Beyond Mapping III

Topic 7 – Basic Spatial Modeling Approaches

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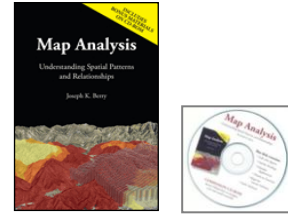
Suitability Models Find the Good, the Bad and the Hugag
(GeoWorld, July 2004)

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A simple habitat model can be developed using only reclassify and overlay operations. For example, a Hugag is a curious mythical beast (see figure 1) with strong preferences for terrain configuration:

- Prefers **low elevations** (severe nose bleeds at higher altitudes)
- Prefers **gentle slopes** (fear of falling over and unable to get up)
- Prefers **southerly aspects** (a place in the sun)

A binary habitat model of Hugag preferences is the simplest to conceptualize and implement. It is analogous to the manual procedures for map analysis popularized in the book *Design with Nature*, by Ian L. McHarg, first published in 1969. This seminal work was the forbearer of modern map analysis by describing an overlay procedure involving paper maps, transparent sheets and pens.

For example, if avoiding steep slopes was an important decision criterion, a draftsperson would tape a transparent sheet over a topographic map, delineate areas of steep slopes (contour lines

close together) and fill-in the precipitous areas with an opaque color. The process is repeated for other criteria, such as the Hugag's preference to avoid areas that are northerly-oriented and at high altitudes. The annotated transparencies then are aligned on a light-table and the "clear" areas showing through identify acceptable Hugag habitat.

Hugag

The Hugag is a huge animal of the Lake States. Its range includes western Wisconsin, northern Minnesota, and a territory extending indefinitely northward in Canadian wilds toward Hudson Bay. In size the Hugag may be compared to the moose, and in form it somewhat resembles that animal. Very noticeable, however, are its jointless legs, which compel the animal to remain on its feet, and its long upper lip, which prevents it from grazing. If it tried that method of feeding it would simply tramp it upper lip into the dirt. Its head and neck are leathery and hairless; its strangely corrugated ears flop downward; its four-toed feet, long bushy tail, shaggy coat and general make-up give the beast an unmistakably prehistoric appearance. The hugag has a perfect mania for traveling, and few hunters who have taken up its trail ever came up with the beast or back to camp. It is reported to keep going all day long, browsing on twigs, flopping it lip around trees, and stripping bark as occasion offers, and at night, since it cannot lie down, it leans against a tree, bracing it hind legs and marking time with its front ones. The most successful hugag hunters have adopted the practice of notching trees so that they are almost ready to fall, and when the hugag leans up against one both the tree and the animal come down. In its helpless condition it is easily dispatched. The last one killed , so far as known, was on the Turtle River, in northern Minnesota, where a young one, weighing 1,800 pounds, was found stuck in the mud. It was knocked in the head by Mike Flynn, of Cass lake.

Fearsome Creatures of the Lumberwoods, by William T. Cox, 1910

Figure 1. The Hugag prefers low elevations, gentle slopes and southerly aspects.
(see http://www.fearsomecreaturesofthelumberwoods.com/mainindex.htm for more fearsome creatures)

An analogous procedure can be implemented in a computer by using the value 0 to represent the unacceptable areas (opaque) and 1 to represent acceptable habit (clear). As shown in figure 2, an *Elevation* map is used to derive a map of terrain steepness (*Slope_map*) and orientation (*Aspect_map*). A value of 0 is assigned to locations Hugags want to avoid—

Greater than 1800 feet elevation = 0   *...too high*
Greater than 30% slope = 0   *...too steep*
North, northeast and northwest = 0   *...to northerly*

—with all other locations assigned a value of 1 to indicate acceptable areas.

The individual binary habit maps are shown in 3D and 2D displays on the right side of figure 2. The dark red portions identify unacceptable areas that are analogous to McHarg's opaque colored areas delineated on otherwise clear transparencies.

