Home Range and Habitat Use of New Zealand Falcons (Falco novaeseelandiae) in an Exotic Plantation Forest During the Breeding Season

Authors: Seaton, Richard, Minot, Edward O., and Holland, John D.

Source: Journal of Raptor Research, 47(3) : 223-233

Published By: Raptor Research Foundation

URL: https://doi.org/10.3356/JRR-12-26.1

THE JOURNAL OF RAPTOR RESEARCH

A QUARTERLY PUBLICATION OF THE RAPTOR RESEARCH FOUNDATION, INC.

VOL. 47 SEPTEMBER 2013 NO. 3

J. Raptor Res. 47(3):223–233

HOME RANGE AND HABITAT USE OF NEW ZEALAND FALCONS (*FALCO NOVAESEELANDIAE*) IN AN EXOTIC PLANTATION FOREST DURING THE BREEDING SEASON

RICHARD SEATON,[1] EDWARD O. MINOT, AND JOHN D. HOLLAND
Institute of Natural Resources, Massey University, Private Bag 11-222, Palmerston North, New Zealand

ABSTRACT.—The New Zealand Falcon (*Falco novaeseelandiae*) is a threatened endemic species whose numbers have been reduced by habitat loss and the introduction of exotic predators. The species has recently been discovered breeding in exotic plantation forests. Understanding how New Zealand Falcons use plantation forests is critical to its effective management in this habitat. To determine patterns of habitat selection and inform habitat management, we studied the home-range size and habitat use of 13 adult New Zealand Falcons in Kaingaroa pine plantation. This plantation comprises 180,000 ha of nonnative pine trees that are planted and harvested in discrete 'stands' that create a mosaic of pine stand ages across the landscape. We radio-tracked eight males and five females for 12 wk during the 2004 and 2005 breeding seasons. Mean home-range sizes were 9.2 ± 4.2 km² for males and 6.2 ± 3.2 km² for females (mean ± SD). To investigate habitat use, pine stands were categorized by tree age and further classified into stand edge and stand interior. Both sexes strongly favored the edges between pine stands where stands less than 4 yr old bordered those greater than 19 yr old. Females also preferentially used the interior of pine stands less than 4 yr old, whereas males were more often found along the edges of these young stands. We conclude that if forestry managers wish to enhance the suitability of their estates for the New Zealand Falcon, they should provide a mosaic of different aged stands, while ensuring that stands less than 4 yr old bordering stands greater than 19 yr old are consistently available.

KEY WORDS: *New Zealand Falcon*; Falco novaeseelandiae; *forestry management*; *habitat use*; *home range*; *pine plantation*.

RANGO DE HOGAR Y USO DE HÁBITAT DE *FALCO NOVAESEELANDIAE* EN UNA PLANTACIÓN FORESTAL EXÓTICA DURANTE LA ESTACIÓN REPRODUCTIVA

RESUMEN.—*Falco novaeseelandiae* es una especie endémica amenazada cuyos números poblacionales se han visto reducidos por la pérdida de hábitat y la introducción de depredadores exóticos. Recientemente se ha descubierto a la especie reproduciéndose en plantaciones forestales exóticas. Entender cómo *F. novaeseelandiae* utiliza los bosques implantados es crítico para su manejo efectivo en este tipo de hábitat. Para determinar los patrones de selección de hábitat y conducir el manejo de hábitat, estudiamos el tamaño del rango de hogar y el uso de hábitat de 13 individuos adultos de *F. novaeseelandiae* en la plantación de pinos de Kaingaroa. Esta plantación comprende 180,000 ha de pinos exóticos implantados y que son explotados en rodales discretos que crean un mosaico de rodales de pinos de distinta edad a través del paisaje. Localizamos con radio transmisores ocho machos y cinco hembras durante 12 semanas en las épocas reproductivas de 2004 y 2005. Los tamaños medios de rango de hogar fueron de 9.2 ± 4.2 km² para los machos y de 6.2 ± 3.2 km² para las hembras (media ± DE). Para investigar el uso de hábitat, los rodales de pino fueron categorizados por edad de árbol y clasificados en borde de rodal e interior de rodal. Ambos sexos mostraron una marcada preferencia por los bordes entre rodales de pino, donde los rodales de

[1] Present address: Wingspan Birds of Prey Trust, P.O. Box 993, Rotorua, New Zealand; email address: richseaton@gmail.com

menos de cuatro años de edad bordearon aquellos de más de 19 años de edad. Las hembras también utilizaron preferentemente el interior de los rodales de pino de menos de cuatro años de edad, mientras que los machos fueron encontrados más a menudo a lo largo de los bordes de estos rodales jóvenes. Concluimos que si los encargados de la forestación desean mejorar la aptitud de sus plantaciones para *F. novaeseelandiae*, deberían mantener un mosaico de rodales de edades diferentes, asegurando que los rodales de menos de cuatro años de edad estén bordeando los rodales de más de 19 años de edad.

[Traducción del equipo editorial]

Before the arrival of humans, 98% of New Zealand was covered in forest (McGlone 1989). Today only 23% of that indigenous forest cover remains (Ewers et al. 2006). Along with the introduction of a variety of exotic predators, this extensive habitat loss has precipitated the decline and loss of many endemic New Zealand bird species (Tennyson and Martinson 2006). Today, 20% (1.8 million ha) of New Zealand's forest cover is made up of plantation forest, of which most is nonnative pine forest (Hartley 2002, Statistics New Zealand 2004). As the importance of pine plantations to New Zealand's indigenous biodiversity becomes better documented (Jackson 1971, Clout and Gaze 1984, Ogden et al. 1997, Brockerhoff et al. 2003, Maunder et al. 2005, Pawson et al. 2010), it has become clear that this exotic habitat has the potential to aid the conservation of some species that traditionally occur only in indigenous forest habitats.

