Exhibit A

Green Diamond Resource Company

Northern Spotted Owl Habitat Conservation Plan

Phase One Comprehensive Review

August 30, 2006

The following report is based on a requirement of Green Diamond Resource (formerly Simpson Timber) Company's Northern Spotted Owl Habitat Conservation Plan (HCP) for a ten-year review. The original HCP specified "that a comprehensive review of the HCP and permit conditions be conducted at the end of the first 10 years." The following five questions were listed to guide the review:

- *A comparison of actual and estimated levels of owl displacement;*
- *A comparison of actual and estimated distribution of owl habitat;*
- *A reevaluation of the biological basis for the conservation strategy based on the data collected through the research program and other sources;*
- *A detailed analysis of efficacy of and continued need for the set-asides and of the long-term viability of the owl population on Simpson's property; and*
- *An estimate of annual owl displacement for the remainder of the permit period*.

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CHAPTER 1
SPOTTED OWL DISPLACEMENT

1.A. COMPARISON OF ACTUAL AND ESTIMATED LEVELS OF SPOTTED OWL DISPLACEMENT

Green Diamond's incidental take permit covers all take of spotted owls incidental to timber harvest operations. However, the primary form of incidental take anticipated in the HCP was the displacement of owls due to modification of owl habitat. It was recognized that such displacement could impair essential behavioral patterns and result in actual death or injury to owls. Rather than examining the circumstances of each case to determine whether a take (as defined under the Endangered Species Act) had in fact resulted from Green Diamond's habitat modification, the implementation agreement calls for reporting as a "displacement" any instance in which an owl site is harvested or habitat around an owl site is reduced below thresholds established in the HCP. This approach provides for an ongoing evaluation of the suitability of owl habitat at sites where displacements are reported as a result of timber harvesting.

The total number of displacements reported under this system is significant because: 1) it provides guidance on Green Diamond's compliance with the formal permit limit on incidental taking (50 owl pairs during the ten-year permit term) and, 2) it would have triggered a five-year plan review if more than 33 displacements had been reported within the first five years of the permit period.

During the 1995 reporting period, Green Diamond and the US Fish and Wildlife Service (Service) agreed upon a system for displacement accounting. This system was developed because owls continued to occupy and reproduce at sites where timber harvest triggered a report of displacement under the technical definitions described hereafter. With this system, owl sites in which harvesting occurred were 1) reported and added to the displacement total when timber harvest triggered the criteria for direct or indirect displacement, 2) evaluated subsequently to the harvest that triggered the report of displacement, and, 3) removed from the displacement total if the site met specified post-harvest criteria for owl occupancy and reproduction. The criteria for removing sites from the displacement tally were presented to the Service in the 1996 annual report and are described below (see "Removal of displacements"). Starting in 2002, the Service granted to Green Diamond two three-year extensions of the permit term for incidental taking of spotted owls. These extensions allowed for the permitted incidental taking of 50 owl pairs to occur over a term of 16 years.

Definitions

Green Diamond and the Service agreed upon the following definitions to use when determining displacement:

Owl site: the area within a 152.4 m (500 ft) radius of the activity center of a single owl or activity center/nest site of a pair of owls (= 7.3 ha, or 18 acres). Temporary roosts of

floater owls do not constitute owl sites. Pair status is determined by 1992 USFWS guidelines, except that single status must be determined from at least three site visits.

Perennial owl site: an owl site established for at least two consecutive field seasons.

Newly colonized owl site: a new owl site found in an area that was surveyed in a previous field season and unoccupied by spotted owls.

Newly discovered owl site: a new owl site found in an area not surveyed for owls in a previous field season.

Nest site: a tree in which a pair of spotted owls has nested.

Activity center: When a nest site is not known, the activity center is the location (point on the landscape) most frequently used as a daytime roost during the breeding season. A minimum of three daytime observations is usually needed to establish an activity center. Establishing the central location of an activity center is primarily a biologist's judgment call based on evidence found and evaluated in the field. It may be a primary roost site identified by the consistent presence of owls or whitewash and pellets, or the geometric center of several roosts where owls or owl sign have been detected. In the latter case, the activity center must be located in suitable habitat. Activity centers may be established based on nighttime responses if they are consistently heard in the same area.

Owl home range: areas predominantly used by territorial owls. Home ranges will be determined using the known locations of individual owls, the spatial distribution of all owls in the area of concern, and major topographic features.

Floater owl(s): an owl found sporadically in an area, but not showing sufficient site fidelity to establish an activity center according to the criteria described below (see "designation of activity centers for new responses").

Direct displacement: timber harvesting within an owl site (within a 152 m radius of the site center). Such harvesting is assumed to cause a displacement of spotted owls and therefore triggers a report, whether or not the location of spotted owls in the site actually changes. In most cases, a direct displacement of a single owl occupying a site is considered to be the same as a direct displacement of an owl pair. The accounting of direct displacement for sites perennially occupied by single spotted owls is addressed by including site occupancy (by a single or pair of owls) in the criteria for removal of displacements (see below).

Indirect displacement: timber harvesting that reduces spotted owl habitat within the 203 ha (502 ac, 0.5 mi radius) circle around an owl activity center below the following thresholds:

- 36 ha (89 acres) of stands ≥ 46 years old , and
- 94 ha (233) acres of stands ≥31 years old

Such harvesting is assumed to cause a displacement of spotted owls and therefore triggers a report, whether or not the location of spotted owls in the site actually changes. In most cases, a direct displacement of a single owl occupying a site is considered to be the same as a direct displacement of an owl pair.

Permanence of owl sites: Only the most current owl site within a home range is considered for evaluation of displacement. The current owl site shall be defined based upon the most recent nest site found in the last three years. If spotted owls have not nested in an established home range in the past three years, the most recent activity center shall be used to define the current owl site.

If no owls are detected in a home range after conducting HCP surveys in a given year the following scenarios apply:

- If in the previous year the owl site was either
  newly colonized by a pair that nested,
  perennial, or
  newly discovered,
  the owl site shall be maintained for three subsequent breeding seasons. If after three breeding seasons no occupied sites are found within a home range, past owl sites within that home range will no longer be considered for potential displacement.

- If in the previous year the owl site was established as a newly colonized site in which owls did not nest, the owl site shall be maintained for one breeding season. If the site is found to be unoccupied by owls in the following breeding season, then the site will no longer be considered for potential displacement.

Designation of activity centers for new responses: For owl responses detected during the breeding season in areas where an owl site has not been previously designated, an activity center will be designated if either an owl pair is detected at least two times in the same area for at least one month, a single owl is detected in the same area for at least two months, or an owl detection was not followed-up adequately using the standards described below.

Owl detections will not lead to the designation of an activity center if three adequate, HCP-protocol site visits, at least five days apart, all result in no owls being found within 30 (pair) or 60 (single owl) days of the initial response. If the initial response occurs in March, then at least one of the three site visits shall be completed in April.

Late breeding season detections: Owls initially detected in August will not be used to designate an owl site in areas where no owls were detected earlier in the breeding season of the same year, when the required number or survey visits and follow-ups can not be completed. In addition, the area will not be cleared for timber harvest until after

surveys are conducted in the subsequent breeding season. If the required number of night surveys and follow-up visits are conducted before the end of the breeding season and no owls are detected, the area will be cleared for harvest.

Special displacement circumstances: A direct displacement will not be reported if owls establish an owl site during the breeding season within 152 m of an area where timber falling has already been completed. If owls establish an activity center during the breeding season within 152 m of an active timber harvest unit where timber falling has not been completed, timber harvest will be suspended until the appropriate HCP measures (Sections III.A.1.(a) (3) and III.A.1.(a) (4) of the Implementation Agreement) have been taken to determine reproductive status and protect nesting owls. If harvesting is not suspended until appropriate HCP measures occur, a direct displacement will be reported.

If Green Diamond resumes timber harvesting after complying with the HCP measures, the following shall apply:

- if less than 4 ha (10 acres) remain to be felled, a direct displacement will not be reported
- if more than 4 ha remain, Green Diamond will consult with the Service to determine whether a displacement will be reported.

Indirect displacements are assessed and reported based on the location of all known owl sites at the time that falling is initiated. Any subsequent movement of owl sites during the falling and harvesting period are not assessed for potential indirect displacement. If any other situation arises in which the determination of whether to report a displacement is questionable, the Service will be consulted to resolve the determination.

Removal of displacements

Each direct and indirect displacement is originally reported on the basis of harvest activity in relation to an owl site within a particular home range. Displacement associated with a particular owl site in a home range can occur more than once (i.e. after removal), and individual owls can be displaced more than once if they occupy successive owl sites in different home ranges where harvesting triggers a report of displacement.

Removing previously reported displacements from the cumulative total will be based on the post-harvest performance of owls within the home range in which harvesting triggered the original report of displacement. The performance criteria are based upon occupancy and/or reproduction of any owls at a site; i.e., different owls occupying a site will be judged as if the same individual owls continuously occupied and reproduced at the site. Including occupancy in the criteria allows sites perennially occupied by single owls to be evaluated for removal from the displacement total. Owl performance within a home range where a displacement has been reported may be evaluated in a subsequent annual report to determine whether the displacement will be removed. This evaluation can occur beginning at the third and ending at the fifth breeding season

following a displacement. The displacement removal evaluation is applied to all sites subjected to timber harvest that caused a displacement. If a site meets the removal criteria and is removed from the displacement total, it is no longer considered a displaced owl site. The criteria for removing displacements from the total were developed from demographic data collected on the GDRCo study area and it represented the average occupancy and reproductive rates of owls. All sites not meeting the removal criteria are considered actual displacements and contribute to the 50 permitted to GDRCo.

The criteria for removing displacements from the total are as follows:

Displacement is removed in the third breeding season following the triggering of displacement if

owls nest in at least 2 years, or
owls nest in one year, with 3 years occupancy (including occupancy by single owls).

Displacement is removed in the fourth breeding season following the triggering of displacement if

owls nest in at least 2 years, or
owl(s) occupy the site for four years

Displacement is removed in the fifth breeding season following the triggering of displacement if

owl(s) occupy the site four out of five years.

If cumulative harvest occurs in a home range, the displacement removal assessment will occur between the third and fifth breeding seasons after the last harvest under a Timber Harvest Plan (THP) within the home range that triggered the report of displacement. If the owl site shifts to a new location where harvest occurs within 805 m (0.5 mile) but does not cause displacement, the last year in which harvesting triggered a report of displacement will be the starting point for evaluation of displacement removal within the five-year period. If five breeding seasons have passed since the displacement was triggered and the owls still have not met the displacement removal criteria, the original displacement will not be removed from the total.

Implementation

If a timber harvest plan was determined to require a report of direct or indirect displacement, the report was triggered when the plan was initiated, i.e. when the first tree in a THP unit was felled. This pertained to THPs that were contiguous as well as those comprised of units spaced closely together. If a THP was comprised of several units spaced widely apart, harvest progress was monitored to determine when the displacement would be reported. As indicated in the 1994 annual report, the Service agreed that timber harvest activities could continue in THPs triggering displacement during the owl breeding

season as long as no spotted owl nest was found. If a nest was found, the site was protected by measures described in HCP Section II.A.1

We monitored all owls occupying sites in which timber harvesting triggered a report of direct displacement to determine the owl(s)' response to the harvest. Harvest contractors were informed that spotted owls were in the area, and any owl behavior observed during falling operations was noted. We also conducted post harvest owl surveys as conditions allowed. If possible, the owls associated with direct displacement THPs were located before slash burning was conducted.

Each THP initiated within the reporting period that had an owl site within 805 m of the plan was evaluated for indirect displacement by using the process described in HCP Section IV.B.2. This involved estimating the amount of habitat within the 805 m radius circle around each owl site using Green Diamond's GIS and aerial photographs. If the entire 203 ha circle was not on Green Diamond land, aerial photographs were used to determine the age class or habitat category of areas outside of the ownership, because Green Diamond's GIS does not include data from other ownerships.

Results

From 1993-2005, timber harvest triggered reporting of 45 direct and 24 indirect displacements of spotted owls (Table 1.1). Twenty-five displacements were returned by 2005, yielding 44 actual displacements since implementation of the Habitat Conservation Plan (Table 1.1). Green Diamond's incidental take permit allows 50 owl pairs to be displaced in the first 16 years of the HCP term. The actual number of displacements over the first 10 year period of the HCP was 22 sites via direct displacement and 16 sites via indirect displacement. Forty percent of direct and 29% of indirect displacements were returned, although the proportion of returns from direct and indirect displacements were not statistically different ($P>0.25$).

Discussion

Under the HCP, the five-year review was not invoked because the number of displacements was less than specified in the HCP and Implementation Agreement. In addition, there were no known instances of direct harm or injury to spotted owls as a result of timber harvest operations. The number of displacements projected in the HCP over a 10-year period was three sites per year via direct modification of the nest or roost area and two sites per year via indirect displacement where habitat within the 203 ha circle was reduced below threshold levels. The actual number of displacements over the 10 year period was slightly lower than the estimated number of displacements based on harvesting model forecasts and known owl sites in 1992.

Table 1.1. Spotted owls displaced on Green Diamond lands, by territory, since implementation of the Habitat Conservation Plan. Bold (blue) font indicates direct displacement and normal (red) font indicates indirect displacement. Underscoring indicates territories that met the criteria for displacement returns. Displacements were tallied from 1 September of the previous year through 1 September of the indicated year.

Year	Spotted Owl Sites											Cumulative Displacements	Cumulative Returns	Actual Displacements
1993	Pelletreau	5700	Dolf Cr	Liscom Hill	H510	Buzzard Cr	H300					7		
1994	Boundary Cr	C2300	B140	P200	Tectah Mouth	W100						13		
1995	R200	Quarry Cr	W400	Johnson Cr								17		
1996	B-10	H110	Miñon Cr	D100								21	2	19
1997	Omagar Cr	Cappell Cr	S-12	Morek Cr	Dolly Varden	Lower Dry Cr	Lake Mtn	4230 #1	Powerline North	NF 1300	Ayres Cabin	32	4	28
1998	R1400	T300	Salmon Cr #2	Old 299 #2	Fielder Cr							37	6	31
1999	A400	6400	Klamath Mill	Salmon Cr East	Upper S.F. #2							42	8	34
2000	Bear Gulch	Boundary Cr	Cuddeback South	Little River #1	Upper Little R.	Upper S. F. #1	Walsh					49	13	36
2001	G400	Henderson Gulch	Lower Dolf Cr	Lower S.F. #1	NF1300	Ryan Cr						55	17	38
2002	R13	M-Line Cr	Little River #2	HWY 101	Jackson Hill	Lower S.F. #2	Mule Cr	Quarry Cr				63	20	43
2003	R-8-1											64	20	44
2004	Upper Beach Cr	Salmon Cr East	Klamath Mill									67	23	44
2005	Upper Stevens	M1150										69	25	44

CHAPTER 2
SPOTTED OWL HABITAT

2.A. COMPARISON OF ACTUAL AND ESTIMATED DISTRIBUTION OF SPOTTED OWL HABITAT

A major premise of Green Diamond Resource Company's (GDRC) Habitat Conservation Plan (HCP) for the northern spotted owl was that habitat suitable for owls would increase throughout the 30-year period of the plan. The HCP defined suitable northern spotted owl habitat as forest stands >30 years old because at least some stands in this age class were known to be used by spotted owls for foraging, roosting, and nesting (Folliard 1993). At the time, it was assumed that recently regenerated stands (0-5 years) had no direct value to owls. Stands 6-30 years were known to be woodrat habitat (Hamm 1995) and therefore potential spotted owl foraging habitat. Foraging, roosting, and occasional nesting occurred in stands 31-45 years old, and forest stands >45 years old were considered to be prime nesting and roosting habitat as well as foraging habitat.

The areal distribution in each of the forest stand age classes changes through time as stands age and enter older age classes or as stands are harvested and enter younger age classes. In addition, land acquisition and disposal by GDRC also affects the distribution of stand ages. Re-mapping of stands due to improved timber cruise data was believed to have a negligible effect on the distribution of stand ages.

Methods and Results

We used GIS to estimate the area of spotted owl habitat between 1992 and 2022 at ten-year intervals on a common land area and on a variable land area over time that accounted for land acquisitions and disposals. Based on the original HCP definition, owl habitat increased 51% from 58,257 ha (143,956 acres) in 1992 to 88,048 ha (217,572 acres) in 2022 (Table 2.1) on the common land area. When land acquisitions and disposals are included over the same time period, the amount of owl habitat increased approximately 60% from 65,896 ha (162,832 acres) in 1992 to 105,333 ha (260,285 acres) in 2022 (Table 2.2).

Table 2.1. Area of Green Diamond Resource Company (GDRC) land (hectares) in spotted owl habitat from 1992 to 2022 as defined in the GDRC Habitat Conservation Plan for the northern spotted owl.

Stand Age (yrs)	1992	2002	2012	2022
31-45	30,530	48,712	39,754	29,602
46+	27,727	31,929	50,325	58,446
Owl habitat	58,257	80,641	90,079	88,048

Table 2.2. Area of Green Diamond Resource Company (GDRC) land (hectares) in spotted owl habitat from 1992 to 2022 at ten-year intervals as defined in the GDRC Habitat Conservation Plan for the northern spotted owl. The acres displayed include land acquisitions and disposals that have occurred since implementation of the HCP.

Stand Age (yrs)	1992	2002	2012	2022
31-45	31,877	54,435	44,144	38,901
46+	34,019	52,821	60,579	66,432
Owl habitat	65,896	107,256	104,723	105,333

Discussion

The inclusion of newly acquired timberlands under Green Diamond Resource Company's HCP was provided for in the Implementation Agreement and permit. However, the level of authorized displacement was fixed regardless of how much additional area was added to GDRC ownership. During development of the HCP, timber harvest and growth modeling predicted that the amount of spotted owl habitat would increase on GDRC land through 2022. Current analyses indicate that habitat did increase during the first 10 years of the HCP, and growth of forests into owl habitat is predicted to continue through the term of the HCP.

CHAPTER 3
BIOLOGY

This chapter is based on the requirement for "a reevaluation of the biological basis for the conservation strategy based on the data collected through the research program and other sources." The fundamental premise of the conservation strategy was that spotted owl habitat would develop following timber harvest such that loss versus re-growth of habitat could be balanced over time.

3.A. SPOTTED OWL DIET

Spotted owl diets are easily inferred from analysis of pellets (egested prey remains) found below owl nesting and roosting sites. Five studies have reported the frequency of prey items and the relative biomass of prey items at 13 study sites from across the range of the northern spotted owl (Cutler and Hays 1991, Ward et al. 1998, Forsman et al. 2001, Hamer et al. 2001, Forsman et al. 2004). Across studies, small mammals made up 81-98% of the prey items and 81-99% of biomass consumed by owls. Northern flying squirrels (*Glaucomys sabrinus*) were the primary prey species in the Olympic Peninsula (1 study area), Washington Cascades (3 study areas), Oregon Cascades (4 study areas), and 2 of 3 study areas in the Oregon Coast Range, comprising 29-52% of prey items and 45-75% of prey biomass. Woodrats (*Neotoma* spp.) dominated the diet in the Oregon and California Klamath province (1 study area each), comprising 28-39% of prey items and 49-71% of prey biomass. In the southern Oregon Coast range (1 study area), flying squirrels made up 36% and woodrats made up 18% of prey items, but each prey group made up 37-39% of prey biomass.

Rabbits (primarily *Sylvilagus bachmani* – brush rabbit) and/or hares (primarily *Lepus americanus* – snowshoe hare) were important components of spotted owl diets, especially in Oregon and Washington, where they comprised up to 16% of prey biomass. Microtine voles (*Microtus* spp.), comprised up to 10% of prey biomass, pocket gophers (*Thomomys* spp.) comprised up to 9% of prey biomass, western red backed voles (*Clethrionomys californicus*) comprised up to 8% of prey biomass, American pikas (*Ochotona princeps*) comprised up to 6% of prey biomass, and deer mice (*Peromyscus* spp.) comprised up to 5% of prey biomass on individual study areas (Cutler and Hays 1991, Ward et al. 1998, Forsman et al. 2001, Hamer et al. 2001, Forsman et al. 2004).

Other prey groups found in owl pellets and comprising 0-5% of prey biomass in each study area include shrews (*Sorex* spp), shrew-moles (*Neurotrichus gibbsii*), moles (*Scapanus* spp.), bats (*Chiroptera*), Douglas squirrels (*Tamiasciurus douglasii*), chipmunks (*Tamias* spp.), gray squirrels (*Sciurus griseus*), tree voles (*Arborimus* spp.), heather voles (*Phenacomys intermedius*), frogs, snakes, snails, insects, crayfish, and a scorpion (Cutler and Hays 1991, Ward et al. 1998, Forsman et al. 2001, Hamer et al. 2001, Forsman et al. 2004). Forsman et al. (2004; Appendix) listed 49 mammalian and 41 avian species found in owl pellets in Oregon.

Although woodrats and/or flying squirrels are the primary component of the northern spotted owl's diet, there is evidence that secondary species may be seasonally important and/or influence spotted owl survival and reproduction. For example, predation by spotted owls on snowshoe hares in Washington occurred mostly in spring and summer. Rosenberg et al. (2003) found that deer mouse abundance was positively associated with spotted owl reproductive success in western Oregon (r^2 = 0.68), even though deer mice made up < 2% of the owl diet over all years (0-4% in each of 9 years).

Home range size of northern spotted owls was shown to be linked to the owls' primary prey in the Klamath province of southern Oregon and northern California (Zabel et al. 1995). Home ranges were larger where flying squirrels dominated the diet, and smaller where dusky-footed woodrats (*Neotoma fuscipes*) dominated the diet. This was attributed to the larger body size and higher population density of the woodrats (Zabel et al. 1995).

3.A.1. Spotted owl diet on Green Diamond Resource Company land

Methods

Since 1989, regurgitated pellets were collected opportunistically during spotted owl demographic studies and other spotted owl surveys pursuant to GDRC's NSO Habitat Conservation Plan (HCP). Pellets were collected below roosts or nest sites during breeding season site visits or whenever spotted owls were encountered as part of HCP surveys. Consequently, not all collections were from spotted owls with established territories. Pellets were placed in small plastic bags, labeled, and frozen. Pellets were periodically dissected for content analysis. Where possible, pellet contents were identified to species or placed in categories at the most detailed taxonomic level possible. Pellet contents were also examined for hair fragments of species that may be underrepresented by bone fragments and teeth (e.g. brush rabbits, *Sylvilagus bachmanii*). A collection was comprised of ≥1 regurgitated pellet or prey item collected at a specific site or area during a survey or site visit. A paucity of collections in certain years prevented comparisons between all years and prey species. Therefore, collections were combined as "time periods" one through three. Years 1989-1993 were time period one, 1994-1998 period two, and 1999-2004 period three. Green Diamond ownership was divided into four geographic areas for analysis: Klamath, Korbel, Upper Mad River and Redwood Creek. These areas represented latitudinal as well as longitudinal differences in vegetation types and forest age classes. For reporting purposes and due to difficulty in identification of all prey items to species, we organized pellet contents into seven major groups of species (Table 3.1). Data were summarized as percent composition and percent biomass for all sites combined. Calculations of prey biomass were made from data presented in Forsman (1984) and from in-house data collection on woodrats by multiplying mean weights of species by the number of individuals identified. We examined differences in observed and expected counts of species and species group occurrences between years, time periods and geographic areas using a Chi-square test of independence.

