Nesting Habitat and Selection of the Marbled Murrelet in Central California

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Abstract Old-growth forests have been widely destroyed and fragmented in the Pacific Northwest over the last several hundred years. As a result, species dependent on old-growth forest are at a greater risk for decline. One such species is the marbled murrelet (*Brachyramphus marmoratus*), which nests in coastal, old-growth forests. The population of the species in the southern part of the range has been in decline due to the destruction of the birds' nesting habitat, and in 1992 the murrelet was federally listed as threatened in Washington, Oregon and California (Ralph et al., 1995). Unfortunately, there have been relatively few studies on actual nest sites, because murrelets are extremely elusive nesters. In this project I aimed to better characterize nest trees, nest limbs and vegetation immediately surrounding nest trees of nests in Central California. I looked at 17 nests found in the area since the late 1980s, 10 of which were found in the last several years using radio-telemetry of tagged birds to track nesting birds. I followed the Pacific Seabird Group (PSG) protocol to collect information on the nest tree and vegetation in the surrounding 25-meter radius area. I also aimed to find out if murrelets were selecting for certain features when choosing nest sites over available sites. I did this by collecting data using the PSG protocol for random sites that were within a 1-kilometer radius area of nest sites. I performed paired t-tests on nest and random sites to looked for differences in the two. Results show that nest sites have higher total and midstory canopy cover, are closer to streams, are lower on the slope and that nest sites tend to have larger basal area per hectare of very large trees (>120 cm diameter at breast height (DBH)) including significantly higher basal area/ha of Redwood trees with >120 cm DBH. The results of this study will allow for better understanding of and management of marbled murrelet nesting habitat.

Introduction

The Marbled Murrelet (*Brachyramphus marmoratus*) is a seabird in the family *Alcidae* that forages at-sea but and breeds in coastal, old-growth forests in western North America. The murrelet ranges from the Bering Sea to central California, with approximately 200,000 individuals in Alaska, 50,000 in British Columbia, 5,500 in Washington, 5,000-15,000 in Oregon and 6,450 in California (Ralph et al., 1995). A large gap in the murrelet's distribution occurs in California, where the northernmost population in Humboldt County is separated by 450 km from the southernmost population in central California (Nelson, 1997), presumably due to the harvesting of old-growth nesting habitat in Marin, Sonoma, and Mendocino Counties.

The central California population has been in decline due to the wide-spread destruction of old-growth forests, increases in nest predator populations, and oil spills (Gaston and Jones, 1998; Nelson, 1997; Carter and Erickson, 1992). In 1992, the murrelet was federally listed as a Threatened species in Washington, Oregon and California (Ralph et al., 1995). Murrelet population size is closely related to the amount of unfragmented old-growth forest available (Meyer and Miller, 2002, Raphael et al., 2002).

Because of the importance of nesting habitat to murrelet populations at the landscape scale, defining and quantifying habitat at the stand scale is a critical component of management planning. Previous studies of habitat at this scale have been attempted by comparing vegetation characteristics at occupied and unoccupied stands, where occupied stands are those where a murrelet was observed flying below the canopy (Paton et al., 1990). Typically, occupied sites have a higher percentage of old-growth cover and greater densities of dominant trees than random sites (Hamer, 1995; Grenier and Nelson, 1995; Miller and Ralph 1995).

Studies based on actual nesting sites are lacking because nests have been very difficult to locate due to the birds' secretive behavior (Hamer and Nelson, 1995). Nelson and Hamer (1995) summarized the habitat at 61 murrelet nests in Alaska, British Columbia, Washington, Oregon and California. All nest sites located in California were found in old-growth forests. Nest stands were dominated by coast redwood and Douglas-fir; stands had a mean distance of 13 ± 8 km inland, were located on the lower two-thirds of the slope, were 108 ± 67 meters to the closest stream, had 39 ± 6 percent canopy closure and had multi-layered canopies. Nest trees in California had an average diameter at breast height (DBH) of 278 ± 136 cm, an average height of 73 ± 8 meters, limb diameters of 35 ± 13 cm with 90 ± 28 percent cover above the nest and commonly had declining or broken tops. The sample size for central California was small (n=5), however, precluding comparisons with available habitat.