A **Binary Suitability** map of Hugag habitat is generated by multiplying the three individual binary preference maps (left side of figure 3). If a zero is encountered on any of the map layers, the solution is sent to zero (bad habitat). For the example location on the right side of the figure, the preference string of values is 1 * 1 * 0 = 0 (Bad). Only locations with 1 * 1 * 1 = 1 (Good)

identify areas without any limiting factors—good elevations, good slopes and good orientation. These areas are analogous to clear areas showing through the stack of transparencies.
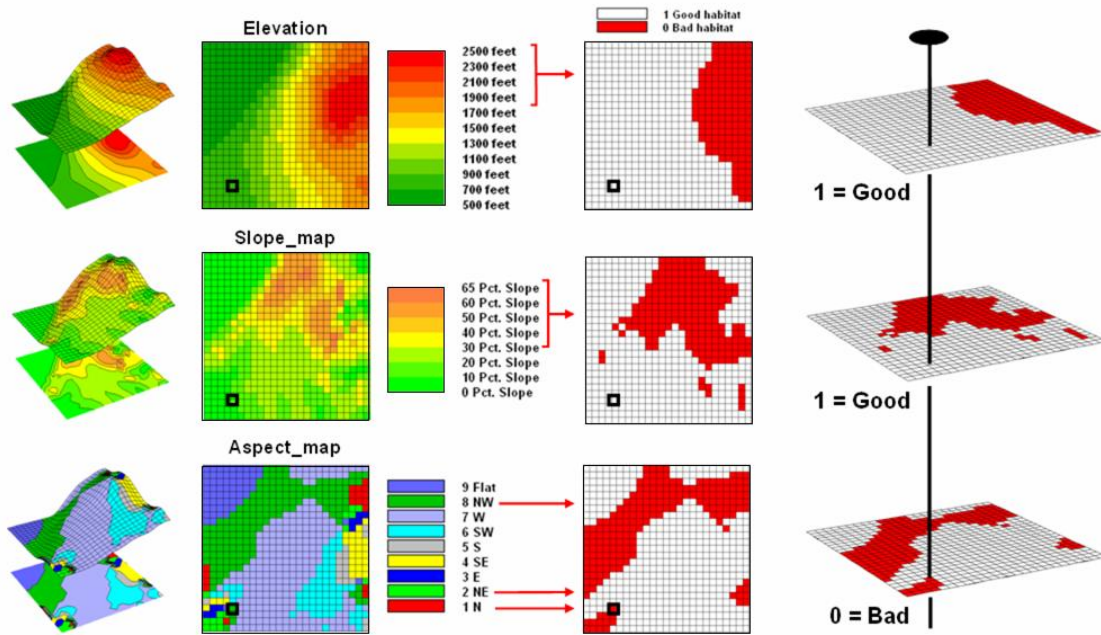

Figure 2. Binary maps representing Hugag preferences are coded as 1= good and 0= bad.

While this procedure mimics manual map processing, it is limited in the information it generates. The solution is binary and only differentiates acceptable and unacceptable locations. But isn't an area that is totally bad (0 * 0 * 0 = 0) different from one that is just limited by one factor (1 * 1 * 0 = 0)? Two factors are acceptable thus making it "nearly good."
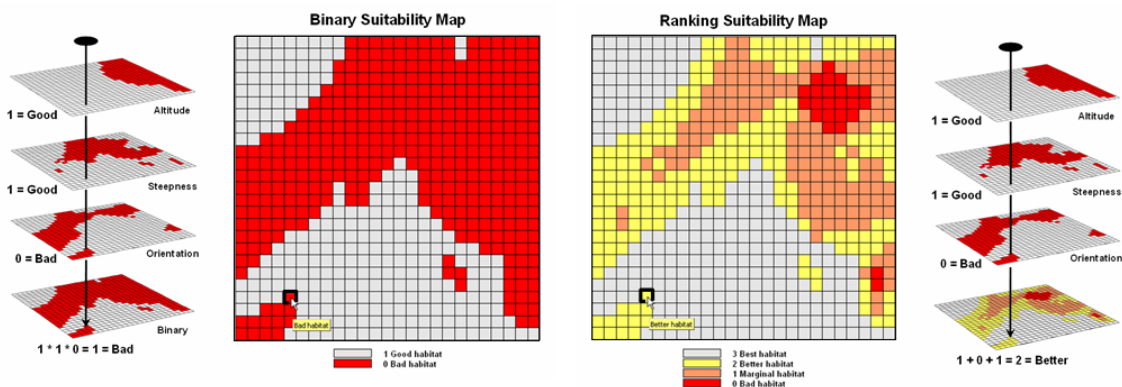

