

COASTAL FOREST MERLIN (*Falco columbarius suckleyi*) BREEDING HABITAT AND CLIMATIC INFLUENCES ON FLEDGING SUCCESS IN WASHINGTON STATE AND BRITISH COLUMBIA

David P. Drummond[1] & Roger C. Stillman[2]

David P. Drummond, Principal Investigator, Coastal Forest Merlin Project

P.O. Box 4123, Bellingham, WA, 98227, USA

merlinology@hotmail.com

Roger C. Stillman, Co-Investigator, Coastal Forest Merlin Project

ABSTRACT

We describe the breeding habitat of *Falco columbarius suckleyi,* the Coastal Forest Merlin at two spatial levels: the activity tree zone (nest tree to 100 m), and the near habitat of the nest tree (nest to 25.2 m). Here, we analyze the influence of habitat and climate on their reproductive success across Washington State and the British Columbia landscapes, from ancient forest to urban environs. Our intent is to encourage a well-informed stewardship of Merlin annual required habitats. We found this Merlin is a facultative breeder in rural, riparian/upland forest interfaces and that it actively seeks habitat complexity in breeding sites. In human-altered zones, Merlin selected nesting trees most like those in old-growth late seral stage sites, as compared with other trees in the available forest canopy. Urban development changed both the structure and composition of the breeding territory and Merlin fledging rates. Climate warming events, also appeared to influence the outcome of breeding success.

RESUMEN

Aquí describimos el ambiente del Falco columbarius suckleyi (también conocido como “Esmerejón Negro” o “Esmerejón Costero-Bosque”), enseñando los habitatos en dos niveles: zona de árboles de actividad (nido a 100 m), y el nido y sus alrededores cercanos (nido a 25.2 m). Aquí, hemos analizado la influencia del habitato y clima sobre el éxito reproductivo a través del terreno ecológico del Estado Washington y Columbia Británica, de los bosques ancianos al desarrollo urbano. Nuestra intención es a compilar un cuerpo de información por la administración sana y informada del Esmerejón y sus habitatos de anidación. Durante esta estudia hemos hallados que este falco es un críador facultativo en sitos dónde se encuentran sistemas ribereñas con terrenos de varias eco-sistemas. El Esmerejón busca por territorios de anidación que tienen complejidad. En zonas cambiadas por actividad humana, los esmerejones han seleccionados árboles de anidación más como los árboles encontrados en bosques ancianos, en comparación con los otros árboles alrededor del nido. El desarrollo urbano, sin embargo, ha cambiado la composición y la estructura del territorio de anidación y la tasa de volantones. Eventos de calentamiento, también parecen tener influencia en el resultado del éxito reproductivo.

KEY WORDS: Merlin, breeding habitats, oceanic index, activity trees, fecundity

INTRODUCTION

Early published accounts of the Coastal Forest Merlin (after Temple 1970) (aka "Black Merlin") breeding habitat are few and qualitative in nature (Dawson and Bowles 1909); (Laing 1935), (Jewett 1953); (Kitchen 1941); (Gabrielson and Lincoln 1959); (Bent 1961); (Campbell et al. 1990); (Smith et al. 1997); (Wahl et al. 2005). Quantitative insights that could lead to this Merlin race's protective stewardship, are not currently available to citizens, non-government organizations or natural resource agencies.

The Coastal Forest Merlin is one of three North American subspecies and is resident in the Pacific Northwest Temperate Rainforest, nesting near riparian zones and forest openings or edges (Johnsgard 1990). This compact falcon uses its speed and agility to prey on small song and shorebirds, insects and sometimes, small mammals (Cade 1982). Merlin often uses the same general area in subsequent years for breeding, but not necessarily the same nesting site (Brown and Amadon 1968). Nests are almost exclusively located high in mature conifers with complex crown structures (Sodhi et al 1993) from elevations that range from sea level to below the tree line.

Historically, this subspecies presumably bred and foraged in ancient old growth forests that were wide spread in Washington and British Columbia, before Euro-American presence. Within the forest canopy well protected top and side cavities would have been the best chamber for nesting and raising their progeny. Alternately, open platforms such as Northwest Crow, Northern Flying Squirrel nests, mistletoe clumps and vegetated, wide branch tops could also be utilized for the brood substrate. This multi-spatial ecosystem has experienced significant decline in quantity, quality and continuity, due to anthropogenic activity during the last 150 years (Whitlock 1992).

Human perception of the conservation status of Merlin varies by source and jurisdiction. In Washington State (WDFW 2013), or Federally (USFWS 2013) and in Canada (COSEWIC 2009) the Merlin is not listed as a Species of Concern. A Bureau of Land Management report (Trimble 1975) indicated that Merlin carried high levels of pesticides leading to a decline in reproductive success. Many sources consider the "DDT Era" as behind us. In light of further anthropogenic changes to the Pacific Northwest since that time period, we asked whether Merlin are adapting to habitat change?

STUDY AREA

The Coastal Forest Merlin's current confirmed breeding distribution (north to south vector) covers an area from southeastern Alaska, northern British Columbia and Vancouver Island to near the southwest coast of Washington State. Our Merlin study area perimeter ran from Seattle, west to the Olympic coast, north across the Straits of Juan de Fuca, up the west coast to north Vancouver Island, northeast to Prince Rupert, inland as far as Prince George, BC, south along the crest of the Coast and North Cascade Mountains to Snoqualmie Pass and back west to Seattle. Peripherally it was bounded by approximately 128° W to 120° W longitude and 46° N to 55° N latitude, an area of 116,660 km^2. (See Fig. 1) Major landforms consist of populated coastal lowlands, heavily forested and rugged coastal mountains and drier inland plateaus. Shore lands occupy a long, narrow glacial trough of many islands, peninsulas and inlets, ranging from sea level to 1500 m up the sides of foothills. This eco-region has a cool, maritime climate with wet winters. One west coast example, the Hoh River valley, receives up to 339 cm of rain per year, a mean January temperature of 4.7° C and mean July temperature of 18° C (See Photo 4). Northeast of the Olympic Range is a second eco-regime, lying within the rain-shadow of these mountains. Most noted, rain-shadow city, Sequim receives much less rain, an average 41 cm/year (Western Regional Climate Center 2014). Both coastal and inland areas are influenced by cooling Arctic temperatures and by warming events in the Pacific Ocean. A third eco-province is found in the west-central plateau of British Columbia. This sub-boreal region receives extremes of temperature from 36° C to -50° C (Province of British Columbia Canada Annual City Climate Statistics 2014).