In the last several years, the use of radio-telemetry to follow the movements of individual birds has greatly increased researchers' ability to locate murrelet nests (Bradley et al., 2002; Newman et al., 1999, Peery et al. in review). The objective of this project is to better characterize Marbled Murrelet nesting habitat in central California by including the five aforementioned nest sites and twelve new sites (total nest sites = 17) that have been found since Nelson and Hamer's study. I will follow the Pacific Seabird Group Protocol for measuring Marbled Murrelet nest sites (Ralph et al., 1992, 1994), which involves standardized measurements of the nest tree, nest limb and nest stand scales.

A second objective is to compare Marbled Murrelet nesting habitat use versus availability, where murrelets are considered to "select" habitat characteristics they use more than are available to them at random (Johnson 1980). Nesting sites will constitute "used" habitat and sites randomly distributed in old-growth forest in the Santa Cruz Mountains will constitute "available habitat". By placing all random sites in old-growth stands, I am asking the question – what habitat characteristics *within* old-growth forests do Marbled Murrelets select for when nesting? Based on previous analyses of Marbled Murrelet nesting habitat associations (Meyer and Miller, 2002, Raphael et al., 2002), I assume that murrelets prefer old-growth forests over second-growth and heavily harvested stands and seek to determine if murrelets have habitat preferences within old-growth forests.

It is important to look at selected nest sites compared to the available habitat. All old-growth redwood/Douglas fir habitat has been assumed to constitute suitable nesting habitat, but that may not be the case. If only a subset of the old-growth forest available is suitable, that may explain in part the degree of population decline and management practices can be altered so that the more specific habitat classification can be given the highest priority. Other avian studies have found that selected habitat differed significantly from available habitat in certain criteria (Herter, et al., 2002; Bakaloudis et al., 2001, Timoney, 1999). Northern spotted owls, for example, which also nest in old-growth forest, were found to select stands that had larger trees at DBH, had fewer trees per hectare and that had greater canopy cover during diurnal roosts (Herter, et al., 2002). Similarly, I will examine if selection occurs with nesting habitat within available old-growth.

I will study Marbled Murrelet nesting habitat selection at the tree and nest stand scales. These scales are important because the structural characteristics immediately surrounding the nest tree influence nest success through concealment from predators and elements (Tarvin and Garvin, 2002). Also, larger scales of habitat selection are represented well with the occupancy studies, and smaller scales of habitat selection, even if very important, would be hard to manage.

I predict that murrelets will select for several criteria. Since it has been shown that murrelets generally occupy sites with relatively low fragmentation (Meyer and Miller, 2002) I hypothesize that murrelets will tend to select nest sites in older forest. This may be quantified by forest stands with higher proportion or density of old growth trees (basal area/ha). At the same time the species has poor agility on land (Gaston and Jones, 1998) so murrelets will also likely choose stands with less total density (basal area/ha) or less total canopy cover.

Study Site The location of this study is in central California, in Santa Cruz and San Mateo Counties (Figure 1).

