

BREEDING ECOLOGY AND HABITAT OF
NORTHERN GOSHAWKS (*ACCIPITER GENTILIS LAINGI*)
ON VANCOUVER ISLAND:
A HIERARCHICAL APPROACH


by
Thomas Joseph Ethier
B.Sc. University of Victoria, 1992

A Thesis Submitted in Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

in the Department of Biology


We accept this thesis as conforming
to the required standard



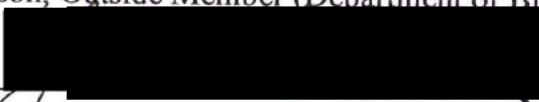
Dr. D.S. Eastman, co-Supervisor (Department of Biology)



Dr. P.T. Gregory, co-Supervisor (Department of Biology)



Dr. R.W. Olafson, Outside Member (Department of Biochemistry and Microbiology)



Dr. J.N.M. Smith, External Examiner (Department of Zoology, UBC)

© Thomas Joseph Ethier, 1999
University of Victoria

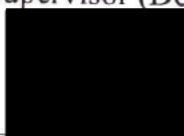
All rights reserved. This thesis may not be reproduced in whole or in part, by photocopy
or other means, without the permission of the author.

ABSTRACT

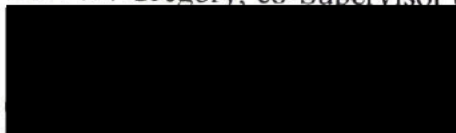
Northern Goshawk breeding habitat was conceptualized and analyzed as a system composed of different sized components organized within a hierarchy. The organization of the hierarchy was asymmetric with smaller components nested within and subordinate to larger components. Components considered in the breeding habitat hierarchy of goshawks were nest tree, nest site, nest territory, foraging area, and landscape. Choice at any level within the hierarchy was contrasted with the next level in the hierarchy. Thus it was found that goshawks chose nest trees with a larger dbh (79.0 ± 4.4 cm) than the nest site average (43 ± 2.7 cm) ($p=0.000036$); the average dbh of the nest site (43.2 ± 3.1 cm) was significantly larger than the territory (33.2 ± 1.9 cm) ($p=0.018$). The nest territory when contrasted with random unoccupied locations in the landscape demonstrated a composition of a central site of trees with larger dbh and fewer stems when compared with the surrounding forest. I hypothesize that this pattern reduces the predation risk at the nest site. I investigated the nest site relative to the assumed foraging area (radius of 3000m; approximately 3000ha). Goshawks selected nest sites which were significantly further from young clearcuts (>10 ha). The average distance from a nest site to a recent clearcut greater than 10 ha was 1,350 m from the nest while for unoccupied sites the average distance was 770 m ($p = 0.011$). Finally, at the landscape level, areas of approximately 10,000 ha, goshawks on Vancouver Island were more abundant, had more nest sites, and had higher productivity per active nest in old growth forests (>120 years) than in either second growth (majority less than 80 years) or fragmented landscapes. The majority of goshawk prey, as determined through pellet analysis was red squirrel (69%). Red squirrels

were equally abundant in second growth and old growth yet less abundant in fragmented landscapes. Despite similar abundance of their main prey item goshawks were not as abundant in second growth forests as in old growth forests. I conclude that the structure of second growth and fragmented landscape reduces the availability of key prey species and therefore the suitability of these landscape for goshawks is lower.

Dr. D.S. Eastman, co-Supervisor (Department of Biology)



Dr. P.T. Gregory, co-Supervisor (Department of Biology)



Dr. R.W. Olafson, Outside Member (Department of Biochemistry and Microbiology)



Dr. J.N.M. Smith, External Examiner (Department of Zoology, UBC)

TABLE OF CONTENTS

ABSTRACT	ii
TABLE OF CONTENTS	iv
LIST OF TABLES	vi
LIST OF FIGURES	vii
ACKNOWLEDGEMENTS	viii
CHAPTER ONE	
<i>INTRODUCTION</i>	1
BIOLOGY OF GOSHAWKS	1
CONSERVATION CONCERN	3
THE RESEARCH QUESTION	4
GOAL AND OBJECTIVES	5
CONCEPTUAL APPROACH	6
CHAPTER TWO	
<i>STUDY AREA</i>	12
ECOLOGICAL SETTING	12
LAND USE HISTORY	15
MAIN STUDY UNIT	15
SUPPLEMENTARY SURVEY UNITS	18
CHAPTER THREE	
<i>INFLUENCE OF LANDSCAPE TYPE ON DIET, ABUNDANCE, AND REPRODUCTION OF NORTHERN GOSHAWKS ON VANCOUVER ISLAND</i>	20
INTRODUCTION	20
METHODS	23
Detection of Goshawks and Nest Site Locations	23
Prey Abundance	24
Goshawk Productivity	25
Goshawk Diet	25
Statistical Analyses	26
RESULTS	28
Sampling Effort	28
Relative Abundance of Goshawks	30
Goshawk Nest Site Abundance and Productivity	31
Goshawk Diet and Relative Abundance of Prey	32
Goshawk Abundance and the Importance of Red Squirrel	35
DISCUSSION	41
Goshawk and Prey Responses at the Landscape Level	41
Annual Variation of Goshawks and Their Prey	45

CHAPTER FOUR*NESTING HABITAT SELECTION OF NORTHERN
GOSHAWKS ON VANCOUVER ISLAND*

	48
INTRODUCTION	48
METHODS	49
Nest Tree Selection	50
Nest site Selection	51
Nest Territory Selection	53
Foraging Area	53
RESULTS	54
Nest Tree Selection within the Nest Site	54
Nest Site Selection within the Nest Territory	55
Nest Territory Selection within the Breeding Home Range	58
Foraging Area Selection	61
DISCUSSION	61
Nest Tree Selection	61
Nest Site Selection	62
Nest Territory Selection	64
Foraging Area Selection	66
 CHAPTER FIVE	 69
<i>CONSERVATION FOR GOSHAWKS ON VANCOUVER ISLAND</i>	69
IMPORTANCE OF GOSHAWK CONSERVATION	69
HABITAT ANALYSIS	70
METAPOPOPULATION CONSIDERATIONS	70
LANDSCAPE LEVEL PLANNING AND WILDLIFE HABITAT AREAS	71
CONSERVING KNOWN GOSHAWK NESTS	73
INVENTORY AND MONITORING PRIORITIES	76
RESEARCH RECOMMENDATIONS	77
 REFERENCES CITED	 79

LIST OF TABLES

Table 2.1. Descriptions of landscape study areas on Vancouver Island.	19
Table 3.1. Relative abundance of goshawks by year and by landscape type on Vancouver Island.	32
Table 3.2. Estimated diet of goshawks on Vancouver Island in 1994-1995, based on pellet analysis.	33
Table 3.3. Relative abundance and selection of prey species in individual landscapes which contained active nest sites (main and supplementary study units).	34
Table 3.4. Mean relative abundance of key prey species on the main study unit, 1994-95.	35
Table 3.5. Comparison of goshawk and prey species relative abundance between the main study unit and supplementary study unit, 1995.	35
Table 4.1. Selected attributes of nest sites used by goshawks compared with those of randomly selected unoccupied sites within the nest territory on Vancouver Island, 1994-1996.	56
Table 4.2. Selected attributes of nest territories used by goshawks compared with randomly selected unoccupied areas on Vancouver Island, 1994-1996.	59
Table 4.3. Selected landscape variables for nest stands used by goshawk compared with randomly selected unoccupied stands.	61

LIST OF FIGURES

Figure 1.1. A schematic of the asymmetric hierarchy of goshawk breeding habitat components used in this study.	8
Figure 2.1. Map of Vancouver Island showing biogeoclimatic zones, the three main study areas(1994-1996) and the six supplementary survey areas (1995).	14
Figure 2.2. Photographs showing character of landscapes of each of the study areas: A) Tsitika Valley (Old Growth); B) Amor de Cosmos (Second Growth); C) Davie Creek (Fragmented).	17
Figure 2.3. Distribution of forest cover by age class in each of the main landscapes.	18
Figure 3.1. The relative proportion of survey effort in relation to the proportion of existing forests, by age class, in the main study areas.	29
Figure 3.2. Proportion of prey items per pellet in 1994 and 1995.	37
Figure 3.3. Correlation of goshawk abundance with key prey species (pooled across years and landscapes).	38
Figure 3.4. Correlation of goshawk productivity with key prey species (pooled across years and landscapes).	39
Figure 3.5. Abundance of red squirrels and red crossbills and seeds per gram of cones.	40
Figure 4.1. Tree species composition at the nest site compared with species used for the nest tree by Northern Goshawks on Vancouver Island.	55
Figure 4.2. Canopy closure pattern around the nest tree and canopy closure pattern found around trees within the nest territory.	57
Figure 4.3. Pattern of average diameter at breast height and tree density at the nest territory and the contrast areas.	60

ACKNOWLEDGEMENTS

I thank the following agencies for their generous support: Habitat Conservation Trust Fund; Forest Renewal British Columbia; BC Ministry of Environment, Lands, and Parks; BC Ministry of Forests; and MacMillan Bloedel Inc.

I could not have carried out this project without the help, guidance, and inspiration of many dedicated biologists. I owe a great deal to Don Doyle, Andy Stewart, Jim Schieck, Myke Chutter, Erica McLaren, Ray Demarchi, and James Quayle for much help, encouragement, and stimulating discussion. I am grateful to the excellent field crew who worked hard and long in difficult conditions: Jennifer Bonnell, Dena Cator, Kiku Dhanwant, Christian Engelstoft, Laura Fagan, Laurie Hunt, Marnie Loedel, Erica McLaren, Laura Meier, Trish Merriman, Damien Power, Gerry Schreiber, Jason Silverman, Tania Tripp, Kathi Vagt, Harry van Oort, and Aubrey Zeeman. Thanks to Andrew Harcombe and Ian Hatter who kindly allowed me a leave of absence from my regular job. I greatly appreciate the careful and meticulous assistance of Roxy Laybourne for microscopically determining to species the remains from the goshawk pellets. I thank my wife, Geneen Russo, for patience, encouragement, and carefully reviewing earlier drafts. My enthusiasm, interest, and approach to raptor ecology was influenced greatly during four enjoyable summers with Dr. Paul C. James. I am indebted to Dr. Don Eastman, my supervisor, for his support, guidance and careful review of all phases of this project. This thesis is dedicated to the Northern Goshawk - *the only bird that matters!*

CHAPTER ONE

INTRODUCTION

BIOLOGY OF GOSHAWKS

The Northern Goshawk (*Accipiter gentilis*) (hereafter goshawk) is the largest holarctic species of the genus *Accipiter* (Brown and Amadon 1968). Body size of male and female goshawks is strongly dimorphic. The smaller males weigh between 631-1091g and females between 860g to 1364g (Mueller et al. 1977; Hoffman et al. 1990; Reynolds et al. 1992).

There are nine recognized subspecies of goshawk worldwide (Brown and Amadon 1968). Three subspecies occur in North America and they are differentiated by subtle variations in colour and body size (Brown and Amadon 1968; Whaley and White 1994; Squires and Reynolds 1997). The most widespread form, *A. g. atricapillus*, occurs throughout the forested areas of continental North America (Squires and Reynolds 1997). *Accipiter gentilis apache*, the largest subspecies, occurs in southwestern United States and northern Mexico (Whaley and White 1994; Squires and Reynolds 1997). *Accipiter gentilis laingi*, the smallest and darkest of the three, is confined to the coastal islands of British Columbia and southeastern Alaska. (Taverner 1940; Johnson 1989; Whaley and White 1994). Within the race of *A.g. laingi*, the Vancouver Island goshawk is the smallest in North America (Beebe 1974; Whaley and White 1994).

Goshawks are efficient predators. Like all *Accipiter*, they possess a morphology of short rounded wings and a long tail for pursuing prey within forests (Whaley and White 1994). They take a diversity of prey that includes medium-sized birds such as passerines, woodpeckers, galliforms; and small mammals, particularly lagomorphs and sciurids (Johnsgard 1990; Reynolds et al. 1992; Squires and Reynolds 1997). Although their diet may be extensive, many studies report that certain prey species are key to reproduction and survival (McGowan 1975; Reynolds 1989; Doyle and Smith 1994; Squires and Reynolds 1997; Widen 1997; Watson et al. 1998).

Goshawk nest habitat has been described in many areas of North America (Reynolds et al. 1982; Moore and Henny 1983; Speiser and Bosakowski 1987; Reynolds et al. 1992; Bright-Smith and Mannan 1994; Squires and Ruggiero 1996). The common finding of these studies is that goshawks select older forests composed of large, densely spaced trees, a canopy closure greater than 60%, and an open understory.

Fewer studies have examined the foraging habitat of the nesting pair (Widen 1997). Nonetheless, radio telemetry research shows that goshawks select foraging sites with larger trees, increased canopy closure, while avoiding open habitats (Austin 1993; Bright-Smith and Mannan 1994; Beier and Drennan 1997).

The goshawk breeding home range is relatively large and can be ecologically diverse. Depending on area and technique, home ranges have been estimated as small as 869 ha and as large as 3982 ha (Austin 1993; Bright-Smith and Mannan 1994;

Hargis *et al.* 1994; Titus *et al.* 1994). Reynolds *et al.* (1992) synthesized existing data and concluded that the average breeding home range in Arizona was between 2000 and 2400 ha. Winter ranges have not been described.

CONSERVATION CONCERN

Until this decade, the effects of forest harvesting on goshawks in North America were poorly documented. In Oregon, Reynolds *et al.* (1982) showed that goshawks nested in mature and old-growth forests. From their research they recommended a 4-8 ha buffer around known nest sites, which was adopted by the U.S. Forest Service (Reynolds 1983). Crocker-Bedford (1990a) tested these recommendations for effectiveness in the forests of northern Arizona. His study design compared goshawk nests which had received a buffer (treatments) with goshawk nests that were not in active forestry areas (controls). He had two significant findings:

- Re-occupancy at nest territories was 12% for treatments versus 78% for controls.
- Productivity at active nest sites was 0.5 fledglings per nest for treatments versus 2.1 fledglings for controls.

These findings questioned the effectiveness of buffers in logged landscapes, and they raised the profile of goshawks with biologists, government agencies, forest industry, and environmental groups. This study catalyzed the debate over forestry and goshawk conservation (Squires and Reynolds 1997).

Since Crocker-Bedford's work, both *A.g. atricapillus* and *A.g. laingi* have been considered or are under consideration for possible listing as a THREATENED or ENDANGERED species under the Endangered Species Act in the United States (Kennedy 1997). In Canada, the Committee On the Status of Endangered Wildlife In Canada (COSEWIC) considers *A. g. laingi* VULNERABLE, while *A. g. atricapillus* is considered NOT AT RISK (Duncan and Kirk 1995). In British Columbia, the Ministry of Environment, Lands and Parks (1996) considers *A. g. laingi* to be red-listed (candidate for THREATENED or ENDANGERED status).

The greater concern in Canada for *A.g. laingi*, both provincially and federally, is because it is an island endemic. Since 1600, 151 species of higher vertebrates have become extinct (Wilcox 1989), with nearly all being human caused (Wilcox 1989; Bibby 1995; Steadman 1997). Of this total, 108 species (71%) have been bird species (Steadman 1997), with the vast majority being island forms (97 species or 90% of all bird species) (King 1985; Bibby 1995; Steadman 1997).

THE RESEARCH QUESTION

Accipiter gentilis laingi was first described by Taverner (1940) as being limited to the coastal islands of British Columbia. He based his description on the specimens' darker colour and stronger barring than the widespread *A.g. atricapillus*. Johnston (1989) reviewed the taxonomy of goshawks from southeast Alaska and found specimens to be more similar to *A.g. laingi* than *A.g. atricapillus*. This work

extended the range of *A.g.laingi* to include the archipelago and mainland coast of southeast Alaska.

This range extension compelled the United States Fish and Wildlife Service to review the conservation status of *A.g.laingi* throughout its range (Cocker-Bedford 1990b). This review concluded that the range had contracted by as much as 55 % because of forest harvesting. As a result, the British Columbia Fish and Wildlife Branch placed this subspecies on their Red List, and that listing provided the impetus for this study which is the first attempt to gather systematic field data of goshawks on Vancouver Island.

Considering current literature, it appeared that forest fragmentation was the key factor adversely affecting goshawks. However, little research in coastal North American forests had addressed this issue. Accordingly, I decided to compare several aspects of goshawk breeding and foraging ecology in landscapes with differing forest conditions. Results of this work can be used to assess the status of goshawks on Vancouver Island and provide recommendations for their management.

GOAL AND OBJECTIVES

The general goal of this project was to study the breeding habitat of goshawks on Vancouver Island in three different types of forested landscapes: Old Growth, Second Growth, and Fragmented. Within this goal, I established three objectives:

Objective 1. *Goshawk abundance and productivity*: To investigate the relationship between abundance and productivity of goshawks and landscape character (Chapter 3).

Objective 2. *Goshawk diet and prey availability*: To investigate the relationship between prey use, prey availability, and landscape character (Chapter 3). Specifically, to investigate whether or not landscape affects prey abundance and accessibility and, if so to measure goshawk response.

Objective 3. *Goshawk nest habitat selection*: To investigate nesting habitat selection using a hierarchical approach that includes five levels: nest tree; nest site; nest territory; foraging habitat and landscape(Chapter 4).

CONCEPTUAL APPROACH

This study analyzed goshawk breeding habitat as a hierarchically organized system. Encountered in many academic disciplines, the term “system” appears to be a very natural product of the human mind. For example, astronomy focuses on the solar system, neurology studies the nervous system, and economics, the economic system. The origin of the word “system” comes from the Greek *systema* which means “organized whole” (Funk and Wagnalls Standard College Dictionary 1978). O’Neil (1986) defines system to be at least two interdependent components that interact together to form an entity: this entity may or may not interact with the surrounding environment. To understand a system one must conceptualize the components and then attempt to understand their organization and integration (O’Neil 1986).

Bird breeding habitat is a complex yet highly organized spatial system composed of many resources required for reproduction. These resources, however, occur at different scales in the environment. For example, a nest is within a very small area while potential prey are distributed over a much broader area.

Many ecological systems are spatially organized within a hierarchy (Johnson 1980; O'Neil 1986). A hierarchy is a structure or a system composed of multiple levels where lower levels are subordinate to higher levels: the relationship between the levels is asymmetric (O'Neil et al. 1986). For example, with bird breeding habitat, an abundant and accessible prey base (higher level) can permit the establishment of a nest site (lower level), but the establishment of a nest site will not establish a prey base. To study bird breeding habitat as a hierarchical system, the relevant sub-habitats need to be partitioned at the appropriate scale(s) and then arranged within a hierarchy.

Wiens (1989) identified two approaches taken by ornithologists in identifying the spatial scale of an investigation. One approach is arbitrary; a predetermined observational scale is imposed on the biological process under study. The hope is that the observational scale reflects the identified biological phenomenon. A sounder approach is to conceptualize the system on the scale at which the phenomena are expressed (Wiens 1989; O'Neil 1986). By identifying the appropriate scale the significance of the observed phenomena is more likely to be elucidated (Wiens 1989).