METHODS

The Coastal Forest Merlin Project (CFMP) field study was intentionally designed as non-invasive (Grier and Fyfe 1987). Protocol surveys to locate Merlin breeding sites were conducted region wide, and we also, networked with volunteers, bird watchers, biologists, as well as trained National Park Service, National Forest Service and Washington Department of Natural Resources wildlife crews to assist our efforts. Additionally, we solicited sightings and audio detections through the Coastal Forest Merlin Project website and at public education events. Citizen-Science input from these sources were confirmed or rejected with first hand, follow-up observations. Rurally, nest sites were located through protocol surveys (adapted from Bibby et al. 1992) and within urban environs via citizen-science networking. These field surveys and random citizen sightings provided the basis for on-site monitoring to document Merlin habitat and prey usage and also, their behavioral ecology.

For standardization of methodologies, the senior author conducted all protocol surveys and follow-up surveys to citizen-science input. Protocol surveys ranged from sea level to 800 m: on roads, trails, rivers, lakes and marine shorelines via hiking, mountain biking, kayaking and rafting travel modes. Linear routes in potential Merlin breeding forested riparian-upland forest habitats were surveyed by a Listening/Looking Method enroute and stopping at 400 m intervals for ten minutes detection time before proceeding. Merlin were often audio-detected before a visual confirmation. Detections and breeding sites were USGS and GPS mapped and coordinates were confirmed with Global Mapper. Surveys were on-going from February to July. Surveying and monitoring constituted 7, 200 hours of direct Merlin observation and the logistics of said, tallied another 10,700 hours over 27 years. To negate potential negative impacts, habitat measurements were implemented in late July and August, once the Merlin fledglings and female were dispersing and the male was mostly absent.

Vegetation (veg) plots were tree measurements and calculations of all trees within circular areas with a radius of 25.2 m (0.2 ha) and 100 m (3.14 ha) from the nest tree. Landscape parameters were: slope position, aspect, angle, elevation, ambient temperature, precipitation, distance to: bench and bearing, water type, structures, roads and trails. Vegetation attributes were: forest edge distance/type, forest zone, plant associations, site history, management history, canopy cover %, canopy layers, canopy height, dominant tree height. Nest stand attributes: year of nest, nest tree species, nest tree height, DBH (diameter at breast height), (See Photo 5), top condition, cover class, distance to alternate platforms, mistletoe rating, crown ratio %, vertical crown position and species. For each activity tree we measured distance to prey exchange trees number one and two, distance to mating tree, distance to pluming tree, distance to other activity trees (cache, perch etc.), distance to last nest and plant associations (USFS-FS Handbook 1988). The tree codes by species in order of appearance are: TSHE (*Tsuga heterophylla* = Western Hemlock), PSME (*Pseudotsuga menzesii* = Douglas Fir), PISI *(Picea Sitchensis* = Sika Spruse), ABAM (*Abies amabilis* = Silver Fir), ABGR (*Abies grandis* = Grand Fir), CONI (other conifers), ACMA (*Acer macrophylum* = Big-leaf Maple), ACCI (*Acer circinatum*), ALRU (*Alnus rubra* = Red Alder), BRDLF (other broadleaf), SNAG (dead tree).

Nest characteristics were: aspect, type, height, access, support branch diameter, nest bole diameter, distance from bole, distance to branch above and below, vertical cover (%), horizontal cover (%) in cardinal directions. Tree size classes by DBH and species were: 10-31cm, 32-62 cm, 63-92 cm, 93-122 cm, >122 cm. Also, snag numbers, size classes and site maps were included for each breeding site. In all, 57 variables were considered in 204 veg plots of which 58% were in Washington State and 42% in British Columbia, Canada.

Distance from nest to riparian zone (water edge) was determined using the Washington State Watercourse Hydrography Dataset and the Canadian National Council on Hydro Network. Veg Plots provided "ground truth" data, which described the breeding territory activity trees habitat and the Merlin nest microhabitat.

Old Growth and Mature (OGM) (Franklin 1981), Intermediate (INT) (Dawson and Hosteller 2010), Rural Residential (RR) (USDA 1961) and Urban Residential (UR) (Nowak 2010) forests were compared using CHI Square tests. Correlations indicated when possible associations were present between data sets. When there were multiple hypotheses derived from the same pool of data, we set higher confidence levels (conf. level) of $\alpha = 0.01$ or 99%, instead of 95%. For one degree of freedom (df1), the Z statistic was 3. The X^2 statistic for four habitats, df3, was 11.3.

Climate is a major force in these eco-regions and we posit, in Merlin reproductive success. Field temperatures and weather conditions were regularly recorded during surveys and monitoring sessions. Since field records may vary with microhabitat and time of day, they were compared with Pacific comprehensive weather data, provided by the National Weather Service, for Seattle, and through NOAA, Climate Prediction Center, Oceanic Niῆo index (ONI). Local weather stations, including U. S. and B. C. National Park and U.S. National Forest locations provided incomplete datasets.

The ONI measures Pacific Ocean surface temperature, which have been found to influence climate and weather in the Pacific Northwest (Johnstone and Mantua 2014). NOAA calculates a 30 year average for each month, then creates an index of temperatures above or below the base, for every three month period (February/March/April; etc.). For example, an increase of over +0.5° C would be considered warmer than the base. We processed our own field temperatures and the Seattle records as close to the ONI methodology as possible, limiting our calculations to the parameters of the breeding season: February through August. All temperature and precipitation data was correlated to fledging rates for each breeding season. To accomplish this, we also created a similar index for fledging events per site, where 0 signified the average fledgling rate over the course of the study and a positive or negative score indicated the yearly difference from the average.

RESULTS

Macrohabitat

Coastal Forest Merlin breed across a forested landscape mosaic, described by botanist's in four basic habitats of our study area. The regional representation of tree species was largely conifers (67.78%) and fewer broadleaf (25.99%). The Merlin's native Old-Growth and Mature forest (OGM) was characterized by late seral stage forests, bisected by streams to rivers, riparian corridors, with natural openings from wind throw, landslides and meadows of successional growth.