Results

From 1989-2004 we made 965 collections that were composed of 3,056 identifiable prey items ($\bar{x}$ =1.40, SE = 2.15) on the Green Diamond study area. A minimum of 32 different animal species (Appendix 3.A) were identified in the pellets collected at 245

Table 3.1. Percent frequency and percent biomass of major animal species or species group identified from 3,056 prey items in 965 collections of regurgitated northern spotted owl pellets collected on the Green Diamond Resource Company study area, 1989-2004.

	Neotoma	*Sylvilagus*	*Glaucomys*	OSRI[1]	*Arborimus*	Aves	*Peromyscus*	Other[2]
% frequency	48.4	2.7	10.0	11.1	16.3	4.0	5.0	2.5
% biomass	73.9	8.9	7.7	3.9	2.9	1.8	0.7	0.2

[1] OSRI (Other Small Rodent or Insectivore)
[2] Other (Insecta, Chiroptera, Mustelidae, Teleolstei, Reptilia)

different owl sites or locations across the study area. Mammals represented 93.8% of the diet, birds 4.0%, insects 1.5% and reptiles 0.7%. The overall mean weight of prey items was 150.5g (SE = 2.0). The major species or groups identified and percent composition of the diet is shown in Table 3.1. Rodents and insectivores comprised 90.8% of the owls' diets. Birds, lagomorphs and other prey items accounted for the remaining 9.2%. Many of the avian prey could not be identified to species, but band-tailed pigeon (*Columba fasciata*) and Stellar's jay (*Cyanocitta stelleri*) were two identifiable species of avian prey. The most common rodent species in the diets was the dusky-footed woodrat (*Neotoma fuscipes*) with 48.4% frequency and 73.9% of the biomass. Woodrats were present in pellets collected at 89.8% of the owl sites or collection locations. The northern flying squirrel (*Glaucomys sabrinus*) occurred at a frequency of 10.0%, comprised 7.7% of the biomass and was found at 53.5% of the owl sites or locations. The Sonoma tree vole (*Arborimus pomo*) and red tree vole (*A. longicaudus*) comprised 16.3% of the diet, 2.9% of the biomass and were found at 50.2% of the sites or locations. The brush rabbit was the primary lagomorph present in the diet with 2.7% of the frequency and 8.9% of the biomass. Lagomorphs occurred at 24.9% of the sites. Deer mice (*Peromyscus maniculatus*) were present but in relatively low frequency (5.0%) and biomass (0.7%) but they occurred at 33.9% of the sites.

The chi-square tests for independence of observations resulted in rejection of the null hypothesis of no difference when comparing species observed and expected occurrences across years, time periods and geographic areas. The analysis of time periods indicated a significant difference in species occurrences across the three time periods ($\chi 2$ = 60.29, P = 0.000, d.f. = 14). The prey species groups that varied the most over time (greatest chi-square contribution) were Aves, OSRI and Other. The presence of tree voles also appeared to be variable over time with more observations than expected in the second time period. The most common prey item, dusky-footed woodrats, showed the least amount of variation over time. The analysis of geographic

areas also showed a significant difference in observed and expected counts of prey items across the four regions ($\chi 2 = 143.72$, $P = 0.000$, d.f. = 21). The species that exhibited the greatest amount of variation across geographic areas were tree voles, flying squirrels, OSRI and brush rabbits. Birds, dusky-footed woodrats, and Other exhibited the least amount of variation across areas. A chi-square test for independence between the three most common rodent species (tree voles, flying squirrels and woodrats) and all other species combined from 1989-2000, resulted in a significant difference in observations across years ($\chi 2 = 159.21$, $P = 0.000$, d.f. = 33). The analysis of annual data for tree voles, flying squirrels, woodrats and Other from 1989-2000, indicated that the occurrence of woodrats in diets varied the least over this 12-yr period. Tree voles showed the greatest amount of variation over the 12-yr period, followed by flying squirrels.

Discussion

Composition of Diet

In our study area, spotted owl diets consisted of a variety of small mammals, birds, reptiles and insects. Our results were similar to other studies where small mammals dominated the diets but a few species in particular contributed to the majority of the biomass and frequency. Our results of the prey base analysis are consistent with other studies within the California range of the northern spotted owl where woodrats predominate. Barrows (1980) found that dusky-footed woodrats were the predominant prey item in northern California and that northern flying squirrels and tree voles ranked second and third respectively in biomass. Zabel et al. (1995) found that woodrats were the most frequently encountered prey items in the northern California portion of their study area. Similarly, Smith et al. (1999) found that dusky-footed woodrats dominated the diets of California spotted owls in terms of frequency and biomass. Our results closely mirrored those of Smith (1999) in frequency of woodrats and overall biomass of mammals. In our study area, the dusky footed woodrat dominated the diets comprising almost three-fourths of the biomass. In southwestern Oregon, Cutler and Hays (1991) found that northern flying squirrels dominated the diets at four high elevation sites. They also found that bushy-tailed woodrats (*Neotoma cinerea*) were an important component of the diet biomass. Rosenberg et al. (2003) found that northern flying squirrels dominated the diets in western Oregon while leporids and bushy-tailed woodrats were other important components of the diet in overall biomass. Forsman et al. (2004a) reported that spotted owl diets in Oregon were dominated by mammals with northern flying squirrels most numerous across their seven regional study areas. Woodrats were most important in the interior southwest and south coast regions of their study and red tree voles were important in the south coast and central coast areas. The interior southwest and south coast regions were nearest to our study area. Zabel (1995) also found that northern flying squirrels and woodrats were taken in similar numbers in their northernmost California study area and flying squirrels and red tree voles dominated the Oregon study area. In Washington, Forsman et al. (2001) found that northern flying squirrels were the most important prey item in most areas. Northern flying squirrels were the third most frequent species encountered in diets in our study area and analyses across regions indicated that flying squirrels were more abundant in diets in the Klamath region (from the Klamath River north to the Oregon border)

indicating a similar shift in prey as observed in other studies. The three most common species in the diet (woodrat, tree vole and flying squirrel) are arboreal or semi-arboreal, consistent with the observation that spotted owls spend most of their time foraging in the forest canopy (Forsman 1984, 2001), although it is unknown where the prey were located at the time of capture.

Annual Variation

In our analysis, the observed variation in diets of spotted owls across time periods and years is likely due to annual fluctuations in prey species abundance. However, this variation does not appear to represent large shifts in the owls' diets from one prey species to another. We do not have annual data on prey species abundance to compare with percentages represented in the diets. Similar to our observation that woodrats varied the least over time, Smith (1999) found that the percentage of woodrat biomass in diets of California spotted owls did not differ among years. The variation in numbers of birds taken between time periods in our study could be a result of opportunistic prey switching in certain years when some species of birds were more abundant. We were not able to analyze the contribution of birds to diets on an annual basis or determine which species were more abundant, but their frequency in the diet could be related to climatic conditions that favor greater reproductive success for bird species and subsequently a more abundant prey source for spotted owls. Small mammals (mainly rodents and insectivores) and "Other" prey items exhibited more variation than the two most abundant prey species, woodrats and flying squirrels. However, combining the data into time periods will likely mask any substantial annual fluctuations in prey species abundance. We could not analyze all years separately due to a low number of collections toward the end of the study period, but annual comparisons of the more prolific prey species over decade one suggested that tree voles and northern flying squirrels exhibited greater variation than woodrats and all other prey species combined. The variation in tree voles over time is consistent with the observation of others regarding annual fluctuations in populations of Microtine rodents (Pugh et al. 2003). We have anecdotal observations that vole nests are rather ephemeral and data from Thompson and Diller (2001) indicated that the median persistence time for vole nests was 28.6 months and the probability of nests persisting beyond 60 months was <0.1. In Washington, Forsman et al. (2001) observed small changes in the annual diets of owls at certain territories where the primary source of biomass shifted from flying squirrels to snowshoe hares, and in Oregon Forsman et al. (2004) observed similar small annual fluctuations overall, but red tree voles and deer mice did have larger fluctuations in frequency at certain territories. Their data did not suggest large annual changes in relative abundance of different prey items across the regions. We suspect some bias in the pellet collections in that territories where pairs successfully reproduce may tend to over represent the prey items being taken because these owls are more easily located than non-nesting owls and a greater number of pellets can be collected at these sites.

Regional Variation

Our data on composition of spotted owl diets suggests that woodrats are widespread across the study area, and on an annual basis, they provide a relatively stable prey

base for spotted owls. Studies of woodrat abundance and habitat use on GDRCo lands (Hamm 1995, Hughes 2006, see below) indicate that woodrats are present in all stand ages represented on the ownership but are most abundant in the young seral stages (5-30 yrs) of redwood and Douglas-fir forest. Smith et al. (1999) observed a positive relationship between elevation and percent biomass of woodrats in pellets of California spotted owls. They speculated that this relationship may have resulted from a vegetational gradient and a lack of other medium sized small mammals at higher elevations. We did not examine the relationship with elevation in our study. Tree voles exhibited the second greatest amount of variation among regions within our study. Given the life history characteristics of this species, it is not surprising that occurrence is likely to vary across geographic area as does the tree species that is the primary component of their diet. The coastal redwood zone does not likely provide the optimum habitat for this species, which feeds almost exclusively on conifer needles except for redwood. Hemlock, Douglas-fir and white fir are present in the redwood dominated areas, and tree voles do occur there, but the amount of fir increases along an eastern gradient and with increasing elevation. Given the food habits of this species, we may expect to see an increasing occurrence of this species as palatable conifer species become more prevalent on the landscape. Tree voles did occur at approximately one-half of the collection locations, indicating a well-dispersed prey base. Tree voles occurred more often than expected in pellets collected from owl sites at our easternmost region. This area is comprised entirely of Douglas-fir and oak woodland habitat that may be favored by tree voles. Northern flying squirrels were the third most frequent species encountered in diets in our study area and analyses across regions indicated that flying squirrels were more abundant in diets in the Klamath region (from the Klamath River north to the Oregon border). This is consistent with other studies in Oregon where flying squirrels become the predominate prey item for spotted owls. Our sample sizes for some species were not large enough for valid comparisons, but the empirical data on species such as pocket gophers and other microtinae suggested that they were preyed upon more frequently in the southeastern portion of the ownership in the Douglas-fir/oak woodlands with intermixed natural grasslands, which is the typical habitat for these species.

Size of Prey

Numerous studies have shown that spotted owls primarily forage on medium sized small mammals such as woodrats and flying squirrels (Courtney et al. 2004). Our data support this observation, although the mean mass of prey in our study was generally greater than observed in other studies (Forsman et al. 2001, 2004). The proximate cause is due to the greater percentage of woodrats in the diet of owls in our area. The mass of woodrats is generally 1.5-2 times that of the average flying squirrel, the primary prey item observed in Washington and Oregon. We speculate that the ultimate cause for this high percentage of woodrats in the owl's diet in our study area occurs because woodrats appear to be the most abundant and available food source to spotted owls. In our area, dusky-footed woodrats, exhibited the least amount of variation over time and geographic area. In addition, this species was found at almost 90% of the collection locations.

Conclusions

Dusky-footed woodrats were the most important prey item in our study area, but tree voles and flying squirrels were also important in overall composition of the diet. In some areas, brush rabbits may be an important seasonal component of the diets by contributing substantially to the biomass. Managing forest seral stages to promote an abundance of woodrats is likely to have the greatest positive influence on spotted owl populations in our area. However, consideration for the habitat requirements of the other important prey species such as tree voles, flying squirrels and brush rabbits will provide for a more diverse prey base for spotted owls.

3.A.2. Summary of northern spotted owl diet from nearby areas

In Redwood National and State Parks, 369 individual prey items were identified from 194 spotted owl pellets (Schmidt 2005). The majority of prey items were woodrats (31%), Sonoma tree voles (18%; *Arborimus pomo*), northern flying squirrels (10%), and microtine voles (9%). Deer mice, pocket gophers, birds, brush rabbits, shrews, gray squirrels, California red-backed voles, and bats each comprised < 5% of prey items (Schmidt 2005).

3.B . WOODRAT ECOLOGY

3.B.1. Woodrat ecology on Green Diamond Resource Company land

The dusky-footed woodrat (*Neotoma fuscipes*) is a nocturnal rodent that is semi arboreal and endemic to the Pacific coastal states. The species occurs in a wide variety of habitats including chaparral, oak woodlands, pinyon and juniper woodlands, and coniferous forests from Baja California north to the Columbia River. In California, the woodrat is found from sea level at the coast to 2700 m at its eastern limits of distribution in Baja California and in the Warner Mountains of northeastern California (Murray and Barnes 1969, Hall 1981). There is little information on the abundance patterns and habitat associations of dusky-footed woodrats in the coastal redwood (*Sequoia sempervirens*) and transitional redwood/Douglas-fir (*Pseudotsuga menziesii*) region of California.

Dusky-footed woodrats typically are associated with dense vegetation that offers protective cover, an abundant food source and sites for construction of stick “houses” (Hooven 1959, Horton and Wright 1944, Murray and Barnes 1969). Cover for protection is vital and as such, the dusky-footed woodrat is absent from open grasslands and woodlands lacking underbrush (Hooven 1959). As a packrat constructing large dwellings composed of sticks and plant clippings, the woodrat attracted the interest of researchers investigating its habitat associations and abundance patterns in oak (*Quercus* sp.) woodlands (Linsdale and Tevis 1951, Vreeland and Teitje 1999), Douglas-fir (*Pseudotsuga menziesii*) associations (Hooven 1959), juniper (*Juniperus* sp.) woodlands and chaparral habitats (Cranford 1977). The dusky-footed woodrat was also identified as an important small mammal reservoir for tick-borne agents such as

Borrelia burgdorferi (Lyme disease) (Brown and Lane 1992, 1994), granulocytic ehrlichiae (Nicholson et al. 1999), the piroplasm parasite *Theileria youngi* (Kjemtrup et al. 2001), a contributor to tree damage in young Douglas-fir forests (Nettleton 1957, Hooven 1959) and as an important prey species for forest carnivores and raptors, particularly the northern spotted owl (*Strix occidentalis caurina*) (Thomas 1990).

The predator-prey association between northern spotted owls and dusky-footed woodrats also initiated studies on abundance of dusky footed woodrats (Sakai and Noon 1993), spotted owl reproduction and fitness (Ward et al. 1998, Thome et al. 1999), and spotted owl habitat use (Carey and Peeler 1995, Zabel 1995). In California, dusky-footed woodrats were most abundant in early stages of Douglas-fir forest regeneration (Sakai and Noon 1993), but in Oregon, Raphael (1988) observed a bimodal distribution where dusky-footed woodrats were abundant in young as well as mature and old growth stands. Carey et al. (1999) found that empirical counts of dusky-footed woodrats in mixed conifer forests of Oregon suggested abundance was greater along streams and in old forest than young (40–90 yr old) managed forests. In Oregon, there is a shift in prey consumption by spotted owls with northern flying squirrels becoming predominant. The dusky-footed woodrat is rare in spotted owl diets in northern Oregon and absent in Washington since its northern distribution ends at the Columbia River. The dusky-footed woodrat may function in a role as a keystone species in coniferous forests of northwest California, because of its potential influence on populations of spotted owls and other forest predators.

Green Diamond Resource Company (GDRCo) conducted studies of dusky-footed woodrats in redwood forest in 1992-1993 (Hamm 1995) and in Douglas fir forests in 2000-2001 (Hughes 2006). We also conducted a retrospective study to investigate woodrat abundance in relation to stand age and forest thinning in redwood forests in 1999.

The woodrat studies were conducted on private timberlands owned by Green Diamond Resource Company. The study area was located in Humboldt County, California within the Redwood Creek, Mad River and Little River watersheds. Within the Redwood Creek and Mad River portion of the study area, the majority of the forested areas were clearcut harvested at least once starting ca. 1920 resulting in a landscape of second and third growth forest from zero to 80 years of age. In the Little River watershed, the second growth land base was managed by the Louisiana–Pacific Corporation (LP) until July of 1998 when Green Diamond Resource Company purchased the approximate 28,340 ha ownership. This area was also subjected to clearcut harvesting starting ca 1920, but after 1991, LP began conducting large acreage commercial thinnings where 25–50% of the conifer basal area was removed in one or more logging entries. Under this silvicultural regime, most of the poorly formed and defective conifers were removed as well as the hardwood component. This management regime resulted in stands that were relatively homogeneous in overstory tree species composition and age. Coast Redwood was the predominant conifer over most of the coastal Mad River and Little River watersheds with Douglas-fir becoming common in the higher and more xeric locations in the inland Mad River and Redwood Creek areas. Hardwoods such as

Tanoak (*Lithocarpus densiflorus*), Red Alder (*Alnus rubra*), Pacific Madrone (*Arbutus menziesii*), California Bay (*Umbellularia californica*), and Big-Leaf Maple (*Acer macrophylum*) were common stand components. Elevations ranged from near sea level to 1828 m. Mean summer temperatures were 18 C, and annual precipitation was 81 cm in 1992, 110 cm in 1993 and 100 cm in 1999 (National Weather Service, Eureka, CA).

3.B.1.i. Woodrat studies in redwood forests

Objectives

The objectives of the woodrat studies in redwood forests were to: (1) estimate abundance of dusky-footed woodrats in four seral stages of coastal redwood forest that had been clearcut harvested; (2) estimate abundance of woodrats in redwood forest that had been subjected to varying levels of commercial thinning as the silvicultural treatment; and (3) develop habitat models predicting woodrat occurrence within the thinned stands.

Methods

We conducted fieldwork from April to October 1992–1993 and from August to November 1999. We used a stratified random sampling design to select 24 forested stands in 1992–1993 and 15 stands in 1999 that were >16 ha and accessible by vehicle or a short hike (< 15 min). We sampled ≥ four stands from four age categories: seedling/shrub (5–9 yr); sapling/brushy pole timber (10–20 yr); small sawtimber (21–60 yr); large sawtimber (61–80 yr). The age categories corresponded to stand development criteria used in other studies (Carey 1991, Sakai and Noon 1993). We used forest inventory data contained in GDRC's Geographic Information System to ensure that sampling was restricted to redwood dominated stands. In 1999, we sampled four clearcuts 9–15 yrs of age and 11 stands 50–70 yrs old with varied levels of commercial thinning harvest. For sampling purposes, we categorized thinned stands as light, medium and heavy based on the basal area removed (light = least volume removed). We placed thinned stands into discrete categories for comparative purposes; however, the thinning gradient exists as a continuum. The thinned stands were harvested 6–8 yrs prior to this study. Based on our previous studies in 1992–93, this provided sufficient time for woodrats to colonize the thinned stands.

We used a random process to locate two live-trapping grids in each selected stand with the following constraints: (1) Grids were >100 m apart; (2) Grids were randomly placed 15–30 m from roads. Live-trapping grids were 1.2 ha and consisted of 100 Tomahawk live traps (Model #201 Tomahawk Live Trap Co., Tomahawk, WI) placed at the intersections of a 12-m grid. We baited traps with dry COB horse feed (rolled corn, oats, and barley) and covered them on three sides with four mil black plastic to minimize exposure of captured animals. We trapped for five nights. However, trapping was discontinued after three nights if no woodrats were captured and sign of woodrats (houses, latrines, fresh clippings of vegetation) was absent from the area. Dusky-footed woodrat sign is typically very conspicuous, and if resident individuals are present, they are easily captured within three nights of trapping even when in low abundance (K. Hamm, pers. obs.).

We checked traps every morning and tagged captured woodrats in both ears with identically numbered ear tags (#101, National Band and Tag Co., Newport, KY). At each capture location, we recorded age class (adult, subadult, juvenile; Linsdale and Tevis 1951), sex, mass (g), reproductive condition and trap number. We promptly released individuals at the site of capture following handling. We did not trap during the week of a full moon or during precipitation. We estimated abundance of woodrats on each trapping grid as the minimum number known to be alive (MNA).

In 1999, we sampled vegetation at 15 trap stations within the 100-trap grid. We randomly selected 1 of 10 trap lines and then randomly selected a number between 1 and 10, which corresponded to a trap station, to begin sampling. Once the first trap station was selected we selected every third station within the line and every other trap line. At each of the 15 trap stations, we sampled ground cover along an 8 m transect. The 8 m transect was oriented in a random direction from 1–360º. Ground cover was classified into 1 of 5 categories (Table 3.2). We estimated the percent slope at each station and averaged it across the grid. Orientation of each trapping grid was estimated using stereo-pair aerial photographs and placed into 1 of 8 categories (N, NE, E, SE etc.). We estimated log volume (m^3/ha) by measuring the length and diameter of logs (≥ 9 cm on the small end) when the log was located within a 4 m wide belt transect established between the trap stations sampled on each line within a grid. We calculated stem density and basal area of trees using variable radius (20 basal area factor glass prism) plots centered at the 15 trap stations. We recorded species and diameter at breast height (dbh) for trees within plots.

In 1999, we assessed understory foliage density (shrub layer) through ocular estimates of the percentage vegetation obscuring a cover board (Nudds, 1977). Foliage density (vertical cover) was the relative amount of leaf-bearing stems and leaves present. The cover board was 2.0 m high, 30.5 cm wide and it was divided into 4-0.5 m segments alternately painted red and white. We estimated foliage cover at the 15 randomly chosen trap stations by selecting a random direction and placing the board 8 m from the trap station in the random direction. The distance of 8 m was chosen because this distance produced the greatest variability in percent cover in a pilot study in our area. We ranked the foliage cover for each height interval as a single density score ranging from 1 to 5, which corresponded to the mean percent concealment for the following ranges: 0–20; 21–40; 41–60; 61–80; 81–100. We recorded the predominant type of vegetation obscuring each 0.5 m band and calculated the proportion for each vegetation type across the grid.

We used non-parametric tests (Kruskal and Wallis 1952, Zar 1974) on data from each of the 4 age classes and thinning treatments to assess differences in woodrat abundance among age classes and thinning treatment groups. We identified differences among age classes and treatment groups using Tukey-Kramer multiple comparisons.

We fit a Poisson generalized linear model with logarithmic link (McCullough and Nelder, 1989) in the regression analyses using MNA from individual trapping grids in thinned forested stands as the response variable. We excluded clearcuts from regressions, because woodrat abundance estimates were different in clearcuts and management

interest resided in the mature stands. We fit all possible Poisson regression models relating MNA to stand and understory variables (Table 3.2) and ranked them according to AICc (Burnham and Anderson, 2002). We adjusted standard errors of model coefficients for estimated over-dispersion (McCullagh and Nelder, 1989; Venables and Ripley, 1994). We chose to model woodrat numbers with conifer stems >45.7 cm because this diameter was relevant to seed tree retention standards under the California Forest Practice rules (California Forest Practice Rules, 2006) and these trees represented dominant or codominant overstory trees. Due to high correlation among conifer stems >45.7 cm, conifer and hardwood stems >45.7 cm, basal area of conifers >45.7 cm and basal area of conifers and hardwoods >45.7 cm, only 1 of these variables was allowed in the model at a time. We considered all two-way interactions between the stand variables and topography variables (slope and aspect). We developed an understory vegetation model using the same approach as described for the stand model.

