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Evaluation of the Basis and Effectiveness of Habitat Assessments in Wetland Functional Assessment Methods

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Evaluation of the Basis and Effectiveness of Habitat Assessments in Wetland Functional Assessment Methods

A thesis submitted to the Graduate Faculty of the Department of Biological Sciences of the State University of New York College at Brockport in partial fulfillment of the requirements for the degree of Master of Science.

By Amy Elizabeth Gardner

May 15, 2006

THESIS DEFENSE

AMY GARDNER

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Chairman, Graduate Committee

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Biographical sketch

I was born in [redacted], and later moved with my family to Rochester, New York. I graduated from Gates-Chili High School, and went on to receive a Bachelor of Science degree in Biology from the State University of New York at Geneseo in 1995. I live in Gates with my husband, Doug, and two children, Emma and Cecelia.

Dedication

This thesis is dedicated to my children, Emma and Cecelia Gardner.

Acknowledgments

I would like to acknowledge and thank the members of my graduate committee, Drs. John Hunter, Christopher Norment, and James Haynes, for their support and guidance throughout the completion of my degree and the writing of this thesis; Jones and Stokes Associates of Sacramento, Placer County Planning Department, and the California Department of Fish and Game, for allowing me to use their Riparian Ecosystem Assessment data sets; and my mom, Christine Coleman, and husband, Doug Gardner for their help and encouragement throughout my studies and the completion of my degree.

Abstract

I studied the basis and effectiveness of wetland assessment methods in providing habitat assessments. While it is well understood that wetlands and riparian areas provide important ecological functions and habitat for a wide variety of wildlife species, much is still to be learned about providing meaningful, accurate and repeatable methods for assessing them. I examined and evaluated four assessment methods to determine their accuracy and usefulness in assessing a site's provision of habitat.

One hypothesis I tested is that if the assessment methods studied provide an accurate assessment of wetland functions, then the resulting site scores for the methods should be correlated. The second hypothesis is that there is a correlation between the site scores and an independent measure of function, specifically the number of riparian-associated bird and butterfly species observed at each site.

Biological and physical data collected from 47 riparian sites in California's Central Valley were used to calculate site scores using Habitat Assessment Technique (HAT), Rocky Mountain Riparian Hydrogeomorphic (HGM), Southern California Riparian Model, and Reference Wetland assessment methods. The rankings of these site scores were also calculated for each method. Correlation coefficients (r) were calculated between the site scores of the four methods, as well as between the site scores and the numbers of riparian-associated bird and butterfly species for each plot.

The site scores were mostly uncorrelated. Only one statistically significant correlation was demonstrated between the site scores for the Southern California Riparian Model and Reference Wetland methods ($df = 46$, $r = 0.46$, $p = 0.00103$, with Bonferroni correction). With Bonferroni corrections ($p < 0.00625$), the site scores were also

uncorrelated with the numbers of riparian-associated bird and butterfly species. Without Bonferroni corrections, only two statistically significant correlations were demonstrated: between the number of riparian-associated bird species and the HAT score ($df = 46$, $r = 0.37$, $p = 0.0095$) and the number of riparian-associated butterfly species and the Reference Wetland score ($df = 46$, $r = 0.38$, $p = 0.0092$).

I rejected both original hypotheses, which demonstrated that the assessment tools currently available do not consistently produce relatively precise, or reproducible results. Possible reasons for these problems include attempting to assess a function that is too broadly defined, inappropriately or subjectively selected variables, subjectively assigning values to variables, or inappropriately selecting reference sites.

The existing attempts at assessing wetland or riparian function are important steps in the right direction toward assessment of wetland and riparian sites and achievement of "no net loss," but functional assessment must be considered a work in progress.

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While much is yet to be learned about the ecology of particular types of wetland and riparian systems, it is well understood that wetlands and riparian areas provide important ecological functions. Wetlands are defined as areas where water covers the soil, or is present either at or near the surface of the soil all year or for varying periods of time during the year, including the growing season (USEPA 2005). The types of plant and animal communities living in the soil and on its surface are determined by the saturation of the wetland site (USEPA 2005). "Riparian" comes from the Latin *ripa*, meaning stream or river bank (DePuydt 1996), so riparian areas are generally described as lands bordering rivers, streams, and lakes, and their associations with water are an important part in the structure and function of these areas (National Academy of Sciences Committee 2003).

Riparian areas and the wetlands within them are important as sources, sinks and transformers of many chemical, biological and genetic materials (Mitsch and Gosselink 2000). The stream or river and its riparian area together form a stream corridor. The plant communities within stream corridors can provide stability for riverbanks because of the presence of roots, interstitial flow through sediments, and a large supply of wood, which can increase the complexity of the water channel (National Academy of Sciences Committee 2003). Additional examples of the important ecological functions provided by riparian areas include provision of riparian vegetation that shades streams (thus controlling water temperatures and primary production), and of detritus as a food source for stream invertebrates (Mitsch and Gosselink 2000). Due to the periodic flooding that occurs in riparian areas, they tend to be more productive than adjacent upland areas because there is adequate water for plants, because flooding supplies nutrients and alters soil chemistry favorably, and because the continual movement of water allows for more oxygenation for roots than stagnant water would (Mitsch and Gosselink 2000).

Wetlands are also valuable for their natural resources, as wildlife habitats, for environmental controls such as wastewater treatment and sedimentation control, and have other socioeconomic values (Confer and Niering 1992). In fact, wetlands are referred to as the "kidneys of the landscape" as they are a downstream receiver of natural and human waste products (Mitsch and Gosselink 2000). Wetlands' important role in fostering biodiversity has earned them a nickname as "biodiversity supermarkets." Some of the species that are wetland dependent include animals that are harvested for pelts, such as muskrats (*Ondatra zibethicus*) and nutria (*Myocastor coypus)*, waterfowl, including Wood Ducks (*Aix sponsa)*, diving ducks (*Aythya* and *Oxyura* species), dabbling ducks (*Anas* species), and herons, such as the Great Blue Heron (*Ardea herodias),* as well as a large number of fish and shellfish species (Mitsch and Gosselink 2000).

Wetlands are also valuable as habitats for a variety of endangered or threatened species. According to 1998 data, 28 percent of endangered or threatened plants are associated with wetlands, and the proportions are high for other endangered and threatened species, too: mammals, 20 percent; birds, 68 percent; reptiles, 63 percent; amphibians, 75 percent; mussels, 66 percent; fish, 38 percent; and insects, 38 percent (Mitsch and Gosselink 2000). Overall, about 50 percent of species on the endangered and threatened lists are wetland-dependent (Mitsch and Gosselink 2000). Wetlands can also be important economically to some communities as sources of products such as sphagnum, cranberries and rice (Mitsch and Gosselink 2000).

The farming of fish and shellfish, or aquaculture, also depends on wetlands. Aquaculture produces about 20 percent of the world's fish and shellfish harvest, with the greatest production occurring in Asia (Mitsch and Gosselink 2000). Often, farmers take advantage of seasonal flooding and use a technique called "intercropping" in which fish crops are rotated with another crop, such as rice. Shrimp (*Penaeus* species) and crawfish (*Procambarus clarkii*) are commonly intercropped. Catfish (*Ictalurus* species), bullhead (*Ictalurus* species), carp (*Cyprinus carpio*) and salmon (*Oncorhynchus* species) are among the most valuable fish crops associated with wetlands (Mitsch and Gosselink 2000). With the increasing popularity of fish and shellfish, there is greater pressure for these farms to increase efficiency and production. In many cases, smaller family owned farms are yielding to larger aquaculture farms made by dredging wetlands and mangroves to make ponds with pump-regulated water levels. This practice is resulting in a significant loss of wetland and mangrove habitat (Mitsch and Gosselink 2000).

Despite the important functions and values of wetlands and riparian areas, their extent has been reduced substantially by human activities (Mitsch and Gosselink 2000). The rate of wetlands lost globally is uncertain, though wetlands experts estimate about 50 percent have already been lost worldwide. Wetland losses in the United States are better documented, with losses believed to be about 50 percent in the lower 48 states since European settlement (Mitsch and Gosselink 2000). In some regions of the country, even greater losses have occurred. For example, in California's Central Valley, over 95 percent of riparian areas have been lost, largely due to conversion to agricultural lands, urbanization, clearing of vegetation for flood control, livestock grazing, and invasion by non-native plant species (USFWS 2005). Warner and Hendrix (1984) estimated that there were approximately 373,000 ha of riparian areas in the Central Valley after 1848; as of 1984 about 41,300 ha remained and of that amount, half was significantly disturbed or degraded. The clearing of riparian zones for other uses began following the arrival of European settlers in the United States. The most prominent use of riparian land was for farming, as the floodplain soils of riparian areas are very fertile; other uses for riparian land included transportation corridors (construction of canals, highways, and railroads) and harvesting of wood as the size of riparian trees and their close proximity to a waterway made them ideal sources of lumber (National Academy of Sciences Committee 2003).

Wetland conservation reached a turning point with the passage of the Clean Water Act of 1972. The Clean Water Act is the "primary Federal statute regulating the protection of the nation's waters" (USEPA 2005). Section 404 of the Clean Water Act establishes the program to deal with the placement of dredged or fill materials into any water of the United States. This Section provides regulation for fill for development, water resource projects such as dams or levees, mining activities, and development of infrastructure, such as roads and airports (USEPA 2005). Thus, Section 404 is the legislation that has jurisdiction over activities that would lead to loss of wetland or riparian areas.

The U.S. Army Corps runs the Section 404 mitigation program using guidelines established by the EPA. The current wetland mitigation policy, implemented in 1991, aims for a goal of "no net loss" of wetland functions and values (Keating and Edmonds 1997). Under this mitigation policy, a permit must be obtained before placing fill into a wetland. As defined by the US Environmental Protection Agency, "fill material" is "material placed in waters of the U.S. where the material has the effect of either replacing any portion of a water of the United States with dry land or changing the bottom elevation of any portion of a water" and may include rock, sand, soil, clay, plastics, construction debris, overburden from mining activities and any other material used to construct any structure (USEPA 2002). Typically, such fill is permitted provided the developer agrees to mitigate for the loss of wetland acreage. Mitigation typically involves creating an equal or greater area of new wetland in another place or restoring a degraded wetland site (Salvesen 1995), or occasionally by preserving or enhancing an existing wetland site (Keating and Edmonds 1997). The intent of the mitigation is to ensure no loss in wetland functions and values.

This wetland mitigation policy, while clearly stating a desirable goal, has experienced many problems in implementation. For example, permits for wetland development issued by the U.S. Army Corps of Engineers do not consistently list what criteria are to be used to consider the mitigation a success, and when such information is included on the permit, it generally is just a list of relatively simple criteria that usually rely on vegetation structural characteristics such as percent cover or plant dominance (Cole 2002). However, it is not clear that measurements of plant structure alone provide any meaningful indication of function (Cole 2002). Often, mitigation projects have been abandoned, improperly carried out, poorly monitored, or have resulted in wetlands with "limited ecological value" (Neal 1999).

Another major shortcoming of the Clean Water Act is that its protection of wetlands does not generally cover riparian areas, although they provide many of the same ecological roles and functions as wetlands (National Academy of Sciences Committee

2003). The National Research Council undertook a comprehensive study of riparian areas in 1999, with the goal of increasing awareness of riparian functions and their value (National Academy of Sciences Committee 2003). Although some large riparian areas have been set aside in national parks and forests and are protected by U.S. policy, most riparian lands are protected less strictly than other wetland areas, with poor organization and implementation (National Academy of Sciences Committee 2003).

Making the goal of "no net loss" a reality in the United States requires significant improvements to the management and follow-up of mitigation projects, but it also requires a consistent, workable method for evaluating the functions and values of wetlands and riparian areas. Without a method for assessing wetlands, not just in terms of area or plant types, but more importantly in terms of function, there is no way to ensure that wetlands lost are at all equal to those gained through mitigation. Consequently, one difficulty that exists in developing a method for wetland functional assessment is in determining what functions are to be considered. Typically, functions are considered to be rates and processes (Simenstad and Thom 1996).

Wetland function was defined by the National Research Council as "...all processes and manifestation of processes that occur in wetlands" (Cole 2002). At the ecosystem level, processes include hydrodynamics, plant productivity, nitrogen fixation and cycling, and carbon sequestration and decomposition. Brinson and Rheinhardt (1996) state that there are four main categories of wetland functions: hydrologic, biogeochemical, plant community maintenance, and animal community maintenance. A sampling of wetland researchers generated a list of a wide variety of wetland functions: life support, open space and aesthetics, short- and long-term surface water storage, cycling of nutrients, dissipation of energy, accumulation of peat, and plant and animal habitat, among others (Cole 2002). While there are some differences in what various authors would list as wetland functions, most wetland ecologists can define what constitutes a wetland function.

What is more problematic is that these functions are rarely measured directly in a regulatory context due to time and financial considerations. Nearly all wetland functions have been measured in a variety of wetland types, but these numbers are trivial when compared to the thousands of wetland permits submitted annually. Consequently, indicators of these functions have been frequently used instead of direct measurements. For example, Kentula *et al.* (1992) found that data on site morphology and species present are more readily available and are often quicker and more economically feasible to assess than direct measures of wetland function (Cole 2002).

There is a need to develop an accurate, pragmatic, and appropriate method for assessing wetland function so that data are available to ensure that "no net loss" is attained. In response to this need, a large number of different wetland functional assessment methods have been developed. In fact, over nine methods have been developed, and combined these methods have used over 115 different variables to assess wetland function. Though these methods measure different variables, all aim to quantify one or more wetland functions, most typically for a particular type of wetland in a particular region. It would also be helpful if a universal method of wetland assessment could be used consistently to make comparisons and data sharing between agencies and companies both more meaningful and feasible.

Functional assessment methods give a value to a wetland parcel based on its ability to carry out a function that is characteristic of a wetland. These functions may be roles or processes carried out by wetlands, such as a wetland's ability to support characteristic plant, bird or wildlife communities by providing high quality habitat and food sources, or the ability to recycle nutrients and elements; or directly measured characteristics, such as percent plant cover or number of plant species present. Many of these functions are calculated using a composite score resulting from the insertion of several variables into an equation that has been designed to represent the relationship between these variables and the capacity of a wetland site to provide a given function.

Unfortunately, how well these assessment methods actually work has not been adequately studied. Assessment methods have rarely been tested by comparing their evaluations of sites to direct measurements of functions provided by sites. The consistency between various assessment methods in the ranking of wetland sites also has rarely been evaluated. Yet, these tests are essential for assessing the accuracy of the functional assessment methods and for identifying comparable methods. Therefore, I have conducted such tests for four representative methods for assessing the functions of riparian wetlands in the western United States, using a riparian data set from the Sacramento Valley in California (Jones and Stokes 2004). This data set includes attributes commonly used in functional assessments (e.g., vegetation cover, adjacent land uses) and information on species observed during surveys of the sites.