For this study, I have conceptualized goshawk breeding habitat as a hierarchical system composed of five levels, based on resource requirements reported

in the literature. The highest level in the hierarchy is the landscape followed by foraging area, nest territory, nest site, and nest tree. Upper levels constrain lower levels. The nest tree is chosen from what is available at the nest site; the nest site is chosen from what is available within the nest territory, the nest territory is chosen from within the foraging area; and the landscape is chosen from what is available on Vancouver Island (Figure 1.1). The following is a description of each level in the hierarchy:

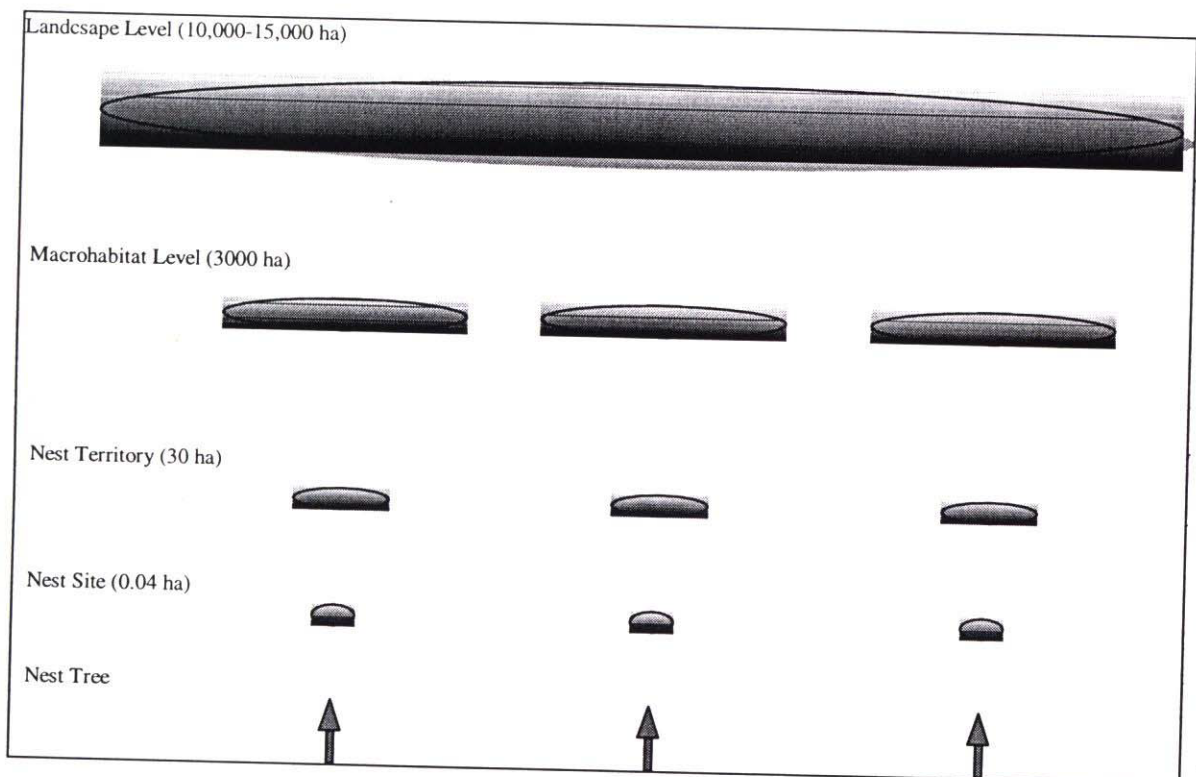


Figure 1.1. A schematic of the asymmetric hierarchy of goshawk breeding habitat components used in this study.

Landscape Level

The term landscape is often used but rarely defined (see Carey et al. 1992; Holt and Martin 1997). Nonetheless, most studies consider it to be a relatively large area that accommodates a given population or community, and contains much ecological heterogeneity. I define the landscape similarly as being a large area that may contain >1 breeding pair of goshawks. For this study I examined goshawks within landscapes of approximately 10,000 ha.

Foraging Area

The foraging area is an extensive area surrounding the nest and is influential in nest placement (Bosakowski and Speiser 1994; Bosakowski et al. 1992; Reynolds et al. 1992). Several studies have examined the size of the foraging area based on telemetry (Austin 1993; Titus et al. 1994). The goshawk literature synthesis by Reynolds et al. (1992) concluded that the average goshawk foraging area is approximately 2400 ha. This figure will vary with prey density. In the numerically reduced prey systems of southeast Alaska, goshawk foraging areas have been recorded up to 4000 ha (Titus et al. 1994). Given the limited prey base on Vancouver Island, I estimated a breeding foraging area of approximately 3000 ha, although further work is required to substantiate this estimate.

Austin (1993) and Titus et al. (1994) have reported that goshawks avoid openings and clearcuts within the foraging area. Beir and Drennan (1997) found significant differences between kill sites and reference sites and determined that goshawks chose hunting areas based on habitat structure and not on prey density.

Thus forest clearing, at the level of foraging area, may impact goshawk reproduction and nest site selection.

Nest Territory

In 75% of the 81 raptor genera, including *Accipiter*, a nesting pair defends the vicinity of the nest and a variable amount of surrounding area (Newton 1979). The risk of predation at nest sites is a very important consideration in nest site selection (Martin 1993). Birds have two general strategies to reduce this risk: 1) concealment of the nest, either physically or visually and/or 2) vigorous defence against intruders.

The size of a nest territory of a goshawk has not been determined rigorously. Reynolds (1983) found that goshawks responded to human intruders 300 m from the nest. Kennedy and Stahleker (1993) found that nesting goshawks were most likely to respond to simulated goshawk calls starting at a distance of 300 m. These studies indicate that a goshawk nest territory can extend up to 300 m out from the nest tree or an area of approximately 28 ha.

Nest Site

The nest site is the immediate area surrounding the nest tree. It provides a secure area for breeding activities such as courtship, prey exchange, incubation, nestling development, and early dispersal by fledglings. A goshawk nest site is usually described as an area of 0.04 ha centred on the nest tree (Mosher et al. 1987; Squires and Ruggiero 1998). Studies have concluded that the nest site is composed of large trees with a closed canopy, gentle to medium slope, and sometimes a particular

aspect (McGowan 1975; Reynolds 1982; Hall 1984; Speiser and Bosakowski 1987; Hayward and Escano 1989; Titus et al. 1995; Squires and Ruggiero 1996),

Nest Tree

Goshawks throughout their range prefer the largest tree (as indicated by height and diameter) within the area of the nest site (McGowan 1975; Reynolds et al. 1982; Moore and Henny 1983; Speiser and Bosakowski 1987; Kennedy 1988; Hayward and Escano 1989; Reynolds 1989; Squires and Ruggiero 1996; Schaffer 1998). There are at least three benefits to goshawks for choosing the largest tree. A large tree will provide a suitable platform to hold the goshawk's big and bulky nest. Increased height from the ground will reduce visibility of the nest to mammalian predators and allow for a good vantage point for early detection of potential predators. Finally, a large tree can create structural gaps in the forest canopy, which provides an access point into and out of the nest site.

CHAPTER TWO

STUDY AREA

ECOLOGICAL SETTING

Mild temperatures, a wet climate, and rich soils have provided Vancouver Island with a highly productive temperate rainforest (Commission on Resources and Environment 1994). The island has three forest biogeoclimatic zones: Coastal Douglas-fir, Mountain Hemlock, and Coastal Western Hemlock. A biogeoclimatic zone is a large geographic area influenced by a similar climate that results in a broadly similar plant community (Clayoquot Scientific Panel 1995).

This study was located in the Coastal Western Hemlock (CWH) biogeoclimatic zone, which is the most productive forest region in Canada (Pojar et al., 1991) (Figure 2.1). It is also the dominant biogeoclimatic zone on Vancouver Island, comprising 84% of the land base (Commission on Resources and Environment 1994). The dominant tree species in the CWH is western hemlock (*Tsuga heterophylla*), while western redcedar (*Thuja plicata*), Douglas-fir (*Pseudotsuga menziesii*), amabilis fir (*Abies amabilis*), yellow cedar (*Chamaecyparis nootkatensis*), Sitka spruce (*Picea sitchensis*) and red alder (*Alnus rubra*) also occur under varying conditions. Major shrubs include *Vaccinium spp.*, *Gaultheria shallon*, *Mahonia nervosa*, *Rubus spectabilis*, and *Oplopanax horridus*.

The CWH consists of rugged mountains dissected by many creek drainages. Elevations range from 0 m at the coast to > 900 m inland. The climate consists of

cool, wet winters and warm, dry summers. Mean temperatures range from 0 C in winter to 18 C in summer, and annual precipitation ranges from 100 cm to 400 cm, most of which falls as rain.

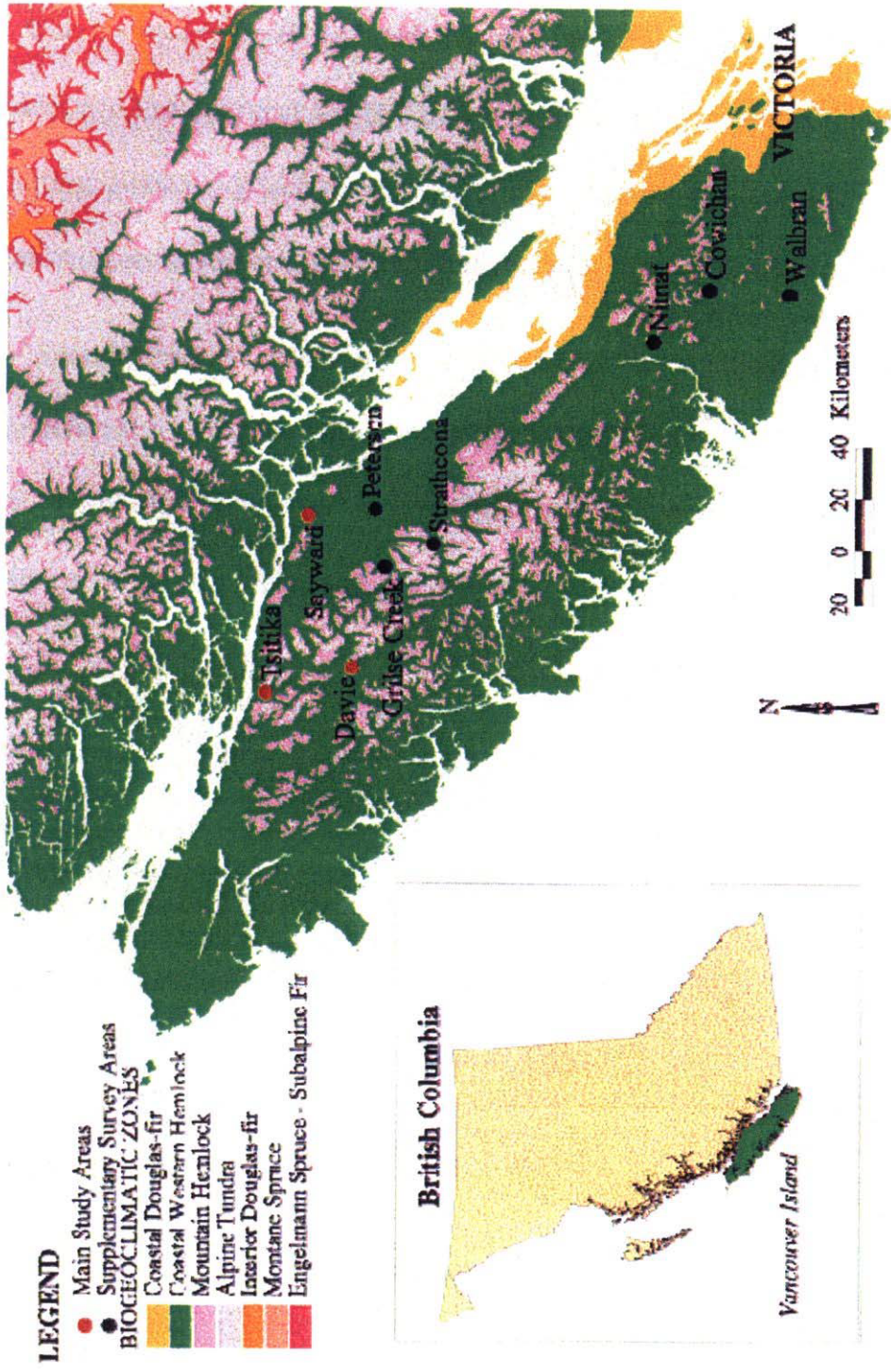


Figure 2.1. Map of Vancouver Island showing biogeoclimatic zones, the three main study areas (1994-1996) and the six supplementary survey areas (1995).

LAND USE HISTORY

The forests of Vancouver Island have been heavily harvested for the past 100 years, with the lower elevations being the most intensely logged (Commission on Resources and Environment 1994). The dominant harvesting method has been clearcutting; a process which removes all trees in a given area in one pass (Commission on Resources and Environment 1994; Clayoquot Scientific Panel 1995).

Recently, values other than wood fibre have been recognized as important, and some forest stands have been retained for wildlife and fishery needs and for visual quality. Where this practice has occurred, the forest has become fragmented with older forest stands of variable size surrounded by young plantations.

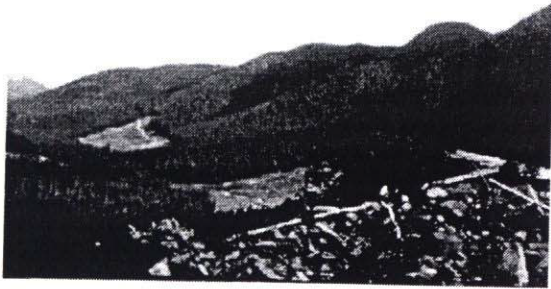
As a result of the extensive logging, few unlogged watersheds remain on the island (Moore 1990). There are no watersheds on the east coast of the island that have not experienced some logging activity; only two watersheds on the west coast of the island have no logging. Approximately 46% of the island has forests greater than 120 years, 28% is between 40 and 120 years and 17% has been logged in the past 40 years (Commission on Resources and Environment 1994).

MAIN STUDY UNIT

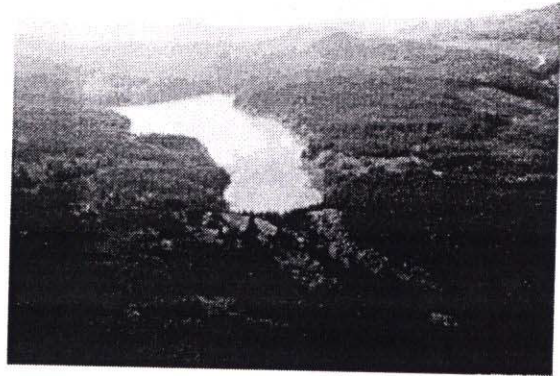
Within the CWH on northeastern Vancouver Island, I chose three landscapes in the same general area, which differed on the basis of logging history and the

resultant forest cover (Figure 2.2). Each area was approximately 10,000 ha and I categorized them by current forest cover: Old Growth; Second Growth; and Fragmented. The Old Growth landscape was situated in the Tsitika River Valley (Latitude: 50°12'15" and Longitude 126° 24'00"). The Tsitika is a deeply incised valley running generally east to west with an elevation range of 0 m - 1600 m. The Fragmented landscape was in the Davie River drainage (Latitude: 50°10'00" Longitude: 126°27'00"). The Davie River drainage flows south to north into the Nimpkish river system. It is broader and somewhat drier than the Tsitika and has an elevational range of 200 m to 1000. The Second Growth landscape was situated in the Amor de Cosmos drainage (Latitude: 50°18'02" and Longitude: 125°38'05"). The Amor de Cosmos area is the broadest of the three landscapes with an elevational range of 0 m to 800 m.

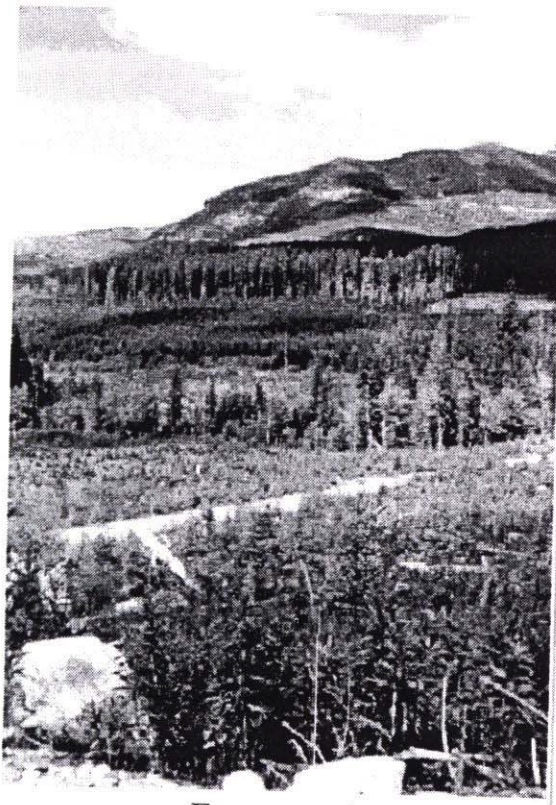
I quantified the forests of each of these landscapes by overlaying a grid on forest cover maps and randomly sampling 100 points. At each point I recorded dominant tree species and forest age. Forest age was categorized into four classes: Age class 1: 0-40 years; Age class 2: 41-80 years; Age class 3: 81-120 years; and Age class 4: >121 years.



Old Growth



Second Growth



Fragmented

Figure 2.2. Photographs showing character of landscapes of each of the study areas: A) Tsitika Valley (Old Growth); B) Amor de Cosmos (Second Growth); C) Davie Creek (Fragmented).

The Fragmented area has sustained extensive logging in the past 40 years with 52% of the forest < 40 years of age (Figure 2.3). The Second Growth had an extensive fire and subsequent salvage logging in the 1930's (Don Doyle, pers. comm.). Thus 54% of the forest cover is between 40 and 80 years of age, with 24 % > 121 years. Logging in the Old Growth is quite recent and 78% is > 120 years with only 16% < 40 years of age.

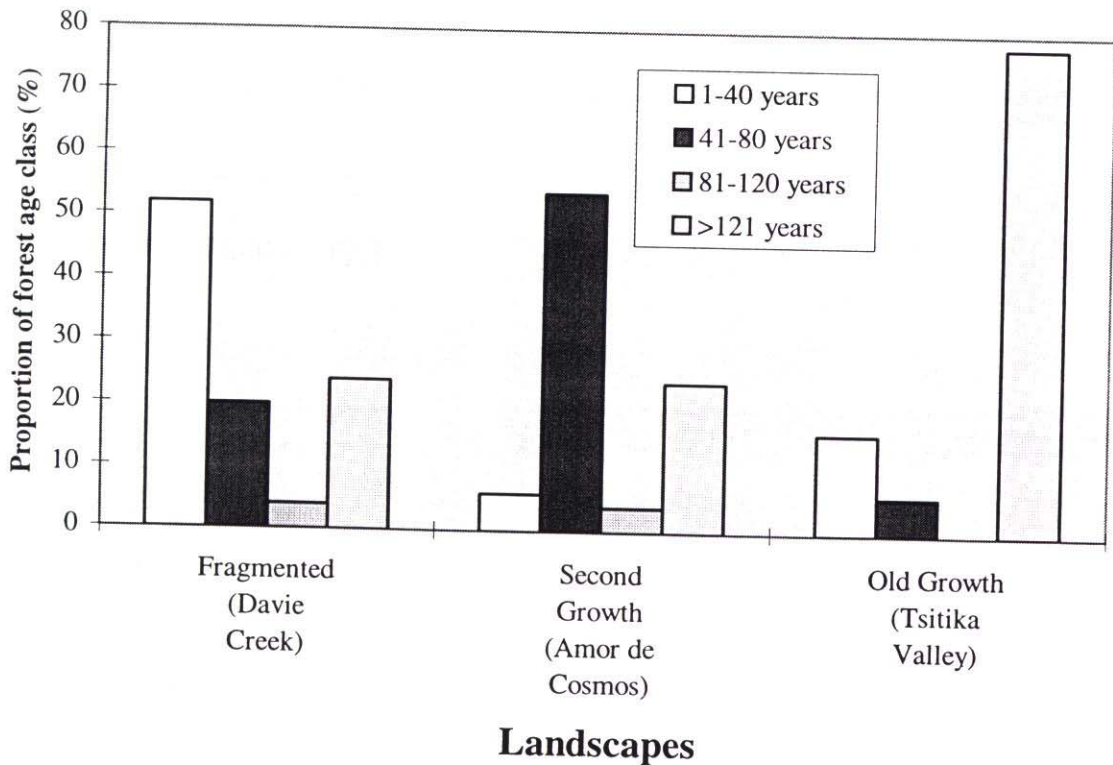


Figure 2.3. Distribution of forest cover by age class in each of the main landscapes.

SUPPLEMENTARY SURVEY UNITS

In 1995, additional surveys were conducted by the Ministry of Environment, Lands, and Parks (Wildlife Program) in similar landscapes of central and southern Vancouver Island (Quayle et al. 1995). These surveys quantified and assessed the abundance, nest location, productivity, and diet of goshawks by landscape type (Table 2.1). Since I participated in the selection of the survey landscapes, trained all personnel in goshawk surveys and described all of the nests, data from these surveys are comparable with mine. Data from these supplementary survey units are used in this thesis with the permission of the Vancouver Island Region, Ministry of Environment, Lands, and Parks.