The New Zealand Falcon (*Falco novaeseelandiae*) is an island endemic (Miskelly et al. 2008) that has recently been discovered breeding in exotic pine plantations (Stewart and Hyde 2004, Addison et al. 2006, Pawson et al. 2010). Due to historical and ongoing habitat loss, predation by introduced predators, and persecution by humans (Fox 1977, Lawrence 2002, Gaze and Hutzler 2004, Seaton et al. 2009, Bell and Lawrence 2009) the New Zealand Falcon is classified as a threatened species in New Zealand (Miskelly et al. 2008).

Traditionally regarded as a forest falcon, the New Zealand Falcon occurs in indigenous podocarp forest, southern beech forest (*Nothofagus* spp., Fox 1977, Barea 1995) and plantation pine forest (Stewart and Hyde 2004). On the South Island of New Zealand it also inhabits more open habitats including tussock lands and roughly grazed hill country pasture (Fox 1977, Gaze and Hutzler 2004); however, the species is largely absent from the intensively farmed landscapes that make up a large proportion of modern-day New Zealand.

The use of plantation forests by New Zealand Falcons emphasizes the species' ability to adapt to novel, human-made environments. Understanding the habitat variables these falcons select within plantation forests is key to determining management practices suitable to support the recovery of this species in this and other highly modified habitats. We determined patterns of habitat selection by examining the home-range size and habitat use of adult male and female New Zealand Falcons in an exotic pine plantation during the breeding season, in order to provide forestry and conservation managers with the information necessary to create landscapes that benefit the conservation of the New Zealand Falcon.

STUDY AREA

Our study focused on a population of New Zealand Falcons that had recently been discovered breeding within Kaingaroa Forest (Stewart and Hyde 2004). Kaingaroa Forest is situated on the central plateau of the North Island of New Zealand and comprises 180 000 ha of exotic, planted radiata pine (*Pinus radiata*) forest. The planted area is characterized by flat to rolling landforms with a temperate climate typified by warm summers and frequent frosts during the winter. Pine stands are harvested by clear-cutting when the trees are between 25 and 35 yr old (Maclaren 1996). The clear-cutting method of forest harvesting employed in Kaingaroa Forest creates discrete blocks of same-aged trees that result in a mosaic of different-aged pine stands and strongly delineated edge habitat (Fig. 1). Pine stands containing trees of the same age are typically 140 ha in size, but range from 10 to 430 ha.

METHODS

Telemetry. During the 2004/2005 and 2005/2006 breeding seasons (September to March), we used radio-transmitters to track the movements of adult New Zealand Falcons relative to different-aged pine stands. In pine forests, New Zealand Falcons typically nest on the ground, within or adjacent to pine stands less than four yr old (Seaton et al. 2010b). The falcons were trapped in the vicinity of the nest using a variety of methods including bal chatri traps, noose hats, and dho-gaza nets (Fox 1977, Bloom 1987, Massey University Ethics approval 01/24 and

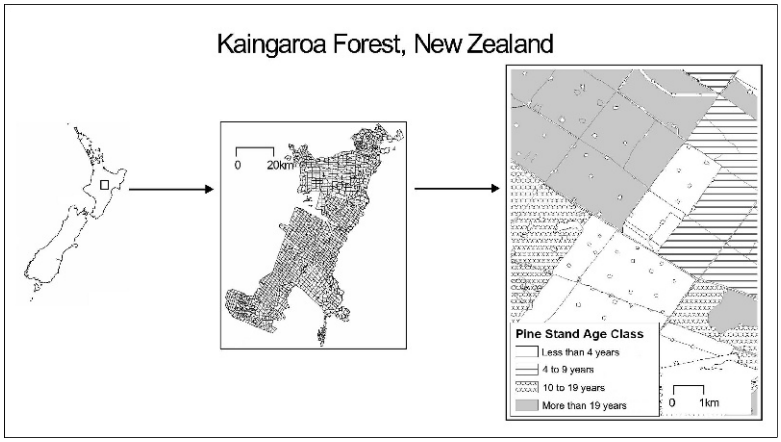

Figure 1. Map of Kaingaroa pine plantation illustrating its location in New Zealand, and the size and compartment/stand structure of the forest.

03/105, RANZ permit 0285, DOC permit BP-13884-RES). Twelve-gram two-stage Sirtrack Ltd. radio-transmitters with a 15-hr-on, 9-hr-off duty cycle were attached to 16 adult New Zealand Falcons (nine males and seven females) using backpack harnesses that included a weak link (Kenward et al. 2001). The nest of one pair was depredated within one wk of attaching the transmitters and one transmitter failed after one wk of tracking. The remaining eight adult males and five adult females included five pairs. Four of the pairs had adjacent territories. All tracked individuals and pairs successfully fledged at least one young.

