A LANDSCAPE APPROACH TO RESERVING FARM PONDS FOR WINTERING BIRD REFUGES IN TAOYUAN, TAIWAN

A Dissertation

by

WEI-TA FANG

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2005

Major Subject: Rangeland Ecology and Management

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ABSTRACT

A Landscape Approach to Reserving Farm Ponds

for Wintering Bird Refuges in Taoyuan, Taiwan. (May 2005)

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Man-made farm ponds are unique geographic features of the Taoyuan Tableland. Besides irrigation, they provide refuges for wintering birds. The issue at hand is that these features are disappearing and bring with it the loss of this refuge function. It is ecologically significant because one fifth of all the bird species in Taiwan find a home on these ponds. This study aims at characterizing the diversity of bird species associated with these ponds whose likelihood of survival was assessed along the gradient of land development intensities. Such characterization helps establish decision criteria needed for designating certain ponds for habitat preservation and developing their protection strategies.

A holistic model was developed by incorporating logistic regression with error back-propagation into the paradigm of artificial neural networks (ANN). The model considers pond shape, size, neighboring farmlands, and developed areas in calculating parameters pertaining to their respective and interactive influences on avian diversity, among them the Shannon-Wiener diversity index (H'). Results indicate that ponds with regular shape or the ones with larger size possess a strong positive correlation with H'.

Farm ponds adjacent to farmland benefited waterside bird diversity. On the other hand, urban development was shown to cause the reduction of farmland and pond numbers, which in turn reduced waterside bird diversity. By running the ANN model with four neurons, the resulting *H'* index shows a good-fit prediction of bird diversity against pond size, shape, neighboring farmlands, and neighboring developed areas with a correlation coefficient (*r)* of 0.72, in contrast to the results from a linear regression model ($r < 0.28$).

Analysis of historical pond occurrence to the present showed that ponds with larger size and a long perimeter were less likely to disappear. Smaller (< 0.1 ha) and more curvilinear ponds had a more drastic rate of disappearance. Based on this finding, a logistic regression was constructed to predict pond-loss likelihood in the future and to help identify ponds that should be protected. Overlaying results from ANN and form logistic regression enabled the creation of pond-diversity maps for these simulated scenarios of development intensities with respective to pond-loss trends and the corresponding dynamics of bird diversity.

DEDICATION

For my parents

General Fang, Hsun-Chih and Madam General Fang Huang, Su-Mei

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ACRONYMS

AGENCIES

COA	Council of Agriculture, Executive Yuan, Government of the Republic of China
EPA	Environmental Protection Administration, Executive Yuan, Government of the Republic of China
ROC	Republic of China (Taiwan)
WRA	Water Resource Agency, Ministry of Economic Affairs, Government of the Republic of China
WTO	World Trade Organization

TERMS

α	Alpha
ANN	Artificial neural network
BP	Back-propagation
CON	Consolidated areas
D-C	Distance to coastline
D-U	Distance to urban limit
d.f.	Degree of freedom
ED	Edge density of selected ponds
exp	Exponential
FCA	Foliage canopy area next to waterfront edge of a pond
FEA	Factor elimination approach
ha	Hectares
H'	Shannon-Wiener diversity index

km^2	Square kilometers
LPI	Largest pond index
mi^2	Square of miles
MLR	Multiple linear regression
MPFD	Mean pond fractal dimension
MUDA	Mudflat area in a pond
MPS	Mean pond size
MSI	Mean shape index
NP	Number of ponds
PS	Pond size
TE	Total parameters of selected pond edge
UCON	Non-consolidated areas
WASA	Water surface area in a pond
%BUILD	The ratio of permanent building areas within a radius of 100 ha from the pond's geometric center
%FARM	The ratio of farmland areas within a radius of 100 ha from the pond's geometric center
%PONDS	The ratio of multiple pond areas within a radius of 100 ha from the pond's geometric center
%RIVER	The ratio of all watercourse areas covered by rivers, creeks, channels, and ditches within a radius of 100 ha from the pond's geometric center
%ROAD	The ratio of all road and trail areas within a radius of 100 ha from the pond's geometric center

DEFINITIONS

Avian community	All of the birds in an area or volume; a complex bird association or group that occupies a common environment. (Source: ANDY)
Avifauna	All the birds in a particular region. (Source: CED)
Bank	The sloping side of any hollow of farm pond in the ground. (Source: CED)
Behavior pattern	A relatively uniform series of overt activities that can be observed with some regularity. (Source: DUNSTE)
Biodiversity	(1) Genetic diversity: the variation between individuals and between populations within a species; species diversity: the different types of plants, animals and other life forms within a region; community or ecosystem diversity: the variety of habitats found within an area (grassland, marsh, and woodland for instance). (2) An umbrella term to describe collectively the variety and variability of nature. It encompasses three basic levels of organization in living commonly recognized units of biological diversity, thus public concern has been mainly devoted to conserving species diversity. (Source: WRES/GIL96)
Biological indicator	A species or organism that is used to grade environmental quality or change. (Source: ALL)
Biotic factor	The influence upon the environment of organisms owning to the presence and activities of other organisms, as distinct from a physical, abiotic, and environmental factor. (Source: ALL2)
Biotope	A region of relatively uniform environmental conditions, occupied by a given plant community and its associated animal community. (Source: PAENS)
Border	The dividing line or frontier between geographic regions. (Source: CED)
Constructed area (Area with structures)	Land and other places on, under, in or through which the temporary and permanent works are to be executed and any other lands or places needed for the purposes of construction (Source: LEE).

Coordinate system	A reference system used to measure horizontal and vertical distance on a planimetric map. A coordinate system is usually defined by a map projection, a datum, a central meridian, and possible shifts in the x- and y-directions to locate x, y positions of point, line, and area features (Source: ESRI).
Core area	The central area of a refuge or of a reserve where there can be little interference with natural ecosystem.
Ditch	A long, narrow excavation artificially dug in a ground; especially an open and usually unpaved waterway, channel, or trench for conveying water for drainage or irrigation, and usually smaller than a canal. Some ditches may be natural watercourses. (Source: BJGEC)
Ecological assessment	Ecological assessment consists in monitoring the current and changing conditions of ecological resources from which success or failure of the ecosystem can be judged without bias; understanding more fully the structure and function of ecosystems in order to develop improved management options; developing models to predict the response of ecosystems to changes resulting from human introduced stress from which possible ecosystem management actions so that decision makers can best understand the outcomes of choosing a particular management a strategy.
Foliage	The green leaves of a plant. (Source: CED)
GIS digital technique	A transformation to digital form of data collected by traditional field and documentary methods and of existing historical data such as paper maps, charts, and publications. (Source: YOUNG)
Hedgerow	A line of closely planted trees, bushes, or shrubs, making the boundaries of a field, or a pond. (Source: GOOD)
Human settlement	Cities, towns, villages, and other concentrations of human populations which inhabit a given segment or area of the environment. (Source: NUN)
In-site	In the natural or normal place. (Source: OREN)
Island	A landmass, especially one smaller than a continent, entirely surrounded by water. (Source: AMHER)

Landscape	The traits, patterns, and structure of a specific geographic area, including its biological composition, its physical environment, and its anthropogenic or social patterns. An area where interacting ecosystems are grouped and repeated in similar form. (Source: EPAGLO)
Modeling	An investigative technique using a mathematical or physical representation of a system or theory that accounts for all or some known properties. Models are often used to test the effect of changes of system components on the overall performance of the system. (Source: LEE)
Mudflat	A relatively level area of fine silt covered by shallow water. (Source: BJGEO)
Pondscape	The countryside characteristic of Taoyuan Tableland, with irregular-shaped farm ponds and many hedges and copses. The word "pondscape" refers both to the pond itself and to a landscape consisting of hedges and croplands. Being a small-scale, enclosed landscape, the pondscape offers many variations in biotopes, with habitats for birds, small mammals, amphibians, reptiles, and fish.
Shrublands	The land covered by woody vegetation including shrubs and scrub trees of non-commercial height and form, often seen in the initial stages of succession following a disturbance. Shrub often grows in very dense thickets that are impenetrable to wild animals and serve to suppress the growth of more desirable crop trees. However, shrublands can also serve an important function as desirable habitat for a range of bird, animal, and invertebrate species. (Source: DUNSTE)

SOURCES: General Multilingual Environmental Treasures (GEMET), Taiwan EPA 2005.

CHAPTER I

INTRODUCTION

Farm ponds, or *pi-tang* in Chinese, are defined as an artificial construction made to impound water by constructing a dam or an embankment, or by excavating a pit or dugout (Horton 2000). These small artificial ponds contain many organisms. Usually, attention has focused on the large numbers of birds that use pond fields. Compared to natural ecosystems, farm ponds located within agro-ecosystems have high bird densities. As nutrients from fertilizers applied on agricultural croplands and from residential areas run off into the farm ponds, they nurture numerous types of plankton, which support a variety of fish, shrimp, mollusks, and benthos (Lin 1996). These species attract many wetland birds to feed and nest, making farm-pond areas one of the most productive ecosystems. In some cases, ecologists have studied and declared that rice fields next to ponds provide good avian habitats (Tourenq et al. 2001). Ponds associated with rice fields have often been recognized as being productive and biologically rich areas. These fields provide suitable refuges for birds during wintering migration across the land (Musacchio and Coulson 2001).

