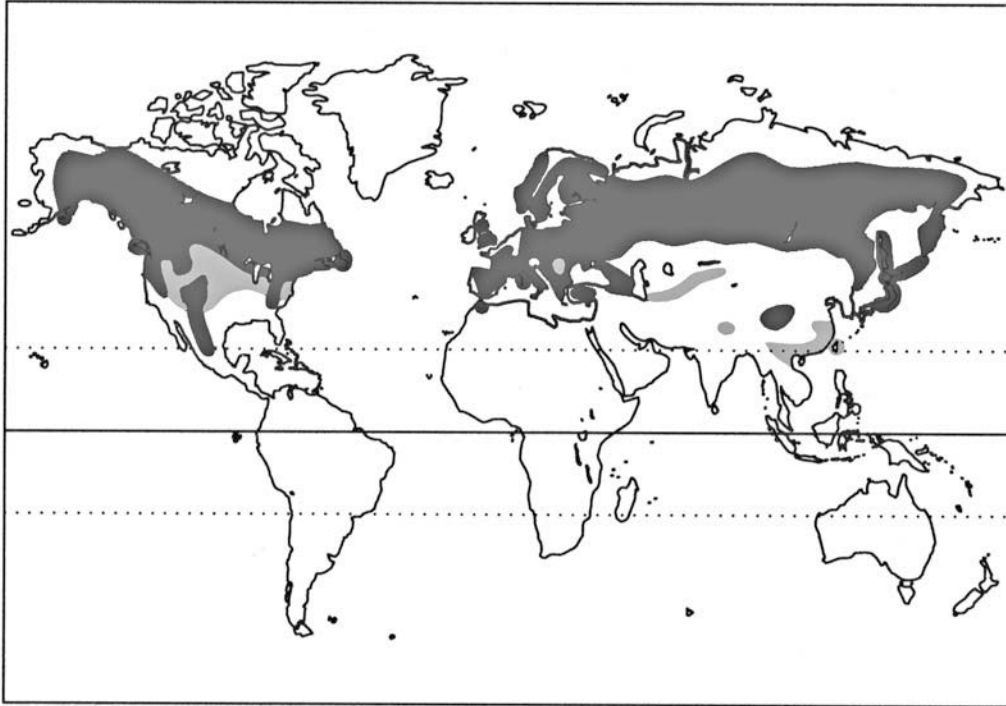
FIGURE 1. Global distribution of the Northern Goshawk. Dark shading delineates current breeding range; light shading indicates areas occupied by goshawks outside the breeding season or in areas where breeding has not yet been documented (from del Hoyo et. al. 1994).

Although few data exist regarding historical changes, Squires and Reynolds (1997) suggested the distribution of the goshawk in the northern and western portions of its range is relatively unchanged since Europeans settled North America. However, the goshawk's range may have been more widespread in the eastern US before the extinction of the Passenger Pigeon (*Ectopistes migratorius*) in the early 1900s, because the pigeon may have been an important prey species. The goshawk's range may also have been more extensive before the substantial deforestation of this region, which reached a peak at the end of the 19th century (Kennedy 1997). Some evidence suggests these populations may be recovering as forests re-establish and mature (Speiser and Bosakowski 1984, Kennedy 1997). For example, during the mid-1950s in Massachusetts, nesting was restricted to the western part of the state, but the species now nests throughout the state (Veit and Petersen 1993). In Minnesota and Wisconsin, the goshawk is currently nesting in more counties then was documented historically (Janssen 1987, Rosenfield et al. 1998, Roberson et al. 2003). Evidence that eastern goshawk populations may be expanding or reoccupying their former range should be interpreted cautiously; such reports could merely reflect increased search efforts (Kennedy 1997).

NORTH AMERICAN WINTER DISTRIBUTION

Goshawks winter throughout their breeding range, extending south to southern California (Small 1994, Squires and Reynolds 1997) and northern and central Mexico (Sonora, Sinaloa, Durango, and Chihuahua). Wintering goshawks are occasionally observed in the lower Colorado River valley of Arizona (Rosenberg et al. 1991), northern and central Texas (Oberholser 1974), and north to Arkansas (James and Neal 1986). During incursion years, a few recorded sightings of goshawks were documented for Missouri (Robbins and Easterla 1992), in the Appalachian Mountains of Tennessee (Robinson 1990), and east to the Atlantic Ocean (Root 1988, American Ornithologists' Union 1998). Christmas Bird Count (CBC) data suggest goshawks generally avoid wintering in southeastern North America (Root 1988), but occasionally winter in northern portions of the Gulf States, including west-central Florida (American Ornithologists' Union 1998).

LEGAL AND ADMINISTRATIVE STATUS IN THE UNITED STATES

History of Goshawk Litigation

Accipiter gentilis atricapillus

Based on findings of Crocker-Bedford (1990) and unpublished research conducted on the Kaibab National Forest in Arizona, environmental organizations sought more extensive protection of goshawk habitat. They thought that current logging practices threatened goshawk viability and thus, violated the National Forest Management Act (NFMA) (Peck 2000). This resulted in a series of legal actions that extend from 1990, when environmental groups first formally requested the Southwestern Region (Region 3) of the USDA Forest Service (USFS) to halt timber harvest in southwestern forests on the Kaibab Plateau, to the present time (Table 1). A goshawk scientific committee (GSC) and a goshawk task force were formed to review goshawk management needs in the Southwest Region of USFS. The GSC produced the *Management Guidelines for the Northern Goshawk in the Southwestern Region* that provides the current basis for goshawk management in this USFS Region (Reynolds et al. 1992).

In September 1991, the USFWS was petitioned to list the goshawk as endangered west of the 100th meridian, and later was listed as a candidate, or category 2 species, under the ESA (Table 1). In June 1992, the petition was denied on taxonomic grounds (no evidence suggests that goshawks west of the 100th meridian are a distinct population), and suits were subsequently filed to reverse the action. From this, the courts claimed the USFWS's findings were arbitrary and capricious and ordered the agency to issue another decision. In 1996, the USFWS issued another decision again denying listing based on taxonomic reasons and the courts again did not support this decision. Thus, in 1997 the USFWS issued a positive 90-d finding that sufficient evidence existed to warrant a status review. They completed their status review in 1998 and concluded there was insufficient evidence to support listing the goshawk under the ESA. This decision has been supported by the courts (Center for Biological Diversity vs USFWS No. 01-35829 [Ninth Circuit Court Decision CV-99-00287-FR issued 21 July 2003]). Also, a recent technical review of this decision by a joint committee of scientists from The Raptor Research Foundation (RRF) and The Wildlife Society (TWS) (Andersen et al. 2005) found that available habitat and demographic information are not sufficient to evaluate goshawk demographic trends.

The USFWS based its decision not to list the goshawk on a review of existing data and the findings of a status review team of nine biologists (including two USFS biologists). The status review team found it was not possible to determine whether goshawk population numbers in the review area were stable, increasing, or decreasing, and concluded the distribution of breeding goshawks in the West did not appear to have changed from the historical range. The USFWS also concluded the goshawk is a forest habitat generalist and is not dependent solely on old-growth forests.

In 1995, the Southwestern Region of the USFS (Region 3) issued an environmental impact statement (EIS) to modify its forest plans to incorporate the Reynolds et al. (1992) goshawk guidelines. The final EIS (FEIS) claims the goshawk is a habitat generalist and this claim was challenged by a consortium of conservation groups, individuals, and state agencies. In November 2003, the U.S. Ninth Circuit Court of Appeals ruled the USFS had inadequately disclosed responsible scientific opposition in preparing the final environmental impact statement for southwestern forests. The court recently reversed and remanded the decision stating the EIS violated the National Environmental Policy Act (NEPA) because it did not review the opposing scientific information that indicated the goshawk was a habitat specialist (Center for Biological Diversity and Sierra Club v. U.S. Forest Service, No.02-16481 [9th Circuit Court opinion No. CV-00-01711-RCB issued 18 November 2003]). The USFS has written a Draft Supplement to the FEIS evaluating the scientific debate over goshawk habitat preferences. The public comment period on the Draft Supplement closed November 2004. Interestingly, the recent RRF-TWS review of the USFWS decision (Andersen et al. 2005) concluded goshawks use late-successional forests in almost all landscapes where they have been studied. However, they also concluded the species demonstrates considerable versatility in habitat use, and thus, assessing its status based solely on the distribution of late successional forest is not warranted based on the current understanding of goshawk-habitat relationships.

Accipiter gentilis laingi

In May, 1994, a petition was filed to list the Queen Charlotte subspecies as endangered under the ESA (Table 2). Twelve months later, the USFWS decided the listing was not warranted. The USFWS acknowledged that continued large-scale removal of old-growth forest in the Tongass National Forest

TABLE 1. THE HISTORY OF LEGAL AND ADMINISTRATIVE ACTIONS RELATIVE TO THE STATUS AND MANAGEMENT OF NORTHERN GOSHAWKS IN THE UNITED STATES (ADAPTED FROM KENNEDY 2003).

Date	Legal or administrative action
February 1990	Formal request to Region 3 regional forester to suspend all harvesting in goshawk territories until long-term survival was assured.
August 1990	Region 3 regional forester organized a goshawk scientific committee (GSC) and goshawk task force (GTF) to review goshawk management needs in USFS Region 3.
September 1991	Petition filed to list the goshawk (*A. g. atricapillus*) as endangered west of 100th meridian.
January 1992	The goshawk (all subspecies) was listed as a candidate species (category 2) for possible future listing under the ESA throughout its range in the US. Category 2 species were those species for which there was inadequate data to justify a listing proposal under ESA at that time.
	The USFWS issued a 90-d finding that the petition did not present substantial information to indicate the goshawk in the western US should be listed. However, the USFWS concluded that the the petition presented substantial information indicating that goshawk population declines and loss or modification of habitat may be occurring. Therefore, the USFWS initiated a status review for the goshawk throughout its range in the U. S. They specifically solicited information to be used to evaluate the potential for distinct population segments within the range of the goshawk.
	GSC produced the Management Guidelines for the Northern Goshawk in the Southwestern Region (Reynolds et al. 1992).
June 1992	USFWS issued a 90-d finding that the petition did not present substantial information to indicate the goshawk in the western US should be listed (57 FR 474). The USFWS found that the petition presented no evidence of reproductive isolation or genetic differentiation between the western and eastern goshawk populations. They also concluded that goshawk habitat was contiguous throughout North America.
1992–1995	Reynolds et al. (1992) generated intense controversy. The focus of the controversy was whether or not the goshawk was a forest generalist. Reynolds et al. (1992) claimed goshawk populations were regulated by prey availability and that data suggest the goshawk is a prey generalist and thus, hunts in heterogeneous landscapes. The opposing state agencies and environmental groups claimed (without any supporting data) the goshawk was an old-growth obligate. Other concerns are detailed in Peck (2000).
1996	Region 3 regional forester issued a record of decision (ROD) to amend all regional forest plans to include the Reynolds et al. (1992) guidelines as well as recommendations from the Mexican Spotted Owl. This ROD is to be in effect for 5–10 yr until the forest plans are revised (scheduled to be completed by 2003) (Cartwright 1996). This is the only region to implement Reynolds et al. (1992) on a regional basis.
February 1996	The U.S. District Court found the June 1992 finding to be arbitrary and capricious, and remanded the finding to the USFWS for a new 90-d determination [926 F. Supp. 920 (D. Ariz. 1996)].
June 1996	USFWS issues a second 90-d finding, again determining the petition does not present substantial information that listing the goshawk in the western US may be warranted (61 FR 28834-35).
September 1996	Suit filed to overturn denial.
June 1997	Court overturns second 90-d finding as arbitrary and capricious, also finding the USFWS national policy on listing populations to be illegal (980 F. Supp. 1080 [D. Ariz. 1997]). The USFWS final policy on distinct population segments (DPS) allowed for only one subspecies per distinct population segment. The USFWS claimed, in the 1997 phase of the litigation, that there were three subspecies of Northern Goshawk west of the 100th meridian, (1) *A.g. atricapillus*, (2) *A.g. laingi*, and (3) *A.g. apache*. The court found this aspect of the DPS policy arbitrary and capricious because the ESA specifically states that in the definition of species, a species may include any subspecies and any distinct population segments of any species. If congress had intended a DPS contain only one subspecies, it would have allowed only the listing of DPSs of subspecies. The court then remanded the case back to the USFWS, which led to the positive 90-d finding in September 1997 (Ellen Paul, Executive Director, Ornithological Council, pers. comm.).
September 1997	USFWS issues a positive 90-d finding on western petition (62 FR 50892). It was then required to conduct a full status review by June 1998.
	Candidate status dropped. Prior to 1997, the USFWS maintained a category 2 list that included species whose status was unknown but of concern due to declines in population trend or habitat. These were also referred to as candidate species. Thus, the goshawk was no longer considered a candidate for listing due to the lack of information supporting a proposed rule (M. Nelson, Chief, Branch of Candidate Conservation, USFWS, pers. comm.).

TABLE 1. CONTINUED.

Date	Legal or administrative action
June 1998	USFWS issues negative 12-mo finding, finding the petition to list the goshawk in the western US as not warranted. (63 FR 35183). See summary of these findings in the text.
February 1999	Suit filed to overturn June 1998 90-d finding.
May 2000	Suit filed against the Sitgreaves National Forest to halt a timber sale which contained 5 of the 42 known goshawk territories on this forest (Center for Biological Diversity v. Bedell U. S. District Court, District of Arizona case No. 3:00-cv-00849-SLV). The suit alleged that the goshawk population on the Sitgreaves is in serious decline and would be extripated in 40 yr if it was a closed population. This case was dropped in 2002 after the parties reached an agreement with the USFS.
September 2000	Suit filed to challenge logging on 3,240,000 ha of forest in the Southwest (Center for Biological Diversity v. Bosworth Civil-01711-PHX-RCB, U. S. District Court, District of Arizona). The plaintiffs have asked for an injunction on logging within goshawk habitat on 11 Arizona and New Mexico national forests until the USFS prepares a new goshawk conservation plan.
June 2001	The USFWS's decision not to list the goshawk as a threatened or endangered species was upheld by a federal judge, who found the USFWS's decision not arbitrary and capricious (U.S. District Court, District of Oregon, Civil No. 99-287-FR).
November 2003	U. S. Ninth Circuit Court of Appeals ruled the USFS had inadequately disclosed responsible scientific opposition in preparing the final environmental impact statement for southwestern forests. The Court recently reversed and remanded the decision stating the EIS violated NEPA because it did not review the opposing scientific information that indicated the goshawk was a habitat specialist (Center for Biological Diversity and Sierra Club v. U.S. Forest Service, No.02-16481 (9th Circuit Court opinion No. CV-00-01711-RCB). Case was sent back to district court.
September 2004	The USFS, Southwestern Region has prepared a draft supplement to the final EIS for amendment of forest plans in Arizona and New Mexico to disclose, review and assess scientific arguments challenging the agency's conclusions over goshawk habitat preferences. The supplement will update the final EIS, which amended the 11 forest plans in the Southwesten Region for goshawks. Public comment period closed November 2004. No further updates are available.

would adversely affect the Queen Charlotte Goshawk in southeast Alaska, but that revised land-use strategies would ensure goshawk habitat conservation. Thus, the USFWS believed the proposed actions to protect goshawks would preclude the need for listing. In September 1996, the U.S. District Court (District of Columbia) remanded the 12-mo finding to the Secretary of Interior, instructing him to reconsider the determination "on the basis of the current forest plan, and status of the goshawk and its habitat, as they stand today." In May 1997, the USFS revised the Tongass Land Management Plan, and the USFWS was granted a 90-d extension to reevaluate the status of the goshawk under the new plan. In April 1998, a suit was filed to overturn the USFWS's refusal to list the Queen Charlotte Goshawk as an endangered species. In August of that year, the U.S. District Court overruled the USFWS's decision not to list the Queen Charlotte Goshawk on the basis that the agency did not use the best available science. However, the U.S. Ninth Circuit Court stated in June 2000 that the district court had exceeded its authority in ordering the government to conduct a population count, stating that the district court is to only consider if the USFWS used the best available science. In May 2004, the U.S. District Court ordered the USFWS to determine if the

Queen Charlotte Goshawk is endangered or threatened on Queen Charlotte Island. In December 2005, USFWS requested public comments on the status of the Queen Charlotte Goshawk throughout its range. This comment period closed February 2006.

In summary, over a decade of litigation over the federal status of *A. g. laingi* and *A. g. atricapillus* has been conducted, respectively. No changes in listing status have resulted from this litigation.

SENSITIVE SPECIES DESIGNATION

The goshawk is listed as a species of concern in all regions of the USFWS and is on the USFS sensitive species list for all regions. The Bureau of Land Management (BLM) lists the goshawk as a sensitive species in six states.

USDA FOREST SERVICE, REGION 3 GUIDELINES FOR SOUTHWESTERN FORESTS AND OTHER MANAGEMENT PLANS

As mentioned in the previous section, the GSC, as assembled by the USFS's Southwestern Region, completed a document in 1992 titled *Management Recommendations for the Northern Goshawk in the*

TABLE 2. The history of legal and administrative actions relative to the status and management of the Queen Charlotte subspecies of Northern Goshawks (*A. g. laingi*) in the United States (adapted from Kennedy 2003).

Date	Legal or administrative action
May 1994	Petition filed to list the Queen Charlotte Goshawk (*A. g. laingi*) as endangered. The petition was based largely upon potential present and impending impacts to the Queen Charlotte Goshawk caused by timber harvest in the Tongass National Forest.
August 1994	USFWS published a positive 90-d finding (59 FR 44124) stating substantial information was presented in the petition indicating the requested action may be warranted.
May 1995	After a 12-mo status review, USFWS decided listing was not warranted (60 FR 33784). In the 12-mo finding, the USFWS acknowledged that continued large-scale removal of old-growth forest in the Tongass National Forest would result in significant adverse effects on the Queen Charlotte goshawk in southeast Alaska; however, at that time the USFS was revising land use strategies to ensure goshawk habitat conservation. The USFWS believed the proposed actions to protect goshawks would preclude the need for listing.
November 1995	Suit filed against the Department of the Interior and the USFWS for their refusal to list the Queen Charlotte goshawk or designate critical habitat [U.S. District Court, District of Columbia (95-cv-02138-SS)].
September 1996	The U.S. District Court remanded the 12-mo finding to the Secretary of Interior, instructing him to reconsider the determination "on the basis of the current forest plan, and status of the goshawk and its habitat, as they stand today." [Southwest Center for Biological Diversity v. Babbitt, 939 F. Supp. 49, 50 (D.D.C. 1996)]
December 1996	USFWS reopens comment period (61 FR 64497) to gather all new information for review. It was extended until 4April 1997 through three subsequent notices (61 FR 69065, 62 FR 6930, and 62 FR 14662). The USFWS has reevaluated the petition and the literature cited in the petition, reviewed the Tongass Land Management Plan and other available literature and information, and consulted with biologists and researchers knowledgeable of northern goshawks in general, and the Queen Charlotte Goshawk in particular. The 1979 Tongass National Forest Land Management Plan, as amended, formed the basis for evaluating the status of the goshawk on the Tongass National Forest.
May 1997	The USFS issued a revised Tongass Land Management Plan. Consequently, the review of the 1979 Tongass Land Management Plan no longer represented the current plan as specified by the court ruling. The USFWS was, therefore, granted a 90-d extension to reevaluate the status of the goshawk under the provisions of the 1997 Tongass Land Management Plan
June 1997	USFWS re-extends comment period.
September 1997	USFWS again finds that a listing of the subspecies is not warranted (62 FR 46710)
April 1998	Suit filed to overturn the USFWS's refusal to list the Queen Charlotte Goshawk as an endangered species [U.S. District Court, District of Columbia (No. 98cv934)].
July 1999	U.S. District Court for the District of Columbia ordered the USFWS to conduct an actual on-site population count. This decision was appealed by the USFWS and a decision was rendered in June 2000 overturning the District Court's decision (Southwest Center for Biological Diversity v. Babbitt 215 F. 3d85). The Court of Appeals sent the case back to District Court.
July 2000	A magistrate of the U.S. District Court for the District of Columbia found that the USFWS failed to make a specific finding as to conservation of the subspecies on Vancouver Island, which constitutes a third of the subspecies' geographic range.
May 2004	U.S. District Court, District of Columbia rejected the magistrate's finding but ordered the USFWS to determine if Vancouver Island is a significant portion of the range and to determine whether or not the Queen Charlotte Goshawk is endangered or threatened on Queen Charlotte Island.
December 2005	USFWS seeks public comment as to the status of the Queen Charlotte Goshawk throughout its range, for the purpose of determining the significance of the Vancouver Island population in relation to the taxon as a whole (70 FR 4284). Comment period closed February 2006.

Southwestern United States (Reynolds et al. 1992). Reynolds et al. (1992) developed these guidelines for southwestern goshawk habitat (ponderosa pine [*Pinus ponderosa*], mixed conifer, and spruce-fir forests). They assessed information available on goshawk ecology, with particular attention on goshawk prey and the ecology of key prey species in the region, as well as ecology of the forests used by goshawks and local silvicultural practices. The recommendations are designed to provide breeding season habitat for the goshawk and 14 of its key prey species (Fuller 1996).

Reynolds et al. (1992) has the following primary components: (1) no timber harvest in three nest

areas (12.1 ha each) per home range, (2) provide three additional nest areas within each home range for future use by goshawks which can receive intermediate treatment or prescribed burning, (3) timber harvest rotation in the post-fledging family area (PFA, 170 ha) and foraging area (2,185 ha) to maintain always a minimum of 60% in late-successional forests (tree classes: 31–46 cm, 46–62 cm, and 62+ cm), (4) restricted management season in nest areas and PFA during the winter season (October through February), (5) openings of 0.4–1.6 ha depending on forest type, and (6) maintenance of reserve trees (1.2–2.4/ha), canopy cover, snag densities (0.8–1.2/ha), downed logs (1.2–2/ha), and woody debris (11.2–13.6 metric tons/ha) in all harvest areas with amount depending upon forest type (Bosakowski 1999).

These recommendations were designed to return current forest conditions (which have been impacted by grazing, fire suppression, and timber management) to relatively open forests dominated by mature trees interspersed with patches of various successional stages. The applicability of this approach to managing goshawk landscapes may not be limited to southwestern forests. As noted by Fuller (1996), the recommendations made by Reynolds et al. (1992) could be used as a model for assessments and strategies in other areas and for other species. However, similar to many wildlife management plans, these recommendations (Reynolds et al. 1992) still remain as an untested hypothesis. Although these guidelines have been adopted by the USFS in Arizona and New Mexico (USDA Forest Service 1995, 1996), their effectiveness at enhancing goshawk population persistence in this landscape has not been evaluated and has been questioned (Greenwald et al. 2005). Braun et al. (1996) and Drennan and Beier (2003) have expressed concerns about the single-species focus of these guidelines and question the practice of managing landscapes for goshawks. According to Bosakowski (1999), some national forests in the Pacific Northwest are providing similar management to that prescribed by Reynolds et al. (1992) for nest sites and PFAs, but no management is being conducted on the foraging areas. Graham et al. (1994) extended the ideas of Reynolds et al. (1992) stressing that forest conditions are temporally and spatially dynamic. Instead of managing individual home ranges, they suggested goshawk management should focus on managing large forest tracts as sustainable ecological units.

For the Olympic Peninsula in Washington, Finn et al. (2002a) developed goshawk habitat-management recommendations based on their analysis of local goshawk nesting habitat at multiple spatial scales. Their results suggest goshawk use of the landscape on the Olympic Peninsula as nesting habitat will be maximized when at least 54% of the home range is late-seral stage forest (defined as >70% coniferous canopy closure with >10% of canopy from trees >53 cm diameter at breast height (dbh) and <75% hardwood/shrub) and no more than 17% is stand initiation (regenerating clearcuts; conifers <7 yr old, <10% coniferous canopy closure). Finn et al. (2002a) also suggest reducing the amount of landscape contrast and edge density (indices of spatial heterogeneity) within home ranges may increase occupancy and maintain potential nest areas.

Goshawk biologists generally agree that goshawk management requires providing suitable nest stands and a large landscape for foraging. However, the need for managing intermediate scales (e.g., PFA) and very small scales (the nest site) is still open to debate.

FOOD HABITS AND ECOLOGICAL RELATIONSHIPS WITH PREY

FOOD HABITS DURING NESTING

Goshawks are opportunistic predators that kill a wide assortment of prey varying by region, season, vulnerability, and availability. Main foods include small mammals, ground and tree squirrels, rabbits and hares, large passerines, woodpeckers, game birds, and corvids (Squires and Reynolds 1997). Goshawks are classified as prey generalists (Squires and Reynolds 1997) and typically forage on a suite of 8–15 species (Reynolds et al. 1992). As with other raptors, the food habits of goshawks have been determined by examination of stomach contents and food removed from crops of nestlings, or more commonly, direct observation of nests, prey remains, and regurgitated pellets (Lewis 2001). Potential biases exist in most of these raptor food habits methods and these biases in *Accipiter* diets are well summarized by Bielefeldt et al. (1992), Younk and Bechard (1994a), Watson et al. (1998), and Rutz (2003a).

Goshawks forage long distances for relatively large-bodied birds and mammals. In Oregon, average prey mass was 307 g (sd = 364, range = 17.6–1,505 g, Reynolds and Meslow 1984); avian prey averaged 195.5g (sd = 207, range = 17.6–1,505.0 g) and mammalian prey averaged 445.2 g (sd = 415, range = 36.8–1,118.6 g). Males can kill prey 2.2 times their mass (approximately 1,600 g),

which is proportionally similar to the largest hares (2,700–3,670 g) killed by females (2.4 x female mass, Kenward et al. 1981).

Although potential prey species are extensive (Appendix 1, Squires and Reynolds 1997), a few taxons are prevalent in most diets. Sciurids occur in most goshawk diets due to their high abundance and broad distribution (USDI Fish and Wildlife Service 1998a). Several studies have documented Douglas squirrels (*Tamiasciurus douglasii*) and red squirrels (*Tamiasciurus hudsonicus*) as important prey (Mendall 1944, Meng 1959, Reynolds et al. 1994, Watson et al. 1998, Clough 2000, Squires 2000,) and they may be especially important during the winter when other prey are unavailable (Widén 1987). Rabbits and hares are also used extensively by goshawks (Reynolds and Meslow 1984, Kennedy 1991, USDI Fish and Wildlife Service 1998a, Clough 2000). Cottontail rabbits (*Sylvilagus* spp.) are abundant in a variety of habitats and are distributed throughout the goshawk's range (USDI Fish and Wildlife Service 1998a) and snowshoe hares (*Lepus americanus*) are also important prey, particularly in northern forests (Mendall 1944, McGowan 1975, Doyle and Smith 1994). In the Yukon, Doyle and Smith (1994) found a positive correlation between goshawk breeding success and a snowshoe hare population peak.