Figure 3. The binary habitat maps are multiplied together to create a Binary Suitability map

(good or bad) *or added together to create a Ranking Suitability map* *(bad, marginal, better or best).*

The right side of figure 3 shows a **Ranking Suitability** map of Hugag habitat. In this instance the individual binary maps are simply added together for a count of the number of acceptable locations. Note that the areas of perfectly acceptable habitat (light grey) on both the binary and ranking suitability maps have the same geographic pattern. However, the unacceptable area on the ranking suitability map contains values 0 through 2 indicating how many acceptable factors occur at each location. The zero value for the area in the northeastern portion of the map identifies very bad conditions (0 + 0 + 0= 0). The example location, on the other hand, is nearly good (1 + 1 + 0= 2).

Mapping Techniques Rate Hugag Habitat Suitability
(GeoWorld, August 2004)

The previous section described a couple of basic techniques for suitability modeling— Binary and Ranking. Both procedures use "binary maps" that identify just good (1) and bad (0) conditions on a set of criteria maps. In the example, three binary habitat maps (good slopes, aspects and elevations) were multiplied together to create a *Binary Suitability* map (bad= any 0 or good=1*1*1) or added together to create a *Ranking Suitability* map (bad= 0+0+0= 0, marginal= 1, better= 2 or best= 1+1+1= 3).

A further extension of the binary techniques uses a mathematical trick. The criteria maps are reclassified to a binary progression of numbers (1, 2 and 4) instead of all 1's for acceptable habitat (figure 1). When these maps are summed the result is a unique value for each combination of values. For example, a location with a sum of 3 can only occur if it is gently sloped (1) plus southerly exposed (2) plus too high (0). The best habitat is indicated by the value 7 (1+2+4= 7).

A *Binary Progression Suitability* map contains a great deal of information beyond that of a simple binary or ranking map as it indicates the actual combinations of acceptable and unacceptable conditions. If there are more than three criteria layers, the progression is just extended (…8, 16, 32, 64, etc.). In all cases the permutations result in a unique sum.

However all binary models suffer the same problem—things are either good or bad with no degree of goodness. It's like pass/not pass grading that doesn't distinguish exceptional performance (either good or bad) and forces a sharp boundary instead of a gradient of performance.
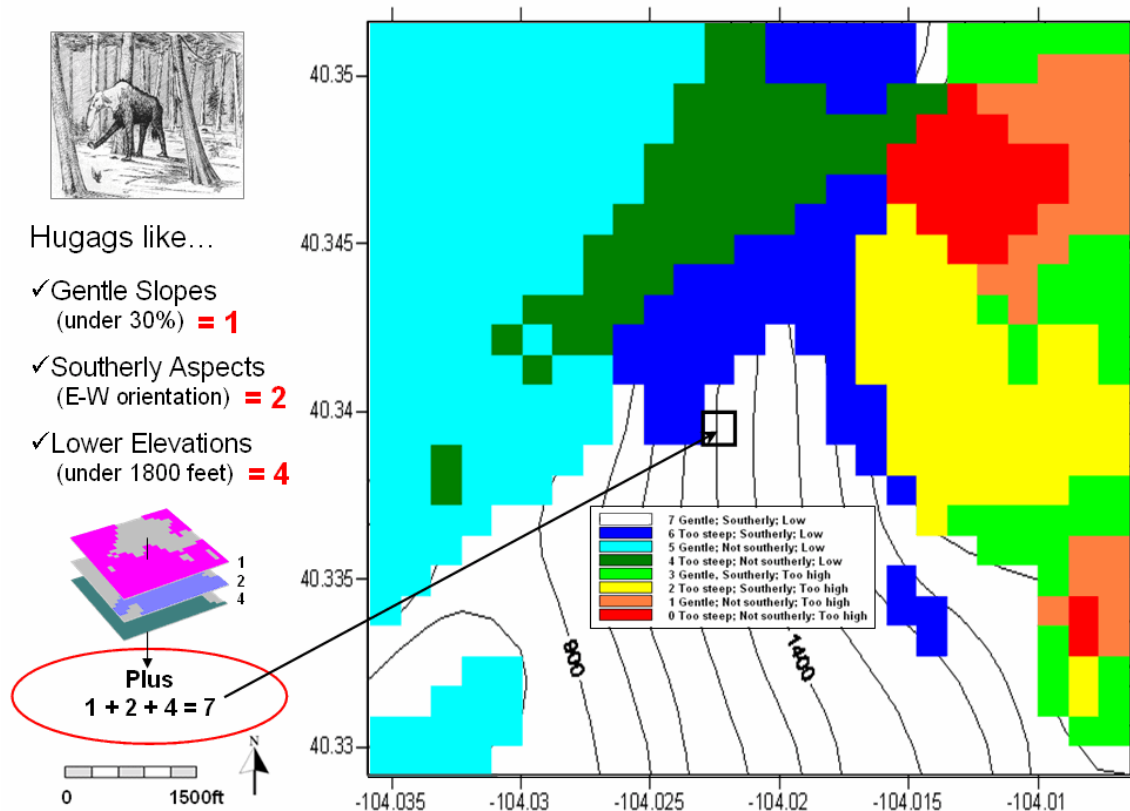
Figure 1. Binary Progression Suitability map with combinations indicated.

