Statistical evaluation and GIS model development to predict and classify habitat quality for the endangered Southwestern Willow Flycatcher.

by

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ABSTRACT

The Southwestern Willow Flycatcher (*Empidonax traillii extimus*) has been studied for over two decades and listed as endangered for most of that time. Though the flycatcher has been granted protected status since 1995, critical habitat designation for the flycatcher has not shared the same history. Critical habitat designation is essential for achieving the long-term goals defined in the flycatcher recovery plan where emphasis is on both the protection of this species and "the habitats supporting these flycatchers [that] must be protected from threats and loss" (U.S. Fish and Wildlife Service 2002).

I used a long-term data set of habitat characteristics collected at three study areas along the Lower Colorado River to develop a method for quantifying habitat quality for flycatcher. The data set contained flycatcher nest observations (use) and habitat availability (random location) from 2003-2010 that I statistically analyzed for flycatcher selection preferences. Using both Pearson's Chi-square test and SPSS Principal Component Analysis (PCA) I determined that flycatchers were selecting 30 habitat traits significantly different among an initial list of 127 habitat characteristics. Using PCA, I calculated a weighted value of influence for each significant trait per study area and used those values to develop a habitat classification system to build predictive models for flycatcher habitat quality. I used ArcGIS® Model Builder to develop three habitat suitability models for each of the habitat types occurring in western riparian systems, native, mixed exotic and exotic dominated that are frequented by breeding flycatchers. I designed a fourth model, Topock Marsh, to test model accuracy on habitat quality for flycatchers using reserved accuracy assessment points of previous nest locations. The results of the fourth model accurately predicted a decline in habitat at Topock Marsh that was confirmed by SWCA survey reports released in 2011 and 2012 documenting a significant decline in flycatcher productivity in the Topock Marsh study area.

DEDICATION

To my husband Terry for all his patience and support and taking care of our animal clan while I was gone for weeks at a time over the last two years, I love you very much. I also want to dedicate this thesis to my mother Winifred, whom I love dearly, for always believing in me and supporting everything I chose to do in life. Finally, to Jackie, Myles and Zia I love you guys so much and I am so sorry I was gone when you needed me most.

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CHAPTER I

INTRODUCTION

The Southwestern Willow Flycatcher (*Empidonax traillii extimus:* SWFL) has been the subject of extensive research for over two decades. The impetus behind the continued investigation of SWFL population dynamics and habitat selection began when early observations during routine bird surveys documented diminished numbers at formerly established sites. Unitt (1987) recounted field studies conducted as early as 1948 that recorded the inexplicable absence of willow flycatchers from known breeding territories. Although many assessments were made prior to the bird's federal listing as endangered in 1995, researchers continue to examine critical habitat requirements. This has led to a better understanding of willow flycatcher ecology and improved methods to mitigate existing threats but the species continues to decline in spite of collaborative efforts to achieve long-term recovery goals.

Early studies investigating the decline of willow flycatchers identified multiple factors contributing to their contracted population numbers. These factors included habitat fragmentation and loss, brood parasitism, depredation and exotic species invasion (Phillips 1948, Unitt 1987, Harris 1991). The fragmentation and loss of riparian habitat and its gradual conversion into mixed exotic and exotic dominated vegetation communities due to dramatically altered hydrological conditions remain the primary focus of flycatcher recovery efforts today (Marshall and Stoleson 2000, USFWS 2002, USFWS 2005). These established threats have led to habitat conservation to recover the species population to sustainable levels. As new research becomes available management of willow flycatcher habitat is modified to reflect the most current information. Initial theories (DeLoach et al. 2000, Stenquist 2000, Dudley and DeLoach 2004) suggested that the rapid spread of introduced tamarisk (*Tamarix spp.* or saltcedar) across most western river systems had directly contributed to the decline in SWFL by providing only substandard food resources, exposing eggs and nestlings to lethal high temperatures and increasing cowbird parasitism and nest predation. DeLoach et al. (2000) theorized that willow flycatchers breeding in tamarisk had lower fitness and reproductive success due to the inferior resources available in tamarisk dominated habitat. To test this Owen and Sogge (2002) investigated the physiological condition of SWFL in both native and exotic habitat using blood chemistry analysis, body mass and physical measurements indicative of fitness. Their results showed no evidence to support the theory that flycatchers breeding in tamarisk were nutritionally impaired or physiologically compromised. Interestingly two of the 12 blood parameters measured indicated that flycatchers foraging in tamarisk had exploited some additional resource that had allowed them to deposit a greater amount of fat than their counterparts foraging in exclusively native habitat, actually suggesting better dietary conditions may exist in some tamarisk dominated sites. Sogge et al. (2005) also investigated reproductive success using data from several long-term studies originally guided by U.S. Geological Survey (USGS) and the Arizona Game and Fish Department (AZGFD). Results of the data analysis examining survivorship found no significant difference between birds in native habitat and those in tamarisk. Though it is generally established that flycatchers do not breed in every tamarisk habitat, the Southwestern Willow Flycatcher recovery team determined that within the six recovery units located throughout the breeding range of the species, almost half (49%) of all flycatcher territories occurred in sites with a minimum of 50% exotic vegetation (USFWS 2002). Within those mixed habitats, 25% contain greater than 90% exotic species (USFWS 2002, Sogge et al. 2008). Long-term studies in Arizona found that some SWFL breeding pairs select tamarisk nest sites “extensively” despite the presence and availability of nearby native habitat (Sogge et al. 2003, 2005). Because flycatchers appear to be selecting tamarisk nest substrate despite their historical use of native vegetation and because tamarisk has adapted so successfully to the transformation of the habitat due to altered flow regimes, many questions remain about the habitat selection behavior of these endangered birds (York et al. 2011). It is not fully understood why some willow flycatchers intentionally select tamarisk over available native willow (*Salix spp.*) though it is suspected that at some locations tamarisk may provide superior structural features like the vertical stems present at branching forks for nest support, dense high canopy and adjacent surface water and saturated soils normally preferred by SWFL in native habitat (Sogge et al.1997).

It is widely accepted that wildlife species instinctively evaluate habitat for its ability to deliver needed resources for reproduction and survival. This adaptive behavior, commonly referred to as habitat selection preference, allows individuals in a population to locate and defend sites with the best quality resources available excluding other factors that may affect their selection preferences such as predator avoidance and intraspecific competition. The habitat concept in ornithology describes selection as the innate and learned behavioral responses that permit birds to discriminate the range of value available in the environment being investigated (Block and Brennan 1993). It is assumed that flycatchers while engaging in this behavior choose specific nesting sites for their perceived value in providing the best quality resources for reproductive success. This suggests that there may be some increased benefit to nesting in tamarisk in some locations. Because only a small percentage of the total breeding population of flycatchers have been documented nesting in tamarisk despite accessible native habitat, some researchers contend (DeLoach et al. 2000, Dudley and DeLoach 2004) that tamarisk is not preferred but inferior to their native habitat. This approach greatly undervalues the significance of habitat selection behavior and the information that can be gleaned from a detailed analysis of the habitat characteristics chosen by nesting flycatchers.

Accurate identification of preferred habitat traits is essential to the designation and protection of critical habitat. Unfortunately one of the most controversial provisions in the Endangered Species Act 1973 (ESA) is the designation of critical habitat further emphasizing the need for accurate and reliable habitat classification methods. The inherent problems with the current designation process are best described by George Guinta Jr. (1992) “Depending on the interpretations given to each of these provisions [referring to “the taking of” and “critical habitat provisions for”], species' habitat are given either extensive or scant protection” suggesting a random inconsistent evaluation for critical habitat designation. In an analysis of 169 peer reviews of 42 critical habitat designations prepared by USFWS between 2002 – 2007, Greenwald et al. (2012) determined that the size of critical habitat area recommended by the majority (81%) of reviewers was reduced on average by 43%. Their results presented evidence that unqualified political appointees had interfered in the peer review process negatively affecting final critical habitat designations. USFWS is required to solicit expert opinions prior to finalizing proposed critical habitat designations (U.S. Department of the Interior and U.S. Department of Commerce

1994). The Federal Register clearly states that the policy should “complement and not circumvent or supersede” the review process in listing and recovery programs. A quantitative approach for identifying critical habitat could protect against interference in the designation process underscoring the important application of scientifically defendable methods.

The goal of this study was to develop a habitat preference model for SWFL within the Lower Colorado-River (LCR) watershed using data from a long-term nest site selection study within the LCR. To accomplish this goal, four objectives were required:

1. Investigate SWFL habitat selection behavior in order to identify preferred habitat traits.
2. Develop selection indices to rank the range of variation within each preferred habitat trait.
3. Develop a means of quantitatively ranking these preferred habitat traits by their level of influence on site selection.
4. Develop a model within a geographic information system (GIS) environment that would predict potential SWFL nesting site selection within the LCR.

CHAPTER II

BACKGROUND LITERATURE

Natural History and Survey Progression for Southwestern Willow Flycatcher

Sonoran riparian cottonwood-willow forests of the Southwest are considered one of the most threatened ecosystems in the United States (Stromberg 1993, Patten 1998, Hultine et al. 2010). A century of persistent anthropogenic disturbances (eg., mining, forestry, grazing, agriculture, hydrologic modification, invasive species introduction) and prolonged drought has permanently altered the ecophysiology of riparian woodlands (Patten 1998). Not surprisingly this has negatively affected neotropical migratory bird communities that spend a significant portion of their annual life cycle in southwestern riparian habitats.

The endangered Southwestern Willow Flycatcher is a riparian obligate species that is acutely sensitive to modifications in riparian habitat. Declines in cottonwood-willow riparian corridors over the last century have simultaneously diminished available flycatcher nesting sites and reduced their distribution and abundance (Phillips 1948, Muiznieks et al. 1994, Sogge et al. 2010). Water from many of the perennial streams in southern Arizona historically exploited by breeding and nesting SWFL in early summer is no longer available in more recent years. As a result, riparian habitat in these areas has either deteriorated in quality or disappeared completely. Muiznieks et al. (1994) studied maps constructed in 1981 of the San Pedro River watershed and determined that nearly 930 miles of riparian river habitat no longer delivered a perennial water source for migratory birds. Riparian habitat has also declined dramatically in the LCR watershed. Notable American ornithologist and field naturalist Edgar Alexander Mearns (1907) reported in his book, “Mammals of the Mexican Boundary of the United States,” that the U.S. Geological Survey explored from Fort Mohave to Yuma in 1902 documenting approximately a half million acres of “alluvial bottomland.” Almost a century later Ohmart et al. (1988) surveyed the same area and found that only a quarter of the original riparian habitat remained and of that remaining area 40% was covered by introduced tamarisk with an additional 43% containing a mix of both native vegetation and tamarisk. In the final estimate, only 0.7% (768 acres) contained cottonwood-willow communities exclusively (Ohmart et al. 1988). Today riparian vegetation communities are more commonly a mixture of native and exotic species with the exception of sites actively managed through conservation and restoration efforts. Similar conditions exist along most western rivers, lakes and reservoirs where tamarisk has become widely distributed, outcompeting native cottonwood-willow galleries in areas affected by reduced water flows from regulated dams, river channelization, groundwater pumping and agricultural and municipal development (Patten 1998, Shafroth et al. 2010). Tamarisk control consumes millions of dollars annually for habitat management and as a result, many land managers focus their efforts on restoring riparian habitat to native species using a variety of removal methods including chemical, mechanical and more recently biological (Shafroth et al. 2005).

In many established flycatcher territories where tamarisk has invaded riparian areas and transformed them into predominantly monotypic stands of dense tamarisk, SWFL have modified their selection behavior and begun nesting extensively in tamarisk canopies (Smith et al. 2004, Sogge et al. 2008, Stromberg et al. 2009). Surveys as early as 1993 documented the use of tamarisk as nesting substrate (Muiznieks et al. 1994). It is now known that approximately 25% of all flycatcher territories are located in tamarisk dominated habitats with another 25% in mixed communities of native and exotic vegetation (USFWS 2002, Sogge et al. 2008). Scientific opinion is strongly divided on whether tamarisk has contributed to the decline of SWFL although studies have revealed that flycatchers often do select tamarisk nesting sites even when native habitat is available (Sogge et al. 2005). DeLoach et al. (2000) suggested that the decline in SWFL was strongly correlated with the increase in tamarisk, which was believed to be an inferior source of dietary insects compared to native. This was later disproved when Owen and Sogge (2002, Owen et al. 2005) found no evidence to indicate the physiological condition of flycatchers nesting and foraging in tamarisk was different from flycatchers nesting in native habitat. Three of twelve blood parameters measured, triglycerides, glycerol, and uric acid were significantly different for birds foraging in tamarisk. Higher triglycerides and lower glycerol parameters confirmed amplified fat production and storage for flycatchers foraging in tamarisk and higher uric acid levels suggested that the same birds were sustained by a higher protein diet than flycatchers foraging in native habitat. Drost et al. (2001) compared food habits of flycatchers at three sites, one population at

Kern River Preserve, California (native cottonwood willow habitat) and two populations at Tonto Creek and Salt River, Arizona (tamarisk dominated habitat). They found significantly different prey compositions among the three sites. At the Kern site (native) flycatcher diets consisted of a greater diversity of prey species than at either the Tonto Creek or Salt River sites (monotypic tamarisk). But flycatcher diet at the Arizona sites had a greater number of large pollinator species and larger species of true bugs and flying insects and beetles. Many argue that the reduced variety of prey in tamarisk suggests a suboptimal diet (Tracy and DeLoach 1999, DeLoach et al. 2000). Yet it appears that birds foraging in tamarisk more than compensate for a lack of insect diversity by increasing the number of larger prey items e.g. leafhoppers, dragonflies, damselflies, bees, wasps and large flying pollinator species attracted to flowering tamarisk.

Paxton et al. (2007) investigated survivorship and productivity from 1996 to 2005 in SWFL populations in Arizona. In tracking banded nesting birds over multiple years they were able to calculate nest success and seasonal fecundity and found no difference in productivity by habitat type. Reproductive success for flycatchers breeding in sites dominated by tamarisk was not different from that of flycatchers breeding in patches dominated by native vegetation.

Historically flycatchers nested in territories dominated by a mosaic of coyote and Goodding's willows (*Salix exigua*; *Salix gooddingii*), *Baccharis*, boxelder (*Acer negundo*) and buttonbush (*Cephalanthus occidentalis*) with an overstory of scattered stands of cottonwoods (*Populus fremontii*) positioned along river or stream banks (Phillips 1948, Finch 1999, USFWS 2002). However, traditionally preferred native habitat has been transformed by the expansion and spread of exotic species, in particular tamarisk. Because tamarisk has a greater tolerance for alkali soils subject to recurrent drought cycles it outcompetes native vegetation to successfully dominate many riparian corridors where water flow is highly managed and controlled (Shafroth et al. 2005, Merritt and Shafroth 2012). The greater presence of exotic species in riparian habitats partially explains why 48.8% of all SWFL territories are located in habitats of mixed exotics and natives or sites dominated by introduced species (USFWS 2002). The other widely accepted view is that flycatchers are actively selecting sites with characteristics or traits similar to their preferred native habitats. These include size and shape of habitat patch, height and coverage of midstory trees and shrubs, soil moisture content and canopy closure, height and branching architecture for nest construction (Sogge and Marshall 2000, Paxton et al. 2007).

Critical Habitat Designation

Under the Endangered Species Act critical habitat is defined as “the specific areas within the geographical area occupied by the species…[in] which are found those physical or biological features (1) essential to the conservation of the species and (2) which may require special management considerations or protection; and specific areas outside the geographical area occupied by the species…that such areas are essential for the conservation of the species” (Endangered Species Act 1973). Protecting geographical locations containing the physical or biological features essential to the recovery of a listed species is the hallmark of critical habitat designation and the interagency policy of the Department of the Interior (DOI) and the Department of Commerce (DOC). The challenge of critical habitat designation is to identify what the “essential” features are for a listed species. If a quantitative method can be developed for predicting habitat quality using long-term data documenting changes in preferred habitat characteristics, then the preferred habitat variables can be used to predict and classify habitat quality at other potential sites frequented by the listed species. Critical habitat classifications provide a method for quantifying the range of existing habitat quality available while concurrently magnifying any deficiencies in the “essential” ecological features available to the species. Predicting changing ecological conditions at locations containing critical habitat features is crucial for the conservation and subsequent recovery of the species.

Identification of the essential habitat characteristics generally emerges following an accumulation of substantial empirical evidence that validates analogous results from numerous independent studies. For this reason the ESA requires both the USFWS and NOAA to “make biological decisions based upon the best scientific and commercial data available.” To reinforce the importance of this mandate, the Interagency Cooperative Policy for Peer Review in Endangered Species Act Activities (Department of the Interior, 1994) states that the USFWS and

NOAA are required to formally solicit expert opinions and analyses on proposed listing rules and draft recovery plans with the participation of the scientific community, state and federal agencies, tribal governments and all other interested parties before reaching a final biological decision on a listed species.

The purpose of this process is to invite an independent peer reviewed response to any recommendations and draft recovery plans to protect the decision making process. Once critical habitat is designated, restricted access to the habitat can affect numerous activities such as water management, livestock grazing, transportation, development, recreation and fire management, amassing claims of large economic losses resulting from the termination of commercial operations. This can lead to pressure being exerted to ignore expert recommendations and instead reduce areas for designation. Greenwald et al. (2012) discovered that political pressure might have influenced the result of the peer review process in nearly eighty one percent of the critical habitat designations they investigated. Using a Freedom of Information Act request, they examined 169 peer reviewed recommendations on 336 species. They determined that 81 percent of the submissions recommending critical habitat designations were reduced by an average of 43.2%, equaling a total of 12,061,037 acres. On average USFWS followed recommendations when reviewers advised subtracting areas for designation but did not follow the peer reviewer’s advice for adding in 92 percent of the 78 recommendations. Concluding evidence suggested that political appointees had interfered with a majority of the designations even prior to the finalization of critical habitat designation. These examples of interference in the designation process magnify the importance of developing reliable and accurate methods to quantify critical habitat.

In addition to the potentially negative consequences of rejecting critical habitat recommendations for reasons not supported by empirical evidence or the effect these actions might have on endangered species recovery plans, the use of standardized habitat evaluation protocols may also become an obstacle toward the accurate prediction of habitat characteristics essential to the recovery of an endangered species. Good et al. (2003) investigated the standardized methods used in recovery plans on federally endangered salmonid species. They reviewed the use of a habitat matrix developed by the National Marine Fisheries Service (NMFS) to assess habitat restoration and modification effects on species recovery and decline for chinook, coho and steelhead salmon. They emphasized that standardized protocols were used in place of supporting data and despite their widespread use as a regulatory tool, had never been tested to define any empirical relationships between variables. Their empirical results on the relationship between habitat matrix scores and salmonid population metrics indicated that trends in population abundance were completely unrelated to the habitat matrix assessments. They warn of the hazards in assuming that quantitative relationships exist between species and habitat without experimental evidence to support the claim. This study reveals that the inherent risk in rejecting the use of empirical data in favor of standardized methods to evaluate ecological relationships can lead to faulty conclusions. Results of a more thorough and accurate investigation method will more successfully survive harsh examination.

