A REANALYSIS OF REGIONAL FISHER SUITABILITY

INCLUDING SURVEY DATA FROM COMMERCIAL FORESTS

IN THE REDWOOD REGION

Final Revised Version: 29 September 2005

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INTRODUCTION

Regional models of habitat suitability are key tools for conservation and restoration of wide-ranging species such as the fisher (*Martes pennanti*). Because these species occupy large home ranges and disperse over relatively long distances, their population dynamics and viability at any particular site will be strongly influenced by the regional distribution of suitable habitat. Carroll et al. (1999) (referred to here as the 1999 model) produced one of the first regional-scale fisher distribution models. That study created a multiple logistic regression model using data from 682 previously surveyed locations located primarily in the Klamath ecoregion's interior Douglas-fir (*Pseudotsuga menziesii*) zone, from Hoopa eastward to Interstate 5 (Figures 1 and 2). The model the authors selected included variables representing indices of canopy closure, tree size class, and percent conifer, averaged over landscapes of 10 km^2 in size. The model also included variables for annual precipitation and UTM northing that helped incorporate regional-scale trends not predicted by the landscape-level variables. The model was validated with new data from 468 survey locations, also from the Klamath ecoregion. The correct classification rate of 78.6% with the new data was similar to that achieved with the original data set (80.4%). Survey data from the coastal redwood zone were not available for either initial model construction or validation.

Recent interest in establishing a new fisher population in the northern Sierra Nevada via reintroduction has stimulated curiosity about a potential source population for the reintroduction. One likely candidate is the fisher population in northwestern California. Should a reintroduction plan continue to develop, it would be helpful to have available a regional landscape habitat model for northwestern California. This model could be used to help select areas for removals based on their relative predicted habitat suitability. The Carroll et al. (1999) model could serve that purpose, but it would be inferior to an updated model that included data from both coastal (redwood dominated) and interior (Douglas-fir dominated) forests. In 2005, redwood zone survey data became available for use in a reanalysis of fisher distribution in northwestern California. These data were used to produce an updated model that will assist the development of a reintroduction plan in California but, more importantly, provide a new source of information on which to base plans for fisher conservation in general.

METHODS

The goals of the reanalysis were to:

1)Test the applicability of the 1999 model in the redwood zone,

2) Describe areas of poor and good fit between the model and redwood zone data,

3) Review similarities and contrasts in the univariate relationships between fisher detection and habitat variables in the redwood zone versus the interior Douglas-fir zone,

4) Create new models based on the overall survey set combining the new redwood data and the interior zone surveys used in the 1999 model,

5) If appropriate, use these new models to predict habitat suitability in the Sierra Nevada.

The newly available data set consisted of a total of 1160 surveys from the redwood zone, carried out by Green Diamond (formerly Simpson Timber Co.), PALCO, and Humboldt State University between 1994 and 2004 (Figures 1 and 2)(Beyer and Golightly 1995, Klug 1997, PALCO unpublished). During the three years (1994, 1995, 2004) that surveys were performed by Green Diamond, a subset of survey locations was revisited at a later date within the same year to evaluate the consistency of detection results between seasons. An additional data set of 364 surveys performed by Redwood Sciences Lab from 2000-2002 (Slauson 2003, Slauson and Zielinski 2003) was made available in the final stages of the reanalysis project, and was incorporated into a subset of the analyses (Figures 1 and 2).

I tested for a significant difference between predicted probability values (1999 model) at sites with and without detections (standard two-sample t-test, $p < 0.05$) in the overall redwood zone survey data set (n=1160) and component data sets. I plotted predicted probability values from the 1999 model at these survey locations, with the locations divided into ten equal-sized bins based on their probability values, against observed fisher detection rate within the binned groups (Boyce et al. 2002).

Plots of the univariate relationship between fisher detection probability and density (canopy closure), tree size class, hardwood QMDBH, percent conifer, elevation, and precipitation were produced using Generalized Additive Models (GAM), a class of non-linear models useful for assessing potential linearity or curvature of univariate relationships between variables (e.g., Carroll et al. 2001). Patterns in GAM plots should only be interpreted through the range of predictor values in which the standard error envelope (the dotted lines in the figures) is relatively narrow, as the scarcity of data points outside this range makes GAM curves sensitive

to outliers. All vegetation variables evaluated here are moving-averages over 10 km^2 circular landscapes, as described in Carroll et al. (1999). Sources of data are described in Carroll et al. 1999. Briefly, vegetation data was derived from the TTF vegetation layer, which is based on a combination of unsupervised and supervised classification of Landsat Thematic Mapper (TM) imagery (California Timberland Task Force 1993). Although the reanalysis was originally planned to be limited to those variables used in the 1999 model, I added Terrain Ruggedness Index (TRI) based on the importance of terrain variables in a recent statewide fisher modeling exercise (Seo et al. in prep.). TRI is calculated as the average elevation difference between a cell and its eight neighboring cells (Riley et al. 1999).

Comparisons were made between the 1999 model and models based on the structure of 1999 model, but with coefficients recalculated with either the redwood zone data only (n = 1160, as the RSL surveys were not available at the time of analysis), or the combined interior and redwood data set (n = 1842). The redwood zone data were represented by 9 data sets: Green Diamond Resources (GDR)1994, GDR1994 Repeat (R), GDR1995, GDR1995R, GDR2004, GDR2004R, Humboldt State University (HSU), Pacific Lumber Company (PALCO), and Redwood Sciences Laboratory (RSL). The GDR and PALCO surveys were conducted in winter/spring whereas the GDR Repeat and RSL surveys were conducted in summer/fall. Survey date information was missing from the HSU data set. Unlike in the 1999 model, survey points were not differentially weighted based on the distance to the neighboring surveys. This step was found to have little effect on the resultant model (Carroll et al. 1999), and would limit comparability between models as neighborhood weights would differ depending on whether the data sets were combined or analyzed individually.

RESULTS

PERFORMANCE OF CARROLL ET AL. 1999 MODEL IN THE REDWOOD ZONE

The 1999 model was a significant ($p < 0.05$) predictor of survey success in the redwood zone for the overall data set and for 5 of the 9 component data sets (two-sample t-test, Table 1). All trends were positive in that sites with detections had higher predicted probability even in those data sets where the difference was not significant. Plotting detection success of the redwood zone surveys binned by their predicted probability values shows a generally increasing trend (Figure 3), but with much greater variation from this trendline than in the original data set,

and the correlation between detection probability and bin rank is not significant (r^s = 0.50, p = 0.14, n=1160 [all redwood zone data except RSL surveys]).

The quantile plot (Figure 3) serves as a diagnostic of model fit, and as such any departure from a monotonically increasing line implies limitations in the accuracy of the model. However, it is not valid one to then describe a new model relationship, such as a threshold, based on the quantile plot. This is because, due to limitations on the sample size of survey locations in each quantile and other factors, there may be a wide confidence interval around each of the ten plotted bin values.

COMPARISON OF UNIVARIATE RELATIONSHIPS BETWEEN FISHER DETECTIONS AND HABITAT VARIABLES IN REDWOOD AND NON-REDWOOD ZONE DATA

GAM plots of the univariate relationship between fisher detection probability and density (canopy closure)(Figure 4), tree size class (Figure 5), hardwood QMDBH (Figure 6), percent conifer (Figure 7), elevation (Figure 8), precipitation (Figure 9), and TRI (Figure 10) are shown. The following patterns are noted:

1) DENSITY: The pattern of linear increase in fisher detections with increased density is consistent between the interior zone and redwood zone data (Figure 4). However, in the redwood zone data, there is a potential decrease in detections in landscapes with more than 80% average density, a relationship which would not be observed in the interior zone data because few sites there had density over 75%. This pattern may be due to the relatively low detection rate in coastal old-growth redwood stands (Slauson and Zielinski 2003).

2) TREE SIZE CLASS: A similar quadratic univariate relationship between fisher detections and size class is noted in both interior zone and redwood zone data sets (Figure 5). However, size class has an inconsistent relationship with fisher detection in the multivariate models, being expressed as a linear negative relationship in the 1999 model, versus a strong linear univariate positive relationship in the redwood zone data. This is likely due to correlations with other vegetation variables.

3) HARDWOOD QMDBH: Within the range of values with narrow GAM standard error bars, hardwood QMDBH has a linear positive correlation with fisher detection in both data sets (Figure 6). This relationship is much stronger in the interior zone data set, perhaps because

interior hardwoods (e.g., *Quercus* spp.) are more likely to be mast-producing, and to form cavities, than are coastal hardwoods such as alder (*Alnus* spp.).

4) PERCENT CONIFER: The univariate relationship between percent conifer and fisher detection is similar in both interior zone and redwood zone data in showing a quadratic relationship with a peak near 55% conifer (Figure 7). This relationship is less evident in the interior zone data as few sites show less than 55% conifer. This relationship is consistent with field knowledge of the species, as "Douglas-fir/mixed evergreen-hardwood forests of the region may produce an optimal combination of habitat resources for fishers: high levels of canopy closure, large wood provided by conifers, and mast and refuges provided by hardwoods" (Carroll et al. 1999:1357). However similarly to tree size class, percent conifer has an inconsistent relationship with fisher detection in the multivariate models, being expressed as a univariate negative relationship in the 1999 model, versus a univariate positive relationship in the redwood zone data.

5) ELEVATION: Elevation shows a negative relationship with fisher detection in the interior zone data, versus a positive association in the redwood zone data (Figure 8). These simply express two segments of a quadratic relationship in which fisher distribution is centered at mid-elevations (~800 m) in the Douglas-fir/mixed evergreen-hardwood zone.