Table 3.2. Forest stand and understory vegetation variables considered in regression model of woodrat abundance on Green Diamond Resource Company land (after Hamm and Diller 2006).

Forest stand variables	Metric
aspect	°
$\bar{x}$ slope	%
conifer stems >45.7 cm dbh	#/ha
conifer and hardwood stems >45.7 cm dbh	#/ha
basal area conifer stems >45.7 cm dbh	m^2/ha
basal area conifer and hardwood stems >45.7 cm dbh	m^2/ha
Forest understory variables	
leaf litter ground cover	%
open dirt ground cover	%
small wood ground cover	%
large wood ground cover	%
moss ground cover	%
log volume (≥ 9 cm on the small end)	m^3/ha
$\bar{x}$ understory cover board value	%
redwood (*Sequoia sempervirens*) coverboard value	%
rhododendron (*Rhododendron macrophylum)* coverboard value	%
tanoak (*Lithocarpus densiflorus*) coverboard value	%
huckleberry (*Vaccinium ovatum*) coverboard value	%
salal (*Gaultheria shallon*) coverboard value	%

Results

During 1992–1993, we captured 1,527 individual woodrats. Woodrat abundance was greatest in the 2 youngest age classes of forest (χ^2 = 13.6, df = 3, P = 0.003) and estimates were 12 to 90 times greater than the 2 older age classes of forest. Woodrat abundance decreased as age of forest increased (r = -0.66, P <0.001). In 1999, we captured 258 woodrats. Our abundance estimates obtained in clearcuts trapped in 1992–93 and 1999 were similar and confidence intervals overlapped, but we did not test for differences in estimates, because trapping occurred at different times of the year. Woodrat abundance differed between clearcuts and thinned forests (χ^2 = 12.54, df = 3, P = 0.006, Table 3.3) and mean estimates of abundance in stands <20 years old were ≥ 12 times the estimates from thinned mature stands (Table 3.3). Abundance estimates from mature unthinned stands and mature thinned stands were similar, although woodrats were rare or absent in mature stands (Table 3.3).

Table 3.3. Estimated mean number ($\bar{x}$) and standard error (SE) of woodrats captured by live-trapping in 1992–93 and 1999 (after Hamm and Diller 2006). Means within columns followed by the same letter do not differ. *n* indicates the number of stands sampled for each age class/thinning treatment.

Age Class (yrs)/Thinning	$\bar{x}$	SE	*n*
1992–1993			
5–9	45.1 A	9.0	8
10–20	45.8 A	10.2	8
21–60	3.6 B	1.4	4
61–80	0.5 B	0.5	4
1999			
5–20	29.8 A	6.5	4
Heavy Thinning	2.5 B	0.3	3
Medium Thinning	0.6 B	0.5	4
Light Thinning	0.0 B	--	4

The top stand model based on AICc contained only density of conifer stems >45.7 cm (Table 3.4). The top AICc model estimated that the average number of woodrats per grid decreased 4.1% for every conifer stem/ha >45.7 cm (~95% C.I. = 1.5%–6.7%). A model equivalent to the top model contained basal area of trees >45.7 cm (ΔAICc = 0.04,Table 3.4). The basal area model indicated that the average number of captured woodrats per grid decreased by 11.1% for every additional m^2 of basal area in conifers >45.7 cm (approximate 95% confidence interval = 4.3% to 17.4%). Woodrat abundance increased with increasing cover of shrub layer vegetation (Figure 3.1). The estimated coefficients in the top AIC_c understory model were negative for log volume, rhodendron cover and salal while the estimated coefficient for total understory cover was positive (Table 3.4). We did not model woodrat abundance with understory vegetation in clearcuts, but our data demonstrated that of the total understory cover in clearcuts, manzanita (*Arctostaphylos manzanita*) and blueblossom (*Ceanothus thrysiflorus*) comprised nearly 40% of the mean proportion of understory cover. These species were absent in thinned stands.

Table 3.4. Top ten models of woodrat abundance incorporating stand variables and top ten models of woodrat abundance incorporating understory variables on Green Diamond Resource Company land (after Hamm and Diller 2006). See Table 3.2 for definitions of variables.

Forest stand models	AIC_c	ΔAIC_c
– conifers >45.7 cm	31.53	0.00
– basal area conifers >45.7 cm	31.57	0.04
– basal area conifers and hardwoods >45.7 cm	32.83	1.30
– conifers and hardwoods >45.7 cm	33.37	1.85
+ slope – basal area conifers >45.7 cm	33.64	2.11
+ slope – conifers >45.7 cm	34.15	2.62
+ slope – basal area conifers and hardwoods >45.7 cm	34.94	3.41
+ slope – conifers and hardwoods >45.7 cm	35.99	4.46
+ slope + conifers >45.7 cm – conifers >45.7 cm:slope	35.99	4.47
– slope – basal area conifers >45.7 cm + basal area conifers >45.7 cm:slope	36.59	5.06
Forest understory models		
– logs + understory cover – rhododendron – salal	18.22	0.00
+ understory cover + redwood – rhododendron – salal	20.11	1.89
+ large wood – logs + understory cover + tanoak	23.36	5.14
+ understory cover – huckleberry – rhododendron – salal	23.38	5.16
– logs + understory cover – rhododendron + tanoak	25.59	7.37
– leaf litter – logs + understory cover + tanoak	25.72	7.52
+ understory cover + redwood –salal	25.79	7.57
+ understory cover + redwood	25.91	7.69
–logs + understory coverc + tanoak	26.80	8.58
–small wood + understory cover + redwood	26.83	8.60

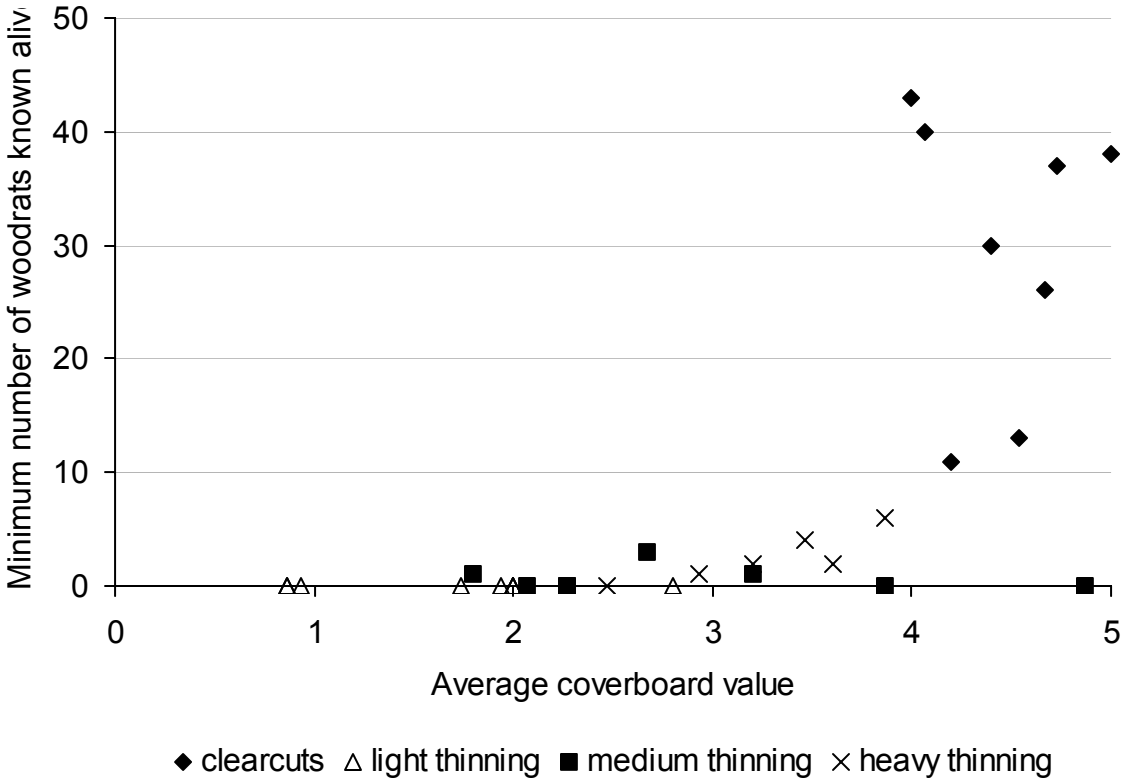

Figure 3.1. Number of dusky-footed woodrats captured on 1.2 ha live-trapping grids in coastal redwood forests during 1999 and associated average coverboard values representing density of shrub layer vegetation (0–2 m high) on each trapping grid (after Hamm and Diller 2006).

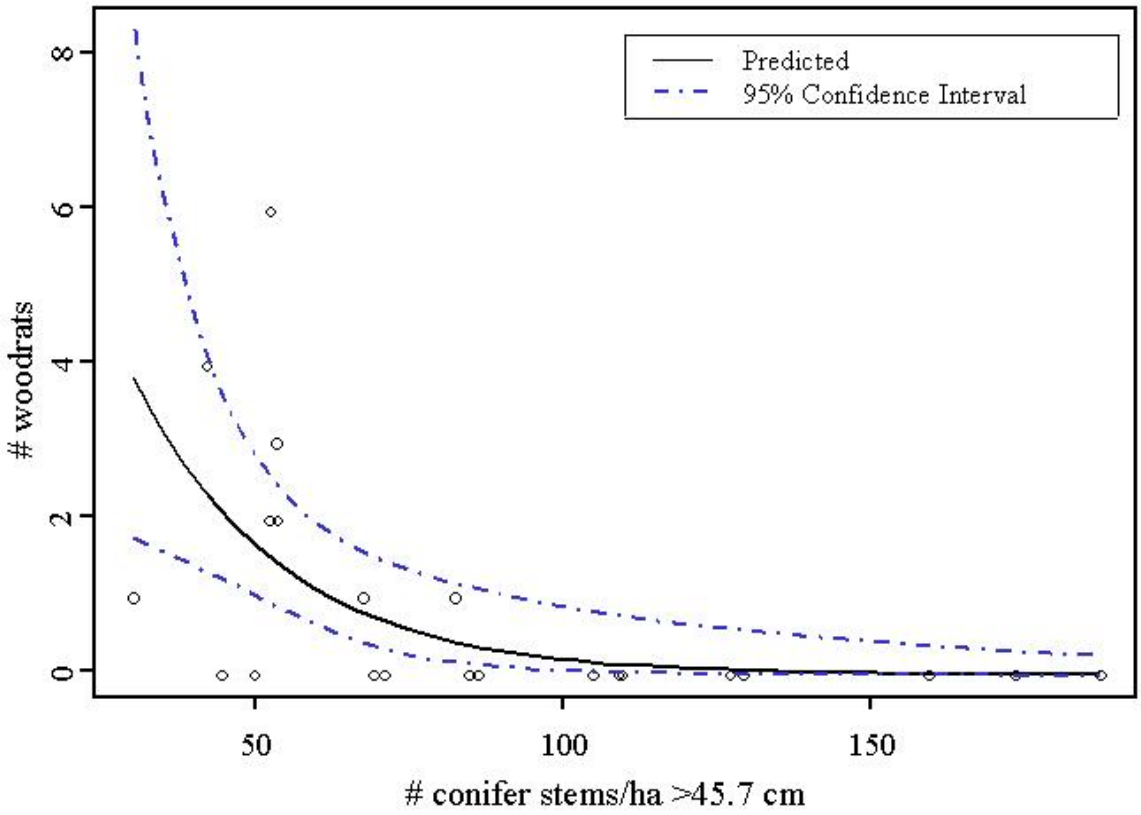

Figure 3.2. Poisson regression of woodrat captures and number of conifer stems (≥ 45.7cm DBH) per hectare (after Hamm and Diller 2006).

Discussion

The results of this study were consistent with other studies of woodrat abundance and habitat associations. Sakai and Noon (1993) found dusky-footed woodrat abundance highest in the sapling brushy poletimber stage (15–40yrs) in Douglas-fir forests in northwest California. They found that woodrats were absent in small sawtimber and large sawtimber, which equated to the 2 older age classes of forest in this study. Woodrats were rare in redwood forests >40 yrs old in our study. A recent study (Hughes 2006) in the Douglas-fir region of GDRCo ownership found a similar pattern in abundance where woodrats were most abundant in stands 5–20 yrs old, moderately abundant in stands 21–40 yrs old and rare or absent in stands >41 yrs. In Oregon, Hooven (1959) found woodrats to be abundant in young Douglas-fir regeneration interspersed with hardwood brush. Fitts and Northen (1992) found woodrat abundance was greatest in 7 and 11-year-old clearcuts in coastal redwood forest in California. Raphael (1988) reported a bimodal distribution of woodrat abundance with a peak in young stands and again in old growth Douglas-fir forests in Oregon. Older stands sometimes have natural openings created by toppling of the large trees or other

disturbances, and within these openings, the young trees and shrubs support woodrats (Carey et al. 1992). In southern Oregon and northwest California, early seral stages of forest that were vegetatively dense had the greatest woodrat abundance.

We observed high but variable numbers of woodrats in young stands in our study. The variability of woodrat numbers was likely a result of differences in vegetative quality, number of suitable nest sites, or species interactions. As forest stands mature following a disturbance such as clearcut timber harvest, they go through stages during which they are unsuitable for woodrats (recently burned clearcut), potentially optimum habitat, and then they gradually decline to marginal habitat. The shrub layer that develops likely contributes to the relative suitability of early successional stages for woodrats. The variable rate at which a stand matures may also explain the variation in woodrat numbers in young stands. The decline in woodrat numbers as a stand matures may be caused by the change in understory floristics and available food, lack of sites suitable for supporting houses, or vulnerability to predation. The number of appropriate sites for construction of houses was likely a limiting factor. Hamm (1995) found that 82% of houses encountered in young stands (5–20 yrs) were associated with redwood sprout clumps. In older stands, houses were evenly distributed among fallen trees, logs, stumps and sprout clumps. The variable density of sprout clumps (and other suitable structures) within a stand may limit the number of suitable sites for construction of houses and subsequently, the number of woodrats. Hughes (2006) also observed a high degree of variability in captures of woodrats in the 5–20 yr age class in Douglas-fir stands on GDRCo ownership and suggested that the structure and composition of sub-canopy vegetation is likely the primary influence on woodrat numbers.

Since dusky-footed woodrats are typically associated with dense vegetation, it could be expected that removal of overstory trees and the subsequent increased growth of understory vegetation may promote woodrat abundance. When forests are thinned, there is generally a short-term increase in the amount of solar radiation reaching the understory until the remaining overstory trees respond and crown growth reduces gaps in the canopy. While we did not quantify pre-harvest and post-harvest species diversity or density of understory vegetation, others studying Pacific coastal coniferous forests have quantified vegetation responses to thinning. Bailey and Tappeiner (1998) who studied paired thinned and unthinned Douglas-fir forests >50 yrs old in the Coast and Cascade Ranges of western Oregon, found that total low shrub cover (0.5–1.5 m) was negatively related to trees/ha, and the greater shrub cover in thinned stands was influenced by increased salal (*Gaultheria shallon*) and bracken fern (*Polystichum sp*) cover. Thomas et al. (1999), studying young Douglas-fir plantations in Washington, found that understory cover was greater under the most intense thinning levels, but that understory cover was highly variable and stands with low levels of thinning exhibited less shrub cover than unthinned controls. We also observed an increasing trend in average understory cover with thinning intensity, but species exhibited different responses to the treatment. For example, huckleberry (*Vaccinium ovatum*) cover was highest at intermediate levels of thinning, rhododendron (*Rhododendron macrophylum*) exhibited a consistent increase and tanoak exhibited a consistent decrease.

In young clearcut stands, manzanita and blueblossom comprised a large proportion of the shrub layer cover, but these species were absent from the older thinned stands. A

common practice after clearcutting in our study area was to broadcast burn the harvested area in preparation for reforestation. The goal of burning was to reduce the amount of small organic materials with a “cool” or low intensity burn so that conifer seedlings were more easily planted. Manzanita and blueblossom were species that invaded harvested areas where the topsoil had been disrupted and their propagation and release was increased when areas were subjected to burning (Hilton, 1989). Lack of burning and reduced soil disruption in thinned areas may preclude these species from inhabiting the site. In addition, these species are heliophilic (shade intolerant), which further precludes their establishment in forests with relatively dense canopies.

The model competing with the top model (ΔAIC_c<2.0) relating woodrat abundance to understory vegetation showed positive coefficients for average understory and redwood cover and negative coefficients for salal and rhododendron cover. While woodrat abundance can be correlated to density of shrub layer vegetation, it likely was the presence of a few plant species that ultimately influenced the carrying capacity of a particular area. Dusky-footed woodrats are considered generalist herbivores (Vestal 1938, Horton and Wright 1944); however, this species may show a preference for certain oak species (Horton and Wright 1944, Linsdale and Tevis 1951, Cameron 1971). Contrary to the prediction for many small mammal herbivores, dusky-footed woodrats are capable of digesting fibrous vegetation containing tannins and other polyphenolics (Atsatt and Ingram 1983) through ingestion of large quantities of the foliage and through storage at their houses, which may permit detoxification of vegetation during desiccation. As central place foragers, woodrats are adapted to locate their large houses near palatable vegetation and store large quantities of vegetation at these dwellings. The houses also give woodrats increased thermoregulatory abilities. Further investigation of woodrat food habits in coast redwood forest would lend insight into the patterns of their distribution and abundance in various seral stages and forest types. Although we did not quantify this, we hypothesize that certain types of vegetation in the young stands act as food sources for woodrats, because the heliophilic vegetation that grows in open situations is more palatable than shade tolerant species in mature forest. In addition, the coppice regeneration exhibited by redwood, tanoak, madrone, and maple provides sites for woodrat houses as the trees mature. Conversely mature stands that have self-thinned provide fewer sites for woodrats to construct houses. The top model for stand variables indicated a negative association of woodrats with conifers >45.7 cm. Woodrats in our area are probably not directly tied to presence or absence of overstory trees, but rather to the understory plant species diversity, vegetation density and sites suitable for constructing houses.

The dusky-footed woodrat is a key prey item for the spotted owl in California and in our study area comprises approximately 45% frequency and 74% biomass of the owls’ diet. Woodrats may become available to owls when they make forays into adjacent older stands occupied by spotted owls (Sakai and Noon 1997). In northern California (Franklin et al. 2000) where woodrats are the primary prey for spotted owls, landscapes with a mixture of old and young forest appeared to promote spotted owl fitness. Understanding the habitat associations and abundance patterns of prey species such as dusky-footed woodrats may allow biologists and forest managers to make the most

informed decisions as to how various forest management scenarios may influence prey populations and owl demographics over time.

3.B.1.ii. Woodrat study in Douglas-fir/hardwood forests

Objectives

The objectives of the woodrat study in Douglas-fir/hardwood forests were to: (1) determine whether abundance of woodrats was correlated with age of forest stands; (2) assess whether measurements of habitat composition were correlated with woodrat abundance; and (3) evaluate whether vegetation differed between woodrat house sites and random sites.

Methods

We conducted this project in June-December 2000-2001. We randomly selected stands from a GIS database. Selected stands met the following criteria: (1) area greater than 20 ha; (2) overstory dominated by Douglas-fir and/or hardwoods (>50% of the trees within the stand); and (3) located within a 30 minute hike from accessible roads. We selected stands from four age classes (5-20, 21-40, 41-60, 61+ years). We attempted to include all of the natural variation by using even-aged management units as study units; our goals were to sample the stands at a scale relevant to commercial forest management and to assess the habitat variables at a scale representative of woodrat home ranges.

During 2000, we set transects of live traps (model #201, Tomahawk Live Trap Company, PO Box 323, Tomahawk, WI USA). Traps were covered on the top and sides with black plastic sheeting to limit the exposure of captured animals to weather. A small amount (approximately the size of a closed fist) of synthetic “polyfill” was provided as material for bedding, and traps were baited with a commercially available mix of dry corn, oats and barley. Captured animals were aged as juveniles or adults, sexed, weighed, and marked on the ventral fur with hair dye (Clairol Nice’n Easy, Clairol Inc., 1 Blachley Road, Stamford, CT USA). Temporarily dyed fur was evident throughout the period of each trapping session.

We set traps along transects, rather than as grids, because transects are thought to result in reduced variation in the estimates of abundance when sampling a patchy distribution (Sakai and Noon 1993, Pearson and Ruggiero 2003). A 30m buffer-zone was established around the perimeter of each timber unit to be studied. Within this buffer, two parallel trapping transects separated by 50m were placed across the widest section of each stand. Each transect contained 25 trap stations with 10m intervals between stations. Traps were placed beside logs or under shrubs when available but all traps were set within a 1m radius of the center of the trap station to limit biases in captures. Each stand was trapped for five nights. Occasionally, trapping was postponed for one to two day periods due to inclement weather; therefore at some locations the five nights were not trapped consecutively.

We measured vegetation in seven, 0.04 ha (22.6 m diameter) circular plots placed equidistant along each set of trapping transects. We estimated overstory tree density, understory tree density (<10 cm diameter at breast height and >2 m in height), shrub cover and ground cover within each plot. We computed species-specific basal areas (James and Shugart 1970) using a Biltmore stick. Stems from sprout-clumps of overstory and understory trees were measured separately if they diverged close (< 0.5 m) to the ground. Shrub cover was measured along two "line-intercept" transects (Cook and Stubbendieck 1986) of 20 m length set perpendicularly within each plot. Ground cover was estimated within eight 1 m^2 quadrats with species or cover type recorded as Daubenmier cover classes (Table 3.5; Cook and Stubbendieck 1986). When different species created layers of cover in the ground and shrub cover estimates, only the cover of the dominant (highest) species was recorded.

Table 3.5. Daubenmier cover classes and "midpoint" values used for analysis of ground cover along woodrat trapping transects on Green Diamond Resource Company land (after Hughes 2006).

Class	Range	Analysis value
1	0 – 5 %	2.5 %
2	5 – 25 %	15.0 %
3	25 – 50%	37.5 %
4	50 – 75 %	62.5 %
5	75 – 95 %	85.0 %
6	95 – 100 %	97.5 %

During 2001, we quantified habitat variables within 20 m diameter circular plots centered on active woodrat house sites and randomly selected unoccupied plots. We searched transects perpendicular to the trapping transects in an attempt to locate and map all active houses within the area. Each house was evaluated for evidence of occupancy as described by Vreeland and Tietje (1999) with the exception that we did not use the presence of an entrance hole as an indicator of occupancy. On several occasions, we have found houses that appeared to have well developed entrances that were also covered with a heavy layer of spider webs, indicating that an entrance hole may remain long after the house has been abandoned. We recorded vegetation measurements from 10 or fewer randomly selected house plots per stand. We located an equal number of unoccupied plots in each stand by choosing locations randomly and then checking the selected locations to ensure that no active woodrat houses were located within 40 m of the plot center. However, several locations contained woodrat houses in such high density that the number of potential unoccupied plots was limited to less than ten, and in one stand, we were unable to locate any unoccupied plots. All measured plots within a stand were non-overlapping. Vegetation measurements were

identical to those described above with the following exceptions: additional ground cover categories for hardwoods and conifers were estimated directly.