PROBLEM STATEMENT

The issue at hand is that these farm ponds are disappearing and bring with it the loss of bird refuges in Taiwan. The original characteristics of farm ponds have often been destroyed and completely changed by anthropogenic influences for residential, commercial, transportation, and industrial development. These areas, mostly distributed

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This dissertation follows the style and format of Landscape Ecology.

on the plains and table range, are regions of dense human population and flourishing urbanization. Population growth and inappropriate urban development have led to pond disappearances. This has greatly decreased ponds' water storage capacity in the region, ultimately resulting in ecological degradation. This situation suggests that the ecological functioning of these farm ponds will decline when humans utilize, fill, or drain these ponds for socioeconomic purposes. The mildly sloping gradient of the landscape makes this area suitable for economic exploitation, whereas it is fortunate that this area supports a profusion of avian species.

In Taiwan, farm ponds have not been designated as sensitive areas by the current norms because they are not natural. Excluding farm ponds from natural reserves, wildlife refuges, and major wildlife habitats indicates that the specific ecological values of farm-pond ecosystems are currently ignored. In order to protect local biodiversity, farm-pond conservation requires the formulation of concrete and feasible action plans. These areas which obviously serve as avian refuges must be guarded against human disturbances in order to protect valuable species. It is hoped a system will be extended to include ecological patches of interlinked farm ponds, with the aim of fully implementing habitat conservation efforts. The major issue with the formation of avian refuges is understanding how the dynamics of the community assembly, such as ponds and birds, are being altered by anthropogenic influences.

Taoyuan Tableland farm ponds are ecologically significant because one fifth of all the bird species find home on these ponds (Fang 2004a). This tableland, at an area of 757 km^2, comprises an area of 2,898 ha of farm ponds on the northwestern portion of Taiwan. Located approximately 30 km from the capital city of Taipei, this rural area was easy to convert into urban lands due to the aggregated effects of urbanization and commercialization. Socioeconomic benefits are driving public opinion which is urging the government to approve land-use conversion from farmlands into urban uses. Since Taiwan was accepted by the World Trade Organization (WTO) as a member in January 2002, agricultural products such as rice and flour may be imported at relatively lower prices compared with domestic products. Meanwhile, the COA has assumed a policy of "precision agriculture" and is promoting the release of marginal rice fields for conversion into other urban uses. According to farmland release polices, the Water Resource Agency (WRA), Ministry of Economic Affairs is considering a response to reduce the water-supply ratio from a high of 69% of agricultural water to a moderate level of 59% of the total amount of water supplies, and then increasing the amount and ratio of industrial and residential water use in the future. Without farmland irrigation pressures demanding water supplies, the agency predicted that agricultural water uses would drop from 12.4 to 11.8 billion tons/year from 2004 to 2020 (WRA 2004). This would cause farm ponds associated with farmlands rapidly to be converted into urban and industrial developments due to commercial driving forces.

In order to avoid serious chain reactions of pond-losing cases from the farmland-release policy, the Environmental Protection Administration (Taiwan EPA), of the ROC has acknowledged these farm ponds are ecological focal points (EPA 2004). Recent rates of farm-pond losses and the subsequent recognition by the public and Taiwan EPA of the value of winter migratory birds stimulated my research incentives. However, very little documentation was found. None of the avian surveys on a regional scale have been conducted. Some single-plot studies in Taoyuan reported an increase/decrease in individual species but did not tell *how many* ponds were being changed, or *how many* microhabitats and peripheral anthropogenic influences were being added (Lin 1996; Lin 2000a).

This study attempts to investigate bird diversity and its relationship to pond attributes. The results will be useful in ecological planning to solve these aforementioned problems created by anthropogenic driving forces. Hence, the study objective aims at characterizing the diversity of bird species associated with these ponds whose likelihood of survival was assessed along the gradient of land development intensities. Such characterization helps establish decision criteria needed for designating certain ponds for habitat preservation and developing their protection strategies.

RESEARCH QUESTIONS

Regarding farm-pond conversion, wintering bird refuges represent one of the multifunctional perspectives in the restoration of agro-ecosystems. Therefore, an organized survey was conducted for this dissertation to resolve certain issues of area-*per-se* hypothesis (MacArthur and Wilson 1967; Simberloff and Abele 1976; Connor and McCoy 1979). This area-*per-se* hypothesis was also the major factor explaining species diversity in their studies, which were adopted to design water regimes for vernal pools and wetland bird refuges. As the size of a pond increases noted by Simberloff (1976), the likelihood of discovering new creatures increases, thereby increasing its species diversity. In contrast with species-area relationship, Forman (1995) argued that the ecological spatial form was not simply shaped by the effect of area-*per-se*. Some authors inferred that causes of species diversity were affected by habitat heterogeneity. Beyond area, all parameters in pond configuration can be condensed to fall into four categories that address eco-physical identities, such as shape, depth, edge, clustering, and connectivity in a landscape scale (Forman 1995; Linton and Boulder 2000; Leitão and Ahern 2002; Oertli et al. 2002).

In consideration of diversity-area or diversity-habitat relationships, land-use issues are presented. The challenges and opportunities to build wintering avian refuges from farm ponds are as follows.

1. What are the major parameters that have led to the rates of loss of farm ponds by anthropogenic influences? And what are the rates?
2. Does a farm-pond system demonstrate an avian diversity-area relationship? If so, is greater avian diversity found in surveys of larger microhabitat patches selected at random from the ponds?
3. If no avian diversity-area relationship is apparent, are there nevertheless differences in community structure between small and large habitat patches? And, if so, what is driving these differences? Or are there underlying peripheral anthropogenic constraints on areas which can remain as stopover sites?
4. If farm ponds are to be converted into wintering bird refuges, then what are the pond parameters and landscape criteria which should be considered?
5. What are the best landscape scenarios along the gradient of land development intensities for juxtaposing farmland and urban land to protect wintering birds in Taoyuan, Taiwan?

RESEARCH GOALS AND OBJECTIVES

The overall objective of this dissertation was to find a suitable approach to reserving farm ponds for wintering bird refuges in order to improve ecological characteristics at both the landscape and habitat scales. I hypothesized that pond size and shape determine which ponds remain and which disappear. Pond size (i.e., the extent of water regimes, mudflats, and windbreaks) also determines the number of individuals, species richness, and diversity of wintering birds within ponds. Alternative hypotheses are that pond size and shape do not determine which ponds remain and which disappear, and do not determine the number of individuals, species richness, or diversity of winter migratory birds within the ponds. Sub-objectives were used to achieve the overall objective and test the hypotheses and are listed as follows:

1. Develop a logistic regression model to explore the integrated paradigm of internal driving forces (i.e., area, shape, etc.) at mesoscales in Taoyuan, Taiwan; and
2. Carry out correlation analyses to assess wintering bird communities and existing farm ponds juxtaposed against adjacent land uses (i.e., rice fields, construction, transportation, and water regimes) on a small scale in Taoyuan, Taiwan.

If my hypotheses were correct, then the correlations would determine future pond and bird trends as follows:

3. Use the assessment results to develop a simulation model based on the gradients of development intensities (i.e., conservative, moderate, and intensive land uses) according to pond-loss likelihood by size and shape in Taoyuan,

Taiwan;

4. Use the bird survey results to plot an active contour model by forecasting the gradients of hotspots for birds in Taoyuan, Taiwan; and
5. Overlay the two results from (3) and (4), and determine refuge sites with protective priorities to avoid pond and bird losses.

DISSERTATION STRUCTURE

Chapter II documents information about theoretical and empirical studies concerning the concepts of area effects, habitat effects, and anthropogenic disturbances associated with avian communities (i.e., overall species diversity and diversity in guilds). It also presents a proactive positive approach for assessing land uses with respect to regional scale. In order to identify factors that may confound the physical dimensions of pond size, farm-pond trends in historical records are also reported in this chapter.

Chapter III provides the research methods, including digital mapping and models for forecasting the avian communities. Two different survey methods associated with a stratified random sampling method are discussed with respect to their efficiencies at detecting and recording different habitat types of bird communities. An avian survey was conducted on four occasions between November 2003 and February 2004. All bird species were recorded in 45 ponds.

Chapter IV presents the results of comparing historical digital maps. The mapping results from original printed maps of 1904, 1926, 1960, and 1999 as well as a digital map of 2002 are demonstrated and analyzed. Map changes are discussed in terms of the observed pond configurations, which have an important effect upon the dynamics of urban development. A simulation model was developed by incorporating logistic regression to predict pond-loss likelihood between 1926 and 1960.

In Chapter V, results of surveys of the avian communities conducted from November 2003 to February 2004 are presented, and the functional groups and guilds of the detected species are discussed. Numbers of individuals, species richness, and diversity of the avian habitat groups that were detected are compared to determine within-group diversity and within-month diversity. Changes in migrant and resident populations by month are discussed in terms of the observed species compositions, which may have an important effect upon the internal dynamics of the community. In Chapter V, pond area and the associated land were tested to determine whether there is a relationship between pond size and numbers of species and individuals, the richness, and diversity determined by standardized sampling units. Correlation analysis was carried out on the sampled ponds to test for an effect of pond area and adjacent land uses. Patterns at the entire assemblage level may mask or reflect patterns at lower levels of relations within the entire bird community; therefore taxonomic richness within separate taxonomic (i.e., Common Teal *Anas crecca*) and functional groups (i.e., waterfowl) were calculated and correlated against microhabitat areas. In this chapter, multivariate methods were used to investigate differences in community composition along a gradient of pond size. Spatial diversity relationships were plotted to examine distribution patterns across the complex on both the habitat scale and landscape scale by month.