If the assessment methods that I evaluated provide an accurate assessment of the functions provided by a wetland site, the different methods should lead to similar results for each site, and thus the resulting site scores should be correlated. In other words, a site that scores particularly well using one method could reasonably be expected to score well using other methods. Alternatively, if one or more of these methods provide relatively inaccurate assessments of the functions provided by the sites, then there may be low or no correlations among the scores of the different methods. Therefore, I tested the hypothesis that assessment scores produced by the different methods are correlated. The null hypothesis was that assessment scores produced by different methods are uncorrelated.

If the site scores produced by one or more of these methods are not correlated, then analysis of the variables used in the different methods, and the correlation of these variables with each other and with some independent and more direct measure of functions, may indicate why the assessment methods differ and which assessment method is likely to be more accurate. Consequently, I examined correlations among the variables used in the assessments and also tested the hypothesis that the site scores produced by each assessment method are correlated with the number of riparian- associated species observed at each site. In this case, the null hypothesis was that there is no correlation between assessment scores and the number of riparian-associated bird and butterfly species.

Methods

Description of the Riparian Data Set

The California Central Valley is a large flat area in the central part of California containing both the Sacramento and San Joaquin Rivers (Warner and Hendrix 1984). The floodplains surrounding these rivers account for much of the riparian area in central California. Mature riparian habitats are often dominated by cottonwood (*Populus* species) trees (DePuydt 1996) and contain many other deciduous trees such as willow (*Salix* species), alder (*Alnus* species), walnut (*Juglans* species), sycamore (*Platanus occidentalis*), and oak (*Quercus* species) in a state where the majority of dominant woody plants are evergreen (Warner and Hendrix 1984). The architecture of the cottonwood zones of the riparian areas is very complex, with layers of shrubs, herbs and vines beneath the canopy, and this type of forest is used for nesting by more bird species than any other plant community in California (DePuydt 1996). These riparian areas are also used by 25% of land mammals in California; 21 riparian land mammal species are in danger of extinction due to habitat loss (DePuydt 1996). Clearly, these riparian areas in Central California have substantial ecological values that should be conserved.

The data used to evaluate assessment methods were obtained from a study conducted for the County of Placer and the California Department of Fish and Game as part of a Riparian Ecosystem Assessment (REA) for the Sacramento Valley and adjacent foothills of the Sierra Nevada and the inner coastal mountain ranges (Jones and Stokes 2005). The Sacramento Valley is the northern portion of California's Central Valley, and is drained by the Sacramento River and its tributaries. Along these rivers and streams are riparian forests and woodlands dominated by Fremont cottonwood (*Populus fremontii)*, willow species and valley oak (*Quercus lobata*). Other important tree species include box-elder (*Acer negundo*), sycamore (*Platanus* species), Oregon ash (*Fraxinus latifolia*), and interior live oak (*Q. wislizenii*).

For this assessment 47 plots were randomly selected from over one thousand sites where the Point Reyes Bird Observatory had previously collected data along smaller rivers and streams, and additional sites for which access had been arranged. Sites along the Sacramento, Yuba, Bear, American and Feather Rivers were excluded from the study because these rivers are much larger and functionally distinct from their smaller tributaries, and other assessment techniques were under development for them. All plots surveyed were selected because they were riparian hardwood forests and access to the site was available. Each plot surveyed measured 100 m by 100 m and extended landward from the edge of the channel. Information was collected during May and June of 2003 by researchers with Jones and Stokes Associates, Sacramento, CA.

Site descriptions were recorded for each of the riparian plots, and contained information such as site location, presence of any infrastructure, incised channels, levees, or overflow evidence. The descriptions also noted characteristics of the surrounding land: agricultural land, riparian vegetation, natural vegetation, and developed land within 250 m, 1 km, or 5 km (Jones and Stokes 2004).

Species surveys were conducted at each of the 47 riparian sites. These searches were conducted using specific search protocols, with specific requirements for pre-field tasks, locating the plot, observing the species, and post-field checklists (Jones and Stokes 2003). The data were recorded on forms, which were consistent among the different plots and observers. With regard to plants, recorded for each site was species of shrub and tree, percent cover of trees, shrubs, and herbaceous layer, and information regarding presence of native and invasive species. Species names, numbers of individuals observed and the specific plots where they were found were provided for odonates (damselflies and dragonflies), birds, and butterflies, as well as for those species that are riparian-associated species (Jones and Stokes 2004). Riparian-associated species are those that depend on riparian habitat for successful reproduction and survival; these species use riparian areas for food, water, cover, and migration and dispersal corridors (Jones and Stokes 2005). For example, bird species were recorded as being present in the plots if they were visually observed, or if a call or song was heard. Additional observations were collected for nesting or breeding behaviors, or for food carrying or flocking (Jones and Stokes 2003).

Additional Geographical Information Systems (GIS) data collected included conditions and features of the buffer of the riparian area of 250 m, 1 km, and 5 km. Included were data for total riparian area in ha and land use (i.e. agriculture, open water, fresh emergent wetland, developed land, or urban land) (Jones and Stokes 2004).

Functional Assessment Methods Evaluated

The functional assessment methods studied in this paper and the information sources used are as follows: Habitat Assessment Technique, or HAT (Cable *et al.* 1989); Reference Wetlands (Rheinhardt *et al.* 1997); the Southern California Riparian Model (Stein *et al.* 2000); and Hydrogeomorphic (HGM) assessment of riverine floodplains in the Northern Rocky Mountains (Hauer *et al.* 2002).

These four methods were selected because they represent the range of approaches available for wetland assessment and all can be applied to the REA data set to assess the integrity of wildlife habitat. The HAT method is representative of the methods that use biological data to produce an index of biotic integrity, or IBI, with the underlying assumption that the use of a site by a particular type of animal (in this case, birds) is indicative of the site's functional capacity as wildlife habitat. The Reference Wetland assessment method is an example of the approach that aims to quantify the functional capacity of a site by comparing it to another site that is considered to be in pristine condition, a "gold standard" for a specific type of wetland or riparian site. The Southern California Riparian Model assesses the quality of a riparian site using data for its vegetation and continuity with surrounding areas to determine the site's integrity as a wildlife habitat. The Rocky Mountain Riparian assessment method is representative of the HGM methods that consider some biological as well as geological attributes to generate an assessment score and assign a value for a site's integrity for a particular function, in this case, as wildlife habitat. These four methods are described in more detail in the following paragraphs.

Habitat Assessment Techniques (HAT) measure the functional value of a wetland site as wildlife habitat by assessing its suitability as a habitat for a particular species or guild. This method assigns values of "habitat units" and "species index" to a site as a measure of its habitat suitability. An example of a habitat assessment procedure is presented by Cable *et al.* (1989) and focuses only on birds, using data for bird species diversity and rarity to determine the quality of a wetland site. HAT methods use the premise that richness of birds is an effective way to document changes or disturbances by humans in habitat structure (Croonquist and Brooks 1991). Use of birds to gauge habitat change has been found effective in measuring changes in biological structure due to human perturbation of the landscape and can be used for a "broad perspective of the effects of habitat disturbance on the wildlife community" (Croonquist and Brooks 1991). Cable *et al.* (1989) also consider the size of the wetland parcel being assessed, assigning it an area factor.

Reference Wetland assessment methods are used to compare a particular wetland being assessed to a reference site that has been selected solely for comparison purposes. A reference wetland is a site within a specific geographical region that is chosen, for the purpose of functional assessment, as a relatively unaltered example of a group or class of wetlands, including both natural and disturbance-mediated variations (Brinson and Rheinhardt 1996) - in a sense, a "perfectly typical wetland" for a given area. A set of reference standards is established for the conditions exhibited by the reference wetland corresponding to the highest level of functioning of the ecosystem across a range of functions. The wetlands being evaluated should include a wide range of wetland sites, from those that are high functioning to those that are very degraded; this range of data can then be used to determine the least altered site. The standards drawn from this data set should be taken from the wetland site that is least degraded and therefore performs functions most optimally (Brinson and Rheinhardt 1996). These data from the reference wetland can then be used to determine a score for the wetland being assessed. The reference wetland method is discussed in papers by Brinson and Rheinhardt (1996), Rheinhardt *et al.* (1997), and Findlay *et al.* (2002).

The Southern California Riparian Model assesses the quality of wetland sites alongside rivers, lakes and streams. The formula for this method considers the following evaluation criteria: spatial diversity and coverage of habitats; structural diversity of habitats; contiguity of habitats; percent of invasive vegetation; hydrology; topographic complexity; characteristics of flood-prone areas; and biogeochemical processing (Stein *et al.* 2000). The formula was modified (Hunter *et al.* 2004) to be used with the available data and to provide an assessment of habitat function alone (based on the description of the assessment method in Stein *et al.* 2000); this abbreviated formula takes into account the cover of invasive species, cover and number of genera of riparian species, cover and regeneration of riparian species, and continuity with adjacent riparian and upland vegetation. The Southern California Riparian Model was designed to assign scores of "condition units" to sites to help determine their values as part of determining the acreage necessary for mitigation of wetland losses, and it has been used for that purpose. Loss of a site would require a replacement or gain of an equal number of condition units to result in a net loss of zero.

Hydrogeomorphic (HGM) assessment of riverine floodplains in the Northern Rocky Mountains aims to assess a wetland's ability to perform certain functions as compared to other comparable wetland sites in a particular area (Hauer *et al.* 2002). The terrestrial function this method quantifies is vertebrate habitat, and this is calculated by considering herb and shrub layer cover and native species cover, tree density, inundation frequency, and the connectivity of vegetation types (Hauer *et al.* 2002). A hydrogeomorphic method considers a site's geomorphic setting, water source, and hydrology, and can be used to classify wetland sites into regional subclasses, which helps reduce variation between sites both within a geographic region and from different regions (Hauer *et al.* 2002). A criticism made by Hauer *et al.* (2002) is that while other methods might be usable for many different wetland types, these often lack the ability to detect significant changes in function due to the wide variability of the sites that are assessed (Hauer *et al.* 2002).

Evaluation of Assessment Methods

I evaluated the four selected functional assessment methods by:

1.) Applying each to the REA data set to generate a set of assessment scores derived from each method;

2.) Evaluating the correspondence of scores based on different methods; and

3.) Comparing the species richness (i.e. number of species) of butterflies and birds to assessment scores for terrestrial habitat for each method.

Application of these methods required performing the calculations involved in each method, and adaptation of some assessment formulas in order to base assessments on the REA data set. The calculations and the modifications to equations or data sources are described in the following sections for each method.

Habitat Assessment Technique (HAT), Cable *et al.* 1989

The Habitat Assessment Technique (HAT) method was used to calculate a species index for each of the 47 riparian sites in the data set. This method considers birds observed in the sites as well as their relative rarity. Data for bird species observed in the riparian plots were used, along with breeding bird survey data from the U.S. Geological Survey breeding bird data website (Sauer *et al.* 2005). The USGS website included breeding bird survey (BBS) data collected from 1966 to 2003. The site can be used to access BBS data for any time period within this range, and can also be used to obtain data for a wide variety of states and regions in North America. Among data on the website are the average number of birds of each species per route surveyed. The BBS is conducted on a yearly basis during peak breeding season and data on the number of birds per route surveyed are recorded. The survey is conducted by an observer that stops at 0.8-km intervals and records all birds seen or heard in a 0.4-km radius within a 3-min sampling period (Sauer *et al.* 2005).

To calculate HAT scores for each riparian plot, I used the route-average data for birds in California for the 5-yr period ending in 2003. As Cable *et al.* (1989) assigned species base values to the individual species based on breeding pair population, I did so using the BBS data in lieu of actual breeding pair population values for California. Species base value points were assigned as follows: Bird species with an average number of birds per route of 0.01 to 0.10 were assigned 160 points, giving them the highest number of points as they were the most rare; species with averages of 0.11 to 0.25 birds per route were assigned 80 points; species with averages of 0.26 to 5.00 birds per route were assigned 40 points; species with averages of 5.01 to 15.00 birds per route were assigned 20 points; and those species averaging 15.01 birds or more per route were assigned 10 points, the lowest value as they were the most common bird species. Each riparian site was then assigned base value points for each bird species considered to be wetland-associated observed in the plot. The list of California Central Valley wetland-associated bird species was obtained from the US Fish and Wildlife Service (2005) website. The wetland-associated species points were totaled for each plot, and this total was then divided by the number of wetland-associated species present in the plot to obtain a species index. This species index, "by virtue of the species composition, reflects habitat quality" (Cable *et al.* 1989). In some cases, scientists from Jones and Stokes surveyed riparian plots more than once. In these instances, I combined all of the species observed in a plot over multiple visits to calculate a species index score.

In their paper, Cable *et al.* (1989) also use an area factor to adjust the scores for wetlands of varying sizes. This area factor is calculated using the size of the wetland being assessed as well as data pertaining to the maximum, minimum and optimal size wetlands in the region of the wetland. The species point total for a site is then divided by the area factor to calculate a "faunal index." However, since all plots used in this study were the same size (100 m x 100 m), the area factors would all be equal and thus would not add any meaningful information to the scores. Therefore, area factors were not used. Cable *et al.* (1989) state that the species index, taken independently, "could be used for simple comparisons, particularly if the sites were equal in size" (Cable *et al.* 1989). It is important to consider that although the plots were equal in size, they were located within riparian tracts of varying size, which could potentially affect the numbers of bird species in the plots. However, using the data from the riparian plots, I did not find a statistically significant correlation between the number of riparian-associated bird species and the width of riparian vegetation ($df = 46$, $r = 0.22$, $p = 0.144$).

