Determining if Managed Wildfires and Prescribed Fires Conserve Critical Habitat Structure for Fishers in the Southern Sierra Nevada

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Executive Summary

This is the final report for Park Service agreement P14AC01558, "Determining if Managed Wildfires and Prescribed Fires Conserve Critical Habitat Structure for Fishers in the Southern Sierra Nevada". This study focused on using lidar to assess pacific fisher (*Pekania pennanti*) habitat in the Kings River Fisher Project study area of the Sierra National Forest.

The University of Washington's study was one of two concurrent studies funded by the National Park Service to use airborne lidar data to study fisher use of habitat in the Kings River Fisher Project area. The other study was led by Dr. James Lutz at Utah State University. Lutz' team also to date has failed to find strong relationships between lidar-measured forest structure and used fisher habitat in this study area. Dr. Lutz will take the lead in writing a peer-reviewed paper that publishes the methods and results of both groups' work.

Except for a weak to modest preference for sites with more canopy area in trees >48 m tall, we were unable to find a distinctive habitat feature used by fishers in the study area. This contrasts with the recently completed study of California spotted owl habitat (which also included our fisher study area) where there was a clear preference for nesting sites with substantial numbers of trees >32 m and especially >48 m in height (North et al. 2017). We have developed three possible explanations for the lack of distinctive habitat structures in this study area:

- Fishers may select denning and resting sites based on features that are not detectable using airborne lidar data.
- Fishers make use of a wider range of forest structures than has been suggested by previous field-based studies.
- The characteristics of the forests in our Dinkey study area make large portions of the area suitable habitat.

This project aimed to use lidar remote sensing data to quantitatively characterize fisher habitat in the Kings River Fisher Project study area in the Sierra National Forest (partially covered by Dinkey project area lidar flown for the Dinkey Collaborative Forest Landscape Restoration Project). We then intended to use that characterization to examine the portions of Yosemite with lidar to identify potential fisher habitat, and to assess whether or how fire created suitable habitat. However, because we were unable to identify distinct fisher habitat within the Kings River Fisher Project study area, we were unable to identify locations within Yosemite National Park that would be high priority areas for conservation nor relate those to fire history.

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Introduction

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The University of Washington's study was one of two concurrent studies funded by the National Park Service to use airborne lidar data to study fisher use of habitat in the Kings River Fisher Project area. The other study was led by Dr. James Lutz at Utah State University. They also have failed to find strong relationships between lidar-measured forest structure and used fisher habitat in this study area. Dr. Lutz will take the lead in writing a peer-reviewed paper that publishes the methods and results of both groups' work.

The following introduction is adapted from the introduction of the original agreement, to provide context for the study. For more information on previous work discussing fisher habitat in the Sierra Nevada, see other publications, such as Spencer et al. 2015, Green et al. 2017, Purcell et al. 2009, Zielinski et al. 2004, Zielinski et al. 2013, and Zhao et al. 2012.

The fisher (*Pekania pennanti*) is a rare, reclusive forest carnivore that occupies structurally complex patches of mixed conifer forests in the southern Sierra Nevada, largely on federal land. In these forest types, prescribed fire and wildfires typically "thin from below," removing accumulated litter and duff, small to large diameter woody debris, and stems of pole-sized trees. These fire effects may remove the important elements of fisher habitat at resting and den sites or may create elements of fisher habitat such as cavities. However, within fire perimeters, considerable area may remain unburned, potentially providing local refuge for fishers. Therefore, it is important to determine what forest structural elements fishers select and whether they are retained in forests that are managed with fire, and further research the relationship between fisher occupancy and different fire management strategies.

The West Coast Distinct Population segment of fishers was petitioned for listing under the federal Endangered Species Act four times, but has been declined all four times, most recently in 2016. Recent mitochondrial DNA evidence suggests that the northern and southern California populations diverged approximately 16,700 years ago; thus, the conservation priority for the southern population is important. Although the west coast fisher population was not listed, researchers are still concerned about the Southern Sierra Nevada population and continue efforts to understand the distribution of this rare mammal.

Previous research developed a generalized additive model of fisher occupancy based on presence/absence data that predicts high probability of occurrence of fishers in portions of Yosemite, Sequoia and Kings Canyon National Parks (SEKI), and the National Forests of the Southern Sierra Nevada. Recent investigations of fishers in Yosemite found that they are distributed in low abundance throughout a narrow corridor of habitat in the southern portion of the park that borders the Sierra National Forest, but have also recently been detected north of the Merced River (a single male was found in 2017). Historic sighting data, including records from University of California at Berkeley's Museum of Vertebrate Zoology, indicate that fishers did inhabit this area in the early 1900s (Grinnell 1937). Population modeling demonstrated that a modest increase in fisher mortality (10-20%) could prevent fisher from expanding northward into historically occupied areas, even in the absence of possible geographic dispersal barriers, such as the Merced River drainage (i.e., Yosemite Valley) and Wawona Road (although at least one fisher has been found north of the Merced river). Because Wawona Road (Highway 41) bisects a narrow corridor of highly suitable fisher habitat, vehicle mortalities will continue to be a threat to this portion of the population. Incidentally, eight of the 10 known road-kill fisher mortalities in Yosemite (from 1993-2012) have occurred during the spring fisher denning season (March 1 – June 30) when culverts are filled with snow melt water that might force them to cross above rather than below the road.

Resting and denning structures are the most important habitat element for fishers at localized spatial scales. Fisher resting sites are associated with high canopy cover, large trees and snags, and structurally complex forest patches near water (Purcell 2009, Zielinksi 2004). Denning structures are usually the largest diameter tree or snag located within densely forested patches with a high proportion of black oaks (*Quercus kelloggii*). At larger spatial scales, fishers are positively associated with older, structurally complex forests surrounded by a diverse matrix of forest structural types and conditions.

Yosemite National Park has managed wildfires and prescribed fires for four decades. However, fishers are absent in all but the southern section of the park (including Glacier Point Road and Henness Ridge), near Sierra National Forest, where the USFS has been aggressively suppressing fires over the same period of time. Extending fisher habitat into Yosemite is a goal of fisher conservation and determining whether wildfires and prescribed fires conserve their habitat is critical to the future of the population.

This project aimed to use lidar remote sensing data to quantitatively characterize fisher habitat in the Kings River Fisher Project study area in the Sierra National Forest (partially covered by Dinkey project area lidar flown for the Dinkey Collaborative Forest Landscape Restoration Project). We then intended to use that characterization to examine the portions of Yosemite with lidar to identify potential fisher habitat, and to assess whether or how fire created suitable habitat. However, because we were unable to identify distinct fisher habitat within the Kings River Fisher Project study area, we were unable to identify locations within Yosemite National Park that would be high priority areas for conservation nor relate those to fire history.

Methods

The following methods were developed through consultation and discussion with Sarah Sawyer (Forest Service), Rebecca Green (UC Davis), Kathryn Purcell (Forest Service), Eric McGregor (Forest Service), Craig Thompson (Forest Service), and others.

Fisher Field Data Collection

We were supplied fisher field data collected between 2007 and 2015 in the Kings River Fisher Project area (Green et al. 2017) (Figure 1). During that period, fishers were caught in the fall and winter using baited traps, and radio collars were attached. Field teams collected telemetry data from the radio collars to locate fishers year-round, with special emphasis on females during the denning season (mid-March through June). The authors of the study are confident they identified nearly every den used by a radio collared female (Green et al. 2017). However, they only identified a subset of rest structures, and these were collected opportunistically (Green et al. 2017). Sites were classified as natal dens, maternal dens, or rest structures. Natal dens are where fishers give birth. As the kits develop, the female moves them to a series of 1 to 6 maternal dens. We only included natal dens and the first maternal den used each year to avoid spatial autocorrelation between the maternal dens and to avoid problems caused by different fishers using different numbers of dens.

Lidar Data

We used two separate Lidar acquisitions in the Dinkey Project Area in Sierra National Forest, flown in 2010 and 2012. The 2010 acquisition was collected by Watershed Sciences, Inc. (Corvallis, OR) using a dual-mounted Leica ALS50 Phase II instrument on 12-19 October 2010, with an average pulse density of 10.9 pulses per square meter and up to four returns per pulse. Using the TerraScan 10.009 and TerraModeler 10.006 software packages (Terrasolid, Helsinki, Finland), Watershed Sciences used the lidar data to create the 1 m resolution digital terrain model (DTM). The 2012 acquisition was also collected by Watershed Sciences, using a Leica ALS60 instrument on 14-17 October 2012, with an average pulse density of 14.6 pulses per square meter and up to four returns per pulse. The 1 m resolution DTM was created by Watershed Sciences using TerraScan and TerraModeler 12.004 and 12.002, respectively. The two acquisitions have 25171 hectares of overlap; in this overlapping area, we used the 2012 acquisition.

We processed the lidar return point cloud data to generate metrics relevant to the measurement of forest canopies using the US Forest Service's FUSION software package, version 3.60 (http://forsys.cfr.washington.edu/fusion/fusionlatest.html) (McGaughey, 2016). In particular, we used FUSION's gridmetrics tool to create 30m resolution metrics of commonly used lidar metrics, and its treeseg tool to identify tree approximate objects (TAOs). We divided the TAOs into height bands of 2-16m, 16-32m, 32-48m, and >48m, and calculated the percentage of each 30m pixel that fell in TAOs in each height band.

In addition, to identify potential fisher habitat in another landscape, we used a lidar acquisition in Yosemite National Park. It was collected by Watershed Sciences using a dual-mounted Leica ALS50 Phase II instrument on 21 and 22 July 2010 with an average pulse density of 10.9 pulses per square meter and up to four returns per pulse. The 1 m resolution DTM was created using TerraScan 10.009 and TerraModeler 10.004. We processed it using FUSION in the same manner as the Dinkey acquisitions.

Although the majority of fisher sites were identified in years other than when the lidar was flown, there were no major disturbances in the forest during the entire period of the field fisher study, and we believe the lidar corresponds well to the forest for the entire period of the field study.

Study Area Selection

In order to exclude areas of the acquisitions that are of inappropriate climate or forest type for fishers, we constructed a smaller bounding mask around the fisher sites. We did this in ArcGIS by buffering the fisher sites by 2km, and then debuffering the resulting polygon by 2km. We masked the Lidar data by that shape for all analyses (Figure 1).

Statistical Analysis

This study was done in two phases. During the first phase, we considered a wide variety of lidar metrics produced by FUSION or by our own analysis tools, as well as topographic metrics also produced by FUSION, and climatic variables produced by PRISM (appendix A). We narrowed these metrics down using a combination of comparison with other lidar habitat studies (North 2017), discussions with fisher biologists, and knowledge of which metrics best characterize forest structure (Kane 2010, Kane 2013, Shoot in preparation). In the end, we selected eight metrics for detailed analysis and to discuss in this report, listed in table 1. During this phase, we also tried multiple spatial resolutions, including 5 m (close to the minimum at which lidar metrics can be usefully calculated), and 30 m (a common resolution used in remote sensing, which helps mask inaccuracies in the telemetry of fisher locations). We settled on the 30 m resolution.