Figure 2 depicts an alternative procedure where each of criteria layers are "graded" on a scale from 1= very bad to 9= very good. For this example the calibration was—

  Slope Map: >40%= 1 (very bad); 30-40= 3; 20-30= 5; 10-20= 7; 0-10= 9 (very good)
  Aspect Map: N, NE, NW= 1 (very bad); E, Flat= 5; W= 6; SE, S, SW= 9 (very good)
  Elevation Map: >1800ft= 1 (very bad); 1400-1800= 3; 1250-1400= 5; 900-1250= 7; 0-900= 9 (very good)

…then the individual criteria maps are averaged for an overall score. In addition, lakes are masked as they represent impossible habitat (drowned Hugags).

The result is an *Average Suitability* map containing an overall score for each map location. Note the results for the example location in both figure 1 and 2. The Binary Progression solution ranks it as totally acceptable (7= gentle, southerly, low), while the Average Suitability solution rates it as mediocre habitat (5.3= mid-range on a 1 to 9 scale). The dark green locations, on the other hand, identify very good habitat (8-9 rating) and the bright red locations indicate the worst habitat (1-2 rating).
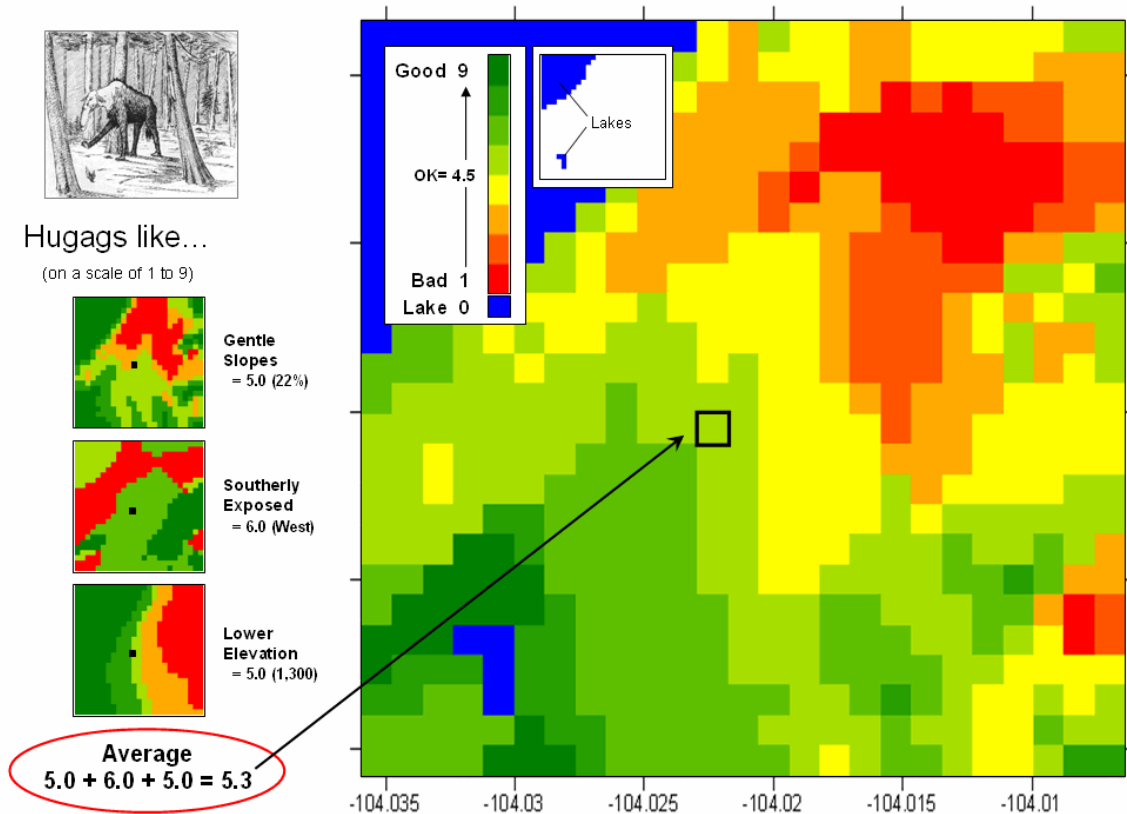
Figure 2. Average Suitability map with an average score for each location.