Rocky Mountain Riparian Hydrogeomorphic (HGM) Assessment Method, Hauer *et al.* (2002)

The Rocky Mountain Riparian Hydrogeomorphic (HGM) Assessment Method was used to calculate function capacity scores for the function "Maintaining Characteristic Vertebrate Habitats" for each of the 47 riparian plots. This function is defined as "the capacity of the river floodplain-wetland complex to maintain the habitats necessary for a characteristic diversity and abundance of fish, herptiles (i.e., amphibians and reptiles), birds, and mammals" (Hauer *et al.* 2002). This function is used as an assessment tool for riparian areas because “river floodplains support a wide variety of vertebrates” (Hauer *et al.* 2002). As used by Hauer *et al.* (2002) the functional capacity index (FCI) for this function is calculated using the following formula:

$$FCI = \left[\left(\frac{V_{HERB} + V_{SHRUB} + V_{DTREE} + V_{NPCOV}}{4}\right) \times \left(\frac{V_{SURFREQ} + V_{MACRO} + V_{COMPLEX} + V_{HABCON}}{4}\right)\right]^{1/2}$$

This formula contains the following variables:

$V_{\mathbf{HERB}}$: Herbaceous plant cover, as percent cover of herbaceous plants per unit area;

$V_{\mathbf{SHRUB}}$: Shrub cover, as percent cover of shrubs per unit area;

$V_{\mathbf{DTREE}}$: Tree density, as number of trees per unit area;

$V_{\mathbf{NPCOV}}$: Percent coverage by native plants;

$V_{\mathbf{SURFREQ}}$: Frequency of surface flooding, in average number of years between surface flooding events;

$V_{\mathbf{MACRO}}$: Macrotopographic complexity, a value reflective of the “distribution and relative abundance of channels and connectivity between” channels (Hauer *et al.* 2002);

$V_{\mathbf{COMPLEX}}$: Proportionality of landscape features, a description of the distribution and abundance of cover types at the landscape scale; and

$V_{\mathbf{HABCON}}$: Floodplain habitat connectivity, a description of “connectivity of floodplain habitats between the surface and subsurface, between and among surface wetland features, and between the wetlands and surrounding upland riparian areas” (Hauer *et al.* 2002).

Collectively, the first four variables (V_{HERB}, V_{SHRUB}, V_{DTREE}, V_{NPCOV}) make up the first half of the equation, which assesses the quality and quantity of vegetation. The second half of the equation, containing the other four variables ($V_{SURFREQ}$, V_{MACRO}, $V_{COMPLEX}$, V_{HABCON}) provides an assessment of habitat suitability.

This assessment method was designed for use in assessing Rocky Mountain Riparian areas, and thus required adjustments to be appropriate for use in riparian areas of California's Central Valley. In the first half of the equation, the variables V_{HERB}, V_{SHRUB}, and V_{NPCOV} were used as described in Hauer *et al.* (2002), but V_{DTREE} was modified slightly. The data for the riparian areas in California contained tree cover as opposed to tree density. In Hauer *et al.* (2002), values for V_{DTREE} ranged from 1 to 20, so the percent tree cover values in my data set were scaled down proportionally (percent tree cover divided by 5) to produce numbers within this range to avoid giving a deceptively large result for this half of the equation. Values for $V_{SURFREQ}$ were given scores of 5, 10 and 20 years between inundation, based on data for each plot regarding the presence or absence of levees, incised channels, and evidence of overflow. While these values are more homogenous than would be found in data for flooding frequency over the long term, these values are appropriate and representative of the flooding potential for each site. Values for V_{MACRO} were provided by Dr. John Hunter (EDAW, Sacramento, CA) based on his knowledge and observations of the sites in the data set. The scores range from the highest value at 1.0 (multiple side and backwater channels and mix of old and new surfaces distributed across the floodplain) to the lowest, 0.0 (no side and backwater channels present on the floodplain surface) (Hauer *et al.* 2002). $V_{COMPLEX}$ represents the percentages of given cover types seen at a landscape scale that would be expected in a plot under varying levels of impact (Hauer *et al.* 2002). Hauer *et al.* provide a listing of the ranges of cover expected for varying impact levels; however many of these cover types were specific to riparian areas in the Rocky Mountains and therefore not applicable to California riparian areas. Instead, $V_{COMPLEX}$ values were assigned based on the make up and land use of areas extending out 1 km from the plot center, with those nearest to reference-type condition receiving the highest values and the most degraded sites the lowest. These degradation scores were calculated by considering the amount of reference condition riparian area in ha for each plot, and subtracting from it the amount of degraded land in the same area, which was classified based on the degree of degradation from an ideal reference condition. The values in ha for riparian vegetation, open water, and fresh emergent wetland within 1 km were each multiplied by 3 to give these unaltered portions of the riparian plots the highest value, and then summed, to assess the amount of "reference-condition" riparian/wetland that existed for each plot. Then, the amounts of land used for agriculture and agricultural crops were each multiplied by –2, to show a significant degradation, and land designated as developed or urban was multiplied by –3 to designate the most severe degradation, to a reference condition. These negative values were then combined with the positive values for riparian/wetland area to give a score that represents degradation for each site. Values for V_{HABCON} were not possible to calculate for the plots using the available data, and V_{HABCON} was therefore not used in the calculation of assessment scores. The assessment scores for the California riparian plots were calculated using the modified equation that follows:

$$FCI = \left[\left(\frac{V_{HERB} + V_{SHRUB} + V_{DTREE} + V_{NPCOV}}{4}\right) \times \left(\frac{V_{SURFREQ} + V_{MACRO} + V_{COMPLEX}}{3}\right)\right]^{1/2}$$

Southern California Riparian Model, Stein *et al.* (2000)

The Southern California Riparian Model as described in Stein *et al.* (2000) also was used to generate a set of scores for the 47 riparian plots. This method in particular was well suited for use with the plots as it was designed specifically for riparian areas in California. This model uses a wide variety of criteria in assessing a riparian area, such as spatial diversity and coverage of habitats; structural diversity of habitats; contiguity of habitats; percent of invasive vegetation; hydrology; topographic complexity; characteristics of flood-prone area; and biogeochemical processing (Stein *et al.* 2000). This equation was modified so that it would work with the data available for the riparian plots. The modified equation uses the following variables: cover of invasive species (I); cover and number of genera of riparian species (SP); cover and regeneration of riparian species (ST); and continuity with adjacent riparian and upland vegetation (CNT). This method, unlike many others, uses a single function to rate the riparian sites; scores for the sites are "condition units." The modified equation is as follows (Hunter *et al.* 2004):

$$\frac{[(1-I)(ST+SP+CNT)]}{3}$$

The riparian data set was used to obtain values for each of the variables in this equation. The data set contained values for cover of invasive species. The variable of SP, as well as ST (cover and regeneration of riparian species) and CNT (continuity with adjacent riparian and upland vegetation) were assigned values of 0.0, 0.2, 0.4, 0.6, 0.8, or 1.0 according to listings of categories described in Stein *et al.* (2000). Using this ratings system, 0.0 is the least desirable and most altered condition for the site, while 1.0 is a best-case scenario representing an ideal condition. Data pertaining to the cover and number of native riparian species present in both the tree and shrub layer was used to derive values for the variable *SP*. Data for cover in the herbaceous, shrub, and tree layers and for presence of tree saplings in the shrub layer were used, along with the value categories ranging from 0 to 1.0 as described in Stein *et al.* (2000) to derive values for *ST*. The values for *CNT* were provided by Dr. John Hunter (EDAW, Sacramento, CA) based on his knowledge of and experience with the riparian sites.

Reference Wetlands, Rheinhardt, *et al.* (1997)

In considering a variety of assessment methods, scores for the riparian plots were calculated using a function for "Supports Characteristic Vegetation" from the method described in Rheinardt *et al.* (1997) using reference wetlands. This method "scores" the assessment area against data from a tract of wetland that is considered to be in pristine condition, or very nearly so. Within the riparian ecosystem analysis data set the plots in the Spears Ranch, Valensin, and Clear Creek areas could be considered "reference-type" areas as they are the least-altered plots in the study. Thus, each of these plots was used as a reference site, and a composite score was also calculated for these areas by averaging the values for each variable from these three reference areas. The three plots as well as the composite plot served as "reference wetlands" against which all plots, including the three averaged for the composite plot, are scored. For each variable, then, a ratio is calculated by dividing the assessment area score by the reference area score; this ratio is called a "similarity coefficient" and provides a numerical value to how a site compares to the reference condition.

The function "Maintain Characteristic Plant Community" uses variables for the composition of canopy, subcanopy, graminoid and forb plants. The equation for this function is as follows (Rheinhardt *et al.* 1997):

$$\frac{\{V_{CVEG} + [V_{SVEG} + (V_{GRAM} + V_{FORB})/2]/2\}}{2}$$

The variables in the equation are all used as similarity coefficients, or ratios, between the assessment area and a highly functioning condition. V_{CVEG} and V_{SVEG}, are canopy (percent tree cover) and subcanopy (percent shrub cover) composition, respectively, and V_{GRAM} and V_{FORB} are graminoid and forb cover. Since data on species of graminoids and forbs are not available for the riparian plots, these variables were combined into a value for herbaceous plant cover, and the equation was modified as follows:

$$\frac{\{V_{CVEG} + [V_{SVEG} + (V_{HERB})/2]/2\}}{2}$$

The resulting value from this equation is then divided by the score for the reference condition; this "index" gives an overall view of how a site compares to a reference area.

Data analysis

The above equations for the four methods were used, together with the data for the 47 riparian plots. For each variable employed by these assessment methods, I determined the range of values and the mean and standard deviation (Tables 1-4). To illustrate the magnitude of the variability in these values, I also calculated the coefficients of variation (*V*), which show the proportion of the standard deviation to the mean (Zar 1999). Correlation coefficients (*r*) (Zar 1999) were calculated between the all of the variables used in the four assessment methods (Appendix A), and between biological and physical data from the riparian sites (Appendix B). Site scores were calculated for each of the 47 riparian plots using each of the four assessment methods. For each assessment method, these scores were organized into tables showing the value of the score for each site, as well as the site's ranking, to demonstrate how the site's score compared to other sites' scores using that method, and to show how each individual site ranked using the different methods (Appendices C-G). A table was organized listing each site with its ranking for each of the four methods (Appendix H). Correlation coefficients (*r*) (Zar 1999) were calculated between each assessment method's scores for the 47 sites to determine what, if any, statistically significant relationship existed (Table 5), and between assessment scores calculated for each site using each of the four methods and the number of riparian-associated bird species and butterfly species observed at each site (Table 6). Correlations between the four assessment methods are also illustrated with a series of scatter plots (Figures 1-6). Statistical significance of correlation coefficients was also assessed using Bonferroni corrections to adjust for error due to large numbers of comparisons. Photographs of some of the riparian plots are included as well (Figures 7-

12). I have included photographs from several plots that are mentioned specifically in this paper, as well as others that illustrate the wide variety of conditions observed in the 47 plots.

Results

The 47 riparian sites varied widely in their attributes, and this variability contributed to substantial differences between the sites' scores using the four methods. For example, in the HAT method (Table 1), the values for number of wetland-dependent species ranged from 6 to 37, with a mean of 19 and a standard deviation of 8 (the coefficient of variation (*V*) in this case was 0.42, or 42%); values for total species points ranged from 150 to 1630, with a mean of 698 and a standard deviation of 336 ($V = 0.48$). Obviously, variability of this magnitude is going to cause significant variability in the scores produced when these values are used in an equation. Likewise, differences of similar magnitude can be noted with many of the other variables used. For the Rocky Mountain Riparian HGM method (Table 2), V_{HERB} had a minimum value of 10 and a maximum of 100, with a mean of 76 and a standard deviation of 27.45 ($V = 0.36$); and V_{SHRUB} had a maximum of 90 and a minimum of 1, with a mean of 41 and a standard deviation of 24.01 ($V = 0.59$). However, not all variables used in the Rocky Mountain Riparian HGM method demonstrated such wide variability: for example, V_{NPCOV} (native plant cover) ranged from 81 to 99 percent, with a mean of 91 and a standard deviation of 4.83 ($V = 0.05$); and the values for V_{MACRO} (macrotopographic complexity) and $V_{COMPLEX}$ (proportionality of landscape features) are assigned only to ratings in six categories between 0.0 and 1.0, which limits variability somewhat. Variability was similar for each of the three variables I used to calculate scores using the Reference Wetland method

(Table 3): CVEG ranged between 0.03 and 0.95, with a mean of 0.46 and a standard deviation of 0.24 ($V = 0.52$); SVEG ranged between 0.10 and 0.90 with a mean of 0.41 and a standard deviation of 0.24 ($V = 0.59$); and herb cover ranged between 0.10 and 1.0 with a mean of 0.76 and a standard deviation of 0.27 ($V = 0.36$).

The Southern California Riparian Model (Table 4) uses three variables that are assigned values from 0 to 1.0: SP (cover and number of genera of riparian species), ST (cover and regeneration of riparian species), and CNT (continuity with adjacent riparian and upland vegetation), and values for all these three variables ranged from 0.4 to 1.0. The values for the variable SP had a mean of 0.76 and a standard deviation of 0.136 ($V = 0.18$); for ST, the mean was 0.64 and the standard deviation was 0.195 ($V = 0.30$); and for CNT the mean was 0.62 with a standard deviation of 0.185 ($V = 0.30$). Cover of invasive species (I) ranged from 0 to 0.4, with a mean of 0.05 and a standard deviation of 0.102 ($V = 0.51$).

The individual variables used in the assessment methods also show very little correlation with each other (Appendix A) and some general physical variables (which can indicate the degree to which a site is altered) also show little correlation with the use of sites by birds and butterflies (Appendix B). When considering riparian-associated bird species, only tree cover ($df = 46$, $r = 0.29$, $p = 0.0478$) and riparian vegetation within 250 m ($df = 46$, $r = 0.31$, $p = 0.0341$) showed statistically significant relationships. Considering riparian-associated butterflies, only tree cover ($df = 46$, $r = 0.31$, $p = 0.0341$) and shrub cover ($df = 46$, $r = 0.29$, $p = 0.0478$) demonstrated statistical significance. With use of Bonferroni corrections, none of these correlations were statistically significant.

Assessment methods differed in the sites that received the highest ratings. Using the HAT method of assessment (Appendix C), the scores for the 47 riparian sites ranged from a high species index of 44.05 (Mehalakis Ranch Plot 2) to a low of 25 (Thomes Creek Plot 15). The plots exhibiting the highest species index scores were Mehalakis Ranch Plot 2, Spears Ranch Plot 2, and Turkey Creek, Plot 1, which ranked first, second, and third, respectively.

The Rocky Mountain Riparian HGM method (Appendix D) produced scores that ranged from a maximum Functional Capacity Index (FCI) of 10.629 (Thomes Creek Plot 15) to the minimum of 4.576 (Dye Creek Plot 25). The highest scoring plots, in order of first, second, then third, were Thomes Creek Plot 15, Turkey Creek Plot 1, and Turkey Creek Plot 2.

The Southern California Riparian Model yielded results (Appendix E) that differed entirely from the previous two methods in the three highest ranked sites. The top three scores belonged to Spears Ranch Plot 1, Mill Creek Plot 15, and Meiss Road Plot 1. The highest score using this assessment method was 0.910 condition units (Spears Ranch Plot 1), while the lowest was 0.400 condition units (Deer Creek Plot 9).