Gallinaceous birds (primarily grouse and pheasants) are particularly important prey for North American (Mendall 1944, McGowan 1975, Gullion 1981a, b; Gullion and Alm 1983, Apfelbaum and Haney 1984) and European Goshawks (Kenward 1979, Sollien 1979 *in* USDI Fish and Wildlife Service 1998a, Kenward et al. 1981, Lindén and Wikman 1983, Tornberg 2001) at northern latitudes. Fluctuations in grouse populations have been shown to affect goshawk productivity, including number of nesting pairs, and number of young per active nest (Lindén and Wikman 1983, Sollien 1979 *in* USDI Fish and Wildlife Service 1998a). Tornberg et al. (1999) analyzed skin and skeletal measurements collected from 258 museum specimens of Finnish Goshawks dated between 1961 and 1997. They reported that as grouse decreased in abundance over this 36-yr period, they were replaced by smaller prey in the goshawk breeding season diet. They also observed morphological shifts in both males and females probably as a result of selective pressures due to changes in prey size.

American Robins (*Turdus migratorius*; Grzybowski and Eaton 1976, Reynolds and Meslow 1984, Kennedy 1991, Squires 2000), corvids (*Corvus* spp.; Meng 1959, Eng and Gullion 1962,

Gullion 1981b), jays (Beebe 1974, Bloom et al. 1986, Kennedy 1991, Bosakowski et al. 1992, Boal and Mannan 1994), and woodpeckers (Schnell 1958, Eng and Gullion 1962, Erickson 1987, Allen 1978, Reynolds and Meslow 1984, Reynolds et al. 1994) are also common prey items found in many parts of the goshawk's range. Northern Flickers (*Colaptes auratus*) are particularly important in many goshawk diets (Grzybowski and Eaton 1976, Reynolds and Meslow 1984, Bloom et al. 1986, Kennedy 1991, Boal and Mannan 1994, Squires 2000).

Goshawks occasionally feed on carrion (Sutton 1925, Squires 1995). Sutton (1925) reported that a goshawk was shot while feeding on a dead bear. Squires (1995) described that goshawks fed on gut piles of mule deer (*Odocoileus hemionus*) left by hunters, and on a bison (*Bos bison*) skull in Montana. It is unclear if goshawks feed on carrion whenever available, or only during periods of low prey availability.

HABITAT NEEDS OF PREY SPECIES

The habitat requirements of important prey species include early seral to mature forests and forest openings. Interspersion (the degree of intermixing of vegetation structural stages) and canopy cover have varying effects on different goshawk prey species (Reynolds et al. 1992). For example, red squirrels respond negatively to a high level of interspersion of structural stages and select closed older forests to attain high-density populations (Klenner and Krebs 1991, Larsen and Boutin 1995). Grouse, on the other hand, respond positively to high interspersion of openings and older forests. Other prey species, such as American Robins, are habitat generalists and are abundant in most structural stages (Reynolds et al. 1992). Although goshawks hunt species with diverse habitat requirements (and a detailed analysis of these requirements is beyond the scope of this paper), several habitat features appear to be important to a variety of species (Reynolds et al. 1992, USDI Fish and Wildlife Service 1998a). These features include snags, downed logs (>30 cm in diameter and 2.4 m long), large trees (>46 cm in diameter), openings and associated herbaceous and shrubby vegetation, interspersion, and canopy cover. Reynolds et al. (1992) stressed the need for large trees scattered throughout the foraging area because this component often occurs in clumps with interlocking crowns that provide unique hiding, feeding, den, and nesting areas for many prey species (USDI Fish and Wildlife Service 1998a). Reynolds et al. (1992) emphasized that foraging areas used by goshawks should include a variety of habitat types and structural classes. In

southwestern pine forests, they recommended foraging habitat include a mosaic of vegetation structural stages interspersed throughout the area and consist approximately of 20% each of old, mature, middle-aged, and young forests, 10% in the seedling-sapling stage, and 10% in the grass-forb-shrub stage. The 60% of the stands that consist of older age classes should have relatively open understories with a minimum of 40–60% canopy cover (Reynolds et al. 1992).

Reynolds et al. (1992) speculated that small to medium openings (<1.6 ha) and various seral stages scattered throughout goshawk foraging habitat enhances availability of food and habitat resources for prey and limits negative effects of large openings and fragmentation on distribution and abundance of prey species that use interior forests. Forests that provide adequate populations of major prey are predicted to have well-developed herbaceous and shrubby understories associated with small to medium openings that provide cover and food for many small mammals and birds in the form of seeds, berries, and foliage.

Winter Food Habits and Seasonal Dietary Shifts

Little is known regarding the winter diets of goshawks in North America. In northern Arizona, Drennan and Beier (2003) found winter diets were dissimilar to those in summer, in part because of the absence of hibernating species, and this reduction in prey diversity may result in individual goshawks specializing on specific species in the winter. Wintering goshawks from this population appeared to specialize on only two species of large-bodied prey—cottontails and Abert's squirrels (*Sciurus aberti*).

Given that most dietary information is limited to the nesting season, we poorly understand seasonal changes in diet selection. The limited available data indicate diet composition may change considerably from breeding to non-breeding seasons. For example, in Swedish boreal forests, birds dominated the diet during nesting, accounting for 86% of prey number and 91% of biomass (Widén 1987). However, the European red squirrel (*Sciurus vulgaris*) was the dominant prey both in terms of numbers (79%) and biomass (56%) during the winter. The proportion of European red squirrels in goshawk diets was high during winters of both high and low squirrel numbers. Seasonal dietary shifts are at least partially due to different migration, estivation, and hibernation behaviors among suites of locally available prey.

During nesting, goshawks may shift their diets to include more fledgling passerines (Zachel 1985,

Lindén and Wikman 1983, Widén 1987, Tornberg and Sulkava 1990), and overall prey diversity may peak as juvenile passerines and other birds become available (Wikman and Tarsa 1980, Marquiss and Newton 1982). In Nevada, goshawks ate more birds such as American Robins and Northern Flickers as Belding's ground squirrels (*Spermophilus beldingi*) began estivation in mid-summer (Younk and Bechard 1994a). In Arizona, no significant difference was found in proportions of mammals and avian prey taken throughout the nesting season (Boal and Mannan 1994).

COMMUNITY ECOLOGY

Goshawks exist within ecological communities composed of interacting species. Thus, goshawk populations are affected by various predatory, competitive, symbiotic, and mutualistic interactions. The importance that community relationships play in structuring goshawk populations is mostly unknown. For example, many anecdotal observations have been made of predatory interactions between goshawks and other raptors, but we do not know how predatory interactions may structure goshawk demography or habitat-use patterns. The lack of knowledge concerning community relationships in North America is an important information need. Only through improved understandings of basic ecological relationships, can we hope to predict how the human-induced changes to the environment may help or hinder goshawk populations.

Functional and Numeric Responses with Prey

A study quantifying numerical and functional responses of breeding goshawks to their prey was conducted by Tornberg (2001) in northern boreal forests of Finland. His objective was to evaluate the impact of goshawk predation on grouse numbers and multiannual cycling patterns. Four grouse species constituted >40% of the goshawk diet during the breeding season in this area from 1988–1998. The numerical response of goshawks to grouse was relatively weak. Goshawk breeding density and site occupancy fluctuated negligibly, but the production of young tended to lag one year behind Black Grouse (*Tetrao tetrix*) density. A functional response of goshawks to changes in grouse numbers was found only in spring when all four grouse species were combined. No patterns were found for individual species, which probably is due to goshawks switching between grouse species. Tornberg suggested the weak response is due to goshawks treating different

grouse species as one. Numerical and functional responses of goshawks to prey warrants further investigation particularly in areas where goshawk predation may be interfering with conservation efforts of its prey species.

Do Goshawks Limit Prey?

The role of raptors in limiting or regulating prey populations has recently become a hot topic in research, particularly in Europe where raptors are still persecuted (albeit illegally) for their predation on galliformes, a popular harvested taxa (Korpimäki and Krebs 1996, Krebs 1996, Redpath and Thirgood 1999, Thirgood et al. 2000, Tornberg 2001). As noted in earlier sections, goshawks are a significant predator of forest-dwelling birds and small mammals. In areas where they are abundant, they could potentially regulate populations of their prey, particularly in areas where they specialize on a few prey species, e.g., boreal forests (Tornberg 2001).

Goshawk predation plays a major role in grouse demography in Europe (Angelstam 1984, Wegge et al. 1990, Swenson 1991, Valkeajärvi and Ijäs 1994). Two studies have estimated goshawks remove roughly between 15–25% of grouse populations during the breeding season (Lindén and Wikman 1983, Widén 1987). Tornberg (2001) found the impact of goshawk predation on grouse varied by species. Losses were highest for Willow Grouse (*Lagopus lagopus*) and lowest for Capercaillie (*Tetrao urogallus*). On average goshawks took 6% of grouse chicks. On an annual basis breeding goshawks took 2–31% of the August grouse population. The most reliable estimates of the goshawk's share of grouse total mortality were for Black Grouse and Hazel Grouse (*Bonasa bonasia*) of which 35% and 40% were removed, respectively.

The contribution of goshawk predation to limiting Eurasian Kestrel (*Falco tinnunculus*) and European red squirrel populations in coniferous forests in northern England has been reported by Petty et al. (2003a, b). Goshawks were extirpated from this area toward the end of the 19th century as a result of deforestation and intense persecution. They were reintroduced in the early 1970s and increased in numbers until 1989, after which their numbers stabilized. This area also contains the largest remaining population of European red squirrels in England and a declining population of Eurasian Kestrels. Petty et al. (2003a, b) used a number of correlative approaches to explore the role of goshawk predation on both species from 1973–1996. They found no evidence that goshawk predation is a major factor

limiting densities of European red squirrels and concluded that conservation management for sympatric populations of red squirrels and goshawks are compatible (Petty et al. 2003b). However, Petty et al. (2003a) did find a significant negative relationship between Eurasian Kestrel and goshawk numbers. Goshawks killed many adult Eurasian Kestrels in the early spring, prior to breeding, when predation would have the most impact on breeding population levels, and there was a temporal trend for this predation to be inversely density-dependent. Petty et al. (2003a) also estimated that goshawks removed more Eurasian Kestrels than were recorded each spring in the study area and concluded the decline of the Eurasian Kestrel was mainly due to goshawk predation.

These correlative studies suggest that goshawk predation may limit prey abundance and productivity in some cases, but without experimental tests of this phenomenon it is difficult to infer cause and effect. The role of goshawk prey regulation in southern latitudes where they are more prey generalists is unknown. Also, information on goshawk impacts on North American prey populations is nonexistent.

GOSHAWKS AS PREY

Although goshawks are formidable predators, they are occasionally killed by other predators, and predatory interactions may regulate some populations. The literature describing predation on goshawks mostly consists of anecdotal observations, with little information regarding population responses. For example, we know that Great Horned Owls (*Bubo virginianus*) kill adults and nestlings (Moore and Henny 1983, Rohner and Doyle 1992, Boal and Mannan 1994, Woodbridge and Detrich 1994). Erdman et al. (1998) reported a Great Horned Owl feeding a female goshawk to its young. Several studies have indicated that predation on goshawk nestlings may increase during periods of low goshawk food availability because female goshawks may be required to spend more time away from the nest foraging instead of protecting young (Zachel 1985, Rohner and Doyle 1992, Ward and Kennedy 1996, Dewey and Kennedy 2001). In Europe, Eurasian Eagle Owls (*Bubo bubo*) eat nestlings between 13–38 d, and often eat the entire brood over several consecutive nights (Tella and Mañosa 1993). Squires and Ruggiero (1995) documented that eagles (Golden Eagles [*Aquila chrysaetos*], and Bald Eagles [*Haliaeetus leucocephalus*] were abundant in the area) killed goshawks in wintering areas. Mammalian predators include pine martens

(*Martes americana*; Paragi and Wholecheese 1994*)* fishers (*Martes pennanti*; Erdman et al. 1998), wolverine (*Gulo gulo*, Doyle 1995), and raccoons (*Procyon lotor*, Duncan and Kirk 1995). One-half of nestling mortalities (N = 12) in New Mexico were attributed to predation (Ward and Kennedy 1996). In Minnesota, Boal et al. (2005a) reported that out of five adult goshawks depredated during the 1998–2000 breeding seasons (four females, one male), two deaths were caused by mammalian predation, two were caused by Great Horned Owls, and one was caused by a diurnal raptor.

We speculate that Great Horned Owls are the dominant predator of goshawks in North America due to their wide distribution, abundance, and capacity to prey on large raptors (Orians and Kuhlman 1956, Luttich et al. 1971, McInvaille and Keith 1974, Houston 1975). Goshawks aggressively defend their nests against predators during the day. However, they are less capable of doing so at night and most reports of predation by Great Horned Owls are losses of nestlings, although adults are occasionally taken (Rohner and Doyle 1992). The effect of Great Horned Owl predation on goshawk populations is unknown (USDI Fish and Wildlife Service 1998a), but predation rates as high as 49% have been reported for Red-tailed Hawks (*Buteo jamaicensis*; Luttich et al. 1971). The ability of Great Horned Owls to kill large raptors indicates they can potentially have an impact on goshawk populations, especially by reducing nestling survival. Great Horned Owls begin nesting earlier than goshawks and occasionally lay eggs in goshawk nests, forcing goshawks to construct or use alternative nest areas (Reynolds et al. 1994, Woodbridge and Detrich 1994). Alternative nest sites are often in close proximity, which may increase the potential for reciprocal predation between the goshawk, the owl, and their progeny (Gilmer et al. 1983, Rohner and Doyle 1992).

Erdman et al. (1998) suggested fisher predation is a major cause of nest failure and incubating female mortality in northeastern Wisconsin, with annual turnover rates of nesting females exceeding 40%. Metal baffles have been used on nest tree trunks in this area since 1988 to reduce predation by mammals (Erdman et al. 1998), but the effectiveness of this technique has not been tested. Duncan and Kirk (1995) reported that Great Horned Owls, raccoons and fishers are the most significant predators of goshawks in Canada.

Predation is a natural mortality factor in raptor populations. It is unknown if predation of goshawks is increasing due to forest management or even if predation rates are significantly reducing survival. However, studies on passerines suggest that predation rates increase in forested communities with increased fragmentation and/or a reduction of canopy cover (Manolis et al. 2000, Zanette and Jenkins 2000).

COMPETITION

Intra-specific competition

In territorial species, interference competition from conspecifics could give rise to an inverse relationship between density and population growth rate. Krüger and Lindström (2001) analyzed a 25-yr data set (1975–1999) of a German goshawk breeding population to evaluate the site-dependent population regulation and the interference competition hypotheses. The site-dependent population regulation hypothesis was first proposed by Rodenhouse et al. (1997) and it integrates habitat heterogeneity, despotic settlement patterns of territories, and density-dependent reproduction. Under this hypothesis, the productivity of high quality territories is independent of population density because they are always settled first, while the progressive addition of lower quality territories at higher densities will lead to a decline in mean per-capita productivity, leading potentially to density-dependent population regulation. Site-dependent population regulation (Rodenhouse et al. 1997) calls for a territory settlement pattern that follows the ideal pre-emptive distribution (a form of the ideal free distribution that accounts for territorial behavior [Fretwell and Lucas 1970, Pulliam and Danielson 1991]), where high quality territories are inhabited first, and these occupied territories are not available for settlement by other birds. Territory settlement patterns in goshawks likely follow this pattern.

Krüger and Lindström (2001) analyzed territory settlement patterns and breeding performance and modeled per capita growth rate using standard time-series analyses and model-selection procedures. In their study area, territories that were occupied earlier and more often had a higher mean brood size; fecundity did not change with increasing density in these territories. A strong negative relationship occurred between mean number of young per breeding pair and its coefficient of variation, suggesting that site-dependent population regulation was more likely regulating this population than interference competition. Although the evidence is correlative, site-dependent population regulation may be a key process structuring goshawk nesting populations in Europe. Based on population modeling, Krüger and Lindström also concluded the most important factors affecting

population growth were habitat quality, weather conditions during the late breeding period, and density. This study is an important step toward understanding population regulation of goshawks. However, we still do not understand what other factors may regulate goshawk populations, or if these results are applicable to North American populations.

In Arizona, Reich et al. (2004) used a Gibbsian pair-wise potential model to describe and predict the spatial dependency of goshawk nests based on territoriality and forest structure. Nest locations were regularly distributed at a minimum distance of 1.6 km between active nests. Spatial analysis based on nest spacing and habitat variables indicated that potential goshawk nests locations were abundant and randomly distributed throughout the landscape. This result supported the notion that the number of high quality nest locations did not limit this goshawk population. Rather, territoriality in the form of non-compressible goshawk territories appeared to limit the local nest density. Thus, goshawks must choose potential high-quality sites within an area delineated by neighboring territories. At a broader scale, the overall territory density may reflect characteristics of prey populations throughout the area.

Inter-specific competition

The extent to which inter-specific competition for habitat as well as prey by potential competitors, such as the Red-tailed Hawk and Great Horned Owl, affect goshawk habitat use is not well understood. In addition, these potential competitors also function as potential predators making the effect of their presence difficult to interpret. Goshawks may be excluded from nest areas by other raptors, although it is common for goshawks and other raptors to nest close to one another (Reynolds and Wight 1978). Great Horned Owls, Spotted Owls (*Strix occidentalis*), and Great Gray Owls (*Strix nebulosa*) often breed in nests previously built by goshawks (Forsman et al. 1984, Bryan and Forsman 1987, Buchanan et al. 1993). In Minnesota, Great Gray Owls have been observed using nests previously used by goshawks with the goshawk pair building a new nest or using an alternative nest nearby (N = 3; A. Roberson, pers. obs.). Although Cooper's Hawks (*Accipiter cooperi*) and goshawks have a similar preference for nest habitat (Reynolds et al. 1982, Moore and Henney 1983, Siders and Kennedy 1996), and nest in the same stands (P. L. Kennedy, unpubl. data), Cooper's Hawks are smaller than goshawks and begin nesting later (Reynolds and Wight 1978); thus, they are unlikely to be effective nest site competitors.

This size effect on potential inter-specific competition has also been demonstrated for the Common Buzzard (*Buteo buteo*) which is a smaller-bodied raptor nesting sympatrically with the European goshawk. Krüger (2002a) recently did a multivariate discriminate analysis of nest site characteristics of the Common Buzzard (hereafter referred to as buzzard) and European Goshawk (392 nests of both species combined). His results showed substantial overlap between the two species and he concluded that this is good evidence for competition for optimal nest sites. The utility of niche overlap data for evaluating competition is debatable, but it suggests the buzzard might be constrained by the larger-bodied European goshawk in its nest site selection. Krüger (2002b) then experimentally examined the behavioral interactions between buzzards and European Goshawks and their effects on buzzard breeding success and brood defense using dummies and playback calls. Buzzards had significantly lower breeding success when presented with a goshawk dummy compared to control broods but there was no effect of buzzard dummies on buzzard reproductive success. European Goshawks were far more aggressive against an intra-specific dummy than buzzards. Krüger concluded that buzzards perceive a goshawk more as a potential predator than a competitor.

In addition to nest site competitors, several species of hawks and owls, and numerous mammalian predators, can potentially compete with goshawks for prey (USDI Fish and Wildlife Service 1998a). The Red-tailed Hawk and Great Horned Owl prey on many of the same species as goshawks (Fitch et al. 1946, Luttich et al. 1970, Janes 1984, Bosakowski and Smith 1992, La Sorte et al. 2004), although neither has the same degree of dietary overlap with goshawks as does the Cooper's Hawk, which also forages in the same habitat (Storer 1966, Reynolds and Meslow 1984, Bosakowski et al. 1992). Because both the Red-tailed Hawk and Great Horned Owl are more abundant in open habitats, such as meadows, edge, forest openings, and woodlands (Spieser and Bosakowski 1988, Johnson 1992), "the extent to which they coexist and compete for food with goshawks probably varies by the openness of forest types and extent of natural and anthropogenic fragmentation of a forest" (USDI Fish and Wildlife Service 1998a).

Determining whether fragmentation has altered inter-specific relationships between generalist avian predators and goshawks has received little research attention. Changes to forested habitats may render habitat more accessible and attractive to competing species such as Red-tailed Hawks and Great Horned

Owls, thereby potentially decreasing habitat available to goshawks (USDI Fish and Wildlife Service 1998a). However, we do not know whether this is a linear relationship or if some threshold level of fragmentation exists where these species may have a negative impact on populations of goshawks via increased predation and/or competition. Johnson (1992) surveyed 469 calling stations for Spotted Owls and Great Horned Owls along 28 roadside routes (total surveyed = 536 km). Landscapes (500-ha plot) surrounding Great Horned Owl detections contained more shrub-forb and shelterwood, less mature-old growth and mature habitat, had a higher ratio of linear edge to mature and old growth area, and were higher in elevation than landscapes surrounding Spotted Owls. The responses of Great Horned Owl declined with increasing amounts of old forests; the greatest number of detections was associated with landscapes containing only 10–20% old growth. Few Great Horned Owls were detected in landscapes containing >70% old growth. Johnson's results are consistent with the prevailing notion that Great Horned Owls are habitat generalists that are most abundant in fragmented landscapes (Houston et al. 1998). It would be very fruitful to both goshawk and Spotted Owl management if current research efforts on the effects of forest fragmentation on Barred Owl (*Strix varia*) expansion into Spotted Owl habitat (Dark et al. 1998, Kelly et al. 2003) were expanded to include Great Horned Owls.

Red-tailed Hawks and goshawks are sympatric on the Kaibab Plateau in northern Arizona. La Sorte et al. (2004) compared habitat differences of Red-tailed Hawk (N = 41) and goshawk (N = 41) nests at two spatial scales—fine scale (0.08 ha) and mid-scale (1,367 ha). At both scales, Red-tailed Hawks were more variable in their habitat-use compared to goshawks. At the fine scale, Red-tailed Hawks selected steep, north-facing slopes with dense understories, while goshawks consistently chose moderate slopes, tall trees, and open understories. The fine-scale differences at nests were attributed to the approaches each species uses to enter nest sites. Red-tailed hawks enter their nest from above the canopy, whereas goshawks enter the nest from below the canopy. Typically, Red-tailed Hawks also nested in areas with commanding views of the surrounding country compared to goshawks that consistently nested in the canopy of mature forests where views are more limited. At the mid-scale, forest fragmentation was greater around Red-tailed Hawk nests, whereas goshawks consistently associated with patches of continuous forests and level terrain. Thus, goshawk habitat would be reduced at both scales with increased fragmentation and Red-tailed Hawk habitat would increase. Results from both Johnson (1992) and La Sorte et al. (2004) indicated that habitat fragmentation can increase the potential for increased abundance of potential competitors and avian predators, like Great Horned Owls and Red-tailed Hawks, but empirical data that demonstrates whether competition is truly affecting the viability of goshawk populations are lacking.

A variety of mammalian carnivores, including foxes (*Vulpes* spp.), coyotes (*Canis latrans*), bobcats (*Lynx rufus*), Canada lynx (*Lynx canadensis*), weasels (*Mustela frenata*), and pine martens, are also sympatric with goshawks in most North American forests and feed on some of the same prey species as goshawks, such as rabbits and hares, tree and ground squirrels, grouse, and other birds (USDI Fish and Wildlife Service 1998a). Erlinge et al. (1984) demonstrated the combined consumption of large numbers of small vertebrates by numerous sympatric species of carnivores, owls, and hawks in Sweden resulted in food limitations to the suite of predators.

SPATIAL USE AND HABITAT PREFERENCES

Goshawks use broad landscapes that incorporate multiple spatial scales to meet their life requisites. This requires that we understand the spatial-use patterns of goshawks as use of habitat types may vary across multiple scales. This is an ambitious goal, given our imperfect understanding of the spatial-use patterns of goshawks. We recognize at least three-levels of habitat scale during the breeding season—the nest area, post-fledging area (PFA), and foraging area (Reynolds et al. 1992, Kennedy et al. 1994; Fig. 2).

Goshawks nest in most forest types found throughout their geographic range (Squires and Reynolds 1997). In eastern deciduous forests, goshawks nest in mixed hardwood-hemlock stands of aspen (*Populus* spp.), birch (*Betula* spp.), beech (*Fagus* spp.), maple (*Acer* spp.), and eastern hemlock (*Tsuga canadensis*; Speiser and Bosakowski 1987, Kimmel and Yahner 1994, Boal et al. 2005b). In western North America, goshawks nest in forests that include Douglas-fir (*Pseudotsuga menzeseii*), various species of pines, and aspen (Reynolds et al. 1982, Hayward and Escano 1989, Bull and Hohmann 1994, Younk and Bechard 1994a, Siders and Kennedy 1996, Squires and Ruggiero 1996, Daw and DeStefano 2001, McGrath et al. 2003). In the Black Hills of South Dakota, and throughout the Southwest, goshawks nest primarily in ponderosa pine and mixed conifer forests (Erickson 1987, Crocker-Bedford and
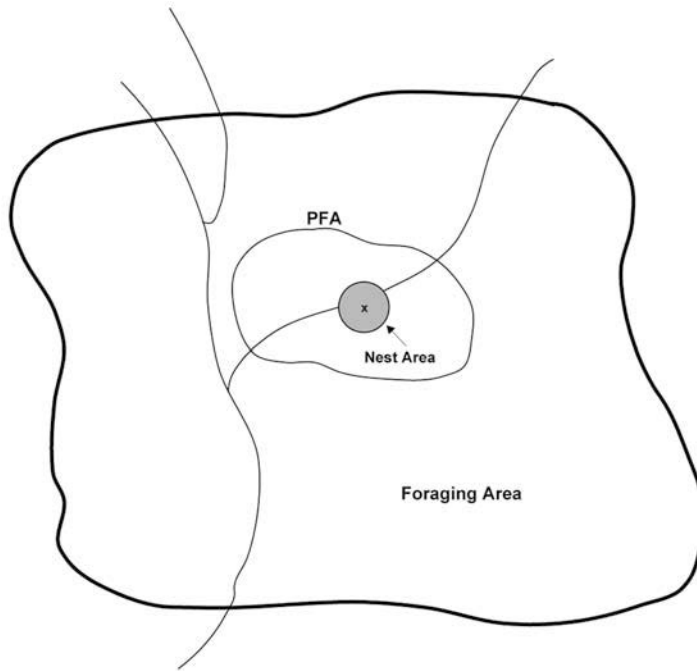
FIGURE 2. Three levels of spatial organization at Northern Goshawk nest sites, including the nest area, post-fledging area (PFA), and foraging area.

Chaney 1988, Kennedy 1988, Reynolds et al. 1994, Siders and Kennedy 1996). Paper birch (*Betula papyrifera*) is a dominant nest stand for goshawks in interior Alaska (McGowan 1975). Goshawks also occasionally nest in tall willow communities along arctic rivers (Swem and Adams 1992).