Critical habitat designations for Southwestern Willow Flycatcher have not been without controversy either. Critical habitat designation for the Southwestern Willow Flycatcher was first proposed in July 1997, twenty-eight months after the species was listed in February 1995 (IEc 2012, Appendix C). This first period of habitat protection lasted only four years before being challenged in court by *New Mexico Cattle Growers Association v U.S. Fish and Wildlife Service* (2001). The resulting judicial decision terminated the critical habitat designations made in 1997 and left Southwestern Willow Flycatchers without critical habitat protections from 2001-2005. In October 2005 USFWS again designated critical habitat for SWFL, but only 70 percent of the stream miles originally proposed were protected on the newly adopted designation. The 2005 critical habitat designation remained in place until a new designation written in 2011 was finalized in 2012. The 2011 critical habitat revision increased protections from the 1,450 stream miles made in the 2005 designation to 2,090 stream miles. Final designations were based on nearly 205 formal, section 7 range wide biological opinions that were submitted as early as 1995, the same year the Southwestern Willow Flycatcher was listed as endangered. When combined, they supported each of the proposed critical habitat designations in 1997, 2005 and 2011.

However, the use of methods that depend wholly on a collection of opinions about the habitat requirements of a listed species to designate critical habitat is problematic. This is not to diminish the benefit of the peer review process but to improve its criteria. Such improvements should guard against special interest abuse and the overuse of generic classifications based on antiquated knowledge to predict the adaptive response of a wildlife species in an altered environment by incorporating empirical evidence to support the use of those techniques.

Historical Use of Habitat Suitability Index (HSI)

Quantifying habitat quality as it relates to resources and conditions present that support occupancy, survival and reproduction of a species is an essential determinant in the prediction of wildlife population decline. Until the 1970s, the generally accepted method for drafting wildlife and environmental impact assessments concentrated on population dynamics, human impact and species richness. This approach only collected existing inventories of plant and animal communities, which did not address the need for predicting future conditions and evaluating their impact (Schamberger and Krohn 1982). In recognition of this limitation, federal land management agencies sought to augment the previous method to include habitat-based assessments that would classify habitat conditions using a standardized evaluation system. The consensus was that all organizations researching the species under investigation should adopt the standardized classification system to share data that would promote better communication about the habitat and improve resource planning and management. A task force of federal, state and private conservation representatives developed the Habitat Evaluation Procedures (HEP) to serve as a new standard for managing habitat quality and quantity data (U. S. Fish and Wildlife Service. 1980a,b, 1981). The newly established guidelines incorporated habitat suitability index modeling into the procedure for classifying habitat quality for specific species or a community of species (Schamberger and Krohn 1982). HEP combined measurements of habitat quantity (habitat area) with estimated values derived from a habitat suitability index (HSI). HSI values were assigned from a quantitative scale between 0.0 (poor quality) and 1.0 (best quality) that was positively correlated with carrying capacity and modeled around a qualitative interpretation of the literature on habitat characteristics associated with the species under investigation. Habitat Units (HU) were calculated from the habitat area x HSI and then averaged to produce a single HSI class value for each cover type. Prior to the advent of today's computer modeling, most ecological studies were conducted using the HEP protocol that applied a "subjective estimation of habitat suitability" based on environmental variables documented in the literature. (USFWS 1980a, 1980b, 1981). This process has been greatly improved with the introduction of more advanced analysis techniques using geospatial software programs such as ArcGIS® that display spatial data on digital maps developed from carefully executed data queries.

The weakest aspect of HEP is the generally accepted practice of exclusive reliance on the literature for classifying existing habitat quality. Habitat classifications are developed from qualitative literature reviews that are unlikely to capture changes in vegetation selection preferences at all geographic locations essential for annual migration and reproduction. Changes in selection behavior can occur for a variety of reasons, in particular the invasion of exotic species that may dominate areas formerly occupied by native plant communities present during earlier studies. Certainly, the cost to conduct field surveys can require a larger investment in man-hours and survey equipment than the more economical practice of establishing classifications based on preferences cited in the literature as critical to the species. Because many organizational constraints exist such as a reduced number of field staff or budget limitations, the use of literature based HSI modeling may be the only method available to some organizations when conducting ecological assessments. However, when this method is adopted, the range of habitat characteristics cited as favored is estimated rather than measured and converted into classes that become the foundation for further analysis. This may not accurately predict changes in the habitat or changes in species habitat selection preferences. Early studies incorporating GIS into their habitat suitability index modeling continued to rely on the literature for documented environmental tolerances in order to develop HSI classifications. In a study conducted by NOAA's Strategic Environmental Assessments (SEA) Division, in cooperation with the Freshwater Inflow Committee of the U.S. Environmental Protection Agency's (EPA) Gulf of Mexico Program (GOMP), Christensen et al. (1997) developed HSI modeling to examine the effects of modifications in freshwater inflow on estuaries in the central Gulf of Mexico. Three indicator species of the Pensacola Bay in Florida were chosen in order to study how freshwater inflow affected salinity, water temperature and dissolved oxygen in selected fishery habitats. Suitability index values were generated from documentation on species tolerance for each of the three environmental conditions that were gathered following a self-described comprehensive search of data and literature. Even in this early example using HSI modeling to classify habitat quality, researchers conceded “Exact values assigned within these ranges (0.0-1.0) were based on findings in the literature coupled with expert judgment” and “Because the relationship between environmental and biological gradients and species distributions is impractical and inappropriate to quantify without a robust data set documenting relative abundance across the complete range of each environmental parameter, variables were not weighted in the conventional manner.”

Despite the potential deficiencies in relying on a documented list of habitat characteristics preferred by the species in place of field measurements at current nesting sites, it is not always possible to collect site-specific habitat variables in the field. In fact, most current studies predict habitat suitability using computerized modeling and Landsat images or aerial photography to map the location and density of the preferred habitat traits to predict species presence. Although many ecological studies still rely on the original HEP protocol to make quick assessments about the habitat in absence of data, its use by SWFL biologists has changed in favor of a method that merges both data collection with extensive computer modeling and a robust statistical analysis. The advanced techniques use computerized statistical software to determine significant parameters that are input into GIS model development.

These advances in research techniques have greatly improved critical habitat assessments for endangered species. SWFL studies have progressed from the direct observation methods of Phillips (1948), Unitt (1987) and Harris (1991) to a modified application of HEP (Ahlers, 2009, York et al. 2011) that incorporates both field data analysis and geospatial model development with emphasis on species habitat preferences documented in the literature. Newer methods to classify habitat suitability include a variety of statistical designs that are used in conjunction with GIS where satellite imagery is used to evaluate areas too large to survey using traditional methods. The resulting maps delineate potential suitable flycatcher nesting habitat and provide a more efficient and economical process for designating critical areas for protection.

Hatten and Paradzick (2003) applied similar techniques when mapping SWFL breeding habitats in Arizona. Their model development integrated aerial photographs and topographic maps with documented SWFL nest locations. Suitable and unsuitable habitat characteristics used to evaluate potential habitat were extracted from the literature on SWFL nesting site habitat descriptions. During their study they continued survey efforts and included any changes from unsuitable to suitable in an effort to identify all potential breeding habitat for mapping accuracy. Variables used in their study concentrated on Normalized Difference Vegetation Index (NDVI) values, which correlated with relative density and biomass of green vegetation and floodplain characteristics. Their model identified 5,294 ha of potential SWFL breeding habitat with 95% model accuracy at their project site. Their study results facilitated a change in survey protocol that focused future efforts on sites having a greater probability of nesting flycatchers and minimizing surveys in undesirable habitat.

The advances in modeling techniques have greatly improved the identification of suitable breeding habitat but continue to rely on traits described in the literature from previous studies as key variables for SWFL nesting habitat analysis. With the introduction of exotic species that monopolize water and space in many western riparian habitats, these species have become a dominant feature in many western rivers. With no abatement in hydrological manipulations and restoration efforts focused on limited sites, exotics are likely to persist in large portions of riparian habitat. As a result, species such as the flycatcher have altered their behavior to nest in the exotic vegetation and in some cases selecting the exotics over their native habitat (Sogge et al. 2003, 2005).

If future research continues to rely exclusively on the previous study descriptions of preferred habitat characteristics to predict suitable SWFL habitat without incorporating measurements of the fluctuations in vegetation characteristics present at current nesting sites, these subtle changes in flycatcher selection preferences and suitable habitat could be overlooked.

CHAPTER III

STUDY AREA

The data used in this study were collected from 2003 to 2010 by SWCA Environmental Consultants for the Bureau of Reclamation (BR) at four different sites located in the states of Arizona and Nevada (Fig. 1). The Pahranagat study area is located on the Pahranagat National Wildlife Refuge (NWR) in Nevada, has an elevation of 1,026m and covers 7.1 ha. The Mesquite study area covers 22.9 ha with an average elevation of 467m and the Mormon Mesa study area covers 105.2 ha with an average elevation of 385m. Mesquite and Mormon Mesa are both located on the Virgin River in Nevada. Topock Marsh is located on Havasu NWR in Arizona, has an elevation of 140m and covers 73.8 ha. All four sites are part of the Lower Colorado River Basin.

Surveys at Pahranagat were done at both the inflow and outflow of Upper Pahranagat Lake. This site is composed primarily of native habitat vegetated by Goodding's willow (*Salix gooddingii*), Fremont cottonwood (*Populus fremontii*) and coyote willow (*Salix exigua*) with the occasional presence of invasive tamarisk and Russian olive in the understory. Canopy closure ranges between 50-80% and surface water is present through much of the SWFL breeding season. The Mesquite site is a mixed habitat of natives and exotics. Cattail (*Typha* spp.) and bulrush (*Scirpus* spp.) marshes are scattered throughout the study area, which receives a significant amount of irrigation runoff from two nearby golf courses and surrounding agricultural fields. Canopy closure at this site is 50- >90%. Mormon Mesa is also a mixed habitat of native and exotic vegetation with tamarisk dominating a large portion of the study area. The average canopy cover ranges from 70-90%. Mormon Mesa is approximately 10 km upstream from Lake Mead. Topock Marsh is a mixed riparian habitat dominated by exotic tamarisk with scattered patches of native Goodding's willow. This study area is bordered by open water from a series of lakes on the Havasu NWR and canopy closure ranges from 70->90% at most survey sites.

Figure 1. Map of the four study areas, Pahranagat, Mesquite and Mormon Mesa, Nevada and Topock Marsh, Arizona.

CHAPTER IV

A HABITAT MODEL FOR SOUTHWESTERN WILLOW FLYCATCHER USING STATISTICAL ANALYSIS AND GIS MODEL DEVELOPMENT

Introduction

Much of the literature on SWFL habitat modeling has concentrated on topographical features and the identification of vegetation characteristics common to flycatcher nesting sites that are then located on aerial photographs or Landsat images using spatial software to predict potential nesting habitat (Hatten and Paradzick 2003, Dockens and Paradzick 2004, Paxton et al. 2007, Hatten et al. 2010). This approach has successfully identified riparian areas where flycatcher nests are most likely to occur, but does not necessarily quantify the range of habitat quality available. Habitat Suitability Index (HSI) models attempt to correct this limitation by organizing the habitat into assigned class values between 0 and 1 representing indices of habitat quality. HSI models are widely used to classify habitat but class rankings are most often developed from subjective interpretations of the literature on a species' habitat selection behavior (U. S. Fish and Wildlife Service 1981, Roloff and Kernohan 1999). To date, habitat suitability index models lack a computational method for calculating classification thresholds or weighted values for interactions between traits.

The objectives of my study were to 1) conduct a statistical analysis of SWFL historical nesting site selection data to identify characteristics essential to flycatcher nesting habitat preferences, 2) to further examine these traits to determine their relative magnitude of influence on habitat selection, and 3) to incorporate these finding into a habitat preference model using GIS software to predict and classify the range of habitat quality available to SWFL within the LCR watershed.

Methods

Habitat Data Screening and Selection

Historic data of SWFL nesting site characteristics and habitat availability for LCR were acquired in cooperation with the Bureau of Reclamation office (BOR) in Boulder, Nevada with actual field data collected by subcontractor, SWCA Environmental Consultants from 2003-2010. All data were collected according to SWCA's survey protocol outlined in their annual reports submitted to BOR (McLeod et al. 2003-2010). Initial variable reduction was performed due to incomplete data following protocol changes during the study period and a high degree of autocorrelation between multiple variables. Traits considered for analysis were reduced from 121 to 68 (Appendix A, Table 1). A statistical analysis and a habitat selection model were developed for each of the three study areas, Pahranagat, Mesquite and Mormon Mesa.

I selected these data because they contained the largest LCR data sets with the most diverse and robust sample sizes for the development of a habitat suitability model. From the LCR dataset, three subsites, Pahranagat National Wildlife Refuge (NWR), Mormon Mesa, and Mesquite, Nevada were selected because they: 1) consistently attracted nesting SWFL breeding pairs or single males defending an occupied territory; and 2) they contained widely stratified vegetation characteristics that best represent the three most common habitats found in western riparian systems, namely native, mixed native and exotic, and exotic dominated habits respectively. Sample sizes ranged from 70-90 documented nesting sites within each site. From these documented nesting sites, I used Excel's Data Analysis random sample function to extract 10 random locations from each of the Pahranagat and Mormon Mesa sites and 30 locations from the Mesquite site, due to its much larger data set, for later use in model accuracy assessment.

Habitat Selection Analysis

In the first step of the statistical analysis I separated the data for each habitat variable (trait) into two categories, nest observations (use) and habitat availability (random location). I further subdivided each trait into classes based on the distribution of the raw data within the trait separately for each of the three sites. I used a Pearson's Chi-square test on the 68 possible SWFL habitat variables to identify which traits were significant at the $P \leq 0.05$ level (Zar, 1999). Traits identified as significant for each of the three sites were then subjected to a test of proportions (Z test) to determine whether classes were "selected," "avoided" or "used as available" (Non Significant; NS).

The second step of the habitat selection analysis was the development of the HSI scaling. I calculated an HSI value for each class within trait as the “percent use” divided by “percent available”. Using these HSI values with their associated Z values, I solved for the unknown upper and lower significant HSI thresholds between class selection behaviors (select, avoid, NS) by means of a linear interpolation between selection or avoidance to the nearest NS classes. I used the Z-value as the independent value and the HSI as the dependent value and a significant Z-value at the $P \leq 0.05$ (two tailed test) as the threshold value. Using the calculated threshold values, in conjunction with an evaluation of the differences between “percent use” and “percent available” I assigned a new scale value (ranging from 1 to 9) for each within trait class (Fig. 2.). Each of the scaled value categories of Suitable, Marginal and Unsuitable contained three additional subclasses, Upper, Middle and Lower quality which were later used in the reclassification of each trait in ESRI’s ArcGIS® Model Builder.

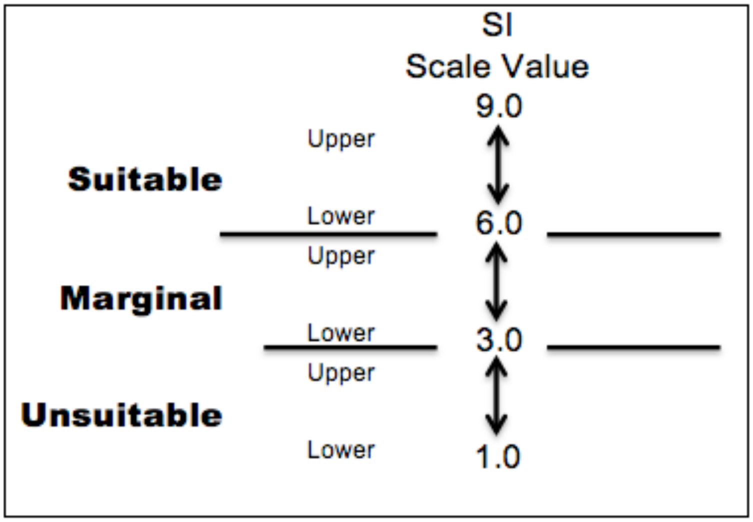

Figure 2. Habitat Suitability Index (HSI) Scale for range of habitat quality available.

The final step of the habitat selection analysis was the determination of the individual trait influence on nest site selection. I used IBM’s® SPSS® version 21 statistical software to run a Principal Component Analysis (PCA) variable reduction technique, separately for each use site, with the documented use location of only the significant traits as input to the analysis.

Only traits with PCA components scores ≥ 0.500 were included in the development of the between trait influence value. The individual influence value (IV_i) was calculated using the equation:

$$IV_i = (CV_{ij} * EV_j) / \sum (CV_{ij} * EV_j)$$

where: IV_i is the influence of habitat trait *i* between 0 and 1, CV_{ij} is the component value for trait *i* in component *j*, and EV*j* is the percent variation explained by PCA component *j*. If a trait was found to have a significant component value in more than one component, then the influence value equaled the sum of the absolute values for each of the components of that trait. The sum of all influence values is 1.

Habitat Suitability Model Development and Assessment

All model development was done using ESRI's ArcGIS® 10.1 Model Builder (Appendices C and D, Fig. C-1-C-3, and Fig. D-1). The first step of the habitat suitability model development was the creation of surface (Grid) maps that represented the spatial distribution of the significant habitat traits identified within each of the three selected study areas. To accomplish this task I used ArcGIS® Geostatistical Analyst point to surface transformation. Input for these transformations was all of the point locations used in the habitat selection statistical analysis for traits found to be significant. The specific transformation method was a universal kriging type with a prediction output type. A total of 45 traits (30 shared between sites) from all three study sites were used to build the output surfaces (Table 1). These were later combined for model validation. Output of the surface transformation was then converted from floating point numbers to integers using a Spatial Analyst Math transformation function. I then reclassified the within trait classes of the integer transformed grid using the scaling values described in the HSI development of the habitat selection statistical analysis. These HSI reclassified grids were then used as the input to the individual habitat suitability models.