Table 2.1. Descriptions of landscape study areas on Vancouver Island.

Study Unit	Study area	Landscape type	Area (ha)	Predominant forest age
Main	Tsitika	Old Growth	10 000	>120 yrs.
	Amor de Cosmos	Second Growth	10 000	41 - 80 yrs.
	Davie Creek	Fragmented	10 000	< 40 yrs.
Supplementary	Walbran	Old Growth	13 500	>120 yrs
	Cowichan	Second Growth	12 500	21 - 60 yrs.
	Nitnat	Fragmented	12 500	< 20 yrs.
	Strathcona	Old Growth	10,000	141 - 251 yrs.
	Petersen	Second Growth	10,000	41 - 100 yrs.
	Grilse Creek	Fragmented	10,000	< 20 yrs.

CHAPTER THREE

INFLUENCE OF LANDSCAPE TYPE ON DIET, ABUNDANCE, AND REPRODUCTION OF NORTHERN GOSHAWKS ON VANCOUVER ISLAND

INTRODUCTION

Availability of food constrains the breeding density, productivity, and ultimately the fitness of animals (Lack 1954; Newton 1979; Milsap et al. 1987; Johnsgard 1990; Ward and Kennedy 1994). The abundance and accessibility of prey determines the availability of food (Garton et al. 1989). Prey abundance is determined by a myriad of factors that impinge on a population whether they are density dependent factors or density independent factors (Begon et al. 1986). Prey accessibility depends on a number of factors including predator foraging strategy, prey behaviour, habitat structure, and habitat condition (DeStefano and McCloskey 1997; Schaffer 1998).

Habitat loss is a major factor in the reduction of raptors worldwide largely because it reduces prey availability (Newton 1979; Wilcox 1989). Newton (1979) conceptualized three ways in which habitat loss impacts foraging by raptors. First, reducing a once continuous habitat into small fragments can isolate and reduce the overall abundance of prey populations. Prey densities will remain high in suitable fragments but will be lower elsewhere. Second, habitat degradation can lower prey population size such that prey are still present throughout the landscape but at a reduced density. Third, alterations to habitat structure can make access to prey more

difficult for raptors even when prey populations are high (Beier and Drennan 1997; DeStefano and McCloskey 1997). All three effects may be observed in raptor populations affected by habitat loss.

The goshawk is an opportunistic predator that takes a wide variety of prey, depending on region and season (Squires and Reynolds 1997). Small- to medium-sized mammals such as ground and tree squirrels, hares, larger passerines and game birds are the main foods (Brown and Amadon 1968; Johnsgard 1990; Reynolds et al. 1992; Squires and Reynolds 1997). Despite this long list of prey species, the goshawk appears limited by abundance and accessibility of a few key prey. Doyle and Smith (1994) reported high densities and productivity (3.9 young per nest) of breeding goshawks during a peak in the snowshoe hare (*Lepus americanus*) cycle in the Yukon. However, when the hares declined, goshawk density decreased and productivity was nonexistent. Linden and Wikman (1983) studied goshawks in Finland, and found the breeding density of goshawks increased with an increase in the density of Hazel Grouse (*Tetrastes bonasia*). When grouse declined, the density of breeding goshawk pairs declined, too. Beier and Drennan (1997) found accessibility to be more important than prey abundance in selecting hunting sites in Arizona. Habitat structure at hunting sites consisted of more large trees, more perch sites, and an open understory but not greater prey density. Widen (1997) reported that goshawks in Finland avoided early successional forests despite a high density of Black Grouse (*Tetrao tetrix*), a preferred prey, there.

Island biogeography theory predicts a reduction in species diversity according to an island's size and distance from a "mainland" (MacArthur and Wilson 1967). *A. g. laingi* on Vancouver Island has a reduced diversity of prey species available when compared with prey species available on the mainland. Key prey species absent from Vancouver Island but found on the British Columbia mainland include snowshoe hare, Douglas squirrel (*Tamiasciurus douglasii*), and various ground squirrels. The only native squirrel on Vancouver Island is the red squirrel (*Tamiasciurus hudsonicus*) and there are no naturally occurring lagomorphs. This paucity of prey species led Beebe (1974) to state that the diet of goshawks on Vancouver Island consisted mainly of Steller's Jay (*Cyanocitta stelleri*) and Varied Thrush (*Ixoreus naevius*). Because of fewer alternative prey species, this island goshawk may be more vulnerable to declines in one of its key prey species, either through a natural factor or due to human-caused habitat loss. The smaller range of potential prey species presents a greater risk to survival and reproduction due to lower food availability.

Forest harvesting has the potential to impact goshawk foraging habitat (Reynolds 1983; Crocker-Bedford 1990a; Bright-Smith and Mannan 1994; Beier and Drennan 1997; DeStefano and McCloskey 1997), yet its effects on both the goshawk and its prey populations are poorly known (Reynolds et al. 1992; Squires and Reynolds 1997). The objective of this chapter is to compare the breeding biology of goshawks on Vancouver Island among three landscape types which differed on the basis of historic forest practices: Old Growth; Second Growth; and Fragmented. Comparisons between landscapes were based on five variables: (1) relative

abundance of goshawks, (2) number of goshawk nests found (3) number of chicks fledged per nest, (4) prey use, and (5) prey abundance.

METHODS

DETECTION OF GOSHAWKS AND NEST SITE LOCATIONS

The three main landscapes were surveyed between May 15 and August 31 in each of 1994, 1995, and 1996, and the six supplementary landscapes were surveyed in 1995 in the identical calendar window. Areas within the landscapes that had an average tree size of > 20 cm diameter at breast height (dbh) were surveyed; other areas were not surveyed because of assumed low goshawk nest site suitability. The Kennedy and Stahleker (1993) method, with the Bosakowski and Vaughn (1996) modification for surveying goshawks in rugged terrain, was used to elicit goshawk responses by broadcasting goshawk calls. Stations and adjacent transects were spaced 400 m apart. Systematic coverage of each landscape was attempted each year. Transect layout was guided by forest cover maps and air photos. Transects generally traversed the elevation contours until the extent of the survey area was reached and then the adjacent transect was located and the survey would progress back along the return transect. When a nest site was found the area 1600 m surrounding the nest tree was eliminated from further survey.

Adult alarm calls were played in May and June and juvenile begging calls were used for July and August. Responses were classified as 1) vocalization only, 2)

sighting only, or 3) vocalizations and sighting. I used portable cassette players and long-range callers to broadcast goshawk vocalizations. Cassettes were played at a volume that produced a sound audible to the human ear at a minimum of 200 m from the source. I used 1:20,000 TRIM maps (Terrain Resource Information Maps) with marked transects and stations for use in the field. At each station, I broadcasted three times in three directions. First, I rotated 60° right or left from the direction of travel, played the taped vocalization for 15 seconds and then listened and searched for hawk responses for 60 seconds. The broadcast and observation procedures were repeated two more times after rotating 120° from the previous broadcast. At the end of each calling session I continued to search for a goshawk response for an additional five minutes. When a goshawk was detected at a call station, I immediately followed with a nest search within 400 m of the detection. Heavy rain and winds exceeding 20 km/h resulted in delay or termination of surveys because these conditions interfered with response detection and sound travel. All surveys were conducted between 0500 h and 1800 h. Goshawk locations were plotted onto TRIM and Forest Cover Maps. At each call station I recorded location (Universal Transverse Mercator), percent slope, elevation, aspect, canopy closure, and forest age class (taken from Forest Cover maps).

PREY ABUNDANCE

For five minutes following the broadcast call for goshawks, I recorded all bird and squirrel species detected by sight or sound or both. This effectively served as a

point count. Since red squirrels and most landbirds are territorial and defend their territories through vocalization and visual display, they can be censused by point counts (Carey 1989; Schieck 1994). In 1994, the pilot year, bird and squirrel detections were recorded at about one-third of all stations. In 1995 and 1996, bird and squirrel observations were recorded at all stations. Either presence or not detected were recorded at each station. These data were standardized to the number of detections per 100 call stations per year or per landscape.

GOSHAWK PRODUCTIVITY

I estimated productivity as the number of juveniles present at a nest site within one week after fledging (Kennedy 1990).

GOSHAWK DIET

To assess the diets of nesting goshawks, I chose to analyze pellets. Analysis of prey remains to assess diet composition are heavily biased towards colourful prey remains (usually of birds), since they are more easily detected by field observers (Kennedy 1990). This method has been shown to under represent the mammalian component of the diet (Younk and Bechard 1994). Given this bias I decided to analyze diet based on pellet content. Pellets were collected within 150 m from the nest tree. Initially, pellets were collected at the nest area from the time of nest discovery and every week until the young had left the area. In successive years, at known nest sites, pellets were picked up when the female began incubating.

Pellets were washed in mild detergent soap and then oven dried. For the purpose of squirrel identification, fur samples from specimens at the Royal British Columbia Museum were used to check pellets for squirrel hair. The complexity of feather fragments make species identification difficult (see Kennedy 1990). For that reason, pellets were analyzed by Dr. Roxy Laybourne, a feather fragment expert at the Smithsonian Institution. Only pellets from 1994 and 1995 were examined for feather identification.

STATISTICAL ANALYSES

Forest raptors are notoriously difficult to study (Carey et al. 1992), and goshawks in particular are very secretive and rare (Campbell et al. 1990). Survey effort in terms of time and cost would only allow me to include one example of each treatment (landscape type). The cost of replication would have been very great. As a result, the quantitative data that I collected on goshawk abundance and prey abundance within each landscape cannot be analyzed with tests of significance (Hurlbert 1984). For goshawk abundance and primary prey abundance by landscape type, I report the mean and the standard error.

However because goshawks and their prey species, may disperse to wintering grounds annually, some degree of evaluation (or re-evaluation) of breeding habitat must be done each season. Therefore call stations surveyed in all three years were treated as independent points for analysis, and I applied inferential statistics to test for differences among years (Germaine et al. 1997).

Presence/absence data collected at point counts have been shown to be an adequate index to animal abundance when large landscapes are the sampling universe and a large number of points are sampled (Bart and Klosiewski 1989). These data were then standardized to the number of detections per 100 call stations by either landscape or year.

I used the Kruskal-Wallis Anova to test for differences in relative abundance among years for goshawks (Statsoft 1996). The frequency of occurrence for goshawk detection in each year was too low to use parametric procedures (Devore 1987).

After determining the most common prey species through pellet analysis, I tested for differences in relative abundance of these primary prey species among years using ANOVA. While these data follow a binomial distribution, it approximates the normal distribution when N is large and np and $n(p-1)$ is not less than 5 (Devore 1987). If H was rejected, I determined significant differences between years using the Tukey Honest Significant Difference Test for unequal N (Statsoft 1996).

To assess and compare selection of a prey species in a landscape, I derived a statistic from the ratio of percent prey at each nest site divided by the relative abundance of that prey in that landscape. Ratios were summed and averaged for each landscape type.

I examined the relationship of goshawk abundance and productivity with the abundance of the main prey species indicated by results of the pellet analysis. To test for significant relationships I used the Pearson correlation coefficient.

RESULTS

SAMPLING EFFORT

A total of 1739 call stations was completed from 1994-1996 in the main study area, and 845 call stations in 1995 in the supplementary study areas. In the main study area, 32% of call stations occurred in Old Growth, 41% in Second Growth, and 27% in Fragmented landscape types. In the supplementary study area 33% occurred in Old Growth, 39% in Second Growth, and 28% in Fragmented.

Within landscapes, allocation of sampling effort by forest age was similar to what was available for Old Growth and Second Growth but not in proportion for Fragmented in the main study area (Fig 4). By constraining survey routes to forest stands with a minimum dbh of 20 cm, most young stands were excluded from surveying. Thus, Fragmented and Old Growth had similar effort in the older age forests (75-80%). In Second Growth 63% of surveys were focused in the 40 - 80 year old stands, which is similar to what was available (57%).

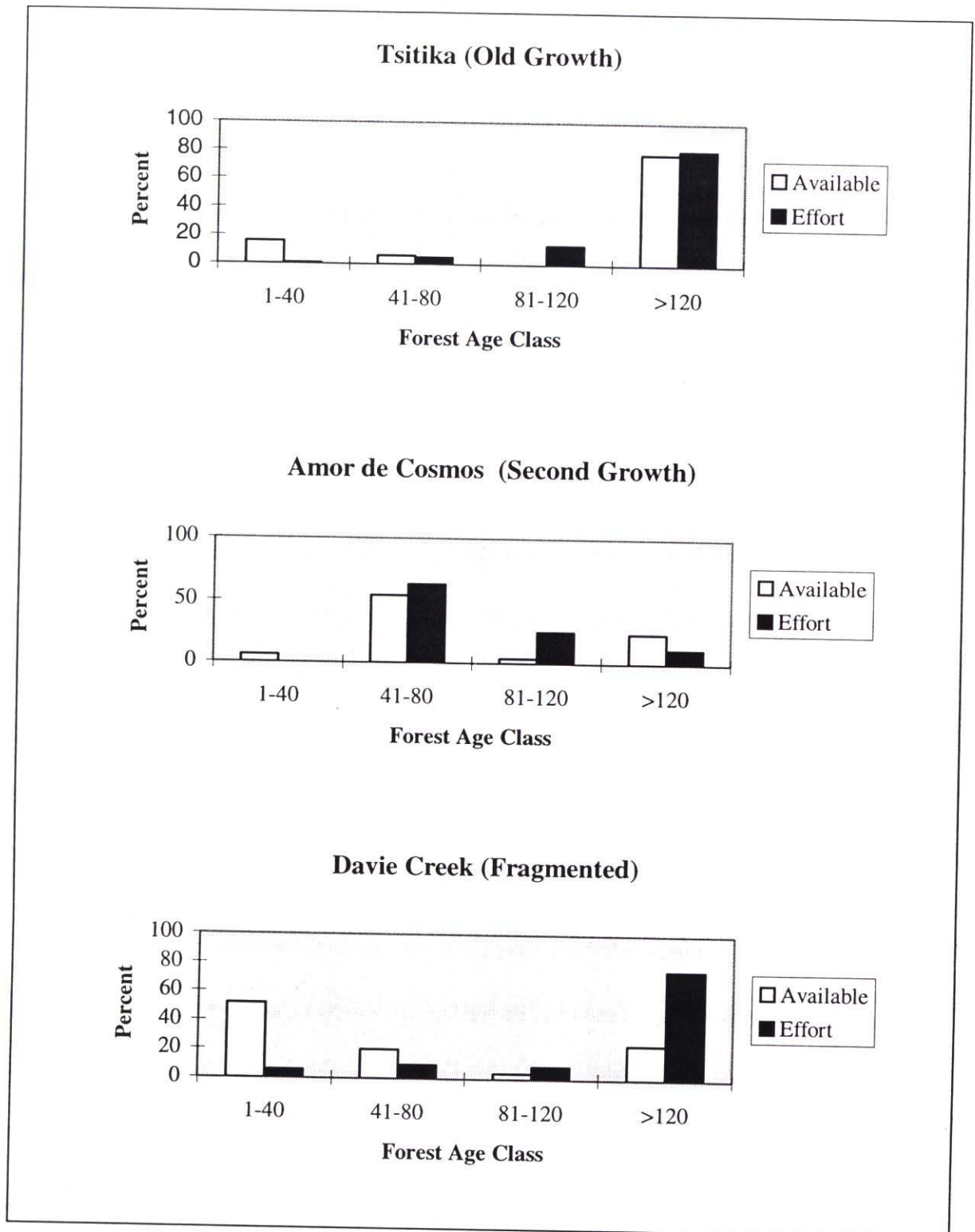


Figure 3.1. The relative proportion of survey effort in relation to the proportion of existing forests, by age class, in the main study areas.

RELATIVE ABUNDANCE OF GOSHAWKS

Goshawks were infrequently detected in call playback surveys. In the main study unit, the combined detection rate for all three landscape types was 1.0 detections/100 call stations, over the three years of surveys. In the supplementary study unit, the combined rate was 0.9 detections/100 call stations in 1995. In total for the 2584 call stations conducted, the overall detection rate was 0.93.

The relative abundance of goshawks varied by landscape type (Table 3.1). In the main study unit, goshawks were least abundant in Second Growth, at 0.4 detections per 100 call stations; more abundant in Fragmented, at 0.8 detections; and most abundant in Old Growth; at 1.9 detections. Thus there was an almost fivefold difference in relative abundance between the three landscape types. Similar though less marked differences were also recorded in the supplementary study units (Table 3.1B).

The relative abundance of goshawks also varied temporally (Table 3.1). Differences were not strongly significant ($P=0.112$) but do suggest annual variation. For the main study unit, average annual detection rates were least in 1995, almost three times higher in 1996 and four times higher in 1994. However, these annual patterns were not consistent across landscape types in the main study unit nor in the supplementary survey units (1995 data only).

GOSHAWK NEST SITE ABUNDANCE AND PRODUCTIVITY

Ten nests were found in the main study area and six in the supplementary study area (Table 3.1). Of the ten in the main study area, five were in Old Growth, one in Second Growth and three in Fragmented landscapes (One additional nest was found in a Second Growth landscape adjacent to the main study area.). In the two supplementary study units, the two Old Growth landscapes had two nests each while the two Second Growth landscapes each had one. No nests were found in the Fragmented landscapes.

Productivity of goshawks varied by landscape type. Productivity at active nest sites in the main study unit by landscape was 2.3 chicks in Old Growth ($n = 2$ years), 2.0 chicks in Second Growth ($n = 2$ years), and 0.33 chicks in Fragmented ($n = 1$ year). Average productivity for all nests in the supplementary study units was 2.0 young.

Productivity of goshawks also varied by year. Active nest sites discovered in the main study unit in 1994 were inactive in 1995 but were active and fledged young in 1996. Average productivity of active nests was 2.5 in 1994, nil (no active nests) in 1995, and 1.6 in 1996.

TABLE 3.1. Relative abundance, number of nests discovered, and productivity of goshawks by year and by landscape type on Vancouver Island.

A. Main Study Unit

Landscape Type	Goshawk relative abundance (detection/100 call stations) (n)				Nests found	Productivity
	1994	1995	1996	mean (n)		
Old Growth	3.50 (171)	0.48 (205)	1.88 (160)	1.9 (536)	5	2.3
Second Growth	1.05 (190)	0.33 (298)	0.00 (216)	0.4 (704)	2 ¹	2.0
Fragmented	0.00 (151)	0.50 (200)	2.03 (148)	0.8 (499)	3	0.33
All Landscapes	1.60 (512)	0.40 (703)	1.1 (524)	1.0 (1739)		
Nests found	4	0	6		10	
Productivity	2.5	0.0	1.60	2.0		

¹ One nest was found outside the main study area.

B. Supplementary Study Unit (1995 data only)

Landscape type	Goshawk relative abundance (detection/100 call stations) (n)			Nests found	Productivity
	Southern Vancouver Island	Central Vancouver Island	mean		
Old Growth	0.93 (215)	1.64 (61)	1.1 (276)	4	2.0
Second Growth	0.50 (220)	0.90 (108)	0.6 (328)	2	2.0
Fragmented	0.00 (161)	2.50 (80)	0.8 (241)	0	0.0
Average Detection	0.5 (596)	1.68 (249)	0.9 (845)		
Nests found	3	3		6	
Productivity (chicks/active nest)	2.0	2.0	2.0		

GOSHAWK DIET

Goshawks ate a total of 13 prey species, based on the analysis of 90 pellets (Table 3.2). All were birds, except for Townsend's vole (*Microtus townsendi*), an unidentified mammal, and red squirrel. The most important prey item was the red squirrel with a frequency of occurrence of 69%. Occurring half as frequently were the Steller's Jay, Varied Thrush and the Northern Flicker (*Colaptes auratus*) (Table 3.2). Marbled Murrelet (*Brachyramphus marmoratus*) occurred less frequently at 15% and

the remaining prey species occurred much less frequently in goshawk pellets, with \leq 8% frequency of occurrence.