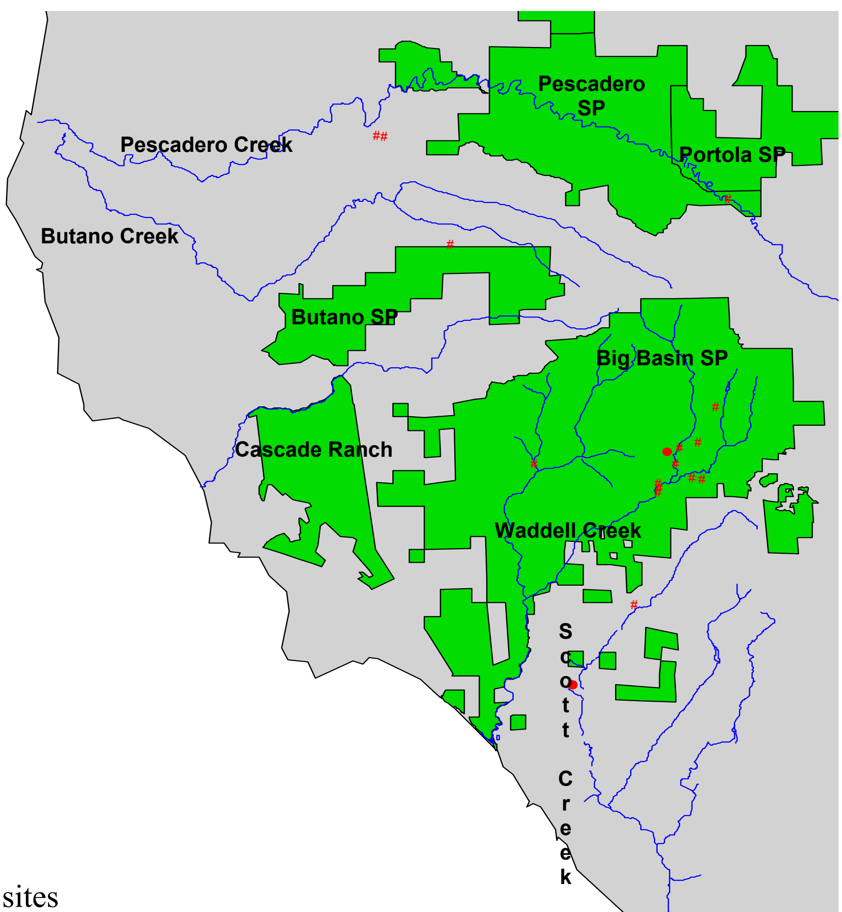

Figure 1 Map of nest sites
Nest sites are marked in red

Methods

The study was based on 17 confirmed Marbled Murrelet nest sites in the Santa Cruz Mountains located during several studies of murrelet nesting behavior with radio-telemetry (n=10) and visual surveys (n=7) (Singer et al. 1991, 1995, Burkett et al. in review, Peery et al. in review, Suddjian unpub.) Visually located nests were found by actively searching (n=4) or by fortuitously observing a nest predation event (n=3). We assume that murrelet nests found using radio-telemetry are random representatives of nesting habitat, but recognize that nest sites located visually may be biased if observers were primarily searching in old-growth stands.

One random site was paired with each nest site in order to compare nesting habitat use versus availability. Ten random Universal Transverse Mercator (UTM) coordinates were generated within a one-kilometer radius of each nest site and the coordinates were then plotted on a map. Randomly generated locations that fell within heavily harvested stands or nonforested areas were excluded and the remaining random sites were scouted by going to the locations in the order that they were generated. The closest tree to the UTM coordinate with a diameter at breast height (DBH) of > 120 cm was designated as the potential nest tree (PNT) at which measurements at the site were centered. If no trees with a DBH of > 120 cm existed in the visual surroundings (within an area of approximately 30 meter radius) of the UTM coordinate, we walked 150 meters in a random direction. The first tree > 120 cm in DBH within 25 meters of the transect was used as the center of the random plot. If no tree was located, the plot was discarded and the next plot scouted.

We followed the Pacific Seabird Group's protocol (Ralph et al., 1992, 1994) when measuring nest and random plots. Measurements were taken on the nest tree (or PNT), on all trees within a 25-meter radius plot centered on the nest tree (or PNT), and on the nest platform (not on PNT for logistical reasons). We also collected information on five random dominant and five random midstory trees each plot. For nest trees and PNT's we measured the DBH (cm), height (m), canopy lift (m) and crown area (m^2). Within each plot we measured the DBH of each tree > 10 cm DBH and oculary estimated the number of canopy layers and the midstory, dominant and total canopy cover (%). We also estimated the elevation (m), slope (%), aspect (^{o}), distance to nearest stream (m), and distance to nearest disturbance (road or clearing) at the center of the plot. We randomly selected five dominant and five midstory trees in the plot, and in addition to the DBH, we measured the height, canopy lift and crown area. When logistically feasible we climbed nest trees (not PNT) and measured the tree diameter at nest height (cm), branch diameter at nest (m), branch orientation (^{o}), nest cup dimensions (cm), platform dimensions (cm), moss depth adjacent to nest (cm) and vertical cover above nest (%).

For analysis purposes, we placed all trees within the 25-m radius plots into one of four size classes based on their DBH: 10-60 cm ("small trees"), 60-90 cm ("medium trees" that consist of large midstory to small dominant trees), 90-120 cm ("large trees" that consist of old-growth trees; definition used by Miller and Ralph, 1995) and >120 cm DBH ("very large trees" that consist of old-growth trees that would quality as potential nest trees in this study). We then calculated the basal area (m^2/ha) in each size class in each plot. We used basal area instead of number of trees for statistical analyses because it was a better representation of the amount of standing timber, especially for the very large size class.