The forestry company (Kaingaroa Timberlands Limited) provided detailed maps of the study area illustrating the pine stand age classes: <4 yr, 4–9 yr, 10–19 yr, and >19 yr. During a 12-wk period from the first week of December, each study bird was tracked for an 8-hr period once every week. During each tracking period we recorded the age class of the stand in which individual birds were located, whether they were located within the stand interior (stand interior being defined as the area >50 m from a stand edge) or along a stand edge (stand edge being defined as the area within 50 m of the border between adjacent stands of differing age, where the age difference was greater than four yr) and the time they spent at each location. The extensive network of forestry roads running along the boundary and within each pine stand enabled individual birds to be continuously followed by an individual observer in a 4WD vehicle. Once a bird perched, individual locations were recorded using a combination of triangulation and visual verification. Observers scored the confidence they had in each triangulated location based on a combination of distance and number of triangulation fixes (the closer the observer and the higher the number of fixes the higher the confidence score). Only locations with the highest score of confidence were used in the analysis. A typical stand size of 140 ha combined with the extensive road network frequently enabled observers to triangulate from distances less than 300 m providing a high confidence in the location of an individual. Although visual verification was commonly achieved, a distance of at least 100 m was maintained to ensure observers did not influence the birds' behavior.

Nest sites were observed continuously during each 8-hr tracking period by an additional observer who maintained contact with the other observer via two-way radios. Nest observers were located close enough that the area around the nest could be seen clearly through 10X binoculars and any vocalizations around the nest site could be heard (both adults call before and during food passes), but far enough away that neither adult expressed any defensive behavior toward the observers (New Zealand Falcons defend their nests from intruders very vocally).

Home-range Calculations. Minimum convex polygon (95% MCP) home ranges were calculated to delineate the home ranges of individuals during the breeding season (post egg-laying to pre-dispersal of fledglings), using Hawth's Analysis Tools 3.17 (Beyer 2004) in ArcMap 9.0. MCP home ranges were

Table 1. Minimum convex polygon home-range sizes (km²) of adult New Zealand Falcons in Kaingaroa Forest during the breeding season.

		95% MCP HOME RANGES			
SEX	INDIVIDUAL	DECEMBER	JANUARY	FEBRUARY	BREEDING SEASON
Male	1	2.41	11.25	2.67	9.51
	2	6.04	9.95	9.73	13.14
	3	1.46	7.74	4.98	5.71
	4	4.37	6.14	3.61	7.81
	5	3.36	5.62	2.39	6.18
	6	5.59	5.74	5.82	7.17
	7	3.60	5.88	2.64	6.53
	8	10.70	12.11	10.62	17.75
	Mean Male	4.69	8.05	5.31	9.23
	SD	2.86	2.67	3.24	4.20
Female	1	0.03	5.40	8.40	10.56
	2	0.37	1.22	0.85	1.48
	3	0.35	3.06	7.45	6.08
	4	0.87	5.68	1.49	6.21
	5	0.04	4.83	5.70	6.42
	Mean Female	0.33	4.04	4.78	6.15
	SD	0.34	1.88	3.44	3.21

calculated monthly and per breeding season for each individual. Differences in home-range sizes between sexes and over the breeding season were evaluated using *t*-tests.

Despite MCP sometimes overestimating home-range size and therefore including some areas that may not be used by an individual (Burgman and Fox 2003), MCP was employed as this technique provides an area delimiter suitable to assess third order habitat selection (Johnson 1980) and does not suffer from the inherent statistical restrictions, such as the need for independent locations, that alternatives like kernel estimators do (Seaman and Powell 1996). Further, because of the relatively small scale over which individuals were tracked and the high location accuracy, these biases were not deemed likely to overestimate the area used to any significant degree.

Analysis of Habitat Selection. MCP home ranges were overlaid over maps of pine stand age in ArcMap 9.0. All the area within each MCP home range was classified as either stand interior or stand edge. These were then further differentiated into the age classes: <4 yr, 4–9 yr, 10–19 yr, and >19 yr. Stand edges were classified according to the ages of the adjacent stands, e.g., a stand less than 4 yr old bordering a stand greater than 19 yr old. A distance of 50 m on either side of the stand edge was applied to calculate the area of stand 'edge.' Using these categories, the area of each stand age class was calculated for every individual's home range.

We used compositional analysis (Aebischer et al. 1993) to evaluate New Zealand Falcons' relative preference for stand age classes comparing use with availability. We measured availability as the proportion of the habitat class within the MCP home range. For each home range the observed use was the proportion of time spent in each habitat class. As outlined in Forsman et al. (2005) the advantages of this method are (1) it treats the individual as the sample unit, (2) it accounts for lack of independence among proportions, (3) it is not sensitive to serial correlations between locations, and (4) it is based on a unique set of observed and expected values for each pine stand class in the home range of each individual. Outputs from this analysis include a numeric ranking of the different stand classes according to their relative preference, and pairwise comparisons (*t*-tests) indicating the degree to which preference differed between stand classes.