In Chapter VI, final results of the evaluation process of the Artificial Neural Networks (ANN) are presented. Since this study produced sound data on the structure of avian assemblages, it should be seen as a pioneer attempt to develop predictive tools that are urgently required. The overall significant diversity-area relationships were applied to produce predictions of the effect of habitat-patch size on the avian assemblages within them. The respective differences in the way individual species or groups responded to a pond size gradient were considered. In addition, the underlying mechanisms responsible for creating distribution patterns across the pondscape complex are discussed.

In Chapter VII, a holistic model was developed by incorporating logistic regression with error back-propagation into the paradigm of artificial neural networks (ANN). The model considers pond shape, pond size, neighboring farmlands, and developed areas in calculating parameters pertaining to their respective and interactive influences on avian diversity. Overlaying results from ANN and form logistic regression enabled the creation of pond-diversity maps for these simulated scenarios of development intensities with respective to pond-loss trends and the corresponding dynamics of the bird diversity. A model with such capability should be a useful tool in helping prioritizing decisions for pond protection and thus better preserving necessary wintering bird refuges. Finally, conclusions and recommendations for designing bird refuges are made to the Taiwanese government based on these research findings.

SUMMARY

Currently, the Taoyuan Tableland has 2,898 ha of farm ponds, but these have not been managed well because of such activities as deforestation, road paving, and urban development on peripheral farmlands. These activities degrade the ecological integrity of the pond as required by avian species. As a result of the disappearance and dysfunction of these ponds, the ecological quality of the area has been degraded. The purpose of this dissertation was to research interactions of land-use activities and avian communities within farm-pond tablelands. The following chapters, aimed at gathering information, attempt to identify land-use types for developing viable approaches to study tableland issues. All studies concerning land-use effects on farm ponds used quantitative methods to measure correlations among related parameters. To understand the relationships among pondscapes, land uses, and avian communities, 45 farm ponds in Taoyuan's Tablelands were studied.

CHAPTER II

LITERATURE REVIEW

This chapter provides a literature review on the topic of landscape assessments of future designs of avian refuges in farm-pond areas. Specifically this review focuses on general concept of pondscape parameters. In addition, a review of the classification of birds as an indicator to prioritize refuges is provided. Information on theoretical and empirical studies comes from cited literature that connects concepts of the species-area hypothesis, species-habitat hypothesis, anthropogenic influences, avian diversity, avian classification, and simulation models. Additional documentation detailing the Taoyuan Tableland was obtained from the Agricultural and Forestry Aerial Survey Institute, the Wildbird Society of Taoyuan, Taoyuan Irrigation Association, Taoyuan County government, and the central ROC government. These documents provide descriptions, aerial photos, inventories, and photographs of the areas. In the following section, detailed literature reviews from geographic and ecological approaches are presented.

METHODOLOGY REVIEWS

Approach to Sampling

According to the methods outlined in *Research and Management Techniques for Wildlife and Habitat* published by The Wildlife Society, some methods can be applied for this study (Bookhout 1996). In this book of guidelines, eight approaches for avian sampling and surveys of a regional area are presented. Bookhout (1996) describes these approaches as: (1) simple random sampling, (2) systematic sampling, (3) stratified random sampling, (4) clustered sampling, (5) point sampling, (6) plots along a transect sampling, (7) line transect sampling, and (8) road sampling. Among these, approaches 1 to 4 are categorized as sampling designs, while approaches 5 to 8 are categorized as sampling survey methods. In some cases, simple random sampling would not be useful because this approach is only suitable for homogeneous areas

<u>Approach to Survey</u>

Avian survey methods were also reviewed and compared (Table 2-1). According to the *Guidelines of Environmental Impact Assessment for Animal Ecology* by the Taiwan EPA (Environmental Protection Administration 2003), avian survey methods can be divided into the following approaches to estimate avian density: (1) capture-recapture, (2) nest counting, (3) territory mapping, (4) air-scape estimates, (5) airborne thermal scanning, (6) line transects, and (7) point counts.

Table 2-1. The comparison of methods of sampling and survey.

Sampling method	Survey method	Investigation method	Suitable scale	Requirement to overcome shortcomings	Shortcomings overcome?
Stratified random sampling (divided layers of random samplings)	Line transect (road passing across footpaths, trails, and lines)	Moving along roads or curvilinear paths, recording birds by sight and sound; suitable for open ground	Suitable for grouping in the meso-scale study.	Errors identifying species by sight and errors of listening to bird sounds.	Yes (by using reputable and experienced observers)
	Point count	Staying in one place, analyzing, and recording birds seen; suitable for pond and woodland surveys from a fixed position	Suitable for grouping in the meso-scale study.	Only for observations from a fixed position, thus, outside points unable to be reached.	Yes (point surveys were used with line transects)

Sources: Bookhout (1996) and Environmental Protection Administration (2003).

Due to access flexibility, the field scale, and limited budgets, I had to give up on approaches 1~5. I reviewed the two approaches of line transects and point counts to carry out this project because the tableland does not have dangerous side slopes or passes, and the entire area is covered by footpaths and ways to form road networks for detailed personal field surveys. Therefore, avian observers were able to reach all farm ponds by visual surveys and focus on the hotspots of water surfaces, mudflats, banks, and vegetation characteristics of microhabitats. So for this avian-survey project, I reviewed stratified random sampling as well as point counts associated with line transects, and considered to divided sub-regions of random samplings; these were synchronously investigated to calculate avian species and individuals to achieve accurate results.

Approach to Pondscape Analysis

Farm-pond areas are dominated by fields separated by hedgerows and windbreaks, and have scattered woods of various sizes. Distributions of avian species within such land mosaics are correspondingly discontinuous, depending on the locations of preferred habitats, density-dependent processes, and the quality of individual patches (Mitsch and Gosselink 2000). The presence of trees and shrubs is a critical feature for migrants and residents, and densities of both hedgerows and woodlands are good predictors of avian communities. These configurations are surrounded by built-up areas, rivers, roads, and farmlands.

Given the remarkable diversity of farm-pond configurations and the complexities of their compositions, *pondscape* is defined as “a series of water surfaces of ponds association with various surrounding landforms including farms, creeks, canals, roads, houses, woodlands, and other open spaces" following the remarks of some authors (Froneman et al. 2001; Takekawa et al. 2001; Francl and Schnell 2002; Schneider et al. 2002). Located between natural areas and urban areas, pondscape in agricultural fields create ecotones from aquatic plants, windbreaks (i.e., the families Casuarinaceae and Meliaceae), anthropogenic crops, to fragmented woodland cover (i.e., the families Moraceae and Euphorbiaceae). These areas, associated with rotation of crops in agricultural fields, include food and horticultural uses.

In pondscape studies, selected parameters are used to measure the spatial arrangement of wooded and aquatic landscapes and to compare significant differences between them. These parameters have been used to measure temporal changes in actual landscapes and changes in intensively used landscapes (Li and Reynolds 1994; Leitão and Ahern 2002). Many studies on pondscapes have focused on the aforementioned spatial configurations, such as biodiversity, pond size, pond depth, pond shape, and pond sustainability. Some pondscape parameters as total area (TA), largest pond index (LPI), mean pond size (MPS), mean shape index (MSI), mean pond fractal dimension (MPFD) can be considered. To some extent, descriptive statistics were used for statistical data processing to combine parameters in spatial analysis (Halsey et al. 1986; Evertsz et al. 1992; Gustafson and Parker 1992; Hastings and Sugihara 1993; Gustafson and Parker 1994; McGarigal and Marks 1994; Cheng and Agterberg 1995; Kronert et al. 2001; McGarigal et al. 2002).

Unfortunately, very few documents were applied for temporal-spatial analysis by incorporating prediction models to measure pond dynamics (Lin et al. 2001). For pondscape perspective, logistic regression can be applied to predict pond-loss trends.

This approach using *Logit*, also called "maximum likelihood estimates", was to predict the likelihood of the occurrence of an object remaining or disappearing. The term *Logit* was first used by Berkson who took advantage of it for bioassay calculations (Berkson 1944). The *Logit* of a number *p* between 0 and 1 is the plot of *Logit* in the range 0 to 1, based on *e*. If the likelihood of a pond loss is *Pi,* then the probability of an existing pond is *(1 - Pi)*. *Pi*/ (*1 − Pi*) is the corresponding odds, thus, providing an additive mechanism for combining odds-ratios. Estimation and prediction by this method are called logistic regression. The logistic regression model is:

$$Pi/(1-Pi)=e^{\beta_0+\beta iXi} \text{ or} \tag{2.1}$$

$$ln[Pi/(1-Pi)] =\beta_0+\beta iXi \tag{2.2}$$

where

ln is the natural logarithm, $\log_e$, where e = 2.71828…

Pi is the likelihood that pond-loss occurs,

Pi/(1-Pi) is the "odds ratio",

ln[Pi/(1-Pi)] is the log odds ratio, or "*Logit*",

all other components of the model are the same, such as:

$$\hat{P}_i = \frac{e^{\hat{y}_i}}{(1+e^{\hat{y}_i})} \tag{2.3}$$

while

$$yi = exp(\beta_0+\beta_1x_1+...+\beta_mx_m)/[1+exp(\beta_0 +\beta_1x_1+...+\beta_mx_m)]$$

$$\text{or} \quad \bar{y}_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \cdots + \beta_m x_{im} \tag{2.4}$$

where $x_{i1}....x_{im}$ is the parameters of pondscapes.