The continuous gradient solution provides significantly more information than any of the binary techniques. In practice, the individual map layers are assigned weights to indicate their relative importance and a weighted-average is computed. The areas with high scores can be isolated and designated sensitive habitat areas for natural resource planning.

Figure 3 shows the average suitability model applied to a larger area based on freely available 30m digital elevation data. When the suitability map is draped on the terrain surface its results are easily evaluated. The best areas (dark green) align with the gentle, southerly sloped and relatively low areas. The worst areas (bright red) align with steep northerly sloped and relatively high areas.

In practical applications, habitat modeling considers many more factors than simply terrain configuration. For example, the model could be extended to evaluate the additional criterion that "Hugags would prefer to be within or near forested areas" (proximity to Forest map); or that "Hugags would prefer to be near water" (proximity to Water map); or that "Hugags would prefer to be far from roads" (proximity to Roads map). In GIS modeling, each of these consideration

would be treated as a separate sub-model to derive the necessary criteria, then calibrated on a 1 to 9 scale and weigh-averaged for an overall habitat score.

Hugags like… Gentle Slopes, Southerly Aspects, Lower Elevations

Applying the Average Suitability model to a larger area shows its strong relationship to terrain configuration. Note that the areas of best habitat (dark green) occur on the fairly gentle slopes that are southerly oriented and at lower elevations. Note that the worst areas (bright red) occur on steep, northerly slopes at higher elevations.
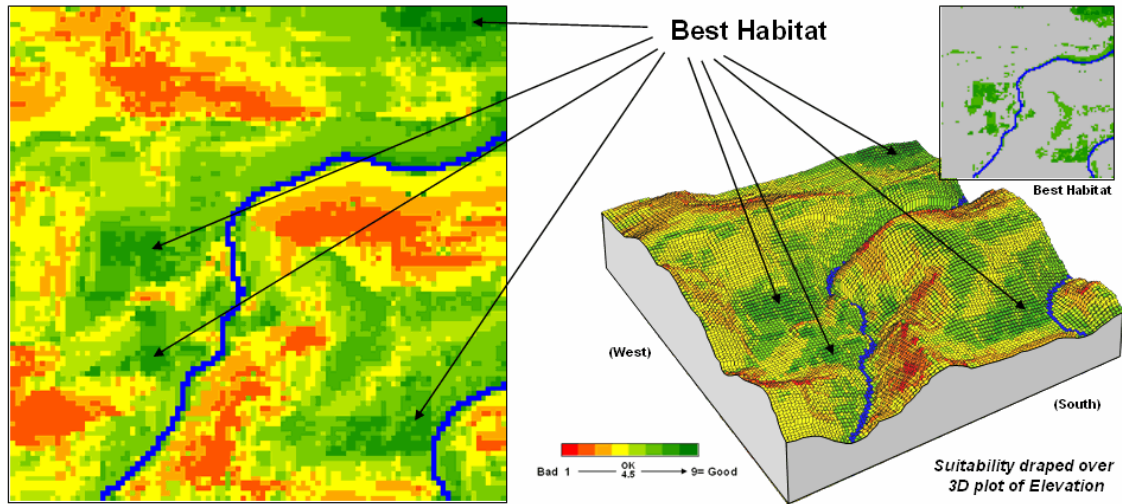
Figure 3. Draping the Average Suitability map over the Elevation surface shows good alignment with critical terrain features.