6) PRECIPITATION: The relationship of fisher detections to precipitation shows a similar pattern to that with elevation, peaking at ~1900mm (Figure 9). This would imply that the positive coefficient for precipitation in the 1999 model may have low generality.

7) TERRAIN RUGGEDNESS (TRI): TRI shows a relatively consistent positive relationship with fisher detection in both data sets, although there is a possible decline at very high TRI values (Figure 10).

NEW LOGISTIC REGRESSION MODELS INCORPORATING REDWOOD ZONE DATA

In the comparisons between models based on the model structure of 1999 model, but with coefficients recalculated with the redwood zone data only, the percent conifer, precipitation, and interaction terms (density * percent conifer and size * precipitation) became non-significant. The quadratic relationship with UTM northing retained significance, although one term was non-significant (Table 2). The coefficient for density decreased in magnitude and that for size class switched from negative to positive. In the model calculated from combined interior and redwood

zone data (Model 1), the percent conifer and size * precipitation terms became non-significant. The size class coefficient was slightly positive and the quadratic effect of UTM northing was stronger than in the 1999 model (Table 2).

Because of the strong effect of the trend surface variable (UTM northing quadratic term), both the redwood zone model and Model 1 limit fisher distribution in a north-south gradient more strongly than does the 1999 model, showing near zero probabilities of detection north of the latitude of Jedediah Smith State Park and south of Humboldt Bay. An alternate model, developed from the combined data set but excluding the trend surface variable from the model structure, produced a predicted probability surface similar to that of the 1999 model (Model 2, Table 3, Figure 11). This model contained the variable TRI, in addition to terms for density, size class, percent conifer, precipitation, and density * percent conifer.

EXTRAPOLATIONS TO THE SIERRA NEVADA

The most recent California survey data suggests that fishers are absent from the northern Sierra Nevada (Zielinski et al. in press) making it impossible to produce a habitat suitability model using field data from this region. One alternative is to use fisher survey data from elsewhere and extrapolate predictions to the northern Sierra Nevada. Seo et al. (in prep) have conducted this exercise, identifying topographic ruggedness as one of several important predictors. Because TRI also proved to be one of the most significant terms in the new models produced here, I also extrapolated predictions from the models developed here outside of northwestern California to the Sierra Nevada. For this purpose, minimal models were developed using only terms for TRI and either density (Model 3, Table 3, Figure 12) or density as derived from WHR closure class (Model 3b). Deriving density from WHR closure class allowed extrapolation of Model 3b seamlessly across the entire extent of the TTF data set (Figure 12). In contrast, model 3 could be extrapolated to the Sierra Nevada (Figure 13) only by assuming comparability between the density measurements in two disparate vegetation data sets (TTF for northwestern California and USFS Remote Sensing Lab for the Sierra Nevada). When models were compared using the Bayesian Information Criterion (BIC), BIC values for Model 2 (1611.2) were superior to those for Model 1 (1625.4) or Model 3 (1644.2), as were Akaike Information Criterion (AIC) values.

Extrapolating Model 3b to the Sierra Nevada correctly predicted known fisher

distribution east of Interstate 5 in northern Shasta County. Model 3b also predicts suitable habitat on the northern Plumas National Forest (e.g., the Feather River Canyon)(Figure 12), similar to the prediction of Seo et al. (in prep.) in this region. Extrapolating Model 3 using density data for all Sierran USFS lands developed by the USFS Remote Sensing Laboratory also identifies these northern Sierra habitat areas, as well as successfully predicting known Southern Sierra fisher range (Figure 13). However, all predicted Sierran habitat areas are of small extent compared to predicted habitat within northwestern California.

In contrast to a univariate model based on TRI (Seo et al. in prep.), the models described here based on both density and TRI generally predict low habitat suitability in high elevation areas. However, congressional-designated reserves (wilderness) in the Klamath region, atypically of reserves in the western US, does encompass areas of mid-elevation, closed canopy forest (such as Wooley Creek [Marble Mountains] and New River [western Trinity Alps]), and these areas show higher predicted habitat suitability.

In both the Carroll et al. (1999) model and the subsequent models described here, the eastern interior Klamath region (e.g., around Trinity Lake) is predicted to have lower habitat suitability than areas to its west, based on survey data from HSU studies used in developing these models. Thus while fishers may occur there, the model results imply that they occur at lower densities. However, because the eastern interior region has received lower levels of survey effort, model uncertainty may be higher there and further survey effort would likely improve model accuracy.

DISCUSSION

The relatively good fit between the model of Carroll et al. (1999) and the redwood zone survey data is encouraging, given that no redwood zone data was used in constructing the 1999 model. It implies that predictor variables such as canopy closure are biologically-relevant limiting factors whose correlation with fisher distribution has some generality across forest types and ecoregions. The generality of the link between fisher habitat and landscapes of high canopy closure has been demonstrated in the Klamath (Carroll et al. 1999), the Rocky Mountains (Carroll et al. 2001), and redwood zone (this study), and is consistent with results from finer-scale field studies (Powell et al. 2003, Zielinski et al. 2004). Canopy closure is generally higher in the Klamath region than in other parts of the Pacific states due to the major evergreen

hardwood component, and the relative resilience of the Klamath fisher population has been attributed to this (Carroll et al. 1999).

It is important to clarify that the landscape-scale canopy closure metric is similar to the percentage of the landscape in older forest (Slauson and Zielinski 2003) or stand size (Rosenberg and Raphael 1986). Therefore, although redwood zone *sites* may reestablish high canopy closure at an early age, due to the intensive rotations characteristic of industrial timberlands the surrounding *landscapes* will differ widely in average canopy closure (Figure 4). I use the term older forest here to contrast to early seral regenerating stands that not yet achieved high canopy closure. Thus older forest as used here is not synonymous with old-growth forest. More evidence currently exists for the importance of landscapes with a high proportion of older forest to fishers than for the importance of old-growth characteristics on a landscape scale. Intensive timber harvest activities on industrial timberlands and some areas of public lands in the study region have reduced the extent of older forest in this sense, at the same time as fire suppression has allowed increased canopy closure within older forest in some forest types.

The high significance of terrain ruggedness (TRI) in the models is less clearly linked to biologically limiting factors. Although some carnivores such as the mountain lion (*Puma concolor*) benefit directly from terrain ruggedness through increased prey vulnerability (Seidensticker et al. 1973), this has not been hypothesized for the fisher. Topography was not a significant predictor of fisher distribution in the Rocky Mountains (Carroll et al. 2001). The correlation of fisher distribution with TRI in California may be due to spurious correlation with other factors such as past trapping access or it may simply index human access, with less accessible (more rugged) locations having less overall human disturbance. This might limit the ability to extrapolate this relationship to adjacent regions. However, due to its lack of trend surface variables, the density/TRI model does appear more generalizable than the 1999 model, and correctly predicts fisher distribution in Shasta County and the southern Sierra Nevada (Figures 12 and 13). It may therefore be useful for predicting potential habitat in the northern Sierra Nevada. However, predicted habitat there is limited in extent when compared with that in the Klamath region, suggesting caution in reintroduction efforts (Figures 12-13). Predictions for areas outside of northwestern California are presented in the report as working hypotheses to inform future research and are too preliminary for use in fine-scale management (e.g., detailed planning of reintroduction sites).

Despite the overall fit between the 1999 model and redwood zone data, some surveys, especially in the northern redwood zone (north of Redwood Creek), fit the 1999 model poorly. At least four potential explanations exist for the lack of significant correlation between predictions and survey results in four of the nine redwood zone data sets.

1) SAMPLE SIZE: The GDR1995R and GDR2004R data sets were much smaller than the other seven data sets, making statistical detection of an effect of the same magnitude more difficult.

2) CHANGE IN VEGETATION OVER TIME: Vegetation data used in the 1999 model dates from 1990. Therefore the Slauson surveys (2000-2002) and GDR2004 and GDR2004R might show the most contrast between vegetation as used in the model and vegetation at time of survey. Changes in canopy closure might be especially evident in areas experiencing recent logging or in the early stages of regrowth. However, some older data sets fit the model poorly (GDR1994R, GDR1995R, HSU) and some later data sets fit the model well (GDR2004, PALCO).

3) SEASONAL EFFECT: The GDR1994R, GDR1995R, GDR2004R, and RSL surveys (all except for GDR1994R with poorer fit to the 1999 model) were conducted in summer/fall, whereas the GDR1994, GDR1995, GDR2004, and PALCO surveys (all with good fit to the 1999 model) were conducted in winter/spring. Survey date data is missing for the HSU surveys, but the study plan describes surveys as occurring in summer as well, consistent with the HSU data's poor fit to the original 1999 model. This effect might be related to contrasts between seasons in spatial patterns of prey availability or other influences on habitat selection (e.g., thermoregulatory needs) or detectability. Detection success is somewhat lower overall in the summer surveys versus winter surveys (12.68% versus 18.04%), which could be due to increased bear damage during summer. However, the original data set used in Carroll et al. (1999) was a combination of summer and winter surveys, so one would have to speculate that this effect was more evident in redwood zone than in interior zone data. The 1999 model is not a stand-level model of within-home range habitat selection, but instead uses landscape-level variables to predict where fishers may locate their home ranges (Carroll et al. 1999). Therefore any seasonal effect would be hypothesized to be affecting landscape-level detectability rather than occupancy of a specific stand-level habitat type.