Our primary statistical goal was to quantify how similar or distinct fisher areas were to the general study area. The main method we used for this was the niche overlap metric. This metric compares the similarity of two distributions and produces a value between 0 and 1, with 1 being perfect similarity and 0 being perfect dissimilarity. On continuous variables (which all of our lidar metrics are), the niche overlap analysis is done by calculating a kernel density estimate (we used R’s density function), taking the minimum density of the two distributions, and performing a trapezoidal approximation of the integral of that distribution. Conceptually, this is the area of the overlap if you plot the two density curves (Figure 2).

We also calculated p-values for all niche overlap measures as follows. We selected several random points in the study area equal to the number of fisher sites under consideration, and calculated niche overlap using those random points. We repeated this process 999 times, for 1000 total niche overlap values including the one using the true fisher sites. The p-value was the proportion of those values that were less than the true niche overlap value. In other words, in order for a niche overlap value to be statistically significant, the fisher sites must be more distinct from the entire study area more than 95% of all random selections of an equal number of points.

We first calculated niche overlap between the actual locations of fisher sites and the entire study area. We extracted the values of each metric from the pixel containing each fisher site, and compared each of natal dens, maternal dens, and rest structures to the overall study area. We made no effort to correct for inaccuracies in the GPS coordinates of fisher sites. We also calculated niche overlap between the study area and areas of various distance from fisher sites. We identified these areas by selecting all pixels whose centers fall within 0-30 meters of an appropriate fisher site, within 30-60 meters, and so on. Finally, we calculated the 90th percentile distance that fishers move between successive dens, and calculated niche overlap between the study area and areas within that distance of fisher dens.

Finally, we defined forest structure classes on the entirety of the Dinkey and Yosemite lidar acquisitions, in the hopes that fishers would prefer some structures over others, which could then be extrapolated to Yosemite. We defined them using five metrics identified in previous lidar habitat work (North 2017). We used a random sample of 30,000 grid cells between the two areas (5% of the total area). Because of colinearity between the metrics, we used the axes of variation from a principal component analysis (PCA) to define the structure classes. We used hierarchical clustering to classify the study area at a 30x30 m (0.09 ha) resolution using the PCA axes of variation (Legendre and Legendre, 1998). We used weighted Euclidean distances (weighted by the importance of each component) and Ward's linkage method within the ''hclust'' function of the R statistical package (release 2.6.1) (R Development Core Team, 2007) for this analysis. We used the classified random sample of 10,000 grid cells as training data to classify the vertical structure of all grid cells within the study area using the Random Forest algorithm (Breiman, 2001) in the randomForest R statistical package (Liaw 2002). We then examined which structure classes are used by fishers at a greater or lesser rate than the presence of that class in the study area.

Results and Discussion

Comparison between Fisher Sites and Study Area

In testing for statistically significant differences between the overall landscape and natal dens, maternal dens, and rest sites, we found that the habitat used by fishers was indistinguishable from the available habitat in most metrics. We reach this conclusion based on several lines of evidence. First, we calculated the niche overlap between these areas and tested whether the overlap was statistically significant (Table 2, Figure 3). While most of the comparisons showed a statistically significant difference from the overall study area, few of them showed an ecologically meaningful difference. We defined a meaningful distinction as a niche overlap value of 0.8 or lower, which is the point when the differences appear visually notable when graphed.

The two exceptions to this this overall result are January minimum temperature and canopy area >48 m. Most of the fisher locations were reported for lower elevations where it would be easier for fishers to maintain their body temperature. These are also areas where snow pack would be non-existent to minimal and the fishers would be able to traverse their range without punching through the snow. Most fisher sites found at higher elevations were rest sites, and these may include portions of the larger home ranges used by males (Rebecca Green, personal communication). It is also possible that some of the preference for lower elevations represent a bias in the radio collaring process, rather than in the true distribution of fishers (Rebecca Green, personal communication). A study area that was focused on the area used for denning would likely have shown much less distinction in January temperature between dens and the reduced study area.

For forest structure, the only meaningful, significant difference between used habitat and available habitat was canopy area >48 m, with fishers selecting for sites with greater area in that stratum. This distinction held for natal dens, maternal dens, and rest sites. The niche overlap is not statistically significant for natal dens, though it is suggestive ($p<0.1$). The statistical insignificance results from the zero-inflated nature of this variable (that is, there are many more pixels with a value of zero than you would expect from a smooth curve). Relatively small differences in the degree of zero inflation will result in relatively large distinctions in the resulting density curves, which drives niche overlap values down. The value of 0.62 present in table 2 is on the low end of possible random variation.

The canopy area for >48 m TAOs surround dens remains distinct out to approximately 400 m suggesting that fishers are seeking patches with numerous very tall trees (Figure 4). We speculate that the distinctiveness of >48 m TAO density might have been greater if these patches were more prevalent within the appropriate temperature range for denning sites. As it is, some percentage of fishers may be forced into habitat without >48 m tree cover. The increased selection for >48 m tall trees in maternal dens might also indicate greater reproductive success in areas with tall trees, under the assumption that natal dens with no corresponding maternal dens indicate stillbirths, early infant mortality, or some other problem with the kits. Future field work might investigate directly whether fisher dens in areas with tall trees result in better reproductive success.

We were surprised that canopy cover in used habitat was not meaningfully distinct from overall habitat because field-based studies have frequently cited high canopy cover as a distinguishing feature of used fisher habitat (Zielinsky 2004, Purcell 2009, Aubry 2013). One explanation may be that canopy cover is difficult to measure consistently over large areas in the field but is easily measured with lidar data. It may also be that fishers do not select for canopy cover once a threshold value is crossed, and the Kings River Fisher Project study area generally has high canopy cover values. Alternatively, fishers may be able to accept a wide range of canopy cover, but there is little variation in canopy cover in the Kings River Fisher Project study area to choose from compared to the variability present over the Sierra Nevadas. Compared to the entire Dinkey lidar acquisition, and other lidar acquisitions in the Sierra Nevada (Figure 5), the study area is missing areas with high canopy cover but shorter (<20 m) trees (Figure 6 and 7). It also has fewer areas of low overall canopy cover compared to other lidar acquisitions.

We also hypothesized that female fishers may select their den sites based on the surrounding forest, to facilitate finding their next den site easily. The 90th percentile of distances between successive dens in the data set was 750 meters, so we defined the 750 m circle around a den as the den area and tested whether these den areas were distinct from the overall landscape

(Figure 8). Unfortunately, with the exception of January temperature, none of the metrics showed a strong (niche overlap <0.8) distinction between den areas and the overall study area. This indicates that if female fishers select for forest types that contain multiple potential den sites, they do so in a manner that we were unable to detect with lidar or that was statistically undetectable due to the large radius used. Future work might consider the forest structure of the den cluster (the area containing all dens used by a female in a single year) to attempt to detect this.

Structure Classes

Using hierarchical clustering, we identified eight structure classes across the two Lidar acquisitions. The classes were identified at a 30 x 30 m scale, using a 90 x 90 m moving window to assess the structure at that location. Because of the nature of hierarchical clustering, it is impossible to produce explicit rules for assigning pixels to one class or another, but it is possible to characterize the structures associated with each class (Figure 9). The classes are ordered by median canopy area >48m (so class 2 has more area in that stratum than class 1, and so on). Because we defined the structure classes using a sample of the entirety of the Dinkey and Yosemite lidar acquisitions, several classes have very little area in the either the Dinkey study area or in the Yosemite lidar data area (Figures 10 and 11).

As figure 7 shows, there is a noticeable difference in which the use of structure classes for natal dens, maternal dens, and rest structures occurs (Figure 12). Unfortunately, due to the relatively small number of dens in the dataset, none of the pairwise comparisons using natal dens or maternal dens are statistically significant using a niche overlap permutation test (though the difference between rest structures and the overall landscape was statistically significant, due to the larger sample size). Compared to the entire study area, natal dens are overrepresented in classes 3 and 8. Class 3 is dominated by canopy area 16-32m and class 8 is dominated by canopy area 32-48m and >48m. Seemingly contradicting that result, natal dens are underrepresented in class 6 (which is dominated by 16-32m and 32-48m TAOs). We hypothesize that these structure classes correlate with forest attributes that we cannot directly measure with lidar. For instance, the literature suggests fishers often rest in area with oak trees (Zielinski 2004). We cannot directly measure where oak trees are, but the confluence of multiple different forest attributes may indirectly suggest where they are; this may be what our structure classes are truly representing. Alternatively, because these results are not statistically significant, these results may not represent any true fisher preferences.

Maternal dens mostly have similar distributions to the overall landscape, but are underrepresented in class 6 (16-32m and 32-48m) and overrepresented in class 8 (32-48m and >48m). Notably, maternal dens are present in class 3 (16-32m) in roughly the same percentage as the study area, while natal dens were overrepresented in class 3. It’s difficult to know how to interpret the differences between the distributions of natal and maternal dens without a better understanding of what the structure classes represent in the forest and a larger sample size; this is a potential avenue for further study.

Conclusions

Except for a weak to modest preference for sites with more canopy area in trees >48 m tall, we were unable to find a distinctive habitat feature used by fishers in the study area. This contrasts with the recently completed study of California spotted owl habitat (which also included our fisher study area) where there was a clear preference for nesting sites with substantial numbers of trees >32 m and especially >48 m in height (North et al. 2017). We have developed three possible explanations for the lack of distinctive habitat structures in this study area:

1. Fishers may select denning and resting sites based on features that are not detectable using airborne lidar data. For example, field-based studies have found that fishers will select trees and snags which high diameters for denning, which is not directly measurable using lidar. Tree height is correlated with diameter and is measurable, but the height to diameter ratio varies from species to species and snags often have much higher diameters than their heights would indicate, due to broken tops. Alternatively, the 30m scale we used for the lidar analysis may be too large for the structures fishers are selecting. However, if we increased the resolution, we would run the risk of having a mismatch in spatial precision between the lidar and the GPS coordinates of the fisher sites. Future field studies could potentially use higher-precision GPS units in order to correspond more closely with remote sensing data.
2. Fishers make use of a wider range of forest structures than has been suggested by previous field-based studies. This result is suggested by our analysis by forest structure classes that show fishers used classes dominated by modest height trees in similar frequency to their availability within the entire landscape (Figure 16). This result was surprising given that previous field-based work have found a selection for taller trees (although this has not been universally found, e.g. Purcell et al. 2009). Zielinski et al. (2004) developed a model for predicting suitable resting sites in our study area and found that tree size (as measured by diameter at breast height and its standard deviation) and canopy cover were the only significant forest structure predictors. (Slope and especially distance to water were the other two predictors.) It may be in areas without taller trees, fishers are selecting for structures such as oaks or highly decayed snags not distinguishable from lidar data.
3. The characteristics of the forests in our Dinkey study area make large portions of the area suitable habitat. Compared to other national forests used in the North et al. (2017) spotted owl study, the study area mostly consists of forest with a relatively narrow band of tree height and canopy cover (Figures 7 8). This is likely due to its history of successful fire exclusion, selective timber harvests, and limited harvesting in the past few decades. This has allowed in-growth to reach substantial heights (often >32 m) and create relatively high canopy cover (>50%).