RESULTS

Home Range. Mean adult male home-range size was 9.2 ± 4.2 km² (n = 8) and mean adult female home-range size was 6.2 ± 3.2 km² (n =5; mean ± SD; Table 1). There was no significant difference in

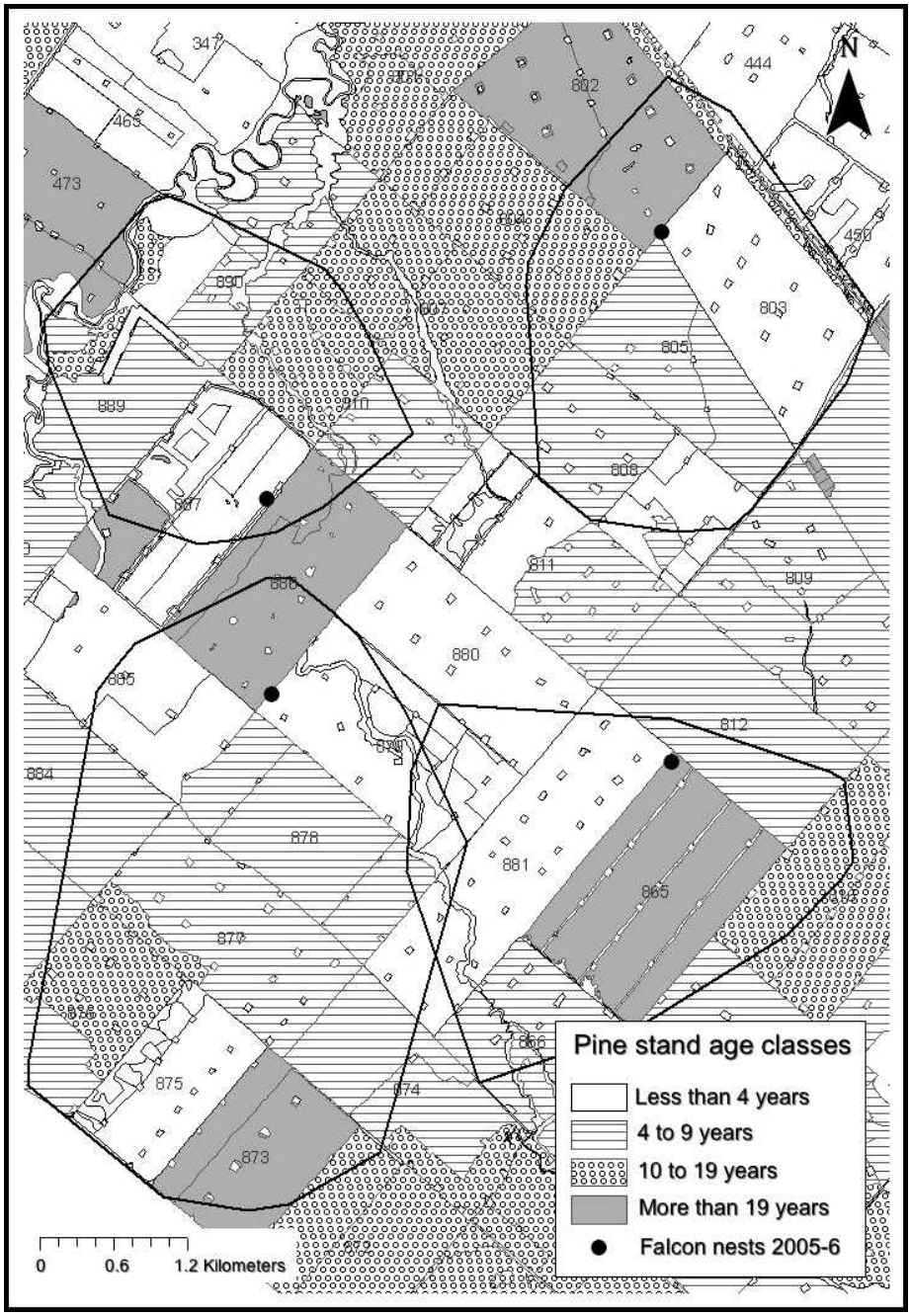

Figure 2. A cluster of four neighboring home ranges of adult male New Zealand Falcons during the 2005 breeding season showing the location of the nest sites, the 95% MCP home ranges and the composition of the pine stand age classes within each home range.

Table 2. Percentage stand class present within the 95% MCP home ranges of male and female New Zealand Falcons radiotracked during the 2004 and 2005 breeding seasons in Kaingaroa Forest. Stand interior was defined as the area >50 m from a stand edge. Stand edge was defined as the area within 50 m of the border between adjacent stands of differing age.

		Stand Classes (Years)									
		Stand Interior Classes				Stand Edge Classes					
Sex	Indiv.	Less than 4	4 to 9	10 to 19	More than 19	<4/ 4–9	<4/ 10–19	<4/ 19+	4–9/ 10–19	4–9/ 19+	10–19/ 19+
Male	1	56.83	10.81	6.39	3.31	1.42	4.02	12.37	0.91	1.66	2.30
	2	24.63	29.28	17.12	6.75	5.97	3.81	3.05	5.33	2.04	2.04
	3	38.13	19.72	7.04	24.63	0.69	0	2.61	1.40	4.55	1.24
	4	45.02	35.92	0	11.16	4.71	0	3.19	0	0	0
	5	27.51	41.89	7.60	13.35	2.96	0.93	2.90	1.49	0.78	0.59
	6	31.09	34.45	8.53	10.58	3.78	5.82	1.24	1.99	0.27	2.25
	7	44.60	0	43.06	0	0	8.63	2.00	0	0	1.70
	8	26.31	15.20	15.37	27.26	5.87	0.66	3.97	3.41	1.03	0.92
	Mean	36.8	23.4	13.1	12.1	3.2	3.0	3.9	1.8	1.3	1.4
	SE	4.0	5.1	4.7	3.4	0.8	1.1	1.2	0.6	0.5	0.3
Female	1	33.39	9.12	10.96	19.82	1.39	3.25	15.88	0.89	2.88	2.41
	2	51.90	9.26	0	21.06	8.17	0	9.62	0	0	0
	3	59.10	0	0	27.12	0.69	3.26	6.43	0	0	3.40
	4	59.72	0	25.09	0	0	13.85	1.34	0	0	0
	5	58.96	10.87	0.60	14.90	7.15	0	6.60	0	0.92	0
	Mean	52.6	5.9	7.3	16.6	3.5	4.1	8.0	0.18	0.8	1.2
	SE	5.0	2.4	4.9	4.6	1.7	2.6	2.4	0.18	0.6	0.7