The second step of the modeling process was the development of individual site-specific models for the three reference sites, Pahranagat, Mormon Mesa, and Mesquite.
This was accomplished using a weighted sum overlay technique. This output was created using the raster calculator function in ArcGIS® using the equation:

$$\mathrm{HSI}_j = \sum(\mathrm{HSI}_{ij} * \mathrm{IV}_i)$$

where the individual cell value within the output grid (HSI_j) is the sum of the cross products of the reclassified scale value (HSI_{ij}) for a specific trait times the influence value (IV_i) for the specific trait. I reclassified the summed output for each site using an HSI Scale of 1.0 - 9.0 (Fig. 2).

TRAITS Shared between sites

Mormon Mesa, Nevada (Exotic)	**Pahranagat, Nevada (Native)**	**Mesquite, Nevada (MIxed)**
TRAIT	TRAIT	TRAIT
1 hab_type		28 hab_type
2 Native Basal Area m^2/Ha.	22 Native Basal Area m^2/Ha.	29 Native Basal Area m^2/Ha.
3 SNAG Basal Area m^2/Ha.		30 SNAG Basal Area m^2/Ha.
4 Total Basal Area m^2/Ha.		31 Total Basal Area m^2/Ha.
5 Percent Native Basal		32 Percent Native Basal
6 Number of Native Vertical Folage Hits at 1m	23 Number of Native Vertical Folage Hits at 1m	33 Number of Native Vertical Foliage Hits at 1m
7 Number of Exotic Vertical Folage Hits at 1m		
8 Percent Native Vertical Folage Hits at 1m		34 Percent Native Vertical Folage Hits at 1m
9 Canopy Height (m)	24 Canopy Height (m)	
10 Mature Exotics Density/HA (DBH> 10.6 cm)		
11 SNAG Density/Ha DBH < 5.5 cm		35 SNAG Density/Ha DBH < 5.5 cm
12 SNAG Density/Ha DBH > 5.5 cm		36 SNAG Density/Ha DBH > 5.5 cm
13 Live Stems Density/ Ha DBH < 2.5cm dbh		
14 Live Stem Density/Ha DBH 2.5-10.5cm		
15 Total Live Stems Density/HA		37 Total Live Stems Density/HA
16 Dead Stem Density/Ha DBH < 2.5cm		
17 Deadstems Density/Ha 2.6-8cm dbh		
18 Total Dead Stem Density/HA		38 Total Dead Stem Density/HA
19 Total Stem Density/Ha DBH < 2.5cm		
20 Total Stem Density/Ha DBH 2.5-8cm		
21 Total Stem Density/ Ha DBH > 8cm		
	25 Total Ground Cover (%)	39 Total Ground Cover (%)
	26 SAGO > 15cm DBH/HA (Salix gooddingii)	
	27 Average Canopy Closure (%)	
		40 Number of Native < 5.5cm DBH/Ha (Immature Salix exigua)
		41 Exotic Basal Area m^2/Ha.
		42 Number of Native 5.6-10.6 DBH/Ha (Intermediate Salix exigua)
		43 Number of Exotic < 5.5 DBH/Ha (Immature Tamarix sp.)
		44 Total Live Basal Area m^2/Ha.
		45 Total Stem Density/HA

Table 1. List of significant traits used in the three habitat suitability index models, Pahranagat (native), Mormon Mesa (Exotic) and Mesquite (Mixed-exotic).

The final step of the model development was the validation process. Using the nest site locations reserved in the habitat selection statistical analysis as expected values and the model output values as the observed, a standard accuracy assessment was performed using a correlation matrix approach.

Model Implementation

The final objective of my study was to integrate the results of the habitat selection analysis and the three reference site selection models into a single model that would predict SWFL breeding site suitability for a given location. For this objective I chose the SWFL breeding site, Topock Marsh, located on Havasu National Wildlife Refuge in Arizona. Raw point data of habitat availability for this analysis came from the same data BOR/SWCA source as that used to develop the analysis on the three reference areas. In addition to the habitat availability data, there were locations of 127 SWFL nest sites documented between 2003-2009 that could be used to evaluate the potential accuracy of a Topock Marsh model.

The initial step in the creation of the Topock Marsh model, was the transformation of the point data to surface maps of each of the 30 previously identified significant habit traits. This transformation was identical to that used in the three reference areas, where the significant traits for each reference area were used to create the appropriately scaled HSI grids for each habitat type category. I applied the reference area specific models (native, mixed native and exotic, and exotic dominated) to all of the appropriate Topock Marsh habitat variables (Appendix D, Fig. D-1). The combination of the appropriate model outputs into the final predictive map was done using a selective masking technique. Individual masks were developed based on the percent native basal habitat trait where: native dominated habitat was defined as percent native basal $\geq$ 66% (Pahranagat), mixed native and exotic habitat as percent native basal of 33 – 66% (Mesquite) and exotic dominated habitat as percent native basal < 33% (Mormon Mesa). Each of these masks was designed to only allow those cells with the individual predictive outputs meeting the definition of the mask to be used in the final predictive model. I then combined the masked outputs using an additive function, and reclassified the result into a single output for Topock Marsh using the HSI scale for habitat quality described in model development (Fig. 2).

Results

Habitat Selection Characteristics

My Chi-square analysis of the Pahranagat study site (native habitat) found only six significant habitat characteristics (Appendix B, table 1). PCA results for the Pahranagat site indicated that native basal, native vertical foliage, canopy height, mature native trees and canopy closure explained 92% of the total variation. A sixth trait, total ground cover, was also included in the HSI habitat model for Pahranagat due to a variance well above the previously established 0.5 limit for inclusion. Native basal area and the number of native trees > 15 cm DBH/ha were the two habitat characteristics with the highest influence values at 28.5 and 18.1 % respectively. SWFL appeared to respond positively to the presence of all levels of these traits, and negatively to the absence of them. The remaining four habitat traits, number of vertical foliage hits, canopy height, average canopy closure and total ground cover had influence values ranging from 16.4 to 11.3%

I identified a total of 21 significant characteristics from the Chi-square analysis for the Mormon Mesa study site (exotic dominated habitat) (Appendix B, table 2). PCA results for Mormon Mesa showed that four traits, percent native basal, native basal, habitat type and native vertical foliage explained 78% of the statistical model variation. A total of 21 traits with calculated component values > 0.5 were included in the development of the HSI habitat model for Mormon Mesa. The individual influence of these traits ranged from a high of 6.7% to 1.3%. Percent native basal exerted the greatest influence on SWFL nesting site selection among all traits (6.7%). Though results showed that flycatchers preferred 100% presence (SI = 4.14) they more strongly avoided (SI = 0.69) areas where native basal was absent. Both habitat type and native basal each exerted an influence of 6.6%. Habitat type 1 (> 90% basal area native) was more strongly preferred to habitat type 2 (50-90% basal area native). Habitat type 3 (10-50% basal area native) was used as available and habitat type 4 (< 10% basal area native) was strongly avoided. Native vertical foliage had an influence of 6.2%. SWFL preferred areas with densities > 10 vertical foliage hits at one meter and avoided areas where vertical foliage was absent.

My Chi-square analysis identified 18 significant habitat traits for the Mesquite study site (mixed native and exotic habitat) (Appendix B, table 3). PCA results for Mesquite showed that the five traits, total basal, percent native basal, native basal, habitat type and percent native vertical foliage explained 78% of the statistical variance. A total of 18 traits with calculated component values greater than 0.5, were included in the HSI habitat model for Mesquite. The individual influence of these traits ranged from 9.4% to 1.2%. Total basal and percent native basal had the strongest influence values of 9.4% and 8.0% respectively. Flycatchers preferred a total basal area density of $\geq$ 30 m^2/ha, while avoiding sites where total basal area density was < 10 m^2/ha. Their preference for the percent of native basal present was not as strong but they did avoid sites having less than 25% native basal. Results for density of native basal showed that flycatchers preferred > 25 m^2/ha with a minimum of 75% native vertical foliage while avoiding sites with < 25%.

Combined results of chi-square analysis indicated that flycatchers selected 30 different traits significantly different than all other habitat traits available indicating selection or avoidance for specific habitat characteristics among the three sites. Three traits, native basal, native vertical foliage and canopy height were significant at all three sites. The ten traits, habitat type, snag basal, total basal, native basal percent, native vertical foliage, native vertical foliage percent, snag < 5.5cm, snag > 5.5cm, total live stems and total dead stems were significant at both the Mormon Mesa and Mesquite sites. The total combined number of traits used for development of the three HSI models was 30 (Appendix B, Tables B1-B3).

Habitat Suitability Models

The highest habitat quality described by the Pahranagat model (Fig. 3) was Lower Suitable. All reserved accuracy assessment points used to test model accuracy were located in the Lower Suitable and Upper Marginal habitat (Table 2). The best habitat quality described by the Mormon Mesa model (Fig. 4) was Lower Suitable, which only covered approximately 1.35 hectares (0.2%) of the entire study area. As a result, six of the ten reserved accuracy assessment points were located in Upper Marginal habitat which is only approximately 14% of the available habitat at the Mormon Mesa study site. Of the remaining 4 points, 3 were located in Marginal and a single point in Lower Marginal. The best habitat quality described by the Mesquite model (Fig.

5) was Lower Suitable. Ninety-seven percent of the nest test points for Mesquite were located in the top two habitat classes, Lower Suitable and Upper Marginal.

Study Site	Upper Unsuitable.	Lower Marginal	Marginal	Upper Marginal	Lower Suitable	n
Pahranagat	NA	0	0	6	4	10
Mormon Mesa	0	1	3	6	0	10
Mesquite	0	0	1	7	22	30

Table 2. Reserved accuracy assessment points and habitat quality for all three study sub-sites.

Model Validation

The results of the Topock Marsh model indicated that the majority of habitat available at this site (87%) is composed of the two habitat classes, Unsuitable and Lower Marginal (Table 3) (Appendix D, Figure D-1). The map of the HSI output from the model indicated that from 2003-2009 the best habitat quality available, Upper Marginal, was only a small portion (12.8%) of the total area (831 ha) surveyed for nest sites (Fig. 6). The model also predicted the quality of habitat at Topock Marsh was declining during the same period. In 2003, only 38% of all nest sites were located in the Unsuitable habitat class. In 2005 the proportion of nests in the Unsuitable Habitat class expanded to 45% and continued to increase to 60% in both 2006 and 2008.

Study Site	Unsuitable	Lower Marginal	Marginal	Upper marginal	n
Nest points 2003-2009	40	71	0	15	126
% Study Area	41	46	0.2	12.8	100
Area (sq km)	3.4	3.8	0.0135	1.1	8.3

Table 3. Results of the accuracy assessment of the Topock Marsh model.

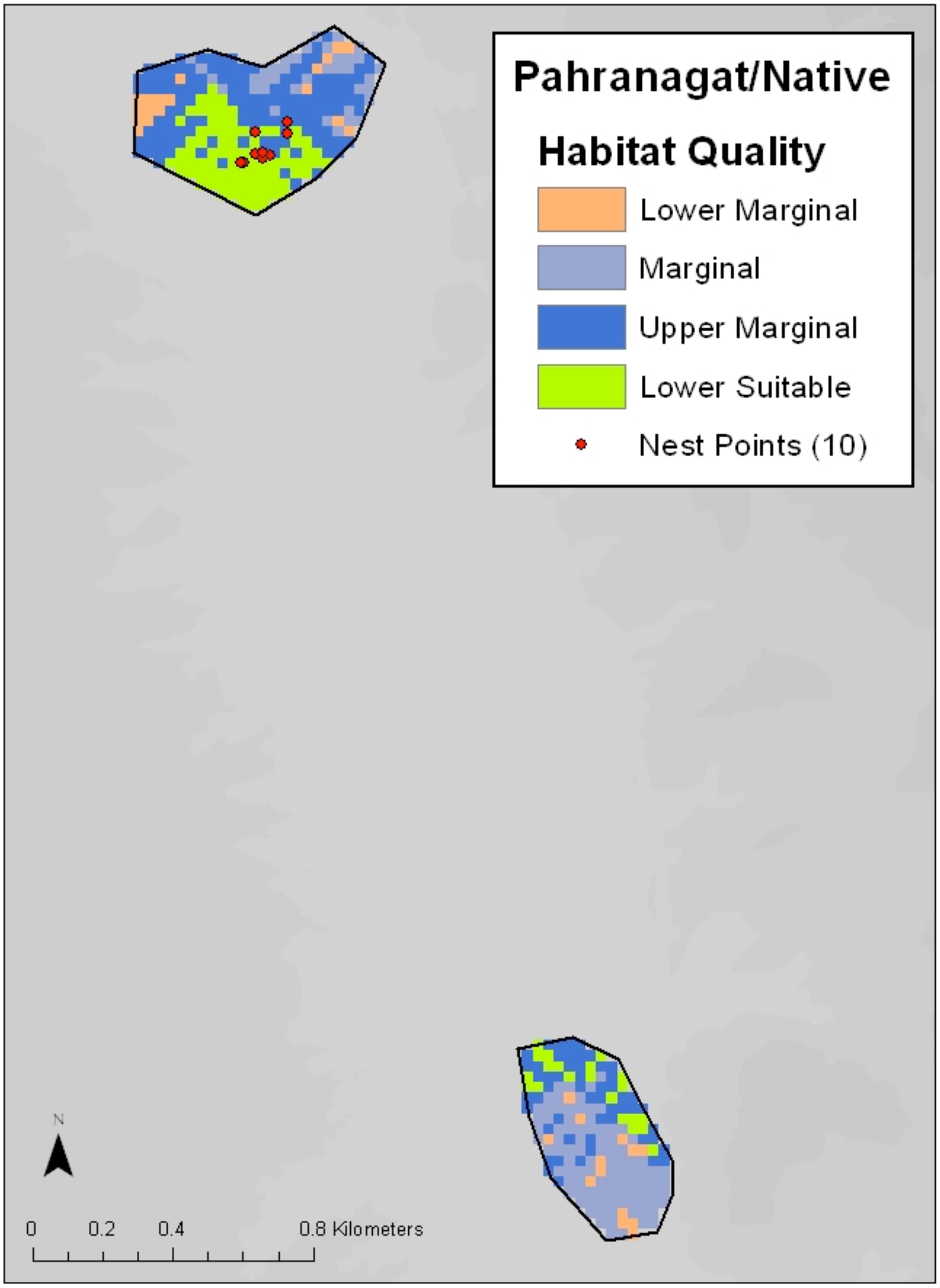

Figure 3. Range of habitat quality predicted by the model for the Pahranagat study site.

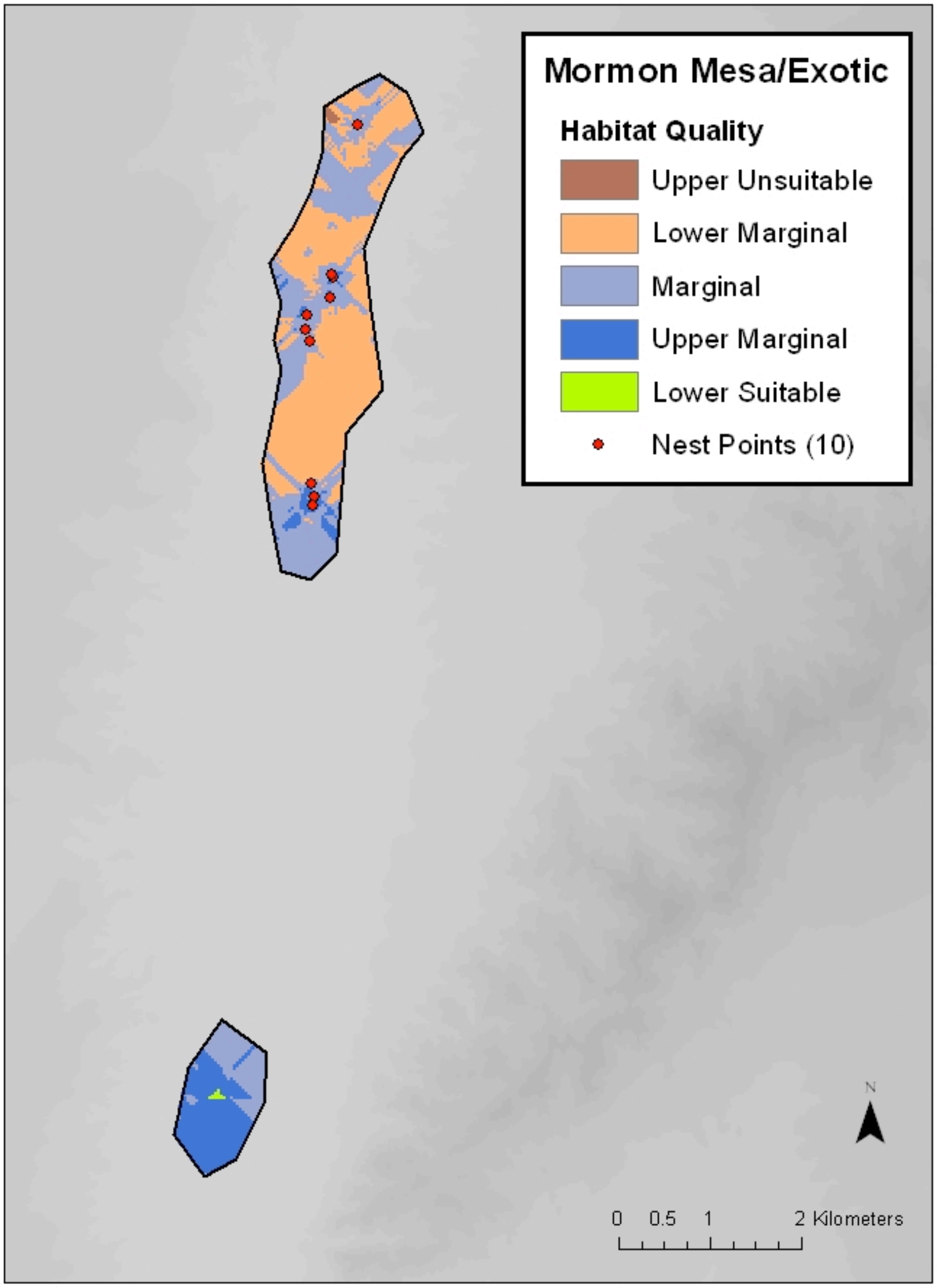

Figure 4. Range of habitat quality predicted by the model for the Mormon Mesa study site.