4) GEOGRAPHIC PATTERNS IN MODEL PERFORMANCE: The redwood zone data fit the 1999 model well in the southern and central portions of the redwood zone, but poorly north of Redwood Creek (Redwood National and State Parks). The RSL data is from the northern zone,

and the HSU data is primarily from this zone. This suggests that there are strong geographic patterns in the degree of fit between the 1999 model and the redwood zone data. Such geographic patterns in prediction error could arise because of the structure of the 1999 model. Fisher populations within northwestern California are hypothesized to be linked in a regional metapopulation, such that occupancy in any particular site depends upon both the characteristics of that site and the distance from regional source habitat (Carroll et al. 1999). Incorporating this type of spatial dependence into a habitat selection model is difficult (Latimer et al. 2005), and the 1999 study has been criticized for not adequately incorporating spatial autocorrelation (Manly et al. 2001). In Carroll et al. (1999), the spatial correlation structure of the data was modeled as a combination of coarse-scale trend and finescale variation, referred to as first- and second-order effects (Bailey and Gatrell 1995). The authors modeled first-order effects through the use of linear and higher-order polynomial functions of the spatial coordinates, a technique known as trend surface analysis (Haining 1990). They modeled environmental covariates as spatially autocorrelated mesoscale or second-order variation using a moving-average function that assigns to each cell the mean value of the vegetation attributes within a circular moving window (Haining 1990). Although these techniques were “state of the art” at the time of the study, they have limitations in their ability to mimic the underlying biological processes causing spatial dependence in the data. In particular, the trend surface variables are likely to have poor generality if the model is extrapolated outside the spatial extent of the original survey data set. The low generality of the trend surface component in the 1999 model is likely a major cause of its poor fit to new survey data from the northern limits of the redwood zone. Because metapopulation-level effects (such as the rescue effect due to dispersal (Brown and Kodric-Brown 1997)) would be most apparent in fisher populations at the periphery of the regional metapopulation, the model might be expected to show poorer fit in these areas. Excluding trend surface variables (e.g., models 2 and 3 above) may broaden the generality of the model, but at the expense of overpredicting fisher occurrence in peripheral areas.

Recent advances in spatial modeling using Markov Chain Monte Carlo techniques (e.g., the program WINBUGS (Spiegelhalter et al. 2003)) may provide a biologically-realistic tool for producing more accurate fisher distribution models that incorporate both local habitat factors and metapopulation effects (Latimer et al. 2005). Such spatial models also resolve problems of pseudo-replication caused by incorporating repeated surveys at the same or neighboring sites.

However, data sets of greater than 1000 locations are still very challenging computationally given current computer speeds (Latimer et al. 2005). Spatially-explicit population models such as PATCH (Schumaker 1998) could provide an alternate or complementary tool to explore spatial dependence in fisher metapopulations. Such models directly incorporate the effect of dispersal by modeling individual birth, death, and dispersal events on the landscape (Carroll et al. 2003). In summary, the ability of the 1999 model to predict fisher distribution in the redwood zone is encouraging but also highlights several aspects in which such models can be strengthened to provide more accurate and informative tools for aiding recovery of the species.

ACKNOWLEDGMENTS

David Lamphear, of Green Diamond Resource Company, was instrumental in helping assemble the field survey data for analysis. Lowell Diller, of Green Diamond Resource Company, Sal Chinnici, of Pacific Lumber Company, Rick Golightly of Humboldt State University, and Keith Slauson of the USDA Forest Service Pacific Southwest Research Station provided data for the analysis. Laura Finley, of the USDI Fish and Wildlife Service, helped initiate the project and provided the funds to conduct it.

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TABLES

Table 1. Results of t-tests comparing redwood zone fisher survey data sets with predictions from Carroll et al. (1999) model. GDR = Green Diamond, HSU = Humboldt State University, PALCO = Pacific Lumber, RSL = Redwood Sciences Laboratory. A positive trend indicates that fisher detection sites showed higher predicted probability than non-detection sites.

DATASET	SIZE	% DETECTION	P-VALUE	TREND
GDR1994	238	18.1	0.0445	+
GDR1994R	48	22.9	0.0011	+
GDR1995	236	21.2	0.0188	+
GDR1995R	66	21.2	0.2743	+
GDR2004	230	14.8	0.0038	+
GDR2004R	48	10.4	0.937	+
HSU	119	9.2	0.4352	+
PALCO	175	5.7	0.0137	+
RSL	364	12.9	0.3026	+
OVERALL	1524	14.8	<0.001	+

Table 2. Coefficients in logistic regression models fit with interior, redwood, and combined fisher survey data sets. NS = not significant.

VARIABLE	1999	REDWOOD	COMBINED (Model 1)
Density	0.5365416	0.07573566	0.1971670
Size Class	-0.1287142	2.651877	0.00940196
%Conifer	0.4492566	0.01100843(NS)	0.1584445(NS)
Precipitation	-0.01409821	0.003927531(NS)	-0.0005342987
UTMN	0.001347394	0.005498617(NS)	0.002434118
$UTMN^2$	$-1.495646*10^{-10}$	$-6.050976*10^{-10}$	$-2.667851*10^{-10}$
Density*%Conifer	-0.005364044	-0.0007361238(NS)	-0.002409484
Size*Precipitation	0.005575764	-0.001101238(NS)	-0.00009.847074(NS)

Table 3. Coefficients in new logistic regression models fit with combined fisher survey data sets.

VARIABLE	Model 2	Model 3
Density	0.262561	0.04594283
Size Class	-2.127242	
%Conifer	0.2080611	
Precipitation	-0.0009734838	
Density*%Conifer	-0.002673655	
TRI	0.02816412	0.0226603

FIGURES

Figure 1. Distribution of survey locations for the three groups of surveys referenced in this report. Redwood = 1160 locations from surveys conducted by Green Diamond, PALCO, and HSU, RSL = 364 locations surveyed by Redwood Sciences Lab, 1999 = the 682 locations analyzed in the model of Carroll et al. (1999).

Figure 2. Distribution of fisher detections from the three groups of surveys referenced in this report and shown in Figure 1.

Figure 3. Plot of predicted probability values from the 1999 model at survey locations, divided into ten equal-sized bins plotted against observed fisher detection rate within these binned groups. The red line represents results from the 1999 data set (n=682), while the black line represents results from the redwood zone data set (n=1160).

Figure 4. Generalized additive modeling (GAM) plots of the univariate relationship between density (canopy closure) and fisher detection probability for (a) the 1999 data set (n=682), (b) the redwood zone data set (n=1160), and the combined 1999 and redwood zone data set (n=1842).

Figure 5. Generalized additive modeling (GAM) plots of the univariate relationship between tree size class and fisher detection probability for (a) the 1999 data set (n=682), (b) the redwood zone data set (n=1160), and the combined 1999 and redwood zone data set (n=1842).

Figure 6. Generalized additive modeling (GAM) plots of the univariate relationship between hardwood QMDBH and fisher detection probability for (a) the 1999 data set (n=682), (b) the redwood zone data set (n=1160), and the combined 1999 and redwood zone data set (n=1842).

Figure 7. Generalized additive modeling (GAM) plots of the univariate relationship between percent conifer and fisher detection probability for (a) the 1999 data set (n=682), (b) the redwood zone data set (n=1160), and the combined 1999 and redwood zone data set (n=1842).

Figure 8. Generalized additive modeling (GAM) plots of the univariate relationship between elevation and fisher detection probability for (a) the 1999 data set (n=682), (b) the redwood zone data set (n=1160), and the combined 1999 and redwood zone data set (n=1842).

Figure 9. Generalized additive modeling (GAM) plots of the univariate relationship between precipitation and fisher detection probability for (a) the 1999 data set (n=682), (b) the redwood zone data set (n=1160), and the combined 1999 and redwood zone data set (n=1842).

Figure 10. Generalized additive modeling (GAM) plots of the univariate relationship between terrain ruggedness (TRI) and fisher detection probability for (a) the 1999 data set (n=682), (b)

the redwood zone data set (n=1160), and the combined 1999 and redwood zone data set (n=1842).

Figure 11. Probability of fisher detection as predicted by a model built from the combined 1999 and redwood zone data set (Model 2: Table 3), with a model structure similar to that of the 1999 model but excluding the trend surface variable (UTM northing) and adding terrain ruggedness (TRI).

Figure 12. Probability of fisher detection for northwestern California and the northern Sierra Nevada as predicted by a model built from the combined 1999 and redwood zone data set (Model 3b), with a model structure incorporating only density (in the form of WHR closure class) and terrain ruggedness (TRI).

Figure 13. Probability of fisher detection for USFS lands in the Sierra Nevada as predicted by a model built from the combined 1999 and redwood zone data set (Model 3b), with a model structure incorporating only density and terrain ruggedness (TRI).

