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ABSTRACT

*We used Interior West Forest Inventory and Analysis (IW-FIA) data to identify conditions where pinyon-juniper woodlands provide security cover, thermal cover, and suitable amounts of big sagebrush (*Artemisia tridentata *spp.) forage to mule deer in Utah. Roughly one quarter of Utah's pinyon-juniper woodlands had a big sagebrush component in their understory. Security cover was the least abundant habitat component investigated and only an estimated three percent of Utah's pinyon-juniper contained forage, security, and thermal cover concurrently. Area of potential mule deer habitat was generally distributed within ecoregion provinces in Utah in proportion to the spatial extent of each province. Quantile regression analysis suggests that when there is less than 22 percent crown cover, more than 20 percent of pinyon-juniper woodlands can be expected to have greater than 15 percent sagebrush cover. We demonstrate the utility of FIA data as an estimator of current habitat features and a long-term monitoring tool and show how quantile regression can be a useful tool for analyzing data with heterogeneous variation.*

INTRODUCTION

Adaptive Management of ecological systems at the regional scale has recently become popular with resource managers in the United States (Johnson and others 1999). These efforts have had varying degrees of success and have always been expensive to implement. Many of the failures of these plans can be attributed to lack of scientific data, inability to interpret data meaningfully, and inconsistencies in data analysis (Arnett and Sallabanks 1998). The funding limitations and small temporal and spatial scale at which most research is conducted also restricts the applicability of these efforts to larger comprehensive projects. As such, it is not surprising that difficulties persist in the collection and application of knowledge to create management tools that are flexible and can be applied at large spatial and temporal scales.

The Forest Inventory and Analysis (FIA) program of the Forest Service, U.S. Department of Agriculture, is responsible for assessing the status and trends of all forested lands in the U.S. (Gillespie 1999). The FIA program conducts inventories on all forested lands of the U.S. using a nationally standardized plot design (figure 1) at an intensity of approximately one field plot per 2,388 ha (5,800 ac). The Intermountain West region of FIA (IW-FIA) is responsible for collecting data on plots in Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming. In the states where FIA is fully funded, field crews visit roughly ten percent of a state's plots every year and measure up to 140 different variables on each plot. Plots belonging to each annual panel are distributed across each state so as to be free of geographic bias. The measurements are used to calculate estimates of area, age distribution, growth, mortality, volume, and biomass among others. Once a full cycle is completed, another begins and trend data can be analyzed. The extent, consistency, and perpetual nature of FIA data lends itself to quantifying resources over large areas and monitoring changes in those resources over time.

FIA information can be useful in quantifying habitat components for species that utilize forested environments at some point in their life cycle. One such species is the mule deer (*Odocoileus hemionus*). Mule deer are an important wildlife species in the Intermountain West and recent evidence has suggested population declines in several states (Stewart 1999; Unsworth and others 1999; Wasley 2004). Several reasons for population declines have been suggested including drought, harsh winters, predation, change in vegetative communities and overgrazing by domestic livestock (Wasley 2004; Gill and others 2001; Pojar and Bowden 2004). Mule deer occupy many environments and utilize different habitats as season and resource availability permit. Across much of their range, mule deer spend the warm growing season at higher elevations, taking advantage of seasonally abundant herbaceous vegetation, then gradually migrate to lower elevation shrublands as temperatures cool, food resources disappear, and snow accumulates. The time spent in the transitional areas between summer and winter range can be very important to mule deer, especially where winter or summer ranges have been degraded, fragmented or otherwise isolated (Short 1981; Verme and Ullrey 1984; Sawyer and others 2005). In the Intermountain West, much of this transitional range consists of pinyon-juniper woodlands. The plant community structure in these woodlands can vary dramatically but where certain conditions are met, they can provide important habitat to mule deer. The structure provided by woody shrubs and small trees in these woodlands can be important in providing evaluating security and thermal cover for mule

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deer. Big sagebrush species (*Artemisia tridentata* spp.) are sometimes found in pinyon-juniper woodlands and are known to be an important food resource for mule deer (Reynolds 1960; Papez 1976; Wambolt and others 1987; Wambolt 1996; Welsh 2005). The relationship of pinyon and juniper tree cover and the extent of big sagebrush and other woody vegetation has been explored for western juniper woodlands (Miller and others 2000; Miller 2001) but identifying general relationships in pinyon-juniper woodlands using a landscape-level dataset has not been addressed to a great extent.