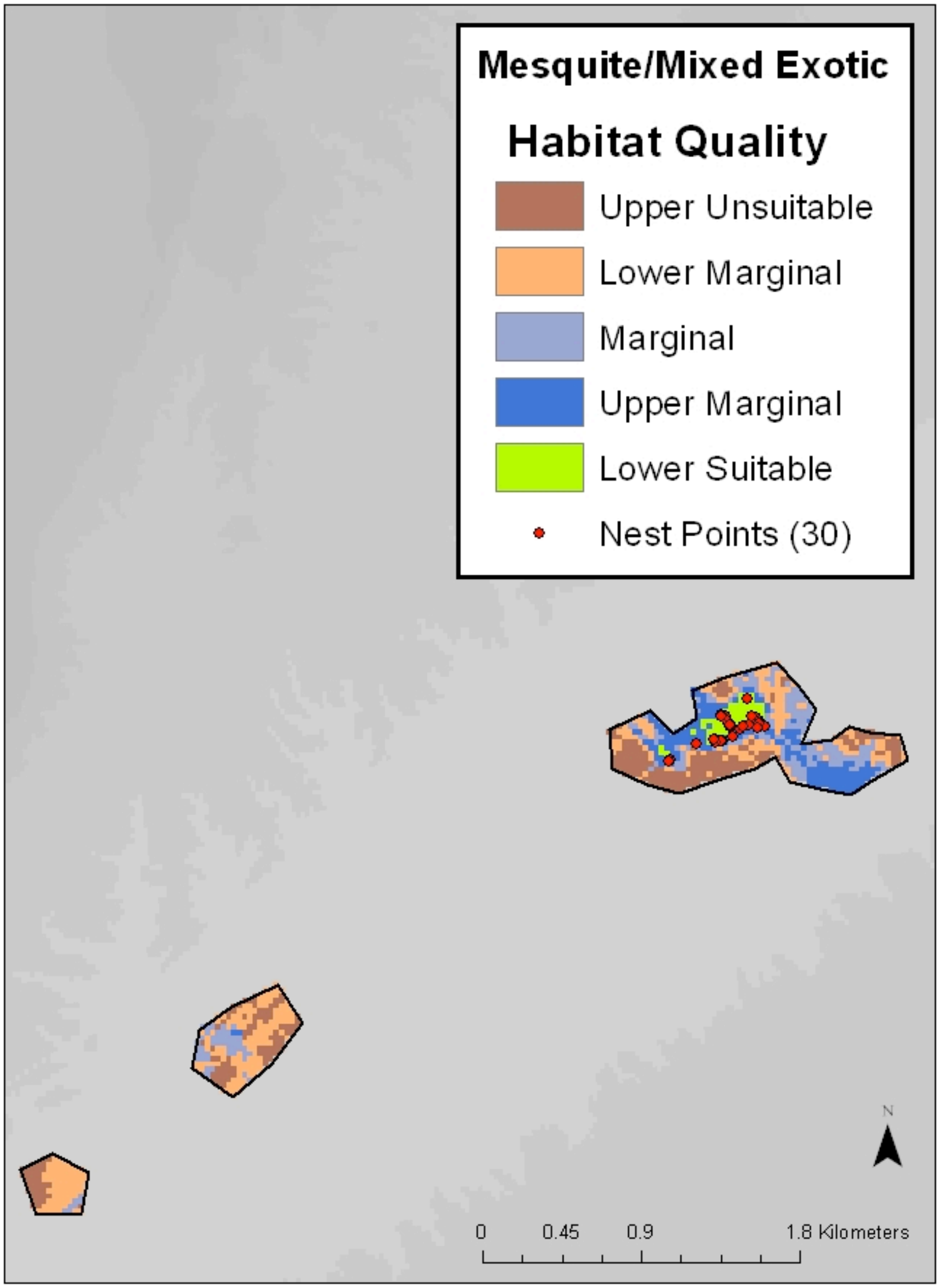

Figure 5. Range of habitat quality predicted by the model for the Mesquite study site.

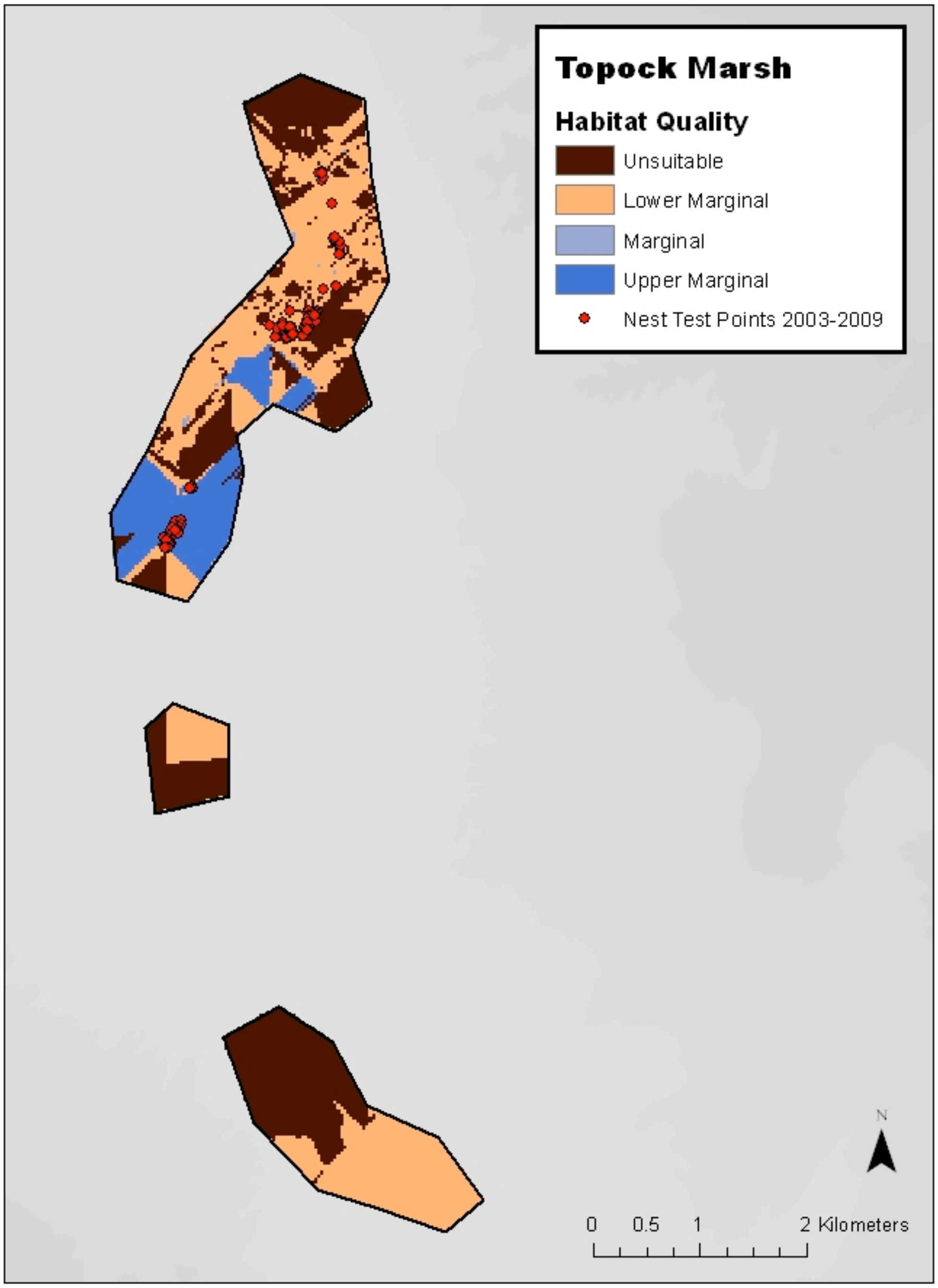

Figure 6. Range of habitat quality predicted by the model for the Topock Marsh study site.

Discussion

Previous literature has documented the importance of moist soil and the presence of water in SWFL breeding/nesting habitat (Paradzick 2005, Ellis et al. 2009, Hatten et al. 2010). Chi-square analysis for “distance to water” was significant at all three sites. However, when PCA’s were conducted for each site, “distance to water” ranked low among all traits or was completely extracted from the “between trait interactions” as in the example of Pahranagat. The PCA for Pahranagat extracted the trait from the component results and only retained a total of seven significant traits overall. The PCA for Mormon Mesa dropped the trait to the last position, which ranked it thirty-second among all the traits entered and only ranked its value higher than 0.5 in one component of the matrix. The PCA for Mesquite ranked the trait 25 out of 27 total traits with no component value higher than 0.48. I conclude that “distance to water” is a significant habitat characteristic that must be present to attract breeding flycatchers to a site but when evaluating potential nest locations, flycatchers do not value this characteristic very high when comparing this trait to other more desirable traits such as variable measurements of native basal, which ranked first among all sites. My analysis suggests that without the presence of water flycatchers will not remain at a site to establish any breeding territories but because water is present at all breeding sites it is not a suitable characteristic for detecting subtle habitat selection preferences being made by breeding Southwestern Willow Flycatchers.

All three habitat models performed exceptionally well when tested for accuracy using the reserved accuracy assessment points for each site. Because the native site, Pahranagat, is located on a national wildlife refuge, restoration of native riparian forest has been a management priority. Because of this effort, Pahranagat has consistently attracted nesting flycatchers each breeding season making it the most productive SWFL breeding site among all BR study areas on the LCR (McLeod and Pellegrini 2012). There were a total of 71 nest sites documented at Pahranagat from 2003-2007. When assessing their placement on the HSI map predicted by the native model, all but one nest point was located in the best quality habitat available, Lower Suitable. The one nest point not located in Lower Suitable was positioned only a half meter from the best quality habitat. A possible explanation for the point’s location outside the optimum habitat could be a minor error in the point's coordinates or possible competition from neighboring flycatcher territories. Flycatchers at Pahranagat primarily nested in mature native willows, which dominate this site. This explains why the trait, "Goodding's Willow (*Salix gooddingii*) larger than 15 dbh", was responsible for the greatest amount of variation in the native model (28%).

The Mormon Mesa model also predicted the best habitat quality as Lower Suitable, but the area covered by this class was such a small portion of the total area measured (0.2%) that only two nests, one documented in 2003 and one documented in 2009 were located in this habitat class. Of the fifty-eight nest sites surveyed between 2003-2009, the exotic model predicted that all but three nests were located in the next top two habitat classes, Upper Marginal and Marginal. Similar to the results of the Pahranagat model, traits related to the native basal characteristic were also found to be significant vegetation features preferred by flycatchers in the Mormon Mesa model. The traits "% basal native" and "native basal" were ranked as the top two characteristics preferred and when combined, explained over half of the variation in the mixed exotic model.

Twenty-two of the 29 accuracy assessment points at Mesquite were located within the best habitat class Lower Suitable with an additional 3 points located on the edge between Lower Suitable and the next class, Upper Marginal. Accuracy of the model was also confirmed when reviewing nest locations surveyed from 2003-2010 and their placement on the map predicted by the Mesquite model. The habitat class Lower Suitable covered only 6% of the study area at Mesquite and attracted most of the breeding flycatchers documented during the years of the study. Over 56% of the breeding flycatchers that nested at the Mesquite site chose the Lower Suitable habitat class during the seven years of the study period. Another 23% nested in the next best habitat class available, Upper Marginal, which may have been their only option if territories were already established in the best habitat class by flycatchers arriving earlier.

Southwestern Willow Flycatchers have been consistently surveyed at Topock Marsh each breeding season, establishing territories, building nests and rearing chicks since monitoring began in 1998. Annual reproductive success at Topock Marsh has historically been somewhat erratic during the last two decades with a peak productivity of 78% in 2003. However, a more recent pattern has emerged that began the following year, documented by lower flycatcher presence and nest failure suggesting a declining habitat at this site, which was also predicted by the Topock Marsh model and confirmed by the recently released 2011 annual LCR flycatcher report to Bureau of Reclamation by SWCA Environmental Consultants (McLeod and Pellegrini 2012).

The data used in this study ended with the 2010 nesting season on the LCR. SWCA later released reports in 2011 and 2012 referencing the 2010 survey data in my study and the data collected the following two breeding seasons. My evaluation provides strong evidence of a continued decline in nest success at the Topock Marsh site that is confirmed in the SWCA reports. The most recent report released by SWCA compiling annual numbers for nest success at Topock Marsh are 13% in 2008, 50% in both 2009 and 2010 and complete nest failure with 0% in 2011 and 2012 (McLeod and Pellegrini 2012, SWCA Environmental Consultants 2012).

Several previous studies have used modeling techniques to investigate flycatcher breeding territories to predict suitable habitat preferred by nesting SWFL. Hatten and Paradzick (2003, Dockens and Paradzick 2004) developed models using a combination of GIS, presence/absence data and multiple logistic regressions to identify patterns of SWFL habitat selection in Arizona. The habitat variables they examined, vegetation density, edge habitat and proximity to patch boundaries, were chosen based on their importance in the literature. They extracted the variables from satellite imagery and digital elevation models (DEM) in order to characterize and predict suitable habitat for SWFL in their project area. In a similar approach, Hatten et al. (2010) developed numerous flycatcher habitat models using the same previous environmental variables of floodplain and vegetation density that are associated with flycatcher habitat, with the new addition of age and stability of vegetation, heterogeneity and distance to water. As in the earlier techniques, they identified the riparian vegetation using Landsat Thematic Mapper images and floodplain features extracted from a DEM to predict territory occurrence. The previous habitat modeling techniques have provided excellent methods for identifying potential breeding habitat but they have primarily relied on satellite imagery to examine and delineate the habitat. My study used a completely different approach to classify suitable habitat for flycatchers, by using extensive long-term vegetation surveys to conduct a comparative analysis of numerous habitat traits found at nest sites (observations) versus non nest sites (random location). My new method using PCA to assign weighting values to significant characteristics provides a more finely detailed approach to the classification and prediction of critical habitat for flycatcher. This was confirmed when I described this method to a known expert on the Southwestern Willow Flycatcher who responded “although there have been numerous vegetation studies on flycatcher habitat, to the best of my knowledge, none have identified this broad a suite of specific traits with scaling and influence values on flycatcher nest selection characteristics” (Mark Sogge, USGS, personal communication).

The results of my study indicate that flycatcher habitat selection preferences are far more complex and subtle than earlier studies have detected. Although these birds are subjected to a constant threat of habitat loss and fragmentation, flycatchers have demonstrated remarkable adaptability by nesting in tamarisk despite their evolution within cottonwood-willow vegetation communities. However, this adaptability may not override their initial pursuit of specific native vegetation features when selecting nesting sites. These endangered birds are simply struggling with a habitat that is changing too rapidly for them to adapt to the new conditions. Because there is also strong evidence suggesting flycatcher habitat selection behavior (Koronkiewicz et al. 2006) may be just as distinct in their wintering habitat (winter survival 54-72%), efforts to recover this species may be far more complicated and challenging and require a more thorough investigation into their habitat selection preferences. Although flycatchers have been documented using a variety of nest substrates at different locations, my study indicates that flycatchers make specific choices for some native habitat traits when selecting nesting sites. The presence of these characteristics may also be a significant factor when flycatchers decide whether to nest, which may have major implications for restoration efforts. These results emphasize the importance of restoration of native habitat in some riparian areas in order to encourage breeding SWFL to consider a site for nesting. Restoration of native riparian vegetation at historical flycatcher nesting sites may be a key factor for improving flycatcher reproduction and population recovery.

CHAPTER V

MANAGEMENT IMPLICATIONS

On June 6, 2012 a report was prepared by Industrial Economics, Incorporated (IEc), under contract to the U.S. Fish and Wildlife Service entitled The Economic Analysis of Critical Habitat Designation for the Endangered Willow Flycatcher. The report was drafted to evaluate the economic impact of the designation on water management, livestock grazing, residential and related development, tribal activities, transportation, oil and gas development, mining and recreational activities. The authors estimated the actual predicted cost would range from $11–$19 million over the first twenty years following designation with an additional cost of $200,000 to $1.4 million over the ten years that follow. These estimates do not include any projected costs for continued implementation of the flycatcher recovery plan or any river restoration projects to improve riparian habitat for this species. The expense of preserving and restoring riparian river habitats has grown exponentially in the last two centuries with conservative estimates for major restoration projects surpassing the $500 million threshold (Follstad Shah et al. 2007). Adding to the cost of critical habitat designation in western river restoration projects is the supplementary expense of removing exotic species to facilitate the reestablishment of native vegetation (Stromberg et al. 2009).

As costs related to the recovery of the southwestern willow flycatcher increase, methods used to evaluate and classify habitat quality for the flycatcher will be strongly scrutinized for cost effectiveness, accuracy of results and all impacts associated with the designation. As a result, habitat evaluation methods used to propose areas for designation must incorporate reliable techniques that utilize both quantitative assessments of existing conditions in the habitat as well as the accurate prediction of future habitat quality consistent with the model developed in this study.

Riparian habitats along rivers in the southwest are subjected to some of the more persistent anthropogenic disturbances of any habitats in the United States. This has led to a major decline in native cottonwood-willow communities historically utilized by endangered flycatchers during the breeding season. Remarkably, recent studies have discovered a change in flycatcher nesting site selection behavior by documenting flycatcher use of exotic tamarisk for nesting, often as a preferred substrate in some locations where native vegetation is available (Sogge et al. 2008, Paxton et al. 2011).

The confirmation of tamarisk as an alternative nesting substrate for flycatchers, often in place of native vegetation, has elevated the exotic species to an unusual protected status at some sites simply due to the absence of the native species available for nesting. Unfortunately the discovery of flycatcher preference for tamarisk has been quickly followed by the emergence of a new threat, a biological control originally released to limit the spread of tamarisk. The introduced tamarisk beetle (*Diorhabda spp.*) a natural herbivore of tamarisk, may cause additional stress to an endangered species that is already coping with native habitat loss and fragmentation.

The flycatcher, having been listed as endangered for nearly two decades, has struggled to maintain a viable breeding population and may not persist under another period lacking critical habitat designation to which it was subjected twice since its listing date. In order to ensure successful continuance of critical habitat designation for flycatchers the habitat evaluation methods used to implement management decisions must provide reliable classifications for accurate habitat assessments. Decisions on sites considered for designation must be made using methods that produce results equipped to survive challenges from the courts and outside interference. The HSI models developed in this study from sequential statistical analyses combined with GIS model development have the potential to support management decisions at any flycatcher nesting site under investigation provided that the habitat variables determined by this study to be significant traits are collected for input into the models.

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APPENDIX A

DESCRIPTION OF INITIAL 68 TRAITS ANALYZED

Table A-1. Trait list and description for initial 68 traits used in the analysis as developed by SWCA.