We used paired *t*-tests (Zar 1984) to compare the mean values for all habitat variables between nest and random plots. Because of the large number of variables (n = 40) relative to the sample size (n = 17), this analysis was exploratory in that we were seeking to identify habitat characteristics that were potentially important for murrelet nesting habitat selection.

Results

Thirteen out of seventeen (76%) nest sites were located within California State Parks boundaries, eleven of which were in Big Basin Redwood State Park (Figure 1). One site was located in Portola State Park and another in Butano State Park. The remaining four nest sites were located in private property in the Scott Creek and Pescadero Creek watersheds. All seventeen nest sites were located in the coast redwood-Douglas fir forest type. All thirteen nest stands in State Parks were unharvested, but all four nest sites located on private property had been lightly to moderately harvested.

The random sites had a very similar distribution in public and private land and harvest history. Twelve of the seventeen random sites were located within California State Parks, one site was located in Pescadero Creek County Park and four random sites were located in private property in the Scott Creek and Pescadero Creek watersheds. Eleven of the twelve random sites in State Parks were unharvested and one of the sites in private property was unharvested, and the remaining five random sites were lightly to moderately harvested. The chi-square analysis did not find significant differences between harvest history of nest sites and random sites (p-value = 0.6975).

Nest trees included seven redwoods and ten Douglas firs. Random plots were centered on potential nest trees (PNTs) that included nine redwoods and eight Douglas firs. The Fisher's exact test (p-value = 0.2145) was not significant although there is a trend for murrelet's to use Doug firs for nest trees over what is randomly available.

Table 1 contains nest limb information. Nest limb information was collected at twelve of the seventeen nest sites. Nest site information was only collected for sites where the nest limb was known. Two sets of nest limb information were collected at a single tree which hosted several nest attempts carried out on different years and on different limbs, bringing the total quantified nest limbs to thirteen. All of the nesting attempts on Douglas fir trees were on limbs. Three redwood nest sites were on broken treetops and the other four nest sites in redwoods (five nesting attempts including the two on the same tree) were on limbs.

	Mean	StdDev	Nest N
Tree diameter at nest height (cm)	104	27	10
Branch diameter at nest (cm)	47	12	12
Branch orientation (º)	186	121	13
Nest platform length (cm)	75	39	11
Nest platform width (cm)	41	16	11
Nest cup length (cm)	13	4	12
Nest cup width (cm)	11	3	12
Nest cup depth (cm)	4	4	12

Table 1 Nest limb characteristics

Means and standard deviations for general site information for nest and random sites are shown in Table 2. Paired t-tests were carried out on all of the characteristics and significance was noted. Table 2 also includes vegetation data broken down to DBH classes and species.

							Paired T-test		
	Nest Mean	Nest StdDev	Nest N	Ran. Mean	Ran. StdDev	Ran N	T-ratio	p-value	Significant?
General site info									
Elevation (m)	287.3	86.1	15	314.7	109.3	17	1.219	0.243	ns
Slope (%)	54.3	18.6	12	47.5	24.1	17	-0.296	0.773	ns
Aspect (degrees)	243.1	98.2	12	173.7	113.5	17	-1.674	0.122	ns
Nearest Stream (m)	109.8	78.2	15	270.0	237.1	17	2.166	0.048	**sig**