We modeled woodrat abundance as a function of habitat variables using Poisson regression (Cameron and Trivedi 1998). Poisson regression is well suited for analysis of abundance data because; it assumes a Poisson distribution that is commonly appropriate for count data (Jones et al. 2002). We analyzed a model with all potential predictor variables included. This "global model" was then used to test whether the variance exceeded the mean in the data, a condition known as over-dispersion (Burnham and Anderson 2002). We found there was a limited amount of over-dispersion present in the data set. Therefore, the software S-plus (S-plus 2000, Insightful corporation, Seattle WA 98109) was used to evaluate the relationship between woodrat abundance and multiple habitat variables using "quasi-maximum likelihood estimation." Quasi-maximum likelihood adjusts the standard errors of the variable coefficients to provide more conservative estimates of coefficient variance when overdispersion is present.

We grouped variables into categories considered to be of functional importance (Table 3.6). "Primary" variables were those considered to be most likely to influence woodrat habitat use directly; these variables included ground cover, shrub cover and understory tree density. "Secondary" variables were those variables considered to influence woodrat habitat use indirectly; these variables included small woody debris (used as house building material), large woody debris (used as house building material or structural support with interstitial spaces incorporated into houses) or basal area of overstory trees. We first tested univariate relationships between the number of woodrats captured and all primary variables. Two and three variable models from primary variables were then constructed. At each stage of the model building, only those models where the coefficients of all variables were significant ($P < 0.01$) were considered for additional model development by adding additional variables. When all biologically meaningful combinations of primary variables had been considered, secondary variables were added to any suitable two variable models. All models were limited to three variables to control over-fitting of the data. Not all combinations of variables were considered to be candidate models. Variables that were derivatives of other variables were not included in the same model. For instance, shrub-level tan oak is a component of shrub-level hardwoods, all live woody shrubs and all shrub cover. Therefore, we did not combine "shrub tan oak" with these variables because the probability of autocorrelation was considered to be too high and the biological basis for doing so seemed of questionable validity. Since stand age was considered a proxy for the overall stand development in the trapping data, we did not include it as a variable in the same model that contained basal area of overstory trees.

We modeled woodrat house presence/absence using multiple logistic regression (SPSS v9.0- SPSS Inc. 233 S. Wacker Drive, Chicago Illinois 60606) following the same model building strategy as described in the population level analysis. Forty five woodrat house plots and 45 unoccupied plots were included in the analysis.

Table 3.6. Variables used in Poisson regression models of woodrat abundance (after Hughes 2006).

Code	Definition
	Primary variables
GCTO	Ground Cover of Tan oak
GCDF	Ground Cover of Douglas-fir
GCCONIF	Ground Cover of Conifers
GCHW	Ground Cover of Hardwoods
SHW	Shrub Cover of Hardwoods
STO	Shrub Cover of Tan oak
SDF	Shrub Cover of Douglas-fir
SCONIF	Shrub Cover of Conifers
AGE	Stand Age (Years Post Harvest)
SALL	Shrub Cover of all Species Combined
SALW	Shrub Cover of all Live Woody Shrubs
USHW	Density of Understory Hardwoods
USTO	Density of Understory Tan oak
USDF	Density of Understory Douglas-fir
USCONIF	Density of Understory Conifers
USALL	Density of all Understory Tree Species Combined
USALLlive	Density of all Live Understory Tree Species Combined
	Secondary variables
GCSWD	Ground Cover of Small Woody Debris (logs and dead woody material >30cm across the narrowest width)
GCLWD	Basal Area of Overstory Hardwoods
OSHWBA	Ground Cover of Large Woody Debris (logs and dead woody material >30cm across the narrowest width)
OSCONIFBA	Basal Area of Overstory Conifers

Results

We obtained 384 captures of 207 individual woodrats over 1450 trap nights. The mean weight of 106 adult female woodrats was 192.1 grams (SE = 5.25) whereas the mean weight of 73 adult males was 228.6 grams (SE = 8.53). There was no significant difference in the mean weight of woodrats trapped in stands of different age classes (Kruskal-Wallis one-way ANOVA on ranks, $\chi^2 = 2.77$, df = 2, $P = 0.25$).

Although the number of woodrats captured was significantly correlated with age of stands ($R^2 = 0.422$, $P < 0.001$), there was considerable unexplained variance in woodrat abundance, predominantly in the younger age classes (Fig. 3.3). One hundred forty-eight woodrats were captured (range = 1-55) in 9 stands in the 5-20 years-post-harvest-age-class. Fifty-one woodrats were captured (range = 0-19) in eight stands aged 21-40 years post harvest. Eight woodrats captured (range 0-3) in nine stands of the 41-60 year age class, and there were no woodrats captured in the three stands last harvested 60 or more years prior to trapping.

The results of the multivariate Poisson regression of woodrat abundance are shown in Table 3.7. The 10 best fitting models are shown ranked by QAICc, and Akaike weights (w_i) are presented to illustrate the relative ranking of each model; the w_i value can be interpreted as being the relative probability that a given model explains the greatest amount of the variation within a data set (Burnham and Anderson 2002). The 95% confidence set of models includes only the first model shown (w_i = 0.98); thus no other model accounted for a considerable amount of the variation in woodrat abundance.

We found 188 woodrat houses in 13 of the 29 stands previously trapped for woodrats (range 0-89 houses/stand). The number of nests found in each stand was significantly correlated with the number of animals captured in a unit (Spearman-rank correlation R = 0.791, $P < 0.001$).

The results of logistic regression of woodrat house presence/absence are shown in Table 3.8. The 10 best fitting models are shown ranked by AICc and w_i values. The 95% confidence set of models includes the top 8 models. Understory hardwood density was included in four of the ten top ranking models. Woodrat houses were frequently located in sprout clumps or aggregated patches of tanoak, tobacco brush, and other types of hardwood shrubs. Similarly shrub tanoak cover was positively related to woodrat house site presence in four of the top ranking models. Understory conifer density and overstory conifer basal area were negatively related to woodrat house site location and were present in five of the top ranking models respectively

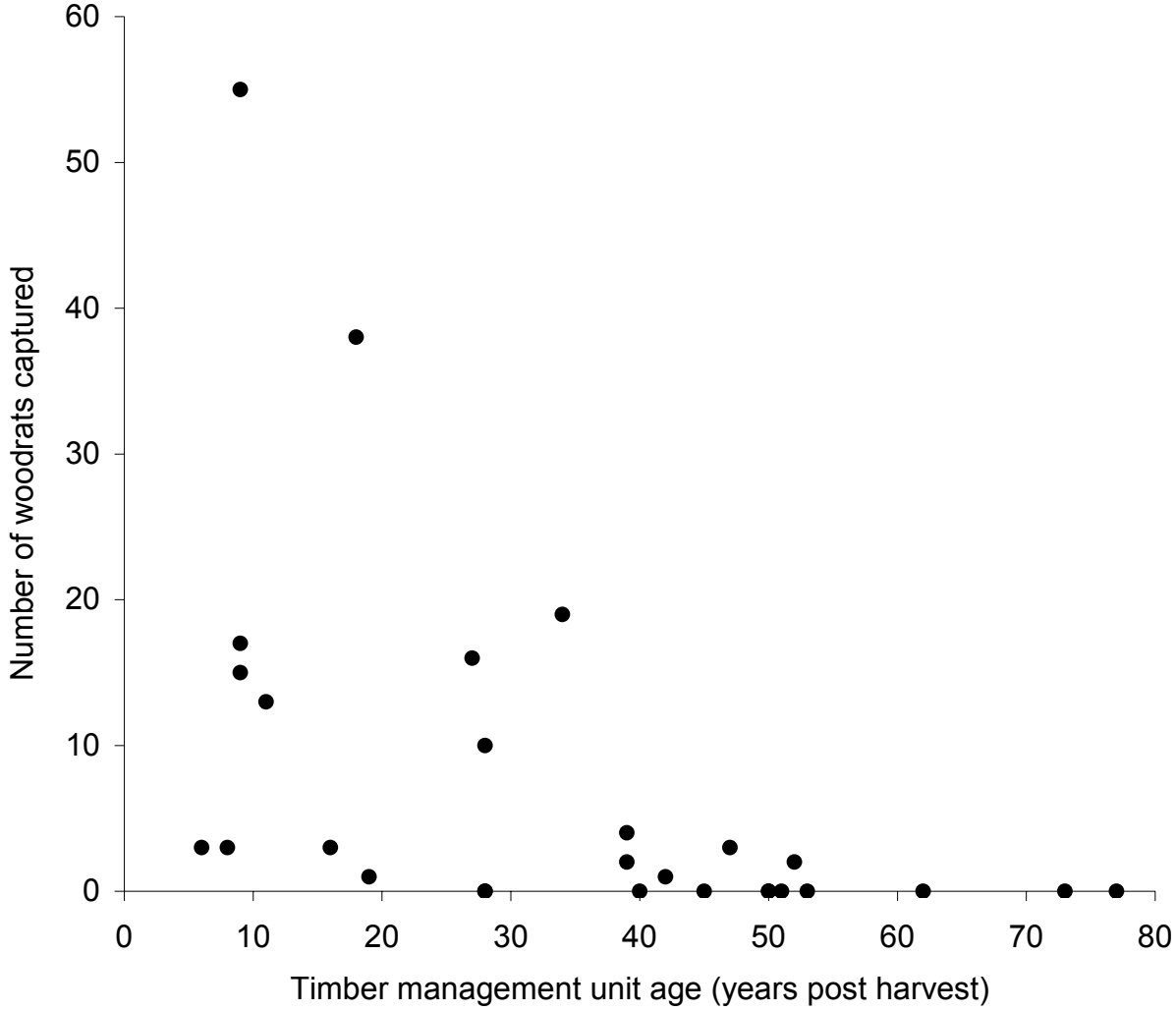

Figure 3.3. Scatter plot of the number of individual woodrats captured per timber management unit vs. years after harvest of timber management unit. $R^2 = 0.422$, $p < 0.001$ (after Hughes 2006).

Table 3.7. Top ten Poisson regression models of woodrat abundance (after Hughes 2006). See Table 3.7 for definitions of variables. Models are ranked by ΔQAICc.

Model (b1 + b2 + b3)	b1	b2	b3	ΔQAICc	w_i	Dev r^2
AGE+GCTO+GCLWD	-0.059 [a]	0.127 [a]	0.151 [c]	0.00	0.983	0.704
AGE +SHW+ GCLWD	-0.035 [a]	0.063 [b]	0.112 [d]	8.52	0.014	0.666
AGE + GCTO + SHW	-0.038 [a]	0.066 [b]	0.037 [d]	12.83	0.002	0.646
AGE+GCTO+GCSWD	-0.045 [a]	0.175 [b]	-0.037 [d]	15.42	0.000	0.635
AGE +SHW+ GCSWD	-0.036 [a]	0.055 [b]	0.020 [d]	15.49	0.000	0.635
SHW+OSCONIFBA	0.075 [a]	0.000 [d]	-	16.19	0.000	0.619
AGE+GCTO	-0.051 [a]	0.112 [b]	-	17.63	0.000	0.613
AGE+SHW	-0.030 [a]	0.064 [b]	-	17.78	0.000	0.612
SHW+GCLWD	0.095 [a]	0.109 [d]	-	19.10	0.000	0.606
AGE+ SHW + USHW	-0.032 [a]	0.069 [b]	-0.007 [d]	19.96	0.000	0.615

[a] $p < 0.001$, [b] $p < 0.01$, [c] $p < 0.05$, [d] $p \geq 0.05$

Table 3.8. Top ten logistic regression models of woodrat nest (*n* = 45) and random (*n* = 45) sites (after Hughes 2006). See Table 3.7 for definitions of variables. Models are ranked by ΔQAICc.

Model (b1 + b2 + b3)	b1	b2	b3	ΔAICc	w_i
USHW +USCONIF + OSCONIFBA	0.124 [b]	-0.890 [b]	0.000 [b]	0.00	0.76
STO +USCONIF + OSCONIFBA	4.985 [b]	-0.590 [c]	0.000 [b]	5.63	0.05
SHW +USCONIF + OSCONIFBA	3.983 [b]	-0.736 [c]	0.000 [b]	5.81	0.04
STO +USHW + OSCONIFBA	4.709 [c]	0.102 [b]	0.000 [c]	6.07	0.04
STO +USALL + OSCONIFBA	5.616 [b]	0.089 [c]	0.000 [c]	7.16	0.02
USHW +USCONIF	0.113 [b]	-0.654 [c]	-	7.61	0.02
STO +USCONIF + GCSWD	7.331 [a]	-0.554 [c]	-0.047 [c]	7.71	0.02
USHW +USCONIF + OSHWBA	0.122 [b]	-0.630 [c]	0.000 [d]	8.11	0.02
USHW +USCONIF + GCLWD	0.117 [b]	-0.670 [c]	-0.078 [d]	8.47	0.01
USHW +USCONIF + GCSWD	0.114 [b]	-0.686 [c]	-0.110 [d]	9.30	0.00

[a] $p < 0.001$, [b] $p < 0.01$, [c] $p < 0.05$, [d] $p \geq 0.05$

Discussion

In the analysis of woodrat abundance, the model that included only a single variable for "timber management unit age" was negatively related to the abundance of woodrats, supporting the results of Sakai and Noon (1993) and Hamm (1995). However, correlations were greater when measures of the subcanopy hardwood component such as hardwood shrub cover, ground cover of tanoak, or understory hardwood density was added to the stand age model. Our finding that shrub and understory hardwood

development may influence woodrat habitat use was suggested in previous studies (Raphael 1987; Sakai and Noon 1993; Hamm 1995).

We observed evidence of extensive pruning of tan oak and other hardwoods such as madrone (*Arbutus menziesii*), blueblossum (*Ceanothus thyrsiflorus*), and tobacco brush (*Ceanothus velutinus)* in several of the high abundance timber management units we trapped. This suggests that these tree and shrub species may be important food sources for woodrats.

In the house site analysis, sub-canopy hardwoods were positively associated with house presence and sub-canopy conifers were negatively associated with house presence. In the top 5 models, basal area of overstory conifers was negatively associated with house presence. Hamm (1995) suggested that in older timber management units large woody debris and fallen hardwood trees might have provided house sites in older timber management units where understory cover was limited. In older timber management units or young timber management units with limited hardwood shrub/understory cover, we typically found woodrat houses in areas that contained remnant patches of hardwood shrubs or fallen tan oak and madrone trees. However, woodrats did not seem to utilize brush patches or downed trees unless they were still alive, suggesting that use of these features may be related to forage availability in addition to cover for house locations. Woodrat house sites in older timber management units were frequently found in remnant hardwood brush patches resulting from topographical features such as rocky slopes and ridge tops which created small areas of low growing tan oak in a timber management unit that would otherwise be classified as mature conifer.

The results of this study indicate that management activities that increase sub-canopy hardwoods may increase the quality of woodrat habitat while activities designed to suppress sub-canopy hardwoods including burning, pre-commercial thinning, and herbicidal control, may decrease the quality of woodrat habitat. Although pre-commercial thinning has been shown to decrease woodrat abundance (Whitaker 2003), in one timber management unit that we studied, pre-commercial thinning of tan oaks by manually cutting them off at the base, in addition to an approximately 30% mortality of overstory conifer trees from bears feeding on the cambium and “girdling” them, resulted in stump sprouting of the tan oaks which also resulted in an increase of subcanopy hardwood cover. Thus the influence of silvicultural management on woodrat habitat quality may not always be clear.

Thome et al. (1999; summarized below) found that the proportion of 21-40 year old timber management units was lower in northern spotted owl locations than in random locations. However, among NSO nest sites, those with the highest fecundity also had the highest proportions of 21-40 year class timber management units. Thome et al. (1999) proposed that increased fecundity of NSO’s was due to higher abundance and availability of woodrats in 21-40 year timber management units. However, we found the number of woodrats captured in this age class varied considerably (range = 0-20), suggesting that coarse classification of habitat based primarily on timber management

unit age may not be sufficient to quantify spotted owl foraging habitat unless additional information regarding sub-canopy vegetative structure is considered.

Although some forest locations may contain high abundances of woodrats, the associated high density of understory shrubs in young regenerating forest timber management units would limit the ability of spotted owls and other aerial predators to feed on them. However, radio collared woodrats from high abundance "young" forest locations were documented straying into more mature forests where predated by spotted owls (Sakai and Noon 1997) suggesting that juxtaposition of those habitats where woodrats are plentiful to habitats where spotted owls can forage must be considered when evaluating habitat quality for spotted owls.

In this study we identified small refugia in mature timber management units where active woodrat houses were located in small patches of sub-canopy hardwoods surrounded by open or conifer dominated understories. Although rare, the woodrats that inhabit these refugia are more susceptible to predation when the surrounding forest contains little subcanopy cover. Conversely, some authors have observed that woodrats may fail to utilize assumed high quality habitats in some areas, presumably because such habitats are rare and isolated within the forests (Carey 1991). This difference likely occurred because the forests within the Green Diamond Resource Company ownership are more intensively managed, with many younger stands in close proximity. Thus, areas with suitable habitat are more likely to be colonized from other source populations.

Summary of woodrat studies on GDRC land

Both woodrat studies indicated that in the redwood/Douglas-fir zone of GDRC ownership, woodrats are in greatest abundance in young stands <40 yrs of age. Use of uneven-aged silviculture techniques such as commercial thinning or selection is not likely to enhance woodrat abundance because these practices generally encourage the proliferation of understory sciophytes that are not palatable forage for woodrats. Silviculture practices that promote a dense and diverse shrub layer of heliophilic species that are more palatable should promote woodrat abundance. However, woodrats also require suitable substrate in the form of redwood or tanoak stump sprouts, trees with basal hollows, logs, and other down material for construction of their houses.

Because woodrats are the primary prey species of northern spotted owls in northern California, forest management practices that influence woodrat abundance have implications to management of populations of threatened spotted owls. Thinning of mature stands is not likely to enhance the primary prey base for spotted owls in this region. The management strategies for threatened populations of spotted owls must take into consideration the habitat needs of the species itself and that of its primary prey.

3.B.1.iii. Woodrat Monitoring on GDRC Land

Dusky-footed woodrats are a vital component of the diet for spotted owls on Green Diamond ownership. GDRC and graduate students at Humboldt State University have conducted several projects on the abundance patterns and habitat associations of dusky-footed woodrats, but information is lacking on annual fluctuations in woodrat populations across the ownership. Information on annual variation in woodrat numbers may help to explain variation in annual survival and fecundity estimates for spotted owls. This information, in conjunction with various other habitat and weather covariates, may aid in the development of resource selection models used to assess impacts of forest management activities on populations of spotted owls. The objectives of this project are to: (1) estimate woodrat abundance at the landscape scale using trapping transects; (2) associate woodrat abundance with forest stand level habitat variables; and (3) estimate annual variation in woodrat numbers at a landscape scale and use these estimates as an index of prey abundance for modeling demographic parameters of spotted owls.

Methods

We divided GDRC ownership into logical units using topographic features, watershed boundaries and broad habitat types. Units varied in size from 6,000-10,000 ha (15,000 to 25,000 acres). Many of these units coincided with forest management areas already in place. The total number of transects was constrained by areas that could be trapped during a three month time period from September to November and the amount of available resources (i.e. traps and personnel). Twenty-four possible transects were identified from eleven units within GDRC ownership. Trapping transects were identified based on a minimum length of 16 km all-season road use (i.e., rock or other stable surface) as well as having a broad distribution across the ownership.

A random start for each transect was determined within the initial 0.32 km of length. Each transect was then partitioned into 0.32 km intervals totaling 50 trap intervals. At each interval, a coin flip was used to determine the side of the road where traps would be positioned. Prior to placing the stations it was determined which side of the road each side of a coin represented. If a trapping station fell in a position of the road that was inaccessible or off ownership it was moved to a safe location within fifty meters. If this was not possible, the trapping station was moved to the next 0.32 km interval. Two traps were placed at each trap station perpendicular to the road at ten-meter intervals. Many of the roads on GDRC ownership are cleared of roadside vegetation and brush to facilitate road maintenance and drying of the road surface. When roadside clearing was present on portions of selected transects, the perpendicular measurements started from the edge of the forest stand and not from the edge of the road.

In the field, trapping stations were permanently marked with a yellow tree tag (J.L. Darling Corporation, Tacoma, WA, Tag #P-1114) and white vinyl flagging. Tree tags were marked with the transect acronym, station location and azimuth to trap locations. If possible, tree tags were nailed to the nearest tree with aluminum nails. If no tree was within 2m of the start of the transect, a wooden stake was driven into ground at the start

of the trap line. Two or three white vinyl flags were placed on trees or vegetation at each trap station and were identified with permanent marker. After the trapping stations were located on the ground, we documented the precise location on 2004 aerial photographs.

Initially traps were baited with rolled corn, oats and barley (COB). COB bait was used on the NF and MR transects in 2004. During this trapping session we had difficulty with bait falling out of the trap. This prompted a switch to Lab Diet 5001 rodent pellet bait for the remainder of the study. Four to six pellets were placed in each trap. Traps were covered with black visqueen that was held in place with two rubber bands. This covering on the top and sides provided shelter from inclement weather conditions and fog drip. Trapping was conducted on four consecutive nights. Captured woodrats were marked on the chest between the front legs with permanent marker for recapture identification purposes. After each capture, transect, trapping station and trap number were recorded on a data sheet. Age, gender, reproductive status, weight, parasite load and physical condition were recorded for each individual. We also recorded each trap that was closed but contained no captured animal.

We used Kodak imaging software to annotate digital images for trapping stations on each transect. The annotated scanned photos were used as base maps for future fieldwork. Road intersection location information for each trap station was transferred into the GIS database. Trap locations were computed using ten and twenty offsets (trap locations) from intersection point and a compass bearing.

Results

In 2004 and 2005, eleven transects were live-trapped from September through November. A total of 8,484 trap nights resulted in the capture of 487 individual woodrats. These individual woodrats were recaptured 346 times. In 2004, 293 individuals were captured ($\bar{x}$ =26.6, SE = 6.9), and in 2005, 194 individuals were captured ($\bar{x}$ = 17.6, SE = 5.7).

Discussion

This work is anticipated to continue as a long-term monitoring study of woodrat abundance. The estimates obtained will be used as an index of primary prey abundance at a landscape scale for future modeling efforts of owl habitat selection and demographic parameters.

3.B.2. Summary of woodrat studies from nearby areas

The U.S. Forest Service Redwood Sciences Laboratory conducted two studies of dusky-footed woodrats on the Six Rivers National forest, which abuts GDRC land (Sakai and Noon 1993 and 1997). In the first study, woodrats abundance was estimated in each of 5 seral stages of Douglas fir/tanoak forest (Sakai and Noon 1993). Using a combination of transect sampling to estimate woodrat nest density and livetrapping, Sakai and Noon (1993) found woodrat density was highest in stands 15-40 yrs old

(81/ha), and much lower in stands <15 yrs old (1/ha), and stands >180 yrs old (<1 ha). No woodrats were found in stands 41-80 yrs old nor in stands 81-180 yrs old.