Results for the Reference Wetlands assessment method (Appendix F) were calculated using four reference sites: Spears Ranch Plot 1, Clear Creek Plot 3, Valensin Ranch Plot 1, and an average of these three plots. Interestingly, each reference site and the average resulted in different score values for individual sites, and the reference sites themselves did not consistently receive high scores. The calculated scores for each of the 47 plots that resulted from the use of the four reference conditions varied, but were consistent in ratio to each other. As the score values were calculated as a proportion, or ratio, of a reference site's score, and because all scores were calculated using the same data set, correlations and rankings of the plots did not change regardless of which reference site was used. Using the average reference score, the highest Index of Function was 1.331 (Spears Ranch Plot 1), while the lowest score was 0.205 (Mill Creek Plot 10). The three plots that had the highest Indexes of Function were Spears Ranch Plot 1, Miner's Ravine Plot 2, and Morgan Creek Plot 2. Interestingly, only one of the three plots selected as being the most pristine and ideal condition, Spears Ranch Plot 1, received a score that supported its relatively unaltered condition. The other reference plots, Clear Creek Plot 3 and Valensin Ranch Plot 1, ranked 35th and 20th, respectively, out of 47 plots. Since the Reference Wetlands methods are designed to have a maximum score of 1 because the score values represent a ratio of the assessment site to the reference site, site scores were also arranged so that any score greater than 1 (due to a comparison to a reference site that did not receive the highest scores) was set to be equal to 1 (Appendix G). This, however, was somewhat misleading. When the results are arranged in this way, it becomes impossible to tell how the scores compare to each other, or even which one was used as the reference site since there are so many sites with scores equal to 1.

A comparison of the sites' score rankings using the four assessment methods revealed many inconsistencies (Appendix H). Spears Ranch Plot 1, which garnered the highest score using the reference wetland assessment method, did not consistently achieve such favorable ratings using the other assessment methods, receiving a species index of 37 (ranking 20th among the 47 sites) using the HAT method, a functional capacity index of 8.32 (ranking 9th) using the Rocky Mountain HGM method. However, it also received the highest score of 0.91 condition units using the Southern California Riparian Model. Inconsistencies were seen in the ratings for the other plots used as reference sites as well. Clear Creek plot 3 ranked 35th using the reference wetland method; it had a species index of 37.86 (ranking 19th) using the HAT method, a functional capacity index of 4.73 (ranking 44th) using the Rocky Mountain HGM method, and a score of 0.76 condition units, ranking 12th using the Southern California Riparian Model. Valensin Ranch, which had a ranking of 20th using the reference wetland assessment method earned a species index score of 36.79 (ranking 24th) with HAT, a functional capacity index of 5.59 (ranking 29th) using the Rocky Mountain Riparian method, and a score of 0.80 condition units (ranking 10th) with the Southern California Riparian model.

The correlation coefficients for the comparisons of the four sets of assessment scores showed little correlation (Table 5). The lowest correlation of 0.020 existed between the HAT and Rocky Mountain Riparian HGM methods; the HAT method had a correlation of 0.226 with the Reference Wetlands method and –0.055 with the Southern California Riparian Model. The Rocky Mountain HGM method showed a correlation of 0.098 with Reference Wetlands and –0.023 with the Southern California Riparian Model. The only significant correlation ($df = 46$, $r = 0.46$, $p = 0.00103$, with Bonferroni correction) was between the scores for the Southern California Riparian Model and Reference Wetlands. Generally, these correlations did not support my hypothesis that a positive correlation would be observed among the scores for the sites using the four different assessment methods. The results indicate that a high score using one method is generally not predictive of a high score using any of the other assessment methods.

Furthermore, only two statistically significant relationships were found when correlation coefficients were calculated between the four sets of assessment scores and numbers of riparian associated birds and butterflies (Table 6). A significant relationship existed between the site scores using the HAT method and the number of riparian associated birds ($df = 46$, $r = 0.37$, $p = 0.0095$); this makes sense considering that the HAT method uses bird data to assess habitat. A significant relationship also occurred between Reference Wetland site scores and the number of riparian associated butterfly species ($df = 46$, $r = 0.38$, $p = 0.0092$). Aside from these two examples, numbers of riparian associated bird and butterfly species did not correlate with the site scores for habitat.

Discussion

I rejected my first hypothesis, that the different assessment methods should produce similar results for each site, and therefore the resulting site scores should be correlated. In only one instance, the comparison of the Southern California Riparian Model and Reference Wetland methods ($df = 46$, $r = 0.46$, $p = 0.00103$, with Bonferroni correction), was a statistically significant correlation demonstrated. My second hypothesis, that the scores produced by each assessment method should be correlated with the numbers of riparian-associated bird and butterfly species at each site, was also rejected. Of eight correlation coefficients calculated, there were no statistically significant relationships with the use of Bonferroni corrections. Without Bonferroni corrections, only two statistically significant relationships occurred in these data: between the number of riparian-associated bird species and the Habitat Assessment Technique scores (*df* = 46, *r* = 0.37, *p* = 0.0095) and between the number of riparian-associated butterflies and the Reference Wetland scores (*df* = 46, *r* = 0.38, *p* = 0.0092).

Some of the methods in this study were modified so that they would be applicable to the riparian data available, or were used to assess sites in a region other than intended, but I have stayed true to the rationales of these methods. My methods remain representative of the intent of their authors and combine the same types of data in the way they were designed. Results of my study suggest that each of the four methods had limitations that may adversely affect their accuracy, precision, or consistency across users and site locations.

The assessment methods included in this study represent the range of approaches currently being used to assess the habitat functions provided by riparian sites. The Rocky Mountain Riparian HGM method assigns scores for vertebrate habitat based on the site attributes, while the HAT method uses bird data only, the Southern California Riparian Model uses site attributes and flora in generating scores for habitat values in general, and the Reference Wetland assessment method uses plant data only to generate scores for habitat values in general. However, these methods produced very disparate results, and possibly none of these methods accurately assessed the relative value of terrestrial habitats provided by riparian areas in the Sacramento Valley.

These methods use a wide range of variables, and assess how suitable a site is for providing habitat for a wide range of organisms, some of them very dissimilar. This wide range of predictor variables has a negative impact on the effectiveness of the functional assessment equations. Because the variables encompass such a large variety of site characteristics, using equations that contain such different variables will not necessarily return results that are meaningful, useful, or comparable. Also, the use of variables that fail to demonstrate consistent relationships with wildlife data, as occurred in my study, will not produce site assessments that are related to habitat values. However, it should be noted that the data set used was limited in the amount of data collected from each site. It is quite possible that more intensive data collection of more parameters could return results that are a better measure of habitat value.

Since the variables used in assessment are selected by authors of the assessment method, there is also the potential for the authors' subjectivity to affect the accuracy and reproducibility of the method's scores. Hruby *et al.* (1995) address the issues of variable selection and author subjectivity, saying

> the scores or weighting factors...usually reflect perceived importance and the best professional judgment of the author(s) rather than the results of rigorous experiments. This approach is necessitated by the lack of quantified relationships between environmental variables and functions that can be used at the scale of most wetland planning efforts. Unfortunately, conversion to numeric scores does not decrease the subjectivity of the original assumptions, but it does allow different users to arrive at the same scores (Hruby *et al.* 1995).

The lack of proven relationships between the functions being assessed and the measurable predictor variables is disturbing. This suggests that it is not yet feasible to determine if any assessment actually measures the function (or functions) intended; consequently, meaningful functional assessment of a wetland or riparian site may also be unfeasible at this time.

A limitation of the assessment methods is that the function of providing habitat is intended to apply to very broad groups of organisms, and is not defined very specifically. "Habitat" may not be a specific enough function, and is open to many different interpretations. There are dramatic differences in what constitutes high quality habitat for the different types of organisms using riparian areas, and the habitat requirements of a vertebrate probably vary dramatically from that of an invertebrate. Vertebrates might use a site with more dense vegetation, particularly in the tree and shrub layers, while invertebrates might prefer more sparse vegetation. For example, requirements for a high-quality habitat for muskrats might include dense vegetation, such as *Typha* and *Acorus*, along with appropriate soil conditions, namely a dense soil with little sand (Findlay *et al.* 2002). Other vertebrates, such as wetland birds, would require habitat with dense trees for nesting and breeding (Findlay *et al.* 2002).

In general, there are numerous differences in habitat requirements among species, guilds, and taxonomic groups. Regarding invertebrates, a study of wetland areas along Lake Michigan demonstrated that the most insects and greatest insect biomass were present in areas of sparse vegetation, as opposed to open water or dense vegetation (Mitsch and Gosselink 2000). Examinations of wetland habitats for other invertebrates such as crayfish, oligochaete worms, snails and many other species, indicate that factors such as abundance of detritus, hydroperiod, and type and quantity of aquatic plant species must be considered (Mitsch and Gosselink 2000). Certainly, even when making comparisons within the kingdoms of vertebrate species or invertebrate species, great differences in habitat requirements will be found.

Even among the bird species observed at the 47 riparian plots, there are great differences in habitat requirements. Some species, such as the Pacific-slope Flycatcher (*Empidonax difficilis)* and Warbling Vireo (*Vireo gilvus)* favor habitat with dense canopy and moist surroundings, while others, including the Oak Titmouse (*Baeolophus inornatus*), Hutton's Vireo (*Vireo huttoni*), California Towhee (*Pipilo crissalis*), and Ash-throated Flycatcher (*Myiarchus cinerascens*) prefer more open woodland forest (University of California Davis 2006). Some species nest in cavities that they find, excavate, or usurp. These cavity-nesting species include the Acorn Woodpecker (*Melanerpes formicivorous*), Barn Swallow (*Hirundo rustica*), and White-breasted Nuthatch (*Sitta carolinensis*) as well as invasive species like the European Starling (*Sturnus vulgaris)*, and they may require different types of cavity-nesting sites including snags and rotting trees (University of California Davis 2006).

Butterfly species also have specific requirements for habitat. Each butterfly species has only a very few plants that can serve as larval host plants. For example, among butterfly and plant species noted in the riparian plots, the Purplish Copper (*Lycaena helloides*) requires willow species, and the Mourning Cloak (*Nymphalis antiopa*) utilizes willow and poplar species (Monarch Watch 2006).

Clearly, as demonstrated with the examples of bird species, a single score based on too few or on unimportant variables will not encompass the wide range of habitat types required by different wildlife organisms. Furthermore, assessment of habitat using only general plant cover data will not determine the presence of the particular plant species needed for butterfly habitat.

Specifying the assessed function more precisely may improve the accuracy and consistency among assessment methods. Different methods that include a measure of habitat suitability are not necessarily measuring habitat suitability for all organisms, and often different methods are actually assessing habitats for different types of organisms. For example, the HAT method assesses bird habitat; the Rocky Mountain HGM method considers vertebrate habitat, and the Reference Wetland and Southern California Riparian Model do not specify the type of organism being considered. Results are vague and difficult to interpret when organism type is not explicitly considered; general habitat measures that rely on vegetation data may indicate that a site provides a very suitable habitat, but they do not indicate what kind of organism this habitat is suitable for (e.g., birds, butterflies, amphibians). Calculating site scores for habitat integrity for a particular wetland- or riparian-associated organism would eliminate this ambiguity, yet such scores might be too specific and not broad enough for an assessment of a site's overall integrity.

For example, the HAT method used a site's suitability as bird habitat to predict overall wetland or riparian integrity. However, the results of the HAT method were not correlated to those of other methods. Perhaps if several methods that all assessed bird habitat were compared, some meaningful relationships would emerge. Yet, a comparison such as this might the prompt the question, "What exactly am I assessing - the site's suitability for birds, or the site's overall integrity?" A method that concentrates on just one specific organism, guild, or taxonomic group may not be a useful tool to predict an overall picture of wetland or riparian integrity, if that is the goal.

One way to overcome this problem would be to consider several organisms characteristic of the type of wetland or riparian site being assessed and to develop a score that incorporates habitat for each. A method that considers a wider range of organisms would likely give a more accurate picture of the site's habitat integrity, and possibly also its overall functional integrity. However, adding more variables to any assessment adds a greater requirement for time and money.

My findings indicate that the HAT method is not a very effective predictor of wetland habitat integrity. Its results were not correlated with other assessment methods or with the number of riparian-associated butterfly species observed at these sites; the only statistically significant correlation was between the HAT method site scores and the numbers of riparian associated bird species at the sites. The authors of the HAT method, Cable *et al.* (1989), did not discuss any limitations of their method that could account for these results. On the contrary, they note,

> the procedure appears to be efficient and effective. Species points provide a reasonable reflection of habitat quality, based on diversity and rarity of wetland-dependent species (Cable *et al.* 1989).

The concession that Cable *et al.* (1989) make about their assessment method is that HAT could greatly underestimate the value of migrant staging areas for birds, because these sites often contain just a few common species, yet these birds may represent a very significant portion of the world's population of those few species (Cable *et al.* 1989). Otherwise, Cable *et al.* (1989) relate nothing but positive findings about their HAT method.

For my riparian data set, a difficulty in calculating scores using the reference wetland method of assessment was the variation among the relatively unaltered sites. The most pristine and least altered sites (that were also in the least altered landscapes) were plots located at Clear Creek, Spears Ranch, and Valensin Ranch; these were the plots selected to serve as "reference sites." However, only Spears Ranch consistently had the highest "scores" for each variable and for the functional index score. With this method, using Spears Ranch as the reference site, Spears Ranch had a score of 1.0 (or "perfect") and all other plots had scores of less than 1.0. Using this method with the data available for the Clear Creek and Valensin plots produced significantly different results. When these sites were used to represent reference conditions, each had a score of 1.0. However, since they did not possess the maximum (or "best") value for each variable, some other sites received scores greater than 1.0, or scored better than the "ideal" represented by the reference condition.

Since the maximum score using a reference wetland assessment method is supposed to be 1, all scores greater than 1 were also reported as 1 (Appendix G). Displaying site scores in this way shows that a great number of sites received scores suggesting an unaltered condition, and illuminates a potential problem with this assessment method. Presenting scores this way results in a range of values being scored as 1, or the ideal condition, when in fact most of the sites that have a score of 1 have been substantially altered. This also limits the range in the scores reported; rating a substantial number of sites as "1.0" obscures the distinctions that exist among them. Only when using Spears Ranch as the reference site were most sites distinguished in the ratings. The authors of this reference wetland method, Rheinhardt *et al.* (1997), did not discuss the effects of variation among reference sites. In their application of this assessment method, they were able to consistently select reference wetland sites that were clearly superior with regard to function. Rheinhardt *et al.* (1997) consider the use of reference site data to be a strength of their assessment method- they state:

> The key element...is that all model variables are indexed relative to standards derived from intact natural ecosystems... (and) using metrics from intact ecosystems also provides standards for restoring wetland ecosystems; it therefore requires that ecosystems, not just individual functions, be restored.