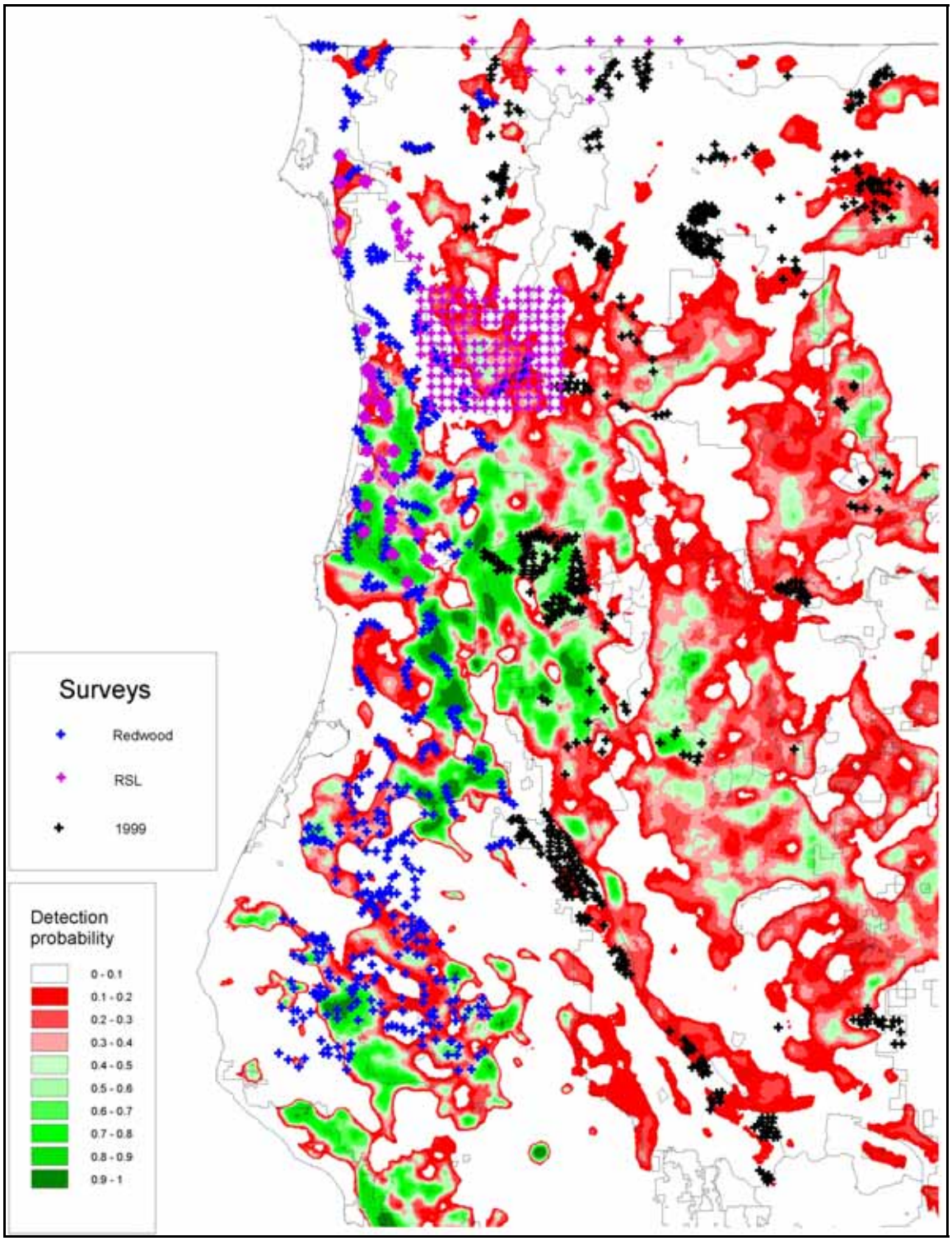

Figure 1. Distribution of survey locations for the three groups of surveys referenced in this report. Redwood = 1160 locations from surveys conducted by Green Diamond, PALCO, and HSU, RSL = 364 locations surveyed by Redwood Sciences Lab, 1999 = the 682 locations analyzed in the model of Carroll et al. (1999).

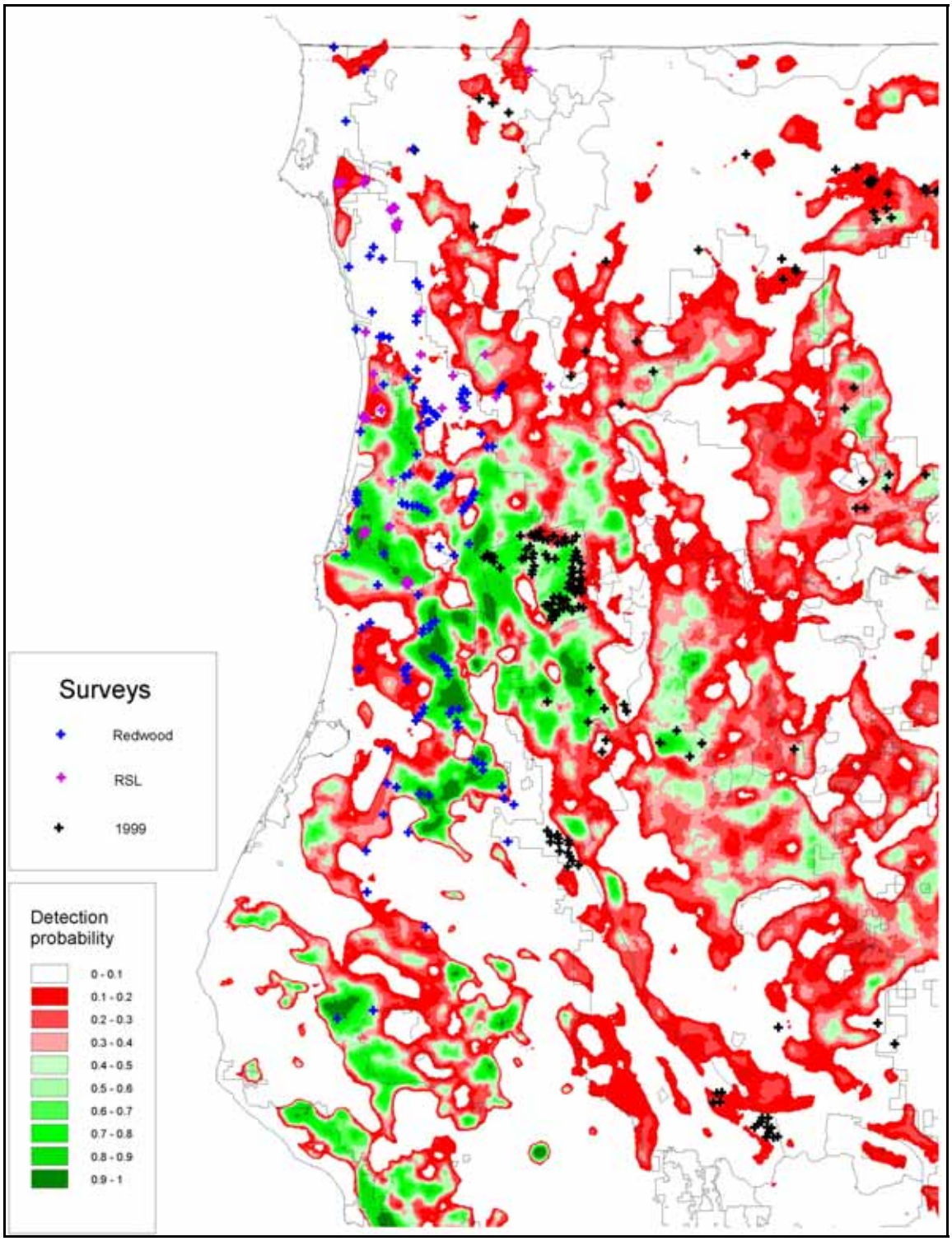

Figure 2. Distribution of fisher detections from the three groups of surveys referenced in this report and shown in Figure 1.

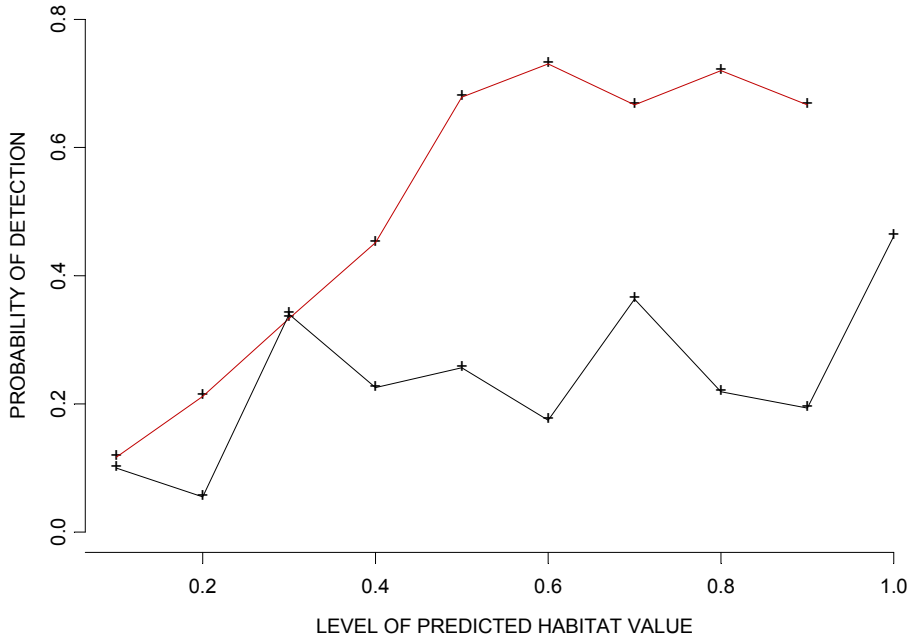

Figure 3. Plot of predicted probability values from the 1999 model at survey locations, divided into ten equal-sized bins plotted against observed fisher detection rate within these binned groups. The red line represents results from the 1999 data set (n=682), while the black line represents results from the redwood zone data set (n=1160).