Nearest Disturbance (m)	141.1	181.6	15	125.2	133.2	17	-0.254	0.803	ns
Nest/Pot.Nest Tree DBH (cm)	216.1	94.6	15	165.7	47.1	17	-1.859	0.084	**as**
Nest/Pot.Nest Tree Height (m)	54.4	9.9	12	51.4	14.2	17	-0.924	0.375	ns
Crown area (sq.m)	125.2	61.8	12	105.1	58.9	17	-1.930	0.080	**as**
Number of Canopy Layers	2.5	0.5	11	2.1	0.3	17	-2.324	0.043	**sig**
Canopy lift (m)	22.5	6.3	11	18.8	7.2	17	-1.323	0.215	ns
Index of platforms	4.6	5.4	11	5.1	3.5	17	0.182	0.859	ns
Dom Canopy cover (%)	27.7	11.4	10	26.8	9.9	17	-0.576	0.579	ns
Midstory Canopy cover (%)	53.1	16.6	10	36.6	13.4	17	-3.578	0.006	**sig**
Total Canopy Cover (%)	71.9	9.5	10	56.1	11.8	17	-4.746	0.001	**sig**
Vegetation data									
DBH by class: No./ 25 m plot									
1.small: 10-50 DBH (cm)	73.2	36.9	15	73.6	32.5	17	0.158	0.877	ns
2.medium: 50-90 DBH (cm)	7.4	3.3	15	12.0	8.6	17	2.294	0.038	**sig**
3.large: 90-120 DBH (cm)	2.4	1.0	15	3.5	2.2	17	0.706	0.492	ns
4.very large: >120 DBH (cm)	6.1	2.0	15	5.1	3.3	17	-0.921	0.373	ns
DBH by class: Basal area/ha (sq.m/ha)									
1.small: 10-50 DBH (cm)	3.6	1.7	15	3.9	1.8	17	0.866	0.401	ns
2.medium: 50-90 DBH (cm)	2.5	1.2	15	4.2	3.1	17	2.330	0.035	**sig**
3.large: 90-120 DBH (cm)	2.0	0.8	15	2.9	1.9	17	0.765	0.457	ns
4.very large: >120 DBH (cm)	17.3	8.4	15	11.6	9.5	17	-1.466	0.165	ns
Species: Basal area/ha									
Redwood –Small	0.82	0.81	15	1.09	1.31	17	0.597	0.560	ns
Redwood – Medium	1.55	1.08	15	2.37	2.87	17	1.350	0.198	ns
Redwood – Large	1.74	0.74	15	2.02	1.51	17	-0.435	0.670	ns
Redwood - Very Large	13.6	9.91	15	9.54	7.34	17	-2.167	0.048	**sig**
Doug fir – Small	0.00	0.00	15	0.46	0.45	17	0.523	0.609	ns
Doug fir – Medium	0.85	0.41	15	1.23	1.18	17	1.709	0.110	ns
Doug fir – Large	0.68	0.02	15	1.77	1.20	17	2.335	0.035	**sig**
Doug fir - Very Large	4.05	2.08	15	6.01	4.62	17	0.763	0.458	ns
Tan Oak – Small	2.36	1.77	15	1.83	0.96	17	-1.095	0.292	ns
Tan Oak – Medium	1.11	1.03	15	1.10	0.60	17	-0.064	0.950	ns

Table 1 General site and vegetation data statistics
DBH and species basal area comparisons were carried out on log transformed data (log basal area + 1)

Nine of the nest sites were on the bottom-third of the slope and the remaining six of the nest sites were on the middle-third of the slope. This differed significantly (chi-square p-value = 0.037) from the random sites, which were evenly distributed on the bottom-third (n=6), middle-third (n=5) and top-third of the slope (n=6). The chi-square p-value for nest and random sites falling on the bottom two-thirds of the slope versus those on the top-third of the slope was 0.0107.

Means and standard deviations for the five random dominant and five random midstory trees for nest and random sites are shown in Table 3. Paired t-tests were performed; no significant results were found.

	Nest mean	Nest StdDev	Nest N	Random mean	Random StdDev	RandomN	Paired t-test T-ratio	p-value	Sig?
Dominant trees									
Ave. Height (m)	45.3	9.5	12	41.4	12.6	12	-0.870	0.403	ns
Ave. Canopy Area (sq m)	75.4	25.6	12	74.2	26.1	12	-0.165	0.872	ns
Ave. Canopy Lift (m)	17.8	4.7	12	17.4	5.7	12	-0.236	0.818	ns
Ave. DBH (cm)	125.3	29.3	12	105.4	41	12	-1.318	0.214	ns
Midstory trees									
Ave. Height (m)	16.8	3.9	12	17	3.5	12	0.117	0.909	ns
Ave. Canopy Area (sq m)	27.5	6.7	12	27.6	8.6	12	0.155	0.988	ns
Ave. Canopy Lift (m)	6.8	29.3	12	7.4	2	12	0.554	0.590	ns
Ave. DBH (cm)	25.9	6	12	28.2	6.1	12	1.108	0.291	ns

Table 3 Random tree summary statistics

Discussion

This study demonstrates that Marbled Murrelets primarily use old-growth, mixed redwood-Douglas fir forests for nesting in the Santa Cruz Mountains, although murrelets were also found nesting in residual stands. It is important to recognize that all four of the entered stands that were selectively harvested contained a significant component of residual old-growth (average of 4.7 very large trees (>120 cm DBH) per 25-m radius plot), and that all nests were located in old-growth trees.