home-range size between males and females overall ($t = 1.40$, df =11, $P = 0.19$), but the home ranges of males were larger than those of females during December ($t = 3.33$, df = 11, $P = 0.007$) and January ($t = 2.92$, df = 11, $P = 0.01$). Male home-range size peaked during January, while female home-range size generally increased from December to February. Where pairs with adjacent territories were tracked in a close group there was very little overlap of 95% MCP home ranges (Fig. 2).

Habitat Selection. Although the area of each pine stand age class within each home range varied among individuals (Table 2), stands <4 yr old made up a large proportion of every bird's home range. Although the composition of male and female home ranges was very similar, resource use within these home ranges differed between males and females. Overall, falcons did not utilize forest resources within their home ranges in an arbitrary manner but favored certain age classes of pine stand. Pairwise comparisons of rank suggest that pine stand edges bounded by trees <4 yr old and >19 yr old were preferred to all other stand classes by both male and female falcons (Tables 3 and 4). Males favored stand edges over stand interiors (Table 3), whereas females favored stands <4 yr old and the stand edges bordering these young stands (Table 4).

Discussion

We found that the home-range size of New Zealand Falcons during the breeding season in a pine plantation varies among individuals, from 5.7 km² to 17.8 km² in males, and from 1.5 km² to 10.6 km² in females. This variation is within the range of home-range estimates recorded during other studies in the same habitat for males, but not for females (Thomas et al. 2010). Thomas et al. (2010) recorded the annual home range of one adult female to vary between 33 km² and 78 km², suggesting that in some cases the home ranges of adult females can be considerably larger than recorded in this study. Variation in the tracking technique, timing of the study, and the home-range estimation method may explain some of the discrepancy between the two studies. However, like the variation amongst individuals recorded in this study, the variation is also likely to be the result of spatial/temporal differences in prey density, habitat suitability, climate, productivity, and/or individual behavior. Our study

Table 3. Results of compositional analysis of pine stand class use for male New Zealand Falcons during the 2004 and 2005 breeding seasons. Rank scores indicate the relative preference of pine stand age-classes from highest (9) to lowest (0). Pine stand age-classes are split into two types of location; stand interior[a] and stand edge[b]. Pairwise *t*-tests indicate the relative preference of pine stand age-classes. Positive *t*-values indicate the row class ranked higher than the column class, and negative *t*-values indicate the row class ranked lower than the column class. A significant *P*-value suggests a high confidence in the direction of the relationship.

Pine Stand Age Class		Less than 4[a]	4 to 9[a]	10 to 19[a]	More than 19[a]	<4 Bordering 4–9[b]	<4 Bordering 10–19[b]	<4 Bordering 19+[b]	4–9 Bordering 10–19[b]	4–9 Bordering 19+[b]	10–19 Bordering 19+[b]	Rank
Less than 4[a]	*t*		1.47	9.65	0.07	−0.71	−0.83	−7.31	2.14	0.51	−0.13	5
	P		0.09	<0.001	0.47	0.25	0.22	<0.001	0.03	0.31	0.45	
4 to 9[a]	*t*	−1.47		−8.94	−2.96	−10.27	−9.84	−14.76	−1.54	−3.01	−3.59	0
	P	0.09		<0.001	0.01	<0.001	<0.001	<0.001	0.08	0.01	0.00	
10 to 19[a]	*t*	−9.65	8.94		−0.59	−5.04	−5.49	−10.15	1.41	−0.21	−0.86	2
	P	<0.001	<0.001		0.29	<0.001	<0.001	<0.001	0.10	0.42	0.21	
More than 19[a]	*t*	−0.07	2.96	0.59		−0.44	−0.52	−6.20	6.46	1.42	−0.78	4
	P	0.47	0.01	0.29		0.33	0.31	<0.001	<0.001	0.10	0.23	
<4 Bordering 4–9[b]	*t*	0.71	10.27	5.04	0.44		−0.57	−9.65	2.76	0.96	0.25	7
	P	0.25	<0.001	<0.001	0.33		0.29	<0.001	0.01	0.18	0.40	
<4 Bordering 10–19[b]	*t*	0.83	9.84	5.49	0.52	0.57		−8.67	2.75	1.02	0.35	8
	P	0.22	<0.001	<0.001	0.31	0.29		<0.001	0.01	0.17	0.37	
<4 Bordering 19+[b]	*t*	7.31	14.76	10.15	6.20	9.65	8.67		11.64	8.41	7.03	9
	P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	<0.001	
4–9 Bordering 10–19[b]	*t*	−2.14	1.54	−1.41	−6.46	−2.76	−2.75	−11.64		−9.06	−13.56	1
	P	0.03	0.08	0.10	<0.001	0.01	0.01	<0.001		<0.001	<0.001	
4–9 Bordering 19+[b]	*t*	−0.51	3.01	0.21	−1.42	−0.96	−1.02	−8.41	9.06		−6.40	3
	P	0.31	0.01	0.42	0.10	0.18	0.17	<0.001	<0.001		<0.001	
10–19 Bordering 19+[b]	*t*	0.13	3.59	0.86	0.78	−0.25	−0.35	−7.03	13.56	6.40		6
	P	0.45	0.00	0.21	0.23	0.40	0.37	<0.001	<0.001	<0.001		