These explanations for our results are not mutually exclusive and we suspect that all three are important factors. Zielenski and Gray (2018) for example note that, “Fishers are among a wide variety of species of wildlife that use cavities or chambers in live and dead trees as daily refugia and for reproduction. These resting and denning (reproduction) structures are most typically the largest diameter standing live trees, snags, or logs (conifers and hardwoods) available yet other woody features, such as platforms of branches or mistletoe in tree canopies, can constitute a significant minority of resting locations." In other words, fishers select for features not readily detectable by airborne lidar and may be present in many stand structures (snags, hardwoods, logs, and platforms of branches or mistletoe).

We reviewed a previous version of this final report with Dr. William Zielinski (retired) with the USDA Forest Service's Pacific Southwest Research Station. He noted that if we had a larger study area with a greater diversity of forest structures and substantial areas with where fishers were not found, we likely would have been able to identify more distinct used habitat characteristics. Unfortunately, the intersection of the Kings River fisher study area and the Dinkey area lidar acquisition have a fairly narrow range of forest structures compared to the overall Sierra Nevada landscape. There were areas within this intersection where there were additional forest structures but no reported fisher use in the data set we were provided. However, it was not clear whether the intensity of field observations for this area was equivalent to the area with reported sightings. We therefore did not use this area in our analysis.

Dr. Zielinski had an additional observation on how the scale of habitat selection by fishers may have affected our results, and we quote it in full: "The strongest habitat selection for fishers and other carnivores seems to occur at the smallest resolution scales (the microsite, i.e. the resting site) and at the largest scales, (the landscape; i.e. the region). We generally find selection most weak at the intermediate, within- home range, scale. The strength of selection is conceptually viewed as a U-shaped curve relating scale on y axis and strength of selection on the x axis. Thus, an animal selects strongly from variation in the landscape when they are first selecting a home range. Once they have found a home range area in which to live, they are likely to demonstrate rather weak selection for stands within the home range. Then the strength of selection seems to ramp up when animals are selecting important microsites (resting) from within-stands."

Future work could attempt to resolve these issues in several ways. Scat dog data or data on the location of traps that caught fishers could be used to produce a better, broader outline of fisher habitat use within the Dinkey lidar area. A broader study area may heighten the statistical distinction between dens and the overall landscape in forest structures that fishers truly select for or against. Using data on where fishers have actually been observed would allow us to draw this boundary without including areas that are inappropriate as fisher habitat with no management implications (e.g. areas that are too hot or too cold). Other work could use vegetation maps to attempt to correlate structure classes with forest attributes that are difficult to detect directly with lidar (such as the presence of black oaks). Finally, rather than considering natal and maternal dens separately (which was done to avoid spatial autocorrelation), we could consider all dens used by a female within a single year as a single denning area and use the denning area as our basic unit of analysis. This may be able to tease out patterns that are only present at a larger scale than the actual denning site.

The characteristics of the forests in our study area make transferring conclusions to other areas problematic. As noted, our study area is dominated by forests with taller trees and greater canopy cover than often found elsewhere. The complete area of the Dinkey lidar acquisition (which is a superset of our study area) does have stands with shorter trees and lower canopy cover, but these lie outside the apparent climatic zone used by fishers in the area (either too low or too high in elevation). It is unknown whether fishers would select forests with shorter trees and lower canopy cover (as found in the Eldorado and Tahoe spotted owl study areas) or with taller trees but lower canopy cover (as found in the lidar acquisition in Yosemite National Park). In fact, the area that is most like our study area in terms of forest structure is the lidar acquisition area in Sequoia National Park, although many of the trees in the latter are substantially taller than those in our study area.

One goal of this study was to predict which areas in the Yosemite lidar (which is north of the Merced River) might be suitable habitat for fishers based on the habitat used by fishers in our study area. Because fishers in our study area use all types of available habitat, the best we can do is to say that areas in Yosemite with taller trees (most of the area under the lidar flight) and canopy cover >50% (roughly half the area) would likely be suitable. We simply have no data to determine whether fishers would use the large areas in Yosemite that have tall trees but lower canopy cover (which are a mixture of mixed conifer that have had low and moderate severity fires and areas outside the fisher climate zone in higher elevation red fir forests).

A number of field studies have noted that fishers prefer to use habitat with greater canopy cover. We recommend caution in using our results to reach the same conclusion. First, taller trees have larger canopies, which directly leads to greater canopy cover. Second, there have not been fires in the Dinkey study area that would produce stands with taller trees but lower canopy cover resulting from fire mortality. (The recent high levels of mortality from the multi-year drought in the study area may, once the resulting snags fall, produce stand structures like those produced by low- and moderate-severity fire in Yosemite.) All that can be said with confidence is that overwhelming majority of habitat available to fishers within their climate zone in the Dinkey study area have higher canopy cover than found across substantial areas of other Sierra Nevada landscapes. If fishers are introduced north of the Merced river in Yosemite National Park, it would be interesting to see if they used the lower-cover stands created by the restored fire regime there, as they are south of the river.

Based on our results, our firmest recommendation is that managers seek to preserve trees >48m, which is a goal already supported by field-based research. As Zielinksi et al. (2004) stated, "Because large trees had such a prominent influence on resting-site selection in each of the top models, managers can have direct effects on the resting habitat of fishers by favoring the retention and recruitment of trees that achieve the largest sizes possible. These are the trees that host most resting structures, and also characterize the vegetation near the structure. We discovered infrequent reuse of the same resting structure, which indicates that fishers use— and may require— many large trees, snags, and logs distributed with- in home ranges. The resting trees, and in many cases, the trees in their immediate vicinity were among the largest standing live and dead trees within fisher home ranges. The objective of recruiting and retaining large trees should not overshadow, however, the goal of encouraging structural diversity; standard deviation of DBH was included in the Sierra model. This observation suggests that developing stands that include variation in the size of trees may be beneficial."

Tables and Figures

Metric Name	Units	Source	Description
Canopy Area 2-16m	%	Tree approximate objects derived from Lidar canopy surface model	Percentage of pixel belonging to tree approximate objects between 2 and 16 meters tall
Canopy Area 16-32m	%	Tree approximate objects derived from Lidar canopy surface model	Percentage of pixel belonging to tree approximate objects between 16 and 32 meters tall
Canopy Area 32-48m	%	Tree approximate objects derived from Lidar canopy surface model	Percentage of pixel belonging to tree approximate objects between 32 and 48 meters tall
Canopy Area >48m	%	Tree approximate objects derived from Lidar canopy surface model	Percentage of pixel belonging to tree approximate objects greater than 48 meters tall
Cover >2m	%	Lidar point cloud	Percentage of Lidar returns greater than 2m above the ground. Roughly canopy cover.
Cover 0.5-2m	%	Lidar point cloud	Percentage of Lidar returns lower than 2m above the ground but higher than 0.5m. A proxy for shrub cover (Shoot in preparation)
P95 Height	m	Lidar point cloud	95th percentile of height of Lidar returns. Roughly dominant tree height
January Temperature	C	PRISM climate normals 1981-2010	Minimum temperature in January in an average year from 1981-2010

Table 1. A description of the metrics used to investigate fisher habitat.

	Natal Dens vs Entire Study Area	Maternal Dens vs Entire Study Area	Rest Structures vs Entire Study Area
Canopy Area 2-16m (%)	0.86* (0.81)	0.82* (0.80)	0.93* (0.95)
Canopy Area 16-32m (%)	0.81 (0.86)	0.85 (0.86)	0.92 (0.95)
Canopy Area 32-48m (%)	0.82 (0.84)	0.89* (0.83)	0.89 (0.93)
Canopy Area >48m (%)	**0.62*** (0.61)	**0.59** (0.60)	**0.70** (0.72)
Cover >2m (%)	0.82 (0.84)	**0.78** (0.84)	0.84 (0.94)
Cover 0.5-2m (%)	0.81 (0.85)	**0.79** (0.83)	0.92 (0.94)
P95 Height (m)	0.85 (0.86)	0.89* (0.85)	0.94 (0.95)
January Temperature (C)	**0.75** (0.85)	**0.76** (0.85)	**0.77** (0.93)

Table 2. Niche overlap values between fisher sites and the overall study area. Our sample had 68 natal dens, 59 maternal dens, and 740 rest structures. Values below 0.8 (roughly the threshold for moderate to strong selection) are bolded for readability. Asterisks indicate values that are not statistically significant. Parenthetical values are statistical significance threshold-- roughly, the lowest you would expect the niche overlap to be if fishers were selecting randomly with respect to that metric. The niche overlap value for canopy area >48m is very low but low niche overlap values are normal for metrics with many zeroes in the landscape (i.e., pixels with no TAOs >48m, approximately 53% of the study area). We do not have a way to quantify the magnitude of this effect.

	Natal Den Areas (750m) vs Entire Study Area	Maternal Den Areas (750m) vs Entire Study Area
Canopy Area 2-16m (%)	0.96*	0.97*
Canopy Area 16-32m (%)	0.90	0.89
Canopy Area 32-48m (%)	0.97*	0.96*
Canopy Area >48m (%)	0.97*	0.96*
Cover >2m (%)	0.89	0.89
Cover 0.5-2m (%)	0.91	0.90
P95 Height (m)	0.98*	0.97*
January Temperature (C)	**0.77**	**0.78**

Table 3. Niche overlap of den areas vs the entire study area. Den areas are defined as the 750m circle around the den location. This radius is the 90th percentile of distance fisher mothers traveled between successive dens in our dataset. Values below 0.8 (roughly the boundary between strong and weak patterns) are bolded for readability. Values with asterisks are not statistically significant.