This, however, is based on the premise that the range of natural conditions in intact systems does not overlap substantially with the range of conditions at altered sites.

A related concern regarding the reference wetland assessment is that the sites selected as ideal reference sites are generally chosen subjectively. Their selection is largely based on the opinion of the researchers. Where relatively unaltered sites vary considerably, this could lead to misleading results. This problem became very clear in my use of the reference wetland assessment method with the riparian data set. When calculating scores for the three plots that were considered to be nearest the ideal reference condition, only one, a Spears Ranch plot, received a score consistently greater than the scores of altered sites. The other two, Clear Creek and Valensin, received only intermediate scores.

The combination of these two factors – subjectively selected reference sites and reliance on a small set of variables - may mean that the method does not accurately assess the condition of a wetland or riparian site and may prevent the reference wetland assessment method from providing accurate or useful results. Again, the authors of this reference wetland method, Rheinhardt *et al.* (1997), did not discuss these issues of concern. It is worth noting, however, that if these and other issues are addressed, reference site methods could be truly useful, providing readily interpreted scores.

In using the Rocky Mountain Riparian HGM method and Southern California Riparian Model, I encountered another problem: the use of broad and vaguely defined categories to assign values for certain variables. In the Southern California Riparian Model, three of the variables utilize such categories. As an example of these categories, the values to use for the variable *ST* (cover and regeneration of riparian species) follow:

> 0.0 = Site permanently converted to land use that will not be able to support native riparian vegetation, such as housing, agriculture, or concrete channel.
>
> 0.2 = No existing riparian vegetation (e.g. covered with upland grasses and scrub, bare ground). However, site has potential for revegetation without extensive structural remodification.
>
> 0.4 = Vegetated areas of the site contain sparse, scattered, patchy, or remnant riparian vegetation that is immature and/or lacks structural (vertical) diversity.
>
> 0.6 = The patches of riparian vegetation on the site contain riparian trees and/or saplings (i.e. perennial dicots) but contain no or poorly developed shrub understory.
>
> 0.8 = The patches of riparian vegetation on the site contain riparian trees and saplings, plus a well-developed native shrub understory.
>
> 1.0 = The patches of riparian vegetation on the site are structurally diverse. They contain riparian trees, saplings and seedlings, as well as developed native shrub understory and herbaceous layer. (Stein *et al.* 2000).

Use of rating systems such as this leaves much room for subjective assessment, and this will ultimately affect the accuracy and score outcomes of such methods. In my experience, assigning these values became a judgment call in many instances. Though I assigned these values based on the data that I had at my disposal, and I worked an individual familiar with the sites (John Hunter, EDAW, Sacramento, CA), I am certain that someone else working with the same data set and familiar with the sites might assign different values to these sites. The authors of the Southern California Riparian Model, Stein *et al.* (2000), do not discuss these rating scales as a weakness, but rather as a strength of their assessment approach: their viewpoint is that such ratings scales enable the method to be tailored to evaluate different ecological functions, based on particular mitigation goals, as this type of rating scale could be readily applied to any function (Stein *et al.* 2000).

The Rocky Mountain Riparian HGM method uses several ratings scales to provide values for variables such as macrotopographic complexity, which assesses the potential interconnectivity of surface flow and surface water storage (Hauer *et al.* 2002), geomorphic floodplain conditions (degree of alteration), proportionality of landscape features, and habitat connectivity. Hauer *et al.* (2002) do not mention any concerns that these rating scales might compromise accuracy or repeatability in any way.

There are other methods that assign numeric values to one or more variables using rating scales with broad categories. One, the California Rapid Assessment Method for Wetlands, or CRAM, was designed to assess the wetlands that are associated with coastal watersheds (Collins *et al.* 2004). This method uses a number of category scales to assign values to variables, and many of these require some interpretation. For example, the variables for buffer condition, water source, riverine hydroperiod and several other features each receive a score of A, B, C, or D based solely upon a corresponding description that uses no specific values or measurements (Collins *et al.* 2004.) Another, the method used for Assessment of Riparian Ecosystem Integrity in the San Diego Creek

Watershed, Orange County, California, uses similar ratings scales for several variables. Some of these are assigned objectively, and the ratings correspond directly with measurements of the watershed. One variable, however, is assigned a rating of 1 to 5 based solely on verbal descriptions of conditions of the sediment regime (Smith 2000); this leaves room for some subjectivity and individual interpretation. The authors of these methods, the Rocky Mountain Riparian HGM method (Hauer *et al.* 2002), CRAM method (Collins *et al.* 2004), and Assessment of Riparian Ecosystem Integrity in the San Diego Creek Watershed method (Smith 2000) did not provide any statistics to assess repeatability of measurements using these scales between different individuals.

Aside from the specificity I found with the HAT method, and to an extent with the Southern California Riparian model, I noted that a large number of calculations are required to arrive at an overall score with the Rocky Mountain Riparian HGM and Reference Wetlands methods. The Rocky Mountain Riparian HGM method uses eight function equations; the Reference Wetlands assessment method included in this paper uses four. Since assessing a greater number of functions requires more variables to be measured and more calculations, this may make these and similar methods more cumbersome and more costly, especially if large numbers of sites must be surveyed. Additionally, if each variable has an associated error, including more variables in an assessment will increase the overall error.

Theoretically, if the wetland assessment methods are accurately assessing the sites' functional capacity, a site that has a high score using one assessment method should be a fairly high quality riparian site. Thus, the quality of the site should be reflected in the scores generated by other assessment methods. Likewise, unaltered sites should get similar, and consistently high, scores. In my study, this did not occur. This is a significant problem that carries implications for the design of assessment methods. The scientific literature does not have any discussion on this topic; I found that while there are many articles that describe or review a single type of assessment method, comparisons among them do not exist. This is an area of great potential for research. Exploring relationships between different assessment methods provides an opportunity to determine the methods' accuracy, precision, geographic applicability, and repeatability as well as elucidating ways to improve them.

There are many ways to improve the usefulness of functional assessment methods. First, variables should be selected carefully, so that they provide an accurate, meaningful, widely applicable, and reproducible result. Assessment methods must use variables that should be appropriate to the region being assessed, the variables should be correlated with the function being assessed, and they should be measurements of qualities that effectively demonstrate the site's capacity for that function. One concern is that many assessment methods rely solely, or very heavily, on only biological data, and often the biological data pertains to a relatively narrow range of organisms. The assessment equations should take other variables into consideration, such as including different groups of organisms (and not focusing on birds only, or vegetation only) and including some of the physical attributes of the site being assessed as well as its surrounding land. Many assessment methods do use data for physical attributes, but often they are categorized along a scale of 0 to 1.0 using descriptions of each rating. As discussed, this leaves room for error or subjectivity in interpretation and cannot illustrate a site's condition as clearly as an actual measurement. For example, actual measurements of native riparian vegetation cover and riparian plant species present in the tree, shrub, and herbaceous layers would provide more objective and precise data than describing these same qualities with just a single value chosen from a scale of 0 to 1.0.

Additionally, the variables used in the four assessment methods studied are nearly all structural measures (e.g. species richness, cover, diversity), although they are being used to estimate a presumed function. This possibly inappropriate use of structural variables most likely contributes to the inaccuracy of the assessment methods. These variables might be entirely appropriate and more effective in assessing a structural outcome for a wetland or riparian site, as opposed to a functional outcome. Possibly a return to the use of structural goals for sites would improve the effectiveness, usefulness, and accuracy of assessment.

The methods should employ enough variables in assessment equations so that an anomaly in the value for one variable will not excessively skew the score of a site, in either a positive or negative direction. Yet the number of variables that need to be measured should be limited somewhat to prevent the assessment from being unrealistic in terms of time, personnel, or money. Ultimately, what is needed are assessment tools that are geographically appropriate to the areas being assessed, and that produce accurate, relatively precise, and reproducible results.

Conclusion

The conservation of wetlands and riparian areas is an issue of growing concern, and with it comes an urgent need for reliable tools to assess the functional value and overall integrity of a site. Consequently, a large number of assessment methods have been developed, most of which rely on readily collected data to indicate the functions provided by a site. I had hypothesized that the assessment methods would demonstrate their usefulness by generating scores that were correlated with other methods and with the number of riparian-associated bird and butterfly species using 47 riparian sites in California's Sacramento Valley. However, the four assessment methods produced ratings for habitat functions provided by 47 sites that were not correlated with each other, and were not correlated with observations of riparian-associated bird and butterfly species. Factors potentially contributing to these results include too broad a function being assessed; inappropriately or subjectively selected or uncorrelated variables; and subjectivity in choosing variables, assigning values to variables or in selecting reference sites.

This lack of consistency among methods is a problem for the selection and application of assessment methods. Using any single method, a set of scores can be generated for any number of sites that would, ideally, show how the sites compare in quality. If one method is not compared with any other, its results may be accepted as correct when in fact they might be far from accurate. The comparison of different assessment methods in this study showed clearly that a site scoring well using one method often scored much more poorly with a different method. Clearly, if the same data set is used to calculate assessment method scores for each site, as it was in this study, then there are some problems inherent in the variables used by the assessment methods, in the design of the assessment equations, or the application of the assessment method to my particular data set.

The existing attempts at assessing wetland or riparian function and the integrity of sites are important steps in the right direction, but functional assessment must be considered a work in progress. Another disturbing tendency is that assessment methods are presented in literature with a discussion of why the variables used were selected, how they work, and what they are aiming to measure, along with examples of their application, but their results are never compared to those from any other methods or to more direct measurements of the functions they purportedly indicate to demonstrate whether the results are accurate and precise.

Wetland assessment methods must undergo improvements and be demonstrated as accurate assessment tools before they can be depended on for providing an assessment of the value, health, or function of wetlands, riparian areas, or other ecosystems. In their current condition, the four wetland assessment methods evaluated are not suitable for making comparisons among wetland or riparian sites or, even more importantly, for determining amounts of wetland that would be required to achieve a result of "no net loss."

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Table 1. Descriptive statistics for variables used in Habitat Assessment Technique. Values are for 47 riparian sites in the Sacramento Valley, California. (For variable definitions and formulas, see text of methods section.)

Variables	**Range**	**$\overline{X} \pm 1$ S.D.**
Total species points	150- 1630	698 ± 336
Number of wetland-dependent bird species	6- 37	18.9 ± 7.9

Table 2. Descriptive statistics for variables used in Rocky Mountain Riparian HGM. Values are for 47 riparian sites in the Sacramento Valley, California. (For variable definitions and formulas, see text of methods section.)

Variable	**Range**	$\bar{X} \pm 1$ **S.D.**
V_{HERB} **Herb cover (%)**	10- 100	76 ± 27.5
V_{SHRUB} **Shrub cover (%)**	1- 90	41 ± 24.0
V_{DTREE} **Tree density**	1- 19	9 ± 4.83
V_{NPCOV} **Native plant cover (%)**	81- 99	91 ± 4.8
$V_{SURFREQ}$ **Freq. Of surface flooding (Avg # years)**	5- 20	9 ± 5.5
V_{MACRO} **Macrotopographic Complexity**	0- 1	0.61 ± 0.18
$V_{COMPLEX}$ **Proportionality**	0- 1	0.56 ± 0.28

Table 3. Descriptive statistics for variables used in Reference Wetland assessment for the function "Maintains Characteristic Plant Community." Values are for 47 riparian sites in the Sacramento Valley, California. (For variable definitions and formulas, see text of methods section.)

Variable	**Range**	$\bar{X} \pm 1$ **S.D.**
CVEG **Canopy vegetation cover (trees)**	0.03- 0.95	0.46 ± 0.24
SVEG **Subcanopy vegetation cover (shrubs)**	0.01- 0.90	0.41 ± 0.24
VGRAM+VFORB **Variables combined as Herb cover**	0.10- 1.0	0.76 ± 0.27

Table 4. Descriptive statistics for variables used in the Southern California Riparian Model. Values are for 47 riparian sites in the Sacramento Valley, California. (For variable definitions and formulas, see text of methods section.)

Variable	**Range**	**$\overline{X} \pm 1$ S.D.**
I **Cover of invasive species**	0- 0.4	0.05 ± 0.102
SP **Cover and number of genera of riparian species**	0.4- 1.0	0.76 ± 0.136
ST **Cover and regeneration of riparian species**	0.4- 1.0	0.64 ± 0.195
CNT **Continuity with adjacent riparian and upland vegetation**	0.4- 1.0	0.62 ± 0.185

Table 5. Correlation coefficients (*r*) showing correlations between assessment methods studied in this paper. Value in bold has a p-value of less than or equal to 0.0083, with Bonferroni correction.

	Habitat Assessment Technique (HAT)	*Rocky Mountain Hydrogeomorphic (HGM)*	*Reference Wetlands*	*Southern California Riparian Model*
Habitat Assessment Technique (HAT)	1.00			
Rocky Mountain Hydrogeomorphic (HGM)	0.02	1.00		
Reference Wetlands	0.23	0.10	1.00	
Southern California Riparian Model	-0.06	-0.02	**0.46**	1.00

Table 6. Correlation coefficients (*r*) between the numbers of riparian associated bird species with the site scores and riparian associated butterfly species with the site scores using the Habitat Assessment Technique (HAT), Rocky Mountain Riparian Hydrogeomorphic (HGM), Reference Wetland, and Southern California Riparian Model methods for 47 riparian sites in the Sacramento Valley, California. Values in bold have a p-value of less than or equal to 0.05, without Bonferroni correction. With Bonferroni correction ($p < 0.00625$) there were no statistically significant correlations in this table.

	Number of Riparian Associated Bird Species	**Number of Riparian Associated Butterfly Species**
HAT scores	**0.37**	0.24
Rocky Mt. HGM scores	-0.15	0.10
Reference Wetland scores	0.27	**0.38**
Southern California Riparian Model scores	0.03	0.04

Figure 1. Scatter plot of assessment scores calculated using the Habitat Assessment Technique (HAT) and the Rocky Mountain Riparian HGM methods for 47 riparian sites in the Sacramento Valley, California ($r = 0.20$).