This study showed that these forests generally have a 50% or more closed canopy (See Photo 6) in our vegetation plot measurements and calculations. Analysis revealed these forests consist primarily of conifers: Western Hemlock (*Tsuga heterophylla*, TSHE 57.59%), Douglas Fir (*Pseudotsuga menziesii*, PSME 6.89%), Western Red Cedar (*Thuja plicata*, THPL 4.78%), Sitka Spruce (*Picea sitchensis*, PISI 5.09%) (See Photo 7), Grand Fir (*Abies grandis*, ABGR 0.36%) and deciduous broadleaf ACMA, ACCI, ALRU (<25%). The presence of trees greater than a certain diameter (which we defined as 122 cm DBH), as well as a diversity of tree diameters were indicative of old growth and mature forests (See Fig. 2). Compositionally, climax forests include: saplings to snags of multi-species trees, which upon falling, open the canopy, leaving old-age decadent logs, toward forest regeneration (See Photo 8). Snags (dead topped and total trees) and open-topped trees, sky-piercing above the forest canopy are very important to Merlin breeding for visual detection by the prospective genders, hunting, as well as defense of the nest and territory (See Photo 9).

Most ancient forests are gone or fragmented, with less then 2% remaining of the region's former 80% coverage into isolated tree stands outside of conservation designated enclaves (Franklin 1981), or in low to mid-altered human zones (Harris 1992). In these specific habitat types, some new forest growth and surviving tree stands share characteristics with OGM and are often found in urban arboretums, parks, golf course edges, or private reserves. We found Merlin breeding in these Intermediate (INT) (See Fig. 3) tree stands.

As of now, much of rural Washington State and British Columbia is pasture or agricultural fields and low density, residential places. This Rural and Rural Residential habitat (RR) (See Fig. 4) are sometimes used for breeding by Merlin, but more often used for hunting forays. About mid-way (1999) from our study start in 1987 to 2013, Coastal Forest Merlin were observed colonizing urban residential areas (UR) (See Fig. 5). Highly developed, planted, young/regenerating forests (See Photo 10), and non-vegetated habitats were surveyed, but as they were not used for Merlin breeding purposes, we did not include these habitat types in our analysis.

Merlin nest sites were located in four habits: 82 nests in OGM (old growth and mature conifer forests); 37 nest sites in INT (intermediate forests, low and mid development); RR (rural and rural residential; 23 nests in low development) and 77 nest sites in UR (urban residential, mid development). The average elevation for Coastal Forest Merlin breeding sites was 114m, but in the four habitats where we found Merlin nesting, all varied from this average: OGM 206.71m, INT 70.17m, RR 59.04m and UR 75.01m. Intermediate forest stands and urban-residential sites are close in elevation. This fits with INT sites being found in parks or park-like settings in or near cities.

We hypothesized that Coastal Forest Merlin are facultative breeders in rural, riparian-upland forest interfaces. Facultative breeders, versus obligate breeders, are those who have flexibility in choosing a breeding habitat, rather than those who are locked into a certain reproductive scenario. They may select a breeding habitat from several habitat options, if the nest site and its surroundings have a combination of factors that meet their needs. If they were obligate rural/riparian breeders, there would be no nest sites in urban and non-riparian zones.

Rural-riparian habitats are those found near rivers, streams and bodies of water with upland forest interfaces adjacent upslope (See Photo 11). We considered a riparian/upland site one that was within the observed 500 m defended area of the Merlin pair (See Photo 12). Our veg plots had distance to water data on 153 sites. Our ground measurements showed that the average distance from nest site to water generally increased, as Merlin moved from more forested areas into urban zones: OGM 98 m, INT 170.93 m, RR 85.75 m, and UR 399.55 m. There were 163 out of 171 fledglings (95.32%) that came from riparian sites; 11 nest sites were outside the riparian zone with 8 fledglings (4.68%) from non-water-related sites. Fifty-three of 159 (33.3%) of the sites were UR, but all OGM and RR sites were riparian.

Of Merlin nests with fledglings (See Photo 13), 21 were within 25 meters of water, 48 were 26-100 m from water, 94 were 101-500 m from water, and only 8 were fledged more than 500 m from water. The correlation of fledging rates to distance to water was $r = -0.81$. Which suggests the further from water the fewer fledglings. Coastal Forest Merlin tend to choose sites with complex ecotonal interfaces. Ecotones are where one habitat type meets another.

Weather and Climate

In this section "r" means correlation. Correlations range between -1 and +1, with r = 0 being no relationship. We also use "N" to stand for sample size. Correlation suggests, but is not proof.

Regional weather should be included in any description of the Coastal Forest Merlin breeding habitat. As explained above, the ONI index of Pacific Ocean surface temperatures appears to influence local weather (Johnstone & Mantua). Our study found a + 0.65 correlation between Pacific surface temperatures and Seattle temperatures. There was a + 0.47% correlation between the ONI and our field temperatures. We found, however, that there was little relationship between the ONI and local precipitation (+ 0.13).

We compared the ONI to our fledging index to see if warming events effected fledging rates over the 27 year course of the study. There was a negative correlation, when at least five active breeding sites were monitored in a season *r* = -0.34. When at least 10 active breeding sites were monitored per season r = - 0.50. The ONI to fledging correlation for all sites and years was r = -0.23, N =184). We compared the breeding season ONI to fledging averages over 27 seasons to see if Pacific Ocean Surface temperatures may have an effect on Merlin reproductive success. There was a negative correlation: (N=184, r = -0.23537). When outliers were excluded by limiting the seasons to ONIs between - 0.5 and + 0. 5, the correlation grew stronger: N=154, r = - 0.36852. This reinforces Johnstone and Mantua's findings that seasonal temperatures influence fledging.

The fledging per nest in cool versus warm years also revealed a similar pattern (See Fig. 6). Years with negative ONIs had fledging rates of 2.44 (N=80), while warm ONIs had a lower rate of 1.5 (N=104). This appears at a glance to be incongruent, as the UR sites in general had a higher fledge rate of (2.38 N=81), but these urban residential sites were hit hardest in warm ONI years. Here is the correlation by habitat: OGM -0.0394; INT -02759; RR -0.0059; UR -0.36751.

Defended Territory

The most conspicuous change of the Merlin habitat in the Euro-American era has been extensive deforestation. Our data from veg-plots show a drastic thinning of the forest canopy as one moves from rural locales into urban areas. The number, density and bole size of trees Merlin encounter and use drops significantly. The average basal tree area (BTA) declined in our veg plots, as follows: OGM 12.22m^2 (N = 61), INT 7.99 m^2 (N = 33), RR 4.84 m^2 (N = 26), and UR 2.99 m^2 (N = 83) (See Fig. 7). To access the significance of these declines, we used OGM's basal tree area as our comparison (where Z = 3 or more significant at 99%) and we found the following: Comparing OGM with INT, the score was 5.35 > 3. of OGM to RR produced a larger score of 9.77 > 3. The OGM to UR score was very large, 31.61 > 3. All were significant differences.

