Developing a Habitat Suitability Index Model for Masked Bobwhite

Progress Report

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Background and Introduction

Since the initial discovery of masked bobwhite in 1864 and subsequent description in 1884, the species has had a tenuous history. Masked bobwhite were thought to be extirpated in southern Arizona by 1900 and believed extinct in Sonora, Mexico by 1950. Three isolated, wild populations were subsequently re-discovered in Sonora between 1964 and 1992, one or two of which are thought to have since disappeared. During the past 10 years, only two populations were known to exist in the wild, one on the Buenos Aires National Wildlife Refuge (BANWR) and one on several private ranches in north-central Sonora, Mexico. Numbers of birds in these two areas have declined in recent years and no birds were detected in either location during the 2009 standardized survey effort (although BANWR staff reported several incidental detections of birds in 2009).

The last four decades of masked bobwhite recovery efforts have had limited success. The sole population in the U.S. (at BANWR) required annual supplementation of captive-reared individuals. The sole wild population in Mexico is: 1) small, and possibly extirpated, 2) adversely affected by over-grazing by livestock and planting of buffelgrass, and 3) likely dependent on more intensive conservation or habitat management efforts. Successful recovery of the species will likely require a concerted, international collaborative effort between the United States and Mexico. The Masked Bobwhite Recovery Plan suggests a habitat suitability analysis to guide habitat management and bobwhite reintroduction efforts in the U.S. and Mexico. Masked bobwhite recovery is therefore dependent upon synthesizing masked bobwhite habitat requirements, identifying areas with remaining habitat, and managing existing habitat to improve habitat suitability. Unfortunately, traditional methods of developing and testing a habitat suitability model are not feasible because of the virtual lack of wild birds. Moreover, results from a habitat suitability investigation on birds occupying sub-optimal habitat could lead to incorrectly identifying poor habitat as optimal. In order to overcome these obstacles, we are pursuing a novel method which incorporates both published literature and expert opinion to develop a suite of habitat suitability index models for Masked Bobwhite.

Habitat suitability index (HSI) models were introduced by the Biological Services Division of the U.S. Fish and Wildlife Service in 1981 to better evaluate fish and wildlife habitat needs by combining expert opinion and published literature to clearly define the suitability of important habitat components (Shamberger et al. 1982). The method was developed in response the *Habitat Evaluation Procedures* (U.S. Fish and Wildlife Service 1980), which was a technique for evaluating changes to wildlife habitat resulting from land and water use changes. HSI models are divided into three components: 1) written description, 2) graphical representation, and 3) mathematical representation. Typical HSI models combine both published literature and multiple expert opinions into a single model to consolidate information from multiple sources into a single document. The original intention of HSI models was to create testable hypotheses of species-habitat relationships (Shamberger et al. 1982) rather than proven cause and effect relationships.

Unfortunately, development of a single HSI model for masked bobwhite would be very difficult and not very informative. There is a only limited amount of published literature on the masked bobwhite and much of this research was conducted either on birds in Mexico during a period of severe population decline, or on captive bred birds in the U.S. that may or may not exhibit the same habitat affiliations as wild birds. For these reasons we believe it is appropriate to approach the literature with caution. Likewise, there is a diversity of opinion among species experts about the most suitable habitat for masked bobwhite. Rather than attempting to incorporate disparate opinions into a single model we are developing a series of separate habitat suitability models one for the published literature and one for each species expert. The individual models can then be used as competing hypotheses where they differ and management guidelines where they agree.

Project Objectives

Our three primary goals for this project are: 1) Determine important habitat features for masked bobwhite; 2) Quantify the explicit relationship between these important habitat features and habitat suitability for masked bobwhite; and 3) Translate the various bivariate relationships between habitat features and habitat suitability into a suite of mathematical habitat suitability models.

Progress to Date

*Objective 1*. We identified 12 species experts and asked them if they were willing to meet with us for one-on-one interviews to provide their knowledge of masked bobwhite habitat suitability. Three of the experts we contacted did not respond to multiple requests for an interview (G. Camou, E. Gomez, and J. Levy). We used the following questions to aid in collecting information about masked bobwhite habitat from the remaining 9 experts.

* What has prevented masked bobwhite from establishing or recovering?
* What are the most important habitat variables for masked bobwhite?
* How does season (time of year) affect these variables and their importance?