Table 3.2. Estimated diet of goshawks on Vancouver Island in 1994-1995, based on pellet analysis.

	Species	Proportion of Diet (%) ^a		
		All landscapes*	Old Growth**	Second Growth***
Red Squirrel	<i>Tamiasciurus hudsonicus</i>	69	83	48
Varied Thrush	<i>Ixoreus naevius</i>	39	45	30
Steller's Jay	<i>Cyanocitta stelleri</i>	38	15	73
Northern Flicker	<i>Colaptes auratus</i>	34	48	13
Marbled Murrelet	<i>Brachyramphus marmoratus</i>	15	25	-
American Robin	<i>Turdus migratorius</i>	6	2	13
Band-tailed Pigeon	<i>Columba fasciata</i>	5	8	-
Gray Jay	<i>Perisoreus canadensis</i>	4	6	-
Barn Swallow	<i>Hirundo rustica</i>	2	3	-
Northern Pygmy Owl	<i>Glaucidium gnoma</i>	1	2	-
Swainson's Thrush	<i>Catharus ustulatus</i>	1	-	3
Western Wood Pewee	<i>Contopus sordidulus</i>	1	2	-
Townsend's Vole	<i>Microtus townsendi</i>	1	3	-
Unidentified Mammal		1	-	3

^a no pellets recovered from nests in Fragmented landscapes

* n = 90 pellets analyzed from 10 nests

** n = 55 pellets analyzed from 6 nests

*** n = 35 pellets analyzed from 4 nests

ABUNDANCE OF PREY

The relative abundance of prey was examined for the following four species that comprised the principal items in the goshawk diet: Red Squirrel, Varied Thrush, Steller's Jay, and Northern Flicker. These species showed variation in abundance according to landscape type and year (Tables 3.3 and 3.4).

Varied Thrush was more abundant in Old Growth than in Second Growth and it occurred more frequently in Old Growth diet than in Second Growth. These data

suggest that Varied Thrush was taken approximately in proportion to its abundance: landscape type did not appear to affect its rate of consumption. Northern Flicker was about equally common in both types but occurred more than four times as frequently in Old Growth diet than in Second Growth diet. These data suggest that goshawks were most successful in capturing flickers in Old Growth. Regarding Steller's Jay, it was half as abundant in Old Growth as in Second Growth but occurred far more frequently in Second Growth diets (15% vs. 73%). This suggests that goshawks were more successful in capturing Steller's Jays in Second Growth. Finally red squirrel was equally abundant in both landscape types, but it occurred more frequently in Old Growth diet than in Second Growth diet. These results suggest that goshawks were more adept at capturing red squirrels in Old Growth than in Second Growth.

Table 3.3 Relative abundance and selection of prey species in individual landscapes which contained active nest sites (main and supplementary study units).

Species	Landscape			
	Old Growth (n=6)		Second Growth (n=4)	
	Relative abundance*	Availability**	Relative abundance*	Availability**
Red Squirrel	7.2	30.6	8.1	5.8
Varied Thrush	31.0	0.5	24.4	1.5
Steller's Jay	11.4	2.1	7.2	15.8
Northern Flicker	5.5	7.8	4.3	3.9

* Relative abundance is the mean associated with measures from landscapes which contained nest sites.

** Availability is the \sum (% prey species in pellet at a nest/associated prey species relative abundance at associated landscape)/ number of nests.

Table 3.4. Mean relative abundance of key prey species on the main study unit, 1994-95.

Species	Relative Abundance (mean \pm s.e)			p-value
	1994 (n = 113)	1995 (n = 703)	1996 (n = 524)	
Red Squirrel	16.8 \pm 3.5	0.1 \pm 0.1	9.7 \pm 1.3	<0.05
Varied Thrush	43.4 \pm 4.7	<u>26.7 \pm 1.7</u>	<u>22.1 \pm 1.8</u>	<0.05
Steller's Jay	10.6 \pm 2.9	12.2 \pm 1.2	16 \pm 1.6	ns
Northern Flicker	1.8 \pm 1.2	2.8 \pm 0.6	3.6 \pm 0.8	ns

^a P values are for ANOVA. Underlined values were not significant in Tukey's unequal N test.

Table 3.5. Comparison of goshawk and prey species relative abundance between main study unit and supplementary study unit, 1995.

Species	Relative Abundance		p-value*
	Main study area (n = 703)	Supplementary area (n = 845)	
Northern Goshawk	0.4	0.7	0.0109
Red Squirrel	0.1	2.2	0.0002
Varied Thrush	26.7	20.8	0.0058
Steller's Jay	12.2	11.0	0.5386
Northern Flicker	2.8	4.0	0.1983

*t-test for independent samples

GOSHAWK ABUNDANCE AND THE IMPORTANCE OF RED SQUIRREL

Although red squirrel was not the most abundant prey species detected at call stations it was the commonest remains found in pellets; this suggests a strong propensity for eating red squirrel over other prey items (Table 3.2). The squirrel component of goshawk diet was much higher in 1994 and 1996 than in 1995. In 1995 goshawks had higher proportions of other prey suggesting that these other species provided a buffer when squirrel populations were low (Figure 3.2)

Goshawk abundance was strongly but not significantly correlated with red squirrels (Fig. 3.3), while goshawk productivity was significantly correlated with red squirrel abundance (Fig. 3.4). As the abundance of red squirrels in a landscape increased so did average productivity at a nest/landscape (1994-1996). Because there is only one species of squirrel on Vancouver Island and no lagomorphs, the importance of red squirrel to the diet of this population of goshawks appears to be enhanced.

Red squirrels in coniferous forests are highly dependent on the annual cone crop as a food source (Kemp and Keith 1970; Obbard 1986). I used two data sets to assess annual variation in cone crops to discover if they explained the variation in abundance of squirrels by year (Table 3.4). One set was a measure of seeds per gram of cone collected by cone collectors for nursery trees for the Ministry of Forests. These data came from the Ministry's cone crop database. The cone crop as measured by number of seeds per gram of cone harvested was highest in 1994, dropped by more than 55% in 1995 and surpassed 1994 levels by 10% in 1996 (Fig. 3.5). The other set was abundance measures that I made for Red Crossbills. Since Red Crossbills feed entirely on the seeds of conifer trees (Newton 1972; Benkman 1993), I used their abundance as a surrogate to conifer seed abundance. Red Crossbills were at their highest level in 1994, dropped by 62% in 1995 and then recovered in 1996 (Fig 3.5).

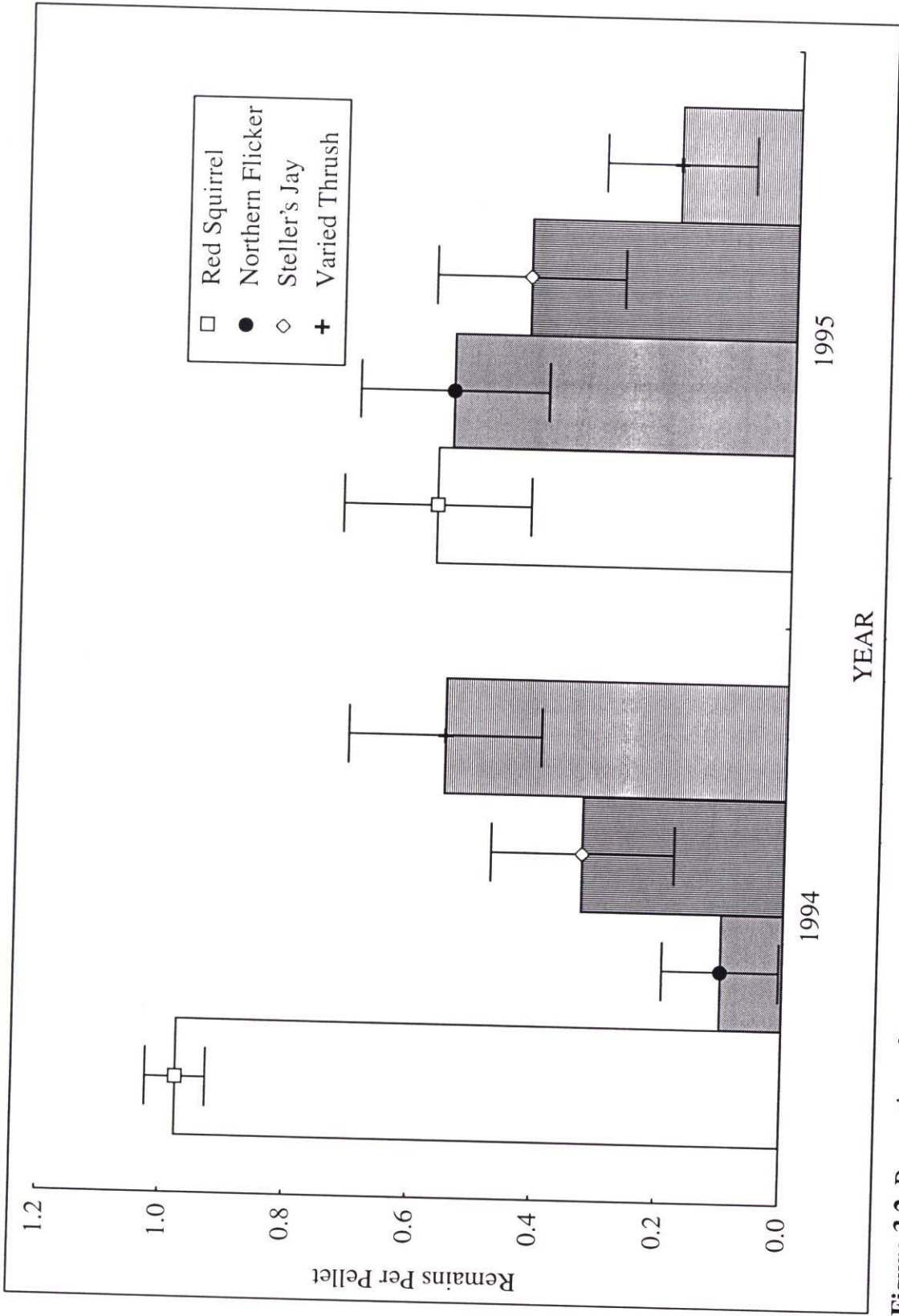


Figure 3.2. Proportion of prey items per pellet in 1994 and 1995.

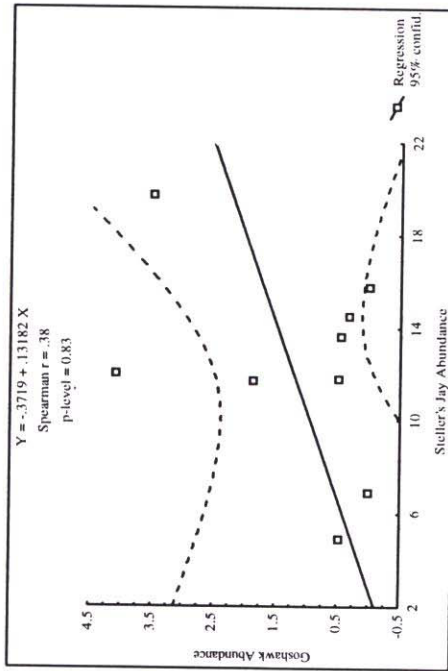
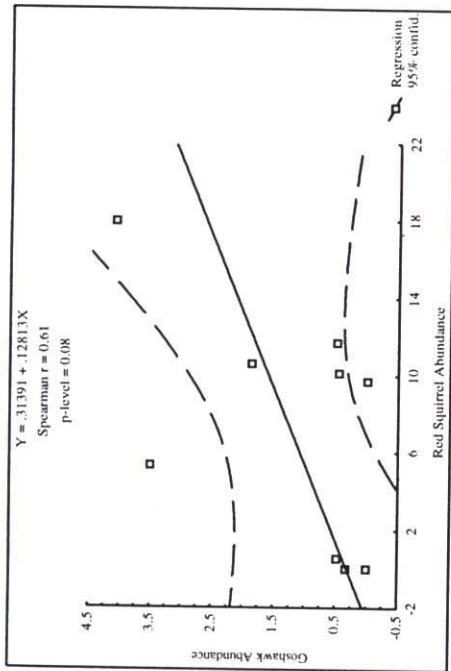
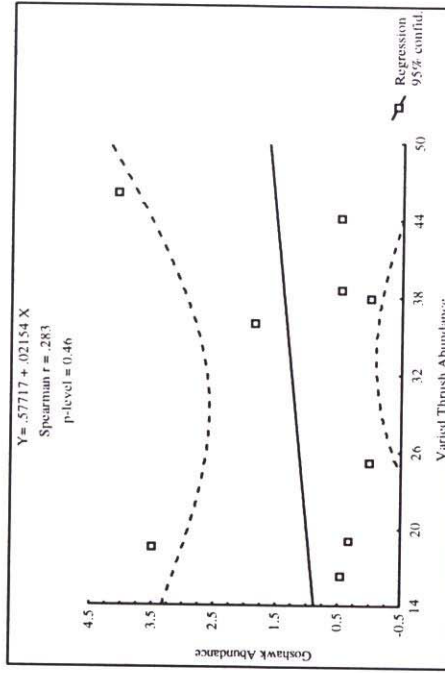
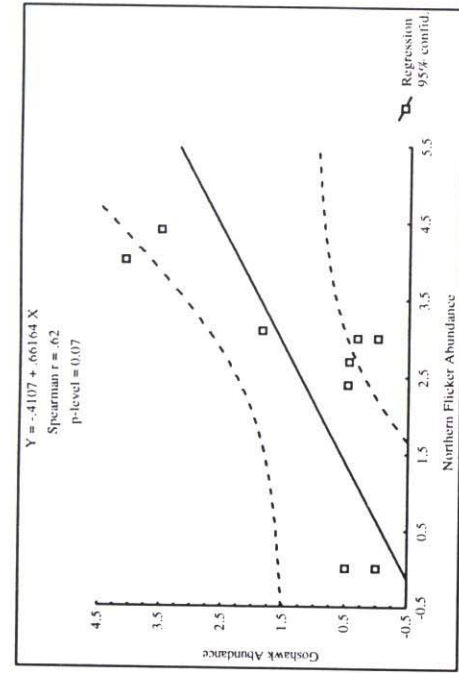


Figure 3.3. Correlation of goshawk abundance with key prey species (pooled across years and landscapes)

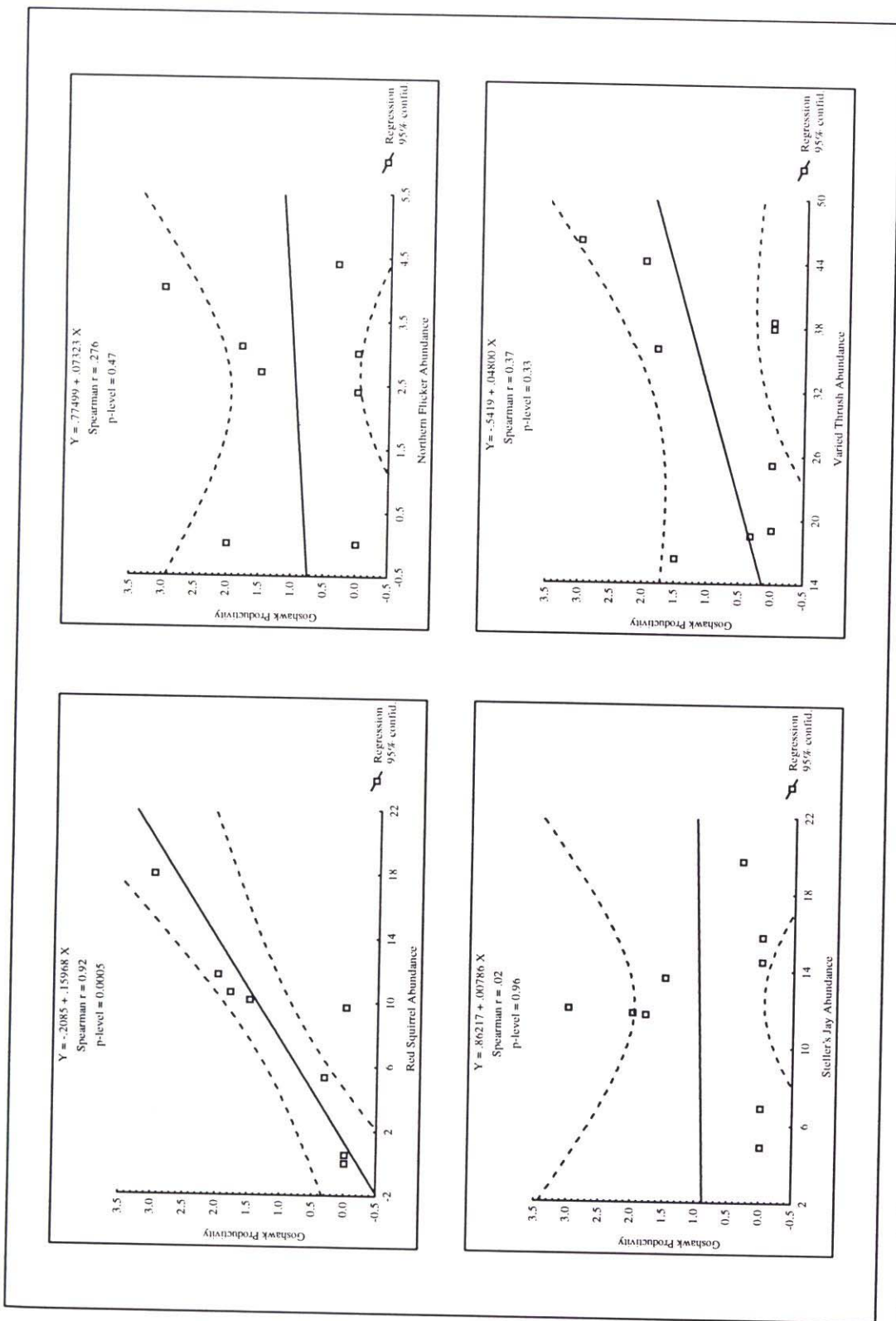


Figure 3.4. Correlation of goshawk productivity with key prey species (pooled across years and landscapes).

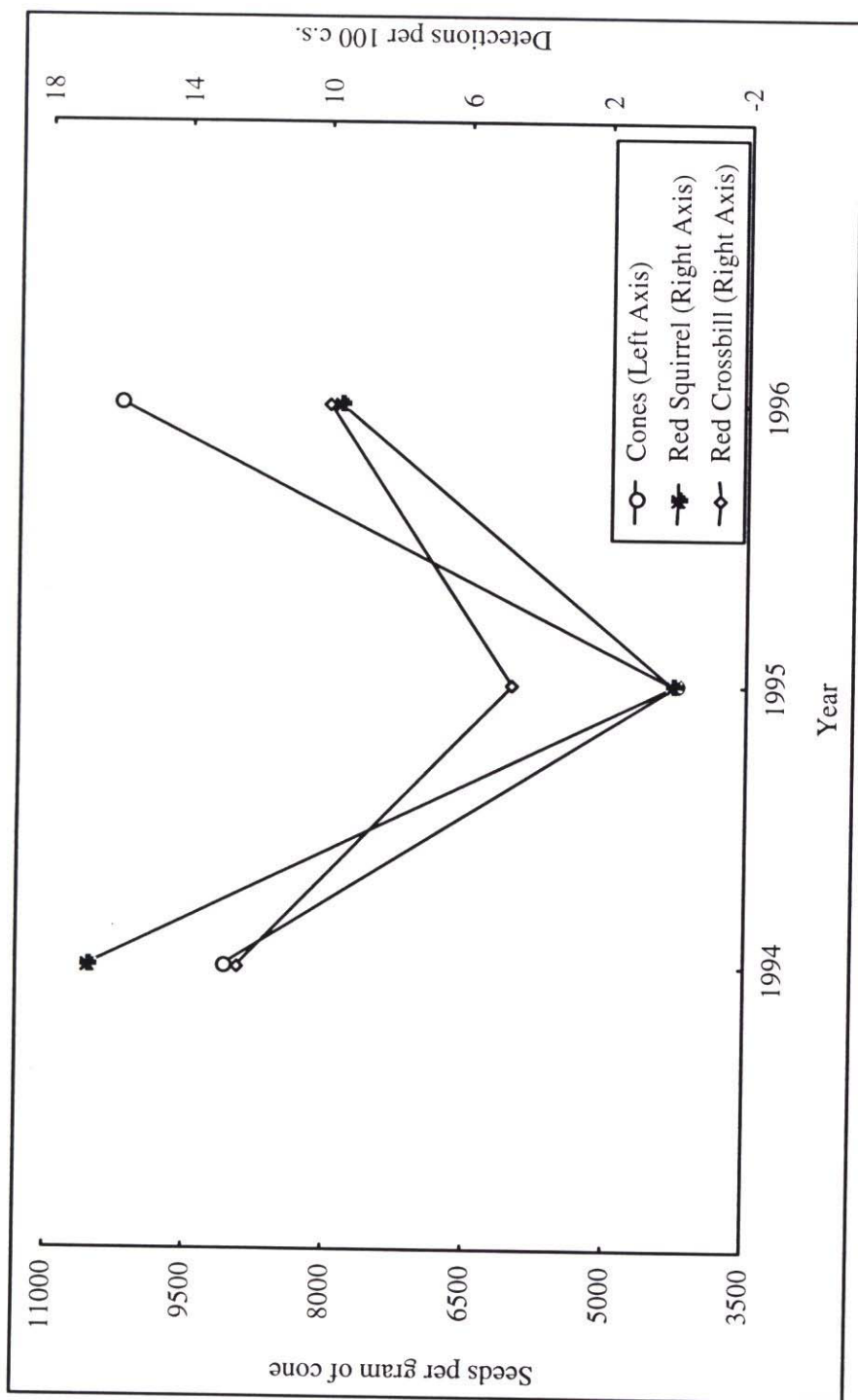


Figure 3.5. Abundance of red squirrels and red crossbills and seeds per gram of cone.