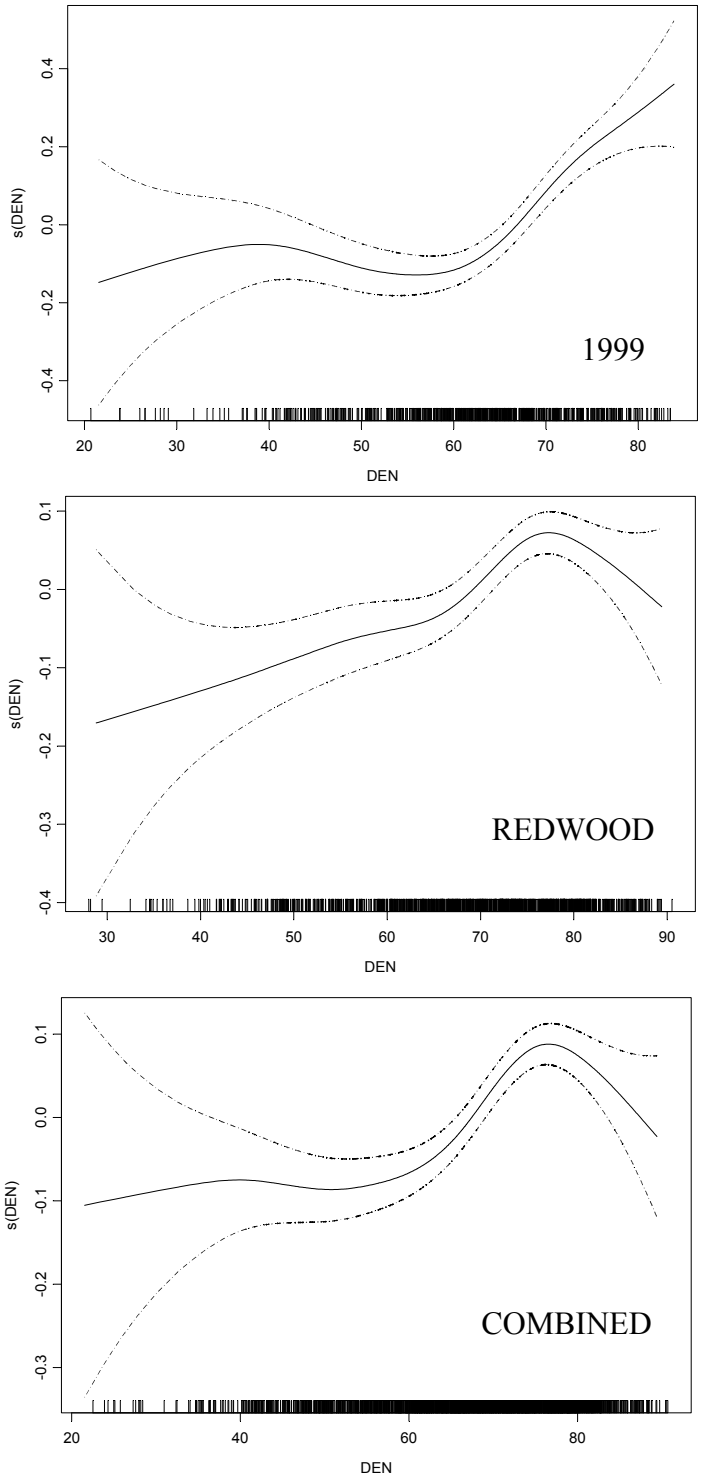

Figure 4. Generalized additive modeling (GAM) plots of the univariate relationship between density (canopy closure) and fisher detection probability for (a) the 1999 data set (n=682), (b) the redwood zone data set (n=1160), and the combined 1999 and redwood zone data set (n=1842).

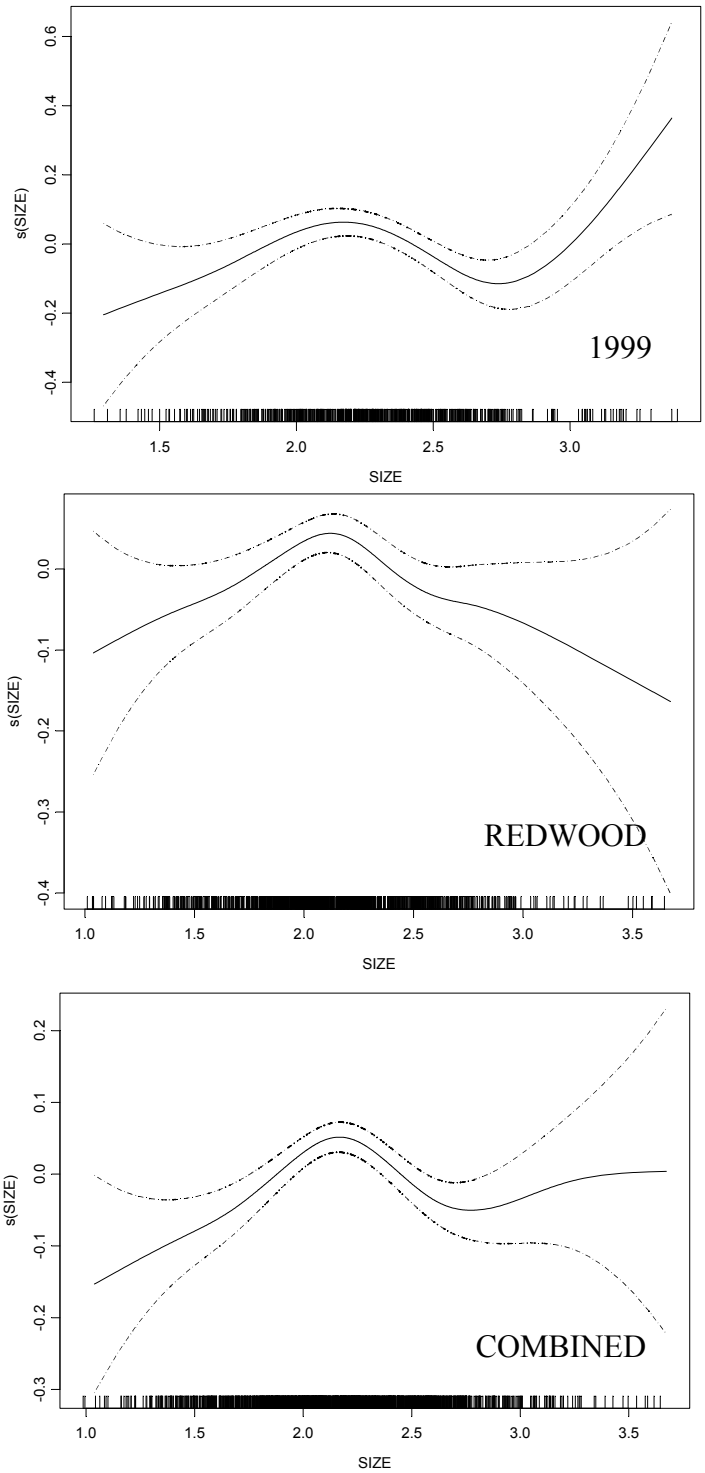

Figure 5. Generalized additive modeling (GAM) plots of the univariate relationship between tree size class and fisher detection probability for (a) the 1999 data set (n=682), (b) the redwood zone data set (n=1160), and the combined 1999 and redwood zone data set (n=1842).