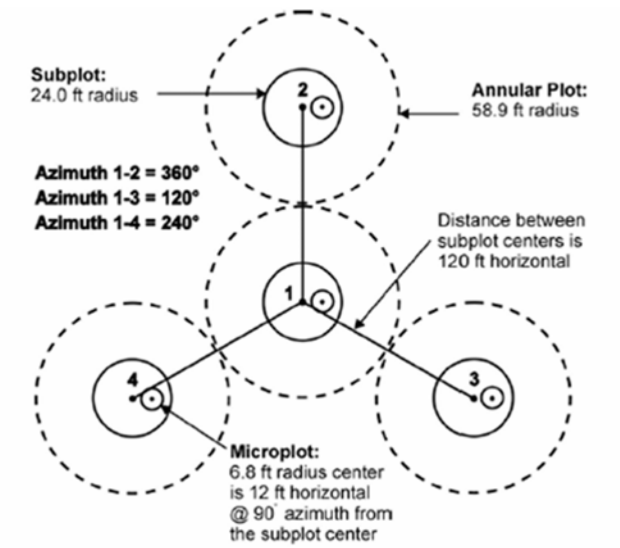

Figure 1—Standard Forest Inventory and Analysis Phase 2 plot diagram.

In this study we demonstrate the utility of FIA data as a census and monitoring tool when applied to mule deer habitat over large areas. We use Interior West Forest Inventory and Analysis data for Utah from 2000 to 2007 to estimate has of pinyon-juniper woodlands that provide security cover, thermal cover, and forage in the form of big sagebrush (*Artemisia tridentata* spp.) across the state and by the five major ecoregion provinces found in Utah as described by Bailey (1995). Since FIA plots are uniformly distributed geographically, we can translate statements involving percentage of plots into percentage of land. Area estimates are produced using methods outlined in Bechtold and Patterson (2005). We also use quantile regression (Cade and Noon 2003; Koenker 2005) to identify thresholds of tree crown cover as it relates to potential cover of sagebrush available to mule deer.

DATA AND METHODS

The FIA program conducts inventory on all forested lands of the U.S. at an intensity of approximately one field plot per 2,308 ha. FIA defines "Forest" as those lands 0.4 ha or greater in area and at least 36.6 m wide having five percent or greater crown cover of tree species tallied by FIA crews (USDA 2007). Where plots meet these criteria, IW-FIA also estimates aerial cover of understory vegetation by dominant species. Dominance is defined as those occurring at or greater than five percent cover on any subplot. Field crews also estimate cover by major life form (graminoid, forb, shrub and trees 12.7 cm or smaller diameter at breast height [DBH]) within three different horizontal layers to provide additional information on forest structure.

Crown cover on plots is estimated using four 7.62 m transects running in the cardinal directions from each subplot center. The presence or absence of aerial cover of tally trees 2.54 cm and greater diameter at breast height (DBH) is recorded every 30.48 cm along each transect. Percent cover of tree and shrub understory from two layer classes (47 to 183 cm and > 183 cm) is estimated on each 0.017 ha subplot using techniques described in USDA 2007. Cover of individual species is recorded if estimated aerial cover meets or exceeds five percent of the subplot area in a particular condition (in this case a pinyon-juniper forest type). We defined big sagebrush as being present if it occurred with at least five percent cover across the plot (or portion of the plot in the pinyon-juniper condition) while those having less than five percent cover of sagebrush were classified as having none.