In the second study, Sakai and Noon (1997) radio tracked woodrats of both sexes and three age classes and found that woodrats made short-term, temporary movements from the 15-40 yr-old stands in which they were trapped, into old growth (>180 yr old) stands. These two studies suggested that brushy/sapling stands adjacent to older forest may benefit spotted owls by increasing the availability of woodrats to the owls.

3.C. TREE VOLE ECOLOGY

Taxonomists disagree about the genus of tree voles, with some placing it in the genus *Phenacomys* with the heather vole (*P. intermedius*), and with the white-footed vole (*P. albipes*) in the subgenus *Arborimus*, and others elevating the subgenus *Arborimus* to the genus level (Bellinger et al. 2005). Genetic studies have so far have not resolved this debate (Murray 1995, Bellinger et al. 2005). We use the genus *Arborimus*, following Johnson and George (1991), who first proposed the species *A. pomo* (the Sonoma tree vole) as distinct from *A. longicaudus* (the red tree vole).

Tree voles are small, arboreal rodents that are an important component of the diet of the northern spotted owl where the owls and voles co-occur (Forsman et al. 2004a, 2004b), including on GDRC land (see section 3A, above). The red tree vole occurs from the Klamath River in California north to northwestern Oregon, whereas the Sonoma tree vole occurs from the Klamath River south to Sonoma County, California (Johnson and George 1991). Both tree vole species are restricted to Douglas fir forests and feed only on conifer needles, primarily those of Douglas fir (Maser et al. 1981). After consuming the fleshy part of the needles, the voles discard the resin ducts (Benson and Borell 1931). Vole nests can be identified by the presence of these resin ducts in the nest or on the ground below the nests. Tree vole populations are patchily distributed (Carey et al. 1991) and are easily identified by the presence of nests. Nests are constructed of twigs, feces, conifer needles, lichens, and discarded resin ducts and are most common in the lowest third of the canopy (Carey 1991).

3.C.1. Tree vole ecology on Green Diamond Resource Company land

Tree voles (*Arborimus spp*) are small arboreal rodents found primarily in Douglas-fir (*Pseudostuga menziesii*) forests of the Pacific Northwest (Carey 1991). They are nocturnal and canopy dwelling, and are unique in feeding exclusively on conifer needles (Huff et al. 1992). Within Green Diamond Resource Company's (GDRC) ownership, the Klamath River is thought to be the demarcation between the red tree vole (*Arborimus longicaudus*), occurring north of the river and the Sonoma tree vole (*Arborimus pomo*) south of the river. Recent studies have suggested that these species could be vulnerable to local extirpations as a result of the loss or fragmentation of old-growth and mature Douglas-fir forests (Ruggiero et al. 1991, Gillesberg and Carey 1991, Meiselman 1992). Tree voles were identified by the California Department of Fish and Game as a "Species of Special Concern" because "declining population levels, limited ranges

and/or continuing threats have made them vulnerable to extinction" (California Department of Fish and Game, 2006).

3.C.1.i. Abundance, nest characteristics, and nest dynamics

We studied the abundance, nest characteristics, and nest dynamics of Sonoma tree voles on GDRC land (Thompson and Diller 2002). To estimate abundance of tree vole nests, we sampled 46 stands in the Mad River and Redwood Creek drainages, from 6 stand age classes (6-9 stands per age class; Table 3.9). We randomly selected the stands from GDRC's GIS database. Within each stand, we used line transect sampling to estimate the number of tree vole nests. Nests were deemed active by one or more of the following: the presence of freshly discarded (green) resin ducts in or below the nest, small, fresh conifer boughs on top of the nest (Benson and Borell 1931), or sighting a tree vole at the nest. To evaluate the characteristics of vole nest trees, we randomly selected vole nests in each of the sampled stands, and measured the dbh of all trees >7.5 cm dbh within a 0.04-ha circular plot centered on the nest tree. To estimate nest occupancy over time, we intensively surveyed 100-m x 100-m grids for tree vole nests, with 6 sampling periods: in the fall of 1994; winter, spring, and fall 1995; and winter and fall of 1996. For estimating nest occupancy, we non-randomly selected 2 stands each within the 5 oldest stand age classes known to have high densities of tree vole nests.

Table 3.9. Number and median density of active Sonoma tree vole nests by stand age class on Green Diamond Resource Company lands (after Thompson and Diller 2002).

	Stand age class					
Parameter	10-19	20-29	30-39	40-49	50-59	≥ 60
Number of stands searched	6	7	9	8	8	8
Number of stands with nests	0	4	9	6	7	7
Total transect distance (m)	3250	3850	4300	3900	3870	3550
Number of nests	0	11	40	45	44	45
Number of active nests	0	7	29	33	22	39
Median density of active nests (number/ha)	0	1.00	3.40	3.99	2.01	6.21

We found 185 Sonoma tree vole nests in the five oldest stand age classes sampled (Table 3.9), and no nests in the 10-19 yr old age class, although we had occasionally observed vole nests in 10-19 yr-old stands elsewhere on GDRC land. Density of active

tree vole nests increased with stand age among the 5 oldest age classes (ANOVA, $F_{4,34}$ = 2.904, P = 0.036) , ranging from 1.00 nests/ha in 20-29 yr-old stands to 6.21/ha in = 60 yr-old stands. It is unknown whether the number of vole nests accurately reflects the number of voles, because tree voles may have multiple nests. However, assuming the number of nests used does not vary with nest density or stand age, we believe that the density of active nests indicates the relative abundance of tree voles in different aged stands.

We found vole nests in 8 species of tree and one nest on the ground. Eighty percent of nests were in Douglas fir trees; tanoak was the next most common tree species used for nesting by voles. Most of the nests found in tanoaks appeared to have been constructed initially by squirrels. As stand age increased, vole nests were located in larger trees ($F_{4,179}$ = 9.56, P < 0.001), higher in trees ($F_{4,179}$ = 8.30, P < 0.001), and farther from the bole of the tree (X^2_4 = 9.75, P < 0.05). Nest trees were similar in size to surrounding trees in younger stands, but became disproportionately larger than surrounding trees as stand age increased.

Nest persistence did not differ among stand age classes (X^2_{12} = 16.9, P = 0.154). Estimated median persistence time for vole nests was 28.6 mo (95% CI = 25.8 to 34.8 mo). We found unusually high proportions of destroyed nests during different sampling periods among different aged stands. We hypothesized that this observed pattern was consistent with predation, wherein a predator that discovered 1 nest would likely discover other nests in the area.

3.C.1.ii. Distribution and abundance of tree voles

Tree vole populations have been found to be patchily distributed in the forest (Carey et al. 1991). This combined with their arboreal existence and unique food habits make the species difficult to study (Huff et al. 1992). Areas of activity are most easily evidenced by the presence of nests, which are constructed of fine twigs, feces, conifer needles, lichen and discarded resin ducts (Carey 1991). These resin ducts remain after voles consume the fleshy part of conifer needles (Benson and Borell 1931).

In this region, tree voles have the potential to provide an important food source for several forest predators including the northern saw-whet owl (*Aegolius acadicus*) (Forsman and Maser 1970) and the threatened northern spotted owl (Forsman et al. 1984). Tree voles constitute an important component of the diet of northern spotted owls within GDRC's ownership. An analysis of regurgitated spotted owl pellets collected from 1989-2004 indicated that tree voles comprised approximately 16% of the owl's diet in frequency and 3% in biomass. Tree voles are also an important component in the Central and South Coast regions of Oregon where some owl territories have >20% of the prey numbers represented by this species (Forsman et al. 2004b).

The primary objective of this study was to investigate the distribution and abundance of Sonoma tree vole nests within Douglas-fir forests on GDRC ownership in northwestern

California. We also investigated forest habitat and other landscape attributes associated with areas used and not used by Sonoma tree voles.

Methods

The population of forested areas within GDRC ownership was identified based on forest age (>20 yrs.) and basal area of Douglas-fir (>30%). Forested areas meeting these criteria in the Korbel Operations area and Klamath Operations area south of the Klamath River were identified using GIS. To select sample plots, a grid pattern with 10 ha cells was randomly placed on GDRC ownership. Each 10ha cell that intersected a forested area meeting the age and basal area criteria entered into the population from which samples were selected. Forest age was classified into one of four strata. Age classes were: 20-29, 30-39, 40-49, and 50+. A systematic random sample of 100 10 ha quadrats was selected. Each 10 ha quadrat was the sampling unit.

Quadrats were located in the field using aerial photographs and handheld global positioning system. Line transects were established within each 10 ha quadrat. Sixteen transects with 20 m spacing were established in the 20-29 yr age class and 12 transects with 26 m spacing were established in all other age classes. A narrow strip width was necessary to effectively census the quadrat area. Two to four observers walked transects within each quadrat. Observers started at one edge of the 10 ha quadrat and systematically complete all transects within the quadrat. Transects were traversed using a compass and distance was measured using a hip chain. Observers visually searched all trees for the presence of vole nests. When a nest was detected, observers visually inspected the structure from the ground and used a time-constrained search limited to 5 minutes to identify discarded resin ducts at the base of the tree in which the nest is located. When resin ducts were found, the nest was considered as that of a tree vole. When resin ducts were not located, the nest was not counted as a vole nest. Upon confirmation as a vole nest, observers measured the perpendicular distance to the nest tree, marked the approximate location on a topographic map with a 1:2,400 scale and continued with the transect. After all transects were completed, observers randomly selected one transect completed by other observers and then resampled these transects for vole nests. Observers had no prior knowledge of the number or location of vole nests detected by the other observer. The purpose of resampling transects was to approximate g (0) in the detection function.

After completion of transect sampling, observers systematically numbered all vole nests plotted on the topographic maps and habitat sampling occurred at all vole nests located on the grid. The nest tree was identified to species, and measurements were taken on diameter at breast height (DBH) and nest height. The placement of the nest on the tree was recorded as limb or bole. Observers made a determination if the vole nest was inhabited or uninhabited based on the presence of fresh (green) conifer clippings on the top of the nest. A 0.042 ha plot (23.4 m radius) was centered on the nest tree. A 20 basal area factor prism was used to assess tree species composition and basal area. All trees ≥ 10 cm were measured and identified to species. All snags >2 m in height were measured and identified to species where possible. Overstory canopy was measured with a spherical densiometer at four locations 5 m from plot center in each of

the cardinal directions. The number of stumps (natural and man-made <2 m in height) within the fixed plot was recorded. The amount of large wood within the plot was estimated by measuring logs at both end diameters (minimum end diameter of ≥ 24 cm) and total length. Understory vegetation (<2 m in height) was quantified using a line intercept approach along one randomly chosen 23.4 m orientation line on the fixed plot. A minimum of four random plots were selected within each 10-ha grid. The same habitat information was gathered on random plots.

Results

From September to January 2001-2004, 68 10-ha square grids were sampled and 32 of these areas were found to be inhabited by tree voles. A total of 129 vole nests were located with a range of one to 19 per grid. Of the vole nests located, 46.5% were assessed as inhabited and 83.7% were located at the bole of the tree. Nests were located in seven species of tree and five different deformities or structures on the tree (Table 3.10). Nests were found in a wide range of tree sizes ($\bar{x}$ = 53 cm, SE = 15 cm) and heights ($\bar{x}$ = 11.9 m SE = 0.5 m).

The age of forest stands sampled ranged from 23 to 129 years. Mean dbh of trees on nest plots were not different from random plots (t = 0.17, P = 0.86). Log volume was greater on random plots than nest plots (t = -2.7, P = 0.007) and random plots contained more stumps than nest plots (t = -4.0, P = 0.000). There was no difference in slope (t = 0.78, P = 0.44) or canopy closure (t = -0.04, P = 0.97) in nest versus random plots. We observed a positive relationship between vole abundance and forest age (F = 18.7, P < 0.000) and distance from coast (F = 32.6, P < 0.000). Abundance appeared to be greatest toward the southern interior of the study area (Fig. 3.4).

Table 3.10. Tree species containing tree vole nests and type of tree deformity in which the nest was located during sampling of 68 10-ha quadrats on Green Diamond Resource Company land, 2001-2005.

Tree species	*n*	Tree Deformity	*n*
Douglas-fir	117	Broken-top	19
Tanoak	1	Cavity	11
White Oak	1	None	33
Black Oak	6	Mistletoe broom	22
California Bay	1	Forked top	28
Redwood	1	Undetermined	16
Other	1		

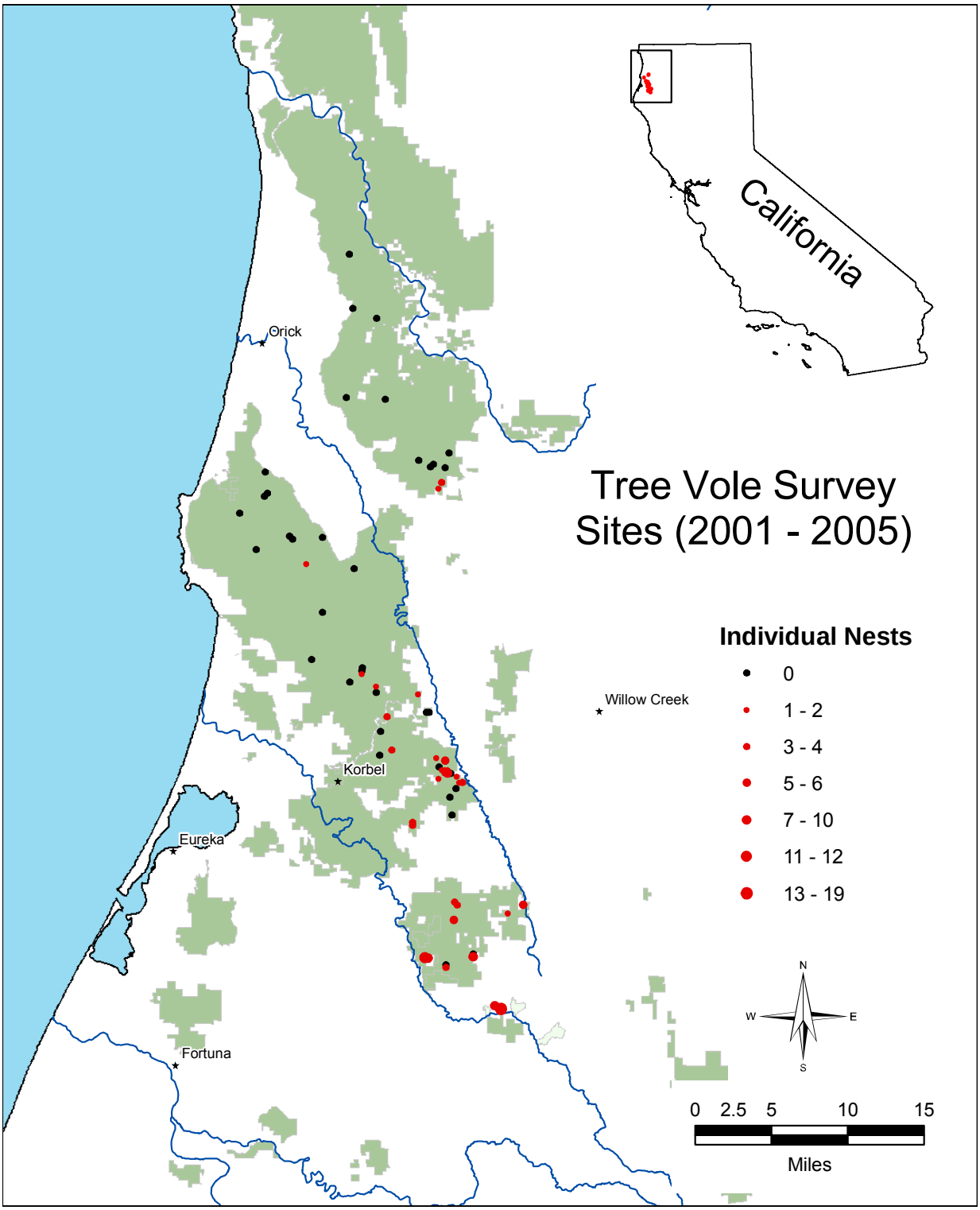

Figure 3.4. Density of tree vole nests on Green Diamond Resource Company land, 2001-2005.

Discussion

Our study and analysis indicates that tree voles are rare or absent from the coastal portions of the study area and increase in abundance with increasing distance from the coast. This phenomenon is most likely linked to the increasing presence of Douglas-fir, their primary forage, in the more interior areas. In an examination of vole abundance and distribution from regurgitated owl pellets, Forsman et al. (2004b) found that tree voles (*A. longicaudus*) were widely distributed in Oregon, but were more abundant in the southern and central coast regions of their study. These regions of their study area were out of the coastal redwood zone and dominated by Douglas-fir and grand fir. We found that tree voles were present in a wide range of forest ages but abundance of nests was positively related to forest age. These results are consistent with those of Thompson and Diller (2003), a study conducted within the same ownership.

3.C.2. Summary of tree vole studies from nearby areas

Meiselman and Doyle (1996) studied Sonoma tree voles in young (<100 yr old), mature (100-200 yr old), and old-growth (> 200 yr old) Douglas fir forests, in Mendocino County, California. Vole nests were most abundant in old-growth forest (G = 9.02, P < 0.01, df = 2). Tree diameter was greater for nest trees than for unoccupied trees, and nests were patchily distributed. All vole nests found were in Douglas fir trees (n = 79). In contrast to our results, vole nests were most frequently located adjacent to the trunk, as opposed to farther from the tree bole (Meiselman and Doyle 1996).

Jones (2003) compared tree vole abundance among stands of three size classes on Pacific Lumber Company land in Humboldt County, California, in 2000. Mature stands (>61 cm dbh) contained approximately 6 times the number of nests found in either pole stands (15-28 cm dbh) or unthinned young stands (28-61 cm dbh; $F_{2,9}$ = 11.88, P = 0.003). In 2001-2002, Jones (2003) studied habitat associations of Sonoma tree voles in Redwood National and State Parks, Humboldt Redwoods State Park, and Angelo Coast Range Reserve, in Humboldt and Mendocino counties, California. Using transect sampling, Jones (2003) found 531 nests; 93% of nest trees were Douglas fir.

In Oregon, Swingle (2005) fitted 52 red tree voles with radio-transmitters and followed the voles for 8-307 days to observe daily movement patterns. Based on telemetry locations, vole home range sizes averaged 0.159 ha (SE = .032 ha). By following transmittered voles, Swingle (2005) located 56 vole nests not initially detected from ground based surveys and determined that 31 of the nests were not visible from the ground.

3.D. SPOTTED OWL HABITAT

We summarized spotted owl nest tree species, nest types, and nest locations on GDRC land. In addition we conducted two studies to better understand the vegetation conditions associated with spotted owl nesting habitat and the influence that these conditions have on spotted owl reproductive output.

3.D.1. Spotted owl nest species, nest types, and nest locations

We located 273 nests at 126 spotted owl territories in 1992-2004. Because many of the nests were used in multiple years, the 273 nests represent 726 nesting attempts. Fifty-two percent of nests were located in platforms, including mammal nests (nests of flying squirrels, tree voles, and dusky-footed woodrats), bird nests, and debris platforms (Table 3.11). Douglas-fir, redwood, and tanoak accounted for > 75% of nest tree species. Mean percent slope at nest locations was 39% (range 4-90%; Fig. 3.5). Nest trees were well distributed across slope aspects (Fig. 3.5). Mean nest tree diameter at breast height was 129 cm (SE = 5 cm). Mean nest tree height was 18.4 m (SE = 0.5 m).

Of 46 nests measured by Folliard (1993), mean length and width was 57 x 47 cm. Nest structures were similar in size across nest types. Mean canopy closure directly above the nest was 96% (SD = 5, range = 78-100).

Table 3.11. Tree species and nest types of northern spotted owl nests on Green Diamond Resource Company land, 1992-2004.

Nest tree species	Nest type Platform	Cavity	Chimney	Unknown	Total	Percent
Douglas-fir	55	13	11	10	89	33%
Redwood	35	27	15	7	84	31%
Tanoak	15	9	3	2	29	11%
Cedar	6	4	7	2	19	7%
Western hemlock	13	1	1	1	16	6%
Grand fir	8	0	0	0	8	3%
Maple	2	5	1	0	8	3%
Black oak	0	0	6	0	6	2%
California laurel	2	3	0	0	5	2%
Fir species	2	0	0	0	2	1%
Pacific madrone	0	2	0	0	2	1%
Red alder	1	0	1	0	2	1%
White fir	1	0	0	0	1	0%
Unknown	1	0	1	0	2	1%
Total	141	64	46	22	273	
Percent	52%	23%	17%	8%		

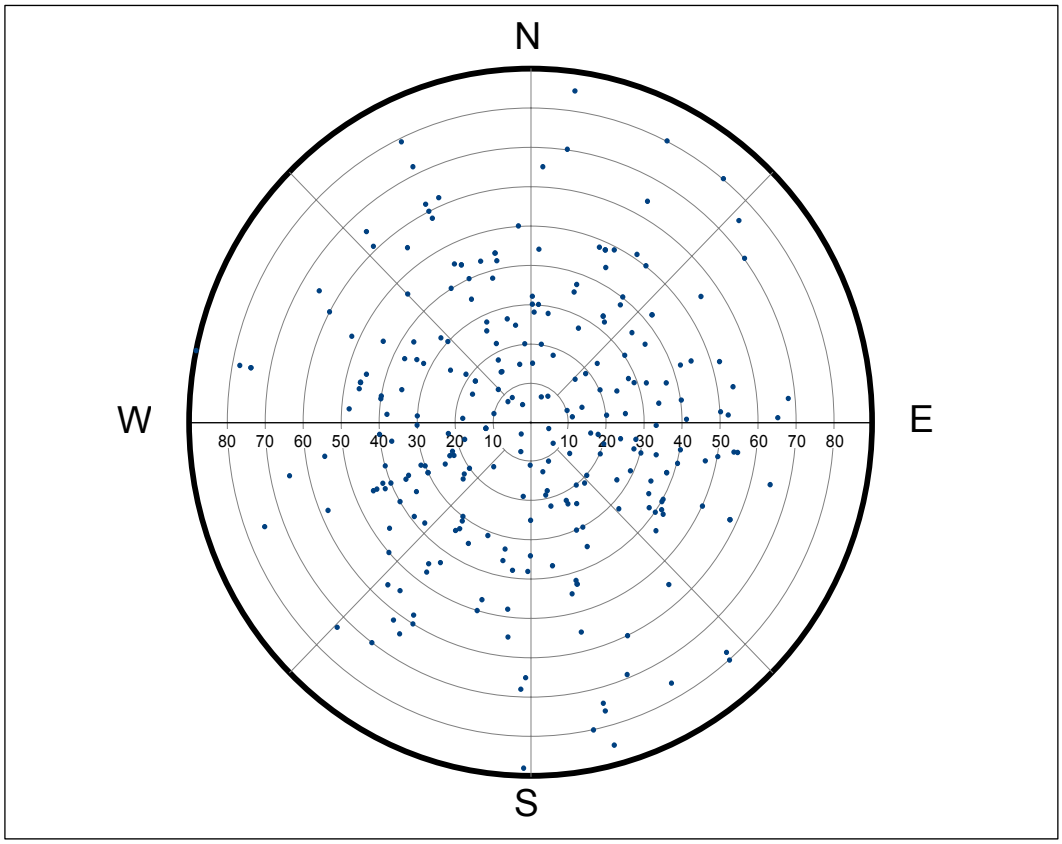

Figure 3.5. Location of 273 northern spotted owl nest sites on Green Diamond Resource Company lands in relation to aspect and percent slope.