1	hab_type	Numeric code for exotic (4), mixed exotic (3), mixed native(2), and native habitats (1) - based on percentage of the basal area in each plot that consists of native species (<10%, 10-50, 50-90, >90)
2	percent_basal_ native	Percent of the basal area that consisted of native species =native_basal/(native_basal+exotic_basal)*100
3	percent_avgvf_ native_1m	Percent of the live vertical foliage hits at plot center and 1m points that consisted of native species
4	percent_native_vf_ basal_1m	Average of the percent native for basal area and vertical foliage (plot center and 1m points) = (percent_avgvf_native_1m + percent_basal_native) /2
5	native_basal	Basal area (in square cm) of native species =SAEX_basal + SAGO_basal + POFR_basal + BASL_basal + PRSP_basal + PLSE_basal
6	exotic_basal	Basal area (in square cm) of exotic species =TASP_basal + ELAN_basal
7	native_vf_avg_1m	average number of native vertical foliage hits per plot (average of plot center and 1m points)
8	exotic_vf_avg_1m	average number of exotic vertical foliage hits per plot (average of plot center and 1m points)
9	Canopy_ Height	Canopy height within the plot; in m
10	Total_Ground_ Cover	Average of the four ground cover readings =average(Ground_Cover_N, Ground_Cover_E, Ground_Cover_S, Ground_Cover_W)
11	Avg_Can_ Clos	Average of the two canopy closure readings =average(Canopy_Closure_N, Canopy_Closure_S)
12	dist_wat	Distance to water (m) as recorded during veg data collection
13	dist_can	Distance (m) to a canopy gap
14	dist_bro	Distance (m) to nearest broadleaf tree
15	total_basal	Total basal area of all species, live or dead.
16	total_live_ basal	Total basal area of all live stems.
17	TASP_1	Total number of tamarisk stems < 1cm dbh within 5m of plot center (sum of single and multi-stems)

Table A-1. (continued)

18	TASP_1to25	Total number of tamarisk stems 1-2.5 cm dbh within 5m of plot center (sum of single and multi-stems)
19	TASP_26to55	Total number of tamarisk stems 2.6-5.5 cm dbh within 5m of plot center (sum of single and multi-stems)
20	TASP_56to8	Total number of tamarisk stems 5.6-8 cm dbh within 5m of plot center (sum of single and multi-stems)
21	TASP_81to 105	Total number of tamarisk stems 8.1 - 10.5cm dbh within 5m of plot center (sum of single and multi-stems)
22	TASP_106to 15	Total number of tamarisk stems 10.6-15 cm dbh within 5m of plot center (sum of single and multi-stems)
23	TASP_15	Total number of tamarisk stems >15 cm dbh within 5m of plot center (sum of single and multi-stems)
24	tasp_tre	Number of tamarisk >8cm dbh in the 5 to 11-m-radius circle around plot center
25	TASP_basal	Total basal area of tamarisk = TASP_basal_lt15+TASP_basal_15_sum
26	SAEX_1	Total number of stems < 1cm dbh within 5m of plot center (sum of single and multi-stems)
27	SAEX_1to25	Total number of coyote willow stems 1-2.5 cm dbh within 5m of plot center (sum of single and multi-stems)
28	SAEX_26to 55	Total number of coyote willow stems 2.6-5.5 cm dbh within 5m of plot center (sum of single and multi-stems)
29	SAEX_56to8	Total number of coyote willow stems 5.6-8 cm dbh within 5m of plot center (sum of single and multi-stems)
30	SAEX_81to 10.5	Total number of coyote willow stems 8.1 - 10.5cm dbh within 5m of plot center (sum of single and multi-stems)
31	SAEX_10.6to 15	Total number of coyote willow stems 10.6-15 cm dbh within 5m of plot center (for 2008 and later, this is sum of single and multi-stems)
32	SAEX_15	Total number of coyote willow stems >15 cm dbh within 5m of plot center (sum of single and multi-stems)
33	SAEX_basal	Total basal area of coyote willow = SAEX_basal_lt15+SAEX_basal_15_sum
34	SNAG_1	Total number of snag stems < 1cm dbh within 5m of plot center (sum of single and multi-stems)

Table A-1. (continued)

35	SNAG_1to25	Total number of snag stems 1-2.5 cm dbh within 5m of plot center (sum of single and multi-stems)
36	SNAG_26to 55	Total number of snag stems 2.6-5.5 cm dbh within 5m of plot center (sum of single and multi-stems)
37	SNAG_56to8	Total number of snag stems 5.6-8 cm dbh within 5m of plot center (sum of single and multi-stems)
38	SNAG_81to 10.5	Total number of snag stems 8.1 - 10.5cm dbh within 5m of plot center (sum of single and multi-stems)
39	SNAG_106to 15	Total number of snag stems 10.6-15 cm dbh within 5m of plot center (sum of single and multi-stems)
40	SNAG_15	Total number of snag stems >15 cm dbh within 5m of plot center (sum of single and multi-stems)
41	SNAG_basal	Total basal area of snag = SNAG_basal_lt15+SNAG_basal_15_sum
42	PRSP_15	Total number of mesquite stems >15 cm dbh within 5m of plot center (sum of single and multi-stems)
43	PRSP_basal	Total basal area of mesquite = PRSP_basal_lt15+PRSP_basal_15_sum
44	live_under25	Total number of live stems <2.5 cm dbh = TASP_1+TASP_1to25+SAEX_1+SAEX_1to25+SAGO_1+SAGO_1to25+BASL_1+BASL_1to25+ELAN_1+ELAN_1to25+PLSE_1+PLSE_1to25+POFR_1+POFR_1to25+PRSP_1+PRSP_1to25+UNK_1+UNK_1to25
45	live_26to8	Total number of live stems 2.6 to 8 cm dbh = TASP_26to55+TASP_56to8+SAEX_26to55+SAEX_56to8+SAGO_26to55+SAGO_56to8+BASL_26to55+BASL_56to8+ELAN_26to55+ELAN_56to8+PLSE_26to55+POFR_26to55+POFR_56to8+PRSP_26to55+PRSP_56to8+UNK_26to55+UNK_56to8
46	live_over8	Total number of live stems > 8 cm dbh = TASP_15+SAEX_15+SAGO_15+POFR_15+PRSP_15+TASP_81to105+TASP_106to15+SAEX_81to105+SAEX_106to15+SAGO_81to105+SAGO_106to15+ELAN_81to105+ELAN_106to15+POFR_81to105+POFR_106to15+PRSP_81to105+PRSP_106to15+UNK_81to105+UNK_106to15+UNK_15
47	dead_under 2.5	Total number of dead stems < 2.5 cm dbh = SNAG_1+SNAG_1to25
48	dead_26to8	Total number of dead stems 2.6 to 8 cm dbh =SNAG_26to55+SNAG_56to8

Table A-1. (continued)

49	dead_over8	Total number of dead stems > 8 cm dbh = SNAG_81to105+SNAG_106to15+SNAG_15
50	live_under25_HA	Total number of live stems < 2.5 cm dbh per hectare = live_under25*127.32398
51	live_26to8_ HA	Total number of live stems 2.6 to 8 cm dbh per hectare = live_26to8*127.32398
52	live_over8_ HA	Total number of live stems > 8 cm dbh per hectare = live_over8*127.32398
53	dead_under25_HA	Total number of dead stems < 2.5 cm dbh per hectare = dead_under25*127.32398
54	dead_26to8_HA	Total number of dead stems 2.6 to 8 cm dbh per hectare = dead_26to8*127.32398
55	dead_over8_HA	Total number of dead stems > 8 cm dbh per hectare = dead_over8*127.32398
56	livestems25to105	Total number of live stems between 2.5 and 10.5 cm dbh
57	livestems25to105_ HA	Total number of live stems between 2.5 and 10.5 cm dbh per hectare
58	native_vf_1m_tot	Total number of native vertical foliage hits for plot center and 1m points
59	exotic_vf_1m_tot	Total number of exotic vertical foliage hits for plot center and 1m points
60	totalstems_under25_HA	Total number stems under 2.5 cm dbh per HA
61	totalstems_26to8_ HA	Total number stems 2.6 - 8 cm dbh per HA
62	totalstems_over8_ HA	Total number stems over 8 cm dbh per HA
63	livestems_allsizes _HA	Total number of live stems per HA
64	deadstems_allsizes_HA	Total number of dead stems per HA
65	totalstems_allsizes _HA	Total number of stems per HA (live + dead)
66	SAGO_15	Total number of Goodding willow stems >15 cm dbh within 5m of plot center (sum of single and multi-stems)

Table A-1. (continued)

67	SAGO_basal	Total basal area of Goodding willow = SAGO_basal_lt15+SAGO_basal_15_sum
68	POFR_basal	Total basal area of cottonwood = POFR_basal_lt15+POFR_basal_15_sum

APPENDIX B

HABITAT SELECTION STATISTICAL RESULTS

Table B-1. List of significant traits found at the Pahranagat site (Native) resulting from Chi-square and PCA analysis that generated weight values for the reclassification of trait classes.

Number of Native > 15cm DBH/Ha (*Salix gooddingii*) Wt. Value 0.181

Class	%Use	%Available	Z	Preference	SI	Scale Value
0	22.2%	69.2%	6.13	Avoid	0.32	1
200	25.0%	9.4%	2.68	Preferred	2.66	7
500	30.6%	14.5%	2.46	Preferred	2.10	7
> 500	22.2%	6.8%	2.86	Preferred	3.25	8
	n = 72	n = 117				

$\sum x^2 = 79.26$ P = 4.41E-17 Upper SI = NA Lower SI = NA

Native Basal Area m^2/Ha. Wt. Value 0.285

Class	%Use	%Available	Z	Preference	SI	Scale Value
0	19.4%	68.4%	6.38	Avoid	0.28	1
50	33.3%	11.1%	3.55	Preferred	3.00	8
100	23.6%	10.3%	2.27	Preferred	2.30	7
> 100	23.6%	10.3%	2.27	Preferred	2.30	7
	n = 72	n = 117				

∑x2 = 82.25 P = 1.01E-17 Upper SI = NA Lower SI = NA

Number of Native Vertical Foliage Hits at 1m Wt. Value 0.164

Class	%Use	%Available	Z	Preference	SI	Scale Value
15	11.0%	21.0%	1.47	Avoid	0.54	3
25	22.0%	26.0%	0.36	NS	0.87	4
50	54.0%	36.0%	2.31	Preferred	1.51	7
> 50	13.0%	18.0%	0.79	NS	0.70	4
	n = 72	n = 117				

$\sum x^2 = 11.32$ P = 1.01E-02 Upper SI = 1.2895 Lower SI = NA

Canopy Height (m) Wt. Value 0.139

Class	%Use	%Available	Z	Preference	SI	Scale Value
7.5	5.6%	9.4%	0.65	NS	0.60	4
15	36.6%	20.5%	2.25	Preferred	1.79	7
25	47.9%	47.9%	-0.15	NS	1.00	5
> 25	9.9%	22.2%	1.96	Avoid	0.44	3
	n = 71	n = 117				

$\sum x^2 = 14.94$ P = 1.87E-03 Upper SI = 1.5865 Lower SI = 0.4812

Table B-1. (continued)

Average Canopy Closure (%)				Wt. Value	0.128	
Class	%Use	%Available	Z	Preference	SI	Scale Value
55	1.4%	7.7%	1.55	NS	0.18	5
75	4.2%	11.1%	1.40	NS	0.38	5
95	40.3%	53.8%	1.66	Avoid	0.75	3
> 95	54.2%	27.4%	3.54	Preferred	1.98	8
	n = 72	n = 117				

$\sum x^2 = 28.24$ P = 3.24E-06 Upper SI = 0.7235 Lower SI = NA

Total Ground Cover (%)				Wt. Value	0.112	
Class	%Use	%Available	Z	Preference	SI	Scale Value
10	25.0%	42.2%	2.24	Avoid	0.59	2
25	22.2%	12.9%	1.47	Preferred	1.72	7
50	23.6%	12.9%	1.69	Preferred	1.83	7
75	18.1%	11.2%	1.11	Preferred	1.61	7
> 75	11.1%	20.7%	1.50	Avoid	0.54	2
	n = 72	n = 116				

$\sum x^2 = 22.43$ P = 1.64E-04 Upper SI = NA Lower SI = NA

Table B-2. List of significant traits found at Mormon Mesa site (Exotic) resulting from Chi-square and PCA analysis that generated weight values for the reclassification of trait classes.

Habitat Type Wt. Value 0.066

Class	%Use	%Available	Z	Preference	SI	Scale Value
1	18.4%	1.9%	3.70	Preferred	9.84	9
2	23.0%	8.4%	2.63	Preferred	2.73	7
3	9.2%	16.8%	1.34	NS	NA	5
4	49.4%	72.9%	3.21	Avoid	0.68	2
	n = 87	n = 107				

$\sum x^2 = 158.61$ P = 3.65E-34 Upper SI = NA Lower SI = NA

Native Basal Area m2/Ha. Wt. Value 0.066

Class	%Use	%Available	Z	Preference	SI	Scale Value
5	57.5%	87.9%	4.65	Avoid	0.65	2
10	8.0%	5.6%	0.39	NS	1.43	4
15	3.4%	0.9%	0.72	NS	3.69	6
25	18.4%	4.7%	2.83	Preferred	3.94	7
>25	12.6%	0.9%	3.07	Preferred	13.53	9
	n = 87	n = 107				

$\sum x^2 = 178.61$ P = 1.48E-37 Upper SI =3.7979 Lower SI = 1.2043

SNAG Basal Area m2/Ha. Wt. Value 0.052

Class	%Use	%Available	Z	Preference	SI	Scale Value
5	51.7%	82.2%	4.40	Avoid	0.629	3
10	36.8%	14.0%	3.51	Preferred	2.624	7
15	11.5%	3.7%	1.80	Preferred	3.075	7
	n = 87	n = 107				

$\sum x^2 = 56.01$ P = 6.88E-13 Upper SI = 1.5778 Lower SI = 0.6959

Total Basal Area m^2/Ha. Wt. Value 0.049

Class	%Use	%Available	Z	Preference	SI	Scale Value
10	12.6%	37.4%	3.73	Avoid	0.34	2
20	26.4%	43.0%	2.24	Avoid	0.61	3
30	39.1%	15.0%	3.66	Preferred	2.61	7
>30	21.8%	4.7%	3.39	Preferred	4.67	8
	n = 87	n = 107				

$\sum x^2 = 108.52$ P = 2.28E-23 Upper SI = NA Lower SI = NA

Table B-2. (continued)

Percent Native Basal				Wt. Value	0.067	
Class	%Use	%Available	Z	Preference	SI	Scale Value
0	46.0%	66.4%	2.71	Avoid	0.69	2
25	4.6%	12.1%	1.59	NS	NA	5
50	6.9%	11.2%	0.78	NS	NA	5
100	42.5%	10.3%	5.01	Preferred	4.14	8
	n = 87	n = 107				

$\sum x^2$ = 98.98 P = 2.57E-21 Upper SI = 0.6499 Lower SI = NA

Number of Native Vertical Foliage Hits at 1m				Wt. Value	0.062	
Class	%Use	%Available	Z	Preference	SI	Scale Value
0	34.5%	76.6%	5.76	Avoid	0.45	1
2	12.6%	10.3%	0.29	NS	1.23	4
10	19.5%	7.5%	2.28	Preferred	2.61	4
> 10	33.3%	5.6%	4.81	Preferred	5.94	9
	n = 87	n = 107				

$\sum x^2$ = 156.85 P = 8.79E-34 Upper SI = 2.1729 Lower SI = 1.0367

Number of Exotic Vertical Foliage Hits at 1 m				Wt. Value	0.045	
Class	%Use	%Available	Z	Preference	SI	Scale Value
3	26.4%	7.5%	3.39	Preferred	3.54	8
5	8.0%	10.3%	0.28	NS	0.78	5
10	31.0%	40.2%	1.17	NS	0.77	6
> 10	34.5%	42.1%	0.93	NS	0.82	6
	n = 87	n = 107				

$\sum x^2$ = 45.25 P = 8.17E-10 Upper SI = 1.5453 Lower SI = NS

Percent Native Vertical Foliage Hits at 1m				Wt. Value	0.061	
Class	%Use	%Available	Z	Preference	SI	Scale Value
0	32.9%	76.4%	5.89	Avoid	0.43	1
25	15.3%	11.3%	0.59	NS	1.35	4
50	10.6%	2.8%	1.90	Preferred	3.74	7
100	41.2%	9.4%	4.97	Preferred	4.36	8
	n = 85	n = 106				

$\sum x^2$ = 131.107 P = 3.18E-28 Upper SI = 1.1682 Lower SI = 3.2808

Table B-2. (continued)

Canopy Height (m)				Wt. Value	0.041	
Class	%Use	%Available	Z	Preference	SI	Scale Value
4	15.5%	53.3%	5.23	Avoid	0.29	2
6	44.0%	38.3%	0.65	NS	1.15	5
> 6	40.5%	8.4%	5.09	Preferred	4.81	8
	n = 84	n = 107				

$\sum x^2 = 125.92$ P = 4.53E-28 Upper SI = 2.0225 Lower SI = NA

Mature Exotics Density/HA (DBH> 10.6 cm)				Wt. Value	0.013	
Class	%Use	%Available	Z	Preference	SI	Scale Value
0	74.7%	85.7%	1.78	Avoid	0.87	3
150	12.6%	8.9%	0.61	NS	1.42	5
> 150	12.6%	5.4%	1.57	NS	2.36	6
	n = 87	n = 112				

$\sum x^2 = 11.20$ P = 3.71E-03 Upper SI = NA Lower SI = 0.9333

SNAG Density/Ha DBH < 5.5 cm				Wt. Value	0.056	
Class	%Use	%Available	Z	Preference	SI	Scale Value
1900	12.6%	18.7%	0.95	NS	0.68	5
3800	20.7%	27.1%	0.87	NS	0.76	5
6400	26.4%	28.0%	0.09	NS	0.94	5
> 6400	40.2%	26.2%	1.93	Preferred	1.54	7
	n = 87	n = 107				

$\sum x^2 = 3.83$ P = 2.81E-01 Upper SI = 1.4465 Lower SI= NA

SNAG Density/Ha DBH > 5.5 cm				Wt. Value	0.036	
Class	%Use	%Available	Z	Preference	SI	Scale Value
0	40.2%	69.2%	3.89	Avoid	0.58	1
150	21.8%	11.2%	1.81	Preferred	1.95	7
400	21.8%	12.1%	1.61	NS	1.80	6
> 400	16.1%	7.5%	1.65	Preferred	2.15	8
	n = 87	n = 107				

$\sum x^2 = 34.64$ P = 1.45E-07 Upper SI = 1.8210 Lower SI = 1.7810

Table B-2. (continued)

Live Stems Density/ Ha DBH < 2.5cm dbh				Wt. Value	0.041	
Class	%Use	%Available	Z	Preferedence	SI	Scale Value
500	26.4%	7.5%	3.39	Preferred	3.54	8
1000	23.0%	8.4%	2.63	Preferred	2.73	7
5000	42.5%	51.4%	1.09	NS	0.83	4
> 5000	8.0%	32.7%	3.97	Avoid	0.25	2
	n = 87	n = 107				