Keep in mind that suitability modeling isn't restricted to wildlife habitat analysis. The approach is just as valid for identifying "customer habitat" in geo-business, or crop suitability in agriculture, or pipeline suitability for identifying the best route. Like statistics, the suitability modeling cuts a wide swath through many applications as a fundamental analytical tool.
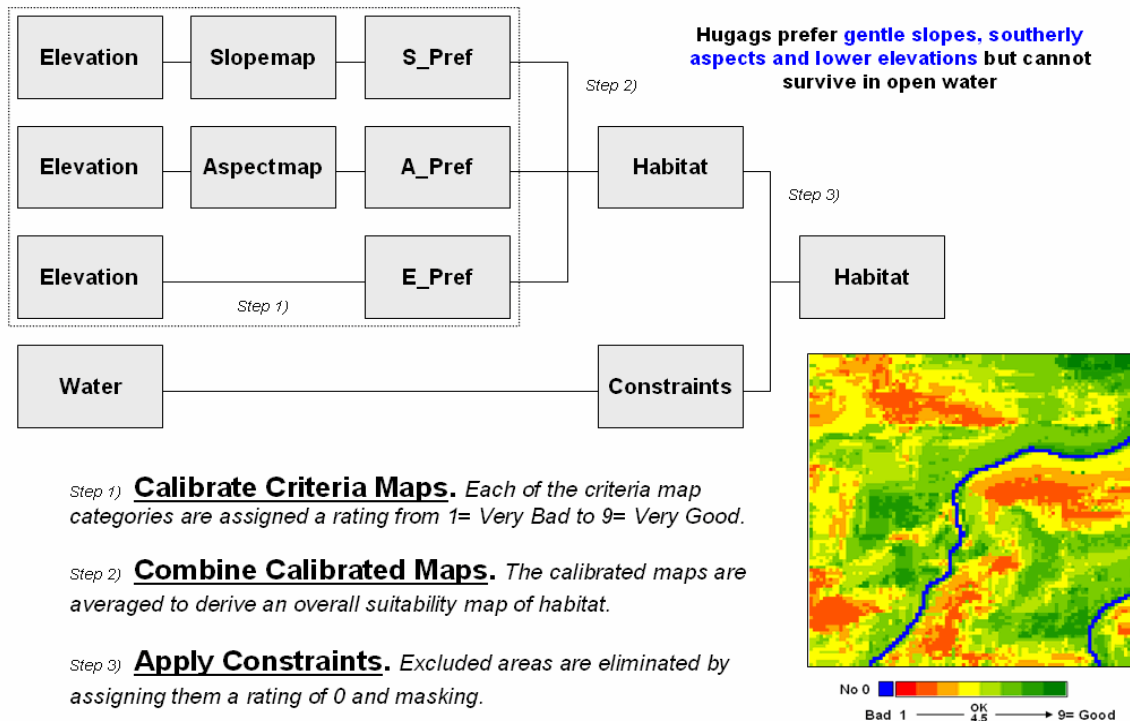
Logic and Extent Elevate Suitability Models to New Levels
(GeoWorld, October 2004)

The previous sections on suitability modeling used wildlife habitat mapping to illustrate the development of progressively more powerful modeling approaches—binary, ranking,

permutation and rating models. All four approaches used the same set of basic criteria—Hugag preference for gentle slopes, southerly aspects and lower elevations—as depicted in figure 1. The difference in how the processing takes place was the focus of discussion.

Figure 1. Model logic for basic Hugag habitat suitability mapping.