3.D.2. Vegetation and landscape characteristics of spotted owl habitat

In the first study of spotted owl habitat characteristics, we characterized nesting habitat at 3 scales (nest microsite, nest stand, and landscape) for 60 spotted owl pairs (Folliard 1993, Folliard et al. 2000). For nest microsite-level comparisons, we measured vegetation characteristics (tree basal area by size class and conifer/hardwood, canopy cover, canopy height, log volume, ground cover, and slope) in 0.07 ha plots centered on nest trees and at 4-5 random locations within each nest stand. For nest stand-level comparisons, we measured the same characteristics in random locations. For landscape-level comparisons, we used GDRC GIS data in combination with 1:12,000 color aerial photos, to classify stands within 0.8 km (0.5 mi) radius (203 ha) circles around owl activity centers and random locations. In addition to quantifying the area of stand age classes, within each 203 ha circle we measured slope position of the nest, length of roads, the amount of edge between different age classes, the amount of high-contrast edge, distance from the nest to the nearest forest opening, distance to water, the number of cover type polygons, and the area of the largest cover type polygon. For stand- and landscape-level analyses, random locations were in stands at least 30 yrs old and thought to be unused by spotted owls (>1.6 km from known owl spotted owl activity centers).

Nest microsites

Ninety-five percent of nest microhabitat plots were not different than random plots within the same stand, based on separate multivariate linear models for each plot (this was not a powerful test). Multivariate analysis of variance (MANOVA) indicated that all nest sites combined differed from all random points within nest stands combined (Wilks' F = 2.586, $P < 0.001$). Univariate t-tests revealed that 5 of 20 variables contributed to these differences ($P < 0.05$): spotted owl nest sites had greater basal area of large conifers (> 90 cm dbh), greater canopy height, lower basal area of small hardwood trees (13-27 cm dbh), lower canopy closure, and greater log volume. Very few snags were present at nest sites, and 82% of nest sites contained no snags >52 cm dbh. Mean basal area of small (9-52 cm dbh) and large (>52 cm dbh) snags in nest stands was 0.99 and 0.92 m^2, respectively.

We compared basal area of large conifers, basal area of small hardwood trees, canopy height, and log volume at successful (n = 47) and unsuccessful (n = 10) nests using t-tests. We found no significant differences (all $P > 0.28$).

Nest stands

Stand cover types used by spotted owls for nesting were Redwood/Hardwood (17%), Redwood/Douglas fir/Hardwood (25%), Douglas fir/Hardwood (23%), and Hardwood/Conifer (35%). The distribution of nest stands did not differ from random stands (χ^2 = 4.365, df = 3, P = 0.225). Eighteen percent of nests occurred in stands 31-45 yrs old, 35% in stands 46-60 yrs old, 30% in stands 61-80 yrs old, 7% in stands 81-200 yrs old, and 10% in stands >200 yrs old. Sixty-two percent of owl pairs nested in stands with residual, older trees present; 38% nested in even-aged stands. Among stands dominated by hardwoods, 90% contained residual trees. Snag density was low in both nest and random stands.

We compared nest stands to random stands separately for conifer- and hardwood-dominated stand types (hardwood-dominated stands were those in which hardwood tree species accounted for > 50% of total basal area). MANOVA indicated that conifer-dominated nest stands differed from conifer-dominated random stands (Wilks' F = 4.483, $P < 0.001$). Univariate tests revealed that 9 of 20 variables contributed to these differences ($P < 0.05$): nest stands had greater basal area of large conifers (>90 cm dbh), lower basal area of small conifers (13-27 cm and 28-52 cm dbh), fewer conifer saplings, steeper slopes, and higher ground cover of shrubs, ferns, forbs, and tree seedlings. Similarly, hardwood-dominated nest stands differed from hardwood-dominated random stands (Wilks' F = 2.875, P = 0.024). Univariate tests revealed that nest stands had lower basal area of small conifers (13-27 cm), and higher ground cover of ferns, forbs, and tree seedlings (all $P < 0.05$).

We entered the variables that differed between nest and random stands into a stepwise discriminant analyses. For conifer-dominated stands, the discriminant function model correctly classified 69% of nest stands and 82% of random stands. Variables included in the model were ground cover of ferns, tree seedlings, conifer sapling density, and

slope. For hardwood-dominated stands, the discriminant function model correctly classified 76% of nest stands and 86% of random stands. Variables included in the model were ground cover of ferns and tree seedlings.

Nesting landscape

Landscape composition of 203 ha circles centered on nests differed from circles centered on random locations (Wilds' $F = 6.073$, $P < 0.001$). Subsequent univariate *t*-tests indicated that 8 of 12 variables contributed to these differences ($P < 0.05$): Nest circles had more 31-45 yr old and 46-60-yr old forest (the age classes representing 53% of nest locations; see above), less 8-30-yr old forest (not used for nesting), and were similar to random stands in the amount of forest >60 yrs old and the amount of forest 0-7 yrs old (Table 3.12). Furthermore, nest circles had greater total edge (juxtaposition of different cover types or age class of the same cover type), were lower on the slope, were closer to water, had lower length of roads, and had a longer distance from the circle center to the nearest forest opening.

We entered variables significantly different between nest and random sites into a stepwise discriminant analysis. Four variables were selected in the final discriminant function model: position on slope, total edge, 31-45 yr old forest, and 46-60 yr old forest. The discriminant function model correctly classified 72% of nest landscapes and 73% of random landscapes. We tested for univariate differences in these four variables between successful ($n = 47$) and unsuccessful spotted owl nests ($n = 8$), and found none.

In the second study of spotted owl habitat characteristics, we used a longer span of spotted owl reproductive data (1991-1995) to compare landscape-level habitat characteristics between sites with high and low fecundity, at 5 spatial scales (Thome et al. 1999). We calculated reproductive success at each site as the proportion of years in which ≥ 1 owlet fledged. We also compared habitat characteristics of random and occupied sites (Thome et al. 1999). The spatial scales we used were 7, 50, 114, 203, and 398 ha. Stand age classes differed from those used by Folliard (1993) and Folliard et al. (2000), and were 0-5-yrs-old, 6-20-yrs-old, 21-40-yrs-old, 41-60-yrs-old, 61-80-yrs-old, and >80-yrs-old.

Using the same data, we compared landscape-level habitat characteristics (at the 398 ha scale) and reproductive output of sites with and without turnover (replacement of one owl by another owl following death or dispersal of the first owl). We recorded turnover as a binary variable (0 turnovers, ≥ 1 turnover; Thome et al. 2000).

Table 3.12. Summary statistics for landscape characteristics measured within 203-ha circular plots centered on 60 northern spotted owl nest sites and 60 random sites on Green Diamond Resource Company land, 1990-1991 (After Folliard et al. 2000, Table 1).

Variable	Nest Landscapes Mean ± SD	Random Landscapes Mean ± SD	F	P
0-7 yr old forest, ha	17 ± 26	23 ± 39	0.065	0.800
8-30 yr old forest, ha	24 ± 38	53 ± 69	4.376	0.039
31-45 yr old forest, ha	46 ± 60	29 ± 50	4.341	0.039
46-60 yr old forest, ha	55 ± 64	34 ± 56	5.314	0.023
>60 yr old forest, ha	42 ± 46	41 ± 49	0.122	0.728
Nonforest, ha	20 ± 19	22 ± 34	0.630	0.429
Total edge, km	8.1 ± 3.1	6.4 ± 2.9	9.273	0.003
High-contrast edge, km	4.2 ± 2.9	4.0 ± 3.2	0.172	0.679
Position on the slope	0.35 ± 0.23	0.52 ± 0.28	14.034	<0.001
Distance to water, m	137 ± 97	191 ± 141	4.711	0.032
Length of roads, km	3.7 ± 2.1	4.8 ± 2.7	5.067	0.026

Owl reproductive success

Sites with higher spotted owl reproductive success had a greater proportion of 21-40 yr old stands and lesser proportion of 0-5 yr old stands within the largest circles than sites with lower reproductive success (Mann-Whitney U-tests, $P < 0.10$). However, spotted owl sites had lower proportions of 21-40 yr old stands than random sites within the smallest four circles (Mann-Whitney U-tests, $P < 0.10$). Forward stepwise logistic regression found 4 of 55 landscape characteristics predicted spotted owl use sites: the proportion of 6-20 and 21-40 yr old stands within the 50 and 114 ha circles were negatively related to the presence of spotted owls. Forward stepwise logistic regression was unable to model reproductive success.

Owl turnover

Spotted owl sites with no turnover (n = 21) had higher proportions of 21-40 yr old stands ($\bar{x}$ = 0.36, SE = 0.06) than did sites with at least one turnover in four annual intervals (n = 30, $\bar{x}$ = 0.23, SE = 0.05). Sites without turnovers had higher reproductive output than

sites with turnovers. However, 50% of the new recruits were subadults, which breed at lower rates and have lower productivity than adult owls. Therefore, reproductive output at sites with turnover was confounded by owl age class.

Discussion

Spotted owls on GDRC land nested in younger stands than elsewhere in the subspecies range (Courtney et al. 2004). As noted by Thomas et al (1990), structural attributes of young redwood stands are similar to those that develop only in very old forests throughout most of the range of the northern spotted owl.

A higher proportion of spotted owl nests found on GDRC land were located in cavities (53%) than elsewhere in the Redwood Region of California. Four other studies found only 12-30% of spotted owl nests in cavities; tree species used for nesting were similar to other studies in the region (Pious 1994, Tanner 1999, Chow 2001, Fehring et al. 2003; summarized in Courtney et al. 2004).

Spotted owl nest microsites on GDRC land had greater basal area of large conifers, greater canopy height, lower basal area of small hardwood trees, lower canopy closure, and greater log volume than random sites within nest stands. Similarly, nest stands had greater basal area of large conifers, lower basal area of small conifers, fewer conifer saplings, steeper slopes, and higher ground cover of shrubs, ferns, forbs, and tree seedlings than random stands. These findings are consistent with habitat associations of northern spotted owls at several spatial scales throughout the range of the subspecies (Courtney et al 2004:5-18):

> "Forest stand structural attributes positively associated with foraging, roosting and nesting included vertical canopy layering, tree height or diameter diversity, canopy volume, canopy closure, snag diameter, snag basal area or volume, tree diameter and log volume. These attributes correspond to those identified by Thomas et al. (1990) as important components of Northern Spotted Owl habitat."

Landscape composition around nests differed from random locations on GDRC land, with nest locations containing more 31-45 yr old and 46-60 yr old forest. The amount of clearcut area did not differ between nest and random sites on GDRC land; this was also found by Meyer et al. (1998) in Oregon. In contrast to all other studies of northern spotted owls except one in the eastern Cascades of Washington, landscapes surrounding nests did *not* contain more older forest (> 60 yrs in our study) than random landscapes (summarized in Courtney et al. 2004).

Although we found associations between reproductive output and forest cover types, we did not evaluate spotted owl survival in relation to habitat variables in these studies.

3.E. FORAGING BEHAVIOR OF SPOTTED OWLS ON GREEN DIAMOND RESOURCE COMPANY LAND

There has been extensive research on northern spotted owls (*Strix occidentalis caurina*) designed to understand the habitat requirements and population viability of this federally listed species (USDI 1990). The focus of habitat based studies has been to identify the structural characteristics and spatial requirements for nesting, roosting and foraging (Forsman et al. 1984, Carey et al. 1990, Solis and Gutiérrez 1990, Ripple et al. 1991 and 1997, Lehmkuhl and Raphael 1993, Hunter et al. 1995, Buchanan et al. 1993 and 1995, Zabel et al. 1995). The majority of these studies have been conducted in landscapes with significant areas composed of mature and old growth forests, the principal habitat for this subspecies throughout much of its range. Due to the influence spotted owls have on forest management, there has been considerable interest in identifying management practices, which could accelerate development of suitable owl habitat in forested landscapes, which currently lack the structural characteristics necessary to support owls. However, because most owl habitat took decades, or even centuries to develop, there have been few opportunities to elucidate the critical components of regenerating forest stands that are first being utilized by spotted owls as habitat.

The coastal region of northern California was recognized early in the 1990's as being somewhat unique for spotted owls (Thomas et al. 1990). In this area, spotted owls were frequently located nesting in relatively young managed stands, in contrast to what had been observed throughout most of the owl's range. Several factors contribute to the uniqueness of the region. Habitat structure develops more rapidly in the moist coastal region due to the rapid regeneration of redwoods (*Sequoia sempervirens*) and other conifers, but it is the coppice growth of a variety of hardwood species, including tanoak (*Lithocarpus densiflorus*), madrone, (*Arbutus menziesii*), and California bay (*Umbellularia californica*), that results in high structural diversity in managed even-aged stands. Dusky-footed woodrats are the primary prey for spotted owls in the study area (see section 3A, above). Dusky-footed woodrats are found in high abundance in young forest stands regenerating after timber harvest (Sakai and Noon 1993, Hamm 1995), so that a limited degree of harvesting of older stands may benefit owls through increased prey availability (Cary et al. 1992, Carey and Peeler 1995). All of these factors contribute to the early development of suitable habitat so that owls can be found occupying landscapes predominantly comprised of stands as young as 30 years of age (Folliard et al. 2000).

This suggests that an investigation of the key habitat elements utilized at night by spotted owls in a managed landscape would not only provide useful information for the coastal region, but may also provide insights that could be applied throughout the north coastal region of California.

Methods

Study Area

The study was conducted in three primary areas on Green Diamond Resource Company ownership. All three areas were heavily roaded which provided for excellent access throughout. The northern area is located north of the Klamath River, in the Terwer, Hunter and Wilson Creek drainages. This is an area of approximately 17,800 ha that was composed of redwood and Douglas fir stands that were mostly 15-30 years old with a few scattered stands of mature and old-growth timber.

The central area was in the Little River drainage, situated between McKinleyville and Big Lagoon, east of Highway 101. This area comprised approximately 30,350 ha, was highly fragmented, and had a mix of redwood and Douglas fir stands ranging from 0-80 yrs old. Silvicultural practices in this area resulted in a wide range of forest stand conditions, including lightly to heavily thinned stands, shelterwood stands, and even-aged stands.

The southern area was in the lower Mad River drainage and consisted of approximately 7,600 ha. The majority of stands in this region were from 0-15 yrs old, with isolated stands of 60-80 yr old second growth timber. The area was predominately redwood with some Douglas fir.

Visual Observations

Owls in this study were fitted with radio-transmitters as part of GDRC's study of nocturnal habitat use. From March-July 1999, we attempted to observe each transmittered owl once/week, and to alternate between early night and late night observations for each owl in subsequent occasions. After triangulating on an owl, we attempted to locate the bird visually with the aid of night vision scopes outfitted with small infrared lights (ITT Night Quest, Model 160 and 190). Our observations were limited to locations in which an owl was reasonably accessible from a road. We attempted to minimize the effect of observers on the owls' behavior by not approaching any closer than necessary to observe the owls through the scope.

We followed individual owls for a minimum of 3 hours per night, with telemetry or visual locations recorded at intervals of 30 minutes or less. Because owls are sit-and-wait predators, 30 minute intervals allowed movement patterns to be established. The monitoring periods included both p.m. and a.m. nocturnal sessions. Data collected on foraging behavior included: time spent per perch, number of prey capture attempts/hour, number of prey captures/hour, and total time spent foraging. Data collected on habitat elements associated with foraging included foraging perch characteristics (tree species, size and location – e.g. stand interior versus edge, habitat retention area, watercourse protection zone, and characteristics – e.g. live tree, snag, stump), perch height, perch structure, percent slope, aspect, and ground cover.

Results

Visual observations often consisted of multiple perches used over a short time span in close proximity to one another. We collected the majority of observations during the

early hours of the owls foraging (1800-2400; Fig. 3.6). We obtained visual observations for 18 of the 22 transmittered owls. However, 5 owls were excluded from comparisons among individuals because they were observed on fewer than 3 perches each. The remaining 13 individuals (6 males and 7 females) were observed on 204 perches over 41.25 observation hours.

We observed 22 attempts by owls to capture prey with an average of 1 prey capture attempt per 9.3 perches, or 1 prey capture attempt per 112.5 minutes of perch time. Overall mean time per perch was 15.7 minutes (SE = 2.75; range = 4.9-43.3). Males spent less time on each perch than females ($\bar{x}$ = 9.5 and 21.0 minutes, respectively; t = 2.49, P = 0.030; Fig. 3.7). Of the 22 attempts by owls to capture prey, we judged 3 to be successful. Two of the captures were observed and the third was inferred by the fact that the male owl being observed promptly flew back to the nest following the capture attempt and gave prey delivery calls.

Multiple estimates of perch height while foraging were only obtained for 5 individual owls. The mean perch height based on 47 observations from three males was 4 m (12.7 ft), which was significantly lower (t = 3.83, P = 0.008) than the mean of 6.5 m (21.2 ft) from 16 observations of three females.

There were biases associated with our ability to visually locate the owl in different types of habitats and with our ability to move at night through different habitats. We obtained the majority of visual observations when the owls were foraging near roads, which existed in most stand types. However, we were not able to quantify the number of foraging observations associated with roads because assigning an owl to this category was too arbitrary. The majority (57) of visual observations occurred in recent clearcuts (<10 years old) when the observer believed the owl was not near a road, followed by riparian buffer zones (4) and forested stands (2).

Approximately 50% of both triangulated and visual owl observations occurred in forest stands >40 yrs old, and 20-30% occurred in stands 10-20 yrs old (Fig. 3.8). In contrast, few observations occurred in the 5-9 or 21-40 year age classes (Fig. 3.8). Eight percent of visual and 13% of triangulated owl observations occurred in the 0-4 age class.

Discussion

The northern spotted owl has been described as a sit-and-wait predator that forages by flying from perch-to-perch to search for its prey (Forsman 1984). Our observations confirm this mode of hunting with an estimated overall mean perch time for both sexes of approximately 16 minutes. Our data also suggested that males tend to spend less time per foraging perch than females, which may suggest a slightly different foraging strategy between the sexes. There is moderate reversed sexual dimorphism in spotted owls with females averaging approximately 15% larger in body mass (Blakesley et al. 1990). Potentially, males may be better adapted to taking smaller more abundant prey and their more frequent movements reflect this foraging strategy (Solis and Gutierrez

1990). It is also possible that this phenomenon is related to behavioral differences between the sexes (Bull et al. 1989). During courtship, males offer food to their mate while the female often sits and emits begging calls (Forsman 1984). Also, during the early breeding season, females do all the incubating and brooding of the young, while the males forage. During the transition period when female behavior shifts from being fed to actively foraging on their own, there may be a tendency for females to wait to be fed by the male for a time before beginning active foraging. Our observations at this time of year may contribute to an estimate of significantly longer perch times for females.

Our data suggest that spotted owls capture prey at few (11%) of their hunting perches and that few (14%) of their attempts to capture prey are successful. This indicates that they successfully capture prey from <2% of their total hunting perches. We observed 3 successful capture attempts in 41.25 hours of foraging or 1 capture every 13.75 hours of foraging. During the shorter summer nights with only 8-9 hours of darkness, an owl would average a single capture approximately every 1.6 nights. This should be adequate to sustain an individual owl that is preying on larger prey such as dusky-footed woodrats (mean body mass = 210 g [Hughes 2006]), the primary prey in our study area (see Section 3A, above). However, a male spotted owl would be unlikely to be able to sustain his mate and several nestling owlets with this level of hunting success. As noted above, this estimate is based on a small sample size and may not accurately reflect average foraging success of spotted owls in our region. In addition, the presence of the observer, who was attempting to remain at a discrete distance while maintaining visual contact with the foraging owl, may have influenced the owl's hunting success, either by influencing the owl's prey or influencing the owl's hunting ability. In an observational study of diurnal foraging by northern spotted owls, capture success rate was 22% (Sovern et al. 1994).

Mean perch height while foraging of 4 and 6.5 m for males and females respectively, suggests that spotted owls in our study area are foraging primarily on the ground and understory. The observation is consistent with preying on dusky-footed woodrats, which primarily nest on the ground (Sakai and Noon 1993). Given the small sample size, the estimated differences between the sexes should be interpreted with caution.

As noted above, there were several inherent biases in this study associated with visual observations of foraging in spotted owls. As a result, we can not assess various aspects of their foraging ecology such as temporal patterns in foraging throughout their activity period and relative amounts of time they spend foraging in different habitats. However, nocturnal locations of spotted owls based on triangulations likely also had biases associated with them. To get a single location, three separate azimuths had to be obtained that converged on a single point. If an owl were actively moving, the probability of getting three converging azimuths was greatly reduced. Generally, it took approximately 15 minutes to travel to three points and get good compass bearings with the directional antennae in this study. As a result, triangulations were most likely biased to locations where owls spent >15 minutes in one location. Given the relatively short mean perch times (9.5 and 21.0 minutes, respectively for males for females) estimated

from direct visual observations of foraging owls, nocturnal locations based on triangulation likely missed much of the active foraging, especially for males. Therefore, studies of nocturnal habitat use based on triangulations likely under estimate actual foraging habitat and tend to reflect habitat used for spotted owls when engaged in other behaviors at night (e.g. resting, grooming, vocalizations and others).

Despite the biases, it is apparent that spotted owls tended to spend the greatest time in older stands (>40 yrs) during their period of activity at night. Stands 10-20 yrs also received high use, and although not a high proportion (7.7% triangulation and 16.9% visual) of all the locations, spotted owls used recent clearcuts (0-4 yrs) more than we anticipated based on previous radio telemetry studies (Sisco 1990, Solis and Gutierrez 1990, Carey et al. 1992). In addition, the foraging in recent clearcuts was not an aberrant behavior of just a few of the birds being monitored since 13 of 22 birds were recorded in these open areas on at least one occasion.

Presumably, the high use in the older stands relates to their ability to use these stands to forage for certain species of prey (e.g. flying squirrels, tree voles, birds and etc.) as well as engaging in other nocturnal behaviors as described above. In contrast, use of the younger stands were mostly likely only associated with foraging for species such as dusky-footed woodrats which are known to be abundant in young stands (Sakai and Noon 1993). We believe the high use in the 10-20 yr old stands occurs, because these stands had high densities of woodrats (Sakai and Noon 1993), and spotted owls were able to forage relatively well in stands of this age. We postulate that the rapid development of coastal forests results in sufficient stand development and canopy lift during the 10-20 age class that woodrats become more vulnerable to avian predators. In contrast, brushy clearcuts that are 5-9 yrs old may have relatively high numbers of woodrats, but they may be too dense to permit access by avian predators. The 0-4 yr old clearcuts may contain relatively few prey items, but those present should be quite vulnerable to an avian predator.