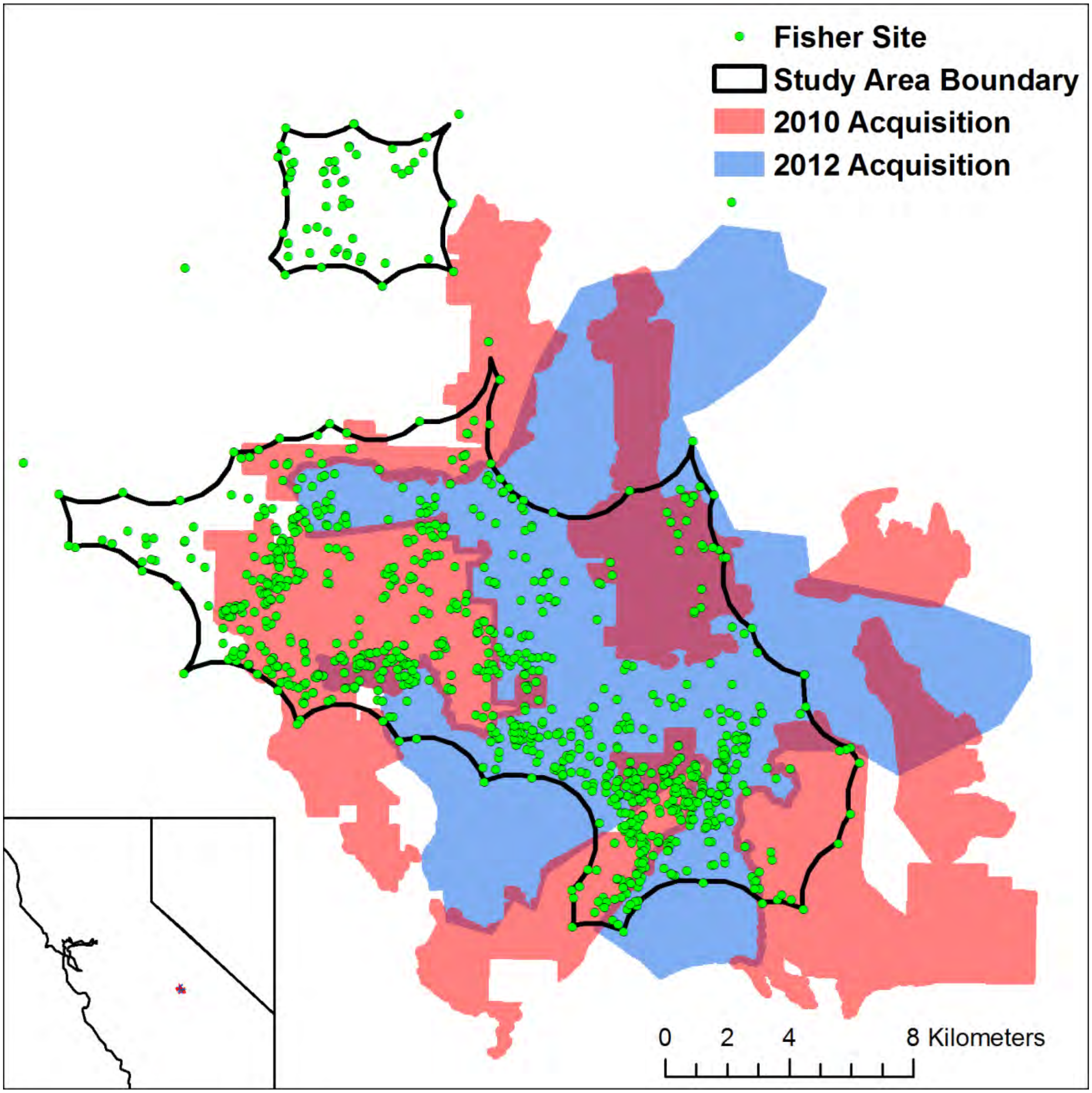

Figure 1. The location in California of the study area (inset), and the relative locations of the two Lidar acquisitions, fisher sites (both dens and rest sites), and study area. The study area is defined to be a bounding polygon around the fisher sites.

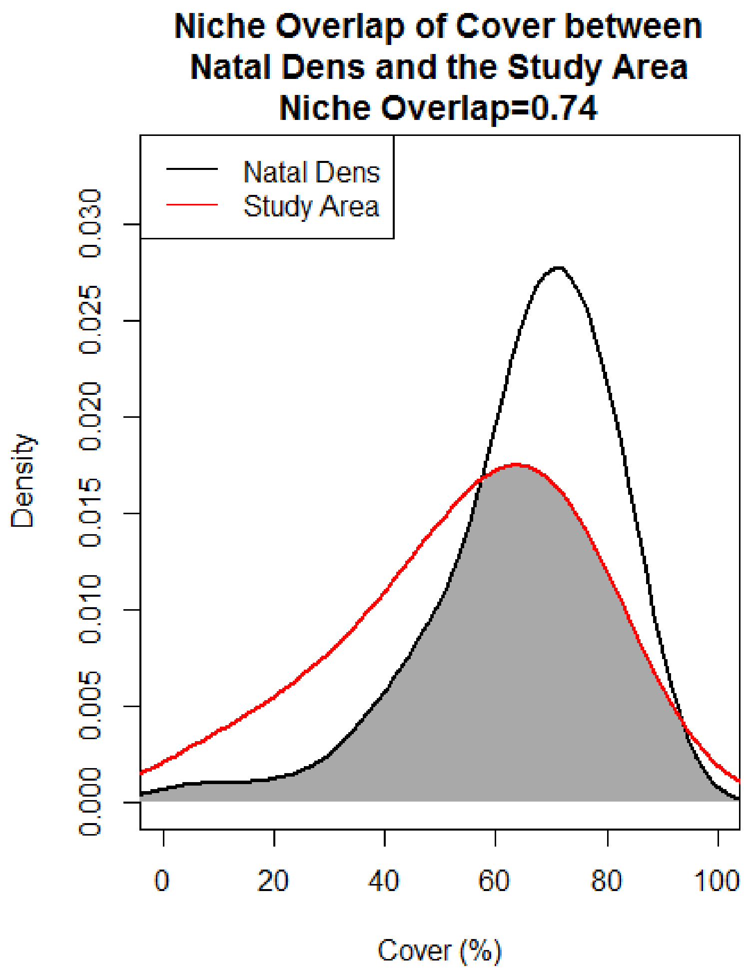

Figure 2. An example of niche overlap. The black and red lines are a kernel density estimate of cover at natal dens and in the entire study area. Kernel density estimation is an algorithm designed to produce smooth distributions for data. The area under each curve is 1. The niche overlap value is the area of the overlapping portion, shaded in gray. The value will be 0 if the two curves don't overlap at all, and will be 1 if they are the same. Lower values indicate a greater degree of dissimilarity.

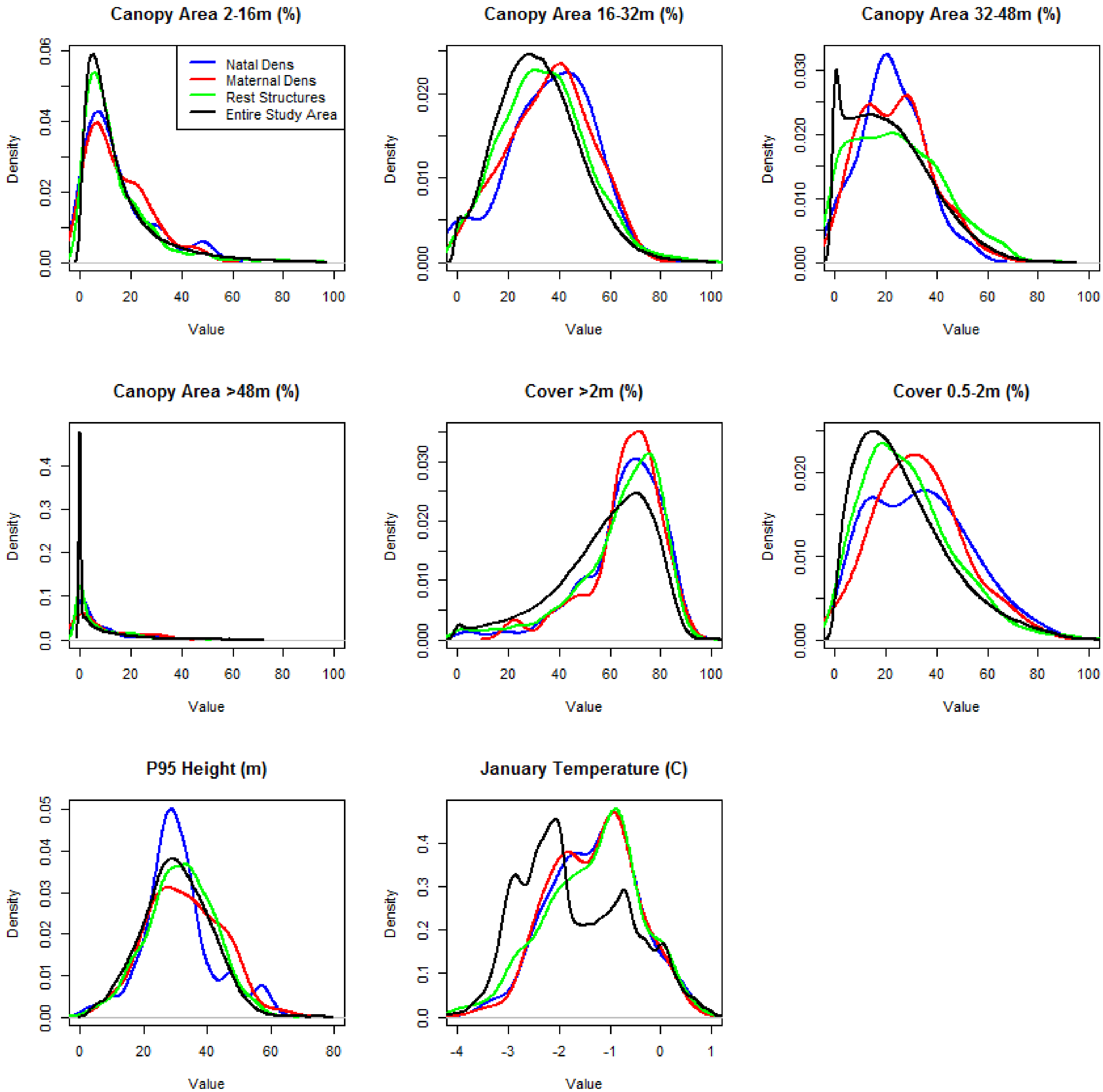

Figure 3. Density curves for selected metrics at natal dens, maternal dens, rest structures, and the entire study area. Niche overlap values are given in Table 2. The distribution for the entire study area is based on a raster with 30m pixels; fisher sites are assigned the values of the pixel they fall in.