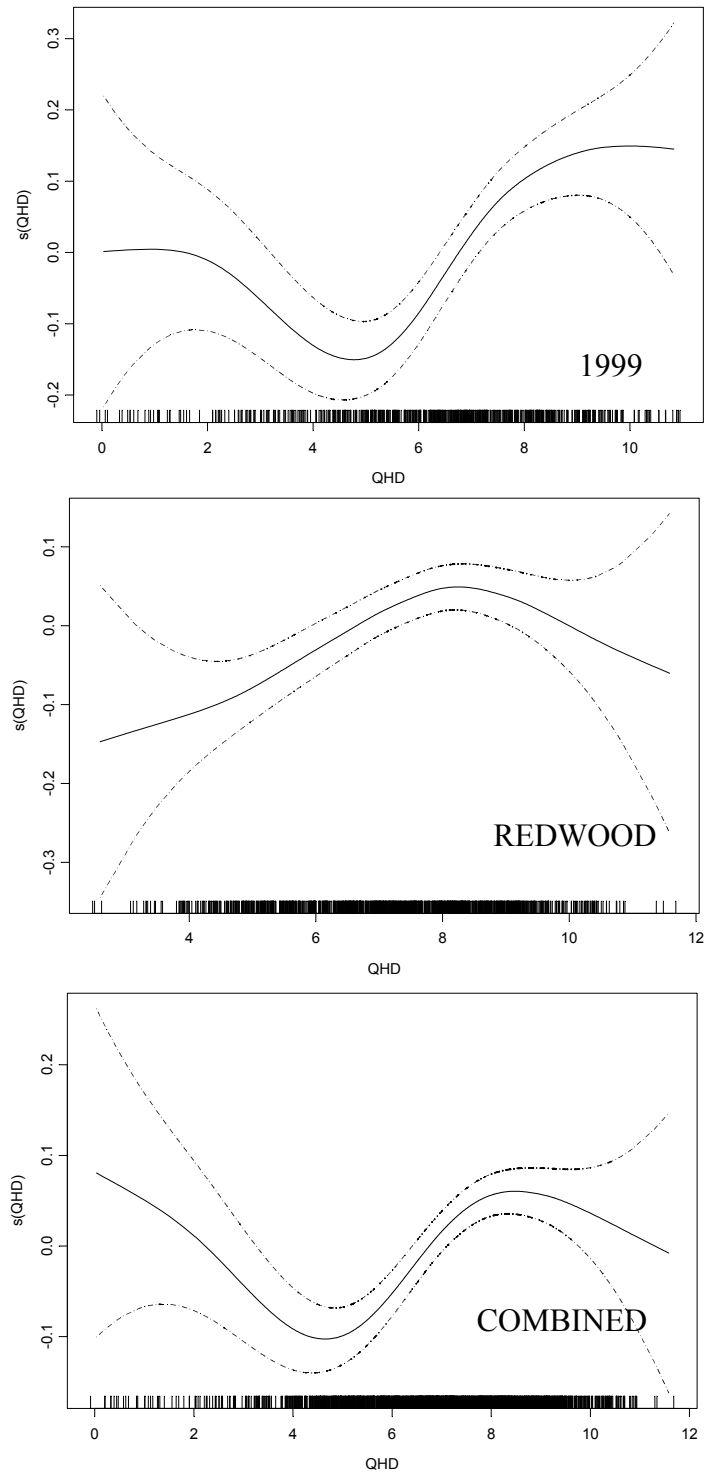

Figure 6. Generalized additive modeling (GAM) plots of the univariate relationship between hardwood QMDBH and fisher detection probability for (a) the 1999 data set (n=682), (b) the redwood zone data set (n=1160), and the combined 1999 and redwood zone data set (n=1842).

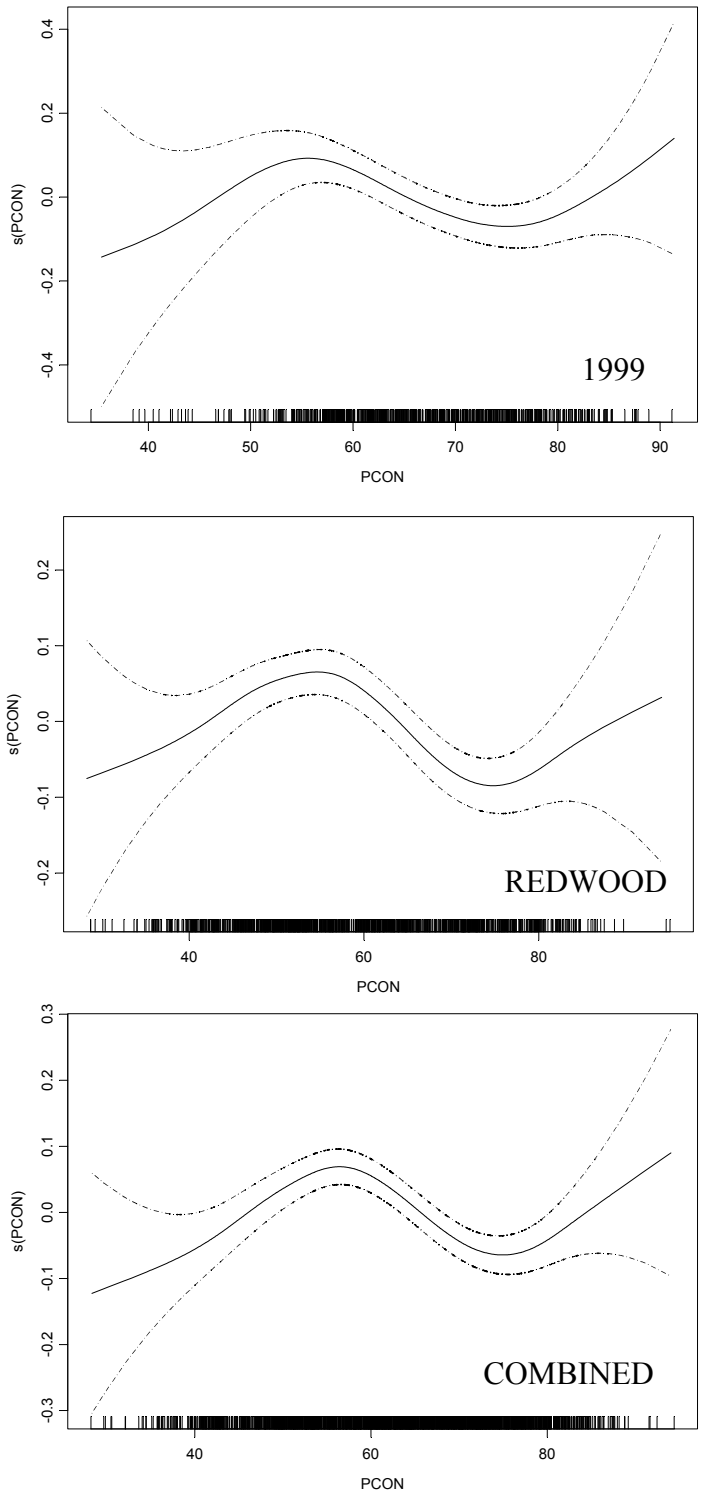

Figure 7. Generalized additive modeling (GAM) plots of the univariate relationship between percent conifer and fisher detection probability for (a) the 1999 data set (n=682), (b) the redwood zone data set (n=1160), and the combined 1999 and redwood zone data set (n=1842).

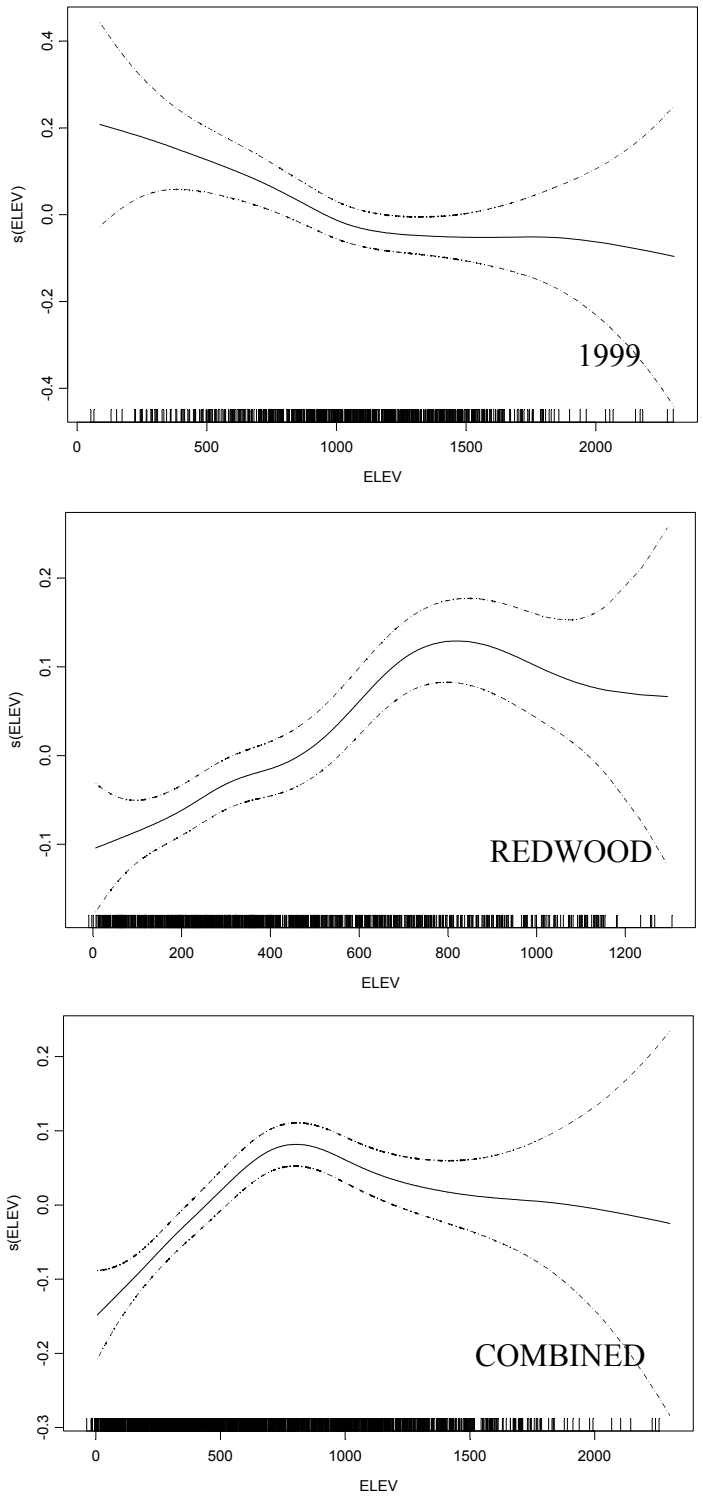

Figure 8. Generalized additive modeling (GAM) plots of the univariate relationship between elevation and fisher detection probability for (a) the 1999 data set (n=682), (b) the redwood zone data set (n=1160), and the combined 1999 and redwood zone data set (n=1842).