The 9 experts identified 22 separate issues that they suggested affects masked bobwhite recovery. We removed 2 of these issues (breeding problems among the released birds and ability of captive birds to survive in the wild) because they were unrelated (or only very peripherally related) to habitat suitability. The remaining issues are a combination of measurable habitat features and ultimate processes that affect habitat selection (e.g., leguminous shrubs and winter food, respectively). We also asked experts to rank each variable in order of importance. The variables and their associated ranks are presented in Table 1. As might be expected, not all experts mentioned (and hence ranked) the same suite of variables. Whenever an expert failed to rank a variable that was mentioned by other experts, we inferred a rank from discussions within the interview. We left the column for rank blank if the variable was not discussed in enough detail by the expert to infer a rank. We summarized the overall importance of each variable (among all 9 experts) by taking an average of the ranks for each variable. We calculated variable weights by taking the inverse of the average rank (Table 2).

*Objective 2*. We initially selected 5 variables which were also present in the published literature to identify the quantitative relationship between each variable and habitat suitability for masked bobwhite: 1) Woody cover (brush and shrub), 2) Bare ground, 3) Nest substrate height, 4) Herbaceous cover, and 5) Visual obstruction (at ground level). We used means (and ranges) of variables from our interviews with species experts and from the published literature to produce a suite of potential relationships for each variable. In cases where we were given a mean but no range we produced three graphs with varying degrees of variance: high, medium, and low. Graphs with high variance would indicate suitability for masked bobwhite over a broad range of conditions. Conversely, graphs with low variance would indicate only a narrow range of habitat conditions are suitable for masked bobwhite. In cases where we were given a range but no mean, we created graphs with varying levels of kurtosis (skew) to create various means (low, centered, and high) within a given range. The number of graphs produced for each variable reflects either the degree of uncertainty about the relationship, or the diversity of opinions among species experts, or both. Graphs of the 5 initial variables, along with their probability density functions are presented in Appendix A. Unfortunately, this effort was not well received by several species experts. Several experts found it difficult to choose a graph because none of the relationships represented were adequately summarized and the relationships represented were too general (i.e. they did not take into account season or geographic location). In response to input from species experts we employed a slightly different technique described below under objective 3.

*Objective 3.* Only 6 of the 9 species experts agreed to assist with this objective. Two experts stated they would have no additional information outside of the published literature or other participating experts (Kuvleski, Dobrott), another expert took issue with our methodology and decided not to participate (Brown). We incorporated feedback from experts and modified our method for obtaining individual expert HSI models. Instead of using pre-determined probability distributions developed from literature and expert interviews for inclusion in individual HSI models, we allowed experts to draw hypothetical suitability relationships between each variable and masked bobwhite habitat suitability. We then developed mathematical probability distributions which replicated each experts drawing. Using this method we have completed draft HSI models for 5 species experts. Once draft models were complete, we sent them back to each corresponding expert for their verification. We have received feedback on the draft HSI models from 5 of these experts and have incorporated suggested changes. We are currently creating the last remaining HSI model and an additional HSI model based solely on the literature.

Additional Work

We have made attempts to incorporate our work with the broader work of the U.S. Fish and Wildlife Service. We initially met with Steve Sesnie, a spatial ecologist for the U.S. Fish and Wildlife Service, on 25 May 2012 to discuss how we could assist his work on spatial models for masked bobwhite habitat. We met again (over the web) with Steve Sesnie and Lacrecia Johnson (U.S. Fish and Wildlife Service Zone Biologist for the Sonoran and Chihuahuan Deserts) on 12 October, 2012. Steve Sesnie and Lacrecia Johnson are currently collecting habitat data on a stratified random sample of 50x20m plots on the Beunos Aires National Wildlife Refuge. They are also submitting a grant application to the Joint Fire Sciences Program to fund a study evaluating the use of fire for managing habitat for masked bobwhites. They were interested in what our models indicated to be important measurements to make on habitat components. We discussed our results thus far and we provided two complete masked bobwhite HSI models for them to reference while collecting habitat information on the refuge (Appendix B). We also discussed how suitability scores based on each HSI model for each plot could then be used to train a remote sensing model for use in additional areas such as northern Mexico. We will continue to collaborate with Steve and Lacrecia as this project moves forward and assist their work in any way we can.