DISCUSSION

GOSHAWK AND PREY RESPONSES AT THE LANDSCAPE LEVEL

The main finding of this study is that goshawk abundance and productivity are influenced by landscape type and red squirrel availability. After three survey seasons goshawks and their nest sites were found to be most abundant in Old Growth when compared with Second Growth and Fragmented forested landscapes. After three seasons of nest monitoring, productivity per nest was similar between Old Growth and Second Growth but significantly lower in Fragmented. Red squirrel, the most important goshawk prey item, was equally abundant in Second Growth and Old Growth but was dramatically lower in abundance in Fragmented. Correlation of goshawk abundance and productivity with red squirrel abundance revealed strong positive correlations (Figs. 3.3 and 3.4). Other studies have also identified the red squirrel as an important goshawk prey item (Schnell 1958; Grzybowski and Eaton 1976; Boal and Mannan 1994). However, with the relatively limited prey base of Vancouver Island, the importance of red squirrel was enhanced. Selection of squirrels and Northern Flickers by goshawks was higher in Old Growth when compared with Second Growth. The apparently greater hunting success and ultimately fitness in Old Growth may be due to unique adaptations of this island raptor to mature forest conditions.

Accipiter morphology is well suited to pursue prey in forested environments (Brown and Amadon 1968; Johnsgard 1990; Reynolds et al 1992; Whaley and White

1994; Squires and Reynolds 1997). Wattel (1973) noted that where accipiter species and subspecies occupied dense forest, short rounded wings were favoured for maneuverability. Mueller et al. (1981) explained how a relatively long tail enhances navigation. Anderson and Norberg (1981) stated that for hawks in general, a reduced body mass would improve flight agility. The subspecies of goshawk on Vancouver Island, *A.g. laingi*, is the smallest in North America yet has relatively the most rounded wings and longest tail (Whaley and White 1994). Whaley and White (1994) speculate that these combined morphological traits provide *A.g. laingi* with an enhanced agility for hunting and penetrating through the comparatively dense forests of Vancouver Island.

Complementing this specialized morphology, goshawks have evolved a hunting strategy well suited for forested environments (Widen 1997; Schaffer 1998). A hunting goshawk will move with stealth through the lower forest canopy, flying from perch to perch scanning for prey on the forest floor or in the shrub canopy. From its perches, where it is well camouflaged due to perch position and feather patterning, it can launch attacks on unsuspecting prey.

Very little information exists on the specific hunting behaviour of Vancouver Island goshawks. However Beebe (1992), an experienced falconer, reports that *A.g. laingi* from Vancouver Island is the most “irascible and difficult goshawk.....(with) some kind of inherent fear of open land and (they) tend to bury themselves in deep woods at every opportunity. Yet they seem to me to be the swiftest of goshawks and certainly the quickest to get going” (Beebe 1992: 276).

Thus the morphology and behaviour of goshawks influence their access to prey and this can directly influence productivity. For example, red squirrels were similarly abundant in Old Growth and Second Growth, yet goshawk abundance was noticeably different. The Second Growth may have reduced goshawk access to prey, perhaps because it provides an environment that is structurally poor for the fly-perch-hunt strategy of goshawks, e.g. a high density of tree stems may obscure flight lines and lower hunt success.

Very little work has been done on the habitat structure associated with goshawk hunting sites (Squires and Reynolds 1997). Beier and Drennan (1997) contrasted apparent kill sites with other sites and found that these sites were not selected based on abundance of potential prey but rather on habitat characteristics. Kill locations were characterized by having a greater density of trees with a diameter at breast height > 41 cm. Other data from the Yukon (Doyle and Smith 1994) documented that 33% of goshawk kills were in mature dense forests even though this habitat was represented in only 18 % of the study area. Bright-Smith and Mannan (1994) found that goshawk foraging habitat consisted of greater canopy closure, a measure often associated with a more mature forest. Using radio telemetry, Austin (1993) found generally that old growth habitat (> 52 cm dbh, canopy closure $>40\%$) was preferred and that open meadows and clearings were avoided.

DeStefano and McCloskey (1997) surveyed for goshawks in the coast range of Oregon and did not find the species where general forest conditions reduced prey accessibility. All of the typical prey species were abundant, yet the dense understory

of the forests was thought to reduce goshawk hunting success. The coast range of Oregon has been heavily logged over the past 150 years and what now remains are stands of “second-growth trees with older stands occurring as islands, fragmented by clearcut logging” (DeStefano and McCloskey 1997: 35).

However the survey methodology that I used may bias these results since it was designed to detect breeding goshawks that are on territory. That there were fewer goshawk detections in Second Growth may be a reflection of fewer suitable nest sites and/or nest trees rather than reflecting prey availability.

Goshawks were reasonably abundant in Fragmented forests but had fewer nests and poorer productivity. The relatively high abundance in the Fragmented landscape in Central Vancouver Island (1995) and the Main study area (1996) may be due to a bias in survey effort which focused on suitable nest stands. These stands were obvious to survey because their size and height contrasted so obviously with the surrounding early seral landscape. This result, however, could also be evidence that these landscapes are suitable for adult survival but not for reproduction.

Of the three located nests, only one nest was successful, fledging only one young. All three nests were in remnant patches of old growth within a matrix of very young conifers. These patches are probably suitable for nest establishment, yet they may be vulnerable to an increased predation risk or have lower available prey within the home range. Red squirrels were least abundant in the fragmented landscapes which may explain the reduced relative abundance, number of nests and poorer productivity of goshawks in this landscape type.

Red squirrels eat conifer seeds (Obbard 1986). Cone crop production varies spatially depending on the age and extent of forest cover (Benkman 1993). Conifer trees do not begin producing seeds until they are about 20 to 30 years of age (Fowells 1965). Thus in recently logged areas, such as the majority of the fragmented landscape, the seed production will be zero for at least twenty years. Even after reaching sexual maturity, conifers do not start producing large cone crops until much later. Burns and Honkala (1990) showed that an old growth stand of Douglas-fir produces 20 to 30 times more cones than a 50 to 100 year old stand. Maximum cone production for some conifers like the Douglas-fir is not reached until the tree is 200 years of age (Fowells 1965). Thus, fewer mature trees and a lower cone production may explain the relatively low abundance of red squirrels in fragmented landscape and hence its lower suitability as goshawk habitat.

ANNUAL VARIATION OF GOSHAWKS AND THEIR PREY

The secondary finding of this study was that goshawk abundance on the main study unit varied among years: 1994 and 1996 had significantly higher numbers of detections of goshawks than in 1995. Red squirrels followed a similar pattern and were nearly undetected in all landscapes in 1995. Occupancy rates of nest sites also fluctuated. The four nests found in 1994 were inactive in 1995, yet all four were active in 1996. Six additional nests were found in 1996. Nest success (percentage of active nests that fledged young) was 100% in 1994 and 67% in 1996. These data may overestimate success: most nests fail early in the breeding season before or soon after

laying (Widen 1985), and most of the nests I found were after hatching. Average number of young per successful nest in 1994 was 2.5 (N=4) and 2.1 in 1996 (N = 8). Two nests failed in 1996.

Differences in the annual reproductive performance of goshawks have been explained in other studies because of fluctuating prey density and severe weather events (Huhtala 1976; Penteriani 1997; Squires and Reynolds 1997; Kennedy 1997; Widen 1997). Adequate food appears critical during the winter for females to put on sufficient body fat reserves for the incubating and nestling period (Newton 1979). Newton (1986) documented that Sparrowhawk (*Accipiter nisus*) females did not breed if they had not increased their body mass prior to breeding. If red squirrels are the key prey for goshawks in winter, and the poor cone crop meant poor survival of squirrels, then this may explain why goshawks did not breed in the main study unit in 1995.

Red squirrel abundance varies markedly among years in response to conifer seed abundance (Smith 1968). Another conifer seed eater is the Red Crossbill. In years when cone crops fail, crossbills move to other areas that have cone crops (Benkman 1993). I documented annual variation in crossbill abundance (Figure 3.5) with highest abundance in 1994, least abundance in 1995, and a recovery in 1996; a similar pattern to the red squirrel. According to the British Columbia Forest Service, 1995 was a poor year to collect cones for reforestation because of a relatively poor seed production (Figure 3.5). This pattern of number of seeds per gram of cones collected is reflected in the relative abundance of red crossbills, red squirrels, and northern goshawks. Thus on Vancouver Island goshawk reproduction appears partly

dependent on cone production since it drives the abundance of its most important prey species, the red squirrel.

Results from the supplementary study unit suggests that the three other important prey items, Steller's Jay, Varied Thrush, and Northern Flicker, can provide a buffer when red squirrel numbers decline (Figure 3.2). A complete dependence upon one prey species could jeopardize a raptor population if that prey species declined (Boal and Mannan 1994; Newton 1979). The near total crash of red squirrel on the main study unit in 1995 suggest that goshawks are very dependent on squirrels. Squirrels were significantly more abundant on the supplementary study units than the main study unit in that year. However mean detection rate was only 2.2 per 100 call stations which was very low compared to the abundance measures obtained in 1994 and 1996 on the main study unit. Data from pellet analysis suggest that goshawks in the supplementary study units relied more heavily on the other prey species during the low in red squirrels (Fig 3.2). However these data are not conclusive since these are different nests being compared and the results could be attributed to different individuals and habitat. Long term studies of goshawk diet and abundance of prey populations in different landscapes are required to resolve this issue.

CHAPTER 4

NESTING HABITAT SELECTION OF NORTHERN GOSHAWKS ON VANCOUVER ISLAND

INTRODUCTION

For successful reproduction, birds require many resources such as a sufficient and accessible prey base, security from predators and competitors, a suitable microclimate for the nest and a secure nest location (Gill 1990). By selecting these (and other) resources, breeding birds distribute themselves throughout the environment. The success of these choices is manifested by reproductive output. Since these resources occur at different spatial scales from small (e.g. nest site) to broad (e.g. breeding home range) (Johnson 1980), choices made at a larger scale affect choices available at finer scales.

The current conservation concern for goshawks has advanced understanding of its breeding habitat. Early work by McGowan (1975) and Hayward and Escano (1989) characterized the vegetation and topography in the immediate area of the nest. As conservation concerns grew it became important to examine the nesting habitat (Speiser and Bosakowski 1987; Crocker-Bedford and Chaney 1988; Squires and Ruggiero 1996; Schaffer 1998). Typically these studies compared areas within goshawk nesting habitat with similar but presumably unused areas nearby. The types

of areas have included the nest tree (Squires and Ruggiero 1996; Schaffer 1998), the nest site (typically 0.04 ha) (Speiser and Bosakowski 1987; Crocker-Bedford and Chaney 1988; Kimmel 1995; Squires and Ruggiero 1996; Schaffer 1998), the nest stand (Squires and Ruggiero 1996), and the macrohabitat level (Bosakowski and Speiser 1994). However, none of these studies have examined goshawk nest selection within the context of a hierarchical system (Chapter 2).

The objective of this chapter is to analyze the selection of nesting habitat by goshawks at four levels within the conceptual hierarchy: nest tree, nest site, nest territory, and foraging area.

METHODS

Squires and Reynolds (1997) caution that much of the literature on goshawk nest selection may be biased because studies are based on unrepresentative samples of nest sites due to biased search techniques. Most goshawk nest site selection studies have used nest sites that were found opportunistically from sources such as naturalists and falconers (Hennesy 1978; Schaffer 1998), and field work associated with forest development layout (Hayward and Escano 1989; Crocker-Bedford 1990a). Other studies have used the call playback technique but have focused their effort in areas of assumed high goshawk suitability (Squires and Ruggiero 1996). I attempted to control for these biases in two ways. First, I had relatively equal search effort in second-growth forest, fragmented forest, and old-growth forest. Second, each forest landscape was surveyed systematically except for clearcuts and recent regrowth sites

(< 20 cm dbh) which were excluded from sampling because current literature demonstrates that goshawks do not nest in these areas.

Nesting areas were located primarily by the call playback method described by Kennedy and Stahleker (1993). I also used stand watches which consisted of passive watching of a hillside.

To assess selection within the habitat hierarchy, I compared the variables of one level with similar variables available at the next higher level. Selection was determined by comparing use in one level with what was available in the next higher level in the hierarchy. Nest tree selection was contrasted with tree availability in the nest site; nest site selection was contrasted with a number of variables available at the nest territory level; nest territory was contrasted with unoccupied random areas within the surveyed landscapes; and landscape patterns of foraging areas were contrasted with landscape patterns found surrounding unoccupied sites. The choice of variables measured at each level was based on those addressed in the literature and my own judgment.

NEST TREE SELECTION

I examined selection of the nest tree by comparing species and size of nest trees with available trees in the immediate nest site area (0.04 ha). I tested species selection using a chi-square and the Bonferonni adjusted simultaneous confidence interval (Neu et al. 1974; Byers and Steinhorst 1984). I analyzed size selection by comparing the average dbh of nest trees with the pooled average dbh of trees at the

nest site. To test for differences between these diameters I used the Mann Whitney U Test.

NEST SITE SELECTION

To investigate nest site selection within the hierarchy, I compared a number of variables collected at the nest site (0.04 ha) with the average of these variables from three other sites (0.04 ha) from within the nest territory. These other sites were selected by taking a random bearing at the nest site and measuring 100 m to a sample site. This process was repeated two more times until I reached the conceptual extent of the territory (300 m radius from the nest tree).

Each sample plot was a 0.04 ha (radius = 11.28 m) radius area centred on the nearest tree (>20 cm dbh). I measured the following variables within the sample plot:

1. Aspect - using a compass
2. Elevation - using an altimeter
3. Slope - using a clinometer
4. Tree Composition and Structure: I measured the dbh of all trees > 10 cm, and classified each tree by species and vigor according to a senescence scale (Resources Inventory Committee 1994). These variables were entered for analysis as average dbh, tree density per 0.04 ha, tree density per size class (10-20 cm, 21-40 cm, 41-60 cm, >61 cm), average of tree senescence, and proportion of species represented in the plot.

5. Overstory Cover: Six transects, 15 m in length radiated out systematically at intervals of 60° from the nest tree and centre trees. I measured canopy at five, ten, and fifteen metres along the transect. I scored the canopy cover using the ocular tube method of James and Shugart (1970). These data were entered into analysis in two ways: 1) as an average canopy closure for the site; and 2) as an average pooled at each interval, i.e., an average at 5 m, 10 m, and 15 m. The latter mean was used to investigate canopy heterogeneity within the site.
6. Understory Cover: I described understory cover using the line intercept method (Cox 1980). I used three, 11.28 m transects radiating from the plot centre at equal intervals of 120° . I recorded the extent (cm) that the line intercepted the individual plant for all species of mosses, herbs, and shrubs. For each of these plant categories I averaged the percent cover at each site. I pooled these averages within the respective categories (Nest site, Nest Territory, and Unoccupied Area) and then used the Mann Whitney U test to compare among categories.
7. Coarse Woody Debris (CWD): Coarse woody debris is wood litter > 10 cm dbh that is no longer associated with a living tree. It can be a large branch or an entire tree. I sampled CWD on two 24 m transects radiating from the plot centre at right angles to each other. I scored each piece of CWD relative to a standardized class of decay of one through five (Resources Inventory Committee 1998), categorized the piece to either

greater than 3 m or less than 3 m, and measured the diameter at the point of intersection perpendicular to the tree axis. I analyzed these data by examining the average number of pieces in two classes < 3 m and > 3 m. I used the Mann Whitney U test to compare variables between these two categories as data were likely non-normal (Devore 1987).

NEST TERRITORY SELECTION

To characterize this area, I sampled the nest site and then randomly sampled three other areas within the 28 ha territory at 100 m intervals up to 300 m from the nest tree or stand centre. Data for these plots and the nest site were pooled and averaged and these were used as the data that described the territory. Unoccupied reference areas (available areas) were centred on stations that I surveyed in the 1994 and 1995 breeding season where no goshawks were detected. I described 19 unoccupied areas, seven in old-growth forests, six in second-growth forests, and six in fragmented landscapes. I used the Mann Whitney U test to compare variables between these two categories.

FORAGING AREA

To characterize foraging area I collected variables from 1:20 000 forest inventory maps created by the forest licensees on my study areas. I collected variables that have been identified in other North American studies as affecting goshawk nest sites through the foraging area: size of continuous forest containing the

nest (patch size), distance from nest to river, distance from nest to lake, distance from nest to logging road, and distance from nest to clearcuts < 20 years but > 10 ha. I contrasted the occupied sites with the unoccupied sites using a Mann Whitney U test. Significant differences between these features strongly suggest that goshawks are either selecting or avoiding these landscape attributes.

RESULTS

NEST TREE SELECTION WITHIN THE NEST SITE

A total of 16 goshawk nest areas were discovered in this study. Of these 16 nest sites, 13 nests were discovered using the call playback method, one from standwatches, one from a forest technician, and one from a park ranger.

All nests were in coniferous trees either Douglas-fir (11) or Western Hemlock (5). Goshawks chose Douglas-fir significantly more often than expected while Western Hemlock was chosen significantly less than expected (Bonferroni confidence interval at $\alpha = 0.05$) (Figure 4.1). No nests were found in other tree species such as Western redcedar or Amabilis fir even though large specimens of these species were present.

Regarding size of nest trees, goshawks strongly selected the larger tree in the nest site. Nest tree averaged 89% larger DBH than the mean diameter of trees in the nest site (79 ± 4.4 cm versus 43 ± 2.7 cm) ($p = 0.000036$, Mann Whitney U Test).

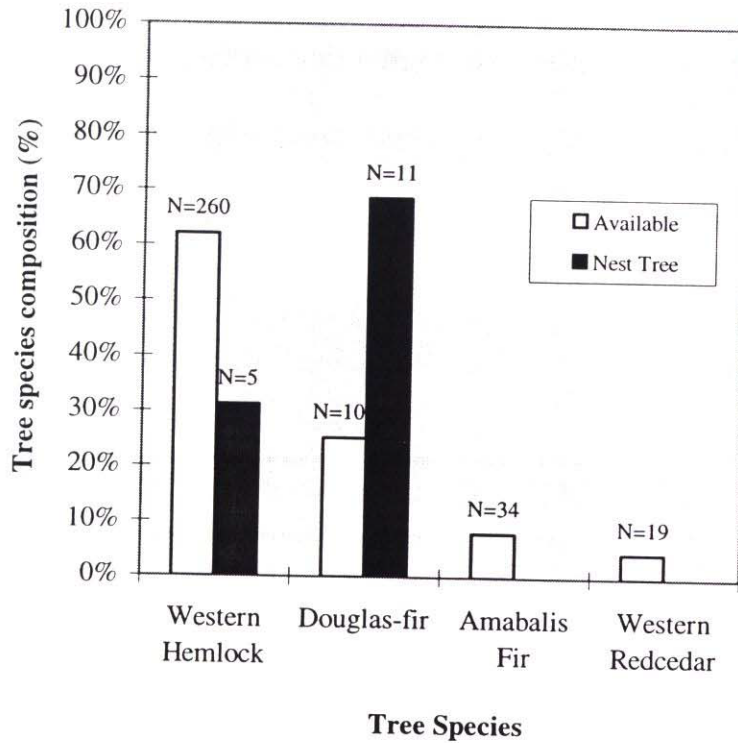


Figure 4.1. Tree species composition at the nest site compared with species used for the nest tree by Northern Goshawks on Vancouver Island.