<u>Designing Avian Refuges</u>

For limited farm pond studies, in general, increasing the pond area or simplifying pond shape increases the pond core area, thereby benefiting birds by enhancing their population persistence (Diamond 1975; Gilpin and Diamond 1980; Higgs and Usher 1980). Some studies have found relevant and direct influences of pond size, while others found more-complex effects (Johnsgard 1956; Tamisier and Grillas 1994; Bird et al. 2000; Fujioka et al. 2001; Quan et al. 2002; Ravenscroft and Beardall 2003). Some conservation scenarios may focus on vulnerable sites, which may be targeted for enlargement by habitat creation at their woody edges, again on the basis that large pond microhabitats are broadly beneficial for biodiversity.

Given the parameter situation in a fragmented area disturbed by urbanization, it is not surprisingly that there is no one *best* size to satisfy the carrying capacities of avian habitats. Similarly, the increase in individuals of various bird species with area of habitat islands is attributed to minimum area requirements interacting with the effects of competition or food demands. Therefore, *"how big is big?"* became an issue in the debate relating to the design requirements of refuges. Several "principles" are provided by the island biogeographic hypothesis (MacArthur and Wilson 1967). First, refuges should be designed to be as large as possible. Second, refuges should be as circular as possible to avoid the "peninsula effect", in which species diversity reduces in elongate areas compared with circular areas of the same size (Forman 1995). However, there have been many debates on this concept for designing bird refuges related to the "species-area relationship" and "species-habitat relationship" (Simberloff and Abele

1976; Forman 1995; Pelletier 1999; Oertli et al. 2002). In this chapter, I review several issues within this debate.

Species-area relationships

The concept of a species-area relationship dates back to Arrhenius (1921) who studied data on plant associations from a number of quadrat samples. Gleason (1922; 1925) came to the conclusion that a straight-line relationship was obtained between species and area. However, his theory was empirically developed in an effort to find a graph to fit certain observed results, and this rule was not based on mathematical reasoning. Later, Preston (1948; 1962) studied large amounts of empirical data to fit this model. He created an equation named the Arrhenius equation as follows:

$$S = cA^z; \tag{2.5}$$

where S is species richness, z is the slope, A is the area, and c is a constant. Species area curves were then calculated for each plot using the equation, given by:

$$\log S = \text{z} \log A + \log c \tag{2.6}$$

Such a general pattern is important not only for fundamental aspects of ecological concepts but also for the ecological basis for designing refuges. Preston concluded that if the number of species *(S)* is recorded in different areas *(A)*, there is almost always an increase in S with increasing A. However, there were many debates which regarded this model as merely a computationally convenient method to fit observed data, despite some undesirable properties.

Forest phenology pattern was one of the parameters to be studied in the relationship between avian communities and area (Forman et al. 1976). Martin (1988) declared that species numbers are related to forest foliage cover. He confirmed that foliage provides the substrate to protect nests from predators. In addition, foliage can also influence the thermal environment for warming birds' bodies in cold weather. Other studies found that birds responded to woody cover, shrub cover, grass cover, and litter cover (Karr 1980; Condit et al. 1996; Hinsley et al. 1998).

There have been many criticisms of this hypothesis (Simberloff and Abele 1976; Sismondo 2000). In nature, the area-*per-se* hypothesis is expected to be observed only within a certain intermediate range of areas, not at all spatial scales. On small spatial scales, the species-area relationship is not governed by equation (1) but is curvilinear on a log-log plot; while on landscape scales, the species-area relationship bends upward toward a limiting slope of unity (Durrett and Levin 1996). Second, species differ ecologically, thus not all units of species (*S)* are equal. Since some habitat generalists are widespread, most species in small patches associated with the surrounding habitat matrix are generalists which choose between major habitats and edge habitats, whereas in large patches, there are specialists which only definitely choose interior habitats (Gaston et al. 1997; Hubbell 2001). Those studies indicated that spatially and taxonomically different species differ from one another in their responses to area (Ney-Nifle and Mangel 1999). Different avian communities are likely to yield different land-use patches (Caswell and Cohen 1993).

Species-habitat relationships

Debates between field domains of the area-*per-se* hypothesis and the species-habitat hypothesis have been ongoing for almost 30 years (Kingsland 2002). However, there are still no conclusions to generalize principles of ecological designs and no final consensus on which hypothesis is better. Birds respond to both food and roost sites during habitat selection as mentioned above. Numbers of individuals of species are correlated with the needs for grass ward, mudflats, open shoreline, and canopy or water surfaces for horizontal heterogeneity. Habitat heterogeneity increases with an increase in area (Harte and Kinzig 1997; Traut and Hosteler 2004). Increased microhabitat diversity allows more species to find an increased number of various niches, resulting in greater species diversity. Bird-habitat relationships, thus, are the results of responses of birds using habitats for different activities, such as foraging, molting, and roosting.

There are many microhabitats from which birds can select in pondscape configurations, with the major category being water regimes. Recent pond-core studies of Lane and Fujioka (1998) found that the species-habitat hypothesis works. They declared that watercourses, connected by ditches around rice fields, affect shorebirds in shallow ponds. Elphick and Oring (2003) suggested that water depth significantly affected bird communities in flooded mudflats. Snell-Rood and Cristol (2003) explained this phenomenon and confirmed that if a pond's water level is too deep, it can often cause respiration to slow down on the bottom due to a lack of oxygen exchange. As Green et al. (2002) said, constructed wetlands cannot replace the value of natural wetlands because water levels in constructed wetlands are too deep, adversely affecting the avian community to a greater degree compared to natural wetlands. They suggested that water levels in constructed wetlands were regulated at about 10~15 cm in depth to better attract shorebirds (of the families Charadriidae and Scolopacidae). So, determining ways to control water levels by drawdown and adjust mudflat areas in order to observe changes of avian diversity has become a major subject of farm-pond management in habitat-scale studies.

Anthropogenic disturbances

As mentioned in the previous section, many studies have focused on microhabitats as well as anthropogenic disturbances of avian communities, such as by drawdown, etc. Anthropogenic disturbances may be beneficial or harmful to avian communities (Musacchio and Coulson 2001). By focusing on both disturbed and undisturbed habitats, authors claimed that more diversity of species was located in undisturbed habitats than at sites with highly disturbed habitat (Bolder et al. 1997; Chamberlain and Fuller 2000). Most cases insisted that intensive anthropogenic influences caused avian declines due to negative edge effects by developed areas (e.g., habitat loss or segmentation) (Herkert 1994; Reijnen et al. 1996; Bolger et al. 1997; Reijnen and Foppen 1997; Hinsley et al. 1998; Miller et al. 1998; Jokimäki 1999; Chamberlain and Fuller 2000; Howell et al. 2000; Fernández-Juricic 2001; Fuller et al. 2001; Burton et al. 2002; Francl and Schnell 2002; White et al. 2004). The edge effect, defined as the "juxtaposition of natural habitat and human-modified habitat", may cause habitat to become less favorable and species likely to become locally extirpated. Some direct and indirect influences from developed areas are indicated, such as (1) habitat loss or fragmentation, (2) introduced exotic species, (3) pollution (of air, water, or soils), (4) population loss of specialists, and (5) overpopulation by generalists. As to the impact of anthropogenic disturbances on habitats, the characteristics of birds were roughly categorized as "specialist" or "generalist". They were grouped into detailed "guilds" to illustrate habitat relationships are described in the following section.

Approach to Avian Analysis

An avian refuge is determined by its habitat quality as well as avian community. A potential refuge can be evaluated by the number of avian species it contains relative to other areas. Therefore, the avian number becomes one of the indices for refuge examination in relation to the area. Different levels of edge disturbance have different effects on avian communities. If the goals are to preserve avifauna in microhabitats as well as at a landscape scale, one must understand how diversity is impacted by different management strategies. Because diversity indices provide more information than simply the number of species present (i.e., they account for some species being rare and others being common), they serve as valuable tools that enable the quantification of diversity in avian communities and a description of their numerical structure. In the following sections, some approaches for calculating species diversity of overall species and of specific functional groups are described and compared, and in this way, a suitable approach to fit avian classification in farm ponds can carefully be selected.

Species diversity

Diversity provides information about the rarity and commonness of species in an avian community (May 1975; Karr 1976). The ability to quantify diversity is an analytical tool for biologists trying to understand environmental quality, such as anthropogenic disturbances and environmental changes (Rosenzweig 1995). After the term "biodiversity" was defined at the Rio Convention in 1992, there was a sudden shift in the literature towards the search for indicators of biodiversity itself (Duelli and Obrist 2003). Since then, however, the term biodiversity has sometimes been used to indicate some aspect of environmental quality by use of diversity indices.

A diversity index is a mathematical measure of the species in a community (Buckley and Forbes 1979; Magurran 1988). It provides more information about community composition than simply species richness (i.e., the number of species present), it also provides an insight into the relative abundances as well as species richness. There are several equations for calculating indices of diversity. For example, the Shannon-Wiener diversity index (also named for Shannon index or the Shannon-Weaver index) is one of many diversity indices used by biologists (Shannon and Weaver 1949). Another is Simpson diversity, and so on. In this section, the above-mentioned indices of species diversity are discussed.

Shannon-Wiener diversity index (H'): The proportion of species (*i*) relative to the total number of species (P_i) is calculated, and then multiplied by the logarithm of this proportion ($\log_2 P_i$). The resulting product is summed across species, and multiplied by -1:

$$H' = -\sum_{i=1}^{S} P_i \log_2 P_i \tag{2.7}$$

where S is avian species richness and Pi is the percentage of species i in the avian community.