In the case of a *binary model* each consideration is treated as either good or bad and results in a habitat map that identifies just good and bad habitat areas. A *ranking model*, on the other hand, uses the same good/bad criteria but identifies the number of good factors for each map location with higher values indicating increasingly higher habitat ranking. A *permutation model* provides even more information by identifying the unique combination of good and bad factors occurring at each location.

A *rating model* is the most powerful approach. It breaks the good/bad dichotomy into a gradient of preference most often expressed as 1= very bad to 9= very good. For example, the preference for gentle slopes (S_Pref in figure 1) was assigned as 1 (very bad) = >40%; 3= 30-40; 5= 20-30; 7= 10-20; and 9 (very good) = 0-10%. In a similar manner, categories for aspect and elevation are calibrated then averaged and masked for constrained areas to generate the overall suitability map shown in the figure. This result contains continuous habitat values—considerably more information than simply the spatial coincidence of discrete areas of good/bad classifications.
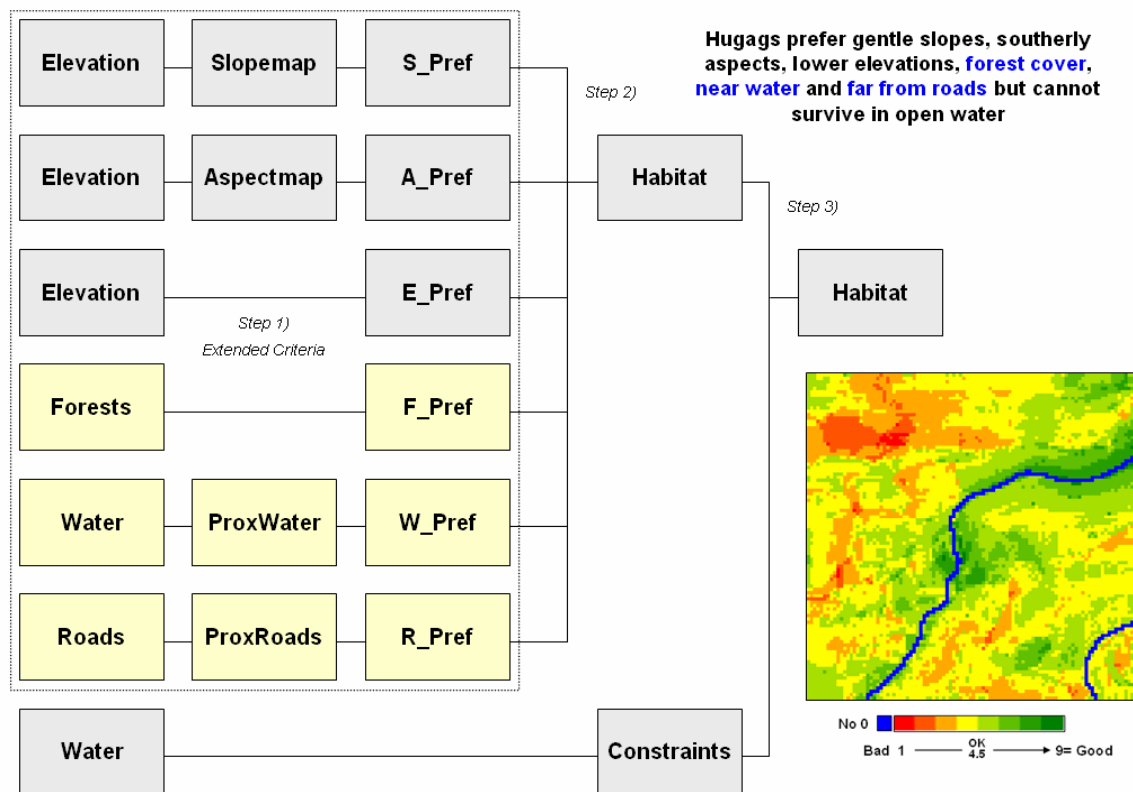
Figure 2. Extended model logic for considering Hugag preference for being in forests, near water and far from roads.