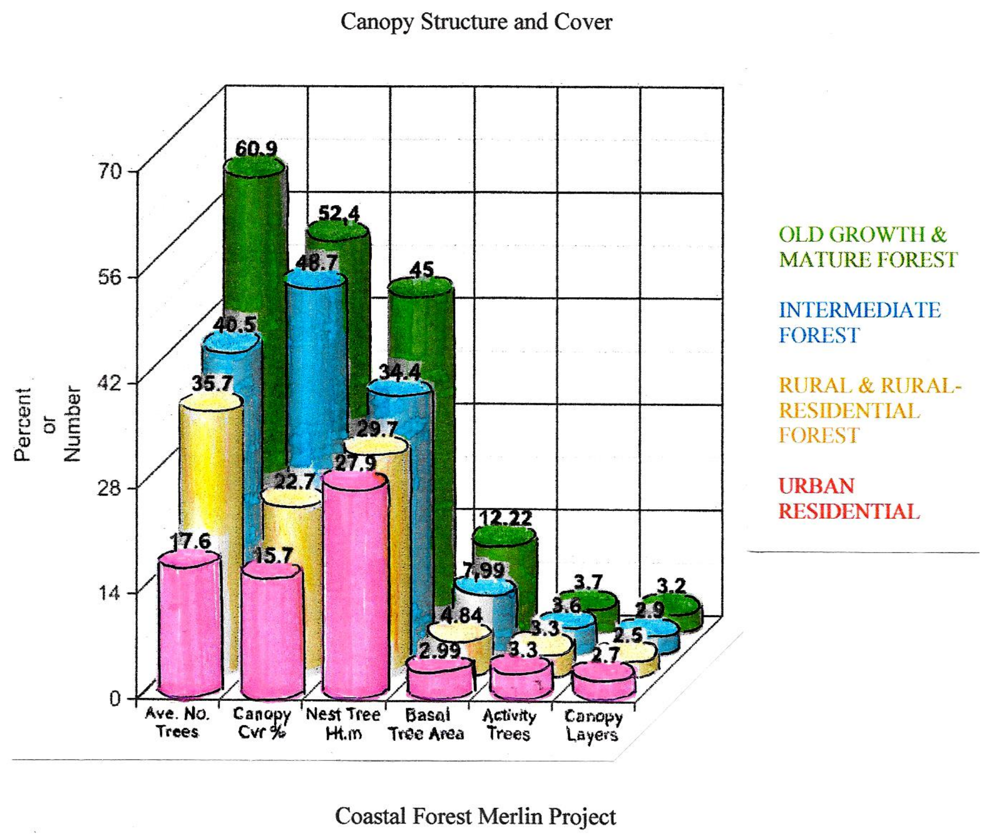

Figure 7.

This lead us to observe that increased development and urbanization changes the use of activity trees around Merlin breeding sites. Activity trees include: nest tree (NT), prey exchange tree (PRXTR), mating tree (MATR) pluming tree (PLTR, where prey is plumed), the cache tree (CATR) and favorite perches. We observed several of these functions centered in one tree in urbanized sites, sometimes resulting in repetitious crow harassment and Merlin nest failure on old corvid platforms (See Photo 14).

We also found that the average number of activity trees drops the more the area is "developed" by humans. Nest tree heights and canopy cover appear to influence the size and complexity of the breeding site activity sphere, including a reduction of activity trees. We looked at averages in nest tree height, canopy height and distance to prey exchange tree by habitat, finding the following: Average nest tree height decreased: OGM 45.04 m, INT 34.39 m, RR 29.7m, and UR 37.78m. There was a positive correlation between nest tree heights and canopy heights: OGM r = + 0.3470; INT r = + 0.5669; RR r = + 0.5013; UR r = + 0.5367. Generally, the greater the height of the nest tree, the less the distance to the PRXTR, except in urban environments, as shown by these correlations: OGM r = - 0.1174; INT r = - 0.1670; RR, r = - 0.0033; UR r = + 0.2008. The different pattern in UR is probably due to the scarcity of trees.

These findings led us to wonder if Merlin had an "internal map" of their breeding area's matrix structure, so we measured the average distances from the nest tree to the other activity trees, by habitat, with these results:

PRXTR distance: OGM 43.53m INT 47.88 RR 43.22m UR 50.96m (See Fig. 8)

MATR distance: OGM 53.5m INT 41.9 RR 48.5 m UR 50.3m (See Fig. 9)

PLTR distance: OGM 58.85 INT 64.20 RR 56.13m UR 61.18m (See Fig. 10)

Clearly, there is a very close and consistent spatial relationship between the activity trees within the four habitat types, suggesting Merlin do look for a specific arena to center their breeding sphere.

Coastal Forest Merlin can use silent and elusive flights to and between all activity trees, except the PRXTR and sometimes the MATR. In fact, the same tree is sometimes used for both functions. They cryptically use the PLTR and CATR. Due to the small sample sizes of CATR, they were too small to be conclusive.

Did the canopy cover of the breeding sites change significantly as sites became more urbanized? We found that the canopy cover of INT and RR tree stands surrounding nest trees was not significantly different than OGM canopies, however urban environment (UR) showed a large difference in canopy cover: OGM 54.39%, INT 48.70%, RR 22.75%, and UR 15.65%. *Z* tests compared OGM canopy cover to each of the other three habitat types. For each test $\alpha < 0.01$, $P > 99\%$. The *Z* statistic = 3. Results were INT 1.3 < 3; RR 2.78 < 3; and for UR 6.47 > 3. The differences were not statistically significant, except for urban sites.

Also, canopy layers are reduced in more human modified settings. We found OGM averaged 3.22 layers; INT 2.91 layers; RR, 2.52 layers, and UR, 2.69 canopy layers (Refer again to Fig. 7).