Table 4. Results of compositional analysis of pine stand class use for female New Zealand Falcons during the 2004 and 2005 breeding seasons. Rank scores indicate the relative preference of pine stand age-classes from highest (9) to lowest (0). Pine stand age-classes are split into two types of location; stand interior[a] and stand edge[b]. Pairwise *t*-tests indicate the relative preference of pine stand age-classes. Positive *t*-values indicate the row class ranked higher than the column class, and negative *t*-values indicate the row class ranked lower than the column class. A significant *P*-value suggests a high confidence in the direction of the relationship.

Pine Stand Class		Less than 4[a]	4 to 9[a]	10 to 19[a]	More than 20[a]	<4 Bordering 4–9[b]	<4 Bordering 10–19[b]	<4 Bordering 20+[b]	4–9 Bordering 10–19[b]	4–9 Bordering 19+[b]	10–19 Bordering 19+[b]	Rank
Less than 4[a]	*t*		9.36	6.25	2.69	4.46	2.50	−1.22	7.63	4.29	3.99	8
	P		<0.001	<0.001	0.01	0.001	0.02	0.13	<0.001	0.001	0.002	
4 to 9[a]	*t*	−9.36		−4.86	−1.59	−8.62	−9.95	−12.61	2.50	−0.41	−0.58	1
	P	<0.001		<0.001	0.08	<0.001	<0.001	<0.001	0.02	0.35	0.29	
10 to 19[a]	*t*	−6.25	4.86		−0.48	−4.50	−6.52	−9.68	4.38	1.06	0.82	4
	P	<0.001	<0.001		0.32	0.001	<0.001	<0.001	0.001	0.16	0.22	
More than19[a]	*t*	−2.69	1.59	0.48		−0.64	−1.40	−4.31	10.07	4.56	3.83	5
	P	0.01	0.08	0.32		0.27	0.10	0.001	<0.001	<0.001	0.002	
<4 Bordering 4–9[b]	*t*	−4.46	8.62	4.50	0.64		−4.74	−9.86	6.54	2.43	2.16	6
	P	0.001	<0.001	0.001	0.27		<0.001	<0.001	<0.001	0.02	0.03	
<4 Bordering 10–19[b]	*t*	−2.50	9.95	6.52	1.40	4.74		−5.43	6.73	3.12	2.90	7
	P	0.02	<0.001	<0.001	0.10	<0.001		<0.001	<0.001	0.01	0.01	
<4 Bordering19+[b]	*t*	1.22	12.61	9.68	4.31	9.86	5.43		13.63	7.00	6.41	9
	P	0.13	<0.001	<0.001	0.001	<0.001	<0.001		<0.001	<0.001	<0.001	
4–9 Bordering 10–19[b]	*t*	−7.63	−2.50	−4.38	−10.07	−6.54	−6.73	−13.63		−8.02	−7.10	0
	P	<0.001	0.02	0.001	<0.001	<0.001	<0.001	<0.001		<0.001	<0.001	
4–9 Bordering19+[b]	*t*	−4.29	0.41	−1.06	−4.56	−2.43	−3.12	−7.00	8.02		−1.17	2
	P	0.001	0.35	0.16	<0.001	0.02	0.01	<0.001	<0.001		0.14	
10–19 Bordering19+[b]	*t*	−3.99	0.58	−0.82	−3.83	−2.16	−2.90	−6.41	7.10	1.17		3
	P	0.002	0.29	0.22	0.002	0.03	0.01	<0.001	<0.001	0.14		

indicates that between the post-egg laying and post-fledging period the home-range sizes of New Zealand Falcon in this habitat are usually between 1.5 km² and 17.8 km².

The abundance of small passerines that make up the majority of the New Zealand Falcon diet (Fox 1977, Barea et al. 1999, Seaton et al. 2008) increases in Kaingaroa Forest between December and February (Seaton et al. 2010a). This increase in prey density coincides with a decrease in the home-range size of males which may allow males to hunt over a smaller range. However, this reduction in home-range size also appears likely to be related to the reduced dependence of the nestlings at this time with most chicks fledging nest around 33–35 d old in December/January (Fox 1977, Seaton et al. 2009).

The differences in the home-range sizes of males and females during the breeding season most likely result from the different roles of males and females. Females undertake the majority of the incubation and brooding duties (Fox 1977), and, hence have little time to hunt and do not begin to roam far from the nest until the young have fledged and are flying well. Other studies in the region suggest falcons do not preferentially use particular ages of pine stand (Thomas et al. 2010). However, our study illustrates that falcons do favor certain age classes of pine stand. The different roles of males and females during the breeding season may also explain some of the differences in habitat selection recorded between the sexes. Nest sites in Kaingaroa Forest are typically located within pine stands less than four yr old and along the boundary of a stand containing trees >19 yr old (Seaton et al. 2010b). The preference of females for pine stands less than four yr old and the edges surrounding them is consistent with Johnson's (1980) hierarchical selection process. For breeding falcons, females use stands <4 yr old more than males because females do more incubation, brooding, and nestling care and hence are more constrained by the nest location.