While processing approach is an important consideration, the model logic and extent can be even more important in determining model accuracy. In practical applications, the habitat model would likely consider many more factors than simply terrain configuration. Figure 2 shows a flowchart of the extended model logic to evaluate the additional criteria that "Hugags would prefer to be in forested areas" (Forest map), that "Hugags would prefer to be near water" (proximity to Water map) and that "Hugags would prefer to be far from roads" (proximity to Roads map).

In suitability modeling, these considerations are treated as separate sub-models to derive the necessary criteria, then calibrated on the 1 to 9 preference scale and averaged with the basic set of terrain considerations for an overall habitat map shown in the figure.

Note that a large part of the model's strength or weakness is established in Step 1—*calibrate criteria maps*. As much as possible, the identification of map criteria needs to reflect good science and/or expert opinion to capture factors that are both important and easily measurable.

Similarly, the calibration of the maps into the 1-9 preference range needs to capture realistic relative values, not whimsical or biased assignments.

Step2— *combine calibrated maps* is another area requiring considerable understanding of the system being modeled. A simple average of the calibrated map layers assumes that all of the criteria are equally important. The right inset in Figure 3 shows the habitat results for expert thinking that Hugags are "10 times more concerned about slope, forest and water considerations than they are about aspect, elevation and roads considerations."
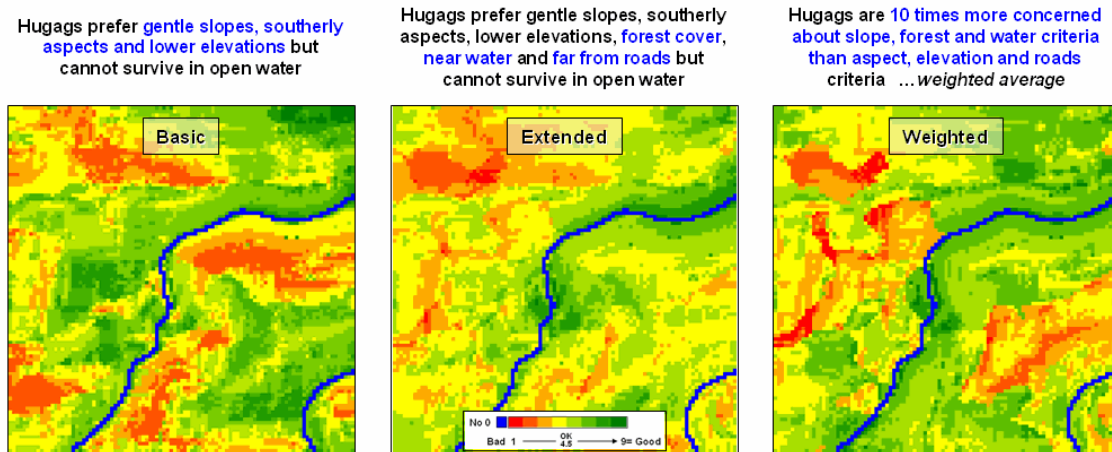

Figure 3. Habitat rating maps for progressively more powerful model logic and processing.

The procedure for determining relative importance involves computing the weighted-average of the six map layers. It is analogous to a professor's grading some exams more important than others in determining a class grade. In this case, the map values correspond to student grades on each exam; each student is represented as a grid cell on the map, kind of like their desk seats in the classroom floor plan.

Note the similarities and differences in the maps induced by the additional criteria (Extended) and relative weighting of map layers (Weighted). Provided expert opinion is sound, the weighted map on the right would be considered the most accurate representation of Hugag habitat.

Keep in mind that calibrating and weighting are extremely critical steps in suitability modeling. Procedures, such as Delphi and AHP, can be used to derive these factors in a quantitative, objective, consistent and comprehensive manner (see Author's Notes). In addition, purposeful changing these factors can reflect different assumption scenarios analogous to "what if" questions applied to traditional spreadsheet analysis.

From this perspective, it is how the suitability maps change that becomes information about the sensitivity of a project area to the interplay of criteria, calibrations and weights.   This takes us well beyond mapping to assessing the spatial relationships within a system and their logical expression within a GIS. As GIS technology matures, the focus is shifting from simply access of static map products depicting physical features for navigation and inventory to a dynamic environment that enables "thinking with a stack maps" within decision-making contexts.

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