Nest-site habitat for the goshawk has been described throughout much of its range in North America and Europe (Shuster 1980, Reynolds et al. 1982, Moore and Henny 1983, Hayward and Escano 1989, Bull and Hohmann 1994, Lilieholm et al. 1994, Squires and Ruggiero 1995, Siders and Kennedy 1996, Patla 1997, Squires and Reynolds 1997, Rosenfield et al. 1998, Daw and DeStefano 2001, McGrath et al. 2003). Several studies in the US and Europe have compared habitat characteristics at nest areas to those available habitats within home ranges or landscapes and can be used to draw some conclusions about goshawk nesting habitat preferences (Speiser and Bosakowski 1987, Kennedy 1988, Bosakowski and Speiser 1994, Hargis et al. 1994, Squires and Ruggiero 1996, Penteriani and Faivre 1997, Selås 1997b, Clough 2000, Daw and DeStefano 2001, McGrath et al. 2003). A few breeding foraging habitat preference studies (Widén 1989, Bright-

Smith and Mannan 1994, Beier and Drennan 1997, Lapinski 2000, Boal et al. 2005a) and three post-fledging habitat preference studies have been conducted (Clough 2000, Daw and DeStefano 2001, McGrath et al. 2003). Comparisons among studies are difficult and may not be meaningful due to differences in methodology.

Goshawk winter habitat preferences are unclear due to a paucity of studies on this topic. Winter habitat studies have been conducted primarily in Europe (Kenward et al. 1981, Tornberg and Colpaert 2001) but three studies (Iverson et al. 1996, Stephens 2001, Drennan and Beier 2003) have been conducted in North America. Winter habitat used by the goshawk is likely more variable then breeding habitat and is likely influenced by its local migratory status. In areas where goshawks are residents, breeding pairs can remain on their breeding season home ranges during the non-breeding season (Boal et al. 2003). However, migratory populations may overwinter in very different habitats from their breeding season home ranges such as low-elevation shrub-steppe. Currently, it is unknown how changes in landscape pattern affect seasonal changes in habitat selection; additional research is needed at larger spatial scales (USDI Fish and Wildlife Service 1998a).

HOME RANGE

In North America, home ranges during nesting vary between 570–5,300 ha, depending on sex, habitat characteristics, and choice of home range estimator (Squires and Reynolds 1997, Boal et al. 2003); extremely large home ranges up to 19,500 ha were documented in southeast Alaska (Iverson et al. 1996). The male's home range is usually larger than the female's (Hargis et al. 1994, Kennedy et al. 1994, but see Boal et al. 2003). Home ranges, excluding nest areas, appear not to be defended and may overlap adjacent pairs. Birds usually have one to several core-use areas within a home range that include nest and primary foraging sites. Core areas have been estimated to be approximately 32% of home range area in one population in New Mexico (Kennedy et al. 1994). Shapes of home ranges vary from circular to almost linear and may be disjunct depending on habitat configuration (Hargis et al. 1994). In Minnesota, home range overlap between members of breeding pairs was typically ≤50% suggesting that home range size of individual hawks used in management plans may substantially underestimate the area actually used by a nesting pair (Boal et al. 2003).

The correlation of home range size to habitat use and preference of foraging goshawks is poorly understood for North American populations (Squires and Reynolds 1997). Although comparison of home range sizes may be useful, particularly on a local scale, it is also important to consider prey and foraging habitat abundance and availability, which likely influence home range size (Keane and Morrison 1994, Keane 1999). For example, T. Bloxton and J. Marzluff, (unpubl. data) recently studied the influence of an unusually strong La Niña event (occurred in late 1998 and early 1999 and caused unusually high levels of winter precipitation followed by a cold spring) on prey abundance, space use and demography of goshawks breeding in western Washington from 1996–2000. They noted a decline in abundance indices unadjusted for detectability of nine prey species following the La Niña event. Home range sizes more than doubled during this time period suggesting that weather can also have a major influence on home range size via modification of prey abundance.

Goshawks may shift home ranges after breeding (Keane and Morrison 1994, Hargis et al. 1994). In California, females (N = 7) expanded home ranges after the nestling stage from 520 ha (sD = 390 ha) to 1,020 ha (sD = 820 ha); two males expanded their ranges from 340–1,620 ha and from 950–2,840 ha (Hargis et al. 1994). A female from this population

shifted its home range 9 km after young fledged. In northern California, home ranges of males (N = 5, 95% minimum convex polygon) increased from 1,880 ha during nesting (June–15 August; range = 1,140–2,950 ha) to 8,360 ha (range = 1,340–15,400 ha) during the non-breeding season (15 August 1992–March 1993); home ranges of females increased from 1,280 ha (range = 690–3,280, N = 5) to 3,180 ha (range = 1,220–4,010 ha) during the same period (Keane and Morrison 1994).

In the few studies that have estimated winter ranges, they were larger on average than breeding season ranges. In northern Finland, winter range size was 3,283–9,894 ha for males (N = 4) and 2,753–6,282 ha for females (N = 11). The variation in range size was due to different estimators. The average size of core use areas of 12 goshawks wintering in Utah was 2,580 ha ± 2,530 ha (Stephens 2001), but winter range size was highly variable (range = 1,000–7,950 ha). Stephens attributed the large variance to three of the goshawks that wintered in landscapes fragmented by agriculture, where home ranges were very large (2,610–7,950 ha).

A study of goshawks in Sweden reported that goshawk winter range size was an inverse function of prey availability (Kenward et al. 1981). At Fortuna, Sweden where pheasants are regularly released, the average goshawk winter home range was 2,000 ha while at Segersjo, where only wild pheasants were present, the average winter range was 5,400 ha (Kenward et al. 1981).

NEST AREA

The area immediately surrounding the nest tree, referred to as the nest site or nest area (Steenhof 1987, Fig. 2), often contains alternative nests and may be reused in consecutive years (Palmer 1988). The nest area includes the forest stand containing the nest tree(s) although definitions beyond the nest stand have varied by location and study. Reynolds et al. (1992) defined a nest area as approximately 12 ha in size that is the center of movements and behaviors associated with breeding from courtship through fledging. Nest stands of goshawks can be delineated based on unique vegetative characteristics (Reynolds et al. 1982, Hall 1984, Kennedy 1988) or homogeneous forest structure (Squires and Ruggiero 1996).

Nests and nest trees

Goshawks nest in both deciduous and coniferous trees (Palmer 1988, Squires and Reynolds 1997) and appear to choose nest trees based on size and

structure more than species of tree (Squires and Reynolds 1997). Goshawks often nest in one of the largest trees in the stand (Reynolds et al. 1982, Saunders 1982, Erickson 1987, Hargis et al. 1994, Squires and Ruggiero 1996), with height and diameter of nest trees varying geographically and with forest type. In Wyoming (Squires and Ruggiero 1996) and California (Saunders 1982), goshawks chose nest trees that had larger diameters than other trees in the nest stand. However, in the eastern forests along the New York-New Jersey border only four of 32 nests were built in the largest tree of the nest area (Speiser and Bosakowski 1989).

Nests are large, often conspicuous structures, that average about 90–120 cm in length, 50–70 cm in width, and 60 cm in depth (McGowan 1975, Allen 1978, Bull and Hohmann 1994). Nests are constructed from thin sticks (<2.5 cm diameter) with a bowl lined with tree bark and greenery. Nests are typically built on large horizontal limbs against the trunk, or occasionally on large limbs away from the bole (Saunders 1982). In eastern forests, nests were usually constructed in primary crotches, with the remainder in secondary crotches or limb axils (Speiser and Bosakowski 1989). Trees with the preferred triple or quadruple crotch branch structures were uncommon in eastern forests suggesting that goshawks actively selected this characteristic when choosing nest trees. In the west, nests are constructed in the primary crotches in aspens or on whorled branching in conifers (Squires and Ruggiero 1996), usually with a southerly exposure relative to the nest-tree bole (Moore and Henny 1983, Squires and Ruggiero 1996). Occasionally, nests are also built on mistletoe clumps (Shuster 1980, Reynolds et al. 1982) or rarely in dead trees (McGrath et al. 2003). Shuster (1980) reported goshawks deserted nest trees (N = 3) that died of beetle infestation, but there are other instances where beetle-killed trees have been used as nest trees for several seasons (T. Dick and D. Plumpton, unpubl. data). Successful nests have been recorded in dead white pines (*Pinus strobus*) in Minnesota (M. Martell and T. Dick, unpubl. data) and Porter and Wilcox (1941) reported a successful nest in a dead aspen tree in Michigan. Snag nesting is a common practice for goshawks nesting in northeastern Utah (S. R. Dewey and P. L. Kennedy, unpubl. data).

The height that goshawks build nests is significantly correlated with nest-tree height (Kennedy 1988, McGrath et al. 2003). Thus, nest heights vary according to tree species and regional tree-height characteristics. Mean nest heights from select populations include 9 m (range = 4.5–16.2 m, N = 41), Alaska (McGowan 1975); 16.8 m (range = 13.4–23.8 m, N = 13), California (Saunders 1982); 16.9 m (SD = 4.5 m, N = 12), New Mexico (Kennedy 1988); 16.2 m (SD = 5.5, range = 4.6–27.4 m, N = 62), Oregon (Reynolds et al. 1982); 13.0 m (SE = 0.48, range = 4.4–30 m, N = 82) Oregon and Washington (McGrath et al. 2003); 11.9 m (SE = 0.4 m, range = 5.1–15.8, N = 39), Wyoming (Squires and Ruggiero 1996); and 7.4 m (SE = 0.7, N = 10) in spruce (*Picea* spp.), 5.8 m (SE = 0.4, N = 6) in aspen, Yukon, Canada (Doyle and Smith 1994). The average height of North American nests was reported by Apfelbaum and Seelbach (1983) as 11.8 m (range = 6.1–25.7 m).

Alternative nests

Typical goshawk breeding areas contain several alternative nests that are used over several years (Reynolds and Wight 1978, Speiser and Bosakawski 1987, Reynolds et al. 1994, Woodbridge and Detrich 1994, Reynolds and Joy 1998). The reason for using alternative nests is unknown, but may reduce exposure to disease and parasites. Although goshawks may use the same nest in consecutive years, nest areas may include from one–eight alternative nests that are usually located within 0.4 km of each other (Reynolds and Wight 1978, Speiser and Bosakawski 1987, Reynolds et al. 1994, Woodbridge and Detrich 1994, Reynolds and Joy 1998, Dewey et al. 2003). Alternative nests can be clumped in one–three nest stands or widely distributed throughout the bird's home range. In northern California, an average of 2.6 nests was used per pair, and only 44% of nest attempts were in the previous year's nest. The mean distance between nests for this California population was 273 m (SE = 68.6 m, range = 30–2,066 m, N = 65 nests, Woodbridge and Detrich 1994). In Oregon, alternative nests were 15–150 m apart, most 60–90 m (Reynolds and Wight 1978). In Arizona, average distance moved from 1991 nests to 1992 alternative nests was 266 m (SD = 157 m, range = 100–635 m, N = 17, Reynolds et al. 1994).

Nest stands

Although the goshawk is considered a habitat generalist at large spatial scales and uses a wide variety of forest types, it nests in a relatively narrow range of structural conditions (Reynolds et al. 1992, Squires and Reynolds 1997). Goshawks prefer mature forests with large trees, relatively closed canopies (50–90%), and open understories (Moore and Henny 1983, Speiser and Bosakowski 1987, Crocker-Bedford and Chaney 1988, Kennedy 1988,

Hayward and Escano 1989, Reynolds et al. 1992, Squires and Ruggiero 1996, Penteriani and Faivre 1997, Selås 1997b, Squires and Reynolds 1997, Daw et al. 1998, Daw and DeStefano 2001, Finn et al. 2002b, La Sorte et al. 2004). McGrath et al. (2003) stated that canopy-cover values of goshawk nest stands may vary due to methodological and site differences. McGrath et al. also compared tree basal area among North American goshawk studies and found that basal area at nest sites ranged from 28.5–50.8 m^2 ha^{-1} compared to 20.7–42.4 m^2 ha^{-1} at random sites; McGrath et al. believed that basal area metrics might better capture site conditions at nest sites compared to canopy cover. Due to frequent bias in goshawk nest detection methods, however, goshawk selection of mature forests over other forest stages has been demonstrated in only a few studies (Squires and Ruggiero 1996, Clough 2000). Squires and Reynolds (1997) state that nests are frequently found near the lower portion of moderate slopes, close to water, and often adjacent to a canopy break. Nesting in stands more dense than surrounding forests may reduce predation and, in combination with north slopes, may provide relatively mild and stable micro-climates (Reynolds et al. 1992). Daw et al. (1998) summarized data from goshawk habitat studies in the West and concluded goshawks tend to select nest stands that are characterized by relatively large trees and relatively high canopy closure (>50–60%), regardless of region or forest type.

Reynolds et al. (1982) reported goshawks in Oregon nesting in dense, mature or old-growth conifers with a mean tree density of 482 trees (>6 cm)/ha and a range of 273–750 trees/ha. Nest areas included forests with few mature trees and dense understory trees to forests with closed mature canopies and sparse understory trees. Most nest areas were in old forests, with only 5% in second growth forests and 4% in mature lodgepole pine (*Pinus contorta*) or mixed stands of mature lodgepole and ponderosa pine. The lodgepole nest areas had relatively open, single-layered canopies (166 trees/ha, 38% canopy closure). In their Oregon study area, Daw et al. (1998) found nests that were located systematically were in areas with an average of 16.4 large trees (>53 cm dbh/ha) and a mean canopy closure of 72.4%. Daw and DeStefano (2001) compared goshawk nest stands to stands with random points in Oregon and found goshawks nested more frequently in stands with dense canopy and late forest structure (i.e., trees >53 cm dbh, canopy cover >50%), but rarely in stands with mid-aged forest structure. They also found nests were positively associated with small dry openings. They reported that average nest-

stand size in older forests was about 100 ha (range = 3–375 ha), but emphasized that stand quality is more important than stand size.

Siders and Kennedy (1996) described the range of stand conditions used by goshawks in northern New Mexico. They reported goshawks used nest trees ranging from 25–31 m in height and 43.3–56.7 cm dbh. Canopy closure at the nest tree was 58–74% and 60–70 % at nest areas. Nest areas had 31–40 m^2/ha basal area, with an overall area density of 800–1,400 trees/ha and overstory trees were spaced 4.8–6.8 m apart. Nest areas were composed of 2.8–8.0% mature, 2.1–11.1% large, 5.2–32.8% pole, and 16.8–85.6% sapling trees. Tree densities by age class were 460–970 sapling trees/ha, 130–370 pole trees/ha, 55–115 large trees/ha, and 53–90 mature trees/ha.

Nest stands of south-central Wyoming goshawks ranged from 0.4–13.0 ha (Squires and Ruggiero 1996). Slopes were more moderate (~11%) than available topography but there was no preference for aspect. Tree densities at nest sites were lower than at random sites but densities of large tress were higher than at random sites. Nest stands were not old-growth in the classic sense of being multi-storied stands with large diameter trees, high canopy closure and abundant woody debris. Rather nest stands were in even-aged, single-storied, mature forests stands of lodgepole pine with high canopy closure (65%), similar to what has been documented in other regions.

In northern California, canopy closure at nests ranged from 53–92% (Saunders 1982), and in northern Arizona, goshawks preferred nest areas that had the greatest canopy closure available, averaging 76%, which was 18% greater than in 360 reference areas (Crocker-Bedford and Chaney 1988). In eastern California, Hargis et al. (1994) reported home range locations used by goshawks were similar to nest areas, and both had greater canopy cover, greater basal area, and more trees/ha than a random sample from the study area.

Despite differences in some habitat characteristics, high canopy closure and tree basal area at nest areas were the most uniform habitat characteristic between study areas in northern Idaho and western Montana (Hayward and Escano 1989). Tree basal area ranged from 29–54 m^2/ha, with most (60%) nest stands between 39 and 46 m^2/ha.

Although goshawks appear to select relatively closed-canopy forests for nesting (Daw et al. 1998), exceptionally they will nest in more open forests (USDI Fish and Wildlife Service 1998a). Goshawks nest in tall willow communities along major drainages in arctic tundra (Swem and Adams

1992), riparian cottonwood (*Populus* spp.) stands (White et al. 1965) and in small stands of aspen in shrub-steppe habitat (Younk and Bechard 1994a). In Oregon, Reynolds et al. (1982) reported seven nest areas had an average canopy closure of 59.8%, although three nests were located in stands of mature lodge-pole pine that were relatively open (38% canopy coverage). Also, Hargis et al. (1994) reported 31% as the average canopy closure of goshawks nest stands in eastern California which was low compared to other studies.

Aspect and slope in nest areas may influence microclimate and goshawk habitat selection but the data are equivocal. Studies conducted in Oregon (Reynolds et al. 1982, McGrath et al. 2003), Idaho, and Montana (Hayward and Escano 1989, Clough 2000) found a significant number (40–60%) of goshawk nest locations on slopes with northwest to northeast-facing aspects. Bosakowski and Speiser (1994) compared goshawk nest sites to random points throughout their study area in New York and New Jersey and found goshawks avoided nesting on slopes with southerly aspects. Average slopes in nest areas were 9% (range = 0–75%) in Oregon (Reynolds et al. 1982) 14% in northeastern Oregon (Moore and Henny 1983), and between 15–35% slope in Idaho and Montana (Hayward and Escano 1989). Although goshawks nesting in New Mexico (Siders and Kennedy 1996) and Wyoming (Squires and Ruggiero 1996) did not exhibit a preference for aspect, most nests were found on moderate slopes. Alternatively, goshawks nesting in the Kaibab Plateau of northern Arizona selected nest sites on gentle slopes (9.6°) with no aspect directionality. Goshawks nesting in northwestern California used slopes averaging 42%, which are some of the steepest slopes recorded (Hall 1984). In contrast, 64% of goshawk nest sites in interior Alaska were on southern aspects with 16% of nests on the upper portion of the slope, 46% on the middle slope, and 38% on the lower slope (McGowan 1975). Clear topographic patterns at goshawk nest sites do not appear to exist.

Penteriani et al. (2001) described goshawk nest site preferences in France by using a multi-scale analysis: nest tree, nest stand (1 ha) and landscape to compare 50 goshawk nest sites with random plots. The landscape was defined as a circular plot with a 2-km diameter centered on each of the 50 active nest trees and random points. Plot diameter was equal to the minimum nearest-neighbor distance. Avian abundance was estimated in each landscape plot as an index of prey availability. Their stepwise logistic regression showed that four nest stand structural variables (larger average dbh, larger crown volume,

higher flight space and shorter distance to trails) and two landscape variables (low avian prey richness for both 100–500 g and 501–2,000 g prey size classes) were significant predictors of goshawk nest sites as compared to random sites. Their results support the results of Beier and Drennan (1997) who argue that goshawks apparently select habitat based on forest structural characteristics and not prey abundance.

Several authors have noted that goshawks often nest near water (Bond 1942, Squires and Reynolds 1997, Shuster 1980, Reynolds et al. 1982, Hargis et al. 1994). Shuster (1980) found all nests in aspen stands were near running water and those nests in pine stands were 10–450 m from water sources. Most South Dakota nests were found within 0.84 km of water although several nests were not within 1 km of a water source (Bartelt 1977). Conversely, some studies have shown that nests are not associated with water (Speiser and Bosakowski 1987, Crocker-Bedford and Chaney 1988) and the potential functional significance of water to goshawk nest sites has not been investigated.

Goshawks commonly nest close to forest openings such as meadows, forest clearings, logging trails, dirt roads, and fallen trees (Gromme 1935, Reynolds et al. 1982, Hall 1984, Erickson 1987, Hayward and Escano 1989). Although the function of forest openings near nests is unclear, openings may help goshawks access or locate their nests (USDI Fish and Wildlife Service 1998a, Boal et al. 2005b).

POST-FLEDGING AREA

Post-fledging areas (PFA) may represent defended portions of the territory (Reynolds et al. 1992; Fig. 2). The PFA surrounds the nest area and is defined as the area used by the family group from the time the young fledge until they are no longer dependent on the adults for food (Reynolds et al. 1992, Kennedy et al. 1994). Reynolds et al. (1992) also assumed that all alternative nests were within the PFA. During the fledgling-dependency period the activities of young are centered near their nests, but they move farther from the nest over time (Zachel 1985, Kenward et al. 1993a, Kennedy et al. 1994, Kennedy and Ward 2003). Post-fledging areas may be important to fledglings by providing prey items on which to develop hunting skills, as well as cover from predators and prey. The PFA (originally described as the post-fledging family area) was conceptualized by Reynolds et al. (1992) and empirically supported by studies of family movement patterns (Kenward et al. 1993a, Kennedy et al. 1994, and Kennedy and Ward

2003). Kennedy et al. (1994) estimated PFA size to be approximately 170 ha in New Mexico. However, PFA size and the functional significance of this spatial scale to goshawk management needs further evaluation because it may vary based on local conditions (McClaren et al. 2005).

The first evaluation of PFA habitat was conducted by Daw and DeStefano (2001). They compared forest structure around 22 nests with forest structure around random points. Comparisons were made at six spatial scales from the nest stand up to a 170-ha PFA. They found that within circles of 12-ha and 24-ha plots around nests, late forest structure was more abundant than around random points. They also reported forest structure at the PFA-scale was dominated by dense-canopied forest and always contained wet meadows.

Reynolds et al. (1992) hypothesized the PFA would be intermediate in heterogeneity between the nest area and home range. This concept was recently supported by a study conducted by Finn et al. (2002a). Finn et al. (2002a) compared occupancy patterns of goshawks (during 1996–1998, N = 30) nesting on the Olympic Peninsula, Washington to habitat structure, composition, and configuration measured at three spatial scales (39 ha nest area, 177 ha PFA; and 1,886 ha home range). Occupied historical sites tended to have a high proportion of late-seral forest (>70% canopy closure of conifer species with >10% of the canopy trees >53 cm dbh), reduced stand initiation cover, and reduced landscape heterogeneity at all three scales, but only the two larger scale models predicted occupancy successfully. Habitat conditions at the nest-area scale were more similar between occupied and unoccupied sites than were habitat conditions in PFAs or home ranges. Also, goshawks occupied areas with more heterogeneity and more early stand initiation forest within their home range than within the PFA.

McGrath et al. (2003) further evaluated this question of goshawk habitat at various spatial scales in an intensive field and modeling study. They compared nesting habitat on four study areas in eastern Oregon and Washington during 1992–1995. Eight habitat scales ranging from 1–170 ha (PFA scale) surrounding 82 nests and 95 random sites were analyzed to describe goshawk nesting habitat at biologically relevant scales and to develop models that could be used to assess the effects of forest management on habitat suitability. At the 1-ha scale, the stage of stand development, low topographic position, and high stand basal area reliably discriminated between nests and random sites. At this small scale, the stem exclusion phase of stand development was preferred, whereas understory re-initiation and old-growth phases were used in proportion to their availability. At larger scales, the middle stages of stand development consisting of stem exclusion and understory re-initiation (both with canopy closure >50% and greater habitat heterogeneity), were more common around nests than random sites. These effects were prevalent up to 83 ha. They provide convincing evidence that in their study area, a core area around goshawk nests where the forest is characterized by large trees with high canopy closure and this core is surrounded by a heterogeneous landscape with forest cover types that are equally abundant. Although the functional significance of this 83-ha area has not been demonstrated, they speculate the habitat conditions within 500 m (approximately 80 ha) may provide the PFA-like conditions described by Reynolds et al. (1992) and Kennedy et al. (1994) in this area. Recently, La Sorte et al. (2004) found that goshawk nests in northern Arizona were consistently associated with regions of continuous forest and gentle terrain out to 645 m from the nest site. They concluded that this non-fragmented, forested area represents the PFA which Kennedy et al. (1994) estimated as a circle centered at the nest with a radius of 732 m. This literature suggests that PFAs likely exist and occur at the scale of 80–200 ha, but vary in size depending on local environmental conditions (i.e., availability of vulnerable prey and predation risk).

FORAGING AREAS

Goshawk nesting habitat is well described at the nest-tree and nest-stand levels, but how goshawks use habitats away from their nests during the nesting season is poorly understood. A few studies have been conducted in North America that describe breeding season foraging habitat (Austin 1993, Bright-Smith and Mannan 1994, Beier and Drennan 1997, Good 1998, Lapinski 2000, Finn et al. 2002a, Boal et al. 2005b). These studies have defined foraging habitat in a variety of ways, which limits our ability to make cross-study comparisons. These definitions include: (1) all habitat within a home range not included in the nest area, (2) habitat at locations of goshawks obtained by radio tracking tagged birds, and (3) habitat at known kill sites located by detailed tracking of radio-tagged birds. Home range analyses estimate home range size based on locations of radio-tagged birds or assume the home range can be represented by a circular area centered on the nest.

Results from some studies suggest goshawks forage in all forest types, but appear to select forests

with a high density of large trees, greater canopy cover and high canopy closure, high basal area and relatively open understories in which to hunt (Beier and Drennan 1997, Finn et al. 2002a, Greenwald et al. 2005). However, other studies report a tolerance for a broad range of forest structures (Kenward 1982, Widén 1989, Austin 1993, Bright-Smith and Mannan 1994, Hargis et al. 1994, Beier and Drennan 1997). Beier and Drennan (1997) suggested goshawks in their northern Arizona study area forage in all types of forest stands. It is also important to note that while some habitats may be avoided by foraging goshawks, they may actually be important in terms of prey production (Boal et al. 2005b).

In southwestern Yukon, Canada, 33% of goshawk kills were in dense forest cover although only 18% of the area contained this cover type (Doyle and Smith 1994). Hargis et al. (1994) found goshawks foraging in forest stands with higher basal area, more canopy cover, and more trees in large diameter classes than were randomly available.

Goshawks can also hunt openings and along edges. Shuster (1980) observed goshawks hunting in openings and clear-cuts in Colorado. In Nevada, three males foraged in open sagebrush away from trees (based on 13 visual locations) and along the edge of aspen groves to hunt Belding's ground squirrels in sagebrush (Younk and Bechard 1994a). In Europe, Kenward (1982) collected detailed movement data on four radio-tagged goshawks. These birds spent a substantial amount of time hunting along edges and crossing openings between woodlands. These studies indicate that goshawks hunt in open and edge habitats; however, the degree to which they rely on these edges for prey is unclear.

Reynolds and Meslow (1984) assigned bird and mammal prey species in forested habitat to four height zones (ground-shrub, shrub-canopy, canopy, and aerial) based on where each species spends most of its time. They found 40% of prey species in goshawk diets were zone generalists, 35% were most often in the ground-shrub layer, and the remaining prey was evenly distributed between shrub-canopy and canopy layers. Reynolds et al. (1992) indicated large-bodied prey might be more important to breeding goshawks than smaller prey. In the Reynolds and Meslow (1984) study, large-bodied mammals and avian prey were primarily associated with lower forest strata or were zone generalists. In Arizona, 62% of prey were captured from the ground-shrub zone, 25% were zone generalists, and 13% were from the shrub-canopy and canopy zones with highly aerial prey, such as swallows, rarely present in the diet (Boal and Mannan 1994).

DeStefano and McCloskey (1997) reported that in the coast ranges of Oregon, goshawks are rare even though goshawk prey species are varied and abundant. Forests in this area contain high understory stem densities and dense undergrowth, which may make prey species difficult to capture. DeStefano and McCloskey (1997) suggested that if a relationship between vegetation structure and prey availability does exist, these forest conditions might limit prey availability to goshawks.