Simpson's dominance index (C): For this index, the greater the value of C is, the more dominant a species is within the avian community:

$$C = \sum_{i=1}^{n} \left(\frac{Ni}{N} \right)^2 ; \tag{2.8}$$

where Ni is the number of individuals of species i and N is the number of individuals in the avian community.

Simpson's diversity index (D):

$$D = 1 - C \tag{2.9}$$

where *C* is Simpson's dominance index.

An ideal index should clearly and accurately discriminate between samples, not be greatly affected by differences in sample size, and be relatively simple to calculate. The Shannon-Wiener diversity index (*H'*) is commonly used to characterize species diversity in an avian community. This index accounts for both the abundance and evenness of the dominant species as well as the rare species. Rare and endangered species are weighted by this log-log index. In the avian survey projects in farm ponds, rare species should be considered in order to take advantage of some protecting priorities. Therefore, a more-complete understanding of the entire structure of avian community used by *H'* is described.

Species guilds

Rare species are emphasized used by *H'* by overall species diversity. However, many debates have occurred between taxonomic diversity of entire groups. Since Howell (1971) began to use five functional groups to examine avian residency in forests, many avian ecologists have used *guilds* to avoid errors involved with large numbers of species counts. Their criticism is that the taxonomic approach to avian studies cannot be commensurate with landscape scales. Alternatively, studies using aggregate species richness or diversity indices are often oversimplified (Karr 1971; Emlen 1972). With the two topics of relative abundance of species (diversity) and distribution along a gradient zonation (guilds), one can begin to determine avian community from landform change (Terborgh 1977). *Species diversity* in entire groups focuses attention upon the first topic. Then, the topic of *guild*s dissects the environmental factors that affect avian distributions in microhabitats and in a region.

Guilds, used to judge environmental conditions, were examined within heterogeneous landscapes. The concept of *guild* provides a beneficial approach by dividing the way birds utilize habitat and then grouping them according to landscape configurations. Root (1967), the first avian scientist to form the guild concept, defined a guild as “a group of species that exploit the same class of environmental resources in a similar way”. He focused on the way that Blue-grey Gnatcatchers *(Polioptila caerulea)* associate with other species in California oak woodlands. Recognizing that the traditional taxonomic approaches had failed to categorize avian communities, he described a “foliage-gleaning guild” that feeds from the foliage and occasionally from branches. This group included five species having similar diets, foraging locations, and feeding behaviors.

After Root defined functional groups based on the traditional guilds--diets and foraging strategies--other authors followed his approach (Emlen 1972; Terborgh 1977; Szaro and Balda 1979; Karr 1980; Folse 1982; May 1982; Blake 1983; Bradley and Bradley 1983; Manuwal 1983; Wong 1986) in studying avian behavior and foraging strategies; other authors studied nesting, resting, singing, or residential locations (Howell 1971; Karr 1971; Emlen 1972; Karr 1976; Riffell et al. 1996; Canterbury et al. 2000; Skowno and Bond 2003); or they studied both, such as foraging strategies and singing location (Recher et al. 1983). However, most studies using functional groups have tended (1) to group species by subjective criteria or by a single behavior, (2) to focus on just one or some groups, and (3) to be applied at only a single location or on a small spatial scale.

Indeed, studies on bio-choices based on entire species can produce objective results on a regional scale. Rather, microhabitat selection due to bio-choices reflects partitioning of spatial variations in heterogeneous landscapes. Clearly explained landscape configuration patterns, i.e., guilds, based on bio-choices can likely be formed as indicators to monitor microhabitat quality. Not assumed to have the same definition as the first "guild" defined by Root (1967), habitat preference was later used to define functional groups (Recher and Holmes 1985; French and Picozzi 2002). French and Picozzi (2002) declared that wintering birds were related to land uses by grouping birds as either generalists or specialists. In order to avoid problems with landscape complexity, avian grouping is a useful approach for deciding avian diversity with respect to microhabitat perspectives.

Due to a lack of prior information about necessary environmental factors which affect avian guilds, cluster analysis was applied in avian studies (Severinghaus 2001). It was used to study groupings of similar parts of the avian community into respective functional groups. As a set of methods for building groups (clusters) from multivariate data, the aim was to identify groups with habitat preferences for certain microhabitats. Then, groups were made as homogenous as possible to reduce differences between them to the extent possible. This produced a result for the existing data correlation hierarchy and expected numbers of functional groups.

Approach to Guild Simulation

While guild classification is formed, it is capable of evaluating the changes in the avian assemblage, and predict guild's diversity with the pondscape complex. In fact, estimating the avian community is a difficult task as various species may inhabit same patch in a heterogeneous landscape, so taxonomic analysis of avian guilds would be advantageously coupled with forecasting techniques based on habitat characteristics relative to other areas. Surprisingly, attempts to estimate entire avian guilds with scientific rigor on such grounds are scarce in the literature, except with a few taxonomic studies (Baltanás 1992; Bailey et al. 2002). Conversely, a wealth of work deals with linear predictions on a regional scale (Boren et al. 1997; Manel et al. 1999; Froneman et al. 2001; Seoane et al. 2004a; 2004b). In this respect, they proposed theoretical linear-relationship models using a wide range of multivariate techniques, including several methods of multivariate linear discriminant analyses, canonical analyses, and logistic regressions.

Many critical reviews have indicated that these conventional models, usually based on multiple regressions, assume simple linear relationships between parameters (Palmer 1990; Reby et al. 1997; Tattari et al. 2003). Based on linear principles, they produce exclusive results since the main processes that determine the level of biodiversity or species abundance are often non-linear. To a limited extent, these methods are often rather inefficient after parameter transformation when the data are non-linearly distributed. In addition, there is no specific a priori mathematical tool for predicting guild biodiversity, so the techniques used for prediction should also work for non-linear transformation. In ecology, multivariate-based models relating environmental parameters to avian communities have been presented by several authors sometimes using non-linear transformations of independent or dependent parameters to improve results. Even so, the results are still insufficient, with a low percentage of variance explained. Therefore, additive parameters regarding bird and pondscape relationships require that networks be interwoven for detailed studies.

Farm ponds at both microhabitat and the landscape scales may be a relevant influence for explaining bird guilds due to a habitat effect or more-moderate and complex effects (Froneman et al. 2001). According to habitat selection as bio-choices, farm-pond patterns associated with various microhabitats provide environmental clues that are used by birds to select stopover sites, such that farm ponds within the range of avian communities may potentially remain unoccupied or sub-occupied if they lack those clues. Second, the appropriate microhabitats for a particular species in a guild might not be spatially constant if the habitat status changes the distance to the edge between pond cores to peripheral habitats, i.e., by water-table drawdown, farmland consolidation, or other anthropogenic influences. Pond-species relationships, thus, are connected like a neural network with a non-parametric nature, as clues suggest.

In recent avian studies, some authors have focused on an approach of artificial neural networks (ANN), which were developed as an original prediction method according to the principle of the operation of the human neural system (Ibarra et al. 2003). Neural networks are determined by the neurons, or units, which are interconnected within the entire dynamic system. The groundwork for neural networks was laid out in the 1940s in the field of neurophysiology. The use of ANN models in ecology is quite recent. However, ANN have shown that they can efficiently model those non-linear systems in avian ecology (Manel et al. 1999). In this research, therefore, I attempted to apply this method to relate the structure and diversity of an assemblage of wintering birds to microhabitats. Based on the area-*per-se* and species-habitat premises, some hypothesized concepts are discussed in Chapters Five and Six, including (1) that some generalists continue to decrease in areas with a high density of construction; while (2) specialists continue to increase in the landscape with a low density of construction, and in areas with high densities of specific microhabitats (i.e., water surfaces, windbreaks, and mudflats). An ANN model was created and discussed in Chapter Six.

SUMMARY

Planning for the future of avian refuges requires recognition of both existing and potential farm-pond sites. Problems of conflicts with pond conservation for refuges are due to increasing urban development exerting pressures on avian communities. Changing land uses, especially consolidation of farming practices associated with urban construction, increase the risks to avian communities in ponds (Fang et al. 2004b). From a review of the previous literature, birds in winter may provide useful raw material to evaluate simulation models for predicting ponds' effects on their behaviors of habitat selection. As such, specific selection based on both microhabitat and landscape scales according to avian assemblages are required. In the farm ponds of Taoyuan, the number of individual farm ponds is increasingly being reduced, thus some evidence of a negative effect of landscape quality is occurring to avian distributions and communities in these fragmented farm ponds. In avian population studies, functional groups associated with pondscape configurations provide an effective tool to determine non-linear relationships based on the concept of neural networks. It was possible to quantify the influences between landforms and avian groups because there are theoretical models and practical experience to help.

CHAPTER III

METHODS

The regional avian survey and analysis were a first attempt to develop predictive tools; there are also no extensive synchronous survey materials from the past. Therefore, the avian community of the farm ponds in Taoyuan Tableland is poorly described in related materials. Farm ponds are more intensively influenced by anthropogenic activities as described in the previous chapter; birds are counted relatively less in disturbed areas because avian observers are generally more interested in non-disturbed areas. This chapter provides results of a detailed survey of the avian community, classified from species to guild. Using a geographical information system (GIS) to describe the avian distribution, this study outlines ecological gradients on a meso-scale as well as a micro-scale (i.e., microhabitats). The basic increase in human disturbance and the area-*per-se* hypothesis or habitat hypothesis is used to discuss the avian communities and their guilds in the winter according to spatial statistical methods.