Based on research by Armleder and others (1994), Tull and others (2001), and Miller (2001), we considered adequate thermal cover to be equal or greater than 35 percent on the plot. We used either crown cover or the combined tree and shrub cover in layer 3 (whichever was greater) to quantify the minimum thermal cover present on a plot. Security cover was defined as vegetative cover greater than 47 cm tall. We calculated security cover on a plot by combining understory cover of trees and shrubs in layer 2. We considered stands with 40 percent or greater crown cover to provide adequate security cover given the low crown morphology and multiple stemmed growth form often exhibited by individual pinyon and juniper trees (Miller 2001; Reading 2004). The amount of big sagebrush that mule deer need in winter depends on many factors including extent of cover, condition of the plants, height in relation to typical snow depth, size of deer herd, and the presence and abundance of additional food resources. In this study, we used plots with at least five percent sagebrush cover to calculate area estimates and used 15 percent sagebrush cover for the purposes of discussing the applications of quantile regression.

For a threshold of big sagebrush cover, we explore the issue of determining a cutoff value of percent crown cover in pinyon-juniper woodlands, where for large percentage of land with crown cover greater than the cutoff value we have a high level of confidence that the percentage of big sagebrush cover is below the user determined threshold. For example, if the user determined threshold is 15 percent, then we would like to make statements of the form, "In pinyon-juniper woodlands that have a big sagebrush component in their understory and crown cover less than "X" percent, we are 95percent confident that "Y" percent of this land has more than 15 percent big sagebrush cover." Since we are interested the tails of the probability distribution of big sagebrush cover, the standard technique of finding the mean of the conditional distribution of big sagebrush cover as a linear function of the crown cover in pinyon-juniper woodlands is of limited usefulness; instead we used quantile regression.

Quantile regression is a technique for estimating the quantiles of the conditional distribution of a response variable as function of a set of predictor variables. Although quantile regression methods have been investigated since the early 18th century, implementation for nonparametric error distributions only occurred with advent of modern computing (Koenker 2005). Quantiles can be viewed as a decimal expression of percentiles. For example, the 80th percentile would be expressed as the 0.8 quantile. For a primer on the uses of quantile regression for ecological processes see Cade and Noon (2003). For this analysis we assumed the heteroscedastic linear model:

$$y_i = \beta_0 + \beta_1 x_i + \sigma(x_i)\varepsilon_i$$

where y is the response variable, X is the predictor variable, β_0 and β_1 are fixed parameters and the $\{\varepsilon_i\}$ are independent identical distributed random errors. Quantile regression has the advantage of accommodating heterogeneous variation in the conditional distributions and not requiring parametric error distributions. We used the **quantreg** package in version 2.5.1 of the R language to conduct the quantile regression analysis.

RESULTS

Area Estimates

From 2000 to 2007, FIA collected data on 1,618 conditions (plots or portions of plots) of pinyon-juniper woodland in Utah. Of these, 424 had big sagebrush cover estimated at or greater than five percent. Because we removed 3 plots from analysis because of obvious errors in crown cover estimates, area estimates and quantile regression are based on 421 plots. Of the estimated 4,568,265 has of pinyon-juniper woodland in Utah, 1,192,778 ha (26 percent) have a big sagebrush understory component (figure 2). Roughly 212,622 ha (18 percent) of the area estimated to have big sagebrush met the requisites for thermal cover while and estimated 142,495 ha (12 percent) met the requirements for adequate security cover. There are roughly 137,120 ha in Utah that simultaneously provide security cover, thermal cover and big sagebrush forage at or greater than five percent. This represents three percent of Utah's pinyon-juniper woodlands and 12 percent of pinyon-juniper woodlands having big sagebrush in them.

The portion of the *Intermountain Semidesert and Desert Province* (341) in Utah is estimated to have the greatest total area of pinyon-juniper with big sagebrush (560,064 ha). This Ecoregion provides the largest estimated area having security cover (62,045 ha) and thermal cover (91,440 ha) as well (figure 3). The *Intermountain Semidesert Province* (342) ha the largest percentage of its pinyon-juniper woodlands having a big sagebrush component (33 percent). In addition, M341 ha the greatest percentage of its pinyon-juniper woodland providing thermal (26 percent) and security cover (16 percent) in Utah. The pinyon-juniper woodlands that provide big sagebrush, thermal cover, and security cover concurrently also reside largely in these two ecoregions.