In southcentral Wyoming, Good (1998) described foraging habitat of five male goshawks at nest sites. He examined four factors at each kill site: prey abundance, habitat characteristics, landscape patterns, and habitat needs of prey species. Similar to Beier and Drennan's (1997) study, Good (1998) found the relative use of kill areas correlated with habitat characteristics rather than prey abundance. The majority of goshawks (N = 3) in his sample returned most often to sites with more mature forests, gentler slopes (6–60%), lower ground coverage of woody plants (1–30%) and greater densities of large conifers (23–37.5 cm dbh, range = 0–11 stems/0.04 ha). Goshawk kill areas were often associated with small natural openings, as were many prey species. Good also suggested that goshawks may return to areas more often where large numbers of prey are present because two individuals in his sample regularly returned to kill sites with high prey abundance.

In western Washington, Bloxton (2002) identified 52 kill sites of 13 goshawks (seven adult males, one juvenile male and five adult females). Goshawks killed prey in stands that ranged from 13-yr-old regeneration stands to 200-yr-old stands; all forest types were hunted except recent clearcuts and shrub-sapling states. Although much variation was associated with kill sites, goshawks made kills in mature forests more than expected based on availability. Goshawks tended to hunt in stands with larger diameter trees and avoid areas composed primarily of small trees (saplings-pole). Kill sites also had greater overall basal area, greater total snag density, and greater small snag density, but the number of large snags did not differ between use and random sites. The forest understory characteristics seemed to have little effect where goshawks killed prey, except that kill sites had 35% less tall understory cover compared to random sites.

WINTERING AREAS

The European studies suggest that prey abundance and not habitat per se may be an important factor affecting habitat use by goshawks during

the winter, particularly at northern latitudes (Sunde 2002). However, a recent study of forest structure and prey abundance at goshawk winter kill sites by Drennan and Beier (2003) suggested that goshawks select winter foraging sites in northern Arizona based on forest structure rather than prey abundance. In their northern Arizona study area, kill sites of 13 radio-tagged adult goshawks (six males and seven females) had more medium-sized trees and denser canopies than nearby paired sites that lacked evidence of goshawk use. Prey abundance indices were nearly equal at used and reference plots. This pattern is consistent with their results for breeding season foraging habitat in the same study area (Beier and Drennan 1997). However, the results of both Arizona studies need to be interpreted cautiously because they used prey abundance indices that do not account for detection probabilities which has been demonstrated to be difficult to interpret by numerous authors (Buckland et al. 2001).

In the winter, goshawks have been reported to use a variety of vegetation types, such as forests, woodlands, shrub lands, and forested riparian strips in search of prey (Squires and Ruggiero 1995, Drennan and Beier 2003). In northern Arizona, adult goshawks continued to use their breeding season home ranges in ponderosa pine and most males moved into lower elevation, pinyon-juniper woodlands during the winter (Drennan and Beier 2003). Squires and Ruggiero (1995) documented that four goshawks, which nested in south-central Wyoming, were short-distance migrants (range = 65–185 km from nesting area). These four goshawks wintered in aspen with mixed conifer stands, large stands of spruce-fir, lodgepole pine, and cottonwood groves surrounded by sagebrush.

Stephens (2001) analyzed landscapes of winter home ranges of 12 goshawks breeding in the Uinta Mountains in Utah. This is the largest sample size of winter birds observed in North America. The four core range habitat types were: (1) mixed-conifer forests at higher elevations composed primarily of lodgepole pine, subalpine fir (*Abies lasiocarpa*), and/ or Douglas fir, (2) woodlands composed primarily of pinyon-juniper and agricultural areas adjacent to the woodland, (3) a combination of the first two habitat types, and (4) lowland riparian areas adjacent to salt-desert scrub. The birds demonstrated a preference for habitats 1, 3 and 4. These data indicate this sample of goshawks had winter home ranges with a higher diversity of vegetation types and more patches than the rest of the study area. Stephens (2001) speculated these areas may have supported a more diverse prey base. His data also support the observations of

Drennan and Beier (2003) that birds will winter in habitats not used for nesting, i.e., pinyon-juniper woodland.

Widén (1989) tracked radio-tagged goshawks (N = 23 males; 20 females) in Sweden that wintered in highly fragmented forests interspersed with clear cuts, wetlands and agricultural lands. In this study, goshawks killed more than half of their prey in large (>40 ha) patches of mature forests (70 yr old) and used these areas significantly more than what was proportionately available. Young and middle-aged forests were used by goshawks in proportion to abundance. Mature forests allowed goshawks to hunt while remaining undetected by prey, but were also open enough for birds to maneuver when attacking prey (Widén 1989).

In England, Kenward (1982) tracked four goshawks that spent 50% of their time in and took 70% of their prey from the 12% of woodland contained within their home ranges. Another study conducted in agricultural areas of England (Kenward and Widén 1989) reported wintering goshawks used edge habitats for foraging. Differences in habitat use may be attributed to different prey distributions (Kenward and Widén 1989). Kenward and Widén (1989) reported that in boreal forests, goshawks prey primarily on squirrels found distributed throughout the forest, whereas in agricultural areas goshawks hunt near forest edges where prey are more abundant. Goshawk home ranges in agricultural areas were smallest where prey densities were greatest, and were largest in areas that contained the least woodland edge, suggesting that prey distribution and availability was the factor that determined the distribution of goshawks during winter (Kenward and Widén 1989).

A recent study by Tornberg and Colpaert (2001) monitored winter habitat use of 26 radio-marked goshawks in northern Finland. These were birds that were trapped in the winter so their residency status was unknown. However, the species is a resident in the northern boreal forest of Finland. Harmonic mean centers of their winter ranges were concentrated near human settlements where they preyed upon human commensals, e.g., brown rats (*Rattus norvegicus*). Goshawks preferred deciduous and mature coniferous forests and avoided open areas such as large fields and bogs. They also avoided very heterogeneous sites, which the authors attribute to avoidance of areas of dense vegetation and not edges as was noted in Sweden by Widén (1989). In Finland, they preferred small to medium-sized patches (<30 ha) of forests and avoided large patches (>30 ha). The results of this study differ from that of Widén (1989)

in Sweden where goshawks showed a strong preference for large patches of mature forest. Tornberg and Colpaert (2001) suggested these differences were due to differences in prey preferences. Goshawks in Sweden mostly took squirrels, which reached their peak densities in old spruce forests. In Finland, wintering goshawks preyed mostly on species associated with deciduous forests (Black Grouse) and early seral stages (mountain hares [*Lepus timidus*]), or urban areas (brown rats).

SEASONAL MOVEMENTS AND DISPERSAL

Movements of goshawks beyond home range boundaries include migration, natal dispersal, and breeding dispersal. Migration is seasonal movement between breeding and non-breeding home ranges. Natal dispersal is defined as movement between a bird's natal area and its first breeding area, whereas breeding dispersal is defined as movements by adults between years among breeding areas (Greenwood 1980, Greenwood and Harvey 1982). Migration and dispersal are important components of population dynamics, yet are poorly understood for most bird populations (Lebreton and Clobert 1991, Newton 1998) including goshawks in North America.

FALL MIGRATION

Goshawks are partial migrants (Squires and Reynolds 1997) meaning that some individuals maintain year-round occupancy of nest territories while other individuals in the population undergo seasonal movements to wintering areas (Berthold 1993). Sonsthagen (2002) used satellite telemetry to monitor migratory movements of 34 female goshawks breeding throughout the state of Utah. She found the goshawks moved throughout Utah and inconsistently used existing forest corridors when they left their nesting territories. The 34 female goshawks exhibited a variety of movement patterns. However, her data support previously reported patterns based on band returns (Reynolds et al. 1994, Hoffman et al. 2002) and radio telemetry (Squires and Ruggerio 1995, Stephens 2001) that goshawk migrations involve short-distance movements (<500 km). Of the 34 birds fitted with platform transmitter terminals (PTT), 19 wintered near their breeding area and 15 were migrants. The migrants moved 49–613 km to wintering areas and only two birds moved >500 km. Band return data from the European subspecies suggest short-distance movements or wandering during the non-breeding season occurs for birds that reside in southern latitudes (Bühler et

al. 1987) and longer-distance migrations are more common for populations from northern latitudes (Hoglund 1964a).

The degree to which populations are partially migratory may relate to food availability on breeding areas during winter. At Kluane, Yukon, goshawks were year-round residents during periods of high snowshoe hare abundance, but winter sightings sharply declined when hare densities were low (Doyle and Smith 1994). In southeast Alaska, males maintained loose association with their nesting home range throughout the non-breeding season (Alaska Department of Fish and Game 1993), but some females moved up to 56 km from nesting home ranges. In Minnesota, 27 of 28 radio-tagged goshawks were recorded within 12.4 km of their nest during three consecutive winters (Boal et al. 2003).

Approximately every 10 yr, large numbers of goshawks are observed migrating to southern wintering areas apparently in response to low prey abundance at northern latitudes (Mueller and Berger 1968, Mueller et al. 1977, Doyle and Smith 1994); incursions usually last at least 2 yr (Squires and Reynolds 1997). The periodic invasions of goshawks along the western shore of Lake Michigan from 1950–1974 were correlated with 10-yr population declines in Ruffed Grouse (*Bonasa umbellus*) and snowshoe hares (Mueller et al. 1977). Irruptive movements of goshawks are composed primarily of adults (Sutton 1931, Mueller et al. 1977); juvenile proportions are variable, probably dependent on reproductive success during the previous nesting season. Incursion years in North America summarized by Palmer (1988) and Squires and Reynolds (1997) include: winters 1859–1860, 1870–1871, 1905–1907, 1917–1918, 1926–1928, 1935–1936, 1952–1954, 1962–1963, 1972–1973, 1982–1983, and 1992–1993. In 1972–1973 near Duluth, Minnesota, observers counted 5,352 goshawks which dwarfed previous counts (Hofslund 1973). In other areas, migration counts indicate some populations irrupt on a 4-yr cycle (Nagy 1977). As noted by Boal et al. (2003), we do not understand the factors that influence goshawk residency patterns.

Fall migrations generally commence after young disperse from natal areas (Palmer 1988) and occur between mid-September and mid-December. Heintzelman (1976 in Bosakowski 1999) shows the fall migration season for goshawks extends from mid-September through November at Hawk Mountain, Pennsylvania. In New Jersey, the peak fall migration occurs mid to late October (Bosakowski 1999). From 1970–1994 counts of migrant goshawks

ranged from 27–347 for Hawk Mountain; 106–5,819 for Hawk Ridge, Minnesota; 9–75 for Cape May, New Jersey; and 63–252 for Goshute Mountain, Nevada. These numbers are difficult to interpret because they are a function of number of observers and observer detection probabilities.

Spring migration is far less pronounced and poorly understood (Squires and Reynolds 1997). In Wyoming, four radio-tagged goshawks exhibited short distance migration (range = 65–185 km) beginning in mid-September and returned to nest sites between 23 March and 12 April 1993 (Squires and Ruggiero 1995). Breeding birds in northeast Utah also returned to their nest sites in March but their winter locations were unknown (Dewey et al. 2003). Habitat used by goshawks during migration has never been documented.

WINTER MOVEMENTS

Winter movements are better understood for European populations. In Fennoscandia, wintering goshawks move in a northeast or southwest direction; the orientation of these movements may be due to geographical constraints or enhanced chances of recovery in certain directions (Marcström and Kenward 1981a). Juveniles tended to move farther than adults, approximately 70% of movements were between 1–50 km, but 4% were >500 km. Juvenile males tended to move further than juvenile females, and adult males were more sedentary (approximately 80% of movements were <20 km) than adult females. However, the movements of females were highly variable with 46% of females moving <10 km and 9% >500 km. In the boreal forests of Sweden, banded goshawks moved from boreal forests to agricultural regions where prey was more abundant; juveniles moved greater distances than adults (Widén 1985b). In Sweden, the migratory movements of goshawks banded as nestlings varied from 50–200 km depending on region (Hoglund 1964a).

DISPERSAL

Information on dispersal is important for investigating issues of population isolation and demography (Johnson and Gaines 1990, Stenseth and Lidicker 1992). Dispersal and mortality may be more important than reproduction in governing population dynamics, but given these processes occur mainly outside of the nesting period, they are difficult to measure (Braun et al. 1996).

Natal dispersal

Given that natal dispersal involves a complex series of movements (Walls and Kenward 1995, 1998), the final natal-dispersal distance is a function of the cumulative history of movements during the dispersal process (Dufty and Belthoff 2001, Wiens 2001). Successful dispersal is critical to the genetic and demographic viability of populations (Greenwood 1980, Arcese 1989, Wiens 1996). Little is known about the habitats used by goshawks during dispersal, or their dispersal directions and distances. The limited information that is available comes from recapture of marked birds, band returns, radio telemetry, and satellite telemetry.

On the Kaibab Plateau, Reynolds et al. (unpubl. data) reported that 24 of 452 fledglings banded were recruited into the local breeding population. Mean natal dispersal distance was 14.7 km (SD = 8.2, range = 3.4–36.3 km) and did not differ among sexes for the recruits. Five banded juveniles found dead outside of the study area demonstrated a potential for long-distance natal dispersal (181 ± 137 km, range = 52–442 km). In addition, two band recoveries in the southwestern US of birds banded that year were 130 km (Kennedy and Ward 2003) and 176 km (Reynolds et al. 1994) from their natal nest. Distances from natal nest areas, for recoveries of juveniles radio-tagged in New Mexico, ranged from 5.5–130 km (N = 16; P. L. Kennedy and J. M. Ward, unpubl. data).

Kennedy and Ward (2003) experimental results suggest that natal dispersal in New Mexico was regulated by food availability for at least the first 4 mo post-fledging. After independence, radio-tagged control birds were never located in their natal areas and by the end of September in 1992 and 1993 they had all left the study area. However, treatment (provided with supplemental food at the natal area) birds remained on the study area for the duration of the experiment (late October in 1992 and late November in 1993). These results support the idea that juveniles monitor their environment at a local scale to make dispersal decisions. These results are corroborated by correlative studies conducted by Byholm et al. (2003) on factors influencing natal dispersal in the European subspecies. Byholm et al. (2003) analyzed 12 yr of band-return data for birds hatched over a wide area in Finland and found local prey availability (as indexed by grouse census data) influenced dispersal distances; juvenile European goshawks remained nearer to the natal area when local grouse density was high than when grouse were scarce.

Breeding dispersal

Goshawk breeding dispersal includes movements between alternative nests within a breeding area, and movements of individuals from one breeding area to another. Although movements of a pair between alternative nests are not important demographically, they may confound detection and interpretation of movement by pairs or individuals to a different breeding area and these two types of movement can only be distinguished when individuals are marked (USDI Fish and Wildlife Service 1998a). Breeding dispersal could result from death of a mate, or may represent an attempt to acquire a better mate or breeding area (USDI Fish and Wildlife Service 1998a), and may be induced by low productivity (Reynolds et al. 1994). The factors influencing breeding dispersal may differ from those influencing natal dispersal, but the probability of remaining close to the natal area is positively related to survival and/or reproductive success (Byholm et al. 2003).

Reynolds et al. (1994) reported that in northern Arizona, three birds that moved from one breeding area to another in consecutive years all produced more young after the move. Reynolds et al. (unpubl. data) reported results of a study of 259 banded adult goshawks breeding in the same study area. Mean breeding dispersal distance for males was 2.4 ± 0.6 km (range = 1.9–3.5 km, N = 6) and for females was 5.0 ± 2.3 km (range = 2.4–9.0 km, N = 11). Both male and female mean breeding dispersal distances were close to the nearest-neighbor distance ($\bar{x}$ = 3.8 km, SD = 3.2, N = 97), indicating that dispersers moved to neighboring territories. In northern California, Detrich and Woodbridge (1994) reported higher rates of breeding dispersal. Over 9 yr, 18.2% of females (N = 22) and 23.1% of males (N = 13) were found breeding in more than one breeding area. Breeding dispersal distances for females averaged 9.8 km (range = 5.5–12.9 km) and for males averaged 6.5 km (range = 4.2–10.3 km). Similar to natal dispersal, detection of maximum breeding dispersal distances is likely constrained by size of study areas and resighting technique (Koenig et al. 1996).

DEMOGRAPHY AND POPULATION ECOLOGY

Goshawk populations fluctuate in response to changes in survival, reproduction, immigration, and emigration. Population ecology is concerned with determining how factors such as genetics, population density, distribution, age structure, resource abundance and availability, habitat distribution, competition, and climate influence these population parameters. Understanding a species' population biology is also mandated by the NFMA that requires the USFS to maintain viable populations of native vertebrates. The ESA reinforces the NFMA by identifying distinct population segments as an appropriate level of protection. These laws, coupled with life-history attributes of goshawks, underscore the pressing need to determine how population vital rates may vary relative to forest management and other human-induced changes to landscapes.

POPULATION VITAL RATES

Longevity

Goshawk longevity is poorly documented because few studies are long term and inherent difficulties exist for following individual birds over time. Age records for wild birds include a 6-yr-old bird in Alaska (McGowan 1975), 6- and 7-yr-old birds in northern California (Detrich and Woodbridge 1994), a 9-yr-old bird in New Mexico (P. L. Kennedy, unpubl. data), an 11-yr-old male in Minnesota (Boal et al. 2002), and a 12-yr-old female in Wisconsin (Evans 1981). Bailey and Niedrach (1965) reported a captive bird living 19 yr.

Survivorship

Survival estimates are poorly documented. We do not understand how seasonal, temporal, spatial, or environmental factors affect goshawk survival, nor do we understand how survival patterns vary by sex and age class. Annual juvenile survival can vary from 0.16–1.00 with most estimates occurring between 0.37–0.57 (Table 3). Average annual adult survival varies from 0.70–0.87 independent of estimation technique and geography (Table 4). However the standard errors of these estimates vary from 0.05–0.1; this low precision limits their utility for estimating annual trends in survival.

Estimated age-specific mortality rates of Finnish and Swedish birds based on banding recoveries (N = 552, years 1950–1966) assuming a 60% reporting rate were: 66% year 1, 33% year 2, 19% year 3, 19% year 4, and 11% for years 5+ (Haukioja and Haukioja 1970). Survivorship between banding and recovery was 287 d for birds banded in Sweden and 221 d for those in Finland (Hoglund 1964a). Winter survival favors birds of higher body mass; males appear to be more vulnerable to food shortage than females (Marcström and Kenward 1981b).

TABLE 3. ESTIMATED POST-FLEDGING SURVIVORSHIP CALCULATED FOR JUVENILE (0–1 YR OF AGE) NORTHERN GOSHAWKS.

Location	Year(s)	Time monitored survivorship (SE)	Annualized survivorship	N	Months post-fledging[a]	Source
North America						
Alaska	1992–1993	0.50 (NA)	0.16	14	4.5	Titus et al., unpubl. data
Northern New Mexico	1992	0.91 (0.09)[b]	0.81	12	5.5	Ward and Kennedy 1996
	1992	0.93 (0.06)[c]	0.85	15	5.5	
	1993	1.00 (0.0)[b]	1.00	9	7	
	1993	0.67 (0.27)[c]	0.50	3	7	
Northeastern Utah	1996	0.87 (0.1)[b]	0.56	15	3	Dewey and Kennedy 2001
	1996	0.89 (0.07)[c]	0.57	18	3	
	1997	1.00 (0)[b]	1.00	19	3	
	1997	0.56 (0.12)[c]	0.43	18	3	
Europe						
Sweden	1980–1987	0.86 (NA)	0.55	22	3	Kenward et al. 1999
	1980–1987	0.69 (NA)	0.48	22	6	
	1980–1987	0.52 (NA)	0.52	22	12	
Fennoscandia	1950–1966	0.37 (NA)[d]	0.37	55	12	Haukioja and Haukioja 1970
Northern Finland	1991–1995	0.50 (NA)	0.37	7	5	Tornberg and Colpaert 2001

[a] The number of months monitored after fledging.
[b] Treatment in supplemental feeding experiment.
[c] Control in supplemental feeding experiment.
[d] Estimated from banding.

TABLE 4. ESTIMATED MEAN SURVIVORSHIP RATES FOR ADULT FEMALE[a] NORTHERN GOSHAWKS.

Location	Year(s)	Survivorship (SE)	N	Source	Method
North America					
Alaska	1992–1996	0.72 (NA)[b]	39	Iverson et al. 1996	Radio tracking
Northern Arizona	1991–1996	0.87 (0.05)	99	Reynolds and Joy 1998	Mark-resight
Northern California	1983–1992	0.70 (0.10)	40	DeStefano et al. 1994b	Mark-resight
Northern New Mexico	1984–1995	0.86 (0.09)[b]	45	Kennedy 1997	Mark-resight
Europe					
Sweden	1980–1985	0.79 (NA)	132	Kenward et al. 1999	Radio tracking
Fennoscandia	1950–1966	0.86 (NA)[b]	552	Haukioja and Haukioja 1970	Mark-resight
Northern Finland	1991–1995	0.75 (NA)[b]	19	Tornberg and Colpaert 2001	Radio tracking

[a] Insufficient data available to estimate male survival rates in all studies.
[b] Annual survivorship reported for adults (male and female combined).

Age at first breeding

During the breeding season, goshawks can be categorized as: subadults (1–2 yr) with primarily juvenile feathers, young adults (2–3 yr) with primarily adult plumage and some juvenile feathers, and adults (>3 yr) with full adult plumage (Bond and Stabler 1941, Mueller and Berger 1968, Henny et al. 1985, Reynolds et al. 1994). Although females occasionally nest as subadults, this has not been documented

for males (USDI Fish and Wildlife Service 1998a). Hoglund (1964a) examined testicular development of 10 subadult males and found the size was variable and only one contained viable sperm suggesting juvenile males may not be physiologically capable of breeding.

Proportion of subadults and juveniles varies geographically from <5% in Oregon (Reynolds and Wight 1978, Henny et al. 1985) and New Mexico (P. L. Kennedy, unpubl. data) to 50% in Nevada (Younk

and Bechard 1994a). In New York and New Jersey, only two females (N = 35 nesting attempts) were in immature plumage and all males (N = 18) were in adult plumage (Speiser and Bosakowski 1991). In Alaska, subadult females occupied 33% (N = 16) of active nests during the only year that subadults nested (McGowan 1975). Reynolds et al., (unpubl. data) reported the mean age of first breeding for 24 young goshawks recruited into their natal breeding population in Arizona as 3.2 yr ± 1.1 (range = 2–5 yr) for males and 4.3 ± 1.9 (range = 2–8 yr) for females. They suggested that low recruitment rates and delayed age of first breeding could indicate a stationary, saturated population of breeders on the study area.

Clutch size

Goshawks usually lay one clutch per year. Renesting appears to be rare but does occur following egg loss, especially if loss is during early incubation (Zirrer 1947, Squires and Reynolds 1997). Clutch sizes are usually two–four eggs, rarely one and five. In North America, the mean clutch size was 2.7 eggs (SD = 0.88, N = 44; Apfelbaum and Seelbach 1983). The average clutch size was 3.2 eggs (SD = 0.45, N = 5; Reynolds and Wight 1978) in Oregon, and 3.2 (range = 1–4, N = 33) in Alaska (McGowan 1975). In Nova Scotia (N = 47), 34 % of nests contained two eggs; 49 %, three eggs; and 17%, four eggs (Tufts 1961). In Great Britain, average clutch size was 4.0 (SE = 0.11, range = 2–5, N = 47); of these clutches, 2% contained two eggs; 21%, three eggs; 55%, four eggs, and 21%, five eggs (Anonymous 1990).

REPRODUCTIVE SUCCESS

Goshawk fecundity is difficult to estimate, but clearly there is considerable spatial and temporal variation across the species' range (Squires and Reynolds 1997). Given the inherent difficulties of directly measuring fecundity, indices of reproductive success are used that require specific terminology (Steenhof 1987). An occupied breeding area is an area with evidence of fidelity or regular use by goshawks that may be exhibiting courtship behavior and may attempt to breed. An active breeding area or nest is an area or nest in which eggs are laid. A successful breeding area or nest is one in which at least one young is fledged. Nesting success is the proportion of active nests that fledge at least one young, or occasionally the proportion of occupied breeding areas that fledge at least one young. Productivity is the mean number of young

fledged per successful nest, the mean number of young produced per active nest, or the mean number of young per occupied breeding area. Estimates of these parameters are often overestimated due to the greater probability of detecting breeding versus non-breeding pairs and successful versus unsuccessful nests (Mayfield 1961, Miller and Johnson 1978, Johnson 1979, Hensler and Nichols 1981, Steenhof and Kochert 1982, Reynolds and Joy 1998, Manolis et al. 2000).

Nesting success and productivity

Estimates of annual nesting success range from 8–94% (Squires and Reynolds 1997, Lapinski 2000, Boal et al. 2005a). Mean nest success ranges from 76–95% in western North America (Table 5). Productivity, defined as the number of young fledged per nest where eggs were laid, is the most commonly used statistic quantifying raptor reproduction (Newton 1979a). It is also common to consider young observed at 80–90% of fledging age as surviving to fledge (Steenhof 1987). Productivity ranges from 1.2–2.0 young per active nest and 1.4–2.7 young per successful nest in western North America (Table 5). Most populations produce between 2.0–2.8 fledglings per successful nest (Squires and Reynolds 1997). In Arizona (N = 98 nests), 85% of nests successfully fledged young, 3% either did not lay eggs or clutches were lost during early incubation, 6% of clutches were lost during incubation, and 6% failed during the nestling period (Reynolds et al. 1994). The highest estimates of productivity in North America are from the northern portion of the goshawk's range in Yukon, Canada, and interior Alaska (McGowan 1975, Doyle and Smith 1994). Although productivity is high for northern populations, it can be highly variable. In the Yukon, the number of fledglings/successful nest varied from zero in 1992 to 3.9 in 1990 (Doyle and Smith 1994).

In long-lived raptors, research suggests some nest areas consistently fledge more young than others, with the majority of young in the population being produced by a few females that are breeding in high quality nest areas. McClaren et al. (2002) evaluated whether or not number of young fledged varied spatially and temporally among goshawk nest areas within three study areas where long-term reproductive data from goshawks were available: Vancouver Island, British Columbia, Jemez Mountains, New Mexico, and Uinta Mountains, Utah. Their analysis indicated minimal spatial variation in nest productivity within the three study locations. Rather, nest areas exhibited high temporal variability in nest

TABLE 5. REPRODUCTION STATISTICS IN WESTERN NORTHERN GOSHAWK POPULATIONS IN NORTH AMERICA.