The purpose of this research was to examine the relationships between avian communities and pondscapes. This chapter provides an overview of the selected study areas and methods that were used to collect and analyze the data. Three indices were used in the study: (1) species richness, (2) numbers of species and individuals, and (3) the Shannon-Wiener diversity index (*H'*). A variety of multivariate procedures, including logistic regression, cluster analysis, and the process of back-propagation (BP) training, one of the artificial neural networks (ANN), were used to analyze and forecast pond loss and avian distribution for modeling within the same functional groups from various different habitats. Relevant materials and methods and materials are given in detail below.

SITE SELECTION

The sample comprised 45 farm ponds from all ponds in Taoyuan Tableland on northwestern edge of the island of Taiwan (Taiwan's map see Appendix E). The Taoyuan Tableland, located approximately 40 km southwest of Taipei, occupies an area of 757 km^2. "Taoyuan" means "peach garden", and is situated in a rich agricultural area where there used to be many peach orchards in the 19th century. Since the extent of urban development has rapidly increased, the Taoyuan metropolitan area is now one of the fastest growing areas among the five metropolitan areas of Taiwan (Taoyuan County Government 1997). The population on the Taoyuan Tableland was 1,766,000 according to census data in 2004 (Directorate-General of Budget, Accounting and Statistics of Taiwan 2004). This area has a population density of 2331 persons/km^2 (9435 persons/mi^2) and its population is increasing at a rate of 2000~3000/month (Taoyuan County Government 2004). Population pressures have contributed to reductions in historical areas of farmlands and farm ponds (Fang 2001). Losses of farm-pond and farmland habitats have had serious effects on a range of avian communities as well as other fauna and flora (Pheasant-tailed Jacana Restoration Committee 2002; Fang and Chang 2004). On the Taoyuan Tableland, agricultural practices are intensifying, which is reducing the heterogeneity of the original landform, and adding pollutants as well as industrial practices. In order to study the anthropogenic influences on farm ponds as well as the natural attributes of the Taoyuan Tableland, historical reviews were used. A retrospective description of the tableland's geography, ecology, and farm-pond situation is provided in the following sections.

Geography

The Taoyuan Tableland lies between the northern border of the Linkou Tableland (23°05'N, 121°17'E) and the southern border of the Hukou Tableland (22°55'N, 121°05'E); it borders the town of Yinge in the east (22°56'N, 121°20'E) and the Taiwan Strait in the west (22°75'N, 120°99'E) (Department of Land Administration 2002)(Figure 3-1).

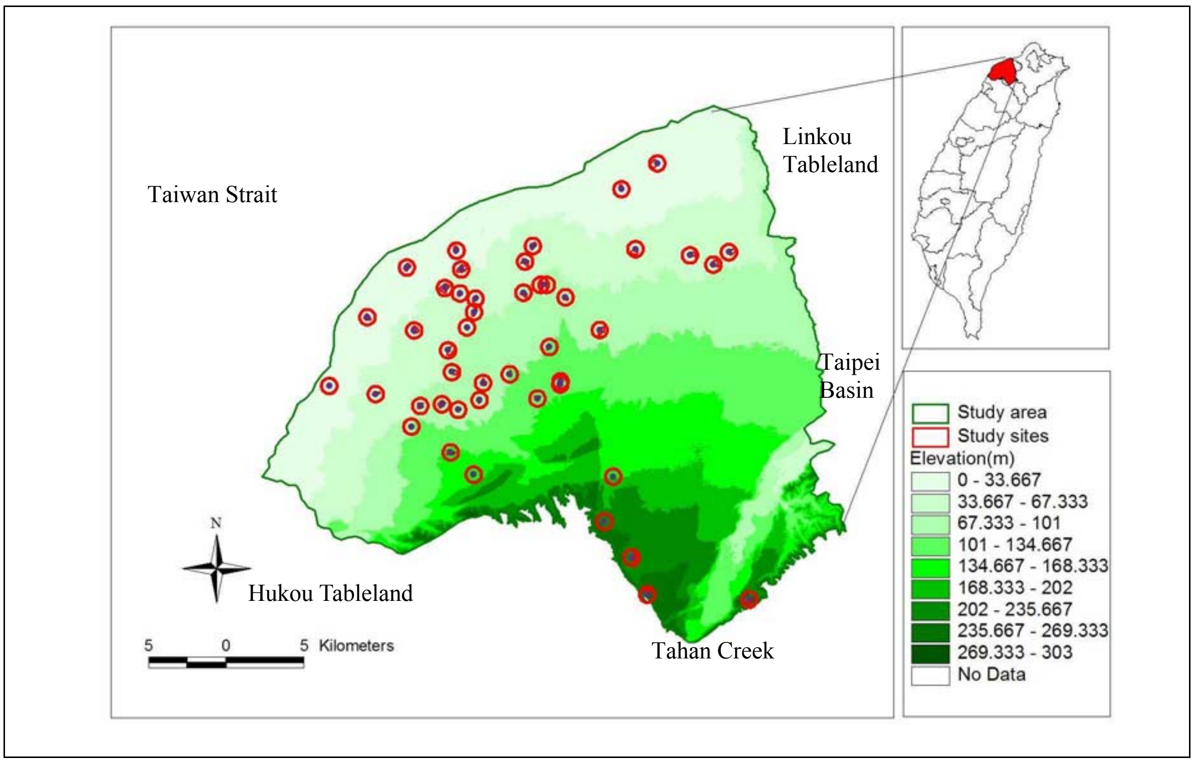


Figure 3-1. Geographic contours of the Taoyuan Tableland at elevations from sea level to moderately sloping tableland up to 303 m (994 ft). [Elevation (m); 0~33.7; 33.7~67.3...; 269.3~303; Distance (km); 5]

It sits at elevations from sea level to 400 m (1,312 ft) and is composed of tableland up to 303 m (994 ft) and hills with sloping gradients from 303 to 400 m (994 to 1,312 ft). It runs in a southeast-to-northwest trend, abutting mountains in the southeastern corner and the shore of the Taiwan Strait at the far end (Huang 1995). With a high average humidity of 89%, the tableland is located in a subtropical monsoon region with humid winters and warm summers. January temperatures average 13 °C, and July temperatures average 28 °C. Annual average precipitation ranges from 1500 to 2000 mm (59.1 to 78.7 in) (Central Weather Bureau 2004).

The tableland gradually rose approximately 180,000 years ago. At that time, the Tanshui River had not yet captured the flow from the ancient Shihmen Creek, which directly poured out of the northwestern coast forming alluvial fans. Eventually, foothill faults caused by earthquakes during the same era, resulted in the northern region of Taiwan abruptly dropping by 200 m (656 ft), and thus, the Taipei basin was born. Since the Taipei area had subsided, the ancient Shihmen Creek which meandered across the Taoyuan Tableland was captured by northward-flowing rivers some 30,000 years ago. The middle streams changed their courses because of the subsidence in the Taipei basin. The resulting Tahan Creek, became the upstream portion of the Tanshui River in the Taipei Basin. Due to blockage of water sources, downstream areas on the Taoyuan Tableland were deficient in water. This caused high flushing and drops in water yields. Historically, it was difficult to withdraw and supply irrigated surface water from rivers due to the tableland's unique topography, thus, forming an obstacle for the development of agriculture (Huang 1999; Chen 2000).

Avian Ecology

Historically, the Taoyuan Tableland was dominated by native pendent reeds (*Arundo formosana*) associated with aquatic and terrestrial species (Luchu Township Office 2004). This region is a stopover site for waterfowl, shorebirds, and seabirds because of its specific pondscapes, back-sloping terrain, and few impacts of the monsoon climate. The aforementioned monsoon rains that occur in the area of Taiwan produce humid, cool, and windy winter and autumn and are highly parameter in magnitude and specific location. As a result, specific stopover sites in Taoyuan may be favored by migrants based on rainfall received across Taiwan.

Because herbicides and insecticides were widely used for reed and pest control in rice paddies in Taoyuan from the1950s to the 1980s, some endangered species had already locally extinct in the dense farmland areas. For example, the Pheasant-tailed Jacana (*Hydrophasianus chirurgus*) occasionally occurred in the early decades of the 1900s, but was locally extirpated by the 1960s from Taoyuan (Pheasant-tailed Jacana Restoration Committee 2002).

Currently, only tolerant and competitive species are present in abundance due to the application of anthropogenic chemicals, such as use of chlordane compounds (CHLs), dichlorodiphenyltrichloroethane (DDT), polychlorinated biphenyls (PCBs), hexachlorocyclohexane isomers (HCHs), and hexachlorobenzene (HCB) (Kunisue et al. 2003). The tolerant species in the farm-pond ecosystems of Taoyuan include common avian species (i.e., Black-crowned Night-Heron (*Nycticorax nycticorax*), Little Egret (*Egretta garzetta*), Light-vented Bulbul (*Pycnonotus sinensis*), Grey Heron (*Ardea* *cinerea*), Eurasian Tree Sparrow (*Passer montanus*), and Great Egret (*Casmerodius alba*) (personal survey).

<u>Pond Sampled</u>

The pond complex on the Taoyuan Tableland is typical of the many farm-pond complexes found in Taoyuan and adjacent Hsinchu County. In order to sample the entire community and to account for birds with different mobility, I used stratified random sampling methods. This method is suitable for the different microhabitats within the ponds. Stratified random sampling based on sub-regions of the tableland was comparatively suitable for use to divide one random sampling case into nine survey groups, and groups were rotated throughout all survey periods.