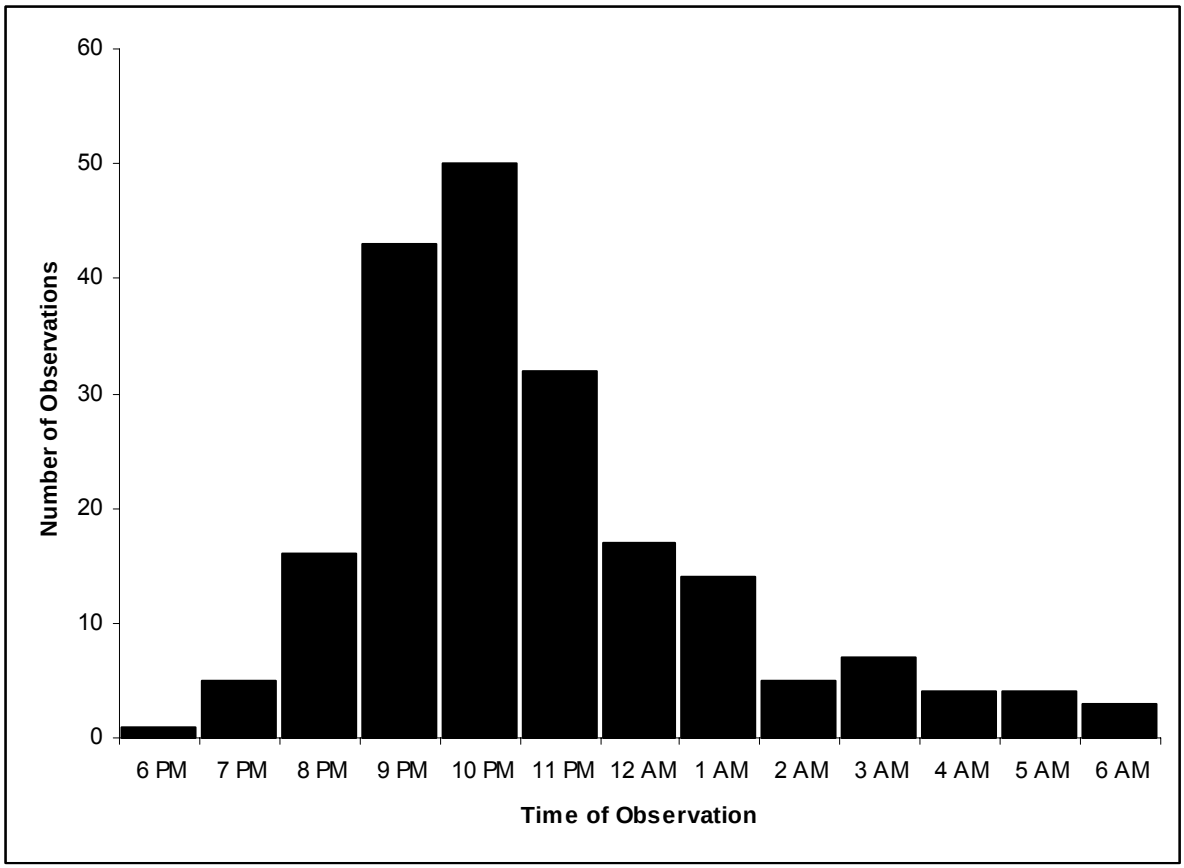

Figure 3.6. Time of night foraging spotted owls were visually observed on Green Diamond Resource Company land.

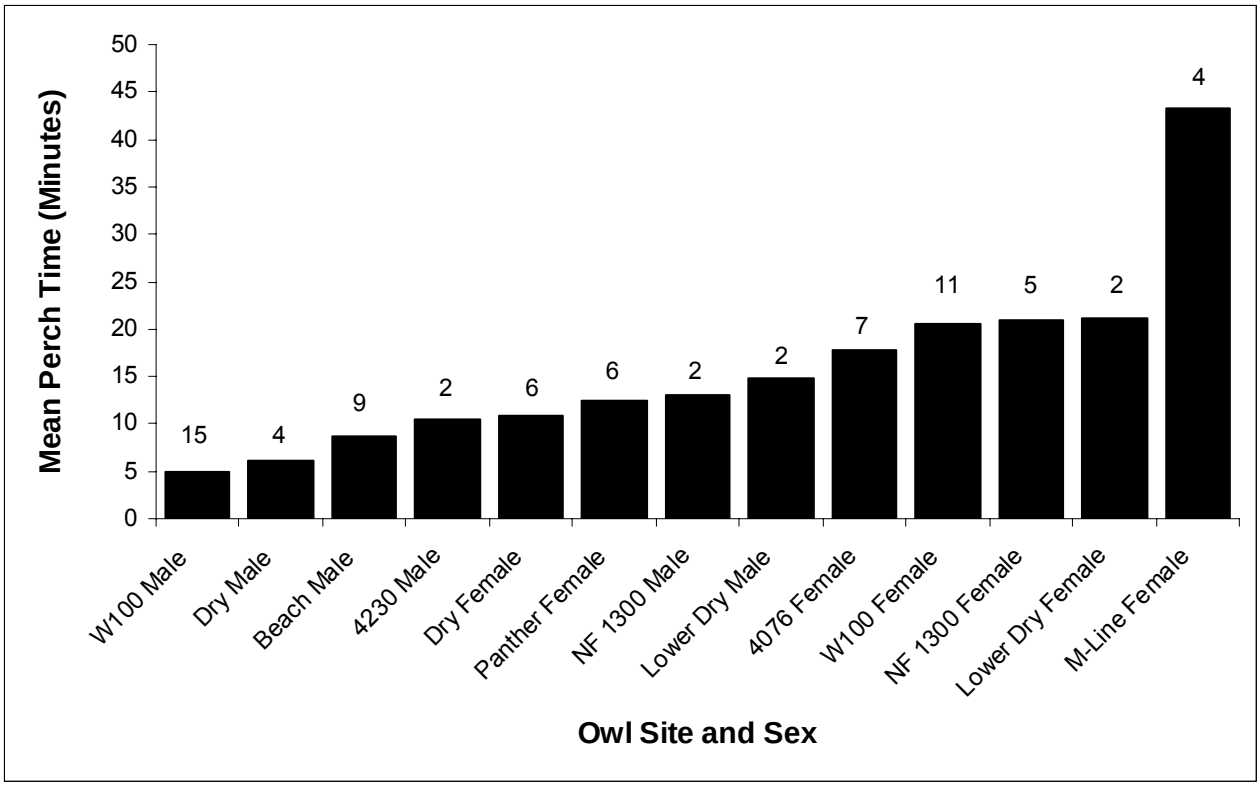

Figure 3.7. Mean time per perch for individual northern spotted owls on Green Diamond Resource Company land.

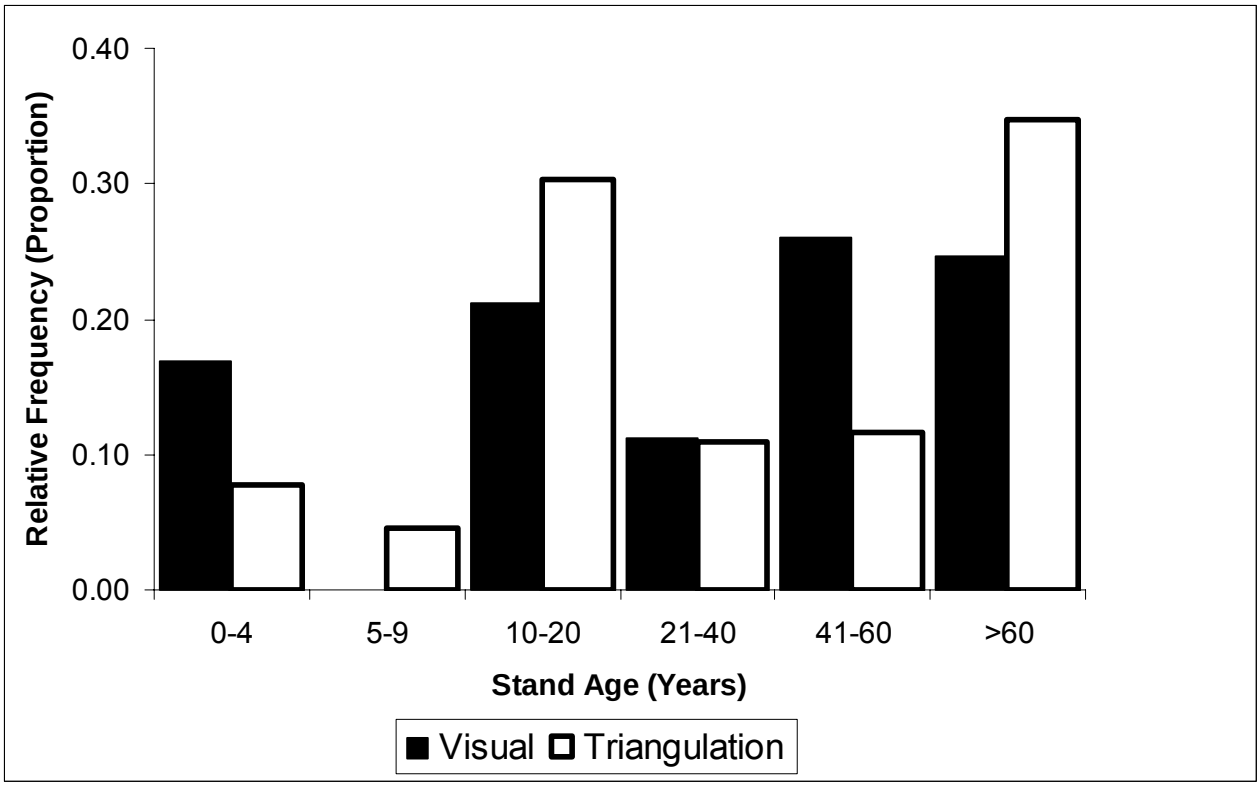

Figure 3.8. Age of forest stands used by northern spotted owls at night on Green Diamond Resource Company land. Observations were based on radio-telemetry triangulation and direct visual sighting.

3.F. BARRED OWLS

Barred owls (*Strix varia*) and northern spotted owls are closely related, are similar in morphology (barred owls are approximately 15% larger), and have similar habitat associations where their ranges overlap (Courtney et al. 2004). Barred owls expanded their range from eastern to western North America in the latter part of the 20th century, arriving in Washington in 1965 (Rogers 1966), Oregon in 1974 (Taylor and Forsman 1976) and California in 1981(Evens and LeValley 1982). The barred owl's range now overlaps essentially all of the range of the northern spotted owl.

Most observations of barred owls in the range of the northern spotted owl were detected incidental to spotted owl surveys and demographic studies (Courtney et al. 2004). Only one study has focused on home range and diet of sympatric barred and spotted owls, in the Washington Cascades (Hamer 1988, Hamer et al. 2001). Home ranges of barred owls were much smaller than spotted owls in Washington (Hamer et al. 1988). However, northern spotted owl home ranges in Oregon and California tend to be smaller than those in Washington; the relative sizes of the two species' home ranges in Oregon and California are unknown. Barred owls in Washington had a more diverse diet than sympatric spotted owls (Hamer et al. 2001). Again, dietary overlap between these two species has not been studied in Oregon or California.

In some regions, barred owl pairs occupy many territories formerly occupied by northern spotted owls (e.g., Olympic peninsula, Scott Gremel, *personal communication*; Washington Cascades, Pearson and Livezey 2003 & Herter and Hicks 2000). It is unknown whether barred owls directly displaced spotted owls in these cases, or whether spotted owls vacated their territories for some other reason, allowing the barred owls to colonize the vacant areas. Occupancy of former spotted owl territories by barred owls has occurred on many types of land ownership (National Parks, National Forests, BLM Districts, tribal land, state land, timber company land, etc.; Courtney et al. 2004), including those that experienced timber harvest and those not available for timber harvest.

In Redwood National and State Parks (RNSP), adjacent to GDRC land, the number of historic and current spotted owl activity centers in which barred owls were detected has risen gradually between 1993 and 2004, concurrent with a decline in the number of spotted owls in the activity centers (Schmidt 2005). For example, 24 spotted owl activity centers were surveyed in both 1995 and 2004. Of these 24 sites, 22 were occupied by spotted owls in 1995 (17 by owl pairs, 4 by single males, and 1 by a single female owl), and only 6 of these sites were occupied by spotted owls in 2004 (all by owl pairs). In 1995, two of the sites with spotted owl pairs each had a barred owl detection and no barred owls were detected in the remaining 22 surveyed sites. In 2005, one of the sites with spotted owl pairs had a barred owl detection and eight additional sites had barred owl detections. The remaining 10 sites had neither spotted owl nor barred owl detections (Schmidt 2005).

Hybridization between spotted and barred owls occurs infrequently. Kelly and Forsman (2004) found records of 47 spotted-barred hybrids in Oregon and Washington, 1970-1999, out of all available spotted owl survey data, including >9000 observations of banded spotted owls. Of the 47 hybrids, 31 were F1 hybrids (a first generation offspring of a pure spotted owl and a pure barred owl) and 16 were F2 hybrids (a second generation offspring of an F1 hybrid with either a pure spotted owl or a pure barred owl; an F2 hybrid could also result from an F1xF1 crossings, but this has not been observed in the field).

Hybrid owls tend to arise from pairings between female barred owls and male spotted owls because both species exhibit reversed sexual size dimorphism (females are larger than males). Male barred owls are similar in size to female spotted owls (Courtney et al. 2004), making this pairing less likely (Kelly and Forsman 2004). On 13 occasions at 6 territories, male spotted owls were paired with female barred owls. In no cases were female spotted owls paired with male barred owls (Kelly and Forsman 2004). In a different study, six of seven hybrid owls genetically sampled proved to have barred owl mothers, whereas only one had a spotted owl mother (Haig et al. 2004).

Eleven F1 hybrids of both sexes were observed paired with barred owls and seven F1 hybrids of both sexes were observed paired with spotted owls, although 15 of 16 F2 juveniles observed were produced by F1 hybrids that backcrossed with female barred

owls. No pairings of F1 males with F1 females were observed. It may be difficult to distinguish hybrid backcrosses in the field (e.g., to distinguish an individual that is ¾ spotted owl and ¼ barred owl from a spotted owl). However, these birds can be distinguished by genetic markers (Haig et al. 2004).

Among 36 sites surveyed from 1993-2004 (not all sites were surveyed each year), only one known hybrid spotted-barred owl was detected in Redwood National and State Parks. This was a hybrid female paired with a spotted owl male in 1998; the pair produced 2 fledglings.

Hybridization appears not to be a threat to the spotted owl because it occurs when and where barred owls are relatively scarce, at the front of the barred owl range expansion (Kelly and Forsman 2004, Courtney et al. 2004). The real threat to spotted owls appears to arise from competition between barred owls for territories, at least in some areas. The 2004 scientific evaluation of the northern spotted owl (Courtney et al. 2004, Chapter 7, p. 43) concluded that "while we are convinced that barred owls are having a negative impact on spotted owls at least in some areas, the extent of this impact and its ultimate outcome is uncertain."

3.F.1. Number and distribution of barred owls over time on Green Diamond Resource Company land

Between 1993 and 2005, a total of 43 barred owl sites were located on Green Diamond Resource Company lands (Figure 3.9). These sites were based on barred owl responses incidental to spotted owl surveys. Except for a few exceptions, follow ups were not done for barred owl responses and these sites do not necessarily represent activity centers or nest sites for resident barred owls. The potential exists that individual barred owls moved around during a given season and resulted in an over estimate in the number of sites. On the other hand, since the surveys were not designed to locate barred owls, there may have been resident barred owls that were not detected. If this is the case, these surveys would not accurately reflect the total number of barred owl sites on GDRC property.

Even though an estimate of the absolute number of barred owl sites is highly suspect, it is apparent that the number of sites has increased over time (Figure 3.10). Spotted owl survey protocols and the level of survey effort have remained relatively constant over time, so that the increase in barred owl sites can most reasonably be attributed to more barred owls. It appears that the maximum number of sites peaked at 14 in 2003, but this should be viewed with caution. It is suspected that "floating" non-territorial barred owls may be more inclined to vocalize, while nesting individuals are relatively silent (B Woodbridge, pers. comm.). It is possible that the apparent decline in barred owl sites was the result of more nesting pairs of barred owl rather than a real decrease.

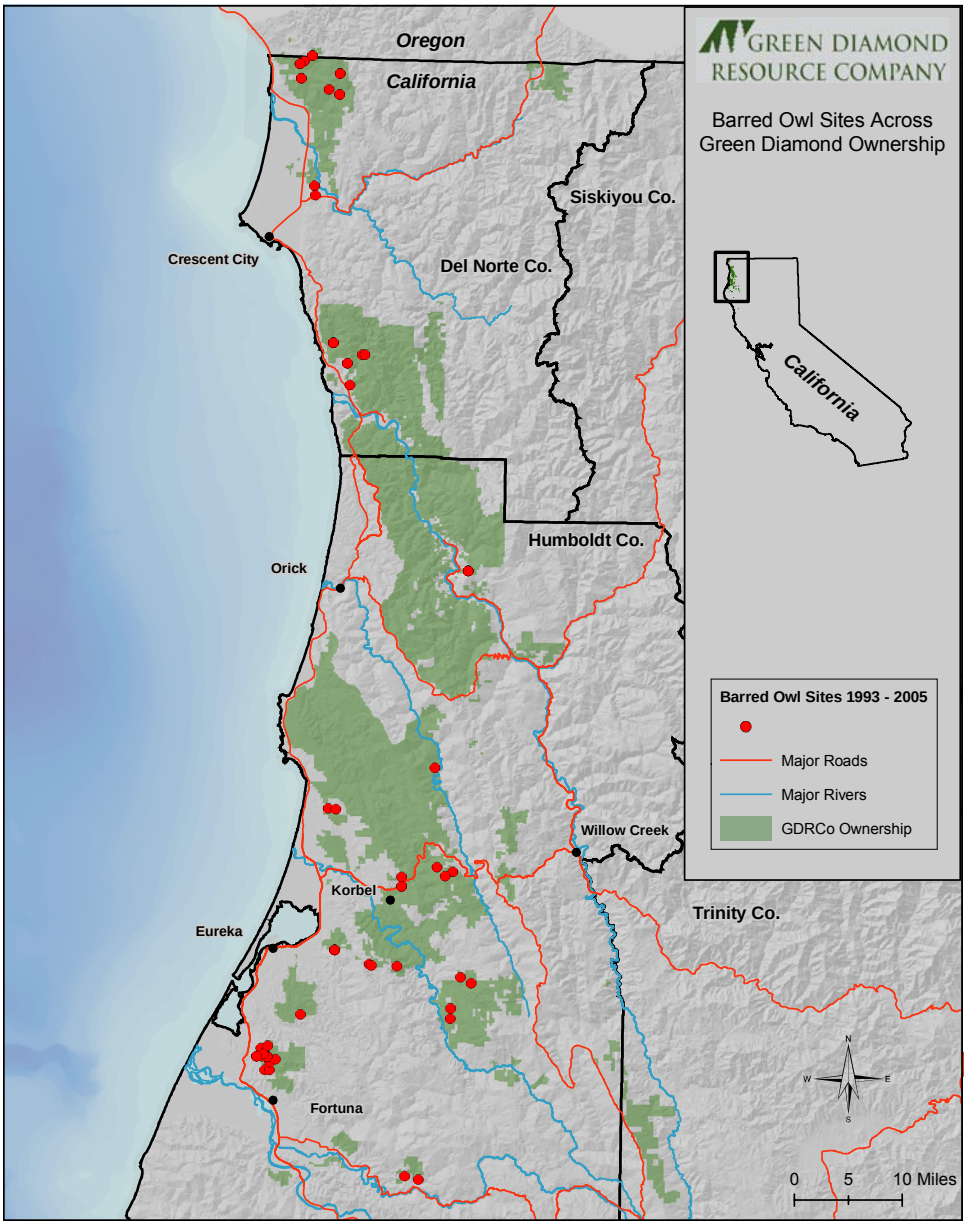

Figure 3.9. The distribution of barred owl sites across Green Diamond Resource Company lands, 1993-2005.

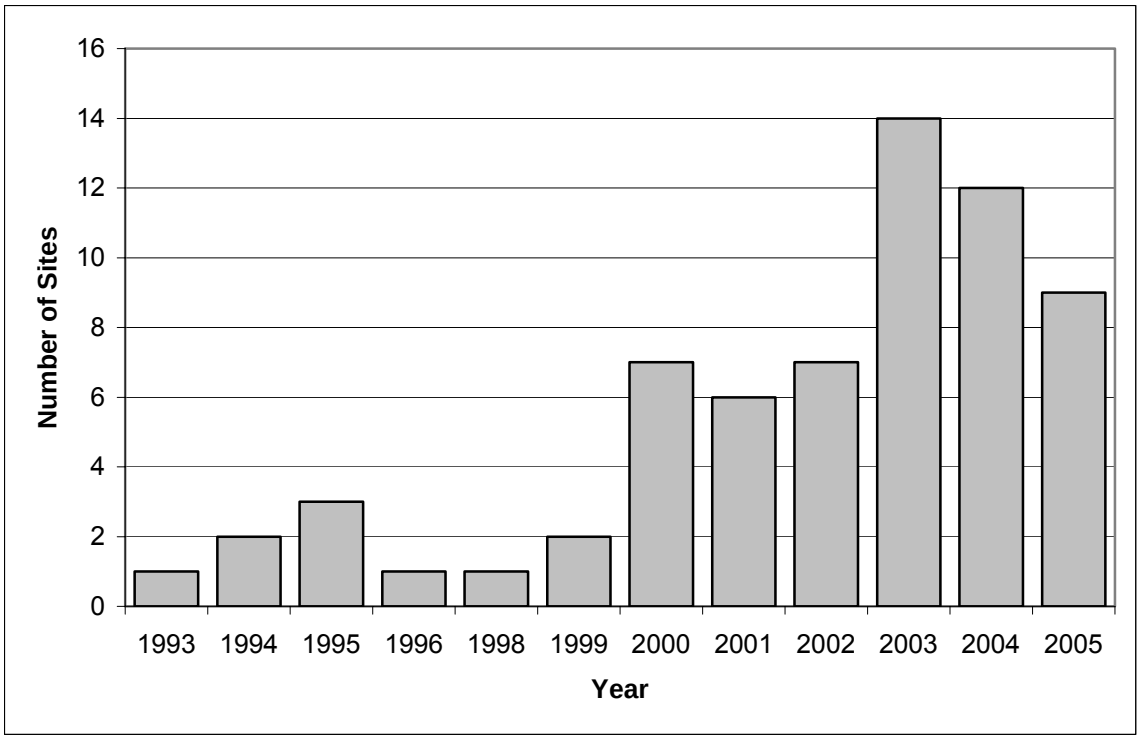

Figure 3.10 Number of barred owl sites on Green Diamond Resource Company lands by year.

3.F.2. Modeling occupancy of spotted owl sites with respect to barred owls in Oregon

Using data collected from 1990-2002 at three northern spotted owl demographic study areas in Oregon, Olson et al. (2005) modeled temporal variation in site occupancy, extinction and colonization probabilities. The effects of barred owls presence was also examined for these parameters. Barred owl presence was found to have a negative effect on spotted owl detection probabilities and either a positive effect on local extinction probabilities or a negative effect on colonization probabilities. The study concluded that because barred owl presence is increasing in the study area, further declines in the proportion of sites occupied by spotted owls was expected. This was one of the first attempts to quantify the impact of barred owls on spotted owl demographic parameters and it supports the growing concern about the potential impact of barred owls on spotted owl populations.