Location	Year(s)	N active nests[a]	N successful nests[b]	Mean N young / active nest	Mean N young / successful nest	Mean nest success (%)[c]	Source
Alaska	1971–1973	33	NA	2.00	2.70	NA	McGowan 1975
Arizona	1990–1992	22	20	1.90	2.20	91	Boal and Mannan 1994
Central Arizona	1990–1991	NA	23	NA	1.72	NA	Dargan 1991
Northern Arizona	1988–1990	NA	NA	1.68	2.00	82	Zinn and Tibbitts 1990
Northern Arizona	1991–1996	273[d]	224[d]	1.55[d]	1.88[d]	82[d]	Reynolds and Joy 1998
Southeastern Arizona	1993–1994	14	11	1.50	1.90	79	Snyder 1995
California	1981–1983	181	164[d]	1.71	1.89[d]	91[d]	Bloom et al. 1986
California	1987–1990	23	18	1.39	1.77	78	Austin 1993
California	1984–1992	84	73[d]	1.93	2.22[d]	87[d]	Woodbridge and Detrich 1994
Idaho–Wyoming	1989–1994	68	62	1.96	2.11	91	Patla 1997[e]
Northcentral New Mexico	1984–1995	80	NA	1.30	NA	NA	McClaren et al. 2002
Oregon–Washington	1994	81	73[d]	1.64	1.82	90	McGrath et al. 2003
Oregon	1992	12	10	1.20	1.40	83	Bull and Hohmann 1994
Oregon	1992–1993	50	NA	1.28[d]	NA	NA	DeStefano et al. 1994a
Oregon	1969–1974	48	NA	1.70	NA	90	Reynolds and Wight 1978
Northeastern Utah	1991–1999	118	NA	1.30	NA	NA	McClaren et al. 2002
South Dakota	1972–1976	17	13	1.35[d]	1.77[d]	76[d]	Bartelt 1977
Vancouver Island, British Columbia	1991–2000	51	NA	1.59	NA	NA	McClaren et al. 2002
Mean[f]	---	---	---	1.59	1.95	86	----

[a] An active nest is one in which at least an egg is laid or is inferred to be laid by a female (e.g., a bird seen in incubation posture).

[b] A successful nest is one that fledges at least one young.

[c] Nesting success is the proportion of active territories that successfully produce young.

[d] Estimated from data presented.

[e] Study done in the Targhee National Forest and encompasses more than one state.

[f] Mean calculated for numeric entries only and not across all studies (i.e., NA entries were ignored).

productivity within each study area. These results suggest temporal patterns, such as local weather and fluctuating prey populations, influenced goshawk reproduction more than spatial patterns such as habitat characteristics. They concluded nest productivity may inadequately reflect spatial patterns in goshawk reproduction; spatial variability among nest areas in adult and juvenile survival rates may instead reflect variation in habitat quality.

The age of pair members also impacts productivity. In Arizona, young-adult to adult pairings produced fewer fledglings per active site (1.1 fledglings, SD = 0.9, N = 9) than adult-adult pairings (2.3 fledglings, SD = 0.8, N = 21, Reynolds et al. 1994); young-adult females and young-adult males were similarly productive. However, in Nevada, young females were as productive as older birds (2.54 vs. 3.0 young per nest, N = 11), but fledged young at a later date (Younk and Bechard 1994a).

Unsuccessful nests usually failed early in the breeding season, before or soon after laying (Widén 1985b). Dead nestlings, usually <10 d, are frequently found below nests with the cause of death unknown (Reynolds and Wight 1978). Pairs rarely fail after nestlings are 3-wk old. In New Mexico, nestling survival varied from 100% (six nests) at control nests (pairs not receiving supplemental-feeding) in 1992, to 37% at eight control nests in 1993 (Ward and Kennedy 1996). In Utah, nestling survival varied from 67% (6 nests) at control nests in 1996, to 57% at seven control nests in 1997 (Dewey and Kennedy 2001). In Alaska, nestling survival estimated at 98% (1971–1973, N = 33, McGowan 1975). On the Baltic island of Gotland, 3% (N = 73) of radio-tagged males and 8% of females that fledged died before dispersal (Kenward et al. 1993c).

Causes of nest failure include human disturbance, i.e., shooting of adults, recreational use of an area, and logging activities (Hoglund 1964a, Hennessy 1978, Bühler et al. 1987), disease (McGowan 1975, Ward and Kennedy 1996), inclement weather (Hennessy 1978, Boal et al. 2005a), avian predation (Hennessy 1978, Ward and Kennedy 1996, Boal et al. 2005a) and mammalian predation (McGowan 1975, Hennessy 1978, Doyle and Smith 1994, Erdman et al. 1998, Boal et al. 2005a). From 1998–2000 in northern Minnesota, 21% of all nesting attempts failed (N = 43) and 52% of these failures were a result of documented or possible depredation from a suite of predators and 35% of the failures were due to inclement weather. Food limitation can result in higher predation rates on nestlings because female goshawks must spend more time foraging and less time defending their young (Ward and Kennedy 1996, Dewey and Kennedy 2001).

Siblicide and cannibalism occurs, especially during periods of food deprivation (Kenward et al. 1993b, Boal and Bacorn 1994, Estes et al. 1999). Estes et al. (1999) presented evidence supporting the hypothesis that siblicide is a mechanism for brood reduction during periods of low food availability. Kenward et al. (1993b) documented that at hatching, nestling sex ratio was 1:1 but females predominated in broods that lost most offspring suggesting siblicidal interactions favor the larger females.

Proportion of pairs breeding

The proportion of goshawks that nest in a given population is difficult to determine, and poorly understood. Widén (1985b) reported 67% of adults radio-tagged (N = 12) during winter in Sweden were later found breeding. In northern Arizona, Reynolds and Joy (1998) found the proportion of pairs (N = 478 breeding area-years) annually laying eggs declined from 77–87% in 1991–1993 to 22–49% in 1994–1996 with low rates likely occurring during periods of low prey abundance.

Environmental Factors Affecting Productivity and Population Dynamics

Weather

Cold spring temperatures and exposure to cold and rain can cause egg (Hoglund 1964a) and nestling mortality (Zachel 1985). Yearly variation in climatic conditions can impact productivity and other demographic parameters (Elkins 1983). Bloxton (2002) demonstrated a profound pattern of reduced survival rates of adult goshawks (with most mortalities occurring during winter) and an almost complete cessation of reproduction after an unusually strong La Niña event. This period (late 1998–early 1999) had unusually high levels of winter precipitation followed by a cold spring. Abundance indices of nine prey species (unadjusted for detection probabilities thus limiting their interpretation) declined following the La Niña winter, and goshawks generally abandoned reproductive attempts during the pre-laying period or failed during incubation. Abandoning reproductive efforts presumably helped goshawks improve their body condition throughout the summer. Bloxton's (2002) results suggest the indirect effects of weather (reducing prey abundance) are more important than direct effects (hypothermia, freezing eggs, and reduced foraging caused by precipitation interference) in influencing goshawk populations.

In Germany (Kostrzewa and Kostrzewa 1990, 1991), Italy (Penteriani 1997), and the US (Idaho; Patla 1997) high levels of spring precipitation negatively impacted goshawk reproduction whereas warm spring temperatures favored goshawk reproduction. Nestlings had retarded development during cold, wet springs (Kostrzewa and Kostrzewa 1990). Conversely, in British Columbia, high rainfall in May was associated with increased goshawk reproduction (Doyle 2000). In Germany and British Columbia, winter weather and breeding success the following season were not related.

Food availability

Prey abundance and availability are important habitat attributes that elicit demographic and population responses of goshawks (Lindén and Wikman 1983, Doyle and Smith 1994, Ward and Kennedy 1996, Squires and Reynolds 1997, Dewey and Kennedy 2001). In their literature review, Squires and Reynolds (1997) reported prey abundance strongly affects breeding area occupancy and productivity. However, Ward and Kennedy (1996) in New Mexico and Dewey and Kennedy (2001) in Utah experimentally determined that goshawks have a demographic response to a super-abundance of available food during some years, but not other years suggesting that food is not always limiting during the breeding season. These results imply that regional-goshawk populations may only be food-limited during periods when cyclic prey species populations are at low densities (Kennedy and Andersen 1999).

Correlative evidence from North America and Europe suggests goshawk reproduction at northern latitudes may be related to cyclic snowshoe hare and grouse (various species) populations (southern coast of Finland, Lindén and Wikman 1983; southwestern Yukon, Doyle and Smith 1994, Doyle 2000; northeastern Wisconsin, Erdman et al. 1998). The most dramatic example of this relationship occurred in the Yukon where goshawks breeding in peak snowshoe hare years fledged 2.8 young/active nest and 3.9 young/successful nest, compared to years when hare populations were at their lows, and no active goshawk nests were located (Doyle and Smith 1994). In Finland, the proportion of nonbreeding pairs increased from 35–52% in an apparent response to declining grouse populations (Lindén and Wikman 1983). In northeastern Wisconsin, Erdman et al. (1998) monitored the productivity of goshawks from 1968–1992; this is the longest dataset published on reproduction for any goshawk population. Fledglings per nesting attempt ranged from a high of 3.2 in 1978

to lows of 0.8 in 1983 and 1989. They found annual productivity was directly related to an index of prey they developed based on prey remains and pellets containing snowshoe hare and Ruffed Grouse, but the mathematical calculations were not reported. Overall, it appears that certain prey items are particularly important for goshawk reproduction and the abundance of these prey may strongly influence reproductive success (Tornberg and Sulkava 1991).

In addition to prey abundance, it is also important to consider whether prey items are *available* to goshawks. For example, even a high abundance of hares may have low availability to goshawks in a dense aspen regeneration or other habitats where goshawks are unable to effectively hunt (T. Dick and D. Plumpton, unpubl. data, Drennan and Beier 2003). Thus, preferences in goshawk foraging habitat are likely determined, in part, by habitat characteristics that influence their ability to access prey as well as prey abundance (Reynolds et al. 1992, Drennan and Beier 2003).

Based on the assumption that goshawk populations are regulated by food availability, Reynolds et al. (1992), emphasizes that forest management practices may strongly influence the availability of prey items for the goshawk, thus being a determining factor in the long-term persistence of the species (Kennedy and Andersen 1999). Beier and Drennan (1997) and Drennan and Beier (2003) concluded that goshawks did not select foraging areas based on prey abundance, but rather selected areas with higher canopy closure, greater tree density, and greater density of trees >41 cm dbh than on contrast plots. They suggest that goshawk morphology and behavior are adapted for hunting in moderately dense, mature forests, and that prey availability is more important than prey density in habitat selection. Drennan and Beier (2003) also hypothesize that goshawk habitat selection may be a two-tiered process. First, goshawks select broad landscapes that support abundant populations of large-bodied prey, before selecting moderately dense stands of mature forests where they can use their maneuverability to capture prey.

Reynolds et al. (1992) emphasized that goshawk prey species depend on a variety of habitats distributed in a mosaic across the landscape, because many important prey such as sciurids (Carey et al. 1992, Carey 1995) and birds (Schwab and Sinclair 1994) are more abundant in old-growth and mature forests compared to young or regenerating forests. Arthropods, the prey base for many forest-dwelling insectivores, which may in turn be prey for goshawks, are significantly less abundant along edges and in small woodlots (Burke and Nol 1998, Zanette

et al. 2000) suggesting food supplies may be reduced by forest fragmentation. Carey et al. (1992) and Carey (1995) demonstrated that scuirid populations were more abundant and remained at relatively constant levels in old-growth forests in comparison to managed second-growth stands. Similarly, Schwab and Sinclair (1994) reported avian populations were more abundant and diverse in mature forests than in younger forests. However, Sallabanks et al. (2001) found little evidence of structural-class specializations by breeding birds in grand fir (*Abies grandis*) forests in northeastern Oregon.

Clearly, a pressing need exists to understand how prey species are influenced by changes in forest structure and pattern resulting from forest management. This information is needed before we can develop sound conservation plans for goshawks (Kennedy and Andersen 1999).

POPULATION DENSITY

Breeding density

Given their large home ranges, nesting goshawks are distributed across broad landscapes at low breeding densities. Determining breeding density of goshawks requires extensive nest searches over large areas (Kennedy and Stahlecker 1993, Joy et al. 1994). This technique relies on several assumptions, including that surveys are complete (i.e., a census) and accurate. This assumption is problematic because non-breeding birds often go undetected (USDI Fish and Wildlife Service 1998a). Nest surveys that attempt to census breeding density require intensive, systematic searches of large areas, and need to be repeated over several years to detect pairs that do not breed every year (Reynolds and Joy 1998). Nest searches are often conducted only in suitable habitat; thus, many studies actually report ecological density (birds per unit of suitable habitat) rather than crude density (birds per unit area; USDI Fish and Wildlife Service 1998a); this may bias our understanding regarding the habitat-use patterns and density of nesting goshawks (Squires and Reynolds 1997).

Densities of nesting goshawks are low, but highly variable seasonally and spatially among and within populations (Kennedy 1997, Squires and Reynolds 1997). The density of mid-latitude populations in the western half of North America, ranges from 3.6–10.7 pairs/100 km^2 (Squires and Reynolds 1997). In Pennsylvania, the density was 1.2 pairs/100 km^2, but the density of this and other eastern populations may increase as populations recover (Kimmel and Yahner 1994). Densities in the range of 10–11

occupied nests per 100 km^2 were reported for three study areas: Arizona (Crocker-Bedford and Chaney 1988), California (Woodbridge and Detrich 1994), and the Yukon (Doyle and Smith 1994). In Montana, the estimated density was 4.6 nests/100 km^2 during 1998 (Clough 2000). Kenward et al. (1991) reported broad-scale density estimates based on various European studies as 3,000 or more breeding pairs in France, Germany and Spain, and at least 14,000 pairs in Scandinavia.

Density varied from 33–270% during 2 yr in Oregon (DeStefano et al. 1994a). The Bly study area censused by DeStefano et al. (1994a) in 1993 was the same study area censused by Reynolds and Wight (1978) in 1974. The number of occupied nest sites located on this study area (N = 4) did not change over the 21-yr period and thus, densities were equivalent (3.6 birds/100 km^2 in 1974 and 3.8 birds/100 km^2 in 1993; variation due to slightly more area censused in 1974).

Density of non-breeders

Currently, no effective survey methods are available for detecting non-breeders. Non-breeding individuals may play significant roles in goshawk demography as they do in other species (Newton 1991, Hunt 1998). Nonbreeding individuals may buffer populations during stress, stabilize breeding population abundance by quickly filling in when breeders die, or serve to quickly increase the breeding density during periods of prey abundance (Iverson et al. 1996, Hunt 1998). Although it is difficult to estimate the proportion of the adult population made up of nonbreeders, several studies in Europe have indicated a substantial portion of the population does not breed (Kenward et al. 1990). Widén (1985b) estimated one third of the adult, sedentary population in his Swedish study area was non-breeding. In Finland, Lindén and Wikman (1983) estimated 35–52% of the goshawks were non-breeders, with higher proportions occurring during periods of low grouse populations.

Winter density

Winter densities are also difficult to estimate and are currently unavailable. The only index of winter abundance for North American goshawks was estimated by Doerr and Enderson (1965) for the foothills of the Front Range near Colorado Springs, Colorado. They operated six–eight traps in this area from 14 November 1963 to 14 April 1964. All traps traversed a 1,000-m section within the upper sonoran and montane life zones. They caught 13 goshawks between

November and January. No birds were caught after 4 February. The un-calibrated index of abundance ranged from 0.24–0.78 goshawks per trap day during this period. The authors concluded goshawks were relatively common in this area until February, after which no birds were present. However, they could have been present but not trappable.

METAPOPULATION STRUCTURE

Metapopulation structure is the degree that individual populations interact with one another throughout broad landscapes (Levins 1969, 1970; Hanski 1982). Knowing the connectivity among populations has conservation ramifications because it affects population persistence from genetic, demographic, and environmental perturbations (Shaffer 1981, Gilpin 1991). We are unaware of literature discussing goshawk population dynamics within a metapopulation framework. We speculate that metapopulation structure is poorly defined given that goshawk are continuously distributed across the western US and are highly mobile. However, clinal differences exhibited across western populations, plus distinct subspeciation suggests some degree of population structuring. Additional genetic sampling and movement studies are needed to address this important information need.

MORTALITY FACTORS

Goshawks die from a wide variety of causes including accidents, starvation, predation, and disease. The degree to which these factors contribute to total mortality found in North American populations has only been evaluated quantitatively for juveniles in New Mexico (Ward and Kennedy 1996) and Utah (Dewey and Kennedy 2001). The cause of death for 12 juveniles in New Mexico was predation (50%), accident (8.3%), spinal injury (8.3%), disease (8.3%), and unknown causes (25%; Ward and Kennedy 1996). In Utah, 12 necropsied juveniles died of starvation (25%), siblicide (16.7%), accident (8.3%), predation (8.3%), blood loss (8.3%), and unknown causes (33.3%; Dewey and Kennedy 2001). Bloxton et al. (2002) reported that two adult females on separate occasions died from apparent choking on mammalian prey. Boal et al. (2005a) monitored the survival of 33 adult goshawk territory holders over a 3-yr period in northern Minnesota (32 were radio tagged). Nine goshawks, eight of which were radio tagged, died during this study. Five (56%; four females and one male) of these nine mortalities occurred during the breeding seasons and were from predation. The remaining mortalities (one female and three males) occurred during the winter months. The female that died during the winter had been shot and the mortality of one male appeared to also be due to human actions. Causes of death could not be verified for the other two male goshawks.

On the Baltic island of Gotland, natural mortality agents included starvation (37%), disease (7%), a combination of starvation and disease (22%), and trauma (33%, including two birds killed by other goshawks). Trauma induced mortalities include shooting, trapping, injuries (Jälefors 1981), and roadkills (Keran 1981); shooting, trapping and poisoning are especially common mortality factors for European populations but human persecution also occurs in North America (Boal et al. 2005a). Of 11 adult recoveries in Britain, two were killed on roads, eight were shot, trapped, or poisoned, and the cause of remaining death was unknown (Marquiss and Newton 1982).

DISEASE AND PARASITES

Although disease has been documented in wild goshawks (Redig et al. 1980, Ward and Kennedy 1996, Lierz et al. 2002a, b), disease has not been shown to significantly affect the long-term persistence of goshawk populations (USDI Fish and Wildlife Service 1998a). However, disease ecology is poorly understood and mortality by disease is difficult to identify without a detailed necropsy on fresh mortality samples. Traditional ecological analyses have largely ignored the importance of disease in mediating ecosystem function and biodiversity (Real 1996) and numerous emerging infectious diseases are developing that pose a substantial threat to wild animal populations (Daszak et al. 2000). For example, the potential impact of West Nile virus on goshawks is unknown. Given our poor state of knowledge, we must assume that disease could play a role in regulating some goshawk populations.

Bacterial diseases include tuberculosis (*Mycobacterium avium* infection; Lumeij et al. 1981) and erysipelas (*Ersipelas insidiosa* infection; Schröder 1981). Symptoms for tuberculosis included loss of balance, leg weakness, trembling and convulsions, necrotic lesions under tongue, necrotic mass in lung, air sacs, and base of heart, and millet-size to walnut-size yellow-white foci in major organs, especially liver and spleen (Lumeij et al. 1981, Schröder 1981). Ward and Kennedy (1996) reported the cause of death of a nestling in New Mexico as heart failure due to severe fibrinous pericarditis on the heart caused by *Chlamydia tsittaci* and *Escherichia* coli.

Mortality from diseases may be exacerbated by changes in other limiting factors such as food shortage (Newton 1979a). The fungal disease from the genus *Aspergillus* can produce granulomas throughout lungs and air sacs when chronic. Of migrants captured at Hawk Ridge in Minnesota, 53% (N = 49) had *Aspergillus* in 1972 (an invasion year) compared to only 7% (N = 45) in 1973 (a non-invasion year; Redig et al. 1980). Redig et al. (1980) suggested trapped goshawks were birds emigrating from northern forests due to low prey abundance, and the epizootic was the result of increased stress from reduced prey availability or migration (Redig et al. 1980).

Internal parasites are common and heavy infestations of ectoparasites, like lice (*Degeeriella nisus vagrans*), may occur in weakened birds (Keymer 1972, Lierz et al. 2002b). Greiner et al. (1975 *in* USDI Fish and Wildlife Service 1998b) estimated 56% of North American birds had blood parasites, including *Leucocytozoon*, *Haemoproteus*, *Trypanosoma*, and microfilariae. *Trichomoniasis* can be transmitted to accipiters that ingest infected prey, usually columbids, which are hosts to *Trichonomonas gallinae*, a parasitic protozoan (Boal et al. 1998). This parasite may cause severe lesions, usually a stomatitis that obstructs the buccal cavity and pharynx and causes the disease known as frounce, a disease of the crop that may be contracted by feeding on fresh pigeons. Beebe (1974) speculated that some goshawk populations may be threatened by ingesting *Trichonomonas* spp. from pigeons, however, data are lacking. In Alaska, 71% of goshawks (N = 31) had parasites (45% had cestods, 32% trematodes, and 7% had both; McGowan 1975). Sarcocystis parasites can cause encephalitis (Aguilar et al. 1991).

POPULATION TRENDS

No long-term indices of population trends are available for goshawks derived from standardized, widespread surveys in North America (Braun et al. 1996, Kennedy 1997). In addition, insufficient data are available to make a status determination throughout the entire breeding range (Andersen et al. 2005). Breeding Bird Survey (BBS) and CBC data are potential sources of information for estimating rangewide goshawk population trends, but they are inadequate because of low number of routes (25 during 1997–2001 with goshawk detections) and low detection rates on routes (from 1997–2001 no goshawks were observed in Kansas and Nebraska, and an average of 2.6, 2.8, and 1.4 sightings/year were observed across all routes in Colorado, Wyoming, and South Dakota, respectively). CBC data are also inadequate

to estimate goshawk population trends because of low encounter rates.

Some authors have speculated that goshawk populations and reproduction may be declining in the western US (Bloom et al. 1986, Crocker-Bedford 1990, Zinn and Tibbitts 1990). However, Kennedy (1997, 1998) concluded that current sampling techniques may be insufficient to detect population trends and that data are lacking to indicate whether goshawk populations are declining, increasing, or stationary. Andersen et al. (2005) concurred with these conclusions. The difficulty in accurately measuring goshawk population trends is due to multiple factors: (1) goshawks are secretive in nature and difficult to survey, (2) many studies have small sample sizes and are temporally and spatially limited in scope, (3) potential biases exist in nest detection methods used in some studies, and (4) research methods, data analyses and interpretation are not consistent among studies, making comparisons across studies difficult (Andersen et al. 2005, Boyce et al. 2005). The development of a reliable population model is further complicated by the spatial and temporal variation in goshawk populations (Kennedy 1997, McClaren et al. 2002).

In response to Kennedy (1997), Crocker-Bedford (1998) stated the rate of population change for goshawk populations in the US may be impossible to calculate because the species is sparsely distributed, measurements of population parameters vary with prey cycles and weather, and immigration, emigration, and survival are difficult to estimate. Crocker-Bedford (1998) suggested that instead of trying to demonstrate a decline in goshawk populations, habitat relationships of goshawks should be examined to evaluate the amount of habitat destruction or modification that has or is occurring. Kennedy (1998) responded that habitat monitoring should augment demographic studies, not replace them, and suggested that once goshawk habitat is well-defined and demographic data are available from several study areas, a model (or models) that predicts the relationship between nesting and winter habitat and population trends and/or performance could be developed. Andersen et al. (2005) concluded in their recent review of the goshawk literature that assessing the status of goshawks based solely on the distribution of late-successional forests is not appropriate based on the current understanding of goshawk-habitat relationships.

Extensive cutting of eastern forests earlier this century may have reduced populations, but goshawk numbers may be recovering as reforested areas mature (Speiser and Bosakowski 1984). Expanding

distributions of goshawks in Connecticut (Bevier 1994), New York (Andrle and Carroll 1988), Pennsylvania (Brauning 1992), and Michigan (Brewer et al. 1991) suggest regional increases. During the mid-1950s, goshawks only nested in western Massachusetts, but now have expanded throughout the state (Veit and Petersen 1993). Similarly, in Minnesota, goshawks formerly nested only in the southeastern region of the state, but their breeding distribution has expanded northward and westward into east-central, central, north-east and north-central regions of the state (Janssen 1987). The breeding distribution of known goshawk nests in Wisconsin (northern two-thirds of the state) is more extensive currently then what was documented in the 1960s (Rosenfield et al. 1998). However, we do not know to what extent the apparent increase in these Great Lakes populations is due to increased search effort.

At Hawk Ridge in Duluth, Minnesota, more goshawks are banded than anywhere else in North America (Palmer 1988). Data from Hawk Ridge indicate that 1972 and 1982 were years of heavy goshawk migration (Evans 1983). Annual totals for the peak migration in the early 1990s (>2,200) were less than those of 1982 (5,819) or 1972 (>5,100; Evans 1981). Do these migration count data suggest anything about goshawk population trends? Smallwood (1998) and others have suggested that goshawk abundance should be evaluated based on changes in migratory counts. The utility of migration counts for monitoring population trends has been much debated (Bildstein 1998). To track population change, a constant proportion of the index (e.g., numbers of goshawk seen per day) to the true population size must be maintained. If this does not occur, then the proportion must be estimated. These validation studies have not been conducted on the goshawk for a local area or range wide, so the trends in the current migration count data are difficult to interpret (Kennedy 1998, Andersen et al. 2005), especially given the periodic incursions from northern populations.

Trends in migration counts could reflect distributional changes or changes in residency patterns rather than changes in population size. For example, CBC data suggest that numbers of the closely related Sharp-shinned Hawk (*Accipiter striatus*) are increasing. However, more Sharp-shinned Hawks, may over winter in North America because of warmer winter climates and/or the abundance of bird feeders that provide a stable over-winter food source (see review in Bildstein 1998). This could account for the recent lower counts of Sharp-shinned Hawks at northern migration stations. Since goshawk migrations are characterized by irruptive invasions, migration counts of this species are more likely to reflect changes in residency patterns than changes in abundance (Bednarz et al. 1990, Titus and Fuller 1990).

Recently, Hoffman et al. (2002) analyzed goshawk band encounter locations accumulated between 1980 and 2001, from birds banded or recaptured at four western migration stations. Their results (although limited by sample size) suggest that migration counts of goshawks generally reflect relatively localized movements (i.e., 400–500 km or less). They hypothesize counts of hatching-year birds, except in invasion years, may therefore serve as an indicator of regional productivity. This hypothesis requires further testing to determine if counting hatching-year birds at regional migration stations could be used to monitor regional productivity.

Three European studies have monitored population trends and one review of regional data in Fennoscandia has been published. Thissen et al. (1982) did a coarse-grain analysis of trends in the number of breeding pairs in the Netherlands for 1950–1981. Based on a review of the literature for the Netherlands and their own data, they concluded that Dutch goshawk populations have increased considerably during the 20th century (180–200 pairs in 1955 to >400 pairs in 1981). They also hypothesized that the steady upward trend from 1900 was interrupted by a population crash during the 1960s, presumably caused by pesticide contamination. After pesticides were banned population growth continued. They further speculated that the major factors contributing to this increase are: the extension of suitable habitat by reforestation, the increase of food abundance (Wood Pigeon [*Columba palumbus*] and Rock Dove [*Columba livia*]), and declines in persecution by humans.