NEST SITE SELECTION WITHIN THE NEST TERRITORY

Goshawks preferred nest sites with more larger trees and fewer smaller trees when contrasted with what was available within the nest territory (Table 4.1). While nest sites had the relatively same overall tree density (26 vs 33 stems per 0.04 ha), nest sites had fewer smaller diameter trees (8 vs. 15 stems per 0.04 ha) than the

average for the territory. Nest sites tended to have more larger diameter trees (40-60 and >60 cm dbh size classes), but not significantly so ($p = 0.097$). While many studies have reported the openness of the understory for goshawk nest sites, my results showed little difference for these attributes when compared with the territory in general. Goshawks showed no statistically significant selection for elevation or slope differences within the territory.

Table 4.1. Selected attributes of nest sites used by goshawks compared with those of randomly selected unoccupied sites within the nest territory on Vancouver Island, 1994-1996.

Variable	Occupied nest site (n=16)		Unoccupied nest site (n=16)		p-value
	mean \pm se	range	mean \pm se	range	
<i>Site Attributes</i>					
slope (deg)	33 \pm 5	0.0 - 63	34 \pm 5	0 - 72	0.924
elevation (m)	362 \pm 42	150 - 650	356 \pm 41	123 - 613	0.895
<i>Understory Attributes</i>					
shrub cover (%)	53 \pm 9	7.2 - 133	47 \pm 6	18 - 88	0.821
herb cover (%)	21 \pm 8	0.0 - 98.0	23 \pm 9	0 - 144	0.497
moss cover (%)	141 \pm 21	1.2 - 277	109 \pm 17	10 - 213	0.327
CWD >3 m	6.7 \pm 1.2	1.0 - 19.8	8.5 \pm 2.7	3 - 13.5	0.050
CWD <3 m	5.5 \pm 1.1	0.0 - 13.3	5.6 \pm 0.8	1.8 - 13.4	0.734
<i>Overstory Attributes</i>					
tree dbh (cm)	43.2 \pm 3.1	24.6 - 71.9	33.2 \pm 1.9	24.5 - 47.3	0.018
total trees	26 \pm 2.8	11 - 54	33 \pm 18	10 - 85	0.327
basal area	1083 \pm 119	550 - 2552	982 \pm 85	448 - 1884	0.651
canopy cover (%)	50 \pm 3.2	19 - 78	49 \pm 3	20 - 71	0.909
<i>Tree density (trees/0.04 ha)</i>					
10-20 cm	8 \pm 1.8	1-23	15 \pm 3	5 - 61	0.014
20-40 cm	8 \pm 1.5	0-25	11 \pm 1.6	3 - 24	0.365
40-60 cm	5 \pm 1.3	0-16	3 \pm 1	1 - 6	0.097
>60 cm	4 \pm 0.7	0-9	3 \pm 0.5	0 - 7	0.146
snags	4 \pm 0.6	0-8	5 \pm 0.8	1 - 11	0.924

The pattern of canopy closure centred on the nest tree demonstrated significant heterogeneity within the site compared with the random sites. (Fig 4.2)

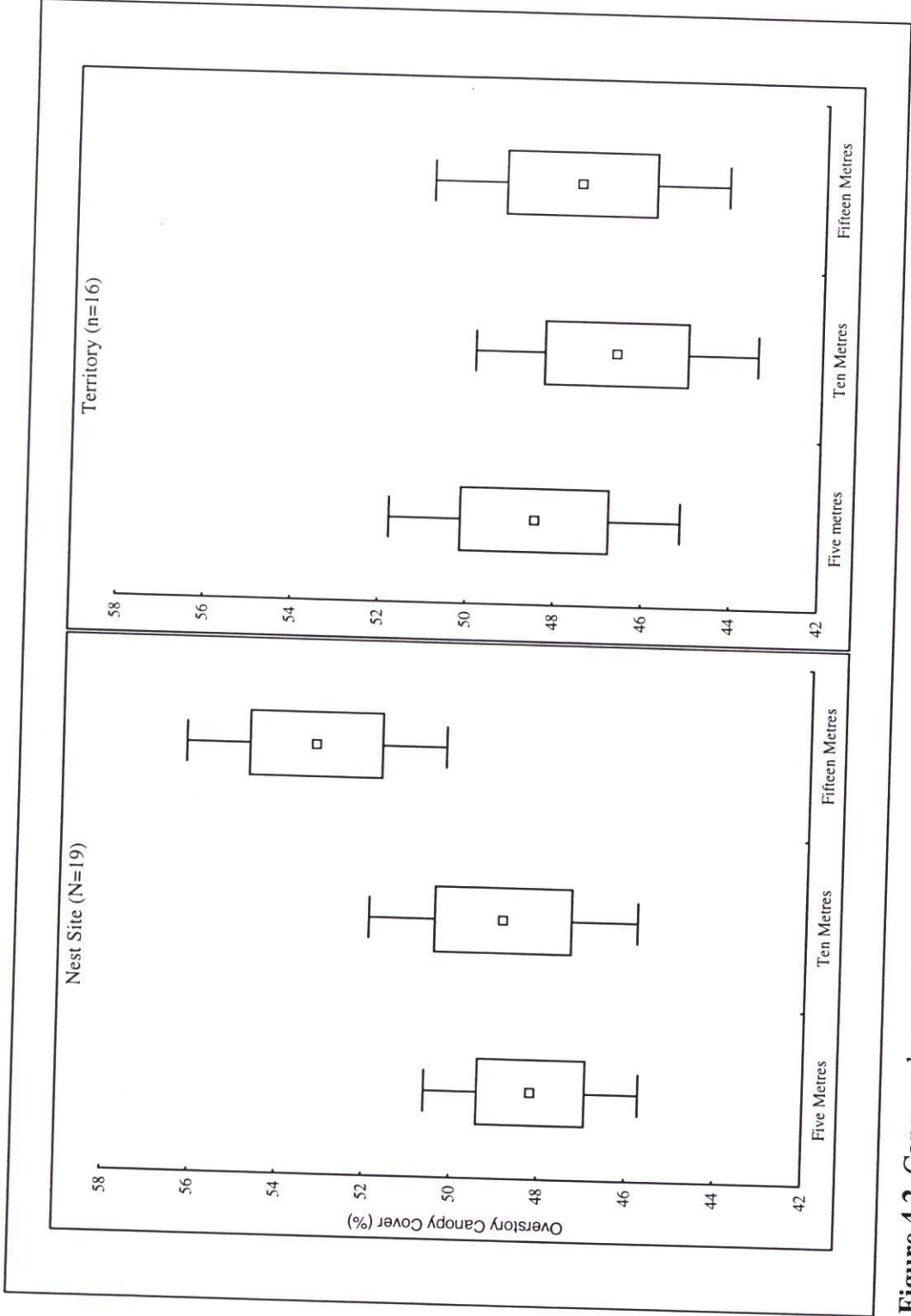


Figure 4.2. Canopy closure pattern around the nest tree and canopy closure pattern found around trees within the nest territory.

NEST TERRITORY SELECTION WITHIN THE BREEDING HOME RANGE

Goshawks demonstrated little preference for variables measured at the level of territory (Table 4.2). Slope, elevation, and aspect showed little difference between nesting territories and randomly selected stands. Canopy closure was significantly less at territories when contrasted with unoccupied stands: goshawks chose sites that were more open. This difference was also reflected in the pattern of tree distribution which showed a spatial pattern of low tree density and high dbh at the nest site. This pattern was not found in the random stands where a uniform pattern was found (Figure 4.3). Territories had a greater, though non-significant, volume of small coarse woody debris than random stands.

TABLE 4.2. Selected attributes of nest territories used by goshawks compared with randomly selected unoccupied areas on Vancouver Island, 1994-1996.

Variable	Nest territory (n=16)		Unoccupied stand (n=19)		p-value
	mean \pm se	range	mean \pm se	range	
<i>Site Attributes</i>					
slope (degrees)	34 \pm 5	0 - 61	31 \pm 3	10 - 56	0.596
elevation (m)	358 \pm 41	132 - 322	339 \pm 39	89 - 662	0.753
aspect (degrees)	290 \pm 21		289 \pm 21		0.380
<i>Understory Attributes</i>					
shrub cover (%)	48 \pm 6	17 - 84	38 \pm 24	7 - 96	0.260
CWD >3 m (no.)	8.1 \pm 0.7	3.2 - 14.5	8.8 \pm 1.0	3.4 - 20.6	0.778
CWD <3 m (no.)	5.6 \pm 0.7	1.4 - 12.3	4.3 \pm 0.5	1.7-11.9	0.104
<i>Overstory Attributes</i>					
tree dbh (cm)	35.7 \pm 2.0	24.6 -53.4	40.3 \pm 3.5	20.5 -89.1	0.487
total trees (no.)	31 \pm 3	11 - 72	32 \pm 3	17 - 58	0.327
canopy cover (%)	49 \pm 3	29 - 69	59 \pm 3	27 - 80	0.011
<i>No. Trees/0.04 ha</i>					
10-20 cm	11 \pm 2	4.5 - 31.3	12 \pm 3	1.3 - 32.7	0.894
21-40 cm	12 \pm 2	4.5 - 31.3	12 \pm 2	4.0 - 21.3	0.816
41-60 cm	4 \pm 1	0.5 - 10.17	4 \pm 0.5	1.3-9.8	0.436
>60 cm	4 \pm 0.5	1.2 - 6.8	5 \pm 1	0.35-15.3	0.791
snags	5 \pm 0.7	0.7 -9.0	4 \pm 0.3	1.7-7.0	0.380

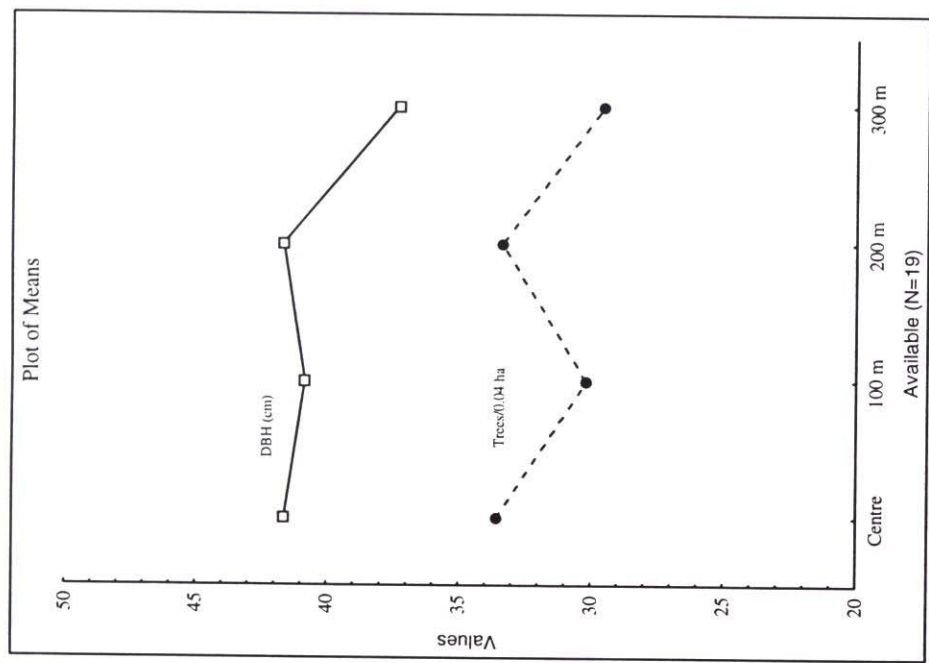
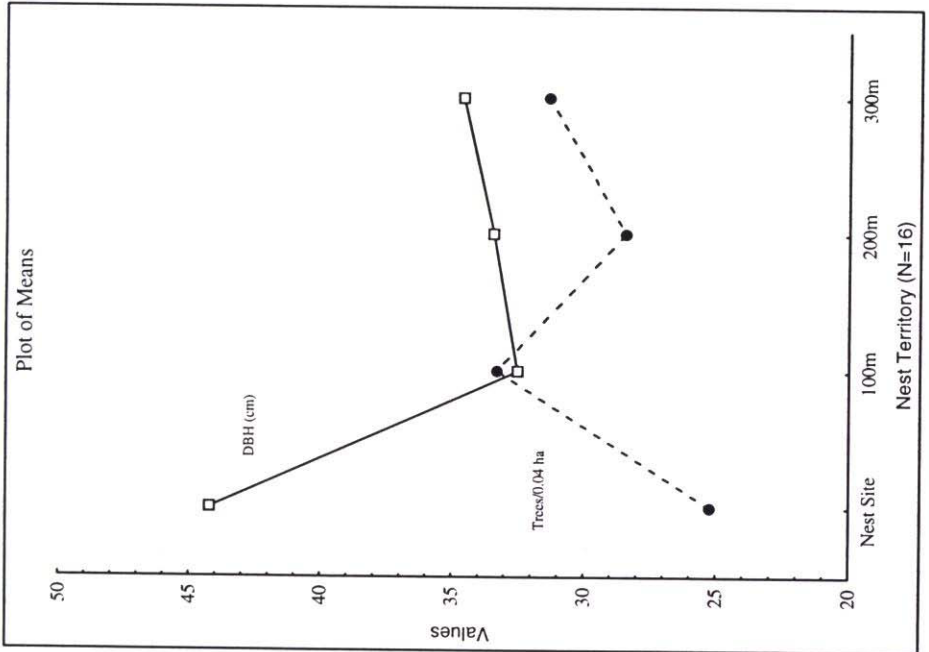


Figure 4.3. Pattern of average diameter at breast height and tree density at the nest territory and the contrast areas.

FORAGING AREA SELECTION

Goshawks selected sites for nesting which were significantly further from young clearcuts and roads than were unoccupied sites (Table 4.3). The average distance to a clearing from nest stands was 1350 m compared to 770 m from unoccupied stands ($p=0.011$). Nest sites were an average of 730 m from a road while unoccupied stands were 74% closer at 265 m. Unlike other studies, no differences were detected for size of patch, nor for distance to a river or a lake.

TABLE 4.3. Selected landscape variables for nest stands used by goshawk compared with randomly selected unoccupied stands.

Variable	Nest (n=16)		Unoccupied (n=19)		p-value
	mean \pm se	range	mean \pm se	range	
Patch size (ha)	1755 \pm 167	10 - 2000	1575 \pm 172	24 -2000	0.393
Distance to river (m)	480 \pm 70	100 -1000	570 \pm 111	100 -1900	0.907
Distance to lake (m)	1730 \pm 350	100 -4800	1835 \pm 381	200 -4000	0.842
Distance to clearing (m)	1345 \pm 193	320 -2500	765 \pm 189	80 -2600	0.011
Distance to road (m)	730 \pm 128	280 -2200	265 \pm 52	40-1100	0.00004

DISCUSSION

NEST TREE SELECTION

Goshawks selected nest trees with a mean diameter greater than trees in the nest site or in the nest territory. Other workers have reported similar results (Moore and Henny 1983; Squires and Ruggiero 1996). In Wyoming, Squires and Ruggiero (1996) found goshawks chose the largest tree (mean = 31.6 cm, range 17.0-50.5 cm) from those available (mean = 23.3 cm, range 2.5 - 45.7cm). Saunders (1982) reported

that the average diameter of nest trees (mean = 74.2 cm, range 43.7-121.9 cm) was greater than that of trees in the immediate nest area (mean = 33.2 cm, range 11.9-67.1 cm).

Beebe (1974) stressed that tree architecture rather than tree species determines nest placement. Tree species with forked (deciduous trees) or whorled branching (conifers) that adequately buttress goshawk nests are suitable nest trees (Reynolds et al 1982; Speiser and Bosakowski 1987). I found that goshawks preferred to nest in Douglas-fir and while they did nest in Western Hemlock it was at a lower proportion to their availability (Fig. 4.1). Western Hemlock have downsweeping branches making them less able to support goshawk nests. Western redcedar were avoided completely and this may be because of the continuous branching pattern further down the bole and downsweeping branches. I am unsure why amabilis fir was avoided but it could be that the branch whorling in this species is not close enough to hold a nest. Also my sample size may have been too small to detect its use. Deciduous trees were not encountered in any of the nest sites although goshawks nest in deciduous trees elsewhere (McGowan 1975; Squires and Ruggiero 1996).

NEST SITE SELECTION

Goshawks chose nest sites with significantly larger trees than in the surrounding territory. Large diameter trees at low density probably provide clear flight paths for critical prey exchanges between the sexes and other activities. Large dbh is correlated with height of trees and the documented difference between the nest site

and the surrounding territory may provide easier access in and out of the forest and also give a visual clue to nest location for returning adults. Hall (1984) found that nest sites of goshawks were in older, less dense and more structurally complex sites than the surrounding trees in the stand.

Tree canopy cover was not different from what was found in the territory. Canopy closure at nest sites was 51% and ranged from 19 to 78%, while at the level of territory, average canopy closure was 49% and ranged from 20 to 71%. High canopy closure is considered to be one of the most important variables in describing goshawk nest sites (Hayward and Escano 1989). In Arizona, canopy coverage in occupied sites averaged 76% or 18% greater than the surrounding landscape ($p < 0.0001$) (Reynolds et al. 1992). Other studies have found goshawks to nest in stands with less canopy cover, e.g., 33 % in Oregon (Reynolds 1983) and 31% in California (Hargis et al. 1994). These differences may be due to differences in methods, or because canopy closure is a necessary resource in climates which are hotter than Vancouver Island and Oregon. Canopy cover may be important in maintaining a suitable microclimate in these areas.

While there is no difference in the average canopy cover between selected and available sites, there does appear to be an interesting pattern around nest trees; there was a break in the canopy adjacent to the nest tree (Figure 4.2). Other studies have found a similar pattern. Speiser and Bosakowski (1987) noted that nest sites in second-growth forests were near old logging trails which affected tree growth such that there were canopy breaks associated with these trails. Schaffer (1998) found

canopy gaps at all 25 documented nests in central Alberta. These openings may provide a “sign post” for returning birds as well as an easy access point into and out of the nest site (Speiser and Bosakowski 1987; Schaffer 1998).

Goshawk nest sites tended to have a western aspect (Table 4.2). Studies in Arizona recorded nest sites with northern aspects while studies in Alaska showed that goshawks chose sites with southern aspects. In Oregon (Moore and Henny 1983) and in Wyoming (Squires and Ruggiero 1996), no preference was indicated for aspect. Goshawks may be selecting for a suitable microclimate in the preference of a warm aspect on Vancouver Island. In southern climates, such as Arizona (Reynolds et al. 1992), goshawks avoided hotter slopes while in cooler climates, such as Alaska (McGowan 1975), warm southerly aspects were chosen.

NEST TERRITORY SELECTION

The exact size of a defended area varies with nest phenology and potential predators (Newton 1979). Based on literature (Reynolds 1980; Reynolds 1983; Kennedy and Stahleker 1993), I defined the territory as being a circle with $r = 300$ m from the nest tree. Speiser and Bosakowski (1991) reported on different goshawk strategies for dealing with human intruders. They observed two nests within 150 m of a popular hiking trail. During incubation the female would not react to the presence of human(s), even ones those who approached the nest tree. She would sit tight on the nest. Once there were nestlings however she would do one of two things. If humans passed by on the hiking trail oblivious to the goshawk nest, the female would not

respond to their presence. However if humans did notice the nest and began approaching, a vigorous defence by the female would ensue. I speculate then that goshawks have two strategies to deal with potential predators near their nest site. The first strategy is one of secretive behaviour which serves to conceal the nest site and/or the young if they believe they are undetected by a potential predator. If they are detected, then they use their considerable flying skills, talons, and vocalizations to drive the predators from the nest.