Quantifying Uncertainty

Quantifying the uncertainty associated with the suite of HSI models we have developed will be very important as land managers attempt to improve masked bobwhite habitat or find new potential release sites. Multiple sources of uncertainty are associated with each HSI model:

1. Variable selection uncertainty
2. The nature of the suitability functions
3. The structure of the model
   1. Relationships between variables
   2. Importance of variables relative to one another
   3. Latent variables (Food, Reproduction, etc.)
4. Measurement error of model inputs

We will focus our efforts on the quantification of uncertainty associated with (2) and (3). Understanding this uncertainty will not just help land managers make decisions about habitat management, but will also identify the habitat variables which contain the greatest degree of uncertainty. Understanding the greatest sources of uncertainty will be important for directing future research efforts.

Uncertainty of Suitability Relationships

Past efforts to quantify uncertainty in expert opinions typically require the expert to explicitly specify their confidence. Unfortunately, an expert’s confidence in their own knowledge is likely to be a function of many factors, only one of which relates to the precision of their knowledge about the species habitat requirements. We are instead using the complete set of expert opinions to quantify uncertainty in the species habitat models (Fig. 3). Our current method assumes the “true” relationship is spanned by the set of expert opinions. Therefore, the degree of uncertainty surrounding any suitability function is defined by the entire set of functions across all species experts. We created graphical representations of this uncertainty for each habitat suitability relationship identified by experts. Figure 1 shows the utility of these graphs for identifying habitat variables with considerable uncertainty. The uncertainty represented in these graphs can be measured by integrating over the domain of the relationship to determine the area of each uncertainty estimate. This method allows direct comparison of uncertainty among all habitat-suitability relationships identified by the experts. Table 3 contains an ordered list of the habitat-suitability uncertainties.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Avian Predators | Winter Food | Invasive Plant spp | Climate | Woodland /Grassland Edges | Thermal Refugia | Brush and Shrub Cover | Vegetation Height (herbaceous) | Leguminous Shrubs | Vegetation Structural Diversity | Arthropod Diversity and Abundance | Bare Ground | Grass Cover | Tree Cover | Mammalian Predators | Herbaceous Species Diversity | Forb Cover | Water |
| Expert 1 | -1 |  |  |  |  |  |  |  |  |  |  |  |  | -1 | -2 |  |  | 6 |
| Expert 2 |  | 1 | -2 | 3 |  |  |  |  | 1 |  | 4 |  |  |  |  | 4 |  | 5 |
| Expert 3 |  |  |  | 1 |  | 2 | 3 |  |  | 5 |  | 4 | 5 | 2 |  | 6 | 3 |  |
| Expert 4 | -8 | 3 | -7 | 6 | 2 |  | 3 | 9 | 3 |  |  | 4 | 1 |  | -8 |  | 5 |  |
| Expert 5 | -4 | 1 |  |  | 5 | 3 | 2 |  |  | 5 |  |  | 6 | 6 | -4 |  | 6 |  |
| Expert 6 |  | 6 |  |  | 4 |  | 3 |  |  | 1 | 6 |  | 4 | 5 |  | 2 | 6 |  |
| Expert 7 |  |  | -1 | 1 | 3 |  | 5 |  | 2 | 3 |  | 4 | 3 | 6 |  | 1 | 2 | 16 |
| Expert 8 |  |  | -16 | 1 |  |  | 6 |  | 3 |  |  |  | 5 |  |  | 2 | 4 | 16 |
| Expert 9 |  |  |  | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | | | | | | | |  | | | | | | | | |  |

Table 1. Map of important variables showing degree of similarity in the rank of each variable by species experts. Not all experts ranked each variable. Where no rank was given to a variable, we inferred a rank from discussions within the interview. We left the rank column blank if the variable was not discussed in enough detail by an expert to infer a rank. All variable ranks will be confirmed in future interviews. Low numbers imply high importance whereas high numbers imply low importance.

Table 2. Variables listed in order from most important to least important according to expert opinion. These values are subject to change after confirmation of variable ranks from species experts.

|  |  |  |
| --- | --- | --- |
| Habitat Variable | Rank | Weight-1 |
| Climate | 1 | 2.166667 |
| Leguminous Shrubs | 2 | 2.25 |
| Thermal Refugia | 3 | 2.5 |
| Winter Food | 4 | 2.75 |
| Herbaceous Species Diversity | 5 | 3 |
| Woodland /Grassland Edges | 6 | 3.5 |
| Vegetation Structural Diversity | 7 | 3.5 |
| Brush and Shrub Cover | 8 | 3.666667 |
| Bare Ground | 9 | 4 |
| Grass Cover | 10 | 4 |
| Tree Cover | 11 | 4 |
| Avian Predators | 12 | 4.25 |
| Forb Cover | 13 | 4.333333 |
| Mammalian Predators | 14 | 4.5 |
| Arthropod Diversity and Abundance | 15 | 5 |
| Invasive Plant spp | 16 | 6.5 |
| Vegetation Height (herbaceous) | 17 | 9 |
| Water | 18 | 10.75 |