Both male and female New Zealand Falcons selected for stand edges, particularly those bounded by trees <4 yr old and >19 yr old. A study of prey abundance in Kaingaroa Forest showed that prey densities were particularly high along stand edges (Seaton et al. 2008, 2010a), suggesting that New Zealand Falcons are selecting areas of high prey abundance for hunting and that nest sites may be located near to edge habitat as part of an optimal foraging strategy (Seaton et al. 2010b). Having evolved in a highly forested landscape, the New Zealand Falcon has many morphological traits that enable it to take advantage of forested and edge habitats, including relatively short, rounded wings and a long tail that make them highly maneuverable, and long legs that allow them to snatch small birds as they try to evade capture (Fox 1977). The prevalence of open-habitat passerines recorded in the diet of falcons in Kaingaroa Forest (Seaton et al. 2008) and the high proportion of activity reported along edges where stands >20 yr old border stands <4 yr old is consistent with New Zealand Falcons employing a perch/glide attack hunting strategy whereby the falcon perches on the edge of a mature stand and initiates a direct flying/glide attack into the more open young pine stands where prey is highly vulnerable to attack (Suhonen et al. 1994). Overall, it appears that the abundance of edge habitat in plantation forests is one of the key factors responsible for the high density of falcons in plantations such as Kaingaroa Forest (Seaton et al. 2010b).

We observed few aggressive territorial interactions and very little, if any, overlap of home ranges for adjacent pairs. This suggests that New Zealand Falcon pairs are very territorial during the breeding season. Whether this changes outside of the breeding season and whether patterns of habitat selection and home-range size change during winter is as yet unknown.

Management Implications. Considering the widespread loss of indigenous forest and the extensive areas of plantation forest present in modern-day New Zealand (1.8 million ha, Hartley 2002, Statistics New Zealand 2004), the New Zealand Falcons' use of this novel habitat represents an opportunity for the plantation forestry industry to make a significant contribution toward the conservation of this threatened species. We suggest that if forestry managers wish to enhance the suitability of their estates for the New Zealand Falcon, they should provide a mosaic of different-aged stands that creates an abundance of edge habitat for hunting, while ensuring that pine stands <4 yr old bordering stands >19 yr old are consistently available for nesting.

Plantation forestry is often criticized for being a planted monoculture that lacks diversity (Maclaren 1996). This study illustrates that when a pine forest is harvested in discrete blocks that provide an abundance of edge habitat, it is the high diversity in habitat structure that provides suitable conditions for New Zealand Falcon. Thus, New Zealand Falcons may be encouraged to use further novel habitats by increasing local heterogeneity in habitat structure and this could be an important factor in the recovery of this threatened species.

ACKNOWLEDGMENTS

This research was made possible by funding and support from Kaingaroa Timberlands, Timberlands Limited, Carter Holt Harvey, Hancock Forest Management Ltd., New Zealand Forest Managers, the Tertiary Education Commission in the form of an Enterprise Scholarship, Massey University, the Waikato branch of the Royal Forest and Bird Protection Society (Valder Grant) and the Conservation Research Foundation (Morley Nelson Fellowship). We thank volunteers M. Clement, S. McPherson, and D. Brill for their hard work in the field, and R. Buxton for statistical advice. We are also grateful for the generous contributions of the New Zealand Department of Conservation, Wingspan Birds of Prey Trust, and the Raptor Association of New Zealand.

LITERATURE CITED

ADDISON, N.J., J.D. HOLLAND, AND E. MINOT. 2006. New Zealand Falcon (*Falco novaeseelandiae*) in pine plantations in the Hawke's Bay. *New Zealand Journal of Forestry* 51:3–7.

AEBISCHER, N.J., P.A. ROBERTSON, AND R.E. KENWARD. 1993. Composition analysis of habitat use from animal radiotracking. *Ecology* 74:1313–1325.

BAREA, L.P. 1995. Habitat use, diet, and nest site selection of forest-dwelling New Zealand Falcons. M.S. thesis. Univ. Waikato, Hamilton, New Zealand.

———, J.R. WAAS, K. THOMPSON, AND N.H. HYDE. 1999. Diet provided by New Zealand Falcons (*Falco novaeseelandiae*) nesting in forested habitat. *Notornis* 46:257–267.

BELL, D. AND S. LAWRENCE. 2009. New Zealand Falcon (*Falco novaeseelandiae*) distribution survey 2006–09. *Notornis* 56:217–221.

BEYER, H.L. 2004. Hawth's analysis tools for ArcGIS, version 2.10. http://www. spatialecology.com/htools (last accessed 1 October 2012).

BLOOM, P.H. 1987. Capturing and handling raptors. Pages 99–123 *in* B.A. Giron Pendleton, B.A. Millsap, K.W. Cline, and D.M. Bird [EDS.], Raptor management techniques manual. National Wildlife Federation, Washington, DC U.S.A.

BROCKERHOFF, E.G., C.E. ECROYD, A.C. LECKIE, AND M.O. KIMBERLEY. 2003. Diversity and succession of adventive and indigenous vascular plants in *Pinus radiata* plantation forests in New Zealand. *Forest Ecology and Management* 185:307–326.

BURGMAN, M.A. AND J.C. FOX. 2003. Bias in species range estimates from minimum convex polygons: implications for conservation and options for improved planning. *Animal Conservation* 6:19–28.

CLOUT, M.N. AND P.D. GAZE. 1984. Effects of plantation forestry on birds in New Zealand. *Journal of Applied Ecology* 21:795–815.