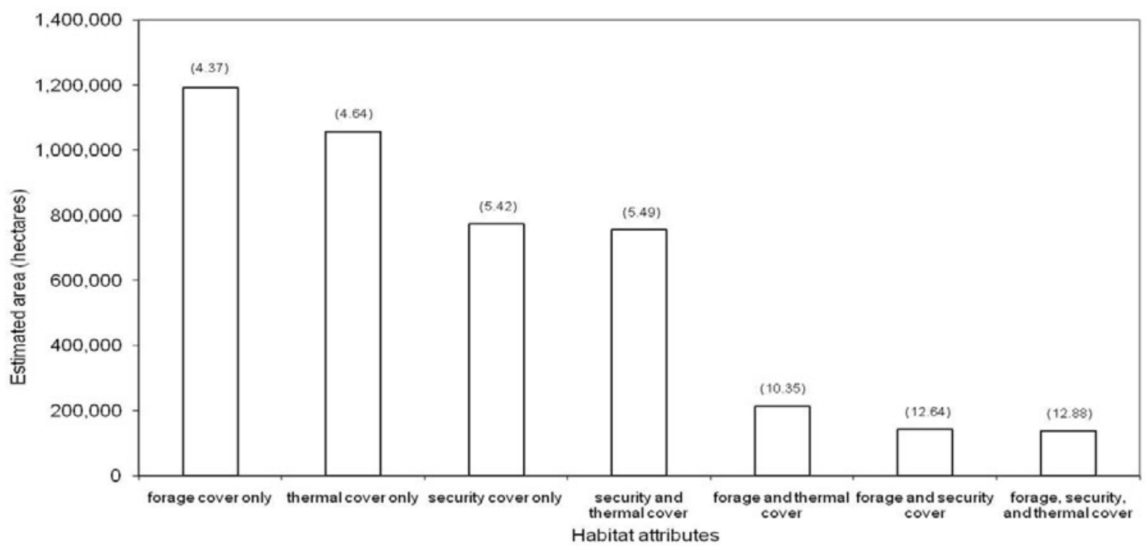

Figure 2—Estimated number of hectares meeting forage, thermal cover, security cover and various combinations of these habitat components in pinyon-juniper woodlands in Utah. Numbers in ( ) reflect percent standard error.