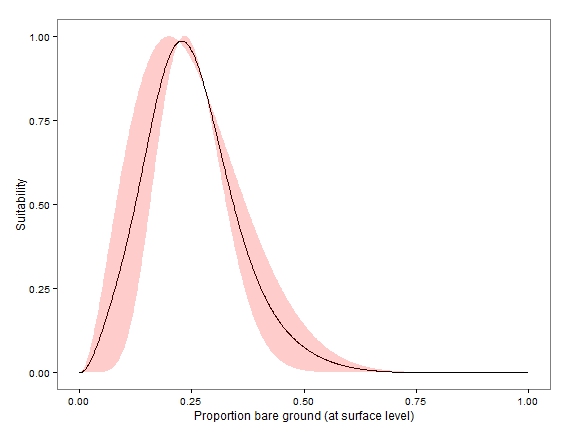
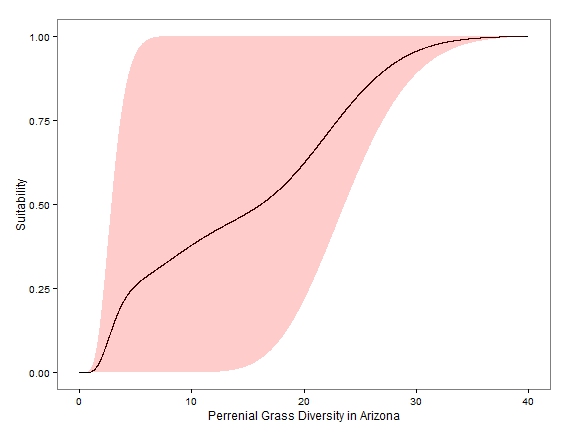
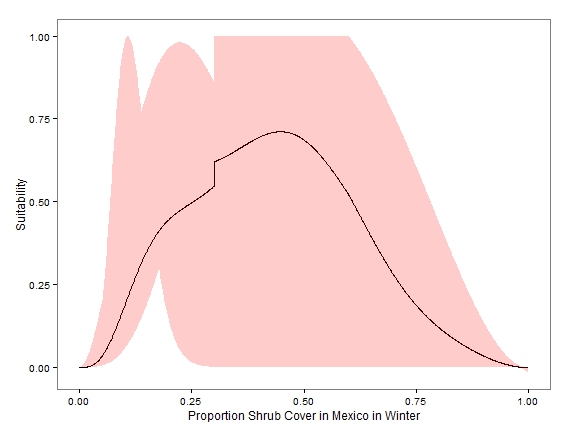


Figure 1. Examples of three habitat-suitability plots with estimates of uncertainty. The black curve represents the mean suitability relationship among all experts and the red band represents the uncertainty associated with the suitability relationship. Uncertainty is measured by the diversity of opinion among experts. The graph on the left shows a great deal of uncertainty whereas the graph on the right shows only a small amount of uncertainty. The middle graph contains a moderate amount of uncertainty but does contain a consensus on an optimal level of grass diversity.

|  |  |  |  |
| --- | --- | --- | --- |
| Habitat Variable | Uncertainty | Habitat Variable | Uncertainty |
| Forb Diversity | 751.4589 |  |  |
| Shrub Cover: MX, Summer | 681.4633 | Annual Grass Diversity, MX | 549.9952 |
| Shrub Cover: MX, Winter | 681.4633 | Annual Grass Diversity, AZ | 549.8661 |
| Forb Height in the Fall | 680.5916 | Forb Height in the Spring | 530.6362 |
| Shrub Cover: AZ, Summer | 669.5275 | Tree Cover: MX, Arroyos, Summer | 527.6743 |
| Tree Cover: MX, Uplands, Winter | 649.679 | Perennial Grass Diversity, MX | 527.2701 |
| Shrub Cover: AZ, Winter | 635.0047 | Perennial Grass Diversity, AZ | 524.865 |
| Tree Cover: AZ, Arroyos, Winter | 632.0208 | Tree Cover: MX, Uplands, Summer | 523.689 |
| Tree Cover: AZ, Uplands, Winter | 603.743 | Tree Cover: AZ, Arroyos, Summer | 522.2229 |
| Perennial Grass Cover, MX | 602.9204 | Grass Height for Nesting | 511.7814 |
| Annual Grass Cover, MX | 601.5158 | Forb Cover: AZ, Winter | 500.3264 |
| Annual Grass Cover, AZ | 592.9706 | Tree Cover: AZ, Uplands, Summer | 480.8542 |
| Perennial Grass Cover, AZ | 587.2909 | Forb Cover: MX, Winter | 466.7073 |
| Tree Cover: MX, Arroyos, Winter | 586.0451 | Forb Cover: MX, Summer | 425.4503 |
| Grass Height for Cover | 557.5849 | Shrub Height | 127.2489 |
| Forb Cover: AZ, Summer | 552.1541 | Proportion of Bare Ground | 125.2965 |