Generally, human modification of the Merlin habitat reduces all measures of forest richness, as the previous results have shown. One measure though, tends upward: the crown ratio of nest and plume trees. The crown ratio is the percent of the tree's height that is branched and foliated. As we monitored Merlin in their defended area, we noticed that certain activity trees tended to have fuller crowns. This was by no means true of the prey exchange trees and mating trees, which often times were in open, lightly foliated and snag topped trees. Plume trees (PT) and nest trees (NT), though appeared to often have fuller crowns, so we "took their measure", expressing the crown ratios as percents. The following data shows how the crown ratio (CR) is higher in human modified surroundings:

	N	OGM	INT	RR	UR		N	OGM	INT	RR	UR
NT	175	45.73 %	63.57 %	65.00%	72.59 %	PT	141	56.38 %	73.32 %	67.19%	74.14 %

Although the crown ratios of these trees increased over the OGM crown ratios, none of these changes were greater than a standard deviation nor statistically significant. All of the Chi Squared values are less than the statistic needed for 95% confidence of significant change.

Due to the amount of alteration of urbanizing canopies, we hypothesized that human impact will change the fledging success of Coastal Forest Merlin. There were 261 nests with 576 fledglings, confirmed by 2013 (Merlin will uncommonly use the same nest site for more then one year).

Nest failures were highest in OGM (32.9%). The other failure rates were: INT (33.3%), RR (20.5%) and UR (11.4%). Fledging rates varied from OGM (1.79 fledges/nest), INT (1.93), RR (2.25) to UR (2.5) (See Fig. 11). We asked ourselves if different levels of predation could account for the differences in nest failures. Over the course of the study, all field observations noted predator species and species agonistic to Merlin. We saw 46.3% fewer potential predator sightings within urban areas, compared to old growth and mature forest sites.

Nest Tree

The relationship between the nest and the nest tree constituted the microhabitat in our study. These Merlin "inner sanctums" must be looked at in 3-dimensions to fully understand their breeding dynamics. The nest tree was usually dominant to or co-dominant within the canopy and the nest was hidden near the top of the canopy. The nest tree however, was not always the dominant tree in the canopy. Most nest platforms were slightly above the upper canopy and on average at 87.6% of the nest tree's height. As explained before, crown ratios of nest trees tended to increase in habitats modified by humans, as compared with OGM sites, most likely in response to increased available light values for tree growth.

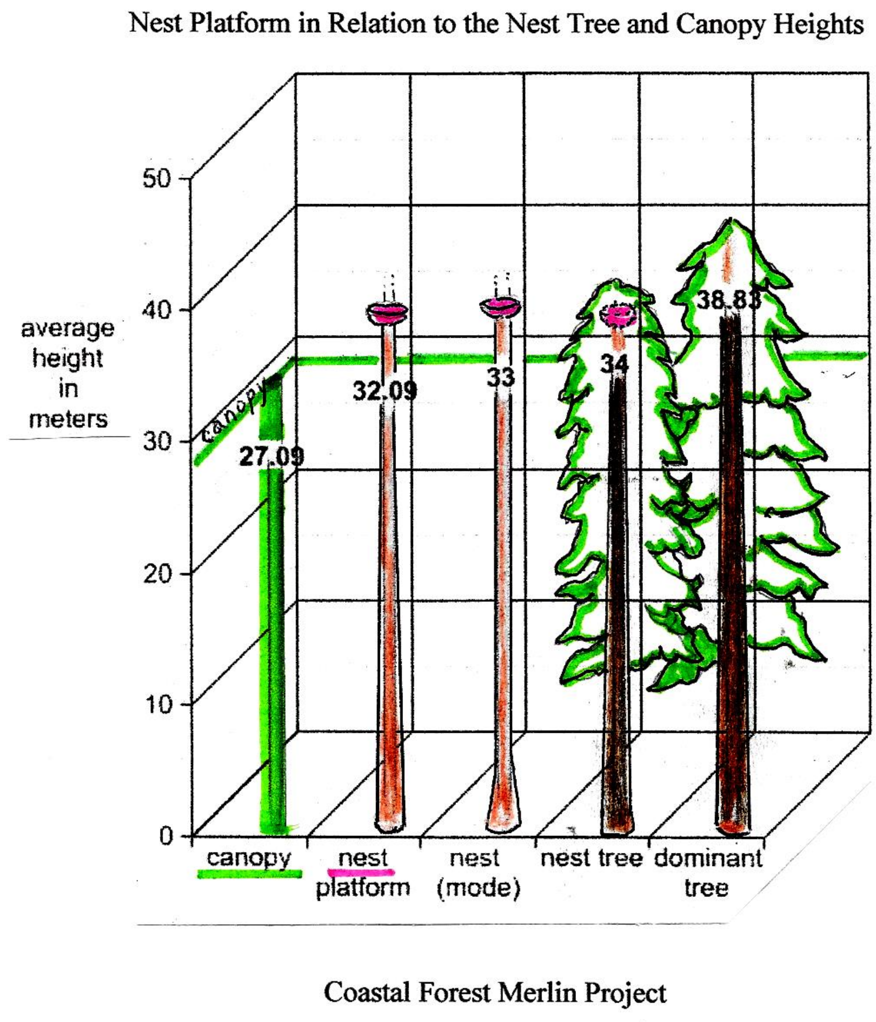

Figure 12

Nest heights in relation to nest tree and canopy heights were slightly taller than the area canopy (See Fig. 12). The average diameters of nest trees were over two and half times larger then the surrounding trees (See Fig. 13).

Native conifers with large boles and good crown cover are typical nest trees. Most nest trees were within one standard deviation of the average metrics of OGM nest trees. This led us to hypothesize that Merlin has an internal idea that the ideal nest tree approximates old growth or mature nest trees, even if the habitat is highly modified. Putting our selves in the hypothetical mindset of a Merlin, the optimal DBH would be at least 36 cm, desirable vertical cover at least 63% and acceptable horizontal cover at least 52%.

For vertical cover the average was OGM 69.3%, INT 81.2%, RR 77.6%, and UR 76.8%. All of these were greater than our 63% standard. The same cannot be said for horizontal cover being at least 52%. Only OGM was greater, at 63.09%. INT was 42.88%. RR was 41.5% and UR was 37.87% (See Photo 15). Average DBH of nest trees in all habitats but, RR was at least 36 cm: OGM 50.1 cm, INT 44.6 cm, RR 35.6 cm, and UR 38.6 cm.

These conifer nest trees often have late seral stage characteristics, when compared to surrounding trees in the breeding habitat, which may be younger or even be broadleaf. The average DBH of Merlin nest trees did not vary significantly from bole diameter of OGM nests trees in *Z* and Chi Square tests. The average DBH of OGM was 50.1 cm ± 55.93 cm. The DBH for INT was 44.62 cm. RR nest trees had an average DBH of 35.56 cm. UR nest trees were 38.61cm.