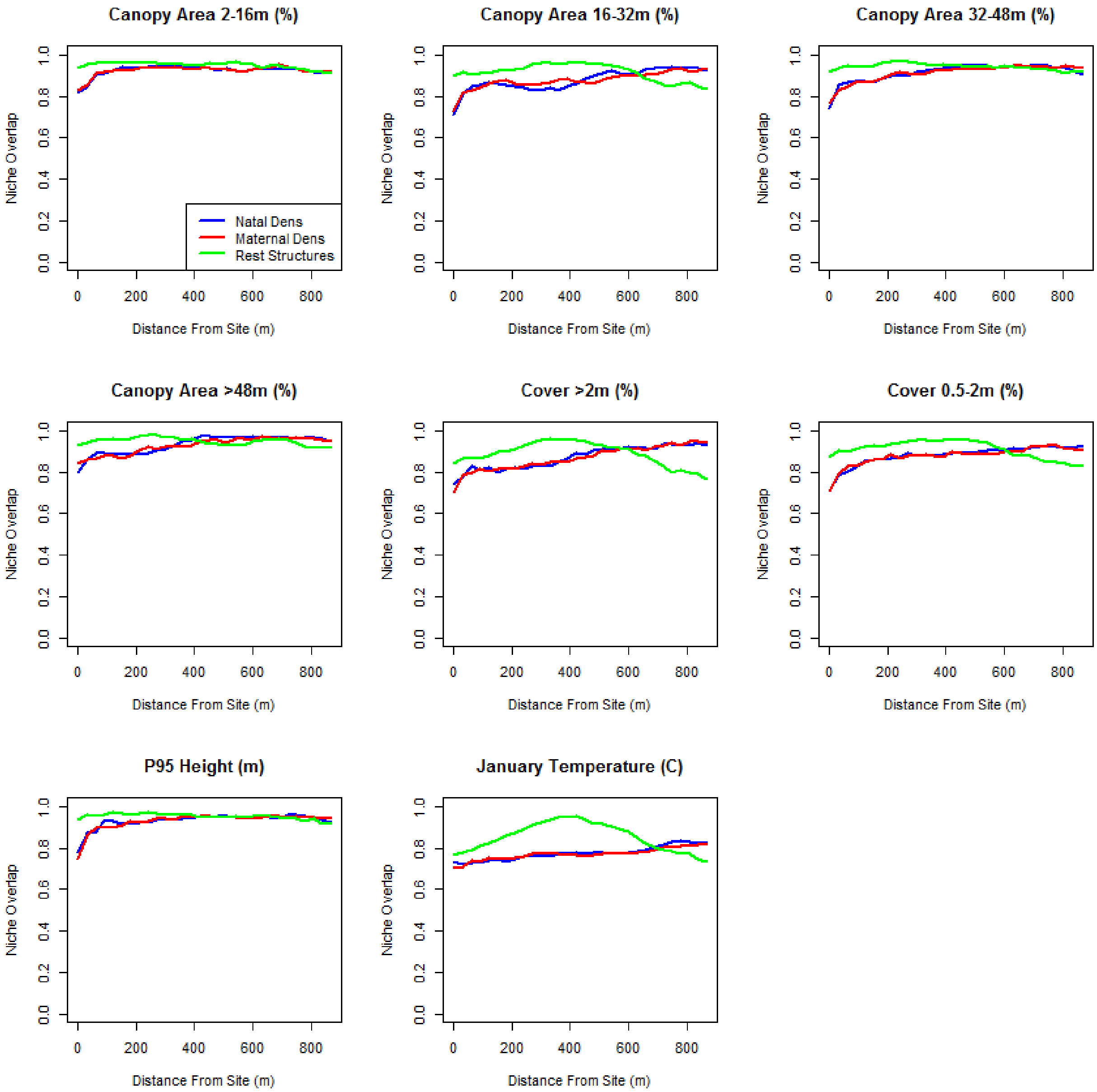

Figure 4. Niche overlap between entire study area and the subset of the area specific distances from natal dens, maternal dens, and rest structures. Lower values indicate greater distinction and suggest a higher degree of selection. The unusual shape of some of the rest structure curves is likely due to the high density of rest structures within the study area; a plurality of the study area (5%) is 400 meters away from a rest structure, which is where the curves peak. In general, it appears that any selection that occurs is very localized to the actual fisher site, with all distinction disappearing within 30-60 meters.

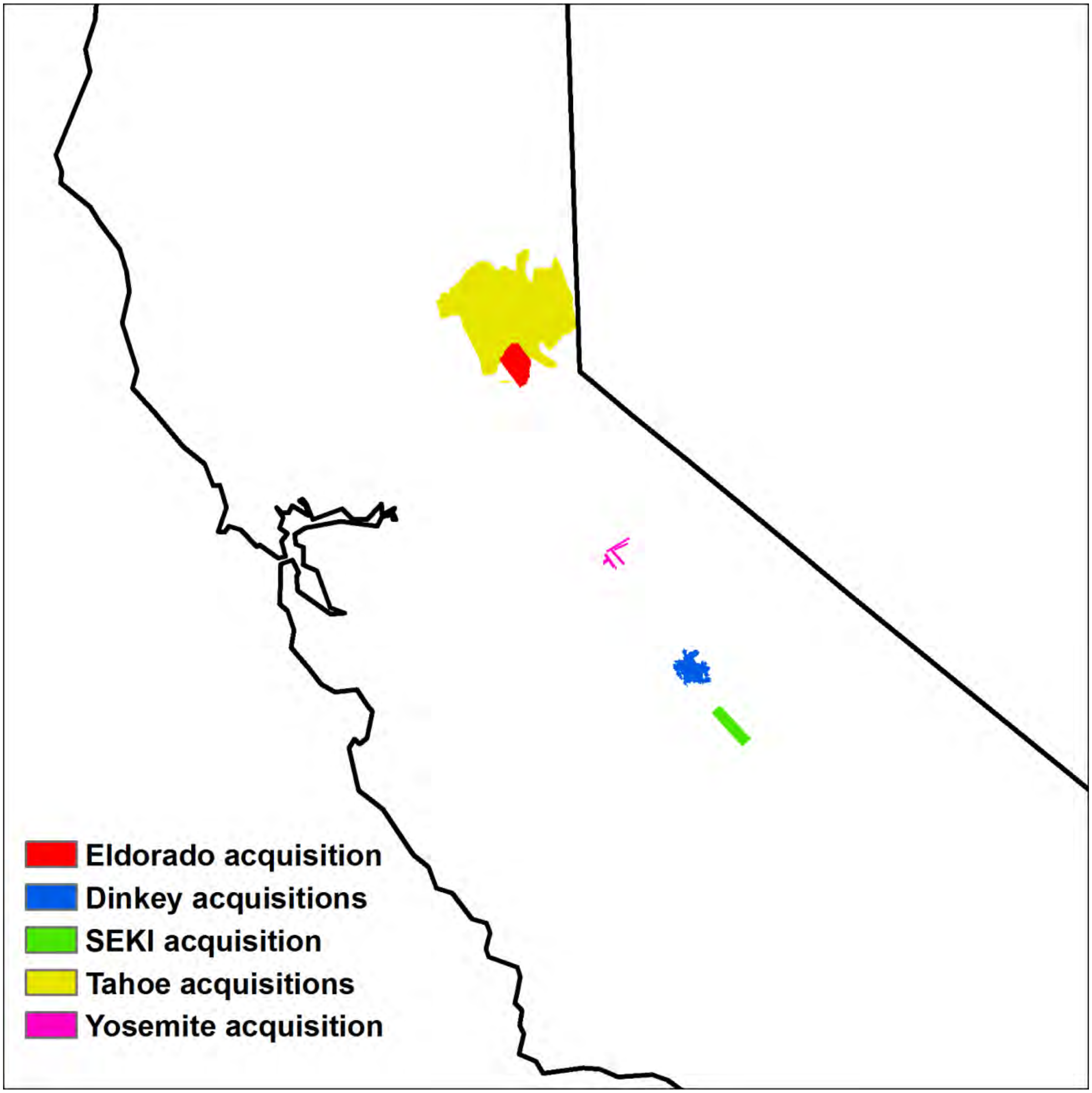

Figure 5. The locations of the lidar acquisitions used in figures 8 and 9.