Kenward et al. (1999) estimated the finite rate of population change (lambda, λ) for a population of goshawks in Sweden. They estimated age-specific survival and productivity based on both radio-tagged birds and banded birds and used these estimates in a deterministic, staggered-entry population model. Their demographic estimates are based on the largest sample size reported for goshawks and one of the largest ever reported for any diurnal raptor (318 radio-tagged goshawks, 446 banded birds, and 39 nest territories; data collected for 8 yr from 1980–1987). Lambda was estimated to be 1.0 for males and 0.98 for females, which would be a 2%/year decline for females. However, if the demographic estimates were modified to reflect the estimated range of variation in these values, (e.g., 8% standard error of female survival rate estimates and productivity),

$\lambda = 0.98$ for females would not likely differ from $\lambda = 1$. Because Kenward et al. (1999) did not run a stochastic population model, the effects of demographic variance on the precision of λ are not known.

Krüger and Lindström (2001) monitored occupancy and productivity of all known nests in two 125-km^2 study areas in Germany. They assumed an annual census of all pairs in each study area. The number of breeding pairs fluctuated between six and 18 during the 25 yr of study (1975–1999). Highest densities in the study area were found at the end of the 1970s, after which the sample of nests decreased sharply during the 1980's. During the last decade, the number of nests returned, albeit with fluctuations, to the level at the study onset.

Genetics

Goshawks exhibit clinal variation in size and coloration (Squires and Ruggiero 1996). The largest goshawks are in the southwestern US and they decrease in size north to the Pacific Northwest; however, the smallest individuals are on the Queen Charlotte Islands, British Columbia. Size then increases from the Pacific Northwest northward through Canada to Alaska (Whaley and White 1994). In British Columbia, wing and culmen length of individuals measured from coastal islands are 2–3% smaller than those of birds from the adjacent mainland (Johnson 1989). Both *A. g. apache* and *A. g. laingi* have darker coloration compared to other populations (van Rossem 1938, Taverner 1940, Johnson 1989) suggesting genetic differences among populations.

Sonsthagen et al. (2004) and Bayard de Volo (2005) characterized genetic structure and gene flow of breeding populations in Utah and northern Arizona, respectively. The Utah population had moderate heterozygosity (50%) similar to levels found in other medium-sized, highly mobile birds. Sonsthagen et al.'s analyses suggested the functional breeding population in Utah extends beyond their sampled area; gene flow is likely maintained by natal dispersal. De Volo et al. (2005) reported high levels of heterozygosity (81%) in the northern Arizona population and also concluded that this high genetic variability occurred because this population was connected to other populations via migration and gene flow from natal dispersal. Sonsthagen et al. observed differences in the haplotype distribution between northern and southern forests in Utah. They speculated that these differences may be caused by clinal variation in haplotype frequencies across western North America. Alternatively, this subdivision

may reflect a contact zone occurring at the southern forests between *A. g. atricapillus* and goshawks of southern Arizona and the Mexican Plateau.

BREEDING BIOLOGY AND DEVELOPMENT OF YOUNG

Parental Roles

Typical of most raptors, male goshawks primarily provision the nest while the larger female defends the site from intruders. However, the degree to which females depend on males for food may depend on prey abundance and thus, delivery rates. Males mostly provision females during pre-laying and early nestling stages, but there is considerable variability. Some females begin hunting during the mid-nestling period while others depend on the male for food until fledging (Younk and Bechard 1994a, Dewey and Kennedy 2001). In Wyoming, males delivered 71% of prey items and females 29% (Good et al. 2001). This relatively high level of female foraging may be attributed to the fact that intensive telemetry was combined with nest observations to accurately assign deliveries to a particular bird. In Alaska, two females provided 12.1% and 8.8% of food delivered to nest during the nestling period (11–28 d; Zachel 1985). These females delivered prey even though the males had already delivered prey. In California, the male provided 85% of food items and the female 15% (Schnell 1958).

Fidelity to Mates and Nest Sites

Pair fidelity has been estimated in birds using genetic analysis to measure the prevalence of extra-pair fertilizations (EPF) or by observing banded birds. Goshawks are monogamous, territorial birds that build nests within large home ranges. Thus, we expect that EPF would be low, but few data are available. Based on genetic analyses of 103 adults and 122 nestlings from 64 nests in northern Arizona, Gavin et al. (1998) found that EPFs were infrequent for this population (9.4% in 1991, 0% in 1992 and 1993). This result is consistent with the species' life history and densities, which probably limits EPFs.

Determining pair fidelity to mates is difficult because the fate of pair members is usually unknown, and mate fidelity can be confounded with mortality. It is also difficult to determine site fidelity given the difficulty of locating alternative nest areas and the goshawk's ability to nest many kilometers from the site used the previous year (J. Squires, unpubl. data). Nonrandom, non-systematic, or incomplete searches

would bias results, especially when based on birds without telemetry.

In California, mates were retained in 18 of 25 pairs where mates were identified in consecutive years (Detrich and Woodbridge 1994); an unknown number of the 28% of remaining birds that found new mates may be due to mortality of the previous mate. Detrich and Woodbridge (1994) observed three pairs for 5 yr and documented that two males and two females bred in three different combinations. Another male bred with three different females in the same territory over a 6-yr period. In northern California, males occupied the same nest area in consecutive years 76.5% (N = 17) of the time, compared to 71.4% for females (N = 49; Detrich and Woodbridge 1994).

In northern Arizona out of 259 adult goshawks banded between 1991 and 2003, six instances of breeding dispersal by males occurred for a rate of 4.9/100 opportunities, and 11 instances by females (6.3/100 opportunities). Only 16% (N = 17) of breeding dispersals had a failed nesting attempt the previous year, whereas mates that failed to return preceded 88% of dispersals. However, most goshawks remained on their territories in subsequent years despite a mate that failed to return (R. Reynolds et al., unpubl. data).

PRE-LAYING PERIOD

Copulation

Goshawk copulations are short (9.3 ± 0.7 sec [S.E.], N = 10) and among the most frequent among birds (518 copulations/clutch, Møller 1987, Palmer 1988). High copulation frequency may help ensure paternity, since the male is often away foraging during egg-laying. In Denmark, Møller (1987) reported two major peaks in copulation frequency. The first was 31–40 d before laying, and the other immediately before and during egg laying. Copulations are most frequent in the morning when egg laying occurs with a minor activity peak in afternoon.

Nest construction

Observations of nest building are few. In Alaska, nest construction begins soon after birds return to territories, even with snow still present on nest bowls (McGowan 1975). Females begin repairing old nests or build new structures during courtship by gathering sticks from the forest floor or breaking them from trees (Zirrer 1947). Additional nesting material is added throughout incubation. Males

occasionally assist with nest construction (Schnell 1958, Lee 1981a).

It is unclear why goshawks often add greenery, usually conifer sprigs, to the nest structure. Possibly there is a hygienic function or it communicates occupancy to neighboring birds. Females place greenery in nests throughout the nestling stage by pulling at the base of live sprigs until they break off (Schnell 1958). Sprigs are then dropped on the nest, but usually not incorporated into the structure.

INCUBATION

Egg laying

Timing of clutch completion ranges from early April–early June, varying among pairs, geographic areas, and years, but completed on average between late April and mid-May (Reynolds and Wight 1978, Henny et al. 1985, Speiser and Boskowski 1991, Bull and Hohmann 1994, Reynolds et al. 1994, Younk and Bechard 1994a, Dewey et al. 2003). Cold, wet springs may delay incubation (Younk and Bechard 1994), as does high elevation (Henny et al. 1985; but see McGown 1975, Reynolds and Wight 1978).

Female goshawks become sedentary as egg laying approaches, presumably to sequester the energy reserves necessary for egg formation (Reynolds 1972, Newton 1979a, Lee 1981a, Speiser and Bosakowski 1991); the male delivers prey directly to the female during this time, but may occasionally help with incubation (Boal et al. 1994). Eggs are laid at 2–3 d intervals (Beebe 1974, Cramp and Simmons 1980); a clutch of four eggs may take 8–9 d to complete (Anonymous 1990). In Denmark, eggs were laid early in the morning (05:28, SD = 9 min, N = 4; Møller 1987).

Females occasionally lay replacement clutches 15–30 d after initial egg loss (Cramp and Simmons 1980), but this appears to be rare (Marquiss and Newton 1982). In Oregon, a bird that failed 24 April completed a second clutch on 15 May (Henny et al. 1985). Although renesting attempts are uncommon, Zirrer (1947) observed a pair that repeatedly attempted to renest.

Incubation length

Females are primarily responsible for incubating eggs (Zirrer 1947), but males may assist for short periods after a food delivery (Lee 1981a, P. L. Kennedy, unpubl. data). Females remain on eggs up to 244 min continuously with short breaks not over

10 min in length (Allen 1978). The incubation period has been estimated at 30–44 d (Brown and Amadon 1968, Snyder and Wiley 1976, Reynolds and Wight 1978, Cramp and Simmons 1980). Differences among estimates may be attributed to individual, geographic, or annual variation, to measurement error (USDI Fish and Wildlife Service 1998a), or prolonged pipping (Palmer 1988). Incubation usually begins with the first or second egg laid, resulting in partial asynchronous hatching. Pipping of eggs may take up to 50 h (Palmer 1988).

Nestling Phase

Goshawks hatch from late May through June (Reynolds and Wight 1978, Dewey et al. 2003) but dates vary considerably. The nestling period varies from 37–45 d (Dixon and Dixon 1938, Reynolds and Wight 1978, Newton 1979a, Kenward et al. 1993a, Boal 1994, Kennedy and Ward 2003) and young generally fledge between late June and late July (Reynolds and Wight 1978, Reynolds et al. 1994, Kennedy and Ward 2003). Males develop faster and fledge sooner than females (Reynolds and Wight 1978, Kenward et al. 1993b, Boal 1994).

The size of goshawk broods typically varies from one–three nestlings. In Arizona 28% of 224 successful broods had one young, 50% had two young and 22% had three young (Reynolds and Joy 1998). However, there may be considerable seasonal and geographic variation in brood size. Nestlings are born semi-altricial and nidiculous, requiring much parental care. Females brood nestlings almost continually for 9–14 d following hatch (Schnell 1958, Boal 1994, Dewey and Kennedy 2001). Brooding at night ceases by 24 d of age except during wet, cold weather (Boal 1994). Females do most of the brooding, but males may occasionally brood young while the female feeds (Schnell 1958, Lee 1981a). Females continue to feed and protect young throughout the nestling stage, whereas the males primarily hunt for the brood (Squires and Reynolds 1997, Dewey and Kennedy 2001).

Nestlings grow rapidly while in the nest; see Schnell (1958), Boal (1994), and Squires and Reynolds (1997) for descriptions of growth and development. Females generally feed nestlings until they are approximately 25 d of age (Schnell 1958, Lee 1981a); males also occasionally feed nestlings, especially when the female is not present (Allen 1978, Zachel 1985). By 32–34 d of age, nestlings are 90% feathered and their tail is approximately two-thirds of adult length (Boal 1994). Nestlings of this age can feed themselves and beat their wings vigorously as they run and hop or momentarily lift from the nest. Nestlings start leaving the nest to perch nearby at 34–35 d (Boal 1994).

Ward and Kennedy (1996) hypothesized that food supplementation during the nestling and fledgling depedency periods affected young goshawk survival not by limiting starvation, but by causing the adult female goshawk to modify her behavior and spend increasing time in the nest stand, allowing more constant protection from predators. Dewey and Kennedy (2001) experimentally tested their hypothesis and found female nest attentiveness is a function of food availability in the nest stand.

Goshawks will aggressively defend their nest stand from human intruders. However, considerable individual, geographic, and seasonal variation occurs in nest-defense behavior. Adult females are particularly defensive toward human intruders later in the nestling period (Boal and Mannan 1994). In New York and New Jersey, females brooded the young for a few days following hatching, and only rarely attacked intruders entering the nest stand during this period (Speiser and Bosakowski 1991).

Fledgling Dependency Phase

The fledgling dependency period is an important period of transition during which the young learn to hunt and protect themselves (Reynolds et al. 1992). Feather growth is not yet complete at fledging (Bond 1942, Kenward et al. 1993a), so young are initially incapable of sustained flight and may have special habitat requirements. Fledglings may delay departing from nest areas when they are fed additional food by researchers suggesting that early dispersal may be in response to food shortages (Kenward et al. 1993a; Kennedy and Ward 2003). Sibling groups of both sexes continue to associate in cohesive units until flight feathers harden (Kenward et al. 1993a). Recent fledglings depend on their parents for food while their feathers harden and they learn to hunt. The distance that fledglings move from the nest gradually increases as they gain independence (Kennedy et al. 1994; Kennedy and Ward 2003). For the first 3 wk after fledging, juveniles in New Mexico remained within 300 m of the nest, and ranged to a mean distance from the nest of 1,955 m by 8 wk after fledging (Kennedy et al. 1994). In Arizona, dispersal from nest areas began in mid August and was completed by late August (Reynolds et al. 1994). On the Baltic island of Gotland, dispersal was often abrupt with approximately 90% of fledglings dispersing from their nest areas between 65–90 d of age (Kenward et al.

1993a). By day 95, 98% of the fledglings dispersed with females moving significantly later than males.

COURTSHIP AND FORAGING BEHAVIOR

COURTSHIP AND PRELAYING BEHAVIOR

Little is known regarding the timing of courtship behavior, but it appears to vary. Most pairs return to nesting territories by March (Zirrer 1947, Beebe 1974, Reynolds and Wight 1978, Roberson 2001, Dewey et al. 2003) through early April (McGowan 1975, Dewey et al. 2003). However, pairs in some regions may return as early as February (Lee 1981a, Speiser and Bosakowski 1991) or remain near their nest year-round (Boal et al. 2003). In Wyoming, migratory adults equipped with transmitters returned to nest areas from 23 March–12 April (Squires and Ruggiero 1995). The phenology of courtship may vary by residency patterns; resident birds may initiate courtship earlier in the season compared to migrants (Dewey et al. 2003).

Courtship behavior may include sky-dance displays when from brief soaring flights, the male dives at the female with closed wings well above the forest canopy, or initiates a direct aerial chase below tree canopy (Beebe 1974, Palmer 1988). Both birds then fly slowly about 1 m apart, with deep, slow wing beats, holding their wings above the body dihedral. The bird's flight undulations may be shallow or they can consist of spectacular dives. Zirrer (1947) describes this flight as wavy gliding approximately 3–6 m above the canopy; at times pair members are close together and then far apart. Pair members may be silent during the display or may be highly vocal, uttering wails and chatters. White under-tail coverts may also be flared 10 cm on either side of the tail (Beebe 1974). Prey plucking (Schnell 1958), frequent copulations (Møller 1987), pre-laying vocal activity (Penteriani 2001, Penteriani et al. 2002a), and conspicuous perching (Lee 1981a) may also serve courtship functions.

FORAGING BEHAVIOR

Hunting methods

Goshawks exhibit behavioral and morphological adaptations for hunting in forests (Squires and Reynolds 1997). Goshawks have been described as sit-and-wait predators that perch briefly while searching for prey before changing perches (Pianka 1983, and Schoener 1971, 1984). Radio-telemetry studies in Sweden (Kenward 1982, Widén 1984) and

in Utah (Fischer 1986) demonstrate that goshawks forage by perching for a few minutes to search for prey, before flying to a new hunting site. Kennedy (1991) confirmed similar results, but she defined the search strategy used by goshawks as saltatory searching. Evans and O'Brien (1988) originally defined saltatory searching as hunting using a stop-and-go pattern where the animal frequently shifts locations when searching for food. The main difference between ambush, i.e., sit-and-wait search, and salutatory searching is the frequency of repositioning moves (O'Brien et al. 1989, 1990). In Sweden, flights between perches averaged 84 s for males and 96 s for females (median flight time is 24 s for males and females, Widén 1984). Males when foraging then remained perched for an average of 8 min, 36 s compared to 10 min, 24 s for females (median perch time 3 min for both). The search method used by foraging goshawks is very different from cruise foragers that hunt prey while moving. Only 3% of prey was attacked from goshawks in flight (Kenward 1982). Attacks on winged quarry rarely last >1 km before the hawk overtakes its prey. In Washington, Bloxton (2002) noted that goshawks may vary their foraging methods by habitat type. Goshawks used salutatory searching 72% of the time overall; this foraging method was used 96% of the time in forest stands >30 yr old. However, goshawks were observed using low soaring foraging on 13% of foraging bouts, generally when hunting young, dense stages of sapling-pole forests.

Goshawks also hunt by flying rapidly along forest edges, across openings, and through dense vegetation to surprise prey (Johnsgard 1990). Goshawks have short, powerful wings and long tails that are highly adapted for rapid acceleration and maneuverability in trees. Most goshawk prey occupies the ground-shrub zone so attacks are usually directed at that zone (Reynolds and Meslow 1984). If the hawk is undetected by prey, the attack may consist of a smooth, silent, accelerating glide that ends in a capture strike without a wing beat (Beebe 1974). However, if detected, the hawk rapidly pumps its wings to capture its intended quarry. Goshawks kill prey by driving their talons into the quarry using a kneading action immediately after impact; their strong feet and bill are capable of killing a wide variety of large-bodied prey.

Foraging success and prey delivery rates

Goshawks deliver prey to the nest one item at a time throughout the day, but peak delivery periods include early morning (0600–0700 H) mid-morning

(0900-1100 H), and late afternoon and evening, (1600–2000 H; Schnell 1958, Allen 1978, P. L. Kennedy, unpubl. data). Foraging success and prey delivery rates vary according to brood size, stage of nestling development, habitat type and prey species, but these relationships have not been thoroughly studied. In Wyoming, the average prey delivery rate from eight females was 0.23 items/hr (Good et al. 2001). This was similar to the average delivery rate for goshawks in Arizona (0.25 items/hr, N = 381 deliveries; Boal and Mannan 1994) and Nevada (0.31 items/hr, N = 51 deliveries; Younk and Bechard 1994a). In California, Schnell (1958) reported 3.9 prey deliveries/day for a single nest. A pair supporting three nestlings brought 34.8 kg of prey during the first 53 d after hatch, or approximately 11.5 kg per nestling (Zachel 1985). In Washington, male goshawks returned to their nests with prey every 4.8 ± 0.6 hr (N = 126 visits by nine birds; Bloxton 2002). He found small prey were generally returned to the nest immediately following capture, whereas larger prey, such as pigeons (360 g), were decapitated and plucked before delivery. Grouse (500–1,000 g) were decapitated, plucked and parceled into two pieces for separate deliveries.

Foraging distance from nest

Male goshawks generally forage away from the immediate nest site (Kennedy 1991, Good 1998). In New Mexico, males hunted between 0.8 and 8 km from the nest (Kennedy 1991). In south-central Wyoming, the average kill distance from the nest was 1,885 m (SD = 1,181m), but was highly variable and could be up to 5,456 m from the nest (Good 1998). Of 37 Ruffed Grouse banded in Minnesota, nine were killed by goshawks within 1,097–2,515 m of the nest, and 26 were killed within a 1.6 km radius of the nest (Eng and Gullion 1962). Large goshawk home ranges coupled with long foraging distances indicate these hunters forage over large areas surrounding their nests. However, female goshawks will attack prey from their nest or within the nest stand. Schnell (1958) observed a female hunting ducklings from her nest.

From central-place-forging theory, we expected a relationship between prey size and distance that goshawks are willing to forage from their nests (Orians and Pearson 1979), and that this relationship would be influenced by habitat use (Rosenberg and McKelvey 1999). In Washington, Bloxton (2002) used radio telemetry (N = nine males, five females) to determine that goshawks traveled an average of 2.2 km from their nests; the average maximum distances was 5.0 km, and 10.2 km was the farthest

a breeding goshawk traveled from the nest during the breeding season. Consistent with central-place-foraging theory, the further they foraged the larger the prey item returned to the nest (N = 28 deliveries pooled across eight hawks, r = 0.42, P = 0.02). Generally, if the birds traveled over 4 km from the nests, they did not return with small prey.

Caching

Caching surplus prey when nestlings are present or for future use has been observed for many species of raptors (Newton 1979a). Goshawks cache prey on branches near the tree trunks, or wedge the item in a crotch between branches (Zachel 1985). Caching rates have not been quantified for this species. Schnell (1958) observed a single nest in California and noted that a female cached food primarily when nestlings were <1 mo old and needed frequent feedings. Most cached items were fed to nestlings the same day, but some were fed at least 32 h after a kill (Schnell 1958).

Plucking perches

Goshawks may repeatedly use particular perches near their nests for plucking prey. Plucking perches may be downed logs, stumps, or old nests, but preferred perches are usually low (<1 m), bent-over trees or saplings (Schnell 1958, Reynolds and Meslow 1984, Bull and Hohmann 1994). Plucking perches are often located in denser portions of the secondary canopy and are often up-slope and fairly close to the nest (Hall 1984). Distances of plucking perches from nests averaged: Oregon, 45 m (range = 27–74 m; Reynolds et al. 1982); north-eastern Oregon, 42 m (range = 7–200 m; Bull and Hohmann 1994); California, 69 m (range = 30–130 m; Schnell 1958). However, these distances may be underestimates because distant perches are difficult to locate.

Social Behavior

Goshawks are solitary outside the breeding season. During migration, they may be observed with other raptors but these interactions are not considered social. Pair members have few interactions during winter as they often use separate wintering areas (J. Squires, unpubl. data). After fledging, siblings of both sexes often remain together in cohesive groups near the nest until dispersal (Reynolds and Wight 1978, Kenward et al. 1993b). Fledglings will also visit adjacent nests where they can be fed by the resident adults (Kenward et al. 1993b).

GOSHAWK CONSERVATION AND
MANAGEMENT

THREATS

A number of factors are cited by researchers and
managers as potentially detrimental to current and
future goshawk viability. These include, but may
not be limited to, habitat alteration, direct human
disturbance, pesticides and other contaminants, and
harvest for falconry. However, the primary concern
throughout the range of the goshawk is habitat altera-
tion due to timber and fire management practices.
The issues cited by researchers, agency personnel,
and others as potential threats to habitat caused by
various silvicultural treatments include forest frag-
mentation, creation of even-aged and monotypic
stands, potential increases in area of younger age
classes, and loss of tree species diversity.

*Habitat alteration due to timber and fire
management practices*

A number of studies describe structural char-
acteristics of goshawk nest stands and goshawk
landscapes but few data are available on the effects
of logging within the nest stand on demographic
performance, particularly in an experimental or
quasi-experimental framework. Although only a
few studies have been conducted on the responses
of goshawks to forest management practices, clearly
some level of habitat change will render a landscape
unsuitable for goshawks (USDI Fish and Wildlife
Service 1998b). This level or threshold may vary
spatially or temporally across the range of the gos-
hawk. Effects analysis of forest management on
goshawk populations should consider the spatial
relationships among different functional levels of
habitat use by goshawks, including nesting habitat,
foraging habitat, winter habitat, and important prey
species and their habitat requirements.

Forest management can impact structure, func-
tion, and quality of both nesting and foraging
habitat by removing nests and nest trees, modify-
ing or removing entire nest stands, and removing
canopy and mature trees, snags, and downed wood
(Reynolds 1989, Crocker-Bedford 1990, Bright-
Smith and Mannan 1994, Woodbridge and Detrich
1994, Beier and Drennan 1997, Desimone 1997,
USDI Fish and Wildlife Service 1998a). Reduction
and fragmentation of habitat may also favor early
successional competitors and predators such as Red-
tailed Hawks and Great Horned Owls (Woodbridge
and Detrich 1994).

Forest-management practices, such as the use of
controlled fire and thinning, may improve habitat for
goshawks by opening up dense understory vegeta-
tion, creating snags, downed logs, woody debris, and
other conditions that may benefit goshawks and their
prey (Reynolds et al. 1992, Graham et al. 1999b).
To determine the effect of silvicultural prescriptions
on potential nest habitat, expected post-harvest stand
density and canopy closure should be compared to
local definitions of mean structural attributes of nest
area habitat (USDI Fish and Wildlife Service 1998a).
For example, in the temperate rainforests of south-
eastern Alaska, forest management would need to
account for long fire-return intervals that produce
old growth forests. These prescriptions could differ
markedly from those for managing goshawks in the
Southwest hwere frequent fires are assumed to affect
the structure of ponderosa pine communities (but
see Baker and Ehle 2001, Schoennagel et al. 2004).
McGrath et al. (2003) provides a good example of
modeling the putative effects of forest management.
For central Washington, they simulated the effects
of three silvicultural prescriptions (no harvest, com-
mercial thin, and implementation of Spotted Owl
guidelines) on goshawk nesting habitat over a 100-yr
interval. All three management scenarios failed to
maintain a modeled nesting population over a 100-
yr period, until habitat heterogeneity was increased
by simulated thinning. Although this study provides
a good example of predicting how forest manage-
ment may be used to enhance nesting populations,
it also illustrates how important it is to understand
basic ecological relationships. For example, it has
not been well established that habitat homogeneity,
per se, reduces population persistence. Thus, the
underlying assumptions of models need to be clearly
articulated and validated, including the extent that
model predictions can be generalized to the diverse
habitats used by nesting goshawks.

Negative effects of timber harvest on goshawk
nest habitat can be described as the area of potentially
suitable forest that meets local definitions of suitable
habitat from nest habitat studies, and that is modi-
fied to a condition no longer meeting the definition
(USDI Fish and Wildlife Service 1998a). Desimone
(1997) prescribed little or no habitat alteration within
aggregate nest stands and Bright-Smith and Mannan
(1994) stated that tree harvest methods that create
large areas with reduced canopy cover of less than
35–40% may be particularly detrimental to potential
goshawk foraging habitat. Reynolds (1989) stated
that practices such as selective overstory removal or
patch and clearcut harvesting, resulting in either a
complete removal of trees or a reduction of the stem

density and canopy cover throughout management units, lower the quality of goshawk nesting habitat. Reduction of canopy closure may result in increased solar radiation and heat stress, reduced buffering from adverse weather, and increased visibility to predators, all of which may singly, or in combination, affect goshawk nesting success (USDI Fish and Wildlife Service 1998b).

Using a quasi-experiment, Penteriani and Faivre (2001) tested some of these assumptions within nest-stand harvest. They examined the effects of shelterwood harvest within nesting stands on European goshawk occupancy and productivity. During this long-term study (1984–1995 in Italy and 1993–1999 in France) they compared trends in occupancy and productivity in logged and unlogged stands and also assessed the logging effects on the same nesting stand (N = nine stands) before and after timber harvest. They found no difference in productivity of goshawk pairs reproducing in unlogged vs. logged stands. When considering the same nesting stand, before and after timber harvest, they noted no short-term differences in productivity. However, they observed that 87.5% of goshawk pairs nesting in logged stands moved away only when the original stand structure was altered by >30% and then the birds moved only to the nearest neighboring mature stand. Although sample sizes were small, the results of this study suggest goshawks can tolerate some levels of timber harvesting within the nesting stand (if harvest is avoided from February through August), as long as cover reduction does not exceed approximately 30%. The applicability of this study to other timber management practices and other portions of the goshawk range is unknown.