Table 3. Estimates of uncertainty associated with each habitat-suitability relationship. Estimates are order from highest (most uncertainty) to lowest (least uncertainty). Estimated are obtained by calculating the area of the uncertainty bands associated with each habitat-suitability relationship (Figure 1). We standardized all variables to control for differences in scale.

**Appendix A:**

For all beta densities listed below, the beta function (B(α,β)) is defined as:

Woody Cover (Brush and Shrub)

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Bare Ground

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Nest Substrate Height

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Herbaceous Cover

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Visual Obstruction (at ground level)

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**Appendix B**

**Habitat Suitability Index Model 1:**

The following habitat suitability index model is the result of information obtained from a single species expert. We developed this model following the U.S. Fish and Wildlife Service guide to the development of habitat suitability index (HSI) models 103-ESM (USFWS 1981). However, unlike typical HSI models this model is intended to be used in conjunction with alternative HSI models developed from additional experts and existing literature. This model represents the best estimates of a single species expert.

1.Model Applicability:

1.1 Geographic area. This model was developed based on knowledge of masked bobwhite habitat in Arizona, specifically Buenos Aires National Wildlife Refuge.

1.2 Season. This model was developed to evaluate habitat needs of masked bobwhites over the entire year.

2. Model Description:

2.1 Overview. This model considers the ability of assessed habitat to meet the food, reproductive, and cover requirements of masked bobwhite as an indicator of overall habitat suitability. All components of the model are assessed by vegetative conditions. The relationship between habitat variables and critical life history requirements of masked bobwhite is illustrated in Figure 1.

2.2 Written Documentation.

The following sections provide a written documentation of the logic and assumptions used to interpret the habitat information for masked bobwhite in order to explain the variables and equations that are used in the HSI model. We present each critical habitat requirement and describe the variables which contribute to it.

1. Reproduction. Reproductive requirements are assumed to be met if all the other critical habitat requirements are adequately addressed.
2. Food. Structural diversity is important and is a function of the species diversity of grasses, forbs, and shrubs. Adequate diversity is important for providing food year-round and can be measured via Shannon Diversity Index or similar method. Forb diversity is important for captive bred “uncultured’ masked bobwhites. Released birds don’t know how to utilize available food so it is important to have high diversity of forbs. This will increase the diversity of seed, vegetative, and arthropod food sources available to masked bobwhites over a greater period of the year. Masked bobwhites require a minimum of approximately 15 forb species before habitat becomes suitable. Habitat suitability generally increases with increasing forb diversity up to a saturation point at which increased diversity has no effect on suitability. Likewise, grass diversity is also an important food source and follows the same habitat suitability curve as forb diversity. Both perennial and annual grass species are important for food and the optimal ratio is likely 1:1. More information is needed about the role of grass diversity as a food resource for masked bobwhites. Shrub diversity is not essential but may provide an additional source of food.
3. Predator Protection. There are two important components of predator protection; 1) concealment, and 2) physical barrier. Concealment is primarily a function of forbs and grasses. Forb height is important for concealment from predators. Optimal height of forbs is between 0.33 and 1 meter. Suitability diminishes both above and below this range. Likewise, forb cover is important as escape cover year round. Forb cover is assumed to be adequate if both total cover and forb diversity are adequate. Grass cover, primarily perennial grasses, is important for concealment. Suitable levels of grass cover can create safe corridors for birds to move on the landscape. Grass cover should be measured both as stem density and as percent ground cover from above since these two metrics will indicate the suitability of grass cover to provide the appropriate cover matrix. Additionally, grass cover should be measured from the side through the use of a cover board (or similar device) to ensure adequate concealment from terrestrial predators while allowing adequate mobility and visibility.