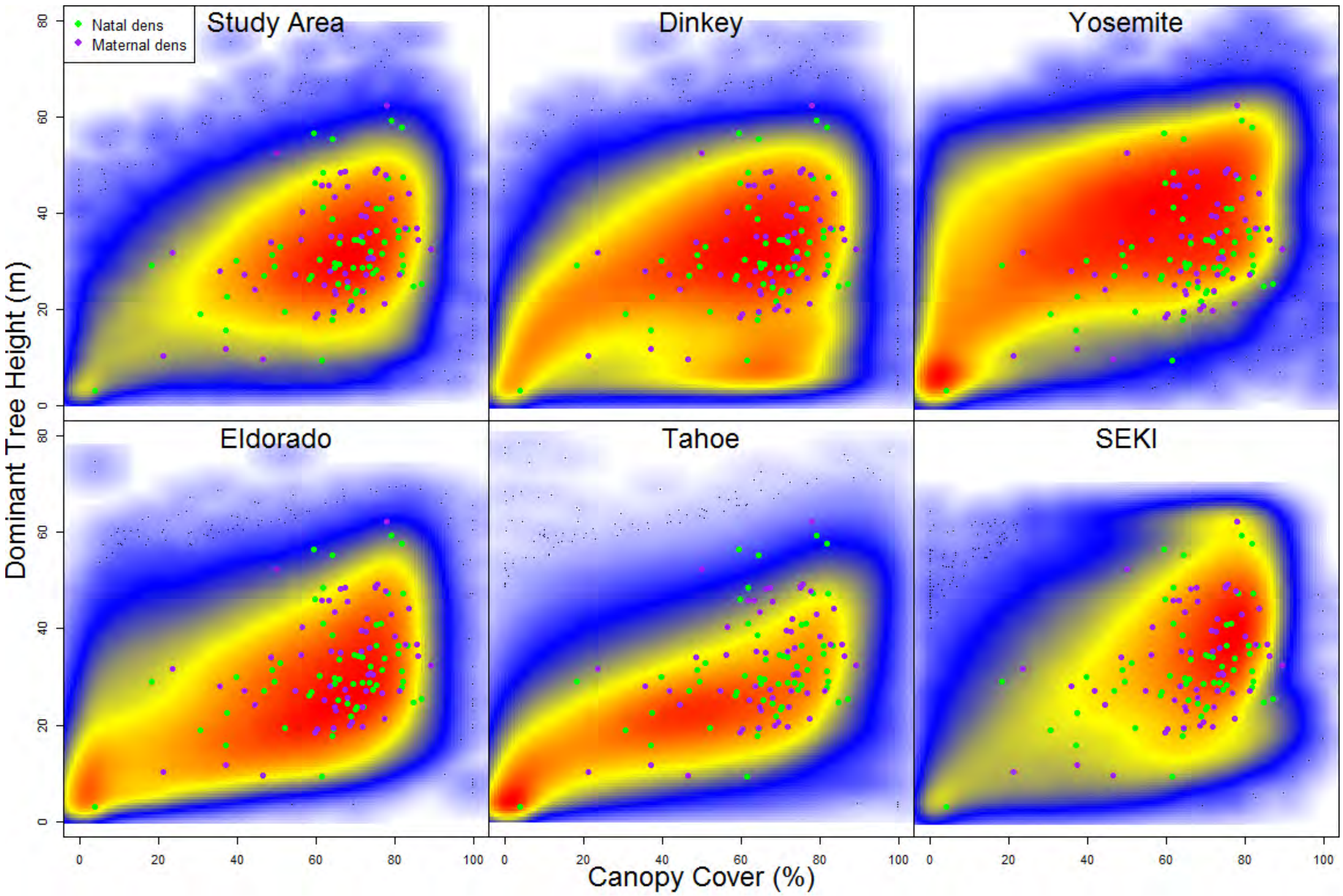

Figure 6. The distribution of two forest structure metrics in the study area, as well as five lidar acquisitions from across the Sierras. Blue indicates values that are relatively uncommon in the area, and red indicates values that are relatively common, with yellow in between. Dominant tree height is calculated as the 95th percentile of lidar returns in a pixel. The Dinkey panel shows the range of the entirety of the two Dinkey lidar acquisitions, of which the study area is a subset. Green and purple points indicate the structure present at natal and maternal dens, respectively. Our results suggesting that fishers are forest generalists with a slight preference with higher cover and tall trees is only directly applicable in the study area; other forests have much wider ranges of forest structure and may present unusable habitat. Figure 11 shows the locations of these acquisitions.

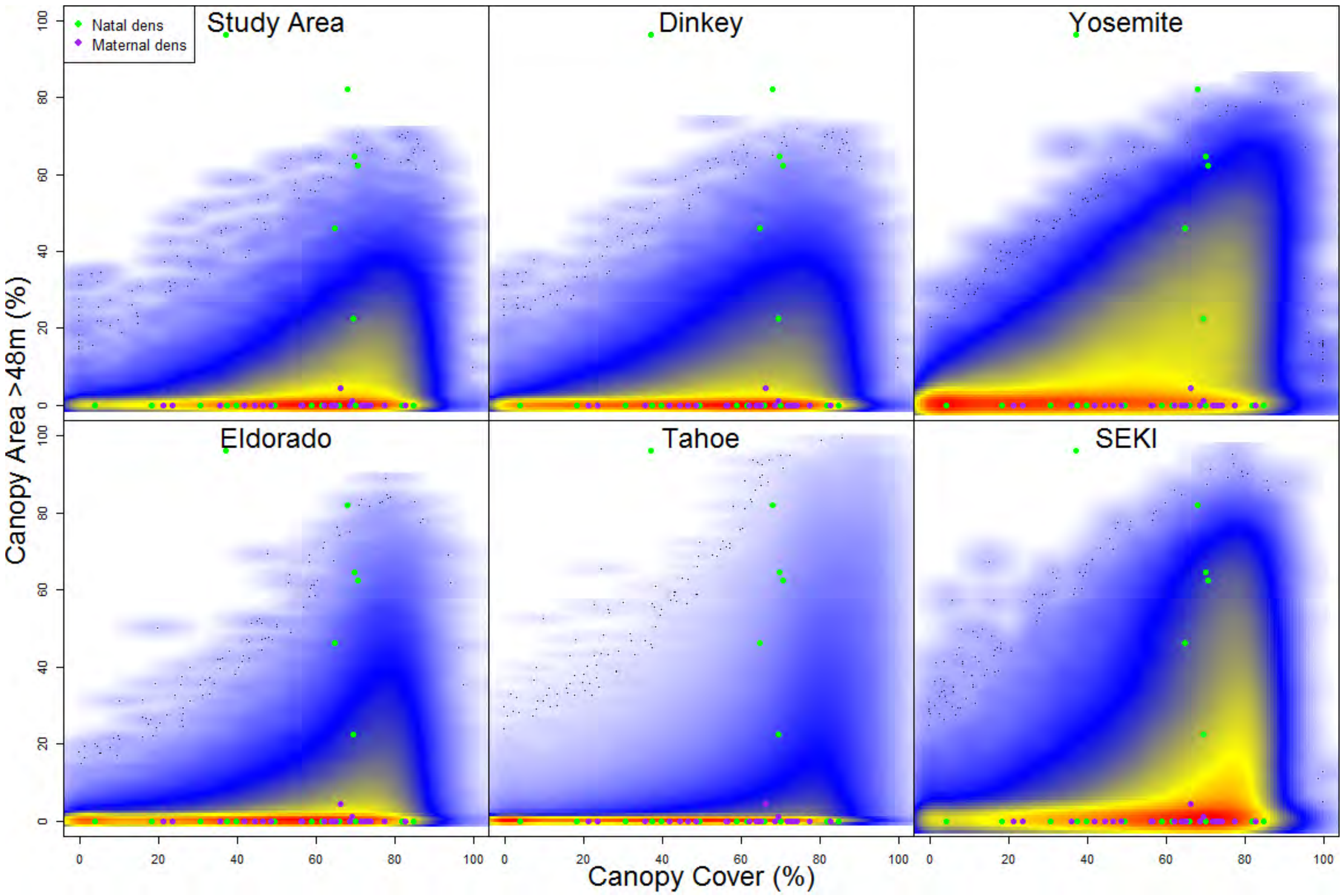

Figure 7. The distribution of two forest structure metrics in the study area, as well as five lidar acquisitions from across the Sierras. Blue indicates values that are relatively uncommon in the area, and red indicates values that are relatively common (with yellow in between). The Dinkey panel shows the range of the entirety of the two Dinkey lidar acquisitions, of which the study area is a subset. Green and purple points indicate the structure present at natal and maternal dens, respectively. Canopy area >48m was calculated on 90-meter pixels while canopy cover was calculated on 30-meter pixels. Our results suggesting that fishers are forest generalists with a slight preference with higher cover and tall trees is only directly applicable in the study area; other forests have much wider ranges of forest structure and may present habitat that is unusable for other reasons. Figure 10 shows the locations of these acquisitions.

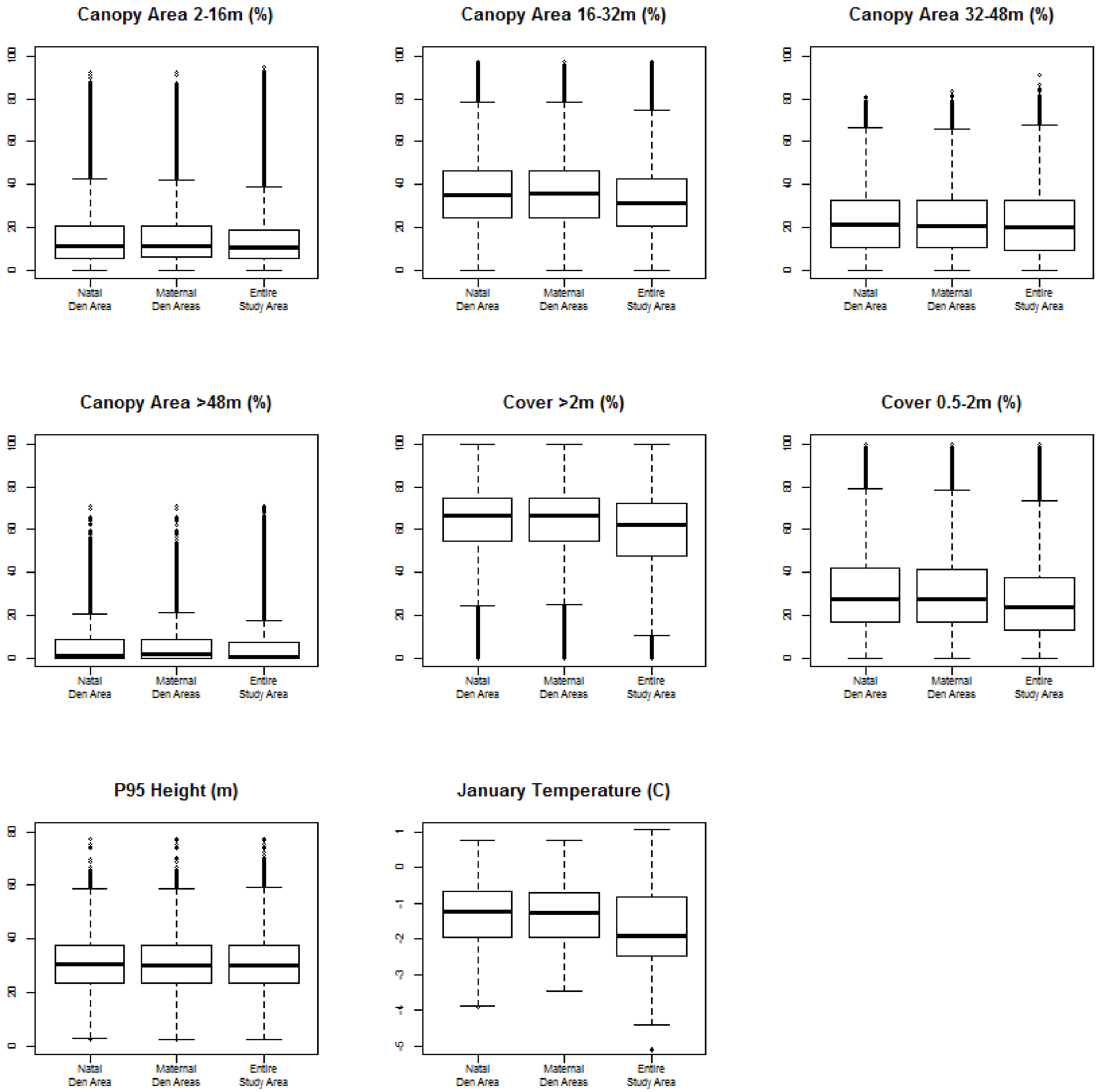

Figure 8. Box and whisker plots of metrics in natal den areas, maternal den area, and entire study area. Den areas are defined as circles with radius 750 meters around the den; this is the 90th percentile of distance fishers will travel between successive dens in the data set. Boxes are calculated using all 30m pixels that fall within the specified areas. The bold central line is the median value. The upper and lower bounds of the box are the 75th and 25th percentiles. The upper and lower whiskers are either the 95th and 5th percentiles, or 1.5 times the interquartile distance. Individual points represent outliers.