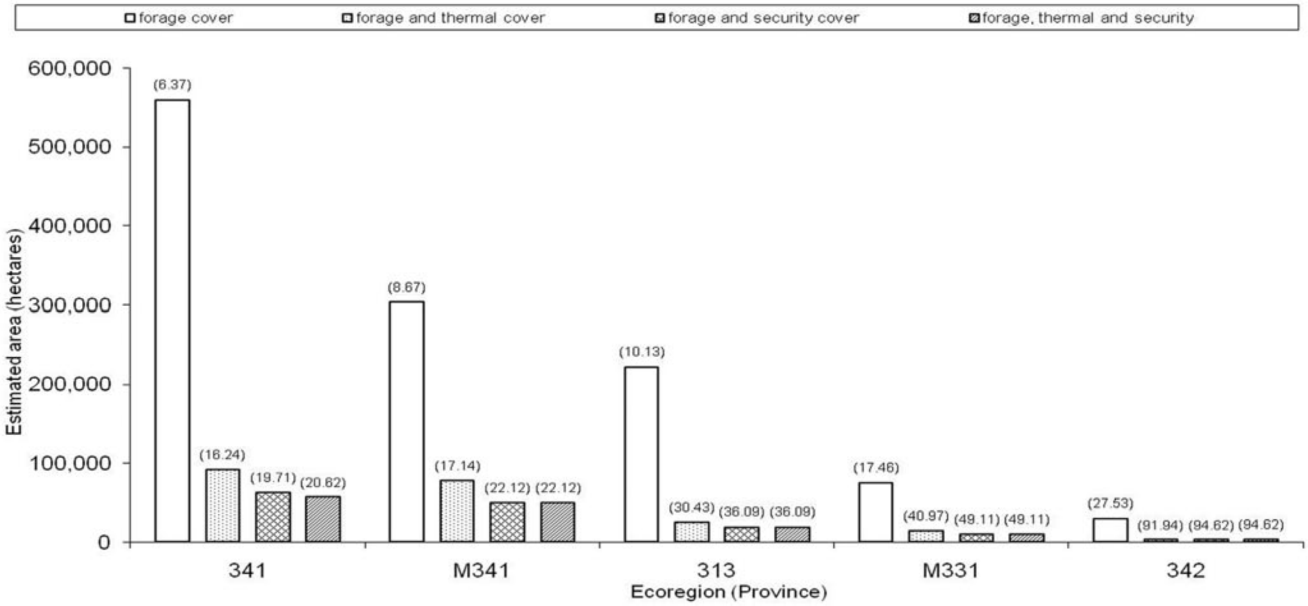

Figure 3—Estimated number of hectares of forage (*Artemisia tridentata* spp.) and a combination of forage and other habitat components in pinyon-juniper woodlands by major ecoregion provinces in Utah. Numbers in ( ) reflect percent standard error.

Cover Thresholds

There were 421 plots used in the quantile regression analysis of big sagebrush cover as a function of crown cover in pinyon-juniper woodlands. A plot of big sagebrush cover versus crown cover indicates there may be a decrease in big sagebrush cover as crown cover increases (figure 4). The graph also contains the quantile regression lines for 90th, 80th, 70th and 50th percentile and the least squares estimate of the mean.

The upper and lower 95percent confidence bounds for the 0.8 quantile of the conditional distribution calculated at selected integer values of the percent crown cover (figure 5). For the 0.9 quantile only the lower confidence bound was calculated at the same selected integer values.

DISCUSSION

Area Estimates

Pinyon-juniper woodlands that provide adequate thermal and security cover as well a big sagebrush component for mule deer appear to be uncommon in Utah. Only three percent of Utah's pinyon-juniper stands meand othersl of the forage, thermal cover, and security cover thresholds outlined in this study. The understory structure thought to be necessary to provide mule deer cover from detection by predators appears to be the least common attribute analyzed here, evident in only 12 percent of the stands that had a big sagebrush component. However, 17 percent of all pinyon-juniper woodland in Utah had adequate security cover. This suggests that shrub and tree species other than big sagebrush are contributing to security cover in many pinyon-juniper stands. There may also be other food resources in these stands as several species other than sagebrush provide forage for mule deer. Therefore, we can not say that the pinyon-juniper stands that have no sagebrush are not providing a food resource to mule deer. It is probable that some portion of the land area having good security cover but no sagebrush is providing food in another form.

Pinyon-juniper stands providing thermal cover were almost as common as those having a big sagebrush component (1,057,031 ha and 1,192,778 ha respectively). However, only 18 percent of pinyon-juniper stands shared both qualities. This was not unexpected as it is known that big sagebrush does not perform well in shaded areas and it is shade from the tree and tall shrub canopy that provides thermal insulation to mule deer during times of temperature extremes. Most big sagebrush does not grow to a height where it would contribute to thermal cover (greater than or equal 183 cm) so any tree or shrub providing thermal cover is likely in direct competition with big sagebrush for important resources.

The standard area estimates produced by FIA data can identify limiting resources for species that utilize resources at large spatial scales. In this case, we have identified mule deer security cover as being less abundant than thermal cover in pinyon-juniper/big sagebrush woodlands. If winter stress on mule deer has been identified as a larger concern than predation, a resource manager may wish to apply management strategies that promote understory growth and limits crown closure. FIA data can then be used to monitor the overall effects on the landscape through time to help maintain a balance between the multiple needs of mule deer populations as well as habitat for other species.