EWERS, R.M., A.D. KLISKEY, S. WALKER, D. RUTLEDGE, J.S. HARDING, AND R.K. DIDHAM. 2006. Past and future trajectories of forest loss in New Zealand. *Biological Conservation* 133:312–325.

FORSMAN, E.D., T.J. KAMINSKI, J.C. LEWIS, K.J. MAURICE, S.G. SOVERN, C. FERLAND, AND E.M. GLENN. 2005. Home range and habitat use of Northern Spotted Owls on the Olympic peninsula, Washington. *Journal of Raptor Research* 39:365–377.

FOX, N.C. 1977. The biology of the New Zealand Falcon (*Falco novaeseelandiae*). Ph.D. dissertation, Univ. Canterbury, Christchurch, New Zealand.

GAZE, P.D. AND I. HUTZLER. 2004. Changes in the abundance of the New Zealand Falcon (*Falco novaeseelandiae*) in Marlborough. *Notornis* 51:117–119.

HARTLEY, M.J. 2002. Rationale and methods for conserving biodiversity in plantation forests. *Forest Ecology and Management* 155:81–95.

JACKSON, R.W. 1971. Birds in exotic forests in New Zealand. *New Zealand Journal of Forestry* 16:61–68.

JOHNSON, D.H. 1980. The comparison of usage and availability measurements for evaluating resource preference. *Ecology* 61:65–71.

KENWARD, R.E., R.H. PFEFFER, M.A. AL-BOWARDI, N.C. FOX, K.E. RIDDLE, E.A. BRAGIN, A. LEVIN, S.S. WALLS, AND K.H. HODDER. 2001. Setting harness sizes and other marking techniques for a falcon with strong sexual dimorphism. *Journal of Field Ornithology* 72:244–257.

LAWRENCE, S. 2002. RANZ/DoC New Zealand Falcon breeding survey 1994–98. DoC Science Internal Series 84. Department of Conservation, Wellington, New Zealand.

MACLAREN, J.P. 1996. Environmental effects of planted forests in New Zealand. New Zealand Forest Research Institute Limited, Rotorua, New Zealand.

MAUNDER, C., W. SHAW, AND R. PIERCE. 2005. Indigenous biodiversity and land use—what do exotic plantation forests contribute? *New Zealand Journal of Forestry* 49:20–26.

MCGLONE, M.S. 1989. The Polynesian settlement of New Zealand in relation to environmental and biotic changes. *New Zealand Journal of Ecology* 12:115–129.

MISKELLY, C.M., J.E. DOWDING, G.P. ELLIOT, R.A. HITCHMOUGH, R.G. POWLESLAND, H.A. ROBERTSON, P.M. SAGAR, R.P. SCOFIELD, AND G.A. TAYLOR. 2008. Conservation status of New Zealand birds, 2008. *Notornis* 55:117–135.

OGDEN, J., J. BRAGGINS, K. STRETTON, AND S. ANDERSON. 1997. Plant species richness under *Pinus radiata* stands on the central North Island volcanic plateau, New Zealand. *New Zealand Journal of Ecology* 21:17–29.

PAWSON, S.M., C.E. ECROYD, R. SEATON, W.B. SHAW, AND E.G. BROCKERHOFF. 2010. New Zealand's exotic plantation forests as habitats for threatened indigenous species. *New Zealand Journal of Ecology* 33:342–355.

SEAMAN, D.E. AND R.A. POWELL. 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. *Ecology* 77:2075–2085.

SEATON, R., E. MINOT, AND J.D. HOLLAND. 2010a. Variation in bird species abundance in commercial pine plantation in New Zealand. *New Zealand Journal of Forestry* 54:3–11.

———, ———, AND ———. 2010b. Nest-site selection of New Zealand Falcons (*Falco novaeseelandiae*) in plantation forests and the implications of this to forestry management. *Emu* 110:316–323.

———, J.D. HOLLAND, E.O. MINOT, AND B.P. SPRINGETT. 2009. Breeding success of New Zealand Falcons (*Falco novaeseelandiae*) in a pine plantation. *New Zealand Journal of Ecology* 33:32–39.

———, N. HYDE, J.D. HOLLAND, E.O. MINOT, AND B.P. SPRINGETT. 2008. Breeding season diet and prey selection of the New Zealand Falcon (*Falco novaeseelandiae*) in a plantation forest. *Journal of Raptor Research* 42: 256–264.

STATISTICS NEW ZEALAND. 2004. The New Zealand official yearbook. Statistics New Zealand and David Bateman Ltd., Wellington, New Zealand.

STEWART, D. AND N. HYDE. 2004. New Zealand Falcons (*Falco novaeseelandiae*) nesting in exotic plantations. *Notornis* 51:119–121.

SUHONEN, J., K. NORRDAHL, AND E. KORPIMÄKI. 1994. Avian predation risk modifies breeding bird community on a farmland area. *Ecology* 75:1626–1634.

TENNYSON, A. AND P. MARTINSON. 2006. Extinct birds of New Zealand. Te Papa Press, Wellington, New Zealand.

THOMAS, B., E.O. MINOT, AND J.D. HOLLAND. 2010. Home range and habitat use of the New Zealand Falcon (*Falco novaeseelandiae*) within a plantation forest: a satellite tracking study. *International Journal of Ecology*. 2010 ID 829702, doi: 10.1155/2010/829702.

Received 1 April 2012; accepted 22 January 2013
Associate Editor: Jessi L. Brown