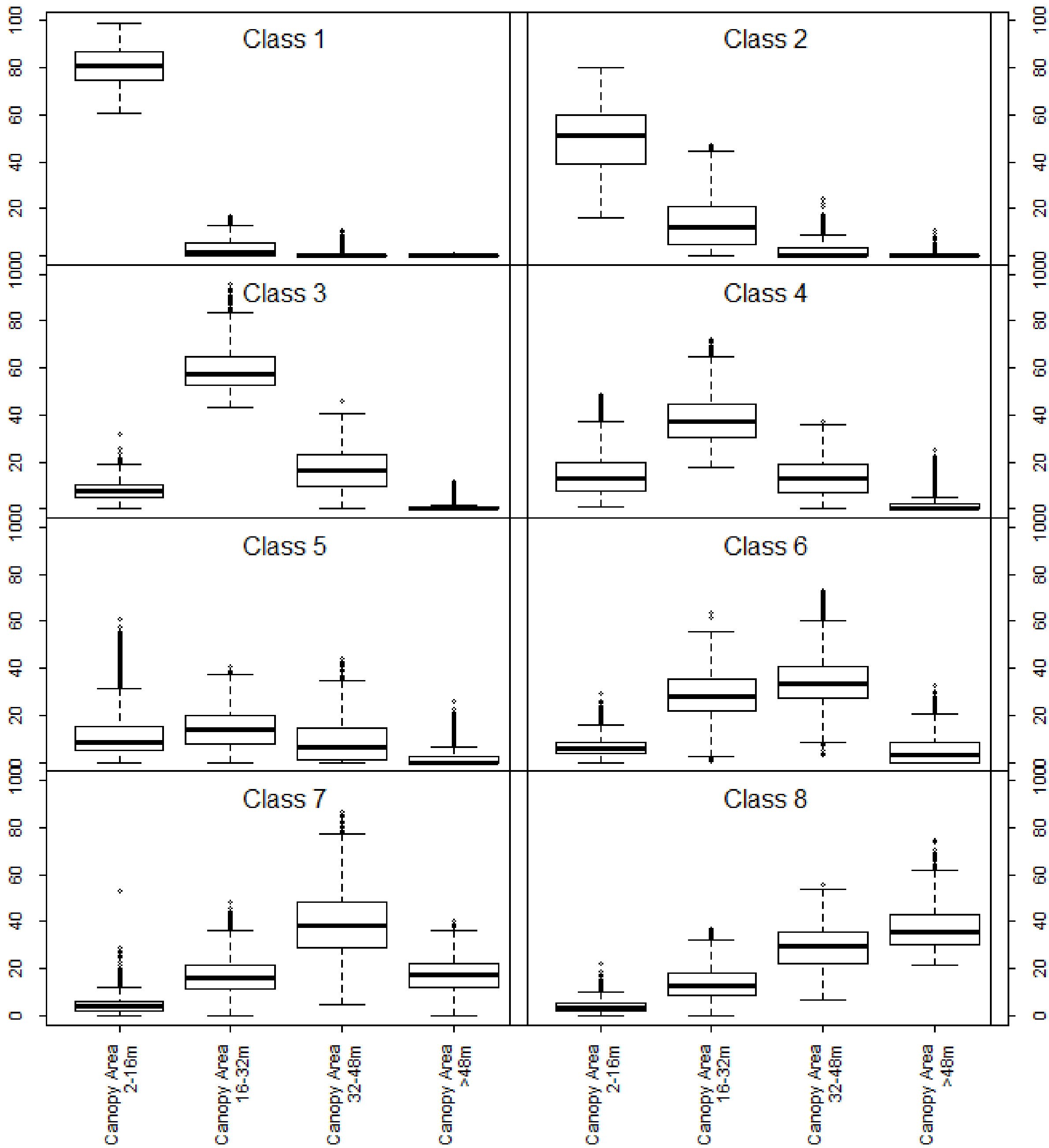

Figure 9. Boxplots illustrating the structure classes. Boxes are calculated using all 30 m pixels that fall within the specified structure classes. The bold central line is the median value. The upper and lower bounds of the box are the 75th and 25th percentiles. The upper and lower whiskers are either the 95th and 5th percentiles, or 1.5 times the interquartile distance. Individual points represent outliers. The classes are numbered in order of increasing mean values of canopy area >48m. Lower overall values across the four canopy areas indicate more area in openings.

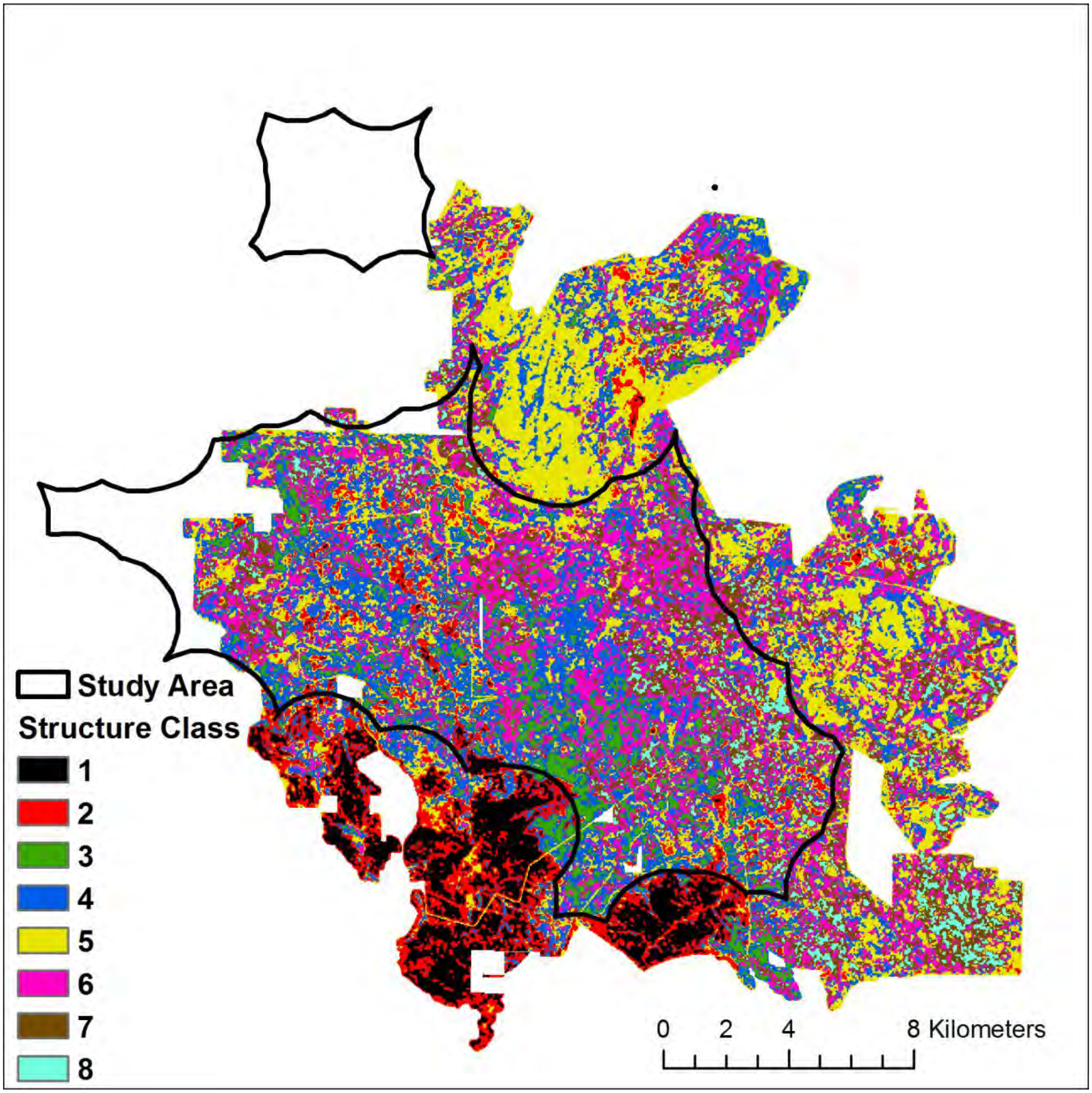

Figure 10. Distribution of structure classes in the Dinkey lidar acquisition area. The black lines indicate the border of the study area. See figure 11 for the distribution in the Yosemite lidar.

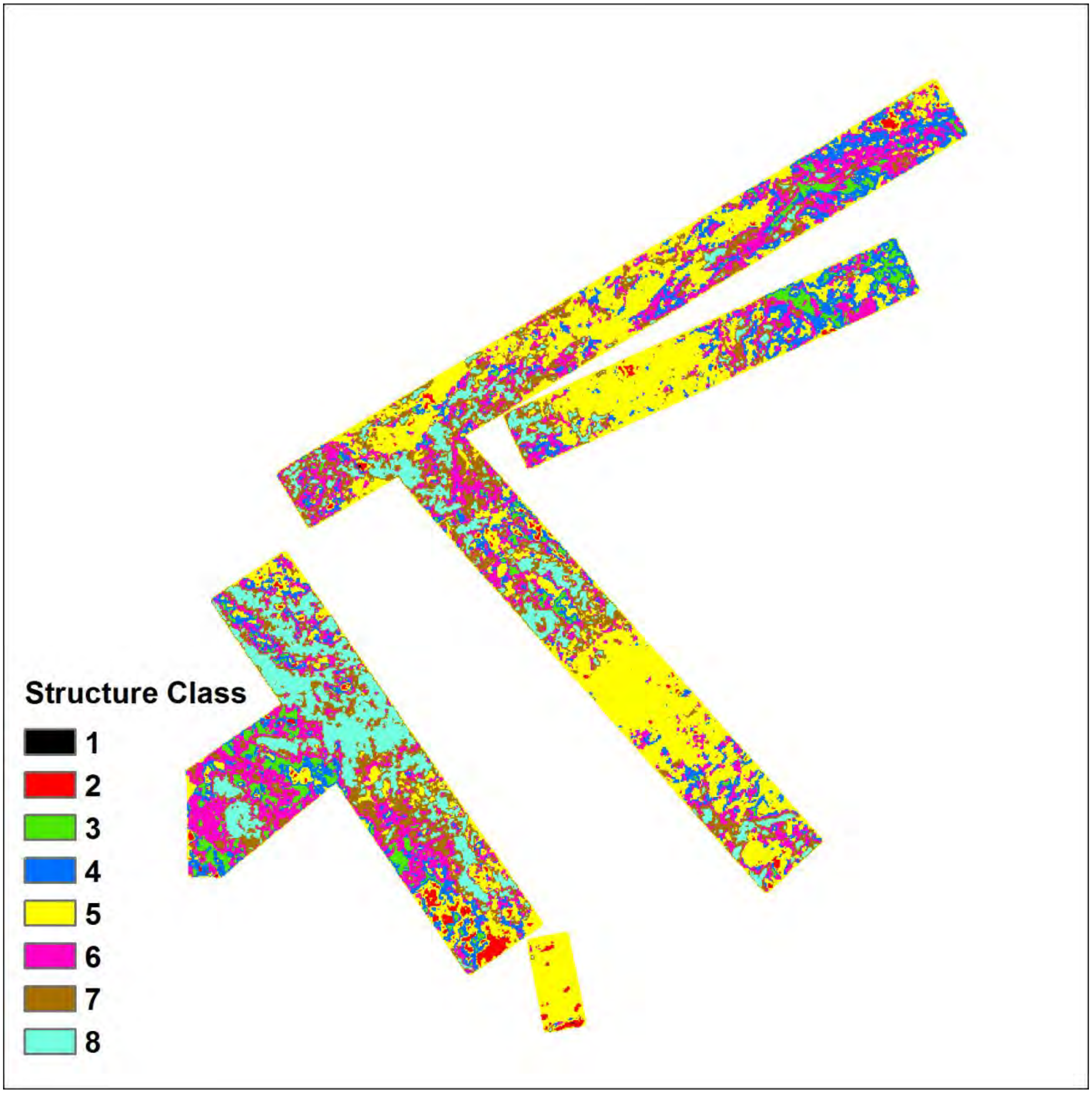

Figure 11. The distribution of structure classes in the Yosemite acquisition.