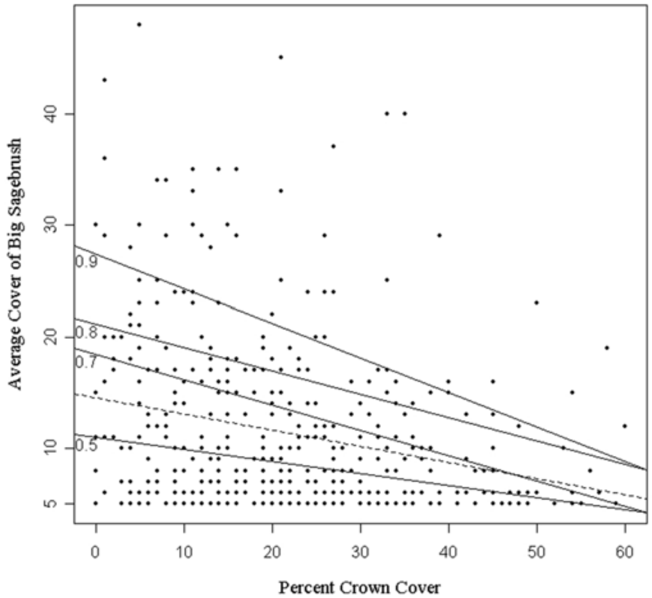

Figure 4—Average percent cover of big sagebrush (*y*) versus percent crown cover in pinyon-juniper woodlands (X) on *n* = 421 plots, the 0.9, 0.8, 0.7, and 0.5 regression quantile estimates (solid lines), and the least squares estimate of mean (dashed line).

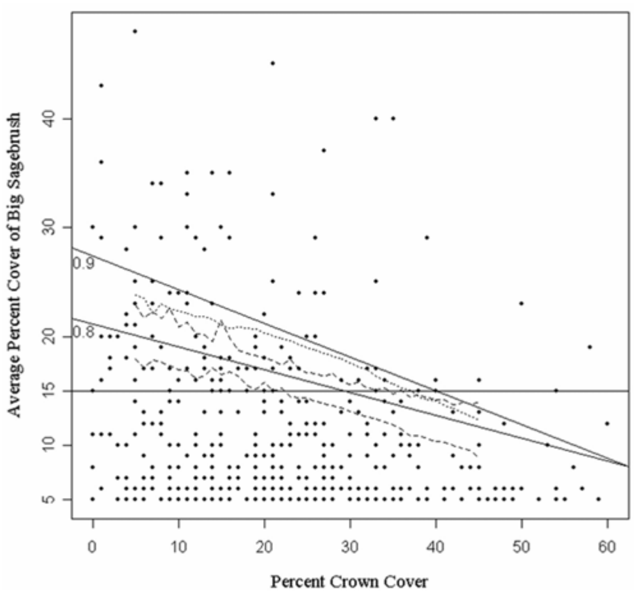

Figure 5—Average percent cover of big sagebrush (*y*) versus percent crown cover in pinyon-juniper woodlands (X) on *n* = 421 plots, the 0.8 and 0.9 regression quantile estimates and *y* = 15 line (solid lines). The dashed lines connect the upper and lower 95% confidence bounds of the 0.8 quantile at integer values of percent crown cover. The doted line connects lower 95% confidence bounds of the 0.8 quantile at integer values of percent crown cover.

Although beyond the scope of this study, it would be interesting to see how the FIA plots with big sagebrush on them were juxtaposed with non-forested sagebrush communities. If these plots occur along ecotones more often than in insular stands, it could have an influence on management of both communities. Pinyon-juniper expansion into shrublands is a much debated issue in the West, often because of the impacts on sagebrush obligates (Blackburn and Tueller 1970; Burkhardt and Tisdale 1976; Soule and Knapp 1999). Management prescriptions for invading pinyon and juniper often include fire and mechanized thinning or removal along the woodland-shrubland interface in order to retard, halt, or reverse the leading edge of woodland expansion. Given the general process of invasion, establishment and succession of vegetative communities, it is likely that these edges include much of the woodland area that has a sagebrush component and other attributes beneficial to mule deer. Managers may be improving habitat for one species of concern while unknowingly degrading the habitat of another.