Brush piles provide both concealment and a physical barrier and can be a replacement for natural cover if properly maintained. Brush piles should be placed approximately 45 meters apart and maintained to prevent collapse. Frames are recommended to prevent collapse of brush piles and maintain open space within the pile. Appropriate levels of shrub cover provide both concealment and physical barrier are preferable to brush piles and do not require regular maintenance. Moreover, shrub cover may provide additional benefits beyond that of predator protection (see Food). Shrubs should be between 0.33 and 2m in height to provide optimal protection from predators. As shrubs grow larger, and lose limbs which are close to the ground, they become less suitable habitat. Shrub cover is important year round but is most important during winter months. Total cover is a more important measure than any single cover metric. Total cover can be measured directly or can be computed from component parts as in Figure 1. Structural diversity creates both concealment and physical protection for masked bobwhites during the entire year while still providing adequate space for movement and visibility. Tree cover is counterproductive for masked bobwhite habitat as it provides perch sites for raptors.

**Figure 1.** The relationship between measured habitat variables, critical life history requirements, and habitat suitability for masked bobwhites.

Measured Habitat Variable Life Requisite Model Output

Forb Diversity

Structural Diversity

Grass Diversity

Food

Tree Cover

Shrub Diversity

Forb Height

Predator Protection

Suitability Index

Grass Canopy Cover

Shrub Height

Grass Height

Grass Stem Density

Grass Cover

Forb Cover

Shrub Cover

Total Cover

Grass Horizontal Cover

Brush Piles

**3. Suitability Functions and Graphs**

|  |  |  |  |
| --- | --- | --- | --- |
| Variable | Description | Suitability Function | Suitability Graph |
| FD | Forb Diversity measured as the total number of forb species on a given home range throughout the year | (Gamma CDF with α=23.5, β=1) | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dave Ellis\FD Ellis.emf |
| GD | Grass Diversity measured as the total number of both annual and perennial grass species on a given home range throughout the year | (Gamma CDF with α=23.5, β=1) | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dave Ellis\GD Ellis.emf |
| ShD | Shrub diversity measured as the total number of shrub species on a given home range throughout the year | (Gamma CDF with α=11, β=1) | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dave Ellis\ShDEllis.emf |
| FH | Forb Height measured as the average height of Forbs on a given home range |  | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dave Ellis\FH.emf |
| GH | Grass Height measured as the average height of grass on a given home range |  | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dave Ellis\GH Ellis.emf |
| SH | Shrub Height measured as the average height of grass on a given home range |  | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dave Ellis\SH Ellis.emf |
| TrC | Tree cover measured as the percent canopy cover of trees on a given home range |  | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dave Ellis\TrC Ellis.emf |
| GC1 | Grass Canopy Cover measured from above the grass canopy as the amount of ground covered by grass foliage on a given home range |  | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dave Ellis\GC1 Ellis.emf |
| GC2 | Grass Cover from the side measured as the average amount of distance until complete visual obstruction on a given home range. |  | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dave Ellis\GC2 Ellis.emf |
| GC3 | Grass basal area measured as the average area occupied by stems of grass on a given home range. | (B(5,20) is the Beta function evaluated at α=5, β=20) | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dave Ellis\GC3 Ellis.emf |
| TC | Total Cover measured as the average total canopy cover of all vegetation (and brush piles) on a given home range. Suitability of total cover differs in winter and summer. | Winter:  (B(3,7) is the Beta function evaluated at α=3, β=7) | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dave Ellis\WTC Ellis.emf |
|  |  | Summer:  (B(4,4) is the Beta function evaluated at α=3, β=7) | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dave Ellis\STC Ellis.emf |

**Equations.**

The final habitat suitability index score is a result of the combination of suitability scores from component variables. The equations which describe this combination are governed by the assumptions and relationships described in section 2.2. Additive equations imply each variable in the equation can compensate for other variables with low scores unless otherwise noted. Multiplication implies a score of zero for any variable results in a suitability score equal to zero (i.e. both variables must have non-zero scores for the habitat to be suitable).

**Habitat Suitability Index Model 2:**

The following habitat suitability index model is the result of information obtained from the consensus of two species experts. Aspects of the model for which the experts failed to reach a consensus are identified as such. We developed this model following the U.S. Fish and Wildlife Service guide to the development of habitat suitability index (HSI) models 103-ESM (USFWS 1981). However, unlike typical HSI models, this model is intended to be used in conjunction with alternative HSI models developed from additional experts and existing literature. This model represents the best estimates of two species experts.