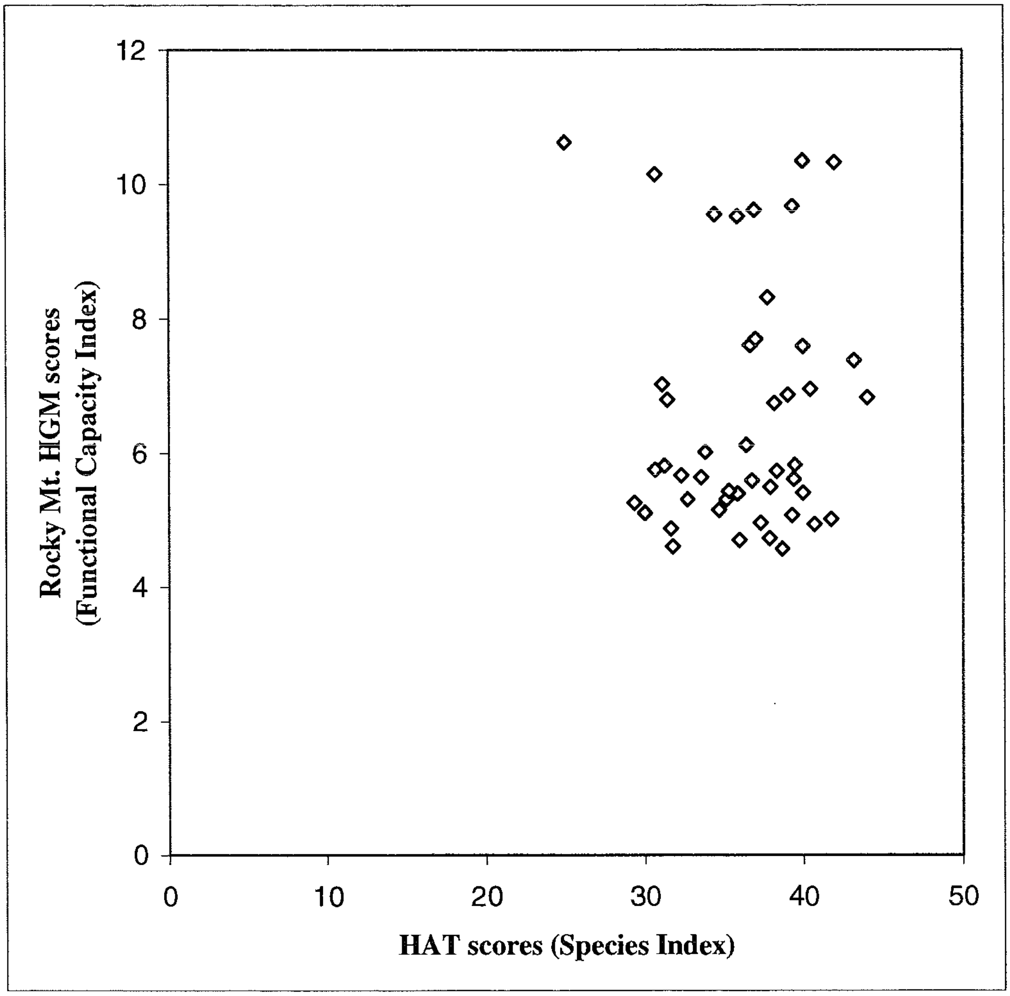

Figure 2. Scatter plot of assessment scores calculated using the Habitat Assessment Technique (HAT) and the Southern California Riparian Model for 47 riparian sites in the Sacramento Valley, California (r = -0.06).

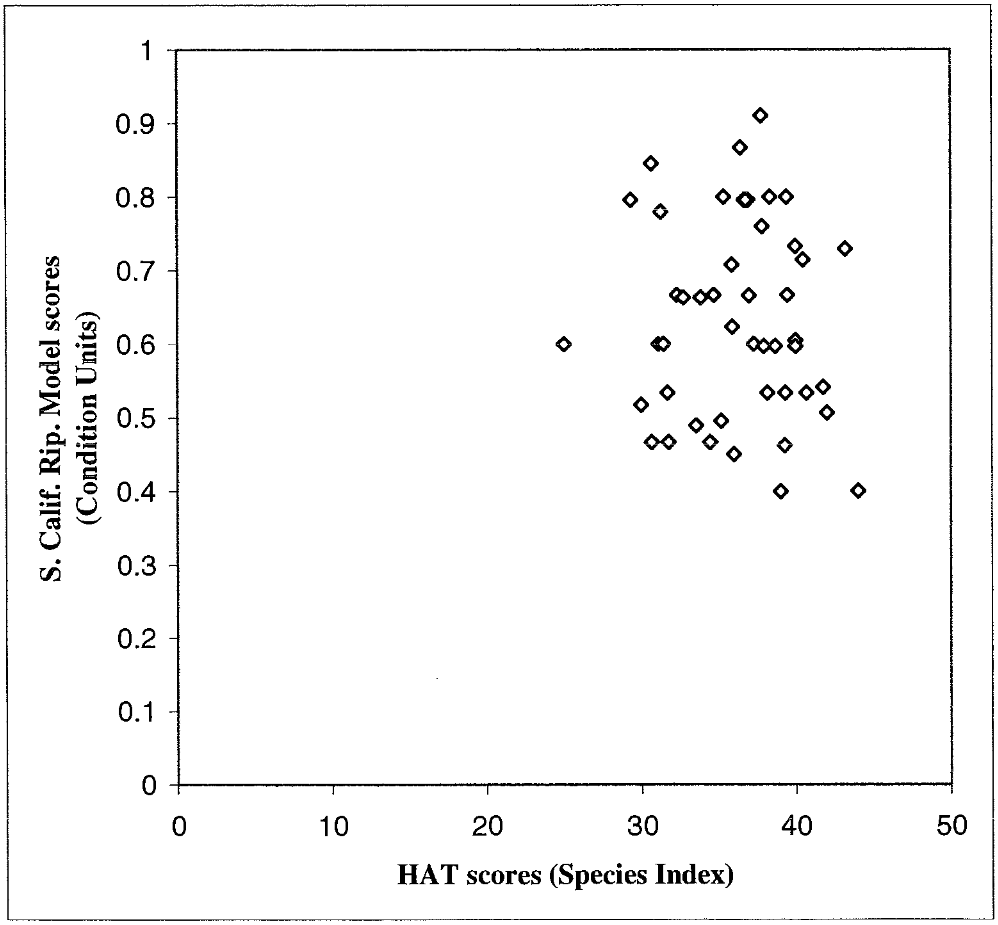

Figure 3. Scatter plot of assessment scores calculated using the Rocky Mountain Riparian HGM method and the Southern California Riparian Model for 47 riparian sites in the Sacramento Valley, California (*r* = -0.02).

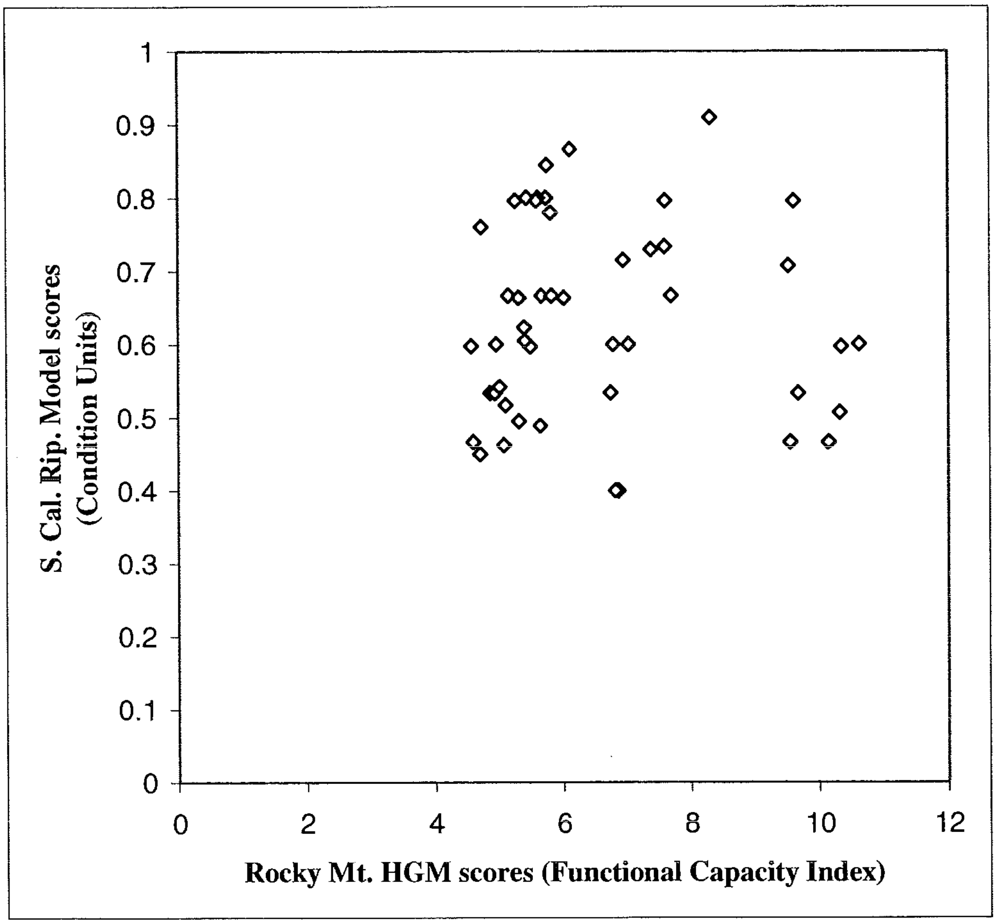

Figure 4. Scatter plot of assessment scores calculated using the Habitat Assessment Technique (HAT) and the Reference Wetland methods for 47 riparian sites in the Sacramento Valley, California ($r = 0.23$). For the Reference Wetland assessment method, Spears Ranch (1) was used as the reference site.

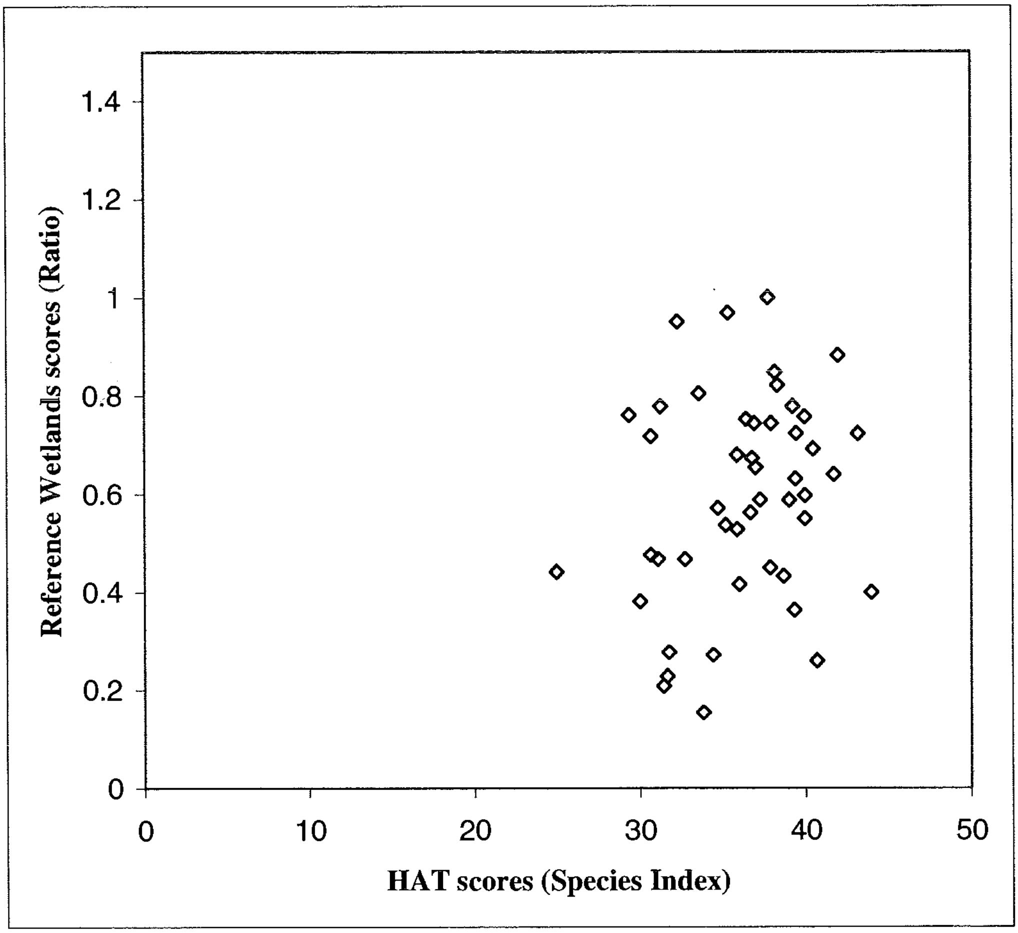

Figure 5. Scatter plot of assessment scores calculated using the Rocky Mountain Riparian HGM and the Reference Wetland methods for 47 riparian sites in the Sacramento Valley, California ($r = 0.10$). For the Reference Wetland assessment method, Spears Ranch (1) was used as the reference site.