$\sum x^2$ = 81.32   P = 1.60E-17   Upper SI = 1.5172   Lower SI = 0.7149

Live Stem Density/Ha DBH 2.5-10.5cm				Wt. Value	0.045	
Class	%Use	%Available	Z	Preferedence	SI	Scale Value
1500	14.9%	11.9%	0.36	NS	1.26	6
2500	13.8%	21.4%	1.11	NS	0.64	5
5000	43.7%	27.4%	2.06	Preferred	1.60	7
> 5000	27.6%	39.3%	1.46	NS	0.70	5
	n = 87	n = 84				

$\sum x^2$ = 14.51   P = 2.29E-03   Upper SI = 1.5116   Lower SI = NA

Total Live Stems Density/HA				Wt. Value	0.046	
Class	%Use	%Available	Z	Preference	SI	Scale Value
4000	33.3%	15.0%	2.85	Preferred	2.23	8
6000	31.0%	25.2%	0.74	NS	1.23	5
10000	20.7%	27.1%	0.87	NS	0.76	4
> 10000	14.9%	32.7%	2.68	Avoid	0.46	3
	n = 87	n = 107				

$\sum x^2$ = 30.53   P = 1.07E-06   Upper SI = 1.6606   Lower SI = 0.6323

Dead Stem Density/Ha DBH < 2.5cm				Wt. Value	0.037	
Class	%Use	%Available	Z	Preference	SI	Scale Value
1000	10.3%	16.8%	1.09	NS	0.61	4
2500	17.2%	28.0%	1.60	NS	0.61	4
5000	56.3%	37.4%	2.49	Preferred	1.51	7
> 5000	16.1%	17.8%	0.11	NS	0.91	5
	n = 87	n = 107				

$\sum x^2$ = 14.27   P = 2.56E-03   Upper SI = 1.2934   Lower SI = NA

Table B-2. (continued)

Deadstems Density/Ha 2.6-8cm dbh Wt. Value 0.051

Class	%Use	%Available	Z	Preference	SI	Scale Value
500	14.9%	26.2%	1.73	Avoid	0.57	3
2000	34.5%	43.0%	1.06	NS	0.80	4
4000	26.4%	21.5%	0.64	NS	1.23	5
> 4000	24.1%	9.3%	2.60	Preferred	2.58	7
	n = 87	n = 107				

$\sum x^2 = 27.01$ P = 5.85E-06 Upper SI = 1.9254 Lower SI = 0.5997

Total Dead Stem Density/HA Wt. Value 0.058

Class	%Use	%Available	Z	Preference	SI	Scale Value
2000	11.5%	15.9%	0.67	NS	0.72	4
5000	26.4%	41.1%	1.99	Avoid	0.64	3
8000	35.6%	29.0%	0.83	NS	1.23	6
> 8000	26.4%	14.0%	1.99	Preferred	1.89	7
	n = 87	n = 107				

$\sum x^2 = 16.52$ P = 8.86E-04 Upper SI = 1.6917 Lower SI = 0.6639

Total Stem Density/Ha DBH < 2.5cm Wt. Value 0.036

Class	%Use	%Available	Z	Preference	SI	Scale Value
2500	17.2%	9.3%	1.42	NS	1.84	6
5000	31.0%	26.2%	0.59	NS	1.19	5
10000	46.0%	46.7%	-0.04	NS	0.98	5
> 10000	5.7%	17.8%	2.31	Avoid	0.32	2
	n = 87	n = 107				

$\sum x^2 = 13.67$ P = 3.39E-03 Upper SI = NA Lower SI = 0.5100

Total Stem Density/Ha DBH 2.5-8cm Wt. Value 0.041

Class	%Use	%Available	Z	Preference	SI	Scale Value
2000	11.5%	8.4%	0.48	NS	1.37	5
5000	25.3%	39.3%	1.90	Avoid	0.64	3
10000	39.1%	44.9%	0.66	NS	0.87	4
> 10000	24.1%	7.5%	3.03	Preferred	3.23	8
	n = 87	n = 107				

$\sum x^2 = 38.26$ P = 2.50E-08 Upper SI = 2.2174 Lower SI = 0.6916

Table B-2. (continued)

Total Stem Density/Ha DBH > 8cm				Wt. Value	0.031	
Class	%Use	%Available	Z	Preference	SI	Scale Value
0	29.9%	52.3%	3.00	Avoid	0.57	3
500	16.1%	23.4%	1.08	NS	0.69	4
1000	27.6%	17.8%	1.47	NS	1.55	6
> 1000	26.4%	6.5%	3.61	Preferred	4.04	8
	n = 87	n = 107				

$\sum x^2 = 67.72$ P = 1.31E-14 Upper SI = 1.7616 Lower SI = 0.6540

Table B-3.List of significant traits found at the Mesquite site (Mixed Exotic) resulting from Chi-square and PCA analysis that generated weight values for the reclassification of trait classes.

Total Basal Area m^2/Ha. Wt. Value 0.094

Class	%Use	%Available	Z	Preference	SI	Scale Value
10	4.1%	61.0%	8.02	Avoid	0.07	1
20	34.0%	27.3%	0.79	NS	1.25	4
30	40.2%	3.9%	5.38	Preferred	10.32	9
>30	21.6%	7.8%	2.30	Preferred	2.78	7

$\sum x^2$ = 405.24 P = 1.62E-87 Upper SI = 1.4261 Lower SI = 1.1081

Percent Native Basal Wt. Value 0.080

Class	%Use	%Available	Z	Preference	SI	Scale Value
25	4.1%	20.8%	3.18	Avoid	0.20	1
50	11.3%	9.1%	0.23	NS	1.25	5
75	20.6%	18.2%	0.21	NS	1.13	5
> 75	63.9%	51.9%	1.44	NS	1.23	4
	n = 97	n = 77				

∑x2 = 16.48 P = 9.03E-04 Upper SI = NA Lower SI = 0.6823

Native Basal Area m2/Ha. Wt. Value 0.078

Class	%Use	%Available	Z	Preference	SI	Scale Value
5	15.5%	68.8%	7.01	Avoid	0.22	2
10	21.6%	15.6%	0.82	NS	1.39	4
15	22.7%	9.1%	2.18	Preferred	2.49	7
25	33.0%	2.6%	4.83	Preferred	12.70	9
>25	7.2%	3.9%	0.61	NS	1.85	5
	n = 97	n = 77				

∑x2 = 291.77 P = 6.45E-62 Upper SI = 2.2752 Lower SI = 1.2338

hab_type Wt. Value 0.076

Class	%Use	%Available	Z	Preference	SI	Scale Value
1	44.3%	33.8%	1.26	NS	1.31	6
2	40.2%	36.4%	0.36	NS	1.11	4
3	14.4%	11.7%	0.31	NS	1.23	4
4	1.0%	18.2%	3.73	Avoid	0.06	1
	n = 97	n = 77				

$\sum x^2$ = 19.92 P = 1.77E-04 Upper SI = 1.3445 Lower SI = 0.7060

Table B-3.. (continued)

Percent Native Vertical Foliage Hits at 1m Wt. Value 0.073

Class	%Use	%Available	Z	Preference	SI	Scale Value
25	5.2%	26.3%	3.71	Avoid	0.20	1
50	12.4%	18.4%	0.89	NS	0.67	4
75	36.1%	6.6%	4.39	Preferred	5.48	8
100	46.4%	48.7%	0.15	NS	0.95	4
	n = 97	n = 76				

$\sum x^2$ = 146.88 P = 1.24E-31 Upper SI = 2.5546 Lower SI = 0.5444

Number of Native < 5.5cm DBH/Ha Wt. Value 0.063
(Immature *Salix exigua*)

Class	%Use	%Available	Z	Preference	SI	Scale Value
2750	16.5%	61.0%	5.91	Avoid	0.27	1
5500	14.4%	11.7%	0.31	NS	1.23	4
8250	21.6%	10.4%	1.77	Preferred	2.08	6
11000	21.6%	9.1%	2.03	Preferred	2.38	7
>11000	25.8%	7.8%	2.88	Preferred	3.31	8
	n = 97	n = 77				

$\sum x^2$ = 101.07 P = 5.82E-21 Upper SI = 2.0088 Lower SI = 1.0044

Exotic Basal Area m2/Ha. Wt. Value 0.060

Class	%Use	%Available	Z	Preference	SI	Scale Value
1	39.2%	58.4%	2.37	Avoid	0.67	2
5	30.9%	23.4%	0.94	NS	1.32	4
10	19.6%	13.0%	0.96	NS	1.51	4
>10	10.3%	5.2%	0.95	NS	1.98	5
	n = 97	n = 77				

$\sum x^2$ = 16.67 P = 8.28E-04 Upper SI = NA Lower SI = 1.001

Number of Native Vertical Foliage Hits at 1m Wt. Value 0.059

Class	%Use	%Available	Z	Preference	SI	Scale Value
5	11.3%	44.2%	4.74	Avoid	0.26	2
10	30.9%	24.7%	0.74	NS	1.25	6
15	29.9%	5.2%	3.93	Preferred	5.76	8
20	21.6%	13.0%	1.28	NS	1.67	7
> 20	6.2%	13.0%	1.28	NS	0.48	3
	n = 97	n = 77				

$\sum x^2$ = 148.19 P = 4.97E-31 Upper SI = 2.2243 Lower SI = 0.4530

Table B-3.. (continued)

Number of Native 5.6-10.6 DBH/Ha (Intermediate Salix exigua) Wt. Value 0.057

Class	%Use	%Available	Z	Preference	SI	Scale Value
250	45.4%	94.8%	6.74	Avoid	0.48	2
500	24.7%	1.3%	4.16	Preferred	19.05	9
> 500	29.9%	3.9%	4.20	Preferred	7.67	7
	n = 97	n = 77				

$\sum x^2$ = 603.82 P=7.62E-132 Upper SI = NA Lower SI = NA

Number of Exotic < 5.5 DBH/Ha (Immature *Tamarix sp.*) Wt. Value 0.056

Class	%Use	%Available	Z	Preference	SI	Scale Value
500	14.4%	37.7%	3.35	Avoid	0.38	2
2500	51.5%	39.0%	1.50	NS	1.32	4
5000	18.6%	13.0%	0.79	NS	1.43	5
> 5000	15.5%	10.4%	0.76	NS	1.49	5
	n = 97	n = 77				

$\sum x^2$ = 22.56 P = 4.98E-05 Upper SI = NA Lower SI = 1.2501

SNAG Basal Area m2/Ha. Wt. Value 0.046

Class	%Use	%Available	Z	Preference	SI	Scale Value
2	19.6%	66.2%	6.08	Avoid	0.30	1
5	30.9%	19.5%	1.54	NS	1.59	3
10	24.7%	9.1%	2.48	Preferred	2.72	6
> 10	24.7%	5.2%	3.28	Preferred	4.76	7

$\sum x^2$ = 135.88 P = 2.93E-29 Upper SI = 1.6121 Lower SI = 1.5927

SNAG Density/Ha DBH > 5.5 cm Wt. Value 0.040

Class	%Use	%Available	Z	Preference	SI	Scale Value
0	45.4%	76.5%	3.83	Avoid	0.59	2
100	20.6%	16.2%	0.52	NS	1.27	4
250	15.5%	5.9%	1.65	Preferred	2.63	6
>250	18.6%	1.5%	3.14	Preferred	12.62	9

$\sum x^2$ = 221.16 P = 9.46E-49 Upper SI = 2.6227 Lower SI = 1.0423

Table B-3.. (continued)

SNAG Density/Ha DBH < 5.5 cm Wt. Value 0.017

Class	%Use	%Available	Z	Preference	SI	Scale Value
1250	26.8%	73.5%	5.77	Avoid	0.36	1
2500	26.8%	8.8%	2.68	Preferred	3.04	7
5000	30.9%	8.8%	3.19	Preferred	3.51	8
>5000	15.5%	8.8%	1.02	NS	1.75	4

$\sum x^2 = 12.66$ P = 5.44E-03 Upper SI = 2.2366 Lower SI = 1.5705

Total Dead Stem Density/HA Wt. Value 0.036

Class	%Use	%Available	Z	Preference	SI	Scale Value
500	3.1%	20.8%	3.47	Avoid	0.15	1
1000	1.0%	11.7%	2.67	Avoid	0.09	2
5000	39.2%	46.8%	0.85	NS	0.84	4
10000	28.9%	9.1%	3.04	Preferred	3.18	8
> 10000	27.8%	11.7%	2.42	Preferred	2.38	7

$\sum x^2 = 88.58$ P = 2.63E-18 Upper SI = 1.6180 Lower SI = 0.6289

Total Live Basal Area m^2/Ha. Wt. Value 0.072

Class	%Use	%Available	Z	Preference	SI	Scale Value
10	16.5%	75.3%	7.64	Avoid	0.22	1
15	26.8%	14.3%	1.82	Preferred	1.88	6
20	29.9%	1.3%	4.76	Preferred	23.02	9
>20	26.8%	9.1%	2.77	Preferred	2.95	7

$\sum x^2 = 699.54$ P=2.63E-151 Upper SI = NA Lower SI = NA

Total Live Stems Density/HA Wt. Value 0.020

Class	%Use	%Available	Z	Preference	SI	Scale Value
5000	2.1%	37.7%	5.90	Avoid	0.05	1
10000	15.5%	29.9%	2.10	Avoid	0.52	2
14000	30.9%	20.8%	1.33	NS	1.49	5
18000	30.9%	3.9%	4.32	Preferred	7.94	9
> 18000	20.6%	7.8%	2.14	Preferred	2.65	7

$\sum x^2 = 452.23$ P = 1.43E-96 Upper SI = 1.9328 Lower SI = 1.0947

Table B-3.. (continued)

Total Stem Density/HA				Wt. Value	0.063	
Class	%Use	%Available	Z	Preference	SI	Scale Value
5000	0.0%	24.7%	4.94	Aovid	0.00	1
10000	2.1%	32.5%	5.29	Avoid	0.06	1
15000	15.5%	16.9%	0.05	NS	0.92	3
20000	25.8%	10.4%	2.38	Preferred	2.48	7
30000	40.2%	11.7%	4.01	Preferred	3.44	8
> 30000	16.5%	3.9%	2.40	Preferred	4.23	6
$\sum x^2$ = 180.78	P = 3.65E-37	Upper SI = 1.9898		Lower SI = 0.6560		

Total Ground Cover (%)				Wt. Value	0.012	
Class	%Use	%Available	Z	Preference	SI	Scale Value
10	38.1%	35.5%	0.20	NS	1.07	4
20	28.9%	17.1%	1.63	NS	1.69	5
30	10.3%	10.5%	-0.20	NS	0.98	4
40	5.2%	9.2%	0.74	NS	0.56	3
50	12.4%	2.6%	2.05	Preferred	4.70	8
> 50	5.2%	25.0%	3.53	Avoid	0.21	2
∑x2 = 60.01	P = 1.21E-11	Upper SI = 1.827		Lower SI = 0.445		

APPENDIX C

SWFL HABITAT MODELS DEVELOPED IN ESRI's ArcGIS® FOR EACH STUDY SITE

Figure C-1. Habitat suitability model developed in ESRI's ArcGIS® for the study site Pahranagat, Nevada.

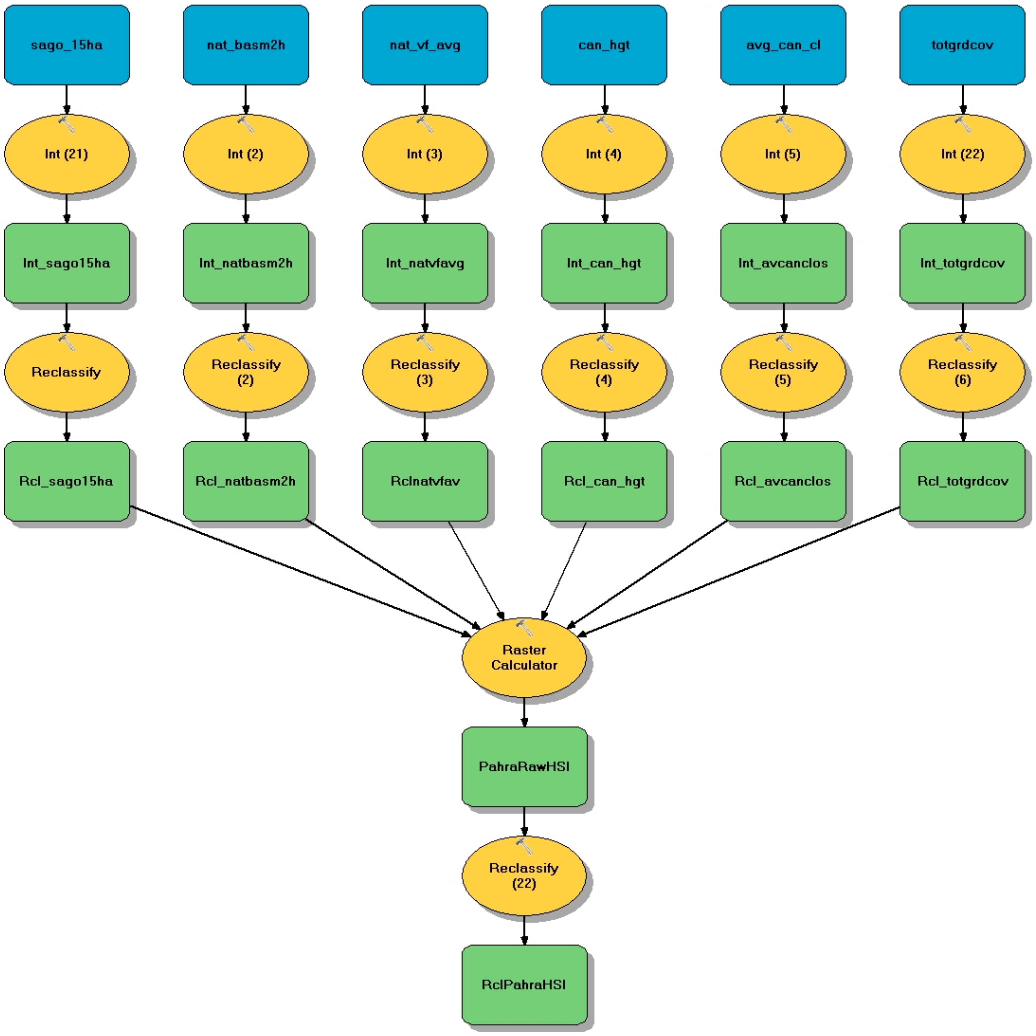


Figure C-2. Habitat suitability model developed in ESRI's ArcGIS® for the study site Mormon Mesa, Nevada.