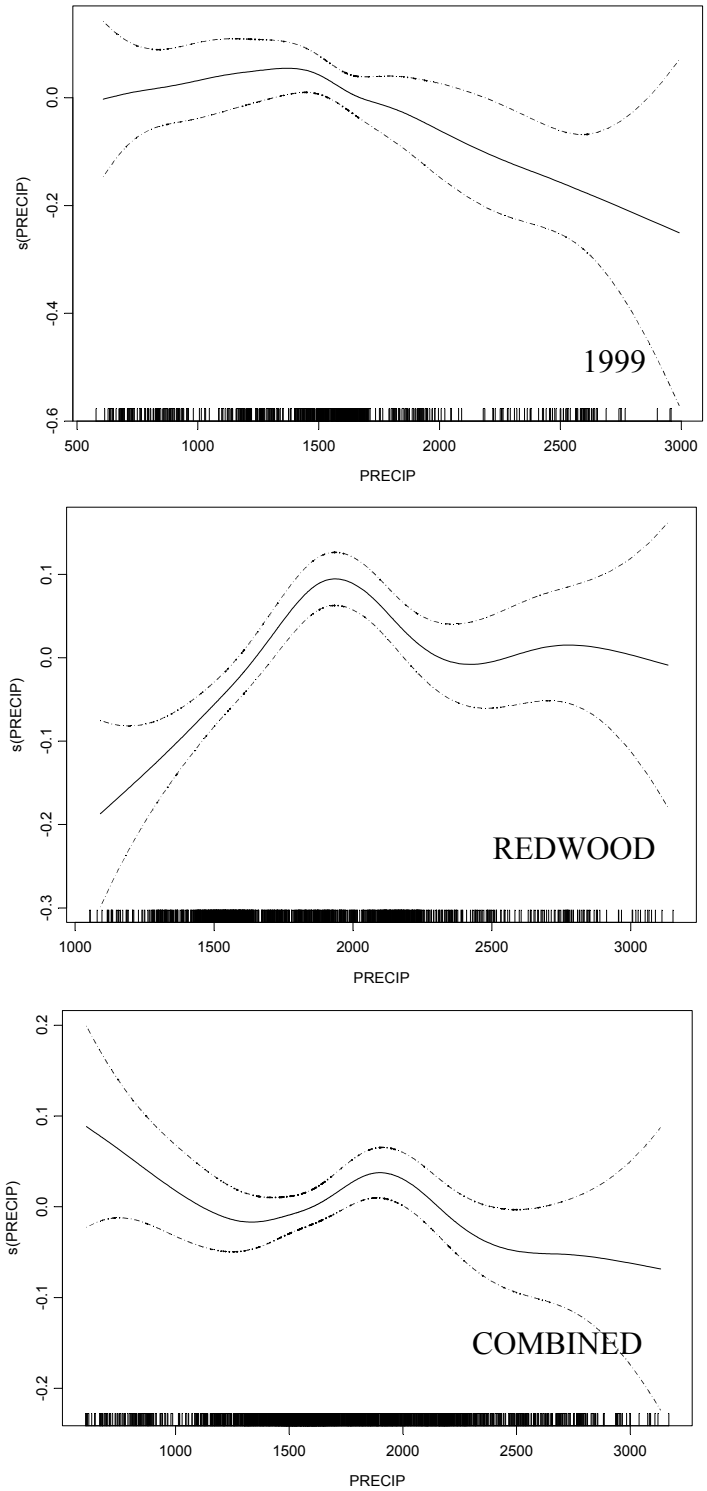

Figure 9. Generalized additive modeling (GAM) plots of the univariate relationship between precipitation and fisher detection probability for (a) the 1999 data set (n=682), (b) the redwood zone data set (n=1160), and the combined 1999 and redwood zone data set (n=1842).

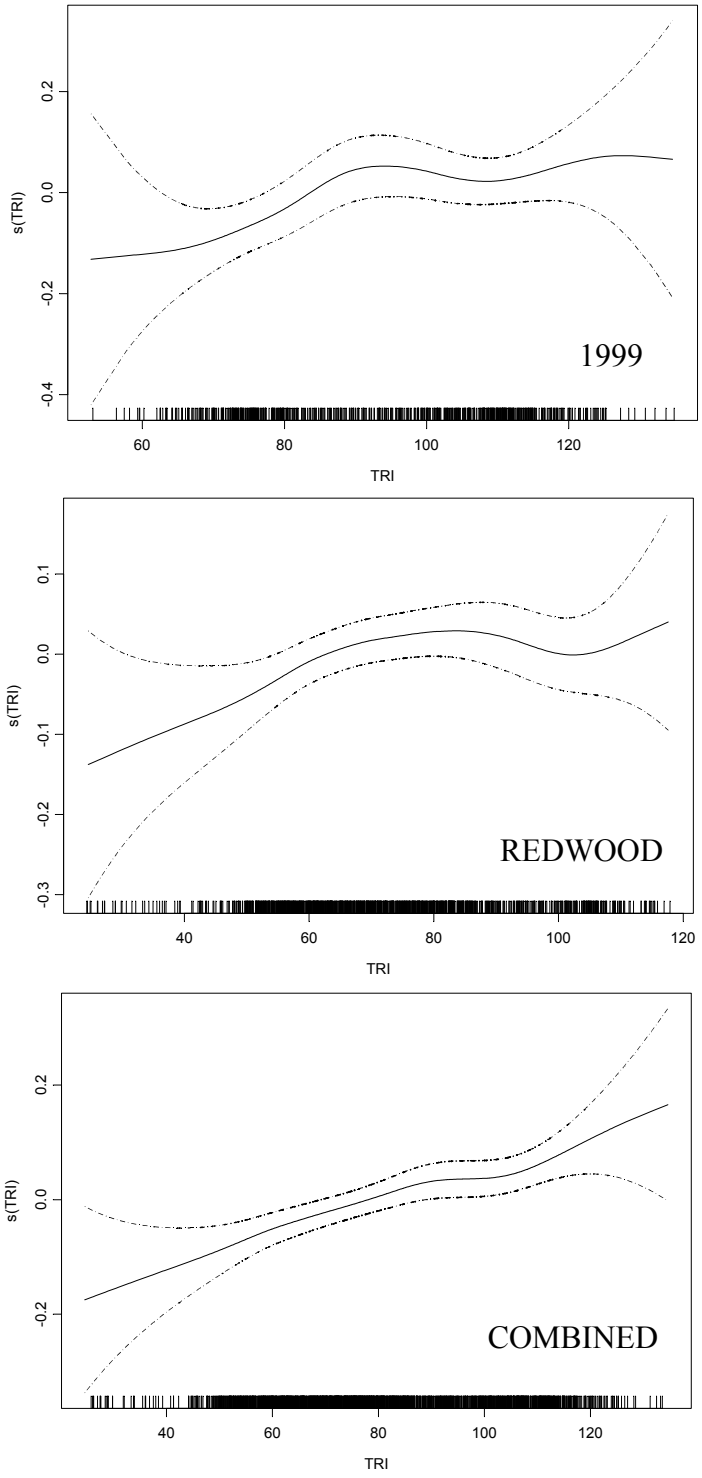

Figure 10. Generalized additive modeling (GAM) plots of the univariate relationship between terrain ruggedness (TRI) and fisher detection probability for (a) the 1999 data set (n=682), (b) the redwood zone data set (n=1160), and the combined 1999 and redwood zone data set (n=1842).

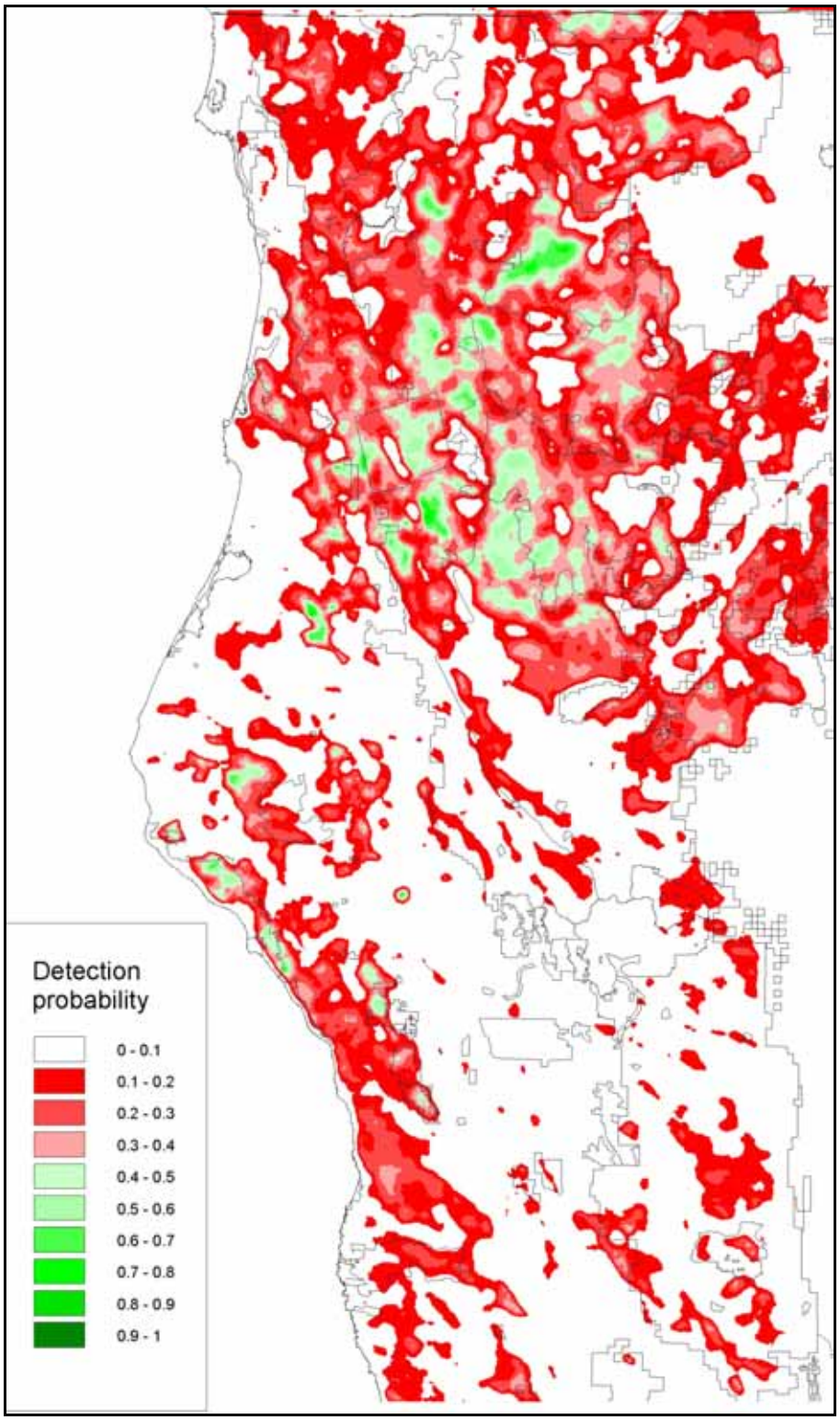

Figure 11. Probability of fisher detection as predicted by a model built from the combined 1999 and redwood zone data set (Model 2: Table 3), with a model structure similar to that of the 1999 model but excluding the trend surface variable (UTM northing) and adding terrain ruggedness (TRI).