The duration to which forest-management impacts goshawks has not been formally studied across the species' range. In areas that support populations that depend on old and/or complex forest structures, the duration of management impacts could be much longer compared to populations that occupy forests that are primarily structured by frequent natural disturbances. However, efforts to determine the duration of impacts need to account for specific habitat needs, the spatial context of the surrounding landscape, and the structure of important micro-sites. We do not always assume that pristine or non-managed forests provide optimal habitat. For example, nest stands in ponderosa pine may be improved by thinning from below to prevent infilling with other tree species (Reynolds et al. 1992) or to promote habitat heterogeneity (McGrath et al. 2003).

Relatively few studies have addressed the size of forest patches selected by goshawks for nesting

(USDI Fish and Wildlife Service 1998a). Based on observations of feathers, whitewash, and prey remains, Reynolds (1983) defined the nest area as approximately 12 ha of intensified use surrounding the nest. Woodbridge and Detrich (1994) suggested that although small (12–24 ha) stands were used successfully for nesting, goshawks preferred larger (34–80 ha) stands for nesting because occupancy rates of forest stands used for nesting decreased with decreasing stand size. The larger (60 ha) core area reported by McGrath et al. (2003) further supports the hypothesis that larger patches of mature forest surrounding goshawk nests may be important (USDI Fish and Wildlife Service 1998a).

Although assessment of habitat condition for goshawk nest areas is often made at broad scales, evidence suggests that landscape features such as slope, aspect, riparian vegetation, meadows, drainages, water, and other features affect location of goshawk nest areas (Allison 1996). Timber harvests associated with these physiographic features may have a disproportionate effect on habitat suitability if selection of nest areas by goshawks is at least partially dependant on them (USDI Fish and Wildlife Service 1998a) and nesting habitat is limiting.

One of the limitations of studies investigating the effects of timber harvest on goshawk nesting habitat is that few studies have investigated goshawk habitat in forests not managed for timber harvest. Studies of goshawk habitat relations conducted on timberland may reflect the history of timber harvest in those areas. Studies of goshawk habitat in protected areas, would provide baseline data that could be used to compare with habitat data from forest lands to determine the degree to which timber management influences goshawk habitat preferences. Finn et al. (2002a, b) included nest sites within Olympic National Park as well as on managed forest lands. They used the park to document that loss of mature forest in managed landscapes was detrimental to goshawk site occupancy and productivity on the Olympic Peninsula.

Habitats used for foraging by goshawks in North America have been documented in a small number of telemetry studies (Austin 1993, Bright-Smith and Mannan 1994, Hargis et al. 1994, Beier and Drennan 1997, Boal et al. 2005b). These studies suggest goshawks select foraging areas with specific structural attributes, including old or mature forest stands with open understories, relatively high canopy closure, large trees, and high stem densities. It is possible; however, that actual foraging habitat selection occurs at spatial and temporal scales difficult to investigate using radio telemetry (USDI Fish and

Wildlife Service 1998a). Small openings, tree fall gaps, edges, riparian zones, and rock outcrops are examples of small-scale landscape elements that may be important to foraging goshawks (Squires and Reynolds 1997). It cannot be assumed, however, that adequate prey will necessarily be available in openings created by timber harvests, which often result in dense re-growth where goshawks would be unlikely to detect or capture prey (USDI Fish and Wildlife Service 1998a). Also, populations of many prey species are linked to structural attributes such as snags, large logs, large trees, soil organic horizon depth for fungi, and hardwoods for mast, and these may not be maintained under silvicultural prescriptions, unless specifically designed to maintain them (Reynolds et al. 1992, USDI Fish and Wildlife Service 1998a).

Goshawk foraging habitat can be maintained or restored through means such as protection of specific areas, control of tree spacing and canopy layering, and management strategies that sustain the structure, function, and ecological processes of forests that are important to goshawks (Reynolds et al. 1992, USDI Fish and Wildlife Service 1998a). Widén (1997) claims goshawk declines in Fennoscandia from the 1950s to the 1980s are a result of changes in forest management practices that have altered goshawk foraging areas in this region. In the 1950s, forest management practices changed from selective cutting to clear cutting, replanting, and thinning. As a result of this intensive management, the boreal forest landscape of Fennoscandia is a highly fragmented patchwork of clearcuts and forest stands in different successional stages and the proportion of old-growth forest has declined dramatically (<5% of Swedish forests are old growth). Widén develops a cogent argument that suggests this landscape change has caused goshawk declines by reducing the availability of foraging habitat not nesting habitat. Goshawks can successfully nest in patches of mature or old-growth forest as small as 0.4 ha, but their foraging ranges cover 2,000–6,000 ha, and in boreal forests in Europe they prefer large patches of mature forest for hunting. He suggests changes in the boreal landscape have resulted in a deterioration of goshawk hunting ranges, making it more difficult for them to secure adequate food for breeding. This factor is probably more important than a shortage of nest sites. He also notes declining prey densities may be associated with forestry which would affect goshawk numbers.

Although we know goshawk demography is strongly influenced by prey availability, the degree to which forest management positively or negatively influences prey availability is not well documented. This is because most investigations of the effects of forest management on goshawk prey typically correlate avian or mammalian abundance—usually not both—with timber management using one–three replicates studied over 1–2 yr. They are also generally conducted on too small of a spatial scale to be relevant to the goshawk (Marzluff et al. 2000). Marzluff et al. (2000) and Sallabanks et al. (2000) suggest some on-going avian studies are correcting these limitations by expanding their scale of investigation, using sound experimental design and relating forest management to avian demography. Such studies will increase our understanding of how forestry affects goshawk prey, particularly if they successfully identify the mechanisms that relate silviculture to prey population processes.

Fire suppression

Goshawks from most populations occupy forests that are structured by fire. Understanding the extent and duration of how fire effects goshawk habitat may become even more pressing in light of changing climates relative to global warming (Dale et al. 2001). The effects of fire suppression on goshawk populations have not been formally researched. Thus, our assessment of how fire suppression may structure goshawk habitat is conjectural at this point based on our understanding of goshawks and fire ecology.

We think the effects of fire suppression on goshawk habitat will vary due to the complex fire regimes found across the species' distribution. To assess the effects of fire suppression, it is important to distinguish between natural understory and stand-replacing fire regimes (Brown 2000). Historically, natural understory fire regimes dominated ponderosa pine communities, with fire-return intervals of 2–15 yr in many stands (Covington and Moore 1994a, but see Baker and Ehle 2002, Schoennagel et al. 2004). These low-intensity fires were readily suppressed resulting in increased fuel loads that increased the risk of stand-replacing fires in ponderosa pine communities (Covington and Moore 1994a, Allen et al. 2002). The impacts are clear—the density of ponderosa pine forests has increased, the herbaceous layer has almost disappeared and stream flow has been reduced significantly. The shift in community structure of ponderosa pine has also been exacerbated by grazing, logging, and invasive exotics (Allen et al. 2002). Fires now burn over larger areas and are more intense compared to earlier times, and crown fires are becoming common because dense stands of saplings provide ladders that carry fire from the forest floor to the tree canopy (Covington and Moore 1994a). Thus, we speculate that fire suppression may

have significantly altered goshawk habitat in ponderosa pine communities.

However, goshawks nesting in northern boreal forests occupy stands that support high-severity, stand-replacing fires that kill most of the canopy either through intense ground fires or flames in the tree crowns (Agee 2000, Turner et al. 2003). The behavior of fires in these habitats can be extreme with daily spread rates of 100 m /min and 13–18 m flame lengths (Kiil and Grigel 1969). The fire-return intervals in subalpine forests tend to be long, ranging from 60 yr in jack pine (*Pinus banksiana*) to 300–350 yr in western boreal stands of spruce (Turner et al. 2003, Agee 2000). Although fires in subalpine forests are often infrequent, they can burn large areas when severe droughts govern regional weather (Turner and Romme 1994, Turner et al. 2003). Thus, infrequent but large-scale fires account for most of the total burned area (Agee 2000, Turner et al. 2003). For example, of over 200 fires between 1972 and 1988 in primarily lodgepole pine forests of Yellowstone National Park, 83% went out by themselves after burning only 0.5 ha (Renkin and Despain 1992). However, the extreme drought and high winds in 1988 produced conditions that burned over 250,000 ha in the Park (Renkin and Despain 1992). Under such extreme fire-weather conditions, variations in fuel structures are of little importance (Bessie and Johnson 1995), and fire suppression has little influence on recent fire behavior during big-fire years (Schullery 1989, Turner et al. 2003, Romme et al. 2004). Effective fire suppression may have been especially difficult in the past because subalpine forests are often in high, remote areas and fire-fighting aircraft have only been available since World War II (Schullery 1989). Thus, we believe that past fire suppression in northern and subalpine conifer forests may have had little effect on goshawk habitat.

On 21 November 2003, Congress passed HR 1904, the Healthy Forests Restoration Act of 2003 with the intent of reducing the threat of catastrophic wildfire to human communities and forest and range lands. New procedures provided under NEPA allow priority fuels reduction and forest restoration projects identified through collaboration with state, local and tribal governments to move forward more quickly. In 2002, federal land management agencies thinned a record 910,000 ha, an increase of 405,000 ha over FY 2000 levels (http://www.USDA.gov [2 Feb 2006]). In 2003, the agencies broke the previous record and treated an additional 1,050,000 ha. Nearly 65% of forest restoration dollars have been invested in the wildland-urban interface, including private lands that surround human communities most at risk from wildfire. From 2001–2003, agencies treated 2,800,000 ha,

and expect to treat 3,800,000 ha by the end of FY 2004 (http://www.USDA.gov [2 Feb 2006]). Thus, forest structures across broad landscapes are being altered as healthy forest initiatives are implemented across the western US. We are unaware of any broad-scale efforts to evaluate the potential effects of the healthy forest initiatives on goshawk populations. In ponderosa pine communities, forest management such as thinning from below may be a necessary first step in restoring goshawk habitat, before prescribed fire can be introduced (Reynolds et al. 1992). However, in other forest types where thinned trees are not consistent with natural forest pattern, there could be a significant negative effect based on reduction in canopy closure. Thus, the degree to which healthy forest initiatives affect goshawk populations will depend on the forest type, extent, spatial arrangement, prescription, and considerations to micro-site requirements (e.g., spatially distributed nest stands) relative to management actions.

Human disturbance

The USFWS (USDI Fish and Wildlife Service 1998a) reported that disturbance generally does not appear to be a significant factor effecting the long-term survival of any North American goshawk population. However, human disturbance such as timber harvesting near nests can cause failure, especially during incubation (Anonymous 1989, Boal and Mannan 1994). Logging activities such as tree cutting, loading, and skidding within 50–100 m of a nest can cause abandonment even with 20-d-old nestlings present (J. Squires, unpubl. data). Camping near nests has also caused failures (N = 2; Speiser 1992). Goshawks in Britain, central Europe, and Japan nest in close proximity to humans in rural landscapes suggesting that some populations are not especially prone to disturbance (Krüger and Lindström 2001, Krüger 2002a, P. L. Kennedy unpubl. data). Lee (1981b) documented that two pairs of goshawks nesting in a ski resort were able to fledge young successfully where they were subjected to daily disturbance in winter and summer due to skiers, snowmobilers, construction, hikers, and horseback riders.

Disturbances associated with research are usually short in duration and believed to have little impact on nesting birds (Squires and Reynolds 1997). Climbing nests for short periods after young have hatched does not cause desertion, nor does banding or attaching transmitters to the adults. The percentage of nesting pairs that successfully raised young with radios (83%, N = 8, 1988–1989) was similar to those without radios (82%, N = 10, 1987–1990; Austin 1993;

but see Reynolds et al. 2003 for effects of transmitter mounts on adult male survival).

Invasive species

The goshawk is not known to interact strongly with any exotic species. Rock Doves and European Starlings (*Sturnus vulgaris*) are consumed by goshawks, but are not documented as frequent prey in diet analyses. No information is available regarding the influence of exotic plant invasions on goshawk habitat and prey. However, the most important exotic plant invasions are occurring on unforested lands at lower elevations where changes in plant communities could influence winter goshawk habitat and prey populations (Stohlgren et al. 2003).

Shooting and trapping

In North America, shooting, trapping, and poisoning are generally illegal and not considered an important mortality factor. However, in the early to mid-1900s, some states like Pennsylvania paid bounties on goshawks, but the effects this had on populations is unknown. European populations were more actively persecuted in efforts to protect private game-bird farms. On the Baltic island of Gotland, 36% of mortalities of radio-tagged birds (N = 67) were killed by humans (Kenward et al. 1991); juveniles were more likely to be shot than adults.

Pesticides and other contaminants

In the early 1970s, pesticide levels were high in Peregrine Falcons (*Falco peregrinus*), Ospreys (*Pandion haliaetus*), Sharp-shinned Hawks, and other raptors in the US, but were low in goshawks (Snyder et al. 1973, Reynolds and Wight 1978). Goshawks, during the 1972–1973 invasion years, contained less organochlorine and polychlorinated biphenols (PCB) residues than other raptors (Havera and Duzan 1986), probably because these birds were from non-agricultural, northern forests. The primary prey species of goshawks tend to accumulate less pesticide in their tissues compared to other accipiters (Rosenfield et al. 1991). The USFWS concluded pesticides and other contaminants appear to have not significantly affected goshawks in the US (USDI Fish and Wildlife Service 1998a).

Kenntner et al. (2003) recently analyzed levels of organochlorine pesticides, PCBs and heavy metals in organ samples of 62 free-ranging goshawks found dead or injured in three regions of Germany from 1995–2001. The contaminant burdens varied significantly among the three regions presumably due to differences in the legislative restrictions on the use of these chemicals in agriculture and forestry prior to German reunification. Extraordinarily high residues of PCBs and DDE, the main metabolite of DDT, were found in livers of goshawks inhabiting Berlin. However, these levels were not high enough to be indicative of acute poisoning and were far below suspected lethal levels in raptors. Levels of contamination were negatively correlated with goshawk age and body condition. Lead concentrations indicative of acute poisoning was detected in one bird and suggested in two other birds. All other heavy metal concentrations were low.

Falconry

Goshawks have been trained for falconry for at least 2,000 yr and were favored among Asian, Middle Eastern, and north European falconers (Cooper 1981). During the 18th century, falconry declined as guns became generally available and goshawks were then viewed as competitors for game. Since World War II, interest in falconry increased and spread to North America. Modern-day falconers value goshawks for their willingness to hunt a variety of prey and their aggressive dispositions (Beebe 1976). In an environmental assessment on falconry and raptor propagation regulations, the USFWS (USDI Fish and Wildlife Service 1988) concluded falconry is a small-scale activity that has no significant biological impact on raptor populations. Mosher (1997) examined data reported by Brohn (1986) and falconers' annual reports and concurred with the conclusions reached by the USFWS. Although falconry has been listed as a potential threat in the western Great Lakes Region (Noll West 1998), no evidence indicated that falconry has an impact on North American populations.

In Britain, Kenward et al. (1981d) determined that captive goshawks had relatively constant annual mortality of about 22% (N = 216 birds) from accidents, infectious diseases, and other clinical conditions. Approximately one-third of the goshawks were eventually lost or released resulting in 13% successfully re-entering the wild in Britain. Once released to the wild, captive goshawks did not require supplemental feeding after they had killed at least twice for themselves.

ECOLOGICAL RELATIONSHIPS WITHIN A MANAGEMENT CONTEXT

To illustrate the ecological linkages described above and how threats may affect these relationships,

we constructed an envirogram for the goshawk nesting in the northern Rocky Mountains (Fig. 3). Envirograms hypothesize the ecological linkages among direct and indirect factors and abundance of a species at a particular time and place (Andrewartha and Birch 1984). Envirograms help researchers and managers organize prior knowledge that spans multiple ecological levels while maintaining a focus on ecological factors and processes that directly or indirectly affect the size of a focal population (James et al. 1997). These ecological flow charts are developed using a standardized conceptual framework following the logic and terminology of Andrewartha and Birch (1984). We have used a modification of their approach developed by James et al. (1997) for the Red-cockaded Woodpecker (*Picoides borealis*).

Envirograms depict each organism within the context of a centrum and web. The centrum is comprised of factors that directly affect the organism's abundance such as resources, hazards, or mates. Resources are environmental components that enhance the organism's chance of survival and reproduction and are either negatively or not influenced by the abundance of the organism, e.g., the goshawk's prey. Hazards reduce survival and reproduction in the focal population, and in turn, benefit from increases in the organism's abundance. Mates convey a positive-positive relationship. Indirect factors comprise the web and include anything that can affect a species by modifying its centrum, including the effects of individuals of the focal species on their own populations. Flow in an envirogram tends from distal indirect influences in the web toward the most proximate direct effects on the organism's population as shown in the centrum (Ward 2001). Similar to James et al. (1997) this envirogram contains sub-models for limiting resources and hazards.

The number of factors and interactions depicted in an envirogram are limited only by the knowledge of the organism's ecology. We constructed the goshawk envirogram based on the information presented in this document and in Kennedy (2003). This envirogram is basically a hypothesis that could be used to develop models with goshawk abundance as the response variable and the factors influencing abundance as dependent variables. Figure 3 is not comprehensive, simply a schematic of possible interactions with an emphasis on the potential effects of forest management on the direct and indirect factors that could influence goshawk populations in the interior mountains of western North America. A wide variety of alternative envirograms could be developed with existing information and these models could be evaluated against empirical data

using a wide variety of techniques. Site-specific envirograms could be used in conjunction with the silvicultural concepts presented in Reynolds et al. (1992) to develop regional or local management plans to prevent goshawk population declines.

In Fig. 3, current management practices that might influence goshawk numbers are indicated by ovals. As indicated in earlier sections, timber-management practices can have a profound influence on all direct and indirect processes that influence goshawk numbers. Progressively more indirect effects appear in the columns of the web. For example, in the sub-model for nest-site availability, if the number of large trees available for nest sites is limiting, the rate of maturation of younger trees must be balanced by the number of older trees lost to harvest and death for population stability. However, nest sites in good condition can be usurped by competitors and the abundance of competitors may be influenced by habitat fragmentation from timber harvest and fire. The other sub-models reflect other management activities that we think influence goshawk abundance and have been discussed in more detail in earlier sections. The pathways could be made more specific if information was available on the types of management actions a management unit is conducting that might negatively impact or enhance goshawk populations.

INFORMATION NEEDS

Effective sensitive-species programs are firmly grounded in ecological knowledge that supports management recommendations (Squires et al. 1998). Understanding the ecological characteristics associated with a given ecosystem such as food webs, predatory relationships, disturbance patterns, and vegetative structure and landscape characteristics are essential for providing the specific habitat needs of sensitive species within the constraints of ecosystem function. To empirically evaluate the envirogram in Fig. 3 and ultimately determine the effects of forest management on goshawk abundance, we need additional information on many aspects of goshawk ecology. The winter ecology of goshawks is almost completely unknown. In addition, positive and negative effects of timber management on goshawk resources need to be rigorously evaluated, ideally with forest-management experiments. We do not know the thresholds above which forest fragmentation may alter competitive interactions, such as increasing Red-tailed Hawks and Great Horned Owls, which ultimately could affect population persistence. Finally, a pressing need exists to assess habitat needs at broader spatial scales, and to have
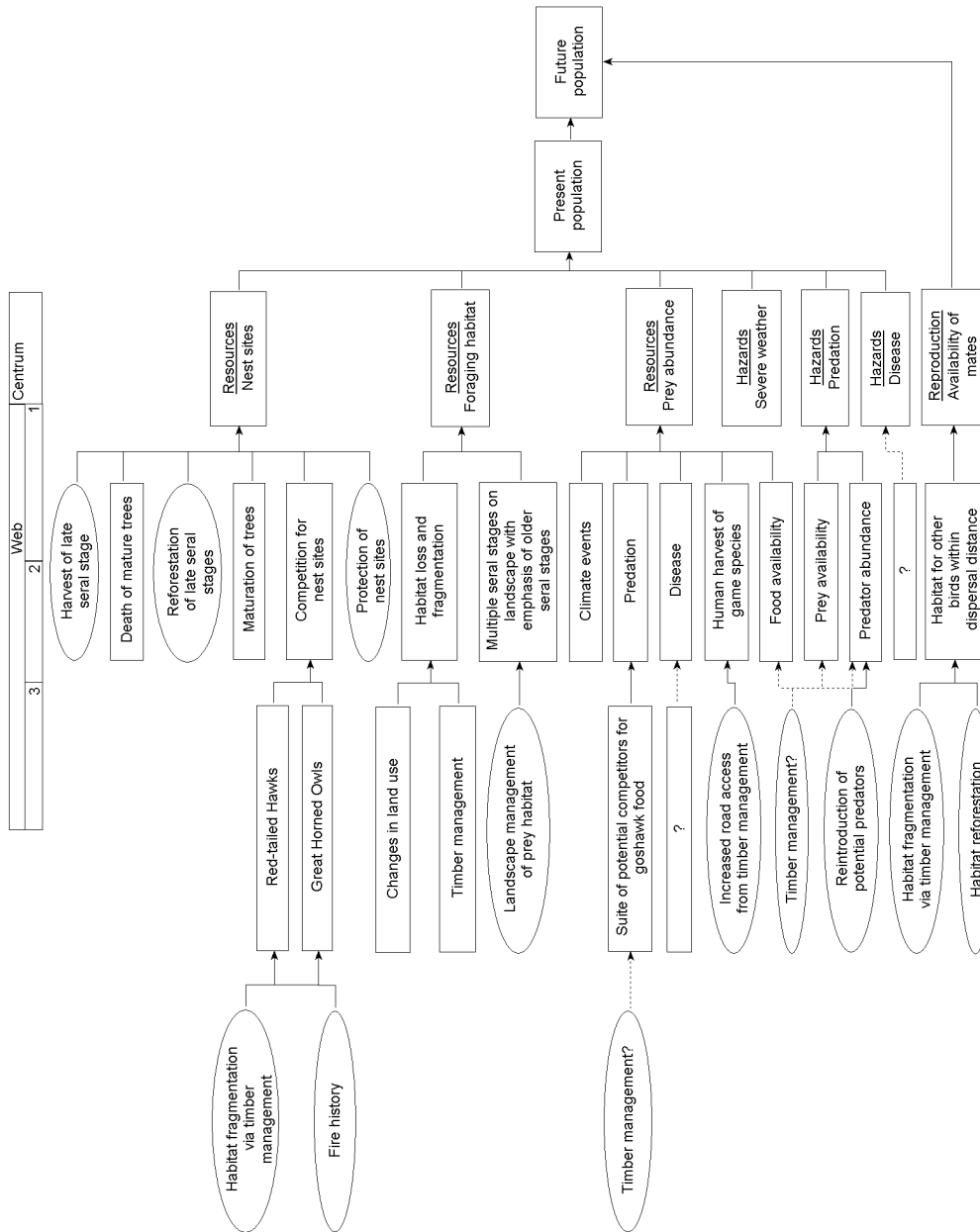
FIGURE 3. Envirogram for the Northern Goshawk in the interior mountain western North America (modified from Kennedy 2003).

the necessary spatial data to monitor changes in forest structure and composition from management across broad landscapes.

Information needs are easy to list, but are often ignored. In many cases, it is exceedingly difficult for agencies to fund the acquisition of new information, and in other cases, decision makers resist new understandings. Successful sensitive species programs depend on a strong commitment by line officers at all levels (Squires et al. 1998). To foster that commitment, researchers must communicate with line officers throughout the planning process; participation builds ownership.

Winter ecology

Given the goshawk's life-history strategy and our understanding of population regulation in similar long-lived avian species (Newton 1998), it is highly likely that over-winter survival of juveniles and adults and the condition of the female entering the breeding season has a stronger influence on goshawk population regulation then conditions that occur after breeding is initiated. However, as indicated earlier, our understanding of goshawk winter ecology is poor. In areas such as Minnesota where goshawks appear to be year-round residents (Boal et al. 2003) they may use similar habitats year-round (Boal et al. 2002). However, the limited evidence on goshawk populations in the inter-mountain west suggest these populations are migratory or partially migratory (Squires and Ruggerio 1995, Dewey et al. 2003) and during the winter are regularly found in open habitats or forest-shrubland ecotones (J. Kirkley, unpubl. data.). Therefore, unlike the Spotted Owl, goshawk habitat requirements may be dramatically different for different stages of its annual cycle. Do we mange the goshawk as a forested species during the breeding season and as a rangeland species during the winter? More information is needed on goshawk winter habitat selection patterns and winter diet before these types of basic management questions can be addressed.

Forest management experiments

As recommended by DeStefano (1998) and Kennedy (1998), on-site experiments are necessary to clearly understand how goshawks and their prey and competitors are affected by forest management. To date, Penteriani and Faivre (2001) have conducted the only experimental analysis of goshawk responses to silvicultural treatments. The absence of such studies in the literature is perplexing considering

these quasi-experiments are being implemented continuously in the form of timber harvests near goshawk nests. Most federal timber sales are identified years before the sale allowing for collection of adequate pre-treatment data. Monitoring pre- and post-treatment movements of even a limited sample could provide fascinating qualitative insights into goshawk responses to harvest and could be the basis for designing future experiments. Also, measurements of prey responses to experimental harvests could be conducted at the same time. We surmise that we would learn more and spend fewer resources about goshawk responses to forest management using this approach then we have learned from the many correlative studies conducted on this topic.

Management databases

Without a database that clearly summarizes past and future management activities conducted by each land management agency, it is impossible to evaluate threats to goshawk nesting habitat and develop potential conservation scenarios. GIS databases that summarize the location, date, and sizes of management activities are needed to assess how goshawk habitat is being enhanced or reduced as indicated in Fig. 3. Spatial databases that relate predicted immediate and long-term changes to forest composition and stand structure are most needed. Spatial databases could also be used to identify the stands that should be monitored to evaluate predicted changes. These spatial databases could be used as a part of the forest-plan development process. Spatial information would also streamline the environmental-assessment process where cumulative effects of forest management are evaluated at the forest and regional scale.

SURVEY AND MONITORING

Population monitoring

Information on goshawk populations is generally obtained by monitoring nesting activity at local scales (Roberson et al., unpubl. data; Kennedy 2003; Hargis and Woodbridge, *this volume*). Although goshawk demographic studies have significantly increased understanding of goshawk population dynamics, no studies to date have generated adequate empirical stage-specific estimates of survival and fecundity for estimating population growth rates (λ) using matrix projection models at the local scale, and demographic data are unavailable to estimate λ over broader spatial extents. In addition, nesting densities are difficult to estimate due to the bird's low

detectability and uncommon status, so trends in this parameter are not available (Kennedy 1997).