An interesting pattern was found that supports the concealment hypothesis. The nest territory was composed of significantly smaller trees surrounding the larger trees of the nest site. Hall (1994) found a similar pattern in California where nest sites composed of mature and old-growth trees were embedded in a matrix of predominantly young conifers.

Martin (1993) reinterpreted much of the previous knowledge about nest-site selection in forest birds as being an adaptation to reduce predation pressure. One of his main conclusions was that the risk of predation decreases with an increase in foliage density. It is more difficult for a predator to find a nest when the nest is concealed. For goshawks, some authors have suggested that the dense cover at goshawk nests reduces predation pressure (Reynolds et al. 1992; Squires and Reynolds 1997)

Goshawks will vigorously defend their nest sites against other predators like Red-tailed Hawks (*Buteo jamaicensis*) (Cranell and DeStefano 1992) and Great Horned Owls (*Bubo virginianus*) (Squires and Reynolds 1997). In the course of this

study I observed goshawks defending their nests against Red-tailed Hawks and Common Ravens (*Corvus corvus*).

Much of the known predation on goshawks occurs at the nest. There are a number of records of Great Horned Owls killing adults and nestlings at the nest (Moore and Henny 1983; Rohner and Doyle 1992; Boal and Mannan 1994; Woodbridge and Detrech 1994). Half of the nestling mortalities in New Mexico were caused by predation (Ward and Kennedy 1994). Mammalian predators include Wolverine (*Gulo gulo*) (Doyle 1995), Martin (*Martes americana*) (Paragi and Wholecheese 1994), and Fisher (*Martes pennati*) (Erdman et al. 1998). McGowan (1975) found claw marks of an unidentified mammal at the nest tree of a depredated nest. Erdman et al. (1998) reports the effect of loss of concealment in the hardwood forests of Wisconsin. During an infestation of forest tent caterpillars, 66% of goshawk nests were lost as a result of defoliation which led to increased predator detection of goshawk nests.

Thus the smaller dense forest that I documented around the nest site may serve as a predator maze which reduces the probability of a potential predator discovering the nest and eating the eggs and chicks. The combination of an attacking adult goshawk and the denseness of the vegetation could confuse the potential predator and force it to abandon its approach.

FORAGING AREA SELECTION

Goshawks avoided nesting close to clearcuts and roads. Since roads and clearcuts are highly correlated it is difficult to determine which variable is more influential. Certainly most of the roads that were associated with nest sites are primarily for logging operations. As these roads are not used heavily by the general public, disturbance due to constant activity can be dismissed as a causal explanation. Probably it is the clearings that are avoided. Clearings may bring more competitors which reduce or displace goshawks, and clearings in foraging areas may also reduce the prey base and foraging opportunities.

Crocker-Bedford (1990) found that goshawk nest success was significantly reduced when logging occurred in or the near vicinity of nest sites. Bosakowski and Speiser (1994) found that goshawks chose remote sites for nesting, thus avoiding human habitats such as roads and dwellings.

Goshawks appear to be sensitive to impacts within the foraging area. Radio telemetry studies (Austin 1993) found that goshawks selected forested habitats of later successional stages (>52 cm dbh, canopy closure >40 %) and avoided open habitat of meadows and early seral stages. Bright-Smith and Mannan (1994) reported that habitat preference increased with increasing canopy closure. Hargis et al. (1994) reported that home ranges surrounding nest sites were composed of higher canopy closure, greater basal area, and more large trees than around random points. Removal

of habitat within the potential foraging area of a nest site may compromise the requirements for successful nesting.

Goshawks however do use and in some situations prefer forest edges. In the higher elevation aspen forests of Nevada, Younk and Bechard (1992) reported that goshawks often foraged in the open shrub-steppe habitat and perched in aspen trees adjacent to the shrub-steppe to hunt ground squirrels in the open area. In agricultural areas of Sweden, wintering goshawks preferred edge habitat where prey was most abundant (Kenward 1982). However, since this was a winter study, it is not directly comparable to mine because non-breeding goshawks are not confined to a central nest site, and they are free to exploit other habitats. Indeed, Kennedy (1997) reports that goshawks are readily observed in open country during the winter.

CHAPTER FIVE

CONSERVATION FOR GOSHAWKS ON VANCOUVER ISLAND

IMPORTANCE OF GOSHAWK CONSERVATION

The Northern Goshawk of Vancouver Island is unique as the smallest race of goshawks in North America (Beebe 1974; Whaley and White 1994). Given the current extinction crisis, conservation of irreplaceable taxa is a priority (Pressey et al. 1993). The findings of this study suggest that extensive areas of old growth forests provide the best habitat for this raptor. This type of forest on Vancouver Island has become less extensive and more fragmented: this trend continues and it places the long term survival of this unique bird at greater risk.

How much land is needed to protect and sustain goshawk habitat on Vancouver Island? This study provides no conclusive answers, and indeed there is no basic rule on how much habitat and/or how large a population is required for viability. Shaffer (1987) suggests that 10 to 25% of the original population is needed for a population to be viable - that is a 99% chance of survival for the next 100 years. Assuming a linear relationship between population size and habitat, approximately 10 to 25% of suitable goshawk habitat on Vancouver Island should achieve long term survival of this population. However, for conservation purposes, more is always better and safer.

HABITAT ANALYSIS

One of the most important tools for conserving Vancouver Island goshawk is a geographic information system (GIS) model of goshawk breeding habitat. Such a tool, with a solid biological basis, could be used to assess goshawk population viability. This type of model should incorporate information on the distribution of goshawk habitat, demographic characteristics, and condition of the landscape in order to assess a status of the population under various conditions. The benefits of such a model for population management have been summarized by Foose et al. (1995: 279):

1. Focus attention and discussion on the biological and ecological problems affecting the populations.
2. Quantitatively describe and evaluate a range of scenarios for the populations under a variety of management (or non-management) regimes.
3. Identify gaps in knowledge in areas that may be important for the survival of the populations.
4. Help formulate specific management actions that maximize the probability of the populations' survival or recovery.

METAPOPULATION CONSIDERATIONS

A natural feature of many populations is that they are composed of smaller, geographically discrete populations; this overall pattern is termed a metapopulation (Hanski and Simberloff 1997). Compared to large populations, each of these discrete small populations have a higher probability of extinction from stochastic events such as forest fires or disease outbreak. However the effects of these disturbances are usually local and do not operate at the same time and in the same way over the entire

range of a species (Hanski 1991). By having many populations geographically dispersed, it is very unlikely that they will all be affected simultaneously by the same disturbance. Hence the overall population, the metapopulation, has a higher chance of persistence even though component populations have lower chances. This trend to more and more disjunct distributions is heightened by human activities such as logging. However, recent provincial initiatives such as the Protected Area Strategy, Forest Practices Code, and Identified Wildlife Strategy may help offset this trend by enabling the long-term conservation of goshawks through a metapopulation strategy.

LANDSCAPE LEVEL PLANNING AND WILDLIFE HABITAT AREAS

In 1992, the provincial government announced a commitment to biodiversity conservation by establishing a planning framework that would accommodate a network of protected areas and ensure the application of integrated management outside those areas. Representative areas of natural diversity would be placed into protected area status with a provincial goal of 12%. While 12% is not based on any science for conservation it does provide a solid bottom rung for conserving many species.

On Vancouver Island, the Commission on Resources and the Environment (1994) recommended 13% of the Island to be set aside in parks and protected areas. These protected areas should be assessed for goshawk suitability through computer modeling. Areas that are predicted to contain sufficient quantity and quality of

goshawk habitat can be considered core population areas for goshawks within a metapopulation structure.

These areas, however, should not be managed in isolation, but rather as critical components of an overall goshawk conservation network. Between these areas, landscape linkages which contain suitable goshawk habitat should connect the core reserves. These linkages can be established in areas where management is integrated with other land use activities.

The Forest Practices Code provides guidelines to sustain wildlife habitat by planning forest harvesting in such a way as to reflect natural disturbances (Ministry of Forests 1995). Under the Forest Practices Code, implementation of harvest patterns will be based on planning done at the level of a landscape unit. A landscape unit is an area of approximately 100,000 ha with boundaries defined according to geographic features such as a watershed or a series of watersheds (Ministry of Forests 1995). Landscape units are managed for three different priorities based on biodiversity and social objectives. At a subregional planning level, such as Vancouver Island, the guidebook recommends 30-55% of the area be managed for low biodiversity; 35-60% as intermediate biodiversity; and 10% be designated as high biodiversity. Seral stage distributions under each biodiversity emphasis option have been recommended. Across Vancouver Island, the low biodiversity emphasis option calls for a range of 8-19% of a landscape unit be mature and old growth combined. Intermediate biodiversity recommends 17-36% in mature and old growth, and high biodiversity recommends 25-54% in mature and old growth conditions. Results from this study

suggest that the low biodiversity emphasis will provide little suitable breeding habitat for goshawks. However medium and high biodiversity landscape units may possibly accommodate the habitat needs of goshawks.

If goshawk conservation is considered in the planning of these landscape units, fragmentation should be minimized by having suitable large areas set aside until an equal proportion of the landscape achieves the mature/old growth stage.

CONSERVING KNOWN GOSHAWK NESTS

Less effective goshawk conservation will be achieved by managing goshawks one nest at a time. There are a few reasons for this: 1) a sufficient number of nests must be found to be conserved to benefit the goshawk (meta)population and this would be extremely costly; 2) goshawk conservation would always be reactive rather than proactive; the forest development prescription at each nest would have to be negotiated between industry and government and this would again be costly and controversial; 3) there would be a high degree of uncertainty for both goshawk conservation and planning for timber harvest. Therefore landscape level planning is the preferred option, to reduce uncertainty for both goshawk conservation and forest harvesting.

Nevertheless known nest sites should not be neglected, and conservation of strategically important nests should be pursued to act as stepping stones between core populations. Under the Identified Wildlife Management Strategy (IWMS) of the Forest Practices Code, up to 2400 ha surrounding a known nest site can be managed

for goshawks. This area, under the parlance of the Forest Practices Code, is called a Wildlife Habitat Area (WHA). For *A.g. laingi*, the WHA is a large area and it will make a substantial contribution to the conservation of the known goshawk nest sites. However other rules and regulations within the IWMS reduce its effectiveness. For example, under the Forest Practices Code, the government decided that the total impact to the annual provincial forest harvest would not exceed six per cent. Within this six per cent, one percent is allocated to wildlife species under the Identified Wildlife Management Strategy. Given the large size of the WHA for *A.g. laingi*, it is not unlikely that a large proportion of the provincial 1% could be applied to goshawk nest sites on Vancouver Island. Clearly this would be unacceptable to other regions of the province and also other species with different habitat requirements on the island.

What needs to evolve is a pragmatic approach to the use of the new tools available in the Forest Practices Code and the Identified Wildlife Management Strategy. Wildlife Habitat Areas for goshawks should be coupled with WHAs of other species which share similar habitat types. For example, Marbled Murrelets nest in old growth forests at low elevations, and there may be some habitat comparability between these two species. Also ungulate winter ranges, which are typically placed in older forests on south-facing slopes, should also be considered as areas for goshawk conservation.

To summarize, I emphasize that before a WHA is pursued for a nest site that the site should meet three criteria:

1. The suitability of the site should be viable for the next few years, barring any catastrophic disturbance.
2. The nest site is within a low or medium biodiversity emphasis area. Given the high likelihood for persistence in high biodiversity emphasis areas, there is little need to place part of the WHA budget into an area that is already likely to sustain goshawks for a significant amount of time.
3. The nest site “makes sense” in terms of the metapopulation strategy that is it should link the core populations within suitable Provincial Parks and High Biodiversity Emphasis Areas.

If a full WHA of a known nest site is not to be pursued because it does not meet the above criteria, conservation measures should still be attempted to monitor how goshawks respond to less conservative measures. At a minimum, the nest territory should be conserved, ensuring that the nest territory not become a separate fragment. Planning Forest Ecosystem Networks, corridors and other options should be considered around these nest sites to minimize impacts on timber harvest and maximize conservation goals. Whatever is approved, monitoring by Ministry of Environment, Lands, and Parks should occur. Documentation of how goshawks respond to silviculture treatments is poor and thus our understanding is poor. “Tinkering” with logging within goshawk foraging areas and territories should be considered in a structured, scientific manner to provide better information and better management of goshawks, that is, adopt an adaptive management approach.

If nests are found in small old-growth patches surrounded by young second growth, then management to reduce the impact of predation on nests should be considered. While I found no evidence of predation in this study, the two nests that I did document as failing were in small old-growth patches in a fragmented landscape. Erdman et al. (1998) managed to reduce fisher predation on goshawk nests by placing a 1 m greased baffle halfway up the tree. They found that this improved reproductive success. Similar techniques should be used on Vancouver Island.

Opportunities for enhancement at the nest site or potential nest site should be investigated. If the goal is to improve young forests (40-80 years) for goshawk suitability, creating canopy breaks near relatively large trees may mimic the natural situation. Also placing of artificial nest platforms in suitable trees may attract breeding goshawks (Petty and Anderson 1985). If younger forests could be made more suitable for goshawks then the risk of endangerment would be reduced.

Overall, a goshawk conservation strategy needs to deal with the spatial hierarchy of the species habitat, recognizing the interdependence and asymmetry of the goshawk system. All levels of the hierarchy need to be considered in an integrated manner if conservation goals for goshawks are to be achieved.

INVENTORY AND MONITORING PRIORITIES

Suitability models should be used when reviewing harvest plans and schedules. As forest development plans come up for approval, areas which show high suitability for breeding goshawks should be inventoried before approving the cutting

permit. Two surveys (method of Kennedy and Stahleker 1993) conducted over two field seasons should be a minimum to detect the absence or presence of nesting goshawks.

All known nest sites should be checked on an annual basis for occupancy and productivity. Any changes to the nest site and surrounding landscape should be documented at the time of the nest visit. Tracking of nests through time will help to improve habitat guidelines.

RESEARCH RECOMMENDATIONS

Given the conservation concern of this species there is a pressing need for research in the following areas:

1. *Telemetry-based Habitat Selection Study.*

Although there are many telemetry-based studies being conducted throughout western North America, the uniqueness of this subspecies and its island ecology requires that specific information such as home range size and winter habitat needs be collected *in situ*. This knowledge can only be acquired through radiotelemetry. I recommend that the telemetry work be carried out on nests in the same core study areas that I used. The strength of this approach then will build on (and perhaps refute) the findings of this study, and it will also allow for a comparative analysis of goshawk habitat use between different forest landscapes. Data from a study such as this would vastly improve suitability models for GIS.

A telemetry study must also consider examining juvenile dispersal and mortality. Again a comparative approach with populations in different forest landscapes will provide the strongest data for these purposes.

2. *Conduct a long-term study of goshawk diet and prey populations to determine how habitat selection and reproduction are influenced by the abundance of preferred prey.*

A more in-depth understanding of the relationship between goshawk and red squirrel (and other prey species) on Vancouver Island is required. Are red squirrels only required by goshawks during the breeding season; how important are they during winter? Additionally a more direct measure of red squirrel abundance and a better understanding of their population ecology in different forest types will provide better management of goshawks throughout the rotation of forests. While much more difficult, the management of the prey base offers enormous potential for conservation of goshawks.

3. *Describe and compare with other goshawk populations, the taxonomic and genetic character of this subspecies.*

While there have been taxonomic studies on this subspecies, no data exist in the literature that were collected from living specimens. All of the taxonomic work comes from museum study skins which, because of non-uniform collection and curation procedures, brings into question the reliability of the data set.

Morphometric measurements taken from living birds known to be nesting on Vancouver Island will answer many of the questions which persist because of the

existing data set. Also a genetic study may assist in illuminating the actual distribution of this subspecies. For example is the *A.g. laingi* form restricted only to coastal islands or, more likely, does it also occur along the mainland coast? A genetic study may be the best way to answer this question.

4. *Test the utility of artificial nest platforms in 40 to 80 year old forests.*

The placement of artificial nest platforms in younger second growth forests has greatly assisted the recovery of goshawks on the British Isles (Petty 1989). My data suggest that goshawks should have been more abundant based on the relative abundance of their main prey, the red squirrel. While it may be that the habitat structure of these younger forests have lower suitability for goshawk foraging it may also be due to low suitability for nest placement. Without suitable nest platforms the density of breeding goshawks will be reduced. This type of study would require a commitment to long-term monitoring but it could also involve local community groups such as Boy Scouts, Girl Guides, Naturalist groups and others. Involving local community groups would enhance the conservation effort required to sustain this raptor.

REFERENCES CITED

- Andersson, M., and R.A. Norberg. 1981. Evolution of reversed sexual size dimorphism and role partitioning among predatory birds, with a size scaling of flight performance. *Biological Journal of the Linnean Society* 15: 105-130.
- Austin, K.K. 1993. Habitat use and home range size of breeding northern goshawks in the southern Cascades. M.Sc. thesis. Oregon State University. Corvallis, Oregon.
- Bart, J., and S. P. Klosiewski. 1989. Use of presence-absence to measure changes in avian density. *Journal of Wildlife Management* 53:847-851.
- Beebe, F.L. 1974. Field studies of the Falconiformes of British Columbia. First Edition. Occasional papers of the British Columbia Provincial Museum No. 17. Victoria, B.C.
- Beebe, F.L. 1992. *The Compleat Falconer*. Hancock House Publishers Ltd. Surrey, B.C.
- Begon, M., J. L. Harper, and C.R. Townsend. 1986. *Ecology: Individuals, Populations and Communities*. Blackwell Scientific Publications. Sunderland, Massachusetts.
- Beier, P., and J. E. Drennan. 1997. Forest structure and prey abundance in foraging areas of northern goshawks. *Ecological Applications* 7:564-571.
- Benkman, C. W. 1993. Logging, conifers, and the conservation of crossbills. *Conservation Biology* 7:473-479.
- Bibby, C. J. 1995. Recent past and future extinctions in birds. Pages 98-110 in J.H. Lawton, and R.M. May, eds. *Extinction rates*. Oxford University Press. Oxford, UK.
- Boal, C.W., and R.W. Mannan. 1994. Northern goshawk diets in ponderosa pine forests on the Kaibab Plateau. *Studies in Avian Biology* 16:97-102.
- Bosakowski, T., and R. Speiser. 1994. Macrohabitat selection by nesting northern goshawks: implications for managing eastern forests. *Studies in Avian Biology* 16:46-49.
- Bosakowski, T., D. G. Smith, and R. Speiser. 1992. Niche overlap of two sympatric-nesting hawks *Accipiter* spp. in the New Jersey-New York highlands. *Ecography* 15:358-372.

- Bosakowski, T., and M. E. Vaughn. 1996. Developing a practical method for surveying northern goshawks in managed forests of the western Washington Cascades. *Western Journal of Applied Forestry* 11:109-113.
- Bright-Smith, D. J., and R. W. Mannan. 1994. Habitat use by breeding male northern goshawks in northern Arizona. *Studies in Avian Biology* 16:58-65.
- Brown, L., and D. Amadon. 1968. *Eagles, Hawks and Falcons of the World, Volume 2*. McGraw-Hill Book Company. New York, New York.
- Burns, R. M., and B. H. Honkala. 1990. *Silvics of North America, Volume 1. Handbook 654*. U.S. Department of Agriculture, Washington, D.C.
- Byers, C. R., and R. K. Steinhorst. 1984. Clarification of a technique for analysis of utilization-availability data. *Journal of Wildlife Management* 48:1050-1053.
- Campbell, R. W., N. K. Dawe, I. McTaggart-Cowan, J. M. Cooper, G. W. Kaiser, and M. C. E. McNall. 1990. *The birds of British Columbia. Vol II: Nonpasserines, Diurnal Birds of Prey through Woodpeckers*. Royal British Columbia Museum. Victoria, B.C.
- Carey, A. B. 1989. Wildlife associated with old-growth forests in the Pacific Northwest. *Natural Areas Journal* 9:151-162.
- Carey, A. B., S. P. Horton, and B. L. Biswell. 1992. Northern spotted owls: influence of prey base and landscape character. *Ecological Monographs* 62:223-250.
- Clayoquot Scientific Panel. 1995. *Sustainable ecosystem management in Clayoquot Sound: Planning and practices*. Government of British Columbia. Victoria, British Columbia.
- Commission on Resources and the Environment. 1994. *Vancouver Island land use plan*. Government of British Columbia. Victoria, British Columbia.
- Cox, G.W. 1980. *Laboratory manual of general ecology*. W.C. Brown Company Publishers. William C. Brown Co. Publishers. Dubuque, Iowa.
- Crannel, D., and S. DeStefano. 1992. An aggressive interaction between a northern goshawk and a red-tailed hawk. *Journal of Raptor Research*. 26:269-270.
- Crocker-Bedford, D. C. 1990a. Goshawk reproduction and forest management. *Wildlife Society Bulletin*. 18:262-269.