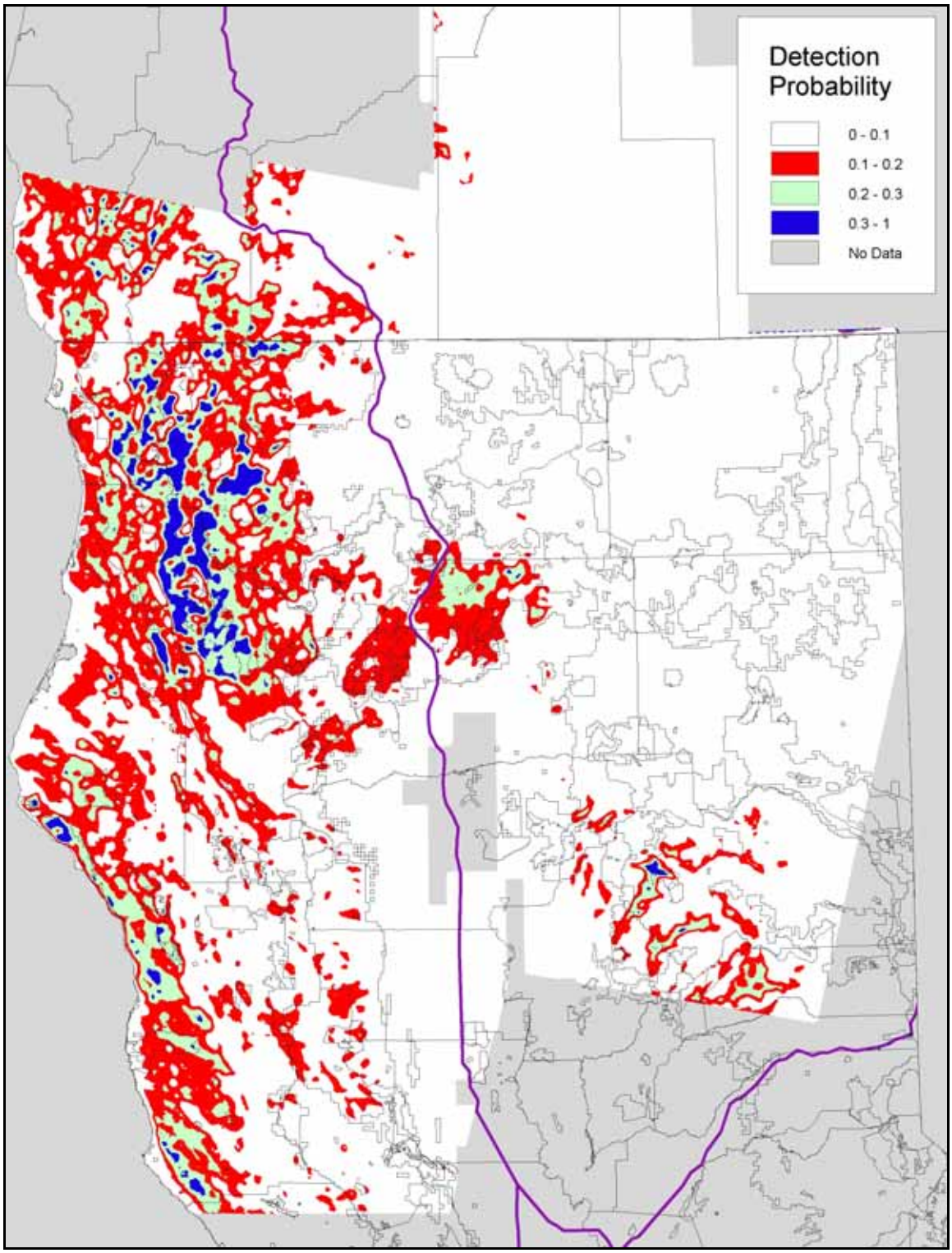

Figure 12. Probability of fisher detection for northwestern California and the northern Sierra Nevada as predicted by a model built from the combined 1999 and redwood zone data set (Model 3b), with a model structure incorporating only density (in the form of WHR closure class) and terrain ruggedness (TRI).

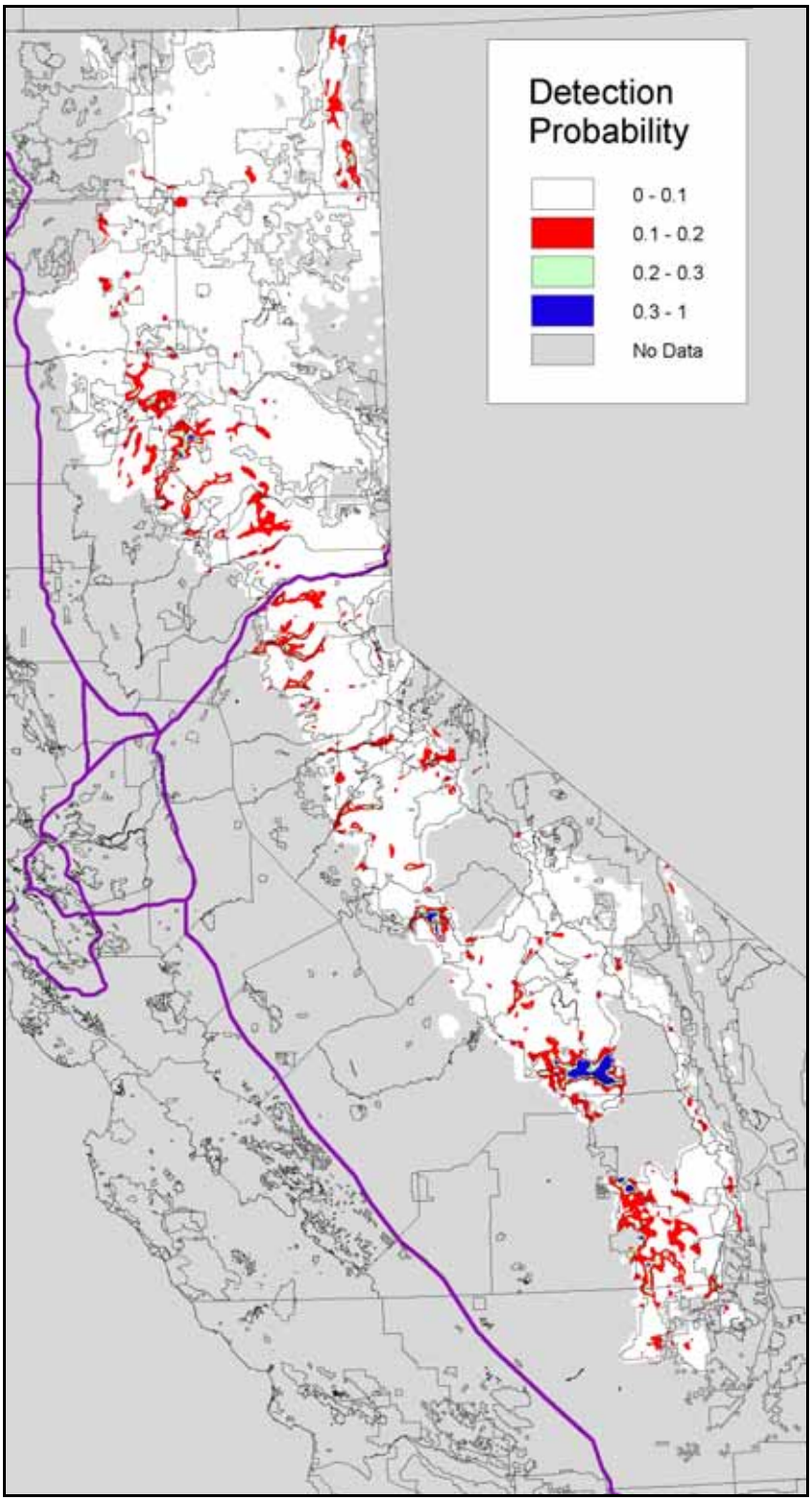

Figure 13. Probability of fisher detection for USFS lands in the Sierra Nevada as predicted by a model built from the combined 1999 and redwood zone data set (Model 3b), with a model structure incorporating only density and terrain ruggedness (TRI).