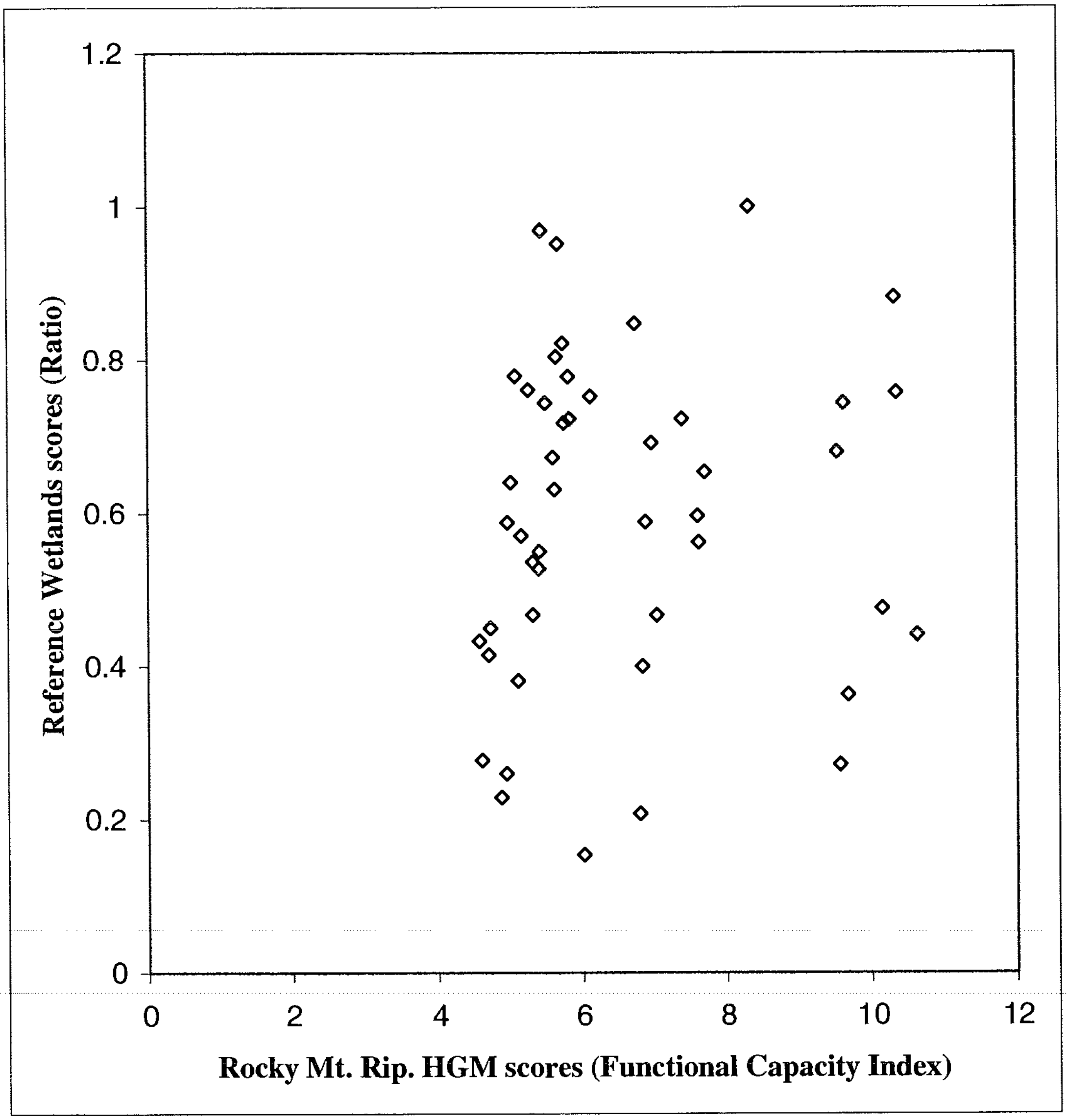

Figure 6. Scatter plot of assessment scores calculated using the Reference Wetland and Southern California Riparian Model methods for 47 riparian sites in the Sacramento Valley, California ($r = 0.46$). For the Reference Wetland assessment method, Spears Ranch (1) was used as the reference site.

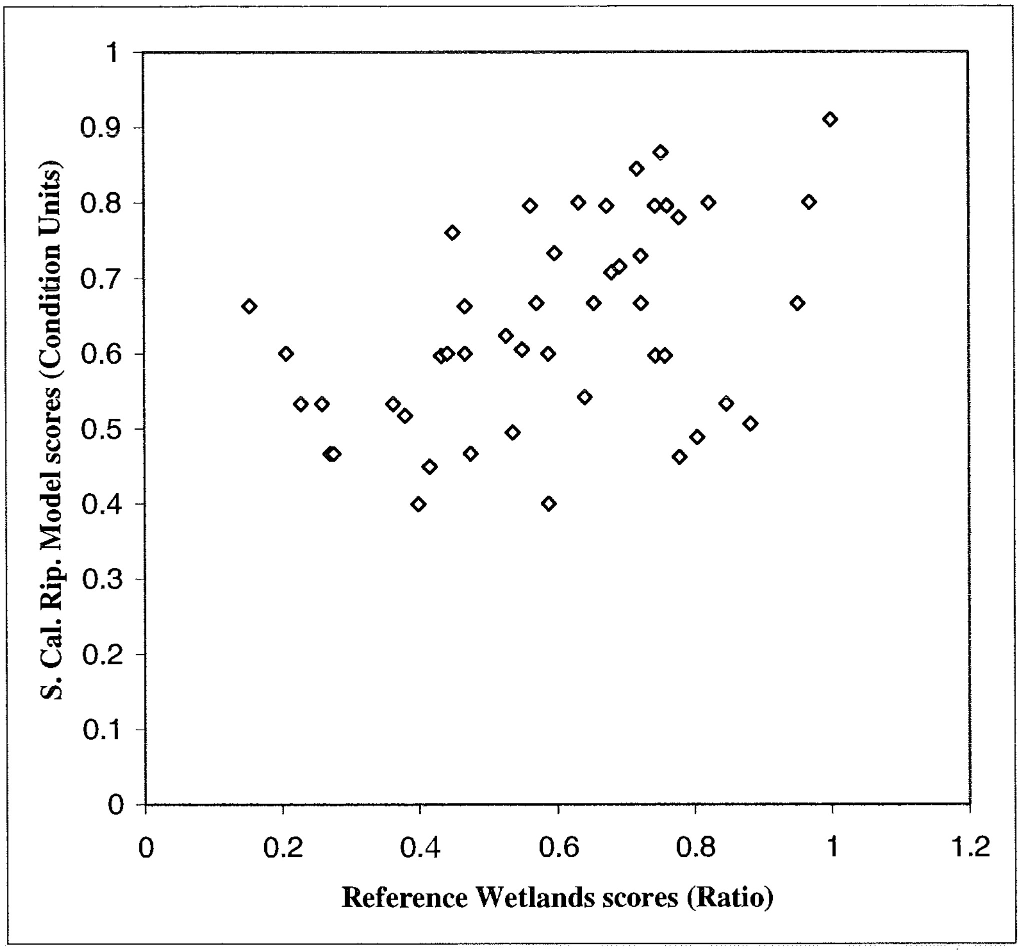

Figure 7. Photograph of Clear Creek Plot 3. This plot was used as a reference site and is one of the least altered sites included in this study. The average width of riparian vegetation for this site is 53 m and the distance to the nearest road is 200 m.

Figure 8. Photograph of Old Mill Creek Plot 10. The average width of riparian vegetation for this plot is 25 m and the distance to the nearest road is 100 m.

Figure 9. Photograph of Roseville Plot 6. This is one of the most altered sites in the study. Its average width of riparian vegetation is 1.7 m, and a road is present in the plot area.

Figure 10. Photograph of Spears Ranch Plot 1. This plot was used as a reference site and is one of the least altered sites included in this study. The average width of riparian vegetation for this site is 32 m and the distance to the nearest road is 300 m.

Figure 11. Photograph of Turkey Creek Plot 1. The average width of riparian vegetation for this plot is 43 m, and this plot has a golf cart path that runs through its non-riparian portion.

Figure 12. Photograph of Valensin Ranch Plot 1. This plot was used as a reference site and is one of the least altered sites included in this study. The average width of riparian vegetation for this site is 200 m and the distance to the nearest road is 600 m.

Appendix A. Correlation coefficients (*r*) between the variables used in the assessment methods. Values in bold have a p-value of less than or equal to 0.00032, with Bonferroni correction. Note that values of 1.00 represent either the variables the correlation of a variable with another variable that was calculated using the same, or a closely related, set of data. (For definition and calculation of these functional assessment variables, see the text of the methods section.)

	Total Sp Pts	***# wetl dep bird spp***	***VHERB***	***VSHRUB***	***VDTREE***	***VNPCOV***	***VSURFREQ***	***VMACRO***	***VCOMPLEX***	***I***	***SP***	***ST***	***CNT***	***VCVEG***	***VSVEG***	***VGRAM+VFORB (VHERB)***
Total Sp Pts	1.00															
# wetl dep bird spp	**0.98**	1.00														
VHERB	0.10	0.08	1.00													
VSHRUB	-0.19	-0.20	-0.39	1.00												
VDTREE	0.21	0.19	-0.01	0.38	1.00											
VNPCOV	-0.07	-0.04	-0.02	-0.10	-0.03	1.00										
VSURFREQ	-0.17	-0.22	-0.01	0.07	-0.11	0.15	1.00									
VMACRO	-0.06	-0.06	-0.03	-0.04	-0.03	0.06	-0.15	1.00								
VCOMPLEX	-0.01	0.02	-0.08	-0.08	0.23	-0.13	0.05	0.22	1.00							
I	0.07	0.04	0.02	0.10	0.03	**-1.00**	-0.15	-0.06	0.13	1.00						
SP	-0.05	-0.05	-0.31	**0.72**	0.64	-0.09	-0.15	0.04	-0.05	0.09	1.00					
ST	0.13	0.14	-0.08	0.52	0.57	-0.16	-0.25	0.14	0.20	0.16	0.62	1.00				
CNT	-0.06	-0.06	-0.03	-0.04	-0.03	0.06	-0.15	**1.00**	0.22	-0.06	0.04	0.14	1.00			
VCVEG	0.21	0.19	-0.01	0.38	**1.00**	-0.03	-0.11	-0.03	0.23	0.03	0.64	0.57	-0.03	1.00		
VSVEG	-0.19	-0.20	-0.39	**1.00**	0.38	-0.10	0.07	-0.04	-0.08	0.10	**0.72**	0.52	-0.04	0.38	1.00	
VGRAM+VFORB (VHERB)	0.10	0.08	**1.00**	-0.39	-0.01	-0.02	-0.01	-0.03	-0.08	0.02	-0.31	-0.08	-0.03	-0.01	-0.39	1.00

Appendix B. Correlation coefficients (*r*) between biological and physical variables for 47 riparian sites in the Sacramento Valley, California. Values in bold have a p-value of less than or equal to 0.00076, with Bonferroni correction. All Bird Spp = number of bird species in plot; Rip. Assoc. Bird Spp = number of riparian associated bird species in plot; All Butterfly Species = number of butterfly species in plot; Rip. Dep. Butterfly Species = number of riparian-dependent butterfly species in plot; Mean width = mean width of riparian vegetation; Tree = tree cover in plot; Shrub = shrub cover in plot; Rip. Veg. w/in 250 m = area of riparian vegetation within 250 m of plot; Nat. Veg. w/in 250 m = natural vegetation within 250 m of plot; Ag. Land within 250 m = area of land used for agriculture within 250 m of plot; Dev. Land w/in 250 m = area of developed land within 250 m of plot; Nearest Road = distance to nearest road.

	All Bird Spp	***Rip Assoc Bird Spp***	***All Butterfly Species***	***Rip Dep Butterfly Species***	***Mean width***	***Tree***	***Shrub***	***Rip Veg w/in 250 m***	***Nat Veg w/in 250m***	***Ag land w/in 250m***	***Dev Land w/in 250 m***	***Nearest Road***
All Bird Spp	1.00											
Rip Assoc Bird Spp	**0.91**	1.00										
All Butterfly Species	-0.01	0.10	1.00									
Rip Dep Butterfly Species	0.05	0.16	0.60	1.00								
Mean width	0.20	0.22	-0.37	-0.20	1.00							
Tree	0.26	0.29	0.13	0.31	0.37	1.00						
Shrub	0.08	0.09	-0.01	0.29	0.05	0.38	1.00					
Rip Veg w/in 250 m	0.16	0.31	0.01	0.16	0.29	0.06	-0.15	1.00				
Nat Veg w/in 250m	0.03	0.06	0.37	0.09	0.12	0.06	-0.06	-0.12	1.00			
Ag land w/in 250m	0.03	0.01	-0.21	-0.06	-0.02	0.01	-0.11	0.21	**-0.61**	1.00		
Dev Land w/in 250 m	-0.07	-0.08	-0.23	-0.04	-0.12	-0.09	0.18	-0.06	**-0.60**	-0.27	1.00	
Nearest Road	-0.32	-0.23	0.02	-0.11	-0.01	-0.13	0.04	-0.11	0.11	-0.15	0.01	1.00

Appendix C. Habitat Assessment Technique (HAT) site scores and ranks for 47 riparian sites in the Sacramento Valley, California.

Site (Plot number)	**Species Index**	**Rank**
Aitken Ranch (1)	34.71	32
Aitken Ranch (2)	31.67	39
Aitken Ranch (3)	40.71	5
Alves (1)	38.18	17
Big Oak Trail (1)	36.67	25
City of Lincoln SE (2)	36.00	27
Clear Creek (3)	37.86	19
Clear Creek/Project Area (10)	41.76	4
Deer Creek (1)	35.19	31
Deer Creek (6)	30.00	45
Deer Creek (9)	39.05	14
Deer Creek (12)	31.25	41
Deer Creek (19)	35.88	28
Dye Creek (10)	39.33	12
Dye Creek (22)	38.67	15
Dye Creek (25)	36.92	23
Dye Creek (27)	29.38	46
Dye Creek (29)	38.33	16
Mehalakis Ranch (1)	34.44	33
Mehalakis Ranch (2)	44.05	1
Meiss Road (1)	40.48	6
Mill Creek (2)	30.67	43
Mill Creek (10)	33.85	34
Mill Creek (15)	36.43	26
Miner's Ravine (1)	37.30	21
Miner's Ravine (2)	35.33	30
Morgan Creek (1)	37.94	18
Morgan Creek (2)	32.31	37
Old Mill Creek (10)	40.00	7
Putah Creek (2)	39.29	13
Putah Creek (5)	33.57	35
Putnam Road (2)	31.76	38
Roseville (1)	39.41	11
Roseville (3)	31.11	42
Roseville (4)	35.88	28
Roseville (6)	31.43	40
Roseville (7)	30.67	43
Sierra College (1)	37.00	22
Sierra College (2)	39.47	10
Spears Ranch (1)	37.78	20
Spears Ranch (2)	43.23	2
Spears Ranch (7)	40.00	7
Thomes Creek (5)	32.73	36
Thomes Creek (15)	25.00	47
Turkey Creek (1)	42.00	3
Turkey Creek (2)	40.00	7
Valensin Ranch (1)	36.79	24

Appendix D. Rocky Mountain Riparian HGM (Hydrogeomorphic) assessment method site scores and ranks for 47 riparian sites in the Sacramento Valley, California. Scores are the Functional Capacity Indexes (FCI) for Characteristic Vertebrate Habitat.