As a monitoring tool, remeasurement of a full cycle of plots provides the best information on large scale trends in forest systems. However, a full 10 year cycle of FIA data is not necessary to detect profound changes in forest structure. Some drought-related responses of pinyon pine (Shaw 2005; Shaw and others 2005) and other conifers (Thompson, unpublished data) have been detected by exploring several sequential years of FIA data. This allows land managers to monitor responses to management prescriptions and disturbances at shorter time intervals. They can then modify their approach should undesirable trends become evident. This is a key feature of adaptive management and it is only possible when baseline information and consistent post-implementation data are readily available.

Quantile Regression

The upper and lower confidence bounds for conditional quantiles can be used to inform management decisions. For example suppose it is desirable to have more than 15 percent cover of big sagebrush. For the estimated 0.8 quantile, an examination of the lower 95percent confidence bounds at integer values of crown cover indicate that for crown cover less than 22 percent the lower 95percent confidence bound is greater than 15 percent (figure 5). So we are 95percent confident that 20 percent of the pinyon-juniper lands with a presence of big sagebrush and with crown cover less than 22 percent have more than 15 percent crown cover of big sagebrush. Based on the estimated 0.9 quantile lower 95percent confidence bounds, we are 95percent confident 10 percent of the pinyon-juniper lands with a presence of big sagebrush and with crown cover less than 38 percent have more than 15 percent crown cover of big sagebrush. The 95percent confidence bounds are not simultaneous confidence bounds, so overall confidence maybe less than 95percent.

An examination of the upper 95percent confidence bounds for the 80th percentile at integer values of crown covers indicate that for crown cover greater than 37 percent the upper 95percent confidence bound is less than 15 percent (figure 5). In other words we are 95 percent confident that 80 percent of the pinyon-juniper lands having a big sagebrush component and with crown cover greater than 37 percent have less than 15 percent cover of big sagebrush.

Since thermal cover is often provided only by tree crown cover in pinyon-juniper woodlands (as opposed to sub-crown vegetation), we can use the quantile regression analysis to say something about the frequency at which we can expect to see both sagebrush forage and thermal cover provided concurrently. Figure 5 illustrates that at 40 percent crown cover, the threshold at which thermal cover is assumed to be provided, one could expect 80 percent of these woodlands to have less than about 14 percent sagebrush cover and 20 percent of them to have roughly 10.5 percent or greater sagebrush cover (the confidence level of this statement would be 90 percent). Whether or not this is enough area for mule deer depends on a multitude of other factors, but at least the resource manager is armed with reasonable expectations regarding the amount of crown cover and associated sagebrush cover potentially available in pinyon-juniper woodlands.

As with any regression analysis there are pitfalls in using the estimates outside the range of the data. In the case the of heterogeneous variance model, the slopes of the regression line can be different and at some point the lines will intersect. Figure 4 indicates this happens for the quantile regression lines with equal 0.80 and 0.90, when the crown cover is slightly greater than 60 (in other words,, for crown cover slightly greater than 60) the estimated quantiles have the disconcerting property that the 80th percentile is greater than the 90th percentile. This is a possible pitfall when pushing quantile regression estimates beyond the range of the data.

CONCLUSION

FIA data can produce area estimates for habitat features for regional or landscape analyses. Habitats of animal species that utilize resources at these scales can be monitored over time by comparing past estimates of habitat feature to present ones. In this case, wildlife managers can use FIA data to monitor the amount and extent of pinyon-juniper woodlands that provide one or many structural features used by mule deer in Utah. However, these types of analyses can be performed for any habitat feature in any forest type measured by FIA field crews. FIA currently collects data on those lands that meet the criteria for forested land, but there are several ongoing initiatives and pilot studies exploring the utility of FIA protocols on rangelands and urban landscapes. It is possible that at some point in the future, FIA data can be applied to the spatial and temporal questions of habitats on all lands in the United States.

Oftentimes the mean of a distribution may not identify interesting relationships that can be useful to managers. Quantile regression is a useful tool for ecologists in that it allows exploration of all portions of a distribution in the presence of heterogeneous variance common in large-scale vegetation data. Looking at meaningful quantiles can help identify relationships and develop predictive models useful to resource managers and others interested in landscape ecology.

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