The tableland was first stratified into 45 study ponds; six in the north, five in the south, and thirty-four in the west. Data on farm ponds were collected at the 45 study sites of various size gradients according to large-area ponds which accounted for 628 individuals (> 1 ha) on the Taoyuan Tableland. Survey ponds were typically large, with 43 (96%) of 45 ponds > 1 ha and only two ponds < 1 ha (Figure 3-1). Mean pond size was 8.373 ha ± 4.984 (range = 0.203 ~ 20.473 ha). The number of farm pond sites selected in each region was roughly proportional to the area of each region accessible by automobile. I did not place sampling sites in the eastern and southern urbanized high-density areas where the human population was relatively intact. This was done because the bird composition of such urban sites containing a large proportion of generalists would have created a large proportional bias with the other sites with more specialists, thus making it inappropriate for diversity analysis. Although I did not select sites based on any predetermined definition of the degree of urbanization along a rural-urban gradient (e.g., distance from an urban core), the relatively large number of randomly selected survey sites ensured that there was a good representation of sites more than 2 km from major urbanized corridors, and far from natural forest areas in the eastern regions. The farm ponds studied ranged from slightly disturbed farmlands to fairly natural farmlands. I placed the linear transect routes in areas that were accessible by trails and footpaths around ponds. Therefore, 40 sites were situated within the western part of the tableland, and five sites were situated among relatively continuous interlocked ponds in the southern portion. All pond sites were randomly selected to minimize the variability in vegetation structure and composition. Detailed measurements of tree species of a subset showed them to be structurally very similar areas (the families Casuarinaceae and Meliaceae).

Bird and Pond Survey

Surveys were conducted during the non-breeding season in the winter of 2003~2004 when deciduous trees were still in leaf in the subtropical region of Taiwan. According to Severinghaus (2001), wetland birds in lowland areas account for 85% of the birds on the island of Taiwan. The total number of individual birds wintering from November to February in the non-breeding seasons comprised the majority of birds (N = 3,430,000, approximately 53% of the total) in a year-round survey (Severinghaus 2001).

In this survey project, I organized an intensive 4-month bird survey in which simultaneous censuses were carried out at 45 ponds four times from November 2003 to February 2004. I did not use a year-round survey due to a lack of information on migratory wetland birds from the breeding season. All surveys were conducted by 45 experienced bird observers starting at the same moment before sunrise and ending at

10:00 am on the same day. Each pond was surveyed and coded for numbers of bird species and individuals within 30 minutes with a point-count approach. Highly windy or rainy days were avoided. To reduce the effects of bird-observer identified bias, three to four observers were grouped and rotated between ponds. The observers counted birds that were in any habitats. Birds belonging to the families Apodidae (swifts) and Hirundinidae (swallows) were also included from counts in flight. The Shannon-Wiener diversity index (*H'*) was calculated to determine bird diversity, and results are discussed in the following chapters. I calculated the numbers of individuals of each species detected at each pond each month. Then, I calculated mean values of these parameters for each study microhabitat across all study ponds in a wintering season.

Foliage species were also recorded following the point-count method. Avian presence/absence on foliage strata was recorded at each pond at each of the following height intervals: edge ground, wetland grasses (< 0.5 m in height), bushes (> 0.5~2.5 m in height), and trees (> 2.5 m in height). Points were sampled at 10-m internals along edge trails established down each side of each pond. Birds were grouped into microhabitat guilds based on actual observations at the sites. Foliage species were initially classified into four height categories: pond-edge ground, low foliage (< 0.5 m in height), middle foliage (> 0.5~2.5 m in height), and high foliage (> 2.5 m in height). Species were subsequently classified into two groups: understory (ground and low foliage groups) and canopy (middle and high foliage groups).

The surrounding area at a 564.19-m basal radius from the pond geometric center (comprising a 100-ha circle) was also surveyed by line-transect methodology. Since the land-use ratio of basal areas (e.g., %FARM, %BUILD, %RIVER, %PONDS, and

%ROAD) within the 100-ha circle were calculated, the area with structures was used to infer attributes unsuitable for wetland birds (i.e., waterfowl, shorebirds, birds of the water's edge, etc.).

Data Mining

At the center of each selected pond, I drew a circle with a 564.19-m radius to delineate an area of 100 ha, and measured the cover ratio of five major land-use types (i.e., ponds, watercourses, farmlands, roads, and structures), and three microhabitat types (i.e., water surfaces, mudflats, and foliage canopy areas). The land-use plots were identified based on field surveys and Taiwan's Geographic Aerial Map at a 1:5000 scale (Department of Land Administration, Ministry of the Interior 2002) and Aerial Photographs at a 1:5000 scale of 2003 (Agricultural and Forestry Aerial Survey Institute 2003). I also measured four parameters related to pond elevations, perimeters, and built-up topologies of waterfronts by GPS and field surveys. In addition, information on consolidated areas as well as distances measured from sources that contained the study sites was derived from the Taiwan's Geographic Aerial Map at a 1:5000 scale (Department of Land Administration, Ministry of the Interior 2002).

RESEARCH PROCESS

As previously outlined, the five proposed sub-objectives of this dissertation were implemented through conceptual modeling, analysis, forecasting, and planning of strategic landscape scenarios. Farm ponds at meso-scale were explored by landscape mapping; the bird and vegetation contours of pond fields on a small scale were also measured. All data were collected from first-hand bird surveys and land-use determinations as mentioned above. The associated GIS model, FRAGSTATS®, was used to analyze pond metrics and land-use ratios, such as urban areas and areas with structures (McGarigal et al. 2002). Logistic regression was used to determine the maximum likelihood of internal driving forces, which have led to pond losses. Correlation analysis and an ANN were employed to determine the relationships between birds (i.e., individuals, species richness, and diversity) and pondscapes. These procedures were essential for developing a decision-supported model, and the holistic prototype for the best scenario to promote pond and bird conversation (Figure 3-2).

CONCEPT MODELING

This procedure was essentially the first part of an integrated procedure for developing decision-making systems on land-use conversion. This procedure was developed to produce a detailed conceptual model of farm ponds. A fundamental paradigm of the anthropogenic and natural driving forces was developed (Figure 3-3), and this conceptual model was utilized to explore three themes: (1) holistic influences of anthropogenic driving forces on ponds and birds, (2) pondscape changes over a long temporal scale, and (3) spatial heterogeneity of the bird community.

Changes in pondscape mosaics are a dynamic process that is driven by human land-use activities over a certain period of time. Therefore, it is important to understand historical changes in pond configurations by a spatial analysis.

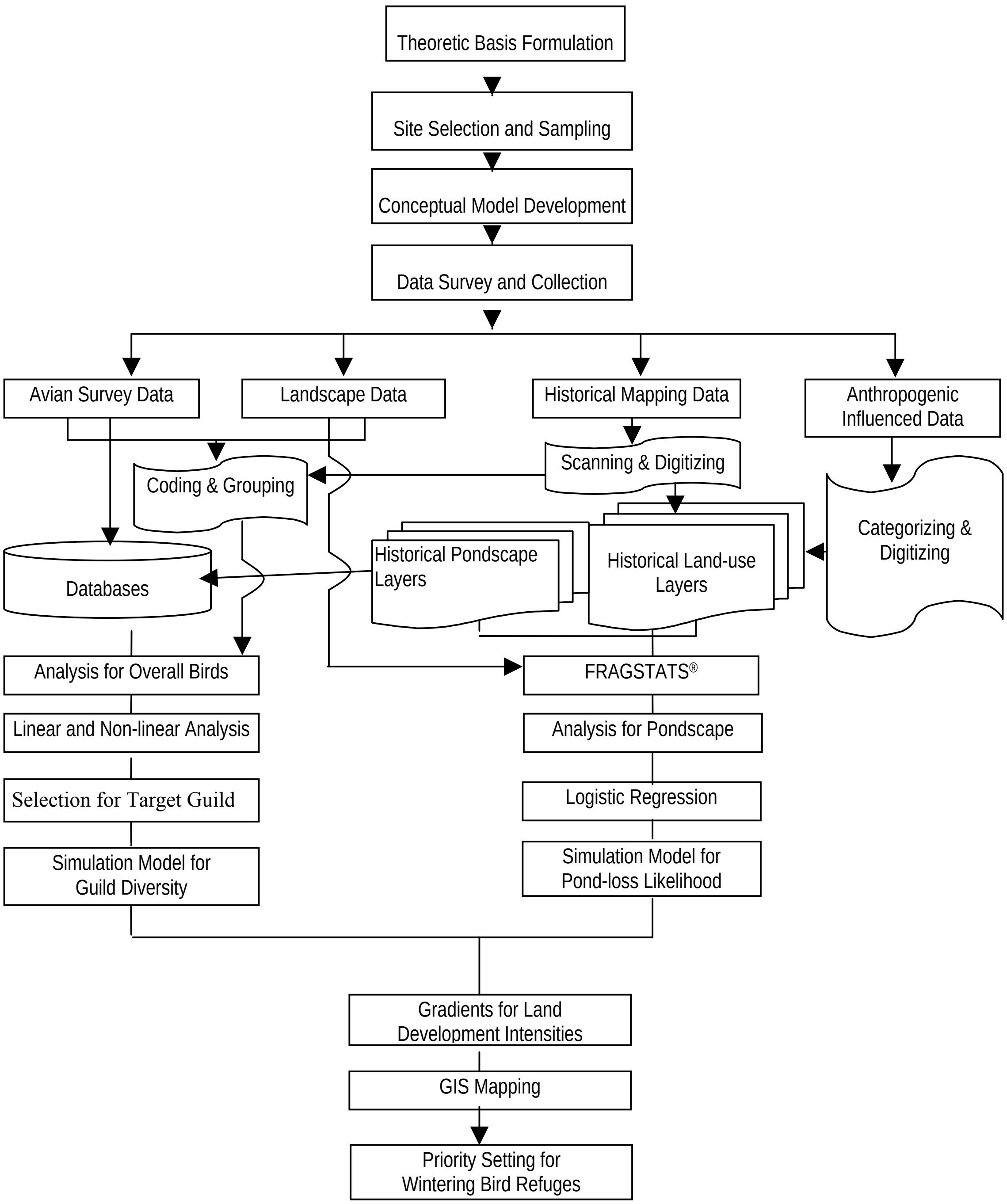


Figure 3-2. Flow chart of research method.