3.G. WEST NILE VIRUS

West Nile Virus (WNV) is an arthropod-borne virus transmitted primarily by mosquitoes. Birds are the primary (reservoir) host of WNV although other mammals, including humans (incidental hosts), may be infected and develop disease. WNV first appeared

in the U.S. in New York City in 1999. By the end of 2004, WNV had spread across the continental U.S. (except for Washington State), causing human, equine, and avian mortality (U. S. Centers for Disease Control and Prevention [CDC] webpage). By July 2005, WNV was found in the U.S. in dead wild birds of >200 species, including 8 owl species and 14 additional raptor species (CDC webpage). Mortality rates among infected birds vary by species, with Corvids especially susceptible. Birds can develop immunity to WNV following exposure.

It is unknown the extent to which northern spotted owls will be affected by WNV. The 2004 scientific evaluation of the northern spotted owl (Courtney et al. 2005, chapter 8, p. 36) stated:

> "It is undeniable that WNV is a new threat to Northern Spotted Owls. WNV also has the potential to reduce population viability throughout the owl's range. But the degree to which this potential will be realized is quite uncertain. It is not certain: (1) what proportion of owls that are infected will die from WNV; (2) how uniform infection will be throughout the range of the owl; (3) when, or if, owls will develop some immunity to the disease and therefore limit the duration of expected mortality; and (4) how the potential indirect benefits of reduced predation (e.g., loss of Northern Goshawks), the potential indirect detriments of increased competition (e.g., relative increases of less susceptible Barred Owls), or reduction in nest site availability by reductions in facilitating species (e.g., Northern Goshawks in eastern Washington, Tracy Flemming, NCASI, *personal communication*) will balance."

GDRC is participating in research on West Nile Virus in conjunction with Dr. Alan Franklin of Colorado State University. We collected oral swabs and blood from 1 adult and 46 juvenile spotted owls in 2004. Using Polymerase chain reaction (PCR) techniques, all 47 samples tested negative for WNV. In 2005, we collected oral swabs and blood from 1 adult and 29 juvenile spotted owls. Tests have not been completed for these samples.

In addition to the oral swabs and blood samples, GDRC participated in sampling small mammals and mosquitoes for West Nile Virus in 2005. The sampling on small mammals involved using a restricted random sampling design to trap and collect serological samples from small mammals on 8-10 spotted owl territories. Within each spotted owl territory, we placed two trap lines, one in older forest near a current roost or nest site of the owls, and one in an adjacent early seral stage area, where small mammals tend to be more abundant. Each trap line was 200m long with 21 trap stations spaced 10m apart. One Sherman and one Tomahawk live trap were placed at each station. Grids were trapped for 4 days with traps baited and set each evening and morning. Both diurnal and nocturnal species were trapped. We collected blood from small mammals using the retroorbital plexus technique (Mills et al. 1995). Animals were anesthetized with isoflurane just prior to collecting blood. Individuals were weighed, sexed, and ear-tagged to prevent sampling individuals more than once.

Mosquito sampling involved 6 trapping stations spaced equally along each of the 200m small mammal transects. At each mosquito trap station we placed one CO_2 baited Center for Disease Control (CDC) light traps (Anderson et al. 2004) and 2 CDC ovitraps to collect eggs and larvae (Fay and Eliason 1966). Three of the mosquito trap stations were placed 7m above ground in trees and three were placed 2m above ground, with high and low stations being alternated along the line. The light traps were used to estimate relative abundance, by species, of mosquitoes, and the ovitraps were used to estimate species presence and composition. Mosquitoes from the collection were separated by trap, site, and date and then frozen. Samples were sent to the Arthropod-borne and Infectious Disease Laboratory at Colorado State University. Testing of these samples has not been completed.

Appendix 3.A. Species of prey items found in 965 collections of regurgitated pellets from 245 northern spotted owl territories or locations on Green Diamond Resource Company lands in northern California, 1989-2004.

Species	Species/Group	Mass (g)	N
Mammals			
Chiroptera			
Lasiurus spp. (unidentified hairy-tailed bat)	Other[1]	10	3
Myotis spp.	Other	10	1
Dipodidae			
Zapus spp. (unidentified jumping mouse)	OSRI[2]	24	2
Geomyidae			
Thomomys spp. (unidentified gopher)	OSRI	87	43
Heteromyidae --- Perognathinae			
Perognathus spp. (unidentified pocket mice)	OSRI	20	1
Leporidae			
Sylvilagus bachmani (Brush rabbit)	*Sylvilagus*	500	80
Lagomorph (unknown)	Other	500	2
Muridae --- Arvicolinae			
Arborimus spp. (Sonoma tree vole/red tree vole)	*Arborimus*	27	497
Clethrionomys spp.(unidentified red backed vole)	OSRI	23	29
Microtus spp. (unidentified vole)	OSRI	39	98
Microtinae (unidentified vole spp.)	OSRI	26	14
Muridae			
unidentified rat or mouse	OSRI	25	94
Muridae --- Murinae			
Rattus rattus (black rat)	OSRI	105	24
Muridae --- Sigmodontinae			
Neotoma fuscipes (dusky-footed woodrat)	*Neotoma*	230	1479
Peromyscus spp. (Deer/white footed mouse)	*Peromyscus*	25	154
Mustelidae			
Mustela spp. (Ermines, minks, weasels, ferrets)	Other	200	3
Sciuridae			
Glaucomys sabrinus (northern flying squirrel)	*Glaucomys*	115	307
Sciuridae (unidentified squirrel)	OSRI	265	8
Tamiasciurus douglasii (Douglas Squirrel)	OSRI	208	1
Soricidae			
Sorex spp. (unidentified shrews)	OSRI	5	14

(continued next page)

Appendix 3.A, continued

Species	Species/Group	Mass (g)	N
Talpidae --- Talpinae			
Neurotrichus spp. (American Shrew-mole)	OSRI	9	5
Scapanus spp. (unidentified western mole)	OSRI	125	5
Talpidae spp. (unidentified desmans, moles)	OSRI	125	1
Birds			
Columbidae			
Columba fasciata (Band-tailed Pigeon)	Aves	340	11
Corvidae			
Aphelocoma spp. (unidentified scrub jays)	Aves	107	1
Cyanocitta stelleri (Steller's Jay)	Aves	74	11
Picidae			
Picoides villosus (Hairy Woodpecker)	Aves	50	1
Picidae spp. (unidentified woodpecker or wrynecks)	Aves	50	1
Sphyrapicus spp. (unidentified sapsucker)	Aves	40	1
Strigidae			
Aegolius acadicus (Northern Saw-whet Owl)	Aves	83	1
Aves (unidentified bird)	Aves	30	95
Insects			
Aerididae (grasshopper spp.)	Other	0.5	1
Arachnida			
Araneus spp. (Wheel weaving spiders)	Other	0.5	1
Coleoptera --- Scarabacidae (dung beetles)	Other	0.5	2
Coleoptera spp.(Sheath-winged beetles)	Other	0.5	30
Diptera spp. (Fly spp.)	Other	0.5	1
Insect (unidentified insect)	Other	0.5	6
Orthoptera --- Gryllacrididae			
Stenopelmatus spp. (Jerusalem Cricket)	Other	1	6
Fishes			
Cyprinidae spp. (minnows and carps)	Other	80	1
Reptiles and Amphibians			
Lower vertebrate (unknown)	Other	10	21

[1] Other (Insecta, Chiroptera, Mustelidae, Teleolstei, Reptilia).
[2] OSRI (Other Small Rodent or Insectivore).

CHAPTER 4
SPOTTED OWL VIABILITY

This chapter is based on the requirement for "a detailed analysis of the efficacy of and continued need for the set-asides and of the long-term viability of the owl population on Simpson's [Green Diamond Resource Company's] property."

4.A. DEMOGRAPHIC RATES

Green Diamond Resource Company (GDRC) participated in two previous region-wide meta-analyses of northern spotted owl demographic data, in December 1998, and January 2004 (Franklin et al. 1999, and Anthony et al. 2004, respectively), along with all other ongoing demographic studies of northern spotted owls in the United States. GDRC attended the first meta-analysis in December 1993, but since our demographic study began in 1990, we did not have data available in the proper format to include in the analysis. The objectives of each meta-analysis included estimation of survival, fecundity, and the finite rate of population change (lambda, λ) for each study area. In addition, participants examined regional and other trends across study areas. Each analysis includes data from all years of each study; therefore, results from later analyses supersede earlier analyses.

Except for data relevant to the ten-year view, the full details of the most recent meta-analysis are included in Anthony et al. 2004 and will not be repeated in this document. GDRC demographic data were collected from 1990-2003, which included survival estimates based on 1,344 total banded owls and 4,087 combined captures and recaptures. Fecundity was based on 1332 total determinations of the number of young produced per female. Although intermediate in the duration of the study, the GDRC dataset was the single largest of any of the 14 demographic study areas scattered throughout the range of the northern spotted owls. Salient results from the most recent northern spotted owl meta-analyses are summarized in Tables 4.1 - - 4.3. Estimated mean apparent survival probability of adult spotted owls on GDRC land was 0.850 (SE = 0.010), similar to estimates from the nearby Willow Creek (NW California) and Hoopa study areas (Table 4.1). GDRC and Hoopa showed no evidence for a decline, but there was evidence for a decline in survival for Willow Creek. Estimated mean annual fecundity for adult spotted owls on GDRC land was 0.326 (SE = 0.037), which was similar to the estimate from Willow Creek and higher than the estimate from Hoopa (Table 4.2). However, there was some evidence for a declining trend in fecundity for GDRC and Willow Creek, but Hoopa showed an increasing trend. Estimated rate of spotted owl population change (λ_{RJS}) on GDRC land was 0.97 (SE = 0.012), similar but slightly lower than the two nearby study areas. The 95% confidence interval for λ_{RJS} did not include 1.0 for GDRC providing evidence that the population was declining from 1990-2003. This was not the case for 9 of the other 14 study areas either because of a larger SE for λ_{RJS} (the GDRC SE was the lowest for any study area), or a higher estimate of λ_{RJS} combined with a larger SE.

Estimates of realized population change represented the trend in owl numbers over the entire period of study. The trend represents the ratio of the population size in each year, expressed relative to the initial population in the first year. Fig. 4.1 indicates that population of spotted owls on the GDRC study area was apparently stable or increasing until the late 1990's when the population appeared to begin a downward trend. During this time, apparent non-juvenile survival remained constant (Fig. 4.2), but there were three years in a row with below average fecundity (Fig. 4.3) from 1998-2000.

The direct demographic factors that determine rate of population change (λ) are survival, fecundity and adult emigration rates. We have no data on adult emigration, but there are no known reasons to hypothesize that this may have changed during the period of study. Since survival appeared constant, this suggests that a change in fecundity was responsible for the downward trend on λ starting in the late 1990's. In the early years of the study, fecundity showed an even-odd year effect with poor years of fecundity in the odd years being offset by high fecundity in the even years. However, starting in 1998, this pattern changed and there were three years in a row with poor nesting success. Franklin et al. (2000) demonstrated that weather, specifically cold wet spring weather, had a strong negative influence on fecundity. Although we lack site-specific weather data, weather records from Eureka, CA indicated that the years 1998-2000 had average amounts of late winter and spring rainfall. Depending on the timing of spring storms (e.g. extended rainfall during the initiation of incubation), it is still possible that weather was the driving factor in the poor reproduction during this period. It was also possible that there was a region-wide decline in key prey species, but all these explanations remain highly speculative.

Table 4.1. Estimated mean apparent survival probability (ϕ), with standard error (SE) and trend in ϕ for adult (≥ 3 yrs old) northern spotted owls (after Anthony et al. 2004, Tables 22 and 24, and summary by Courtney et al. 2004).

Study Area	ϕ	SE	Trend
Washington			
Wenatchee	0.750	0.026	Declining
Cle Elum	0.860	0.017	Declining?[a]
Rainier	0.832	0.020	Declining
Olympic	0.855	0.011	Declining
Oregon			
Coast Ranges	0.886	0.010	Stable
H. J. Andrews	0.883	0.010	Stable
Warm Springs	0.823	0.015	Stable
Tyee	0.878	0.011	Stable
Klamath	0.849	0.009	Stable
South Cascades	0.854	0.014	Stable
California			
NW California	0.869	0.011	Declining
Hoopa	0.853	0.014	Stable
Green Diamond	0.850	0.010	Stable
Marin – females	0.824	0.045	Stable
Marin – males	0.913	0.035	Stable

[a] Variable among years, but with a declining trend.

Table 4.2. Estimated mean annual fecundity (female young produced per adult female), (ϕ), with standard error (SE) and trend in fecundity for adult (≥ 3 yrs old) northern spotted owls (after Anthony et al. 2004, Tables 5 and 24, and summary by Courtney et al. 2004).

Study Area	Mean	SE	Trend
Washington			
Wenatchee	0.491	0.058	Stable
Cle Elum	0.574	0.069	Declining?[a]
Rainier	0.253	0.061	Stable
Olympic	0.293	0.057	Stable
Oregon			
Coast Ranges	0.260	0.050	Declining?[a]
H. J. Andrews	0.321	0.045	Stable?[a]
Warm Springs	0.424	0.070	Stable
Tyee	0.319	0.040	Increasing
Klamath	0.445	0.040	Stable
South Cascades	0.377	0.059	Declining
California			
NW California	0.333	0.032	Declining
Hoopa	0.216	0.043	Increasing
Green Diamond	0.326	0.037	Declining?[a]
Marin	0.530	0.056	Stable

[a] Best model included age and even-odd year effects, but a competing model had a negative time trend.

Table 4.3. Estimated rate of population change (λ_{RJS}) for northern spotted owls, with standard error and 95% confidence interval (after Anthony et al. 2004, Table 22, and summary by Courtney et al. 2004).

			95% CI	
Study Area	λ_{RJS}	SE	Lower	Upper
Washington				
Wenatchee	0.917	0.018	0.882	0.952
Cle Elum	0.938	0.019	0.901	0.976
Rainier	0.896	0.055	0.788	1.003
Olympic	0.956	0.032	0.893	1.018
Oregon				
Coast Ranges	0.968	0.018	0.932	1.004
H. J. Andrews	0.978	0.014	0.950	1.005
Warm Springs	0.908	0.022	0.866	0.951
Tyee	1.005	0.019	0.967	1.043
Klamath	0.997	0.034	0.930	1.063
South Cascades	0.974	0.035	0.906	1.042
California				
NW California	0.985	0.013	0.959	1.011
Hoopa	0.980	0.019	0.943	1.017
Green Diamond	0.970	0.012	0.947	0.993

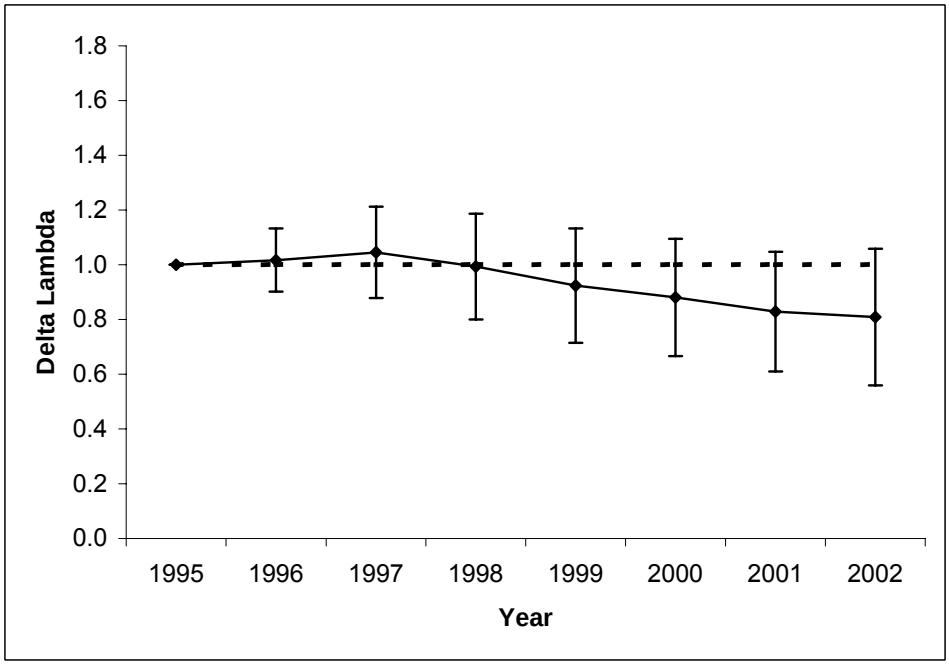

Figure 4.1 Lambda estimates and 95% confidence intervals for 1995 – 2002.

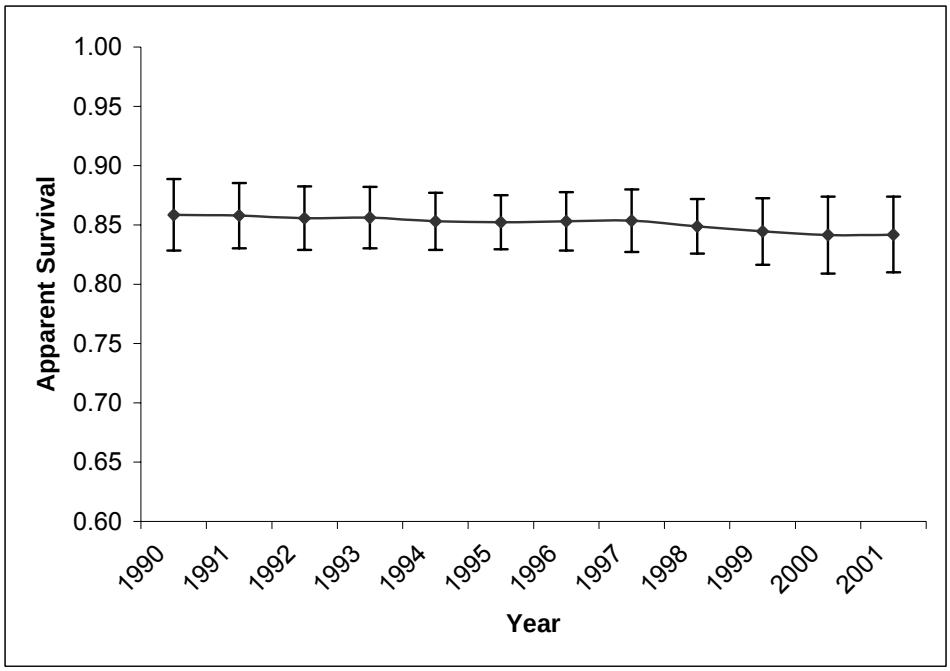

Figure 4.2. Apparent survival estimates and 95% confidence intervals for 1990 – 2001.

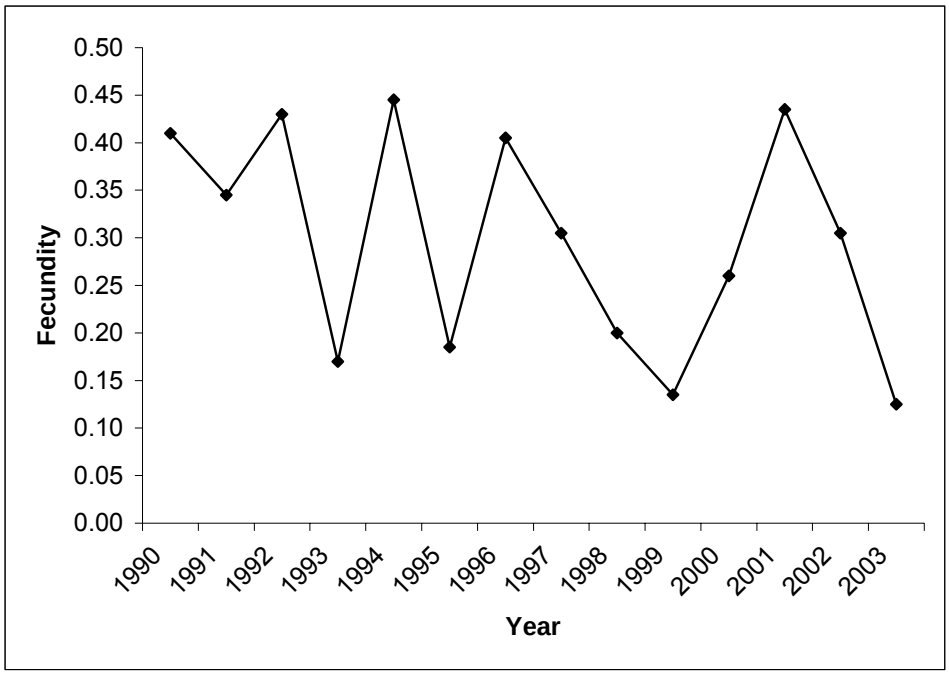

Figure 4.3. Fecundity estimates and 95% confidence intervals for 1990 – 2003.

4.B. ANALYSIS OF SET ASIDES

The number of spotted owls using set asides (Table 4.4) appears to have a somewhat negative trend similar to the rest of the population in the GDRC study area. However, a complete demographic analysis to compare trends in the set asides relative to the remaining population has not been done due to the complexity created by individual birds moving into and back out of the set asides. However, we did a comparison of the mean fecundity of females within, adjacent (nest site within a half mile) and outside the set asides (Table 4.5). This analysis indicated that females within or outside the set asides had almost identical fecundity, while females nesting adjacent to the set asides had the highest fecundity. There is no readily apparent biological explanation for this phenomenon and this will require further investigation.

Table 4.4 Number of northern spotted owl sites with activity centers or nest sites located within the boundaries of set asides and number of spotted owl sites with activity centers or nest sites within a 0.5 mile buffer of the set aside boundary and assumed to be using the set aside, 1993-2003.

Year	Sites in set asides	Sites with owls using set asides	Total sites
1993	32	24	56
1994	31	21	52
1995	30	23	53
1996	31	18	49
1997	33	18	51
1998	30	23	53
1999	32	20	52
2000	28	22	50
2001	27	21	48
2002	30	20	50
2003	26	19	45

Table 4.5. Mean number of young fledged per female owl with their nest site within, adjacent (1/2 mile buffer) and outside set-asides.

Nest location	N	Mean fledglings	SD
Within	137	0.47	0.777
Adjacent	95	0.74	0.890
Outside	235	0.48	0.753
Total	467	0.53	0.788 (column mean)

CHAPTER 5
FUTURE SPOTTED OWL DISPLACEMENTS

This chapter is based on the requirement for "an estimate of annual spotted owl displacement for subsequent portions of the permit period."

5.A. AN ESTIMATE OF ANNUAL SPOTTED OWL DISPLACEMENT FOR THE REMAINDER OF THE PERMIT PERIOD

Green Diamond is requesting an amendment to the 1992 ITP that would allow up to eight additional owl pair takes (displacements) on Green Diamond's ownership in California. These displacements would be above and beyond the 50 owl pair displacements authorized by the existing ITP. The eight additional owl pair displacements would be authorized during the existing permit term expiring in 2022 and would provide Green Diamond operational flexibility while USFWS and Green Diamond further consider and evaluate the findings of a 10-year, comprehensive review of Green Diamond's NSO HCP.

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