We also found that the frequency of species used as nest trees will differ from the demographics of that species within the surrounding habitat. Our tree census, based on 204 veg plots, 7582 trees and 15 species categories showed significant differences in nest tree selection compared to the dominant tree species in the veg plot. The following nest tree species occurred more frequently than their occurrence in the surrounding forests: Grand fir (X^2 = 671.92 > 11.3), Douglas Fir (X^2=23.36>11.3), and Sitka Spruce (X^2 = 86.92>11.3). The exception to this was Sitka Spruce nest trees in intermediate forests, where there was no significant difference in frequency. Chi Square tests were run at P > 99%, test statistic 11.3, df 3.

The following nest tree species occurred less frequently than they occurred in the surrounding forest: Western Hemlock (X^2 = 40.52>11.3), other conifers, non-natives and broad-leafs. In broadleaf, the difference was huge (X^2 = 101.82>11.3). In old growth stands, for example, the dominant tree species were Western Hemlock, but the dominant nest tree choice was Douglas Fir. In intermediate forests and rural tree stands the dominant species was Douglas Fir, but the primary choice for nest trees was Grand Fir. In urban residential areas, Douglas Fir was also the dominant veg plot tree and also the primary choice of nest tree. Urbanization often means the introduction of non-native broadleaf and conifers. We found that Merlin seldom select these trees when choosing nesting platforms, although they occasionally use them for other activities. Also, there was a reduction in number of total trees per nest site in all four habitat types (See Fig. 14), and in turn, the average basal area or tree volume (See Fig. 15).

We wondered if the contrast between nest tree species selection was greater in certain habitats for the five most common conifer categories. Broad-leafs and snags were excluded, since snags were not used for nest trees with one exception and broad-leaf trees were only used twice. The results for OGM were less than significant: 5.99 < 13.3. Other habitats showed X^2 scores greater than 99% significance: INT (23.78), RR (14.66), and UR (19.38). The least to greatest change was in this order: OGM < RR < UR < INT. CHI Square tests were (p>99%, df 4; statistic 13.3).

Nest (Microhabitat)

Coastal Forest Merlin do not build their own nests and opportunistically, appropriate top-cavity, side-cavity, mistletoe and recycle ready-made platforms, usually previously used crow nests. The change in platform options with increased cultural modification become apparent, as seen here. Old Growth platforms were a diverse mix: top and side cavities (46.34%) (See Photo 16), crow nests (41.25%), wide branches (9.76%) and mistletoe (2.44%). Intermediate forests, rural residential and urban residential sites were all in recycled crows nests, except for one anomalous UR site, using a Grey

Squirrel nest. Pooling all four habitat types, overall 78.9% of nest platforms were Northwest Crow nests, reflecting urbanization (See Fig. 16).

The nest's vertical cover is usually greater than the percent of canopy cover. Vertical cover serves the multi-function of providing weather inclemency and predator view shielding over nests and from overheating effects of the sun. We compared vertical cover in OGM nest trees to the vertical cover of nest trees in INT, RR, and UR. We wanted to see if these nest trees were within the late seral stage limits. The vertical cover (VC) over nest platforms was generally greater than the surrounding canopy cover: by 16.9% (OGM); by 32.5% (INT); by 54.9% (RR); by 61.1% (UR). A Chi Square test comparing the VC to the surrounding canopy cover showed that the difference was 44.73 > 11.3, df 3, $P > 99\%$. Z tests also indicated the vertical cover over nest platforms was significantly greater than the canopy cover: OGM 5.59 > 3; INT 15.78 > 3; RR 23.39 > ; UR 37.67 > 3; $P > 99\%$.

Horizontal cover of the nest platform was also greater than the canopy cover, except in INT forest stands: by 10.7% (OGM), by 18.8% (RR), and by 12.1% (UR). In INT, however, horizontal cover of the nest was less than its surrounding canopy cover by 6.2%. A Chi Square test of the cumulative difference in the four habitats showed that overall, the difference was not significant. Z tests indicated that the differences in horizontal cover were only significant in RR and UR, where the rural score was 6.15 > 3 and the urban score was (15.51 > 3, for P > 99%.

Nest aspect (compass direction of the nest, relative to the bole) was not random. 11.0% of the nests were inside top cavities, so lacked a compass aspect direction. Dividing the rest into the quadrants NW-NE, NE-SE, SE-SW, and SW-NW we find the differences in aspect were not dramatic, though the majority faced north (28.7%), south (27.4%), 19.7% east and 24.2% were to the west.

Fledging rates varied by habitat and platform type. 209 nests produced 398 fledglings, but not with equal success, as these fledgling rates show: OGM (1.62 fledgling rate), OGM top cavities (1.9 fledgling rate), OGM crow nests (2.06 fledgling rate), INT (all crow: 1.42 fledgling rate, +/- 1.58); RR (1.73 fledgling rate) and UR (2.38 fledgling rate).

DISCUSSION

Our landscape level observations over 27 years suggest that canopy-dwelling Merlin are choosing nest sites where a variety of habitats come together in complex foliar interfaces, near or within riparian-upland forest zones. They are not obligate breeders in riparian zones, but show a strong preference for nearness to water, perhaps related to increased platform and prey options, as well as efficient activity energetics. We found that distance from nest to water increases in intermediate and urban-residential nest sites. Elevation differences below the tree line do not seem to be a limiting factor for breeding habitats, depending on the nest substrate type, whereas, the majority of recycled crow nest usage occurs at lower altitudes.

The data supported our hypothesis that Merlin seeks out trees that retain late seral stage characteristics. Old growth and mature forests provide a much greater diversity of nest opportunities, especially top cavities, side cavities and mistletoe platforms. In non-rural forests and tree stands, recycling crow nests is the main option for Merlin. With human development there are fewer options, where most trees are second or third growth or even non-natives. Given that crows have colonized cities, it is no surprise that enterprising Merlin, are following these nest builders, making savvy survival use of Corvid intelligence (See Photo 17). Were it not for urban crows, there would probably be no Merlin urban nesting.

We have seen that in Old Growth, Intermediate and Urban Residential habitats the prey exchange tree is often the closest activity tree to the nest tree. The prey exchange tree often does "double duty" as a mating tree. The pluming tree and cache tree are usually located farther away. This suggests that Merlin may have an "internal map" of the distances from the nest tree to various activity trees. Where core and buffer trees are scarce on a breeding site, activity functions begin to be shared by the same tree, with potential deleterious effects rendered by crows, owls, humans, etc. on eggs, nestlings and even fledglings.