1. Model Applicability:

1.1 Geographic area. This model was developed based on knowledge of masked bobwhite habitat in both Arizona, specifically Buenos Aires National Wildlife Refuge, and northern Mexico.

1.2 Season. This model was developed to evaluate habitat needs of masked bobwhites over the entire year. The suitability of certain variables differs among seasons and these differences are noted and described in the model.

2. Model Description:

2.1 Overview. This model considers the ability of assessed habitat to meet the food, reproductive, and cover requirements of masked bobwhite as an indicator of overall habitat suitability. All components of the model are assessed by vegetative conditions. The relationship between habitat variables and critical life history requirements of masked bobwhite is illustrated in Figure 1.

2.2 Written Documentation.

The following sections provide a written documentation of the logic and assumptions used to interpret the habitat information for masked bobwhite in order to explain the variables and equations that are used in the HSI model. We present each critical habitat requirement and describe the variables which contribute to it.

1. Reproduction. Available habitat for masked bobwhites must contain adequate cover for nesting and brooding. Perennial bunch grasses of 1-2 feet (.3-.61m) in height are necessary for nesting substrate. Tree cover provides important perches for calling. Optimal values of tree cover are described under “Cover”. Structural diversity is important for providing the appropriate mix of nesting and brooding habitat. If all other cover components are at optimal levels, structural diversity is assumed to be optimal as well.
2. Food. Forb cover is an important source of food for both adults and juveniles. Masked bobwhites use forb foliage directly and indirectly by eating the insects which are associated with forbs. Optimal canopy cover of forbs is approximately 50% from the late summer through the winter whereas the optimum ranges from 35% to 65% in the spring and early summer. Forbs should be 0—6 inches tall to be directly utilized as food. Forb diversity is important for food during all months of the year, primarily because a diverse forb community will result in a diverse insect community. Forbs are also used directly as a food source early in the summer and forb height should be lower during that time to allow for access to the foliage by masked bobwhites. Food-bearing shrubs are an important source of food in the winter when other sources of food are scarce. Structural diversity is important year-round for food. High structural diversity creates a wide array of micro-habitats which increases species richness of insect prey and diversity of herbaceous plants. Woodland-grassland edges improve habitat quality by providing a greater variety of options for food within a relatively small area. Leaf litter can provide additional food by improving insect abundance.
3. Cover. The height of forbs in the fall and winter should be at least 6 inches (15.24 cm) tall but forbs taller than 20 inches (50.8cm) are optimal to provide adequate cover. Forbs provide cover for masked bobwhites with optimal values for percent cover described above under “Food”. Shrubs are also an important component of cover. Optimal values of shrub canopy cover differed between the two experts. Both experts stated optimal cover should be 10-60%; however one expert stated any value between these two would be optimal whereas the other expert believed that 40% cover is the optimal value with diminishing suitability above and below 40%. Both experts agreed that shrubs should be between 2 and 5 feet (0.91 and 1.5 m) tall with an optimal height of 4 feet (1.22m). Brush piles can substitute for shrubs when shrub cover is suboptimal. Brush piles should be approximately 50 feet (15.24 m) in diameter and 50 yards (46 m) apart, however, these figures can vary without affecting suitability. Brush piles should be low (<6 feet tall, <1.8 m tall) and dense. Brush piles should be placed in areas lacking natural cover, near natural cover and in uplands to provide additional cover during breeding. Perennial bunch grasses are important year round for cover. Optimal canopy cover of perennial grasses is 55%. Annual grasses also provide an important cover for masked bobwhite in the summer and fall with an optimal canopy cover of 45%. The proportion of perennial grasses to annual grasses should be approximately 80:20. The optimal height of grasses differed between the two experts. One expert stated optimal grass height is 4-5 feet (1.22-1.5m) tall whereas the other expert stated optimal grass height is 2-5 feet (.61-1.5m) tall. Trees are used as cover and provide structural complexity. Low tree cover is optimal (5% of canopy cover in the uplands and 30% in arroyos). Small trees can provide suitable cover in the absence of shrubs. Structural diversity is important during all months of the year and helps ensure adequate cover. Woodland-grassland edges provide a greater variety of options for cover within a small area. Bare ground is important during all seasons of the year for mobility of masked bobwhite but is most important in the fall to provide escape corridors after chicks begin to disperse. Areas with 25% bare ground are optimal.
4. Thermal Refuge. Tree cover and shrub cover provides an important source of shade and perch sites for thermoregulation of masked bobwhites. Leaf litter is also important for thermoregulation by retaining moisture.