A viable alternative to monitoring goshawk demographics is estimating trends in site occupancy. Territory occupancy is a reliable index of habitat quality and productivity in breeding raptors (Sergio and Newton 2003). Although, goshawk site occupancy has been monitored in several populations across the species range (Kennedy 1997, 2003), these data have limited utility for monitoring goshawk population trends because standard protocols are not regularly used to determine site occupancy, and analytical techniques for estimating detection probabilities of site occupancy have not been available. Failing to account for imperfect detectability will result in underestimates of site occupancy (MacKenzie et al. 2003). MacKenzie et al. (2002, 2003) addressed this problem by developing analytical approaches to estimate site occupancy rates when detection probabilities are imperfect (<1.0). This is a likelihood-based method that allows for the incorporation of covariates, e.g., habitat type or patch size, into detection probability estimates. These new analytical approaches have considerable promise for monitoring goshawk population performance at large spatial scales. Hargis and Woodbridge (*this volume*) describe a bioregional monitoring program for northern goshawks that is based on this approach.

Habitat-based monitoring

Kennedy and Andersen (1999) suggested that if goshawk habitat can be well-defined and demographic data are available from several study areas for an analysis of population trends, a model or models that predict(s) relationships between preferred breeding season and winter habitat and population trends and/or performance could be developed. The rationale for switching to habitat-based monitoring has been clearly articulated by Roloff and Haufler (1997) and Lint et al. (1999) and includes cost-effectiveness in emphasizing the ecosystem rather than single species and the ability to develop a more proactive management program.

Preliminary habitat models based on available habitat information could be developed to predict goshawk habitat (Kennedy and Andersen 1999, McGrath et al. 2003). These models could be independently validated and modified based on validation results in an iterative process. Kennedy (1997, 1998) suggested the most efficient way to identify consistent patterns in data collected in multiple studies is to conduct meta-analyses of the existing habitat literature. However, meta-analysis is only an approach for model parameterization; it is not a replacement for model testing and validation. The habitat models would require testing with demographic data before such an approach could be implemented. If models can be developed to predict goshawk population performance, then monitoring programs could switch emphasis from population-based to habitat-based monitoring.

Although goshawks may select habitat on the basis of structural characteristics and prey availability, they are also at the mercy of unpredictable factors such as drought, severe storms, or predation (Penteriani et al. 2002b). Habitat models would need to incorporate these stochastic processes to accurately predict population performance. If habitat models do not adequately predict population performance and it is determined that habitat features have little affect on goshawk population dynamics, a strictly habitat-based monitoring program may have limited ability to predict changes in goshawk demographic performance and population-based monitoring would need to be continued (Kennedy and Andersen 1999).

PROCEEDING IN THE FACE OF UNCERTAINTY

Based on our review of goshawk ecology, it is clear that many life-history attributes of this species are unknown. It is a daunting a task to gain the complex ecological knowledge needed to manage top-level carnivores, like goshawks. Land managers are being forced to make land-use decisions based on limited information that varies in reliability. Thus, land mangers are in the difficult position of having to use best available information while making a conscious decision regarding how to proceed in the face of uncertainty.

Science represents a rigorous, systematic approach by which humans gain understanding of nature. Competing ideas regarding how the world works are measured against observations. Research and reliability of knowledge gained from research depend on appropriate application of the scientific method. Unfortunately, not all research in wildlife ecology and management results in reliable knowledge. Unreliable knowledge can result from inappropriate application of the scientific method in the design and implementation of these studies (Romesburg 1981, Nudds and Morrison 1991) and/or confusing subjective, political values with objective, technical knowledge (Nudds and Morrison 1991, Kennedy 1997, 1998, White and Kiff 1998). Obtaining reliable knowledge on wide-ranging

predators, like goshawks, is expensive. Thus, the problem of how to make defensible decisions in the face of uncertainty is a problem that will persist for the foreseeable future.

Society could do much to reduce the uncertainties associated with managing species, but often does not provide the financial or political will. If limited data are available, formal modeling structures can account for uncertainty (Todd and Burgman 1998). Usually, however, few data are available and uncertainty is addressed using ad hoc methods that lack rigorous quantification.

The Delphi approach

The Delphi method is a way to address uncertainty by seeking a consensus of scientific opinion rather than to generate new knowledge (Ziglio 1996). It is common for agencies to assemble panels of experts and ask them their opinion regarding the potential impact of management decisions. For example, the forest ecosystem management assessment team (Forest Ecosystem Management Assessment Team 1993) involved over 70 experts that had special knowledge of species or species groups (Meslow et al. 1994, Ruggiero and McKelvey 2000). Delphi methods, in their various forms, are appealing because they are quick, require no new knowledge, and have been accepted by the courts (Ruggiero and McKelvey 2000). Delphi is also appealing in that it logically follows that species experts should better understand potential impacts compared to local biologists and managers. However, despite these strengths, the primary appeal of Delphi in conservation planning is its expedience (Ruggiero and McKelvey 2000).

Although Delphi methods are quick and require no new information, scientifically they are inappropriate for conservation decisions (Ruggiero and McKelvey 2000). The collective opinions of experts cannot be reproduced; they have an unknown error factor, and an unknown relationship to the species' ecology. In addition, expert opinions do not represent independent votes regarding potential effects. Species-experts often read the same scientific journals, attend the same conferences, and receive similar technical training. Science has many examples of commonly held beliefs that were later proved wrong. Although in the past, Delphi has been admissible the courts, this acceptance may change with new data-quality standards. Thus, in the future, Delphi methods may not provide a defensible method for addressing the uncertainties associated with goshawk conservation and management.

Inductive science

We believe that scientific investigation is the only defensible way for addressing the uncertainties associated with species management. Romesburg (1981) argued that much wildlife science was compromised with respect to providing the reliable knowledge required to make management decisions. He stated that good science based on the hypothetic-deductive (H-D) method is best able to provide reliable knowledge. This method employs three steps: (1) observation and induction (the use of repeated observations to discover laws of association), (2) hypothesis formulation, and (3) tests of these hypotheses, preferably with experimentation. It also includes a methodology for dealing with uncertainty. Romesburg (1981) pointed out that some accepted knowledge about wildlife is untested hypotheses about observations because many studies go through the first two steps but not the third. Induction can provide us with reliable knowledge about associations such as the association of goshawks with forests having certain structural characteristics. However, this method does not provide the mechanism for understanding the processes that underlie this association nor does it provide reliable knowledge about cause and effect. Thus, we can describe the structure of forests used by goshawks, but we cannot ascertain which characteristics are important or why, without application of the H-D method. We can describe patterns through induction but need the H-D method to understand why these patterns occur and which components of those patterns are important. In terms of management, understanding why a pattern has occurred and what caused it are important for predicting effects when observed patterns are changed via management or other processes (USDI Fish and Wildlife Service 1995b).

As Nudds and Morrison (1991) point out, resistance to using the H-D method in wildlife biology is common. The resistance includes claims that: (1) nothing is yet known about a system so hypotheses are not apparent, (2) funding agencies do not support tests of hypotheses, and (3) the H-D method is impossible if experiments are impractical. Nudds and Morrison address the first challenge by admitting there will always be a need for new data from which to generate testable hypotheses. This challenge just reflects the need for more research. The second addresses the difficulty to fund hypothesis tests. This is certainly true given the tight budget constraints facing most agencies, but administrators are recognizing the need. For example, the USFS has embraced the concept of adaptive management that is management based on the evaluation of results

from experimentation, evaluation, and new management experiments (Walters and Holling 1990). Administrators are realizing they should be able to justify why they spend money on tests of hypotheses that explicitly evaluates the cost-effectiveness of their management actions.

The third challenge that the H-D method is impractical to implement assumes the method only allows for manipulative, controlled, and replicated experiments. However, this argument rests on a very narrow definition of experimentation. As Nudds and Morrison (1991) and Murphy and Noon (1991) point out, this challenge does not recognize what is most important about the H-D approach is the attempt to falsify hypotheses and erect better ones. H-D research is not characterized by whether or not it is experimental, because hypotheses can be evaluated with non-experimental data (Ratti and Garton 1994). Data collected in non-experimental or descriptive studies are more limited in terms of their reliability (e.g., one can not infer cause and effect from non-experimental data), but they can be used to test hypotheses and are certainly better then ignoring hypothesis testing completely. Well-designed descriptive studies that include unbiased sampling techniques, adequate sample sizes, and appropriate statistical tests can be used to evaluate management hypotheses.

Demands for Science-based Management

The ESA requires that we use best scientific data when conserving species that are listed as threatened or endangered on the federal level and the ecosystems upon which they depend (Smallwood et al. 1999). This approach should apply to management of sensitive species such as the goshawk. Squires et al. (1998) surveyed USFS wildlife biologists across the country asking them to list two general information needs that would be most useful for managing sensitive species. The biologists responded that information regarding natural range of variation in population characteristics, as well as autecological habitat relationships were their top information needs. Clearly, management of sensitive or listed species should be science based as described above and not based on subjective judgments as is commonly the case (Nudds and Morrison 1991, Kennedy 1997, Smallwood et al. 1999).

Agencies are subjected to increasing congressional and judicial pressures to base their policies and management actions on good science (Data Quality Act enacted in 2002; U. S. Supreme Court, Daubert v. Merrell Dow Pharmaceuticals [113 S.Ct. 2786, 1993 decision; Tellus Institute 2003]). Thus,

land managers and decision makers not only have to determine if their management actions have a scientific basis, but they also must evaluate the quality of the underlying science in terms of peer review, clear objectives, adequate sample sizes, correct statistical analyses, and appropriate methods. In 2003, the Coalition of Arizona-New Mexico counties, the Washington Contract Loggers Association, the Northern Arizona Loggers Association, and a forestry company, Olsen & Associates, jointly submitted industry sponsored data-quality petitions challenging the USFS's decision to restrict logging in order to protect goshawk habitat according to USFS, Region 3 (Reynolds et al. 1992). In a detailed 281-page petition, the petitioners challenged the report as inaccurate, biased and arbitrary. Issues such as nest stand and foraging habitat conditions and canopy cover were contested. The other petitions filed by the industry groups challenged amendments to forest plans and goshawk management in the Black Hills National Forest that followed similar habitat recommendations as in the Southwest. The Center for Biological Diversity, with nine environmental groups co-signing, submitted comments requesting the USFS to reject the petitions because they failed to meet legal requirements and were intended to circumvent the forest planning process (http://www.ombwatch.com [2 February 2006]).

In July 2003, the USFS Rocky Mountain Research Station issued a response letter to the industry petitioners stating, that while eight minor errors were in the document, the inaccuracies did not affect desired forest conditions or specific management recommendations. In addition, Reynolds et al. (1992) had received peer review that was well beyond the norm—19 scientists and managers at universities, state wildlife agencies, and governmental agencies—prior to publication. The letter concluded that the claims of the petitioners had no substantive merit, and that the Reynolds et al. (1992) would not be retracted (http://www.fs.fed.us/qoi/documents/2003/07/rfc3001response.pdf [2 February 2006]).

This example illustrates the high level of scrutiny that management recommendations for sensitive species, like goshawks, can receive. It also illustrates the importance and central role that good science plays in resource decision making, and how data-quality standards can substantially impact the scientific underpinnings of management decisions. Forest planning in the Southwest would have been disrupted greatly had Reynolds et al. (1992) been rescinded due to lack of peer review or was found lacking in other data-quality issues.

CONCLUSIONS

In conservation planning, a fundamental mismatch often occurs between the state of knowledge and the feasibility of obtaining specific knowledge, and the actions that society would have land managers take towards species conservation (Ruggiero and McKelvey 2000). In this paper, we assessed the current knowledge concerning goshawk ecology, and we discussed the pressing information needs for conservation and management. The uncertainty associated with goshawk management is similar to issues confronted by the lynx science team when asked to define appropriate management for Canada lynx (*Lynx canadensis*), a species with a life history that also is poorly understood (Ruggiero et al. 2000). Ruggiero and his colleagues define what they called qualified insights that were an attempt to embrace science while recognizing uncertainty (Ruggiero and McKelvey 2000). Qualified insights are specific statements that are backed by the balance of scientific evidence, but they are fundamentally subjective because they are based on scientific judgment. The specific linkage between data and inference is what separates this method from opinion-based methods, i.e., Delphi. The statements are qualified because the relationships are scientifically known for given areas, and we then infer the degree that these understandings can be transferred to outside areas with local knowledge.

The qualified insights that we offer are based on: (1) our review of the current state of knowledge, (2) the degree this information is applicable to different subspecies and populations, and (3) our combined experience researching goshawks. These insights are on topics of key management concern and for which sufficient information is available to form some preliminary conclusions. The conclusions we present as qualified insights are our attempt to distill our current understandings to the most salient issues affecting goshawk management and conservation. However, we offer these insights fully recognizing our imperfect knowledge of this species' life history. Our conclusions are best viewed as testable hypotheses that merit further research and testing.

ARE GOSHAWK POPULATIONS DECLINING?

The goshawk has been proposed for listing several times under the ESA and its status has been and still is the object of considerable litigation. It is currently not listed as a threatened species but is considered a sensitive species or a species of concern by most governmental agencies and non-governmental

organizations within the Rocky Mountain Region (Region 2) of USFS. Kennedy (1997) evaluated the demographic data available on goshawks through 1996 and concluded that no evidence showed goshawk populations were declining. The USFWS published a status review in 1998 (USDI Fish and Wildlife Service 1998a) and their review supported Kennedy's (1997) conclusions as did a recent technical review of the USFWS status review (Andersen et al. 2005).

No new demographic evidence suggests a decline in goshawk populations. Existing data, including those from migration counts, trends in BBS data, estimates of production, breeding distribution, detection surveys, local studies of population dynamics, and estimates of breeding density are inadequate to assess population trends in goshawks west of the 100th meridian. Although these studies have significantly increased understanding of goshawk distribution and population dynamics, no studies to date have generated adequate empirical stage-specific estimates of survival and fecundity for estimating lambda (λ). Demographic data are unavailable to estimate λ at the scale of western North America. In addition, densities are difficult to estimate due to the bird's low detectability and uncommon status, so trends in this parameter are also not available.

Four European studies have reported on population trends in various locales (Thissen et al. 1982, Widén 1997, Kenward et al. 1999, Krüger and Lindström 2001). Three of the four studies concluded that goshawk populations were stable or increasing (Thissen et al. 1982, Kenward et al. 1999, Krüger and Lindström 2001). One study (Widén 1997) concluded that goshawk populations in Fennoscandia declined by 50–60% from the 1950s to the 1980s. The trend since the 1980s is unknown.

We conclude that no evidence shows that North American goshawk populations are declining. However, we cannot separate the following hypotheses given the nature of the available evidence: the goshawk is not declining, or it is declining but there is not sufficient information to detect the declines. The majority of the data from Europe suggest that the species is not in jeopardy of extinction globally, although populations might be declining in regional pockets, e.g., Fennoscandia.

WHAT FACTORS LIMIT GOSHAWK POPULATIONS?

Experimental evidence shows that food during the breeding season limits goshawk reproduction (Ward and Kennedy 1996, Dewey and Kennedy 2001) and recruitment via natal dispersal (Kennedy and Ward

2003). Predation also limits goshawk reproduction and is influenced by food availability (Dewey and Kennedy 2001). Whether or not food and predation are additive or synergistic (as demonstrated in Song Sparrows [*Melospiza melodia*]; Zanette et al. 2003) has not been determined. The role of food and predation in limiting over-winter survival is unknown. Weather during the breeding season influences goshawk productivity, but the effect of weather on regulating populations is also unknown.

Strong correlative evidence demonstrates that goshawk population growth rate is also regulated by density-dependent territoriality (Krüger and Lindström 2001). In a German population, territories that were occupied more often and earlier had a higher mean brood size, and fecundity did not increase with increasing density in the best territories. Increased usage of poor territories at high densities results in a decrease in per capita reproductive success (Krüger and Lindström 2001). The site factors that influenced territory quality were not identified in this study.

We conclude that goshawk breeding populations are limited by food, predation, and density-dependent territoriality. High-quality territories which are regularly occupied and very productive likely contain high abundance of prey, low abundance of predators, and forest structural characteristics that enhance prey acquisition and predator avoidance. The factors regulating winter populations and the effect of winter conditions on breeding populations are unknown.

WHAT ARE THE PRINCIPAL HABITAT ATTRIBUTES AND RELEVANT SPATIAL SCALES OF NEST HABITAT?

Goshawks nests in many forest types throughout their range (Squires and Reynolds 1997). These forests include mixed hardwood-hemlock stands in the eastern deciduous forests (Speiser and Bosakowski 1987), various pine and aspen forests in western North America (Reynolds et al. 1982, Hall 1984, Younk and Bechard 1994a, Siders and Kennedy 1996, Squires and Ruggiero 1996, Clough 2000, McGrath et al. 2003), and ponderosa pine-mixed conifer forest (Erickson 1987, Crocker-Bedford and Chaney 1988, Kennedy 1988, Reynolds et al. 1994, Siders and Kennedy 1996). Within these types, there are at least three levels of habitat scale that appear to be biologically important during the breeding season—the nest area, the PFA, and the foraging area (Reynolds et al. 1992, Kennedy et al. 1994). How the size of these areas may differ among populations is not well understood.

Nest areas include forests with a narrow range of structural conditions (Reynolds et al. 1992, Squires and Reynolds 1997). Nest areas are usually mature forests with large trees, relatively closed canopies (60–90%), and open understories (Reynolds et al. 1982, Moore and Henny 1983, Speiser and Bosakowski 1987, Crocker-Bedford and Chaney 1988, Kennedy 1988, Hayward and Escano 1989, Reynolds et al. 1992, Squires and Ruggiero 1996, Penteriani and Faivre 1997, Selås 1997b, Squires and Reynolds 1997, Daw et al. 1998, Daw and DeStefano 2001, Finn et al. 2002b, McGrath et al. 2003). Within nest areas, goshawks usually nest in one of the largest trees (Reynolds et al. 1982, Saunders 1982, Erickson 1987, Hargis et al. 1994, Squires and Ruggiero 1996) with some exceptions (Speiser and Bosakowski 1989). Limited data also suggest that forest structure may be more important than prey abundance when selecting nest sites (Beier and Drennan 1997, Penteriani et al. 2001). Although understanding the structural characteristics of nest areas and nest trees is one of the best known aspects of goshawk ecology, it is still difficult to compare preference relationships among studies due to different field methods and biased nest-search methods.

The PFA was conceptualized by Reynolds et al. (1992) and empirically supported by studies of family movement patterns (Kennedy et al. 1994, Kenward et al. 1993a, and Kennedy and Ward 2003). The function of the PFA is unclear, but it may be important to fledglings by providing prey items on which to develop hunting skills or may provide cover from predation (Reynolds et al. 1992). PFAs are usually in mature forests with dense canopies and small openings (Daw and DeStefano 2001, Finn et al. 2002a, McGrath et al. 2003); these structural components appear to be important to site occupancy (Finn et al. 2002a). The size of the PFA was originally estimated at 170 ha (Kennedy et al. 1994), but a study by McGrath et al. (2003) found late-seral forests, high understory growth, and high canopy cover (50%) were more common around nests compared to random sites up to 83 ha. McClaren et al. (2005) measured PFA size for *A. g. laingi* on Vancouver Island, British Columbia, and mean PFA size for 12 juveniles at 12 nests was approximately 60 ha. PFAs likely vary in size depending on local environmental conditions and perhaps there are sub-specific differences in use of habitat by fledglings.

Goshawks use an array of habitat types in foraging areas, but often select forests with a high density of large trees, greater canopy cover, high tree basal area, and open understories (Doyle and Smith 1994,

Hargis et al. 1994, Beier and Drennan 1997), but with much variation (Kenward 1982, Widén 1989, Austin 1993, Bright-Smith and Mannan 1994, Hargis et al. 1994, Younk and Bechard 1994a, Beier and Drennan 1997). Habitat structure may be more important than prey abundance where goshawks kill prey (Beier and Drennan 1997, Good 1998, Bloxton 2002), again with exceptions (Kenward and Widén 1989).

We conclude that at least three spatial scales are biologically important to nesting goshawks—the nest area, the PFA, and the foraging area. Habitat structure may be as important as prey abundance when selecting nest areas and PFAs. The principal structural components include a high density of large trees, high canopy closure, and high tree basal area than generally available in the landscape; these components are provided in mature forests. Foraging areas are more heterogeneous, but often include mature-forest components.

Are Goshawks Habitat Specialists or Generalists?

Goshawks in western North American breed in forested habitats, and in most places appear to select old-growth and mature forests for nesting. Goshawks often place their nests in the larger or largest trees in a stand, and stands in which nests are placed tend to be older than adjacent stands. However, not all goshawk territories are equally suitable. Thus, nesting habitat diversity may increase with nesting density because lower-quality territories are more regularly occupied at higher densities. These lower-quality territories may have different structural characteristics than high quality territories.

A core area seems to exist around goshawk nests (<100 ha) where the forest can be characterized by large trees with high canopy closure, and this core is surrounded by a heterogeneous landscape with a variety of forest cover types and seral stages. Within this heterogeneous landscape, goshawks may forage selectively in forests with a high density of large trees, greater canopy cover, high tree basal area, and open understories.

The limited data on winter-habitat-use patterns suggest that winter-habitat diversity is greater then breeding-season habitat diversity. During the winter, goshawks use forests as well as non-forested habitats and their habitat-use patterns are partially dictated by residency patterns. Year-round they hunt a wide variety of prey species that occur in a variety of habitat types.

We conclude that goshawks have a strong preference for mature and old-growth forests, but this preference is dependent on nest density, scale, and season; this preference seems strongest within approximately 100 ha of the nest stand. As nest density increases, low quality habitats are more likely to be occupied and thus, nesting habitat diversity used by the population may increase. As spatial scale increases from the nest site to the landscape in which home ranges are embedded, habitat heterogeneity increases. Goshawks are more of a habitat generalist at these larger spatial scales then at the scale of the nest site. Finally, the limited data on non-breeding habitat use patterns suggest that goshawks are more of a habitat generalist during the non-breeding season then during the breeding season.

What Human Activities Most Affect the Persistence of Goshawk Populations?

Forest management can have an impact on the structure and function of goshawk habitat (Reynolds 1989, Crocker-Bedford 1990, Bright-Smith and Mannan 1994, Woodbridge and Detrich 1994, Beier and Drennan 1997, Desimone 1997, USDI Fish and Wildlife Service 1998a, Greenwald et al. 2005). Habitat fragmentation may also favor early successional competitors and predators (Woodbridge and Detrich 1994). Forest management, such as controlled fire and thinning, may improve or degrade habitat depending on implementation, especially as they affect the density of large trees and canopy closure. Forest management that reduces the size of nest stands may decrease occupancy rates (Woodbridge and Detrich 1994). Few studies have directly assessed the impacts of timber management on goshawk populations, but limited data suggest goshawks can tolerate timber harvesting near their nesting area below some threshold (Penteriani and Faivre 2001, McGrath et al. 2003). The effects of forest management on prey populations vary by species, and specific effects are poorly documented.

Although human persecution may have had an impact on goshawk populations in the past, it is not believed to be a factor affecting the persistence of North American populations. Likewise, pesticides and other contaminants do not appear to have an impact on North American populations (Snyder et al. 1973, Reynolds and Wight 1978, Rosenfield et al. 1991, USDI Fish and Wildlife Service 1998a), but this topic has received little study in North America. Recent European data suggest some populations of goshawks still show high levels of organochlorines and PCBs (Kenntner et al. 2003), but the effect of these levels on population persistence is unknown. The populations with high levels of contaminants

occur in areas where regulatory control of the use of these chemicals is less stringent then in the US. Although falconry may impact local populations (Noll West 1998), it is not at a sufficient scale to affect North American populations (Brohn 1986, USDI Fish and Wildlife Service 1988, Mosher 1997).

We conclude that forest management—cutting, thinning, and controlled burning—is the primary human-caused activity that has an impact on goshawk populations. These impacts can either enhance or degrade goshawk habitat depending on type and extent of habitat alterations. Effects of timber management on goshawks are poorly documented, especially relative to prey populations and community interactions. The impacts associated with human persecution, pesticides, and falconry are negligible.

Is Goshawk Monitoring Feasible Given Current Tools?

Information on goshawk populations in North America is generally obtained by monitoring nesting activity at local scales (Roberson et al., unpubl. data; Hargis and Woodbridge, *this volume*). These local monitoring programs typically focus on trends in reproduction which indicate extensive temporal and spatial variation and are difficult to interpret in the absence of survival data (McClaren et al. 2002). When survival has been estimated, it is usually based on mark-resighting techniques and the studies have insufficient sample sizes (<100 birds) to estimate survival with acceptable levels of precision (DeStefano et al. 1994b, Kennedy 1997). Although demography data are vital to determining trends in goshawks populations, funding for the goshawk waxes and wanes as the threat of listing the goshawk comes and goes (DeStefano 1998). This is counterproductive to implementing the long-term, large-scale studies needed to evaluate goshawk demographics. Estimating the rate of population change for a non-listed species such as the goshawk may simply be too difficult and take too long to provide meaningful information for listing decisions and other management concerns.

Documenting the distribution of all forest structural stages, including mature and old-growth forests, would be an important step in goshawk management. Such documentation will be important for a number of wildlife species, including the goshawk and has been suggested by Crocker-Bedford (1998), DeStefano (1998), and Smallwood (1998). Although methods to gather and compile data on current forest conditions need to be improved, assessing goshawk status based solely on the distribution of old-growth or mature forests is not appropriate at present because our current understanding of goshawk-habitat relations is poor.

A viable alternative for monitoring goshawk population performance in a rigorous and cost-effective manner is estimating trends in site occupancy (presence or absence of breeding goshawks at a site). Currently the most accurate field method for determining site occupancy is dawn vocalization surveys (Dewey et al. 2003). If these surveys are conducted in a sampling framework that allows for estimation of detection probabilities (MacKenzie et al. 2002, 2003), trends in site occupancy could be used as an index of goshawk population performance. Hargis and Woodbridge (*this volume*) describe a bioregional monitoring program for northern goshawks that is based on this approach.

We conclude that the best current method available for monitoring goshawk population performance is monitoring trends in site occupancy. We recommend using dawn vocalization surveys as described by Dewey et al. (2003) and estimating detection probabilities of these surveys with recent analytical procedures described by MacKenzie et al. (2002, 2003).

Is Goshawk Management a Serious Issue in Terms of Feasibility and Need?

Goshawks have life-history attributes that are specialized in terms of their morphology and their use of nest habitat. The mature forests that provide nesting and foraging habitat for goshawks are often the same areas that are important for producing forest products. As such, forest management does potentially impact goshawk populations. The density of nesting goshawks tends to be low, and is limited through a combination of food availability, predation, and density-dependent territoriality. Low density and general rarity makes it difficult to assess long-term population trends of regional and local populations. Although monitoring the effects of forest management on goshawks is difficult, it is possible given adequate funding and political will.

We conclude that goshawks have life-history attributes that make them sensitive to changes in forest structure and composition. These attributes also make it difficult to monitor population responses to habitat alterations. Thus, goshawk management is a serious issue because management agencies need concerted efforts to monitor goshawk responses to their management actions within an experimental context. This is necessary before the effects of

forestry on goshawk populations are elucidated across the broad landscapes that are congruent with goshawk spatial-use patterns.

ACKNOWLEDGMENTS