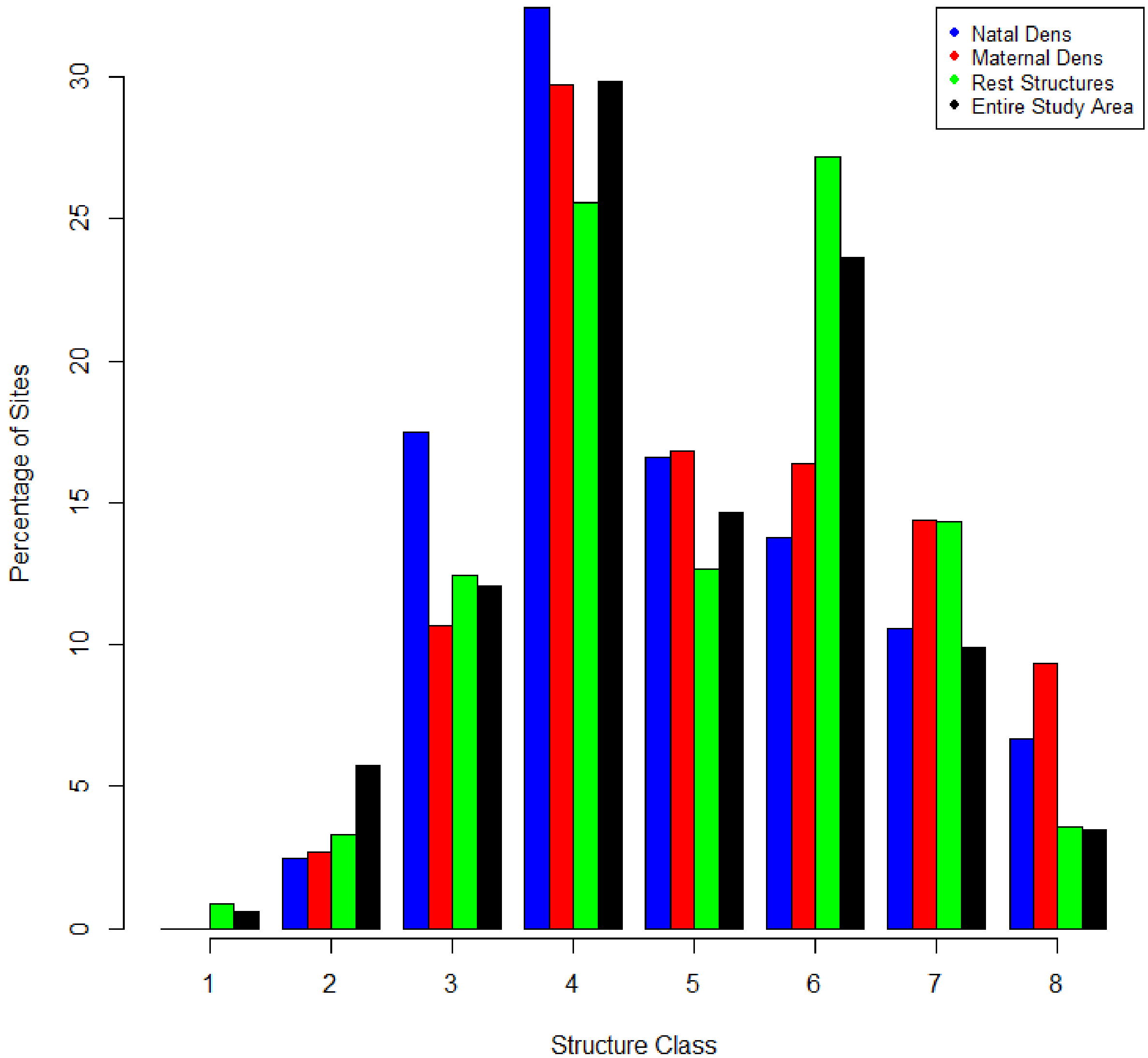

Figure 12. The distribution of structure classes in natal dens, maternal dens, rest structures, and the entire study area. The distinction between rest structures and the entire study area was statistically significant. However, none of the other pairwise distinctions were significant, due to the lower number of dens.

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Appendix A. Summary of metrics tried in early data exploration.

	GLM	RF	Niche
CA.2to8_30m.img	5860.254	0.476243	0.925646
CA.2to8_90m.img	5840.331	0.481825	0.886984
CA.32to48_90m.img	5800.15	0.448583	0.810491
CA.8to16_30m.img	5914.081	0.478952	0.89237
CA.8to16_90m.img	5913.441	0.468295	0.818097
CA.16to32_30m.img	5509.051	0.416051	0.731955
CA.16to32_90m.img	5167.36	0.40117	0.635135
CA.32to48_30m.img	5858.95	0.461449	0.864579
CA.gt32_30m.img	5841.328	0.457341	0.858052
CA.gt32_90m.img	5794.433	0.453825	0.811624
CA.gt48_30m.img	5885.389	0.467387	0.47702
CA.gt48_90m.img	5861.58	0.434953	0.769613
CA.Gap_30m.img	5331.112	0.392615	0.682152
CA.Gap_90m.img	5096.27	0.399892	0.63059
Npatch.Gap_30m.img	5629.024	0.381302	0.760313
Npatch.Gap_90m.img	5260.548	0.32209	0.633527
NLSI.Canopy_30m.img	5597.531	0.445962	0.713814
NLSI.Canopy_90m.img	5313.838	0.41538	0.625049
AI.Allstrata_30m.img	5853.662	0.494203	0.91123
ShannonEven.Canopyonly_30m.img	5906.863	0.496044	0.931724
ShannonEven.Canopyonly_90m.img	5912.186	0.507758	0.946653
all_cover_above2_30METERS.img	5401.113	0.448072	0.723989
elev_ave_2plus_30METERS.img	5905.589	0.487296	0.86141
elev_P25_2plus_30METERS.img	5911.474	0.501259	0.902768
elev_P50_2plus_30METERS.img	5913.805	0.484097	0.871555
elev_P75_2plus_30METERS.img	5900.607	0.476993	0.860865
elev_P95_2plus_30METERS.img	5847.496	0.470682	0.866257
elev_stddev_2plus_30METERS.img	5825.938	0.478827	0.85578
elev_skewness_2plus_30METERS.img	5880.763	0.490007	0.893943
elev_kurtosis_2plus_30METERS.img	5912.404	0.491907	0.910921
strata_0p5to1M_cover_percentage_30METERS.img	5913.234	0.4895	0.888214
strata_16to32M_cover_percentage_30METERS.img	5750.702	0.459219	0.814649
strata_1to2M_cover_percentage_30METERS.img	5869.016	0.465352	0.775194
strata_2to4M_cover_percentage_30METERS.img	5764.829	0.430572	0.692809
strata_32to48M_cover_percentage_30METERS.img	5906.432	0.460856	0.886541
strata_48to64M_cover_percentage_30METERS.img	5908.358	0.486895	0.932754
strata_4to8M_cover_percentage_30METERS.img	5643.202	0.44583	0.719847
strata_64M_plus_cover_percentage_30METERS.img	5911.955	0.525727	0.736873

AET	4917.899	0.344937	0.528979
CWD	5504.71	0.341815	0.569972
JanMinT	5173.85	0.274765	0.492242
JulMaxT	5480.231	0.267376	0.431181
X4000M_tpi_normalized_30METERS.img	5909.514	0.47757	0.892988
X2000M_tpi_normalized_30METERS.img	5895.778	0.500223	0.919446
X1000M_tpi_normalized_30METERS.img	5913.353	0.493684	0.910266
X500M_tpi_normalized_30METERS.img	5912.568	0.497512	0.940898
X135M_topo_aspect_cosine_30METERS.img	5858.986	0.486829	0.860825
X135M_topo_curvature_30METERS.img	5912.893	0.504674	0.939006
X135M_topo_slope_30METERS.img	5819.01	0.465804	0.811577
X135M_topo_sri_reallat_30METERS.img	5877.826	0.481023	0.855449
X15M_topo_aspect_cosine_30METERS.img	5888.468	0.49428	0.904409
X15M_topo_curvature_30METERS.img	5913.866	0.489773	0.919816
X15M_topo_slope_30METERS.img	5831.749	0.4731	0.827758
X15M_topo_sri_reallat_30METERS.img	5886.702	0.498112	0.896766
X200M_tpi_normalized_30METERS.img	5913.777	0.495087	0.938828
X270M_topo_aspect_30METERS.img	5884.746	0.453037	0.803666
X270M_topo_curvature_30METERS.img	5914.229	0.497575	0.952697
X270M_topo_slope_30METERS.img	5786.551	0.469027	0.808285
X270M_topo_sri_30METERS.img	5882.553	0.477854	0.875371
X45M_topo_aspect_cosine_30METERS.img	5880.832	0.492864	0.881771
X45M_topo_curvature_30METERS.img	5914.534	0.496646	0.914185
X45M_topo_slope_30METERS.img	5834.289	0.475455	0.814209
X45M_topo_sri_reallat_30METERS.img	5880.305	0.495023	0.873434
CA.lt32_90m	5662.563	0.407319	0.651607

Table A. A summary of the predictive power of many of the variables we examined during early exploration. The values compare all fisher sites to the entirety of the Dinkey lidar. The first column is the name of the variable, followed by the AIC of a generalized linear model (GLM, lower value indicates more predictive power), the R^2 of a random forest model (RF, higher indicates more predictive power), and the niche overlap value (lower indicates more distinct).