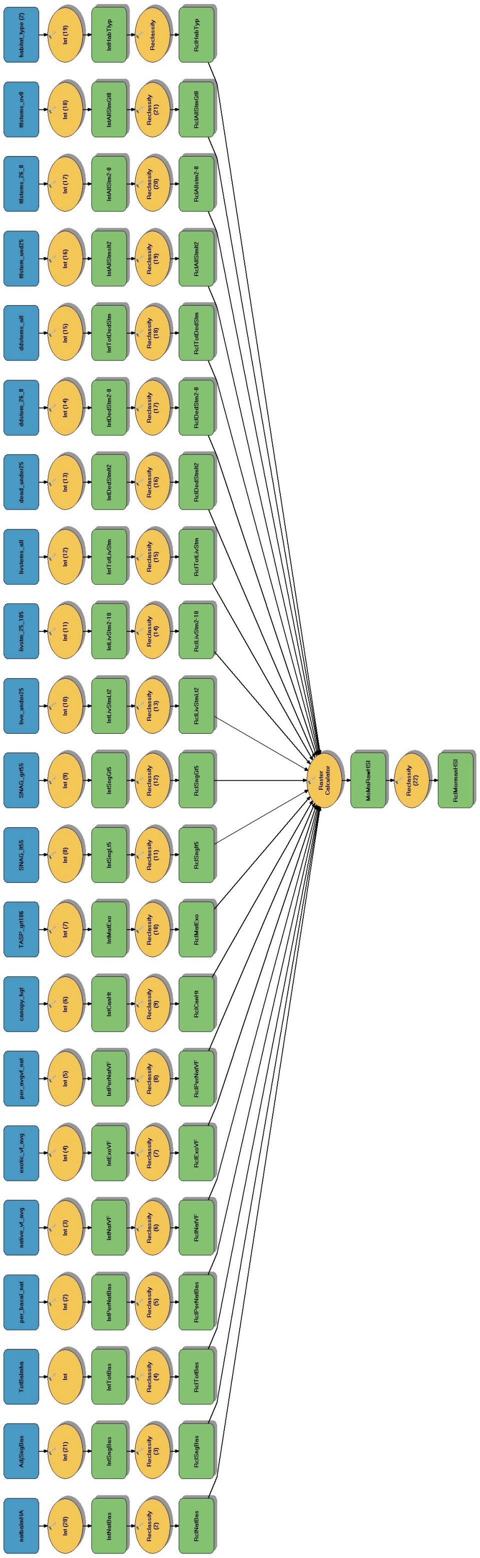
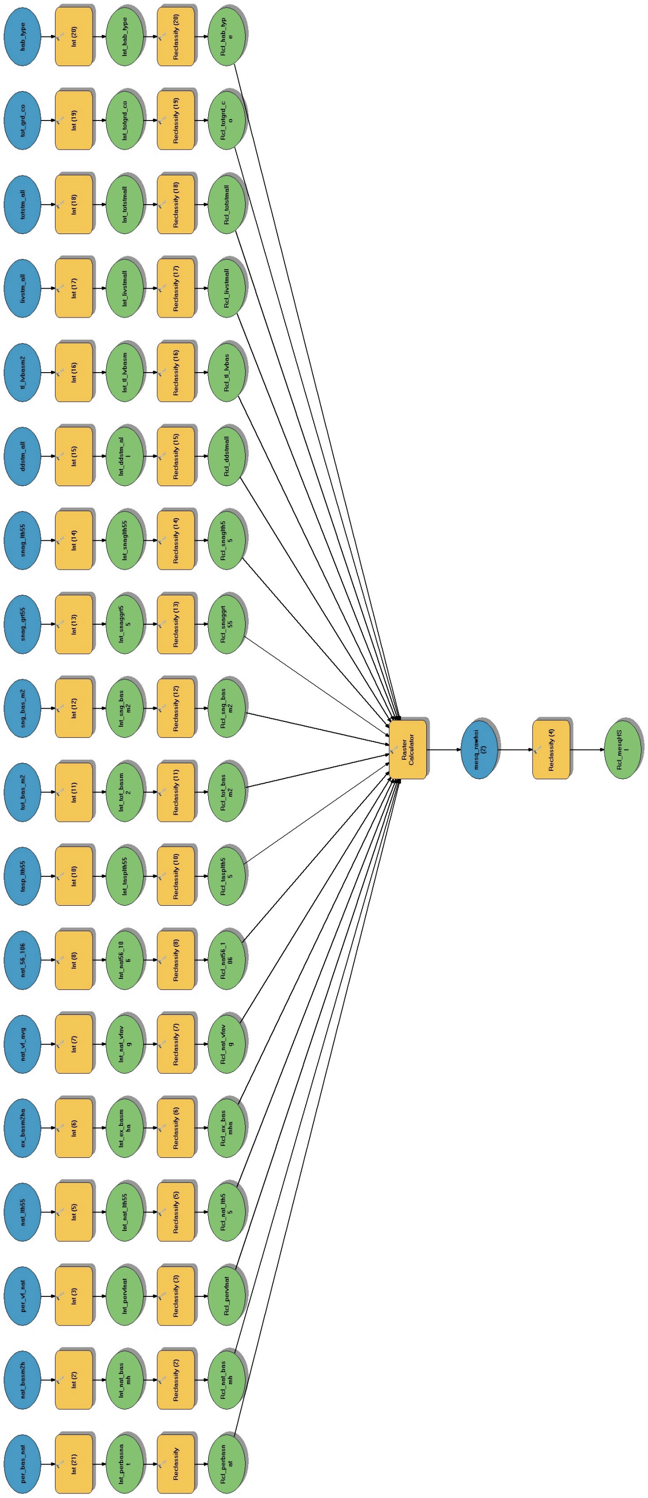


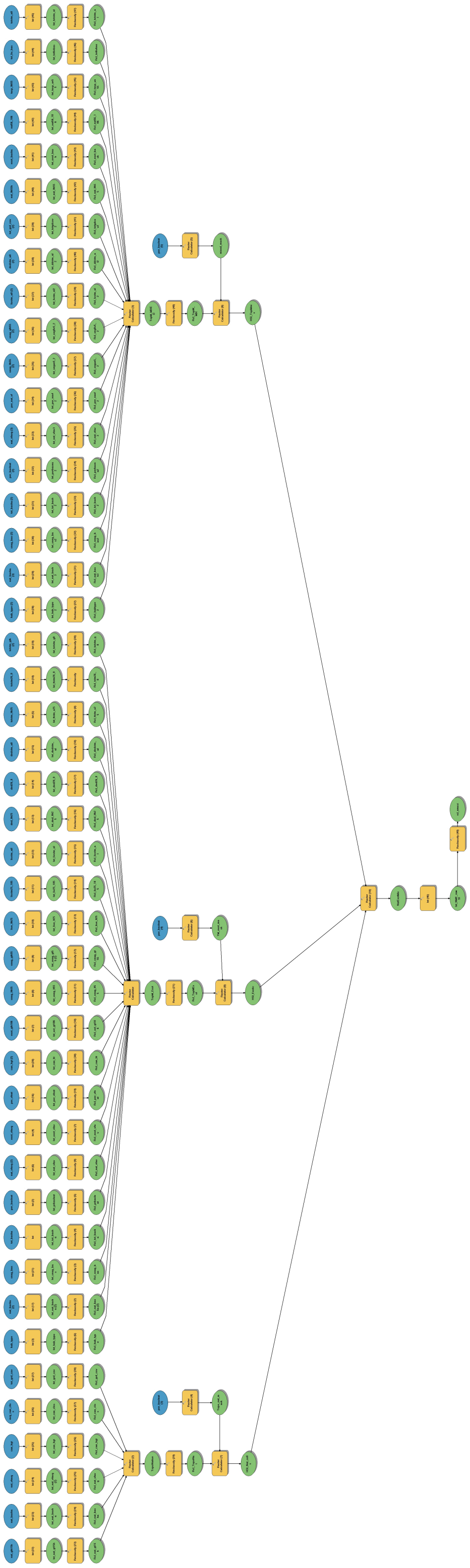
Figure C-3. Habitat suitability model developed in ESRI's ArcGIS® for the study site Mesquite, Nevada.



APPENDIX D

TOPOCK MARSH MODEL

Figure D-1. Habitat suitability model developed in ESRI's ArcGIS® for SWFL test site at Topock Marsh, Arizona.