This study also demonstrates that a high percentage (65 %) of Marbled Murrelets in central California nest near the campground areas in Big Basin Redwood State. These areas have high concentrations of nest predators such as Common Ravens and Steller's Jays. The high degree of overlap between murrelet nesting and predator concentrations does not bode well for murrelet population viability in the region because nest predation is apparently a significantly limiting factor in the region (Peery et al. in press).

Marbled Murrelets demonstrated clear preferences for certain nest tree and stand characteristics, even within old-growth forests. Murrelets selected stands that were significantly closer to streams and which were lower on slope (all nests were on the lower two-thirds of the slope). The nearness of nests to streams may indicate that the birds use waterways to navigate from the ocean inland to the coastal old-growth forests stands. Murrelets also select for stands with higher total and midstory canopy cover and more canopy layers, which may indicate selection for sites with perceived enhanced protection from predation.

Murrelets selected stands that had fewer medium sized trees (50-90 cm DBH cm). It is not clear why having fewer medium trees would be a selected characteristic although it is possible that having fewer trees in this size class may increase the number of canopy layers, which murrelet's select for, by allowing more distinct separation between midstory and overstory canopy layers. We also found that nest sites tend to have larger basal area per hectare of very large trees (>120 cm DBH) including significantly higher basal area per ha of redwood trees with >120 cm DBH. Random sites on the other hand have more large (90-120 cm DBH) Douglas fir trees.

Even with selection of stands dominated by old-growth redwood, murrelets tended to select Doug fir over redwood for their nest trees. Of the redwoods that were used as nest trees, almost half (43%) had nests in broken tops. Nest trees also tended to have larger cm DBH and greater crown area.

The tendency for murrelets to nest in Douglas firs even in redwood dominated plots is likely because Douglas fir trees tend to have more large limbs that are suitable for nesting than redwoods for a given age tree. Even large redwoods may have relatively few platforms in which case the tree would not be suitable for a murrelet nest. If there is no suitable place to nest, including large platforms or other tree irregularities such as broken tops or epicormic branches, then the stand structure and location become irrelevant. In an 1996-1998 study, Hamer and Meekins examined selection at nest limb (platform), nest tree and nest stand scales and found that the number and quality of platforms were much more important in nest selection for murrelets than any stand variables.

We suggest several management guidelines for protecting Marbled Murrelet nesting habitat in the Santa Cruz Mountains based on this study. First of all, we suggest that management plans include protecting and promoting old-growth, redwood dominated stands near streams with a significant midstory canopy. This includes unharvested stands as well as lightly to moderately harvested plots that contain residual old-growth trees. Timber harvesting within such stands should be limited in nature, retain old-growth trees, and seek to conserve as much of the midstory structure as possible. Murrelets may select sites with higher midstory canopy cover as a protection from predators, but further predator protection could also be promoted through predator capture programs. Purchase of non-public old-growth forest as a murrelet habitat conservation measure is also a possibility and has been done in northern California at the Headwaters Reserve (DFG, 2000).

Lastly, we suggest that Marbled Murrelet nesting habitat selection will vary geographically due variation in forest composition and structure as well genetic differences. Nonetheless, we also found that certain habitat features are consistently important throughout most if not all of the murrelet's range. These features include being low on the slope, close to streams (around 100 meters from the nearest stream) and having multiple canopy layers (Hamer and Nelson, 1995; Hamer and Meekins, 1999). The elements of consistency in murrelet habitat throughout the range indicate that research and habitat management efforts in one region lend insight murrelet habitat elsewhere, and I hope that further research on habitat selection or future management plans throughout the range will utilize results of this study.

Acknowledgements

Zach Peery has been an integral part of the project from conception, project design, logistics and analysis. Steve Beissinger has also been very helpful through project advice, setting up timelines and through funding. The other project collaborators, Steve Singer, Esther Burkett and David Suddjian, have allowed the project to be as comprehensive as it is through taking time to show me sites or giving me site data that they worked hard on to collect. Also, I would like to acknowledge the dedicated field crewmembers from the summer and fall semester that include Jay McEntee, Krista Cramer, Chris Neufeld, Maria Fan, Jackie Erbe and Jack Tseng.

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