With the fragmentation and depletion of Old Growth and Mature forests in Washington State and British Columbia, Merlin appear to be increasingly using other foliated environments as a base for reproduction. Curiously, Intermediate and Rural Residential sites are being used less then Urban Residential habitats, perhaps due to the relatively depauperate structural context of these transitional forests and more sparse and nomadic prey species availability. This is especially, the case in commercial production forests, where no Merlin breeding has been documented in this study. A parallel scenario has been found for Spotted Owl, Marbled Murrelet and Northern Goshawk.

As Merlin moves into pockets of surviving forests or urban canopies, they still search for nest trees that most resemble Old Growth or Mature Trees with top and side cavities and mistletoe platforms. Good vertical nest cover and complexity of habitat also seems important (See Photo 18). Platform availability for nesting appears to be one of the key limiting factors in Merlin population maintenance (Sieg and Becker 1990). In urban forests nest platform diversity is limited. Urban crow nests may provide opportunities for Merlin to move to the city (Warkentin and James 1988). Clearly, Merlin nesting habitat has been extensively altered and yet, it's amazing to witness their adaptive resilience to these considerable survival challenges.

Warming events seem linked to reduced fledging rates, with the highest negative correlation to fledging in urbanized areas, areas that on average are the farthest from riparian habitat. One possible explanation for the lower rates of urban fledging in warm episodes could be the lack of canopy cover and distance to water, causing panting and dehydration of the nestlings and fledglings. Old Growth canopies have a cooling, shading effect in conjunction with the riparian shoreline interface. The highest number of non-riparian breeding sites occurred in cities, with minor, but perhaps, adequate shade and cool early in the diurnal cycle and breeding chronology.

The Merlin fledging rate is slightly higher in urban areas than in old growth and mature habitats. These city, recycled crow-nests enjoy higher fledging rates, as well as lower nest failures then their rural relatives in other nest habitats (See Photo 19). This could be related to greater abundance of prey, nest platform availability and possibly fewer predators of Coastal Forest Merlin eggs and nestlings. Predation of Merlin adults, eggs and nestlings were documented in Old Growth or Mature, Intermediate and Rural Residential habitats. There appears to be an apparent contradiction in the fact that the fledging rates were higher in urban environs, yet the failure rates of nests were also higher in cities during warming weather events. In other words, in hotter years, natural selection may act more severely on urban Merlin than those using old growth and mature forest habitats.

During the primary breeding season (February to August), the center of activity of this Coastal Forest Merlin is a zone defined by key activity trees with the nest tree as center. Extending outward and upward (above the canopy) from the nest, there is a defended hemispherical airspace of approximately 500m. The main activity trees in this forest fortress area are: the nest and nest tree, favorite perches, the prey exchange tree(s), the mating tree (often the same as the prey exchange), the pluming tree (where the final pluming of prey is done before delivery to nestlings) and the cache tree (where extra prey is stored).

With deforestation and simplification of breeding habitats due to selective cutting, commercial logging and development, canopy cover becomes sparser and canopy height decreases. Along with canopy reduction, average nest tree height and number of trees per nest site, also becomes smaller. We saw this in vegetation plots, as we compared old growth sites to rural and urban sites. This "shrinkage" is also reflected in the area and height of the whole activity zone. The distance of the activity trees from the nest tree lessens as the canopy height and forest cover diminishes.

In old growth forests with dense canopies, lower branches are shed, leading to smaller crown ratios. In more open, urban residential areas with sparse canopies, nest trees often retain more, lower branches. The increased crown ratio of urban residential nest trees may contribute to the good horizontal and vertical cover surrounding nest platforms. Urban nest sites also do not have the same frequency of snags and dead falls seen in late seral stage forests, largely because damaged to healthy trees are pruned and removed.

The loss of breeding habitat is but one, major area of concern for the long-term success of the Coastal Forest Merlin populations. Land cover in the study area has been increasingly impacted by human activity. Although the natural and developed landscape of the study area presently appears to provide Merlin with an adequate amount of breeding habitat, the combined effect of continued cutting of mature conifers, urbanization of rural areas and climate change, could seriously impact the future of this cool-wet adapted falcon race.

As is already seen in the Nearctic and Paleoarctic with songbird populations, which are thermo-challenged and relocating northward, perhaps this rural predator of passerines will be forced north too. Plausibly, the rural Merlin genetic pool may be replenishing the urban population, so that further depletion of old growth and mature forest could pose a survival bottleneck. Inversely, if the urban residential Merlin are self-perpetuating, they too, are facing increasing loss of conifer nest trees and crow nest platforms due to private property tree removal. Urban songbird prey, especially seed-eaters, seem secure for now. Perhaps, adaptation to human development will become this falcon's survival modus operandi. Here Merlin, as with all life forms, considers the proverbial survival question: What are the trade-offs inherent in the urban stimuli of perceived "convenience" opportunities versus trying to persist on the dwindling continuum of rural habitats?

STEWARDSHIP

We recommend that natural resource people and planners save mature conifers whenever possible. This will promote Merlin breeding opportunities toward their population maintenance. These habitats also facilitate rich, diverse avian and wildlife populations that can be further enhanced by creating greenways planted in conifers with dense crowns, such as Grand Fir and Douglas Fir. Managers in national, provincial and state forests should consider selective cutting rather than clear cutting. Rural landowners can enhance riparian habitat, by utilizing state and land trust programs that create buffer zones of native trees near streams that cross farms and privately owned property. Such measures will help sustain Merlin breeding habitats, the same environs that also protect many species associated with this enigmatic raptor and a diverse, life sustaining ecology for us all.

 

ACKNOWLEDGEMENTS

We would like to thank the many citizens, scientists and photographers who contributed their sightings, field assistance and support to this long-term study in Washington and British Columbia of the Pacific Northwest. We greatly appreciate the WA and BC natural resource agencies, who provided valuable administrative support. Many thanks, also to the numerous Citizen Volunteers and WWU Interns who helped compile the data (See Volunteers and Stewards at website). We acknowledge the anonymous PhD manuscript reviewers for improving this manuscript. We also appreciate Mike Titus creating and maintaining this website for the Coastal Forest Merlin Project.

LITERATURE CITED

BECKER, D.M. and SIEG, C.H. 1987. Home Range and habitat utilization of breeding male Merlins *Falco columbarius* in Southeastern Montana. Can. Field-Nat., 101: 398-403.