Site (Plot number)	**Hauer HGM FCI Char. Vert. Hab.**	**FCI rank**
Aitken Ranch (1)	5.16	37
Aitken Ranch (2)	4.87	43
Aitken Ranch (3)	4.94	42
Alves (1)	6.74	19
Big Oak Trail (1)	7.61	11
City of Lincoln SE (2)	4.71	45
Clear Creek (3)	4.73	44
Clear Creek/Project Area (10)	5.01	40
Deer Creek (1)	5.31	34
Deer Creek (6)	5.11	38
Deer Creek (9)	6.87	16
Deer Creek (12)	5.81	23
Deer Creek (19)	5.40	33
Dye Creek (10)	9.68	5
Dye Creek (22)	4.58	47
Dye Creek (25)	9.62	6
Dye Creek (27)	5.26	36
Dye Creek (29)	5.74	25
Mehalakis (1)	9.55	7
Mehalakis (2)	6.83	17
Meiss Road (1)	6.96	15
Mill Creek (2)	5.75	24
Mill Creek (10)	6.02	21
Mill Creek (15)	6.12	20
Miner's Ravine (1)	4.96	41
Miner's Ravine (2)	5.44	31
Morgan Creek (1)	5.49	30
Morgan Creek (2)	5.67	26
Old Mill Creek (10)	5.41	32
Putah Creek (2)	5.08	39
Putah Creek (5)	5.64	27
Putnam Road (2)	4.60	46
Roseville (1)	5.61	28
Roseville (3)	7.03	14
Roseville (4)	9.53	8
Roseville (6)	6.79	18
Roseville (7)	10.15	4
Sierra College (1)	7.70	10
Sierra College (2)	5.83	22
Spears Ranch (1)	8.32	9
Spears Ranch (2)	7.38	13
Spears Ranch (7)	7.60	12
Thomes Creek (5)	5.31	35
Thomes Creek (15)	10.63	1
Turkey Creek (1)	10.33	3
Turkey Creek (2)	10.35	2
Valensin Ranch (1)	5.59	29

Appendix E. Southern California Riparian Model site scores and ranks for 47 riparian sites in the Sacramento Valley, California.

Site (Plot number)	**SCORES (Condition units)**	**Rank**
Aitken Ranch (1)	0.67	17
Aitken Ranch (2)	0.53	33
Aitken Ranch (3)	0.53	33
Alves (1)	0.53	33
Big Oak Trail (1)	0.80	7
City of Lincoln SE (2)	0.45	45
Clear Creek (3)	0.76	12
Clear Creek/Project Area (10)	0.54	32
Deer Creek (1)	0.50	39
Deer Creek (6)	0.52	37
Deer Creek (9)	0.40	47
Deer Creek (12)	0.78	11
Deer Creek (19)	0.62	23
Dye Creek (10)	0.53	33
Dye Creek (22)	0.60	31
Dye Creek (25)	0.80	7
Dye Creek (27)	0.80	7
Dye Creek (29)	0.80	4
Mehalakis (1)	0.47	41
Mehalakis (2)	0.40	46
Meiss Road (1)	0.72	15
Mill Creek (2)	0.85	3
Mill Creek (10)	0.66	21
Mill Creek (15)	0.87	2
Miner's Ravine (1)	0.60	25
Miner's Ravine (2)	0.80	4
Morgan Creek (1)	0.60	29
Morgan Creek (2)	0.67	17
Old Mill Creek (10)	0.61	24
Putah Creek (2)	0.46	44
Putah Creek (5)	0.49	40
Putnam Road (2)	0.47	41
Roseville (1)	0.80	4
Roseville (3)	0.60	26
Roseville (4)	0.71	16
Roseville (6)	0.60	26
Roseville (7)	0.47	41
Sierra College (1)	0.67	17
Sierra College (2)	0.67	17
Spears Ranch (1)	0.91	1
Spears Ranch (2)	0.73	14
Spears Ranch (7)	0.73	13
Thomes Creek (5)	0.66	21
Thomes Creek (15)	0.60	26
Turkey Creek (1)	0.51	38
Turkey Creek (2)	0.60	29
Valensin Ranch (1)	0.80	10

Appendix F. Reference Wetlands assessment method site scores for 47 riparian plots in the Sacramento Valley, California, based on various reference sites. Ranks are based on the score calculated using Spears Ranch (1) as the reference site, though the rankings would remain unchanged using any of the other reference sites.

Index of Function					
Site (Plot number)	**Spears Ranch (1) as reference site**	**Clear Creek (3) as reference site**	**Valensin Ranch as reference site**	**Average of three sites as reference site**	**Rank**
Aitken Ranch (1)	0.57	1.27	0.85	0.76	27
Aitken Ranch (2)	0.23	0.51	0.34	0.30	45
Aitken Ranch (3)	0.26	0.58	0.39	0.35	44
Alves (1)	0.85	1.88	1.26	1.13	5
Big Oak Trail (1)	0.56	1.25	0.84	0.75	28
City of Lincoln SE (2)	0.42	0.92	0.62	0.55	38
Clear Creek (3)	0.45	1.00	0.67	0.60	35
Clear Creek/Project Area (10)	0.64	1.42	0.95	0.85	22
Deer Creek (1)	0.54	1.19	0.80	0.71	30
Deer Creek (6)	0.38	0.85	0.57	0.51	40
Deer Creek (9)	0.59	1.31	0.87	0.78	25
Deer Creek (12)	0.78	1.73	1.16	1.04	8
Deer Creek (19)	0.53	1.17	0.78	0.70	31
Dye Creek (10)	0.36	0.81	0.54	0.48	41
Dye Creek (22)	0.43	0.96	0.64	0.58	37
Dye Creek (25)	0.74	1.65	1.11	0.99	14
Dye Creek (27)	0.76	1.69	1.13	1.01	10
Dye Creek (29)	0.82	1.83	1.22	1.09	6
Mehalakis (1)	0.27	0.60	0.40	0.36	43
Mehalakis (2)	0.40	0.89	0.59	0.53	39
Meiss Road (1)	0.69	1.54	1.03	0.92	18
Mill Creek (2)	0.72	1.60	1.07	0.96	17
Mill Creek (10)	0.15	0.34	0.23	0.20	47
Mill Creek (15)	0.75	1.67	1.12	1.00	12
Miner's Ravine (1)	0.59	1.31	0.87	0.78	25
Miner's Ravine (2)	0.97	2.15	1.44	1.29	2
Morgan Creek (1)	0.74	1.65	1.11	0.99	13
Morgan Creek (2)	0.95	2.12	1.41	1.27	3
Old Mill Creek (10)	0.55	1.22	0.82	0.73	29
Putah Creek (2)	0.78	1.73	1.16	1.04	8
Putah Creek (5)	0.80	1.79	1.20	1.07	7
Putnam Road (2)	0.28	0.62	0.41	0.37	42
Roseville (1)	0.63	1.40	0.94	0.84	23
Roseville (3)	0.47	1.04	0.69	0.62	33
Roseville (4)	0.68	1.51	1.01	0.90	19
Roseville (6)	0.21	0.46	0.31	0.28	46
Roseville (7)	0.48	1.06	0.71	0.63	32
Sierra College (1)	0.65	1.45	0.97	0.87	21
Sierra College (2)	0.72	1.61	1.07	0.96	15
Spears Ranch (1)	1.00	2.22	1.49	1.33	1
Spears Ranch (2)	0.72	1.61	1.07	0.96	15
Spears Ranch (7)	0.60	1.33	0.89	0.79	24
Thomes Creek (5)	0.47	1.04	0.69	0.62	33
Thomes Creek (15)	0.44	0.98	0.66	0.59	36
Turkey Creek (1)	0.88	1.96	1.31	1.17	4
Turkey Creek (2)	0.76	1.68	1.13	1.01	11
Valensin Ranch (1)	0.67	1.50	1.00	0.90	20

Appendix G. Site scores and rankings from the Reference Wetlands assessment method based on various reference sites and a value of 1 as the maximum site score.

	Indexes of Function				
Site (Plot number)	**Spears Ranch (1) as reference site**	**Clear Creek (3) as reference site**	**Valensin Ranch (1) as reference site**	**Composite site as reference site**	**Rank**
Aitken Ranch (1)	0.57	1.00	0.85	0.76	27
Aitken Ranch (2)	0.23	0.51	0.34	0.30	45
Aitken Ranch (3)	0.26	0.58	0.39	0.35	44
Alves (1)	0.85	1.00	1.00	1.00	5
Big Oak Trail (1)	0.56	1.00	0.84	0.75	28
City of Lincoln SE (2)	0.42	0.92	0.62	0.55	38
Clear Creek (3)	0.45	1.00	0.67	0.60	35
Clear Creek/Project Area (10)	0.64	1.00	0.95	0.85	22
Deer Creek (1)	0.54	1.00	0.80	0.71	30
Deer Creek (6)	0.38	0.85	0.57	0.51	40
Deer Creek (9)	0.59	1.00	0.87	0.78	25
Deer Creek (12)	0.78	1.00	1.00	1.00	8
Deer Creek (19)	0.53	1.00	0.78	0.70	31
Dye Creek (10)	0.36	0.81	0.54	0.48	41
Dye Creek (22)	0.43	0.96	0.64	0.58	37
Dye Creek (25)	0.74	1.00	1.00	0.99	14
Dye Creek (27)	0.76	1.00	1.00	1.00	10
Dye Creek (29)	0.82	1.00	1.00	1.00	6
Mehalakis (1)	0.27	0.60	0.40	0.36	43
Mehalakis (2)	0.40	0.89	0.59	0.53	39
Meiss Road (1)	0.69	1.00	1.00	0.92	18
Mill Creek (2)	0.72	1.00	1.00	0.96	17
Mill Creek (10)	0.15	0.34	0.23	0.20	47
Mill Creek (15)	0.75	1.00	1.00	1.00	12
Miner's Ravine (1)	0.59	1.00	0.87	0.78	25
Miner's Ravine (2)	0.97	1.00	1.00	1.00	2
Morgan Creek (1)	0.74	1.00	1.00	0.99	13
Morgan Creek (2)	0.95	1.00	1.00	1.00	3
Old Mill Creek (10)	0.55	1.00	0.82	0.73	29
Putah Creek (2)	0.78	1.00	1.00	1.00	8
Putah Creek (5)	0.80	1.00	1.00	1.00	7
Putnam Road (2)	0.28	0.62	0.41	0.37	42
Roseville (1)	0.63	1.00	0.94	0.84	23
Roseville (3)	0.47	1.00	0.69	0.62	33
Roseville (4)	0.68	1.00	1.00	0.90	19
Roseville (6)	0.21	0.46	0.31	0.28	46
Roseville (7)	0.48	1.00	0.71	0.63	32
Sierra College (1)	0.65	1.00	0.97	0.87	21
Sierra College (2)	0.72	1.00	1.00	0.96	15
Spears Ranch (1)	1.00	1.00	1.00	1.00	1
Spears Ranch (2)	0.72	1.00	1.00	0.96	15
Spears Ranch (7)	0.60	1.00	0.89	0.79	24
Thomes Creek (5)	0.47	1.00	0.69	0.62	33
Thomes Creek (15)	0.44	0.98	0.66	0.59	36
Turkey Creek (1)	0.88	1.00	1.00	1.00	4
Turkey Creek (2)	0.76	1.00	1.00	1.00	11
Valensin Ranch (1)	0.67	1.00	1.00	0.90	20

Appendix H. Rankings of the 47 riparian sites in the Sacramento Valley, California based on four functional assessment methods.

Rankings				
Site (Plot number)	HAT	Rocky Mt. Riparian HGM	Southern California Riparian Model	Reference Wetlands
Aitken Ranch (1)	32	37	17	27
Aitken Ranch (2)	39	43	33	45
Aitken Ranch (3)	5	42	33	44
Alves (1)	17	19	33	5
Big Oak Trail (1)	25	11	7	28
City of Lincoln SE (2)	27	45	45	38
Clear Creek (3)	19	44	12	35
Clear Creek/Project Area (10)	4	40	32	22
Deer Creek (1)	31	34	39	30
Deer Creek (6)	45	38	37	40
Deer Creek (9)	14	16	47	25
Deer Creek (12)	41	23	11	8
Deer Creek (19)	28	33	23	31
Dye Creek (10)	12	5	33	41
Dye Creek (22)	15	47	31	37
Dye Creek (25)	23	6	7	14
Dye Creek (27)	46	36	7	10
Dye Creek (29)	16	25	4	6
Mehalakis (1)	33	7	41	43
Mehalakis (2)	1	17	46	39
Meiss Road (1)	6	15	15	18
Mill Creek (2)	43	24	3	17
Mill Creek (10)	34	21	21	47
Mill Creek (15)	26	20	2	12
Miner's Ravine (1)	21	41	25	25
Miner's Ravine (2)	30	31	4	2
Morgan Creek (1)	18	30	29	13
Morgan Creek (2)	37	26	17	3
Old Mill Creek (10)	7	32	24	29
Putah Creek (2)	13	39	44	8
Putah Creek (5)	35	27	40	7
Putnam Road (2)	38	46	41	42
Roseville (1)	11	28	4	23
Roseville (3)	42	14	26	33
Roseville (4)	28	8	16	19
Roseville (6)	40	18	26	46
Roseville (7)	43	4	41	32
Sierra College (1)	22	10	17	21
Sierra College (2)	10	22	17	15
Spears Ranch (1)	20	9	1	1
Spears Ranch (2)	2	13	14	15
Spears Ranch (7)	7	12	13	24
Thomes Creek (5)	36	35	21	33
Thomes Creek (15)	47	1	26	36
Turkey Creek (1)	3	3	38	4
Turkey Creek (2)	7	2	29	11

Appendix I. List of riparian-associated bird species observed in one or more of the 47 riparian sites in the Sacramento Valley, California.

Common name	Latin name
American Goldfinch	*Carduelis tristis*
Black Chinned Hummingbird	*Archilochus alexandri*
Black Headed Grosbeak	*Pheucticus melanocephalus*
Blue Grosbeak	*Guiraca caerulea*
Brewer's Blackbird	*Euphagus cyanocephalus*
Common Yellow-Throat	*Geothlypis trichas*
Cooper's Hawk	*Accipiter cooperii*
Downy Woodpecker	*Picoides pubescens*
House Wren	*Troglodytes aedon*
Pacific Slope Flycatcher	*Empidonax difficilis*
Red-shouldered Hawk	*Buteo lineatus*
Song Sparrow	*Melospiza melodia*
Swainson's Hawk	*Buteo swainsoni*
Tree Swallow	*Tachycineta bicolor*
Warbling Vireo	*Vireo gilvus*
Western Wood Pewee	*Contopus sordidulus*
Yellow-breasted Chat	*Icteria virens*
Yellow Warbler	*Dendroica petechia*

Appendix J. List of riparian-associated butterfly species observed in one or more of the 47 riparian sites in the Sacramento Valley, California.

Common Name	Latin Name
Sara Orangetip	*Anthocharis sara*
Pipevine Swallowtail	*Battus philenor*
Lorquin's Admiral	*Limentis lorquini*
Mourning Cloak	*Nymphalis antiopa*
Western Tiger Swallowtail	*Papilio rutulus*
Umber Skipper	*Paratrytone melane*
Satyr Comma	*Polygonia satyrus*
Sylvan Hairstreak	*Satyrium sylvinus*
Red Admiral	*Vanessa atalanta*