- Crocker-Bedford, D. C. 1990b. Status of the Queen Charlotte Goshawk. Unpublished report to Alaska Region of the U.S. Forest Service.
- Crocker-Bedford, D. C., and B. Chaney. 1988. Characteristics of goshawk nesting stands. Pages 210-217 in R. L. Glinski, B. G. Pendelton, M. B. Moss, M. N. LeFranc Jr., B. A. Milsap, and S.W. Hoffman, eds. Proceedings of the southwest raptor management symposium and workshop. National Wildlife Federation Scientific Technical Series No. 11. Washington, D.C.
- DeStefano, S., and J. McCloskey. 1997. Does vegetation structure limit the distribution of northern goshawks in the Oregon Coast Ranges. *Journal of Raptor Research* 31:34-39.
- Devore, J. L. 1987. Probability and statistics for engineering and the sciences. Second Edition. Wadsworth Inc. Belmont, California.
- Doyle, F. I. 1995. Bald eagle, *Haliaeetus leucocephalus*, and northern goshawk, *Accipiter gentilis*, nests apparently preyed upon by a wolverine(s), *Gulo gulo*, in the southwestern Yukon Territory. *Canadian Field Naturalist* 109:115-116.
- Doyle, F. I., and J. M. N. Smith. 1994. Population responses of northern goshawks to the 10-year cycle in numbers of snowshoe hares. *Studies in Avian Biology* 16:122-129.
- Duncan, P., and D. A. Kirk. 1995. Status report on the Queen Charlotte goshawk *Accipiter gentilis laingi* and northern goshawk *Accipiter gentilis atricapillus* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa, Ontario.
- Erdman, T. C., D. F. Brinker, J. P. Jacobs, J. Wilde, and T. O. Meyer. 1998. Productivity, population trend, and status of northern goshawks, *Accipiter gentilis atricapillus*, in northeastern Wisconsin. *Canadian Field Naturalist* 112:17-27.
- Foose, T. J., L. deBoer, U. S. Seal, and R. Lande. 1995. Conservation management strategies based on viable populations. Pages 273-294 in J. D. Ballou, M. Gilpin, and T. J. Foose eds. Population management for survival and recovery. Columbia University Press. New York.
- Fowells, H. A. 1965. Silvics of forest trees of the United States. Agriculture Handbook 271 United States Department of Agriculture. Forest Service. Washington D.C.
- Funk and Wagnalls Standard College Dictionary. 1978. Fitzhenry and Whiteside Ltd., Toronto.

- Garton, E. O., P. H. Hayward, and G. D. Hayward. 1989. Management of prey populations and habitats. Pages 298-304 *in* B. Giron Pendleton ed. Proceedings of the western raptor management symposium and workshop. National Wildlife Federation Technical Series No. 12. Washington, D.C.
- Germaine, S. S., S. H. Vessey, and D. E. Capen. 1997. Effects of small forest openings on the breeding bird community in a Vermont hardwood forest. *The Condor* 99:708-718.
- Gill, F. B. 1990. *Ornithology*. W.H. Freeman and Co. New York. pp 660.
- Grzybowski, J. A., and S. W. Eaton. 1976. Prey items of goshawks in southwestern New York. *Wilson Bulletin* 88:669-670.
- Hall, P. 1984. Characterization of nesting habitat of goshawks (*Accipiter gentilis*) in northwestern California. M.Sc. thesis. Humboldt State University, Arcata, California.
- Hanski, I. 1991. Single-species metapopulation dynamics: concepts, models, and observations. *Biological Journal of the Linnean Society* 42:17-38.
- Hanski, I., and D. Simberloff. 1997. The metapopulation approach, its history, conceptual domain, and application to conservation. Pages 5-26 *in* I. Hanski and M. E. Gilpin eds. *Metapopulation biology: ecology, genetics, and evolution*. Academic Press. San Diego, California.
- Hargis, C. D., C. McCarthy, and R. D. Perloff. 1994. Home ranges and habitats of northern goshawks in eastern California. *Studies in Avian Biology* 16:66-74.
- Hayward, G. D., and R. E. Escano. 1989. Goshawk nest-site characteristics in western Montana and northern Idaho. *The Condor* 91:476-479.
- Hennessy, S. P. 1978. Ecological relationships of accipiters in northern Utah - with special emphasis on the effects of human disturbance. M.Sc. thesis. Utah State University. Logan, Utah.
- Hoffman, S. W., J. P. Smith, and J. A. Gessaman. 1990. Size of fall migrant accipiters from the Goshute Mountains of Nevada. *Journal of Field Ornithology* 61:201-211.
- Holt, R. F., and K. Martin. 1997. Landscape modification and patch selection: the demography of two secondary cavity nesters colonizing clearcuts. *The Auk* 114:443-455.

- Hurlbert, S. H. 1984. Pseudoreplication and the design of ecological field experiments. *Ecological Monographs* 54:187-221.
- James, F. C., and H. H. Shugart. 1970. A quantitative method for habitat description. *Audubon Field Notes* 24:727-736.
- Johnsgard, P. A. 1990. Hawks, eagles, and falcons of North America: biology and natural history. Smithsonian Institution Press. Washington, D.C.
- Johnson, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. *Ecology* 61:65-71.
- Johnson, D. R. 1989. Body size of northern goshawks on coastal islands of British Columbia. *Wilson Bulletin* 101:637-639.
- Kemp, G. A., and L. B. Keith. 1970. Dynamics and regulation of red squirrel (*Tamiasciurus hudsonicus*) populations. *Ecology* 51:763-779.
- Kennedy, P. L. 1988. Habitat characteristics of Cooper's hawk and northern goshawks nesting in New Mexico. Pp. 218-227 in R. L. Glinski, B. Giron Pendelton, M. B. Moss, M. N. LeFranc, Jr., B. A. Milsap and S. W. Hoffman, eds. Proceedings of the southwest raptor management symposium and workshop. National Wildlife Federation, Scientific Technical Series No. 11. Washington D.C.
- Kennedy, P. L. 1990. Reproductive strategies of northern goshawks and Cooper's hawks in north-central New Mexico. Ph. D. thesis. Utah State University. Logan, Utah.
- Kennedy, P. L. 1997. The northern goshawk (*Accipiter gentilis atricapillus*): is there evidence of a population decline? *Journal of Raptor Research*. 31:95-106.
- Kennedy, P. L., and D. W. Stahleker. 1993. Responsiveness of nesting northern goshawks to taped broadcasts of three conspecific calls. *Journal of Wildlife Management* 57:249-257.
- Kenward, R. E. 1982. Goshawk hunting behaviour, and range size as a function of food and habitat availability. *Journal of Animal Ecology* 51:69-80.
- King, W.B. 1985. Island birds: will the future repeat the past? Pages 3-15 in P.J. Moors ed. Conservation of island birds. International Council of Bird Preservation. Technical Publication 3.
- Lack, D. 1954. The natural regulation of animal numbers. Clarendon Press. Oxford, U.K.

- Linden, H., and M. Wikman. 1983. Goshawk predation on tetraonids: availability of prey and diet of the predator in the breeding season. *Journal of Animal Ecology* 52:953-968.
- MacArthur, R. H., and E. O. Wilson. 1967. *The theory of island biogeography*. Princeton University Press. Princeton, New Jersey.
- Martin, T.E. 1993. Nest predation and nest sites. *Bioscience* 43 8:523-532.
- McGowan, J. D. 1975. Distribution, density, and productivity of goshawks in interior Alaska. Federal Aid in Wildlife Restoration, Project Report W-17-445. Alaska Department of Fish and Game. Juneau, Alaska.
- Millsap, B.A, K. W. Cline, and B. A. Giron Pendleton. 1987. Habitat management. Pages 215-238 in B. A. Giron Pedleton, B. A. Millsap, K. W. Cline, D. M Bird, eds. *Raptor management techniques manual*. Institute for Wildlife Research National Wildlife Federation Scientific and Technical Series No. 10. Washington, D.C.
- Ministry of Environment, Lands, and Parks, Wildlife Branch. 1996. B.C. red, blue and yellow listed species in British Columbia. Victoria B.C.
- Ministry of Forests, and British Columbia Environment. 1995. *Biodiversity Guidebook*. Victoria, B.C.
- Moore, K. 1990. Where is it and how much is left? The state of the temperate rainforest in British Columbia. *Forest Planning Canada* 6: 15-19.
- Moore, K. R., and C. J. Henny. 1983. Nest site characteristics of three coexisting *Accipiter* hawks in northeastern Oregon. *Raptor Research* 17:65-76.
- Mueller, H. C., D. D. Berger, and G. Allez. 1977. The periodic invasions of goshawks. *The Auk* 94:652-653.
- Mueller, H. C., D. D. Berger, and G. Allez. 1981. Age, sex, and seasonal differences in size of Cooper's Hawks. *Journal of Field Ornithology* 52: 112-126.
- Neu, C. W., C. R. Byers, and J. M. Beek. 1974. A technique for analysis of utilization-availability data. *Journal of Wildlife Management* 38:541-545.
- Newton, I. 1972. *Finches*. Collins, London, England.
- Newton, I. 1979. *Population ecology of raptors*. Buteo Books. Vermillion, South Dakota.

- Newton I. 1986. The Sparrowhawk. Buteo Books. Vermillion, South Dakota.
- Obbard, M.E. 1986. Red Squirrel. Pages 264-281 in M. Novak, J. A. Barker, M. E. Obbard, and B. Malloch eds. Wild furbearer management and conservation in North America. Ontario Ministry of Natural Resources. Toronto, Ontario.
- O'Neil, R. V., D. L. DeAngelis, J. B. Waide, and T. F. H. Allen. 1986. A hierarchical concept of ecosystems. Princeton University Press. Princeton, New Jersey.
- Paragi, T. F., and G. M. Wholecheese. 1994. Marten, *Martes americana*, predation on a northern goshawk, *Accipiter gentilis*. Canadian Field-Naturalist 108:81-82.
- Penteriani, V. 1997. Long-term study of a goshawk breeding population on the Mediterranean mountain (Abruzzi Appennines, central Italy): density, breeding performance, and diet. Journal of Raptor Research 31:308-312.
- Petty, S.J. 1989. Goshawks: their status, requirements and management. Forestry Commission Bulletin 81. Wildlife and Conservation Research Branch, Forestry Commission, London, England.
- Petty, S.J., and D.I.K. Anderson. 1995. The breeding performance of an introduced population of northern goshawks in Britain: implications for forest management. Journal of Raptor Research 29:44-51.
- Pojar, J.E., K. Klinka, and D. A. Demarchi. 1991. Coastal Western Hemlock Biogeoclimatic Zone. Pages 95-112 in D. V. Meidinger and J. Pojar, eds. Ecosystems of British Columbia. British Columbia Ministry of Forests Research Branch Special Report. Series No. 6. Victoria, B.C.
- Pressey, R.L., C. J. Humphries, C. R. Margules, R.I Vane-Wright, and P. H. Williams. 1993. Beyond opportunism: key principles for systematic reserve selection. Tree 8:124-128.
- Quayle, J., T. J. Ethier, and D. Doyle. 1995. 1995/96 inventory report: the northern goshawk (*Accipiter gentilis laingi*) in British Columbia. Wildlife Branch, Ministry of Environment, Lands, and Parks. Victoria, British Columbia.
- Resources Inventory Committee. 1998. Vegetation resources inventory (VRI): ground sampling procedures. Queens Printer Government Publications. Victoria, BC.
- Reynolds, R.T. 1980. North American Accipiter hawks. CRC handbook of census methods for terrestrial vertebrates. Pp. 288-289.

- Reynolds, R. T. 1983. Management of western coniferous forest habitat for nesting *Accipiter* hawks. General Technical Report RM-102. U.S.D.A. Forest Service, Rocky Mountain Forest and Range Experiment Station. Fort Collins, Colorado.
- Reynolds, R. T. 1989. *Accipiters*. Pages 92 -101 in B. Giron Pendleton, ed. Proceedings of the western raptor management symposium and workshop. National Wildlife Federation Technical Series No. 12, Washington D.C.
- Reynolds, R. T., R. T. Graham, M. H. Reiser, R. L. Bassett, P. L. Kennedy, D. A. Boyce, G. Goodwind, Jr., R. Smith, and E. L. Fisher. 1992. Management recommendations for the northern goshawk in the southwestern United States. General Technical Report. RM-217. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. Fort Collins, Colorado.
- Reynolds, R. T., E. C. Meslow, and H. M. Wight. 1982. Nesting habitat of coexisting *Accipiter* in Oregon. *Journal of Wildlife Management* 46:124-138.
- Rohner, C., and F.I. Doyle. 1992. Food- stressed great horned owl kills adult goshawk: exceptional observation or community process? *Journal of Raptor Research* 26:261-263.
- Saunders, L. B. 1982. Essential nesting habitat of the goshawk (*Accipiter gentilis*) on the Shasta-Trinity National Forest, McCloud District. M. Sc. thesis. California State University. Chico, California.
- Schaffer, W. W. 1998. Northern goshawk habitat characterization in central Alberta. M. Sc. Thesis. University of Alberta. Edmonton, Alberta.
- Schieck, J. 1994. Relationships between the abundance of small mammals and patch size within fragmented forests on Vancouver Island. FRDA II Research Memo No.222. Victoria, B.C.
- Schnell, J.H. 1958. Nesting behavior and food habits of goshawks in the Sierra Nevada of California. *Condor* 60:377-403.
- Shaffer, M. 1987. Minimum viable populations: coping with uncertainty. Pages 69-86 in M.E. Soule, ed. *Viable populations for conservation*. Cambridge University Press. Cambridge UK.
- Smith, M. 1968. Red squirrel responses to spruce cone failure in interior Alaska. *The Journal of Wildlife Management* 32:305-317.

- Speiser, R., and T. Bosakowski. 1991. Nesting phenology, site fidelity, and defense behavior of northern goshawks in New York and New Jersey. *Journal of Raptor Research*. 25:132-135.
- Speiser, R., and T. Bosakowski. 1987. Nest site selection by northern goshawks in northern New Jersey and southeastern New York. *Condor* 89:387-394.
- Squires, J. R., and R. T. Reynolds. 1997. Northern goshawk (*Accipiter gentilis*). A. Poole and F. Gill, eds. *The Birds of North America*, No. 298 The Academy of Natural Sciences, Philadelphia, PA, and The American Ornithologists' Union.
- Squires, J. R., and L.F. Ruggiero. 1996. Nest-site preference of northern goshawks in south-central Wyoming. *Journal of Wildlife Management*. 60:170-177.
- StatSoft, 1996. STATISTICA. for Windows. Tulsa Oklahoma.
- Steadman, D. W. 1997. Human-caused extinction of birds. Pages 139-161 in M. L. Reaka-Kudla, D. E. Wilson, and E. O. Wilson eds. *Biodiversity II: understanding and protecting our biological resources*. Joseph Henry Press. Washington, D.C.
- Taverner, P.A. 1940. Variation in the american goshawk. *Condor* 42:157-160.
- Titus, K., C. J. Flatten, and R. E. Lowell. 1994. Northern goshawk ecology and habitat relationships on the Tongass National Forest (goshawk nest sites, food habits, morphology, home range and habitat data). First Annual Project Report. Contract 43-0109-3-0272 with USDA Forest Service. Alaska Dept. of Fish and Game, Juneau, Alaska. Report to the U.S. Forest Service.
- Titus, K., C. J. Flatten, and R. E. Lowell. 1995. Goshawk habitat relationships on the Tongass National Forest. Final Report to the U. S. Forest Service, contract number 43-0109-4-0209. Alaska Department of Fish and Game, Juneau Alaska
- Ward, J. M., and P. L. Kennedy. 1994. Approaches to investigating food limitation hypotheses in raptor populations: An example using the northern goshawk. *Studies in Avian Biology* 16:114-118.
- Watson, J. W., D. W. Hays, and S. P. Finn. 1998. Prey of breeding northern goshawks in Washington. *Journal of Raptor Research* 32:297-305.
- Wattell, J. 1973. Geographical differentiation in the genus *Accipiter*. Publications of the Nuttall Ornithological Club No. 13. Cambridge, Massachusetts.

- Whaley, W.H., and C.M. White. 1994. Trends in geographic variation of Cooper's Hawk and northern goshawk in North America: A multivariate analysis. *Proceedings of the western foundation of vertebrate zoology* 5:161-209.
- Widen, P. 1985. Breeding and movements of goshawks in boreal forests in Sweden. *Holarctic Ecology* 8:273-279.
- Widen, P. 1997. How, and why, is the goshawk (*Accipiter gentilis*) affected by modern forest management in Fennoscandia. *Journal of Raptor Management* 31:107-113.
- Wiens, J.A. 1989. Spatial scaling in ecology. *Functional Ecology* 3:385-397.
- Wilcox, B.A. 1989. The long-term consequences of environmental perturbations on raptor populations. Pages 263-270 in B. Giron Pendleton, ed. *Proceedings of the western raptor management symposium and workshop*. National Wildlife Federation Technical Series No. 12, Washington D.C.
- Woodbridge, B., and P. J. Detrich. 1994. Territory occupancy and habitat patch size of northern goshawks in the southern Cascades of California. *Studies in Avian Biology* 16:83-87.
- Younk, J. V., and M. J. Bechard. 1994. Breeding ecology of the northern goshawk in high-elevation aspen forests of northern Nevada. *Studies in Avian Biology* 16:119-121.

Vita

Surname: Ethier

Given Names: Thomas Joseph

Place of Birth: Brockville, Ontario, Canada

Educational Institutions Attended:

Okanagan College: 1987 to 1990

University of Victoria: 1990 to 1991

Degrees Awarded:

B.Sc. University of Victoria 1992

Publications:

- James, P.C., T.J. Ethier, and Mauray K. Toutloff. 1997. Parameters of a declining Burrowing Owl population in Saskatchewan. *Journal of Raptor Research* 9: 34-37.
- Ethier, T.J. 1996. Introduction to inventory methodologies in British Columbia. Resource Inventory Committee, Ministry of Environment, Lands and Parks, Wildlife Branch, Victoria, B.C.
- Ethier, T.J. 1994. Standardized inventory methods for songbirds in British Columbia. Resource Inventory Committee, Ministry of Environment, Lands and Parks, Wildlife Branch, Victoria, B.C.
- Ethier, T.J. 1993. Standardized inventory methods for raptors in British Columbia. Resource Inventory Committee, Ministry of Environment, Lands and Parks, Wildlife Branch, Victoria, B.C.
- Ethier, T.J. 1993. Standardized inventory methods for swifts and swallows in British Columbia. Resource Inventory Committee, Ministry of Environment, Lands and Parks, Wildlife Branch, Victoria, B.C.
- Ethier, T.J. 1993. Standardized inventory methods for tailed frog and pacific giant salamander in BC. Resource Inventory Committee, Ministry of Environment, Lands and Parks, Wildlife Branch, Victoria, B.C.
- James, P.C., G.A. Fox and T.J. Ethier. 1990. Is the operational use of strychnine to control ground squirrels detrimental to burrowing owls? *Journal of Raptor Research* 24: 120-123.
- James, P.C., T.J. Ethier, G.A. Fox, and M. Todd. 1989. New aspects of Burrowing Owl biology. *Provincial Museum of Alberta Occasional Paper*. 15: 226-227.