BENT, A.C. 1961. Life Histories of North American Birds of Prey. Vol. 2, U.S. National Museum Bulletin 170, pp. 70-90. Washington, D. C. 1961 edition by Dover Publications, New York, NY.

BIBBY, C.N. BURGESS and D.A. HILL. 1992. Bird Census Techniques, second edition, Academic Press, Elsevier, Philadelphia, PA

BROWN, L.; D. AMADON 1968. Eagles, Hawks and Falcons of the World. Volume 2, Country Life Books, Hamlyn Publishing Group, Feltham, Middlesex, UK. CADE, T. 1982. Falcons of the World, Cornell University Press, Ithaca, New York.

CAMPBELL, W. R., and N.K. DAWE, I. M, McTAGGART-COWAN, J.M. COOPER, G.W. KAISER, M.C.E. McNALL. 1990. Vol. 2, pp. 50-53. Canadian Wildlife Service and the British Columbia Wildlife Branch.

NATIONAL HYDRO NETWORK, CANADIAN COUNCIL ON GEOMATICS, 2004; www.geobase.ca/geobase/en/data/nhn/index.html, (last accessed 13 September 2013)

DAWSON, DAN and M. HOSTELLER. 2010. Forest Remnants; Conserving and observing bird diversity in urban settings. Publication #WEC298, University of Florida IFAS.

DAWSON, W.L. and J.H. BOWLES. 1909. The Birds of Washington. Occidental Printing Co., Seattle, Washington. 536 pp.

FRANKLIN, JERRY., K. CROMACK JR., W. DENISON, A. McFEE, C. MASER, S. SEDELL, F. SWANSON, G. JUDAY. 1981. The Ecological characteristics of old growth Douglas Fir Forests, General Technical Report, PNW-GTR-118, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

GABRIELSON, IN; F.C. LINCOLN; O.J. MURIE; E.R. KALMACH 1959. Birds of Alaska; Stackpole Company, Harrisburg, PA, 922 pages.

GOVERNMENT OF CANADA, GOUVERNEMENT DU CANADA, COMMITTEE ON THE STATUS OF ENDANGERED WILDLIFE IN CANADA (COSEWIC), 2009. www.cosewic.gc.ca, (last accessed 5 January 2015).

GRIER, J.W. and R.W. FYFE. 1987. Preventing research and management disturbance. *In* Raptor Management Techniques Manual. (B. A. Giron Pendleton, B. A.Millsap, K. W. Cline and D. M. Bird, eds.) National Wildlife Federation. Washington, D. C. pp. 173-182.

HARRIS, L.D. 1981. The Fragmented Forest, Island Biogeography Theory and the Preservation of Biotic Diversity, University of Chicago Press, Chicago, IL.

JEWETT, S.G., W. P. Taylor, W. T. Shaw and J. W. Aldrich. 1953. Birds of Washington State. University of Washington Press, Seattle. 767 pp. JOHNSGARD, P.A., 1990. Hawks, Eagles, and Falcons of North America, Smithsonian Institute Press, Washington D.C.

JOHNSTONE J.A. and N.J. MANTUA 2014. Proceedings of the National Academy of Sciences, 19 December 2014 on line publication; DOI: 10.1073/pnas.1318371111, (last accessed 4 January 2015)

KITCHEN, E.A. 1949. Birds of the Olympic Peninsula. Olympic Stationers. Port Angeles, Washington, 262 pp.

LAING, H.M., 1935. Notes on the black pigeon hawk. Auk Vol. 52, pp. 305-307.

NEU, C.W., C.R. BYERS, and J.M. PEEK. 1974. A technique for analysis of utilization- availability data. Journal of Wildlife Management 38:541-545

NOWAK, D.J., E.J. GREENFIELD, S. M. STEIN, P.B. RANDLER, S. J. COMAS, M. CARR, R. J. ALLIG. 2010. Sustaining America's urban trees and forests: a forests on the edge report. USDA, NFS, Northern Research Station, State and private forestry technical report, NRS-62, p. 27.

OLIPHANT, L.W., and E. HAUG. 1985. Productivity, population density and rate of increase of an expanding Merlin population. Raptor Research 19: 56-59.

SIEG, C.H. and D.M. Becker. 1990. Nest-site habitat selected by Merlins in southeastern Montana. Condor 92:688-694.

SMITH, M.R., P.W. MATTOCKS, JR., and K.M. CASSIDY. 1997. Breeding birds of Washington State. Volume 4 *in* Washington State Gap Analysis- Final Report (K.M. Cassidy, C. E. Grue, M. R. Smith and K. M. Dvornich, eds.). Seattle Audubon Society Publications in Zoology No. 1, Seattle, 538 pp.

SODHI, N.S.; L.W. OLIPHANT; P.C. JAMES; I.G. WARKENTIN,1993. Merlin (Falco columbarius). Birds of North America, No. 44 (A. Poole and F. Gill. Eds.). Philadelphia, PA. Academy of Natural Sciences, Washington, D.C.. US Geological Survey (2010), www.usgs.gov. (last accessed 13 September 2014)

SWANSON; G. JUDAY, 1981. The Ecological Characteristics of Old-Growth Douglas Fir Forests, General Technical Report, PNW-GTR-118, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR

TEMPLE, S. A. 1970. Systematics and evolution of the North American Merlins. M.S. Thesis, Cornell Univ., Ithaca, N. Y. 62pp.

TRIMBLE, S.A. 1975. Merlin. Habitat management series for unique or endangered species. U. S. Dept. of Agri. 1988. USFS Forest Service Handbook. U. S. Dept. of Inter., Bur. Of Land Manage. Denver, Colo. 41pp.

USDA - USFS 1988 Handbook of Field Methods.

USDA: Rural development "Report on the definition of rural", Section d343 (A), ConsolidatedFarm and Rural Development Act. revised paragraph 13.

WARKENTIN, I.G., and P.C. JAMES. 1988. Nest-site selection by urban merlins. Condor 90: 734-738.

WASHINGTON DEPARTMENT OF FISH AND WILDLIFE. 2014. Species of Concern, www.wdfw.wa.gov, (last accessed 5 January 2015)

WASHINGTON STATE DEPARTMENT OF NATURAL RESOURCES. 2006. Washington State Watercourse (WC) Hydrography, ROPA.WCHYDRO dataset. www.onrc.washington.edu. (last accessed 13 September 2014).

WHITLOCK, C. 1992. Vegetational and climatic history of the Pacific Northwest during the last 20,000 years: implications for understanding present-day biodiversity. Northwest Environ. Journ. 8:5-28.