Python Script Code for the Topock Marsh Model extracted from ArcGIS® Model Builder Report.

```
# Local variables:
nat_gth15h = " nat_gth15h"
nat_basha = " nat_basha"
nat_vfavg = " nat_vfavg"
can_hgt = " can_hgt"
avg_can_clos = " avg_can_clos"
tot_grd_cov = " tot_grd_cov"
hab_type = " hab_type"
nat_basha__2_ = " nat_basha"
snag_bas = " snag_bas"
tot_basha = " tot_basha"
per_baslnat = " per_baslnat"
nat_vfavg__2_ = " nat_vfavg"
exot_vfavg = " exot_vfavg"
per_vfnat = " per_vfnat"
can_hgt__2_ = " can_hgt"
exot_gth106 = " exot_gth106"
snag_lth55 = " snag_lth55"
snag_gth55 = " snag_gth55"
live_lth25 = " live_lth25"
livstm25_105 = " livstm25_105"
livstm_all = " livstm_all"
ded_lth25 = " ded_lth25"
ded26_8 = " ded26_8"
dedstm_all = " dedstm_all"
totstm_lth25 = " totstm_lth25"
totstm26_8 = " totstm26_8"
totstm_gth__2_ = " totstm_gth"
hab_type__2_ = " hab_type"
nat_basha__3_ = " nat_basha"
snag_bas__2_ = " snag_bas"
tot_basha__2_ = " tot_basha"
per_baslnat__2_ = " per_baslnat"
nat_vfavg__3_ = " nat_vfavg"
per_nat_vf = " per_nat_vf"
snag_lth55__2_ = " snag_lth55"
snag_gth55__2_ = " snag_gth55"
livstm_all__2_ = " livstm_all"
dedstm_all__2_ = " dedstm_all"
tot_grd_cov__2_ = " tot_grd_cov"
nat_lth55h = " nat_lth55h"
exot_basha = " exot_basha"
nat56_106 = " nat56_106"
tasp_lth55 = " tasp_lth55"
tot_liv_bas tot_liv_bas"
totstm_all = " totstm_all"
per_baslnat__3_ = " per_baslnat"
per_baslnat__4_ = "per_baslnat"
per_baslnat__5_ = " per_baslnat"
Int_nat_gt15h = " Int_nat_gt15h"
Rcl_nat_gt15h = " Rcl_nat_gt15h"
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```
Int_nat_basha = " Int_nat_basha"
Rcl_nat_basha = " Rcl_nat_basha"
Int_nat_vfavg__2_ = " Int_nat_vfavg"
Rcl_nat_vfavg = " Rcl_nat_vfavg"
Int_can_hgt = " Int_can_hgt"
Rcl_can_hgt = " Rcl_can_hgt"
Int_can_clos = " Int_can_clos"
Rcl_can_clos = " Rcl_can_clos"
Int_grd_cov = " Int_grd_cov"
Rcl_grd_cov = " Rcl_grd_cov"
TopoNative = " TopoNative"
Rcl_TopoNat = " Rcl_TopoNat"
Int_hab_type = " Int_hab_type"
Rcl_hab_type = " Rcl_hab_type"
TopM_Exot = " TopM_Exot"
Int_nat_basha__2_ = " Int_nat_basha"
Rcl_nat_basha__2_ = " Rcl_nat_basha"
Int_snag_bas = " Int_snag_bas"
Rcl_snag_bas = " Rcl_snag_bas"
Int_tot_basha = " Int_tot_basha"
Rcl_tot_basha = " Rcl_tot_basha"
Int_prbaslnat = " Int_prbaslnat"
Rcl_prbaslnat = " Rcl_prbaslnat"
Int_nat_vfav = " Int_nat_vfav"
Rcl_nat_vfav = " Rcl_nat_vfav"
Int_exot_vfav = " Int_exot_vfav"
Rcl_exot_vfav = " Rcl_exot_vfav"
Int_per_vfnat = " Int_per_vfnat"
Rcl_per_vfnat = " Rcl_per_vfnat"
Int_can_ht = " Int_can_ht"
Rcl_can_ht = " Rcl_can_ht"
Int_xot_gt106 = " Int_xot_gt106"
Rcl_xot_gt106 = " Rcl_xot_gt106"
Int_snag_lt55 = " Int_snag_lt55"
Rcl_snag_lt55 = " Rcl_snag_lt55"
Int_snag_gt55__2_ = " Int_snag_gt55"
Rcl_snag_gt55 = " Rcl_snag_gt55"
Int_live_lt25 = " Int_live_lt25"
Rcl_live_lt25 = " Rcl_live_lt25"
Int_liv25_105 = " Int_liv25_105"
Rcl_liv25_105 = " Rcl_liv25_105"
Int_livstm_al = " Int_livstm_al"
Rcl_livstm_al = " Rcl_livstm_al"
Int_ded_lth25 = " Int_ded_lth25"
Rcl_ded_lth25 = " Rcl_ded_lth25"
Int_ded26_8 = " Int_ded26_8"
Rcl_ded26_8 = " Rcl_ded26_8"
Int_dedstm_al = " Int_dedstm_al"
Rcl_dedstm_al = " Rcl_dedstm_al"
Int_ttstm_u25 = " Int_ttstm_u25"
Rcl_ttstm_u25 = " Rcl_ttstm_u25"
Int_ttstm26_8 = " Int_ttstm26_8"
Rcl_tstm26_8 = " Rcl_tstm26_8"
Int_totstm_g8 = " Int_totstm_g8"
Rcl_totstm_g8 = " Rcl_totstm_g8"
```

```
Rcl_TopMExot = " Rcl_TopMExot"
Int_hab_type2 = " Int_hab_type2"
Int_nat_bash3 = " Int_nat_bash3"
Int_snag_bas2 = " Int_snag_bas2"
Int_tot_bash2 = " Int_tot_bash2"
Int_perbasna2 = " Int_perbasna2"
Int_nat_vfav3 = " Int_nat_vfav3"
Int_per_navf2 = " Int_per_navf2"
Int_sngun5_2 = " Int_sngun5_2"
Int_sng0v5_2 = " Int_sng0v5_2"
Int_lvstm_al2 = " Int_lvstm_al2"
Int_ddstm_al2 = " Int_ddstm_al2"
Int_totgdcov2 = " Int_totgdcov2"
Int_nat_lth55 = " Int_nat_lth55"
Int_exot_bash = " Int_exot_bash"
Int_nat56_106 = " Int_nat56_106"
Int_tasp_un55 = " Int_tasp_un55"
Int_totlivbas = " Int_totlivbas"
Int_totstm_al = "Int_totstm_al"
Rcl_habtype2 = " Rcl_habtype2"
Rcl_nat_bash3 = " Rcl_nat_bash3"
Rcl_snag_bas2 = " Rcl_snag_bas2"
Rcl_tot_bash2 = " Rcl_tot_bash2"
Rcl_perbasna2 = " Rcl_perbasna2"
Rcl_nat_vfav3 = " Rcl_nat_vfav3"
Rcl_per_navf2 = " Rcl_per_navf2"
Rcl_sngun5_2 = " Rcl_sngun5_2"
Rcl_sng0v5_2 = " Rcl_sng0v5_2"
Rcl_lvstm_al2 = " Rcl_lvstm_al2"
Rcl_ddstm_al2 = " Rcl_ddstm_al2"
Rcl_totgdcov2 = " Rcl_totgdcov2"
Rcl_nat_lth55 = " Rcl_nat_lth55"
Rcl_exot_bash = " Rcl_exot_bash"
Rcl_nat56_106 = " Rcl_nat56_106"
Rcl_tasp_un55 = " Rcl_tasp_un55"
Rcl_totlivbas = " Rcl_totlivbas"
Rcl_totstm_al = " Rcl_totstm_al"
TopM_MIXED = " TopM_MIXED"
Rcl_TopM_MIX = " Rcl_TopM_MIX"
Topo_nat_mask = " Topo_nat_mask"
TM_exot_mask = " TM_exot_mask"
mixed_mask = " mixed_mask"
HSI_Nat_cells = " HSI_Nat_cells"
HSI_Exotic = " HSI_Exotic"
HSI_TopMmix = " HSI_TopMmix"
NatExotMix = " NatExotMix"
Int_NME_rawSI = " Int_NME_rawSI"
rcl_nmesi = " rcl_nmesi"

# Process: Int (22)
arcpy.gp.Int_sa(nat_gth15h, Int_nat_gt15h)
# Process: Reclassify (23)
arcpy.gp.Reclassify_sa(Int_nat_gt15h, "VALUE", "-24 0 1;0 89 7", Rcl_nat_gt15h, "NODATA")
# Process: Int (23)
arcpy.gp.Int_sa(nat_basha, Int_nat_basha)
```

```
# Process: Reclassify (24)
arcpy.gp.Reclassify_sa(Int_nat_basha, "VALUE", "-4 0 1;0 17 7", Rcl_nat_basha, "NODATA")
# Process: Int (24)
arcpy.gp.Int_sa(nat_vfavg, Int_nat_vfavg__2_)
# Process: Reclassify (25)
arcpy.gp.Reclassify_sa(Int_nat_vfavg__2_, "VALUE", "-5 15 3;15 25 4;25 30 7", Rcl_nat_vfavg,
"DATA")
# Process: Int (25)
arcpy.gp.Int_sa(can_hgt, Int_can_hgt)
# Process: Reclassify (26)
arcpy.gp.Reclassify_sa(Int_can_hgt, "VALUE", "2 7.5 4;7.5 8 7", Rcl_can_hgt, "DATA")
# Process: Int (26)
arcpy.gp.Int_sa(avg_can_clos, Int_can_clos)
# Process: Reclassify (27)
arcpy.gp.Reclassify_sa(Int_can_clos, "VALUE", "40 55 5;55 75 5;75 95 3", Rcl_can_clos,
"DATA")
# Process: Int (27)
arcpy.gp.Int_sa(tot_grd_cov, Int_grd_cov)
# Process: Reclassify (28)
arcpy.gp.Reclassify_sa(Int_grd_cov, "VALUE", "2 10 2;10 25 7;25 50 7;50 68 7", Rcl_grd_cov,
"DATA")
# Process: Raster Calculator (2)
arcpy.gp.RasterCalculator_sa("(\"%Rcl_nat_gt15h%\" * 0.181) + (\"%Rcl_nat_basha%\" * 0.285)
+ (\"%Rcl_nat_vfavg%\" * 0.164) + (\"%Rcl_can_hgt%\" * 0.139) + (\"%Rcl_can_clos%\" * 0.128)
+ (\"%Rcl_grd_cov%\" * 0.112)", TopoNative)
# Process: Reclassify (29)
arcpy.gp.Reclassify_sa(TopoNative, "Value", "2.121999979019165 2.6820001602172852
2;2.6820001602172852 3.2079999446868896 3;3.2079999446868896 4.1880002021789551
4;4.1880002021789551 4.9180002212524414 4;4.9180002212524414 6.3899993896484375 6",
Rcl_TopoNat, "DATA")
# Process: Raster Calculator (4)
arcpy.gp.RasterCalculator_sa("(\"%per_baslnat (3)%\" > 0.66)", Topo_nat_mask)
# Process: Raster Calculator (7)
arcpy.gp.RasterCalculator_sa("\"%Rcl_TopoNat%\" * \"%Topo_nat_mask%\"", HSI_Nat_cells)
# Process: Int (3)
arcpy.gp.Int_sa(hab_type, Int_hab_type)
# Process: Reclassify (6)
arcpy.gp.Reclassify_sa(Int_hab_type, "VALUE", "0 1 1;1 2 2;2 3 3;3 4 4", Rcl_hab_type, "DATA")
# Process: Int (17)
arcpy.gp.Int_sa(nat_basha__2_, Int_nat_basha__2_)
# Process: Reclassify (2)
arcpy.gp.Reclassify_sa(Int_nat_basha__2_, "VALUE", "-4 5 2;5 10 4;10 15 6;15 17 7",
Rcl_nat_basha__2_, "NODATA")
# Process: Int (21)
arcpy.gp.Int_sa(snag_bas, Int_snag_bas)
# Process: Reclassify (3)
arcpy.gp.Reclassify_sa(Int_snag_bas, "VALUE", "0 5 3;5 10 7;10 12 7", Rcl_snag_bas,
"NODATA")
# Process: Int
arcpy.gp.Int_sa(tot_basha, Int_tot_basha)
# Process: Reclassify (4)
arcpy.gp.Reclassify_sa(Int_tot_basha, "VALUE", "-1 10 2;10 20 3;20 30 7;30 39 8",
Rcl_tot_basha, "DATA")
# Process: Int (2)
arcpy.gp.Int_sa(per_baslnat, Int_prbaslnat)
```

```
# Process: Reclassify (5)
arcpy.gp.Reclassify_sa(Int_prbaslnat, "VALUE", "-40 0 2;0 25 5;25 50 5;50 115 8", Rcl_prbaslnat,
"DATA")
# Process: Int (6)
arcpy.gp.Int_sa(nat_vfavg__2_, Int_nat_vfav)
# Process: Reclassify (9)
arcpy.gp.Reclassify_sa(Int_nat_vfav, "VALUE", "-5 0 1;0 2 4;2 10 4;10 30 9", Rcl_nat_vfav,
"DATA")
# Process: Int (4)
arcpy.gp.Int_sa(exot_vfavg, Int_exot_vfav)
# Process: Reclassify (7)
arcpy.gp.Reclassify_sa(Int_exot_vfav, "VALUE", "2 3 8;3 5 5;5 10 6;10 21 6", Rcl_exot_vfav,
"DATA")
# Process: Int (16)
arcpy.gp.Int_sa(per_vfnat, Int_per_vfnat)
# Process: Reclassify (19)
arcpy.gp.Reclassify_sa(Int_per_vfnat, "VALUE", "-27 0 1;0 25 4;25 100 7;100 138 8",
Rcl_per_vfnat, "DATA")
# Process: Int (28)
arcpy.gp.Int_sa(can_hgt__2_, Int_can_ht)
# Process: Reclassify (30)
arcpy.gp.Reclassify_sa(Int_can_ht, "VALUE", "2 4 2;4 6 5;6 8 8", Rcl_can_ht, "DATA")
# Process: Int (7)
arcpy.gp.Int_sa(exot_gth106, Int_xot_gt106)
# Process: Reclassify (10)
arcpy.gp.Reclassify_sa(Int_xot_gt106, "VALUE", "4 150 5;150 921 6", Rcl_xot_gt106, "DATA")
# Process: Int (8)
arcpy.gp.Int_sa(snag_lth55, Int_snag_lt55)
# Process: Reclassify (11)
arcpy.gp.Reclassify_sa(Int_snag_lt55, "VALUE", "0 1900 5;1900 3800 5;3800 6400 5;6400
15661 7", Rcl_snag_lt55, "DATA")
# Process: Int (9)
arcpy.gp.Int_sa(snag_gth55, Int_snag_gt55__2_)

# Process: Reclassify (12)
arcpy.gp.Reclassify_sa(Int_snag_gt55__2_, "VALUE", "0 1;0 150 7;150 400 6;400 1294 8",
Rcl_snag_gt55, "DATA")
# Process: Int (10)
arcpy.gp.Int_sa(live_lth25, Int_live_lt25)
# Process: Reclassify (13)
arcpy.gp.Reclassify_sa(Int_live_lt25, "VALUE", "-672 500 8;500 1000 7;1000 5000 4;5000 12959
2", Rcl_live_lt25, "DATA")
# Process: Int (11)
arcpy.gp.Int_sa(livstm25_105, Int_liv25_105)
# Process: Reclassify (14)
arcpy.gp.Reclassify_sa(Int_liv25_105, "VALUE", "912 1500 6;1500 2500 5;2500 5000 7;5000
18316 5", Rcl_liv25_105, "DATA")
# Process: Int (12)
arcpy.gp.Int_sa(livstm_all, Int_livstm_al)
# Process: Reclassify (15)
arcpy.gp.Reclassify_sa(Int_livstm_al, "VALUE", "1969 4000 8;4000 6000 5;6000 10000 4;10000
21200 3", Rcl_livstm_al, "DATA")
# Process: Int (13)
arcpy.gp.Int_sa(ded_lth25, Int_ded_lth25)
# Process: Reclassify (16)
```

```
arcpy.gp.Reclassify_sa(Int_ded_lth25, "VALUE", "0 1000 4;1000 2500 4;2500 5000 7;5000
14528 5", Rcl_ded_lth25, "DATA")
# Process: Int (14)
arcpy.gp.Int_sa(ded26_8, Int_ded26_8)
# Process: Reclassify (17)
arcpy.gp.Reclassify_sa(Int_ded26_8, "VALUE", "0 500 3;500 2000 4;2000 4000 5;4000 5555 7",
Rcl_ded26_8, "DATA")
# Process: Int (15)
arcpy.gp.Int_sa(dedstm_all, Int_dedstm_al)
# Process: Reclassify (18)
arcpy.gp.Reclassify_sa(Int_dedstm_al, "VALUE", "0 2000 4;2000 5000 3;5000 8000 6;8000
15517 7", Rcl_dedstm_al, "DATA")
# Process: Int (5)
arcpy.gp.Int_sa(totstm_lth25, Int_ttstm_u25)
# Process: Reclassify (8)
arcpy.gp.Reclassify_sa(Int_ttstm_u25, "VALUE", "727 2500 6;2500 5000 5;5000 10000 5;10000
23282 2", Rcl_ttstm_u25, "DATA")
# Process: Int (18)
arcpy.gp.Int_sa(totstm26_8, Int_ttstm26_8)
# Process: Reclassify
arcpy.gp.Reclassify_sa(Int_ttstm26_8, "VALUE", "873 2000 5;2000 5000 3;5000 10000 4;10000
20888 8", Rcl_tstm26_8, "DATA")
# Process: Int (19)
arcpy.gp.Int_sa(totstm_gth__2_, Int_totstm_g8)
# Process: Reclassify (20)
tempEnvironment0 = arcpy.env.snapRaster
arcpy.env.snapRaster = "C:\\Documents and Settings\\Administrator\\Desktop\\Thesis Model &
Sections\\Topock Marsh\\Int_totstm_g8"
arcpy.gp.Reclassify_sa(Int_totstm_g8, "VALUE", "135 500 4;500 1000 6;1000 2584 8",
Rcl_totstm_g8, "DATA")
arcpy.env.snapRaster = tempEnvironment0
# Process: Raster Calculator
arcpy.gp.RasterCalculator_sa("(\"%Rcl_hab_type%\" * 0.066) + (\"%Rcl_nat_basha (2)%\" *
0.066) + (\"%Rcl_snag_bas%\" * 0.052) + (\"%Rcl_tot_basha%\" * 0.049) + (\"%Rcl_prbaslnat%\"
* 0.067) + (\"%Rcl_nat_vfav%\" * 0.062) + (\"%Rcl_exot_vfav%\" * .045) + (\"%Rcl_per_vfnat%\" *
0.061) + (\"%Rcl_can_ht%\" * 0.041) + (\"%Rcl_xot_gt106%\" * 0.013) + (\"%Rcl_snag_lt55%\" *
0.056) + (\"%Rcl_snag_gt55%\" * 0.036) + (\"%Rcl_live_lt25%\" * 0.041) + (\"%Rcl_liv25_105%\"
* 0.045) + (\"%Rcl_livstm_al%\" * 0.046) + (\"%Rcl_ded_lth25%\" * 0.037) + (\"%Rcl_ded26_8%\"
* 0.051) + (\"%Rcl_dedstm_al%\" * 0.058) + (\"%Rcl_ttstm_u25%\" * 0.036) +
(\"%Rcl_tstm26_8%\" * 0.041) + (\"%Rcl_totstm_g8%\" * 0.031)", TopM_Exot)
# Process: Reclassify (21)
arcpy.gp.Reclassify_sa(TopM_Exot, "Value", "3.1180000305175781 3.8369998931884766
3;3.8369998931884766 4.1610002517700195 4;4.1610002517700195 4.4970002174377441
4;4.4970002174377441 4.8189997673034668 4;4.8189997673034668 5.6030001640319824 5",
Rcl_TopMExot, "NODATA")
# Process: Raster Calculator (6)
arcpy.gp.RasterCalculator_sa("\"%per_baslnat (4)%\"< 0.33", TM_exot_mask)
# Process: Raster Calculator (8)
arcpy.gp.RasterCalculator_sa("\"%Rcl_TopMExot%\" * \"%TM_exot_mask%\"", HSI_Exotic)
# Process: Int (32)
arcpy.gp.Int_sa(per_baslnat__2_, Int_perbasna2)
# Process: Reclassify (34)
arcpy.gp.Reclassify_sa(Int_perbasna2, "VALUE", "-40 25 1;25 50 5;50 75 5;75 115 4",
Rcl_perbasna2, "DATA")
# Process: Int (29)
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arcpy.gp.Int_sa(nat_basha__3_, Int_nat_bash3)
# Process: Reclassify (31)
arcpy.gp.Reclassify_sa(Int_nat_bash3, "VALUE", "-4 5 2;5 10 4;10 15 7;15 17 9", Rcl_nat_bash3,
"DATA")
# Process: Int (20)
arcpy.gp.Int_sa(hab_type__2_, Int_hab_type2)
# Process: Reclassify (22)
arcpy.gp.Reclassify_sa(Int_hab_type2, "VALUE", "0 1 1;1 2 2;2 3 3;3 4 4", Rcl_habtype2,
"DATA")
# Process: Int (34)
arcpy.gp.Int_sa(per_nat_vf, Int_per_navf2)
# Process: Reclassify (36)
arcpy.gp.Reclassify_sa(Int_per_navf2, "VALUE", "-41 25 1;25 50 4;50 75 8;75 143 4",
Rcl_per_navf2, "DATA")
# Process: Int (40)
arcpy.gp.Int_sa(nat_lth55h, Int_nat_lth55)
# Process: Reclassify (42)
arcpy.gp.Reclassify_sa(Int_nat_lth55, "VALUE", "-488 25 1;25 50 4;50 75 6;75 100 7;100 20787
8", Rcl_nat_lth55, "DATA")
# Process: Int (41)
arcpy.gp.Int_sa(exot_basha, Int_exot_bash)
# Process: Reclassify (43)
arcpy.gp.Reclassify_sa(Int_exot_bash, "VALUE", "1 2;1 5 4;5 10 4;10 49 5", Rcl_exot_bash,
"NODATA")
# Process: Int (33)
arcpy.gp.Int_sa(nat_vfavg__3_, Int_nat_vfav3)
# Process: Reclassify (35)
arcpy.gp.Reclassify_sa(Int_nat_vfav3, "VALUE", "-5 5 2;5 10 6;10 15 8;15 20 7;20 30 3",
Rcl_nat_vfav3, "DATA")
# Process: Int (42)
arcpy.gp.Int_sa(nat56_106, Int_nat56_106)
# Process: Reclassify (44)
arcpy.gp.Reclassify_sa(Int_nat56_106, "VALUE", "-999 5 2;5 10 9;10 1160 7", Rcl_nat56_106,
"DATA")
# Process: Int (43)
arcpy.gp.Int_sa(tasp_lth55, Int_tasp_un55)
# Process: Reclassify (45)
arcpy.gp.Reclassify_sa(Int_tasp_un55, "VALUE", "763 18386 5", Rcl_tasp_un55, "DATA")
# Process: Int (31)
arcpy.gp.Int_sa(tot_basha__2_, Int_tot_bash2)
# Process: Reclassify (33)
arcpy.gp.Reclassify_sa(Int_tot_bash2, "VALUE", "-1 10 1;10 20 4;20 30 9;30 39 7",
Rcl_tot_bash2, "DATA")
# Process: Int (30)
arcpy.gp.Int_sa(snag_bas__2_, Int_snag_bas2)
# Process: Reclassify (32)
arcpy.gp.Reclassify_sa(Int_snag_bas2, "VALUE", "0 2 1;2 5 3;5 10 6;10 12 7", Rcl_snag_bas2,
"DATA")
# Process: Int (36)
arcpy.gp.Int_sa(snag_gth55__2_, Int_sng0v5_2)
# Process: Reclassify (38)
arcpy.gp.Reclassify_sa(Int_sng0v5_2, "VALUE", "0 2;0 2 4;2 5 6;5 1294 9", Rcl_sng0v5_2,
"DATA")
# Process: Int (35)
arcpy.gp.Int_sa(snag_lth55__2_, Int_sngun5_2)
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# Process: Reclassify (37)
arcpy.gp.Reclassify_sa(Int_sngun5_2, "VALUE", "0 25 1;25 50 7;50 100 8;100 15661 4",
Rcl_sngun5_2, "DATA")
# Process: Int (38)
arcpy.gp.Int_sa(dedstm_all__2_, Int_ddstm_al2)
# Process: Reclassify (40)
arcpy.gp.Reclassify_sa(Int_ddstm_al2, "VALUE", "0 500 1;500 1000 2;1000 5000 4;5000 10000
8;10000 15517 7", Rcl_ddstm_al2, "DATA")
# Process: Int (44)
arcpy.gp.Int_sa(tot_liv_bas, Int_totlivbas)
# Process: Reclassify (46)
arcpy.gp.Reclassify_sa(Int_totlivbas, "VALUE", "-1 10 1;10 15 6;15 20 9;20 39 7", Rcl_totlivbas,
"DATA")
# Process: Int (37)
arcpy.gp.Int_sa(livstm_all__2_, Int_lvstm_al2)
# Process: Reclassify (39)
arcpy.gp.Reclassify_sa(Int_lvstm_al2, "VALUE", "1969 5000 1;5000 10000 2;10000 14000
5;14000 18000 9;18000 21200 7", Rcl_lvstm_al2, "DATA")
# Process: Int (45)
arcpy.gp.Int_sa(totstm_all, Int_totstm_al)
# Process: Reclassify (47)
arcpy.gp.Reclassify_sa(Int_totstm_al, "VALUE", "2035 5000 1;5000 10000 2;10000 14000
5;14000 18000 9;18000 42742 7", Rcl_totstm_al, "DATA")
# Process: Int (39)
arcpy.gp.Int_sa(tot_grd_cov__2_, Int_totgdcov2)
# Process: Reclassify (41)
arcpy.gp.Reclassify_sa(Int_totgdcov2, "VALUE", "2 10 4;10 20 5;20 30 4;30 40 3;40 50 8;50 68
2", Rcl_totgdcov2, "NODATA")
# Process: Raster Calculator (3)
arcpy.gp.RasterCalculator_sa("(\"%Rcl_perbasna2%\"*0.08)+(\"%Rcl_nat_bash3%\"*0.078)+(\"%
Rcl_habtype2%\"*0.076)+(\"%Rcl_per_navf2%\"*0.073)+(\"%Rcl_nat_lth55%\"*0.063)+(\"%Rcl_e
xot_bash%\"*0.06)+(\"%Rcl_nat_vfav3%\"*0.059)+(\"%Rcl_nat56_106%\"*0.057)+(\"%Rcl_tasp_u
n55%\"*0.056)+(\"%Rcl_tot_bash2%\"*0.094)+(\"%Rcl_snag_bas2%\"*0.046)+(\"%Rcl_sng0v5_2
%\"*0.04)+(\"%Rcl_sngun5_2%\"*0.017)+(\"%Rcl_ddstm_al2%\"*0.036)+(\"%Rcl_totlivbas%\"*0.0
72)+(\"%Rcl_lvstm_al2%\"*0.02)+(\"%Rcl_totstm_al%\"*0.063)+(\"%Rcl_totgdcov2%\"*0.012)",
TopM_MIXED)
# Process: Reclassify (48)
arcpy.gp.Reclassify_sa(TopM_MIXED, "Value", "1.9100000858306885 2.7380001544952393
2;2.7380001544952393 3.25 3;3.25 3.6550002098083496 3;3.6550002098083496
4.3349995613098145 4;4.3349995613098145 5.3879995346069336 5", Rcl_TopM_MIX,
"DATA")
# Process: Raster Calculator (5)
arcpy.gp.RasterCalculator_sa("(\"%per_baslnat (5)%\"> 0.33) & (\"%per_baslnat (5)%\" < 0.66)",
mixed_mask)
# Process: Raster Calculator (9)
arcpy.gp.RasterCalculator_sa("\"%Rcl_TopM_MIX%\" *\"%mixed_mask%\"", HSI_TopMmix)
# Process: Raster Calculator (10)
arcpy.gp.RasterCalculator_sa("\"%HSI_Nat_cells%\" + \"%HSI_Exotic%\" +
\"%HSI_TopMmix%\"", NatExotMix)
# Process: Int (46)
arcpy.gp.Int_sa(NatExotMix, Int_NME_rawSI)
# Process: Reclassify (49)
arcpy.gp.Reclassify_sa(Int_NME_rawSI, "VALUE", "2 2;2 2.5 2;2.5 3 2;3 3.5 3;3.5 4 3;4 4.5 4;4.5
5 4;5 5.5 5;5.5 6 5", rcl_nmesi, "NODATA")
```