**Figure 1.** The relationship between measured habitat variables, critical life history requirements, and habitat suitability for masked bobwhites.

Measured Habitat Variable Life Requisite Model Output

Tree Cover

Forb Cover

Reproduction

Forbs

Forb Diversity

Forb Height

Food

Grass Cover

Suitability Index

Grass

Grass Diversity

Cover

Grass Height

Shrubs

Shrub Cover

Thermal Refuge

Brush Piles

Shrub Height

Bare Ground

Leaf Litter

**3. Suitability Functions and Graphs**

|  |  |  |  |
| --- | --- | --- | --- |
| Variable | Description | Suitability Function | Suitability Graph |
| FC | Forb cover measured as the average percent canopy cover dominated by forbs. The optimal canopy cover of forbs differs between the fall/winter and spring/summer. | Late Summer/Fall/Winter: | X:\Masked Bobwhite\Graphs\Suitability Functions\Dan and Sally\FC Fall-winter Sally-Dan.emf |
|  |  | Spring/ Summer: | X:\Masked Bobwhite\Graphs\Suitability Functions\Dan and Sally\FC Spring-summer Sally-Dan.emf |
| FD | Forb Diversity measured as the total number of forb species on a typical home range (10.9 ha) throughout the year. | (Gamma CDF with α=22.5, β=1) | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dan and Sally\FD Sally-Dan.emf |
| FH | Forb height measured as the average height of forbs. Optimal forb height differs between the spring/summer and the fall/winter. | Fall/ Winter:  (Gamma CDF with α=13, β=1) | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dan and Sally\FH Fall-winter Sally-Dan.emf |
|  |  | Spring/ Summer:  (Gamma CDF with α=13, β=1) | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dan and Sally\FH Spring-summer Sally-Dan.emf |
| GC | Grass cover measured as the percent canopy cover of grass. The optimal canopy cover of grass differs between perennial and annual grasses. | Perennials: | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dan and Sally\GC Perennial Sally-Dan.emf |
|  |  | Annuals: | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dan and Sally\GC Annual Sally-Dan.emf |
| GD | Grass diversity measured as the total number of grass species found on a typical home range (10.9 ha). The optimal number of species differs between perennial and annual grasses. | Perennials:  (Gamma CDF with α=7, β=2.33) | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dan and Sally\GC Perennial Sally-Dan.emf |
|  |  | Annuals:  (Gamma CDF with α=5, β=2.5) | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dan and Sally\GD Annual Sally-Dan.emf |
| GH | Grass height measured as the average height of grass on a typical home range (10.9 ha). The two experts differed on their assessment of optimal grass height. | Expert 1: | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dan and Sally\GH Dan.emf |
|  |  | Expert 2 Cover: | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dan and Sally\GH Sally Cover.emf |
|  |  | Expert 2 Nesting: | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dan and Sally\GH Sally Nesting.emf |
| SC | Shrub cover measured as the average canopy cover of shrubs. The two experts differed in their assessment of optimal shrub cover. | Expert 1: | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dan and Sally\SC Dan.emf |
|  |  | Expert 2: | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dan and Sally\SC Sally.emf |
| SH | Shrub height measured as the average height of shrubs. |  | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dan and Sally\SH Sally-Dan.emf |
| TC | Tree cover measured as the average canopy cover of trees. The optimal value of tree cover differs between the uplands and arroyos. | Uplands: | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dan and Sally\TC Uplands Sall-Dan.emf |
|  |  | Arroyos: | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dan and Sally\TC Arroyos Sally-Dan.emf |
| BG | Bare ground measured as the average canopy cover of bare ground. Bare ground should be in the form of a matrix interspersed with other canopy components |  | C:\Documents and Settings\cnadeau\My Documents\Work\Masked Bobwhite\Graphs\Suitability Functions\Dan and Sally\BG Sally-Dan.emf |

**Equations.**

The final habitat suitability index score is a result of the combination of suitability scores from component variables. The equations which describe this combination are governed by the assumptions and relationships described in section 2.2. Additive equations imply each variable in the equation can compensate for other variables with low scores unless otherwise noted. Multiplication implies a score of zero for any variable results in a suitability score equal to zero (i.e. both variables must have non-zero scores for the habitat to be suitable).