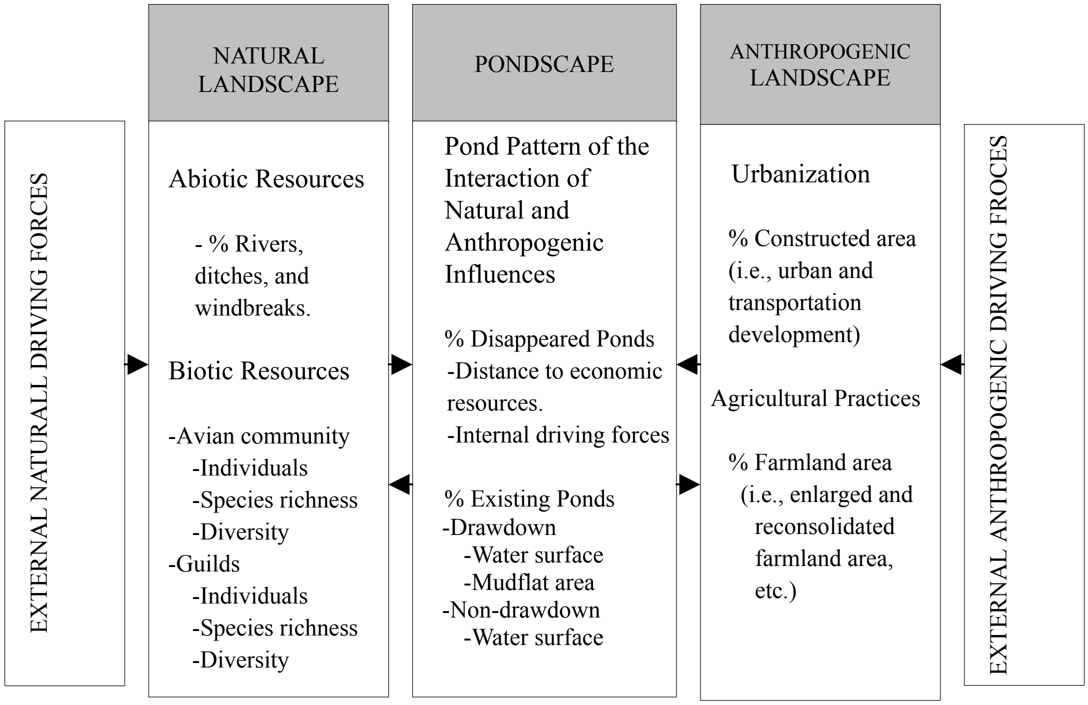


Figure 3-3. Fundamental model of anthropogenic-natural driving forces on pondscape in microhabitat and landscape scales.

PONDSCAPE STUDY METHODS

Spatial pondscape configurations are not static, but dynamic as aforementioned. Therefore, pondscapes at the landscape scale were examined as a complex phenomenon with anthropogenic influences causing the formation of spatial heterogeneities on the landscape scale (Kronert et al. 2001). In order to investigate the major reasons for the changing processes that have led to farm-pond loss, a landscape-based approach was necessary. Since none of the many digital maps (i.e., farm ponds associated with anthropogenic construction) covered the entire Taoyuan Tableland, I decided I had to collect historical maps and create one myself. However, only four publications of historical paper maps and one current digital map are preserved in the national archives. These include the first Japanese colonial maps, drawn in 1904, and kept in the National

Central Library; another drawn in 1926 is in the Library of National Taiwan University; two more drawn in 1960 and 1999 are at Chinese Cultural University; and the last one in digital format was created in 2002, in a database form (Department of Land Administration, Ministry of the Interior 2002).

I was authorized to scan 60 (4 x 15 pieces) of the original paper maps in all four periods with a 5000-MB memory size limited by compact recordable disks. This approach was used to digitize the paper maps from 1904, 1926, 1960, and 1999, which were scanned in the Computer Graphic Center, Department of Geography of Chinese Cultural University from September 2003 to June 2004. Digitized maps were created. The map from the period of Japanese colonial rule was named the Taiwan Fort Map (a sheet version of 1904, reprinted in 1996, at a scale of 1:20,000) (Department of Temporary Land Investigation, Governor Office of Taiwan 1904), Taiwan Topographic Maps (sheet version of 1926, reprinted in 1998, at a scale of 1:25,000) (Department of Survey, Great Japanese Imperial Service 1926), and Taiwan Geographic Maps (sheet version of 1960, at a scale of 1:2500; sheet version of 1999, at a scale of 1:25,000) (The Combined Logistics Command, Ministry of National Defense 1960; Department of Land Administration, Ministry of the Interior 1999) representing 4 years during the century. In acknowledgement of the TM2 cartographic coordinate system, I used two or more control reference points to calibrate and convert the sheet data to true coordinates after developing the necessary transformation skills. Thereafter, I began digitizing thousands of pond locations from paper maps to complete 20 (4 x 5 pieces) historical map layers. To carefully illustrate topographic features, I decided to digitize such features as political boundaries, roads, rail lines, areas with a structure, coastlines, rivers, ponds, and other prominent topographic features. As to the common boundaries of the Taoyuan Tableland's contours, borders encompassing 757 km^2 were finally illustrated. This work was soon put into practice to compare three types of pond configurations (i.e., remaining, losses, and increases).

Descriptive statistics were used at this stage of statistical data processing. The main aim was an initial statistical analysis of the farm-pond trends, such as average values, variance, standard deviation, etc. In the descriptive analysis, historical changes and the current state enabled me to understand anthropogenic mechanisms that were driving the trends of ponds to remain static, decrease, or increase. However, descriptive statistics cannot be used to describe relationships among many influences or to determine the rates between physical factors of farm ponds and their loss. Since this research hypothesized that pond losses are affected by their size and shape, patch analysis associated with a logistical regression model was used to detect this correlation. In the following section, the reasons for pond loss are described in terms of patch analysis, and detailed information on the factors affecting avian distributions are covered in the subsequent two sections.

Pondscape Parameters

Most pondscape studies imply comparisons with rural or natural habitats and tend to group urban and suburban areas into a simple type. But pondscapes associated with farmlands can be quite dissimilar. Both their internal and external factors can greatly vary. To find a habitat relationship, the major parameters affecting species diversity in pondscape patches were categorized to meso-scale and micro-scale distributions; for example, (1) matrix heterogeneity (meso-scale), and (2) habitat diversity (micro-scale) in size, shape, isolation, and boundary delineation of disturbances (Guzman 2003). Parameters were selected which were concerned with major differences in vegetation, the intensity of anthropogenic influences, and the distance from urban limits and the seashore. In this study, matrix heterogeneity was determined by consolidation from intensive farming. Habitat diversity parameters of area and shape were calculated using FRAGSTAT® based on the Taoyuan Geographic Aerial Map (1:5000 scale in a digital database form) (Department of Land Administration, Ministry of the Interior 2002).

These diversity parameters were categorized into as (1) largest pond index (LPI), (2) mean pond size (MPS), (3) number of ponds (NP), (4) mean pond fractal dimension (MPFD), (5) mean shape index (MSI), (6) edge density (ED), and (7) total edge (TE). Indices 1~3 were categorized as indices of "area" (see equations 3.1 to 3.3), while 4~7 were categorized as indices of "shape" (see equations 3.4 to 3.7). Disruption by anthropogenic influences or an isolation index was calculated by measuring (1) the distance to a city limit (m), (2) the ratio of area with structures within a radius of 100 ha from the pond's geometric center (m^2/ha), and (3) the ratio of all road and trail areas within a radius of 100 ha from the pond's geometric center (m^2/ha). The source connectivity index was calculated by determining (1) the distance to the coastline (m), (2) the ratio of all surrounding pond areas within a radius of 100 ha from the pond's geometric center (m^2/ha), and (3) the ratio of all river and canal system areas within a radius of 100 ha from the pond's geometric center (m^2/ha).

Afterwards, the density of drawdown and foliage cover by water table and windbreak boundaries were delineated for the disturbance and buffer zone by field surveys and an examination of aerial photographs of 1:5000 scale (Agricultural and

Forestry Aerial Survey Institute 2003). The composition of the complex landscape matrix described above could modify the degree of effects, possibly by increasing or limiting the availability of foraging sources and resting sites for avian communities. All elevations (m) of ponds and perimeters (m) of pond edges were measured using a Global Positioning System (GPS) (GarminVista-Etrex, Taiwan) and rolling rulers (m) associated with the calibration of aerial photographs at a 1:5000 scale (Agricultural and Forest Aerial Survey Institute 2003). Class and landscape levels had to be calculated for the indices as follows (Table 3-1).

1. Largest Pond Index, LPI.

$$LPI = \frac{\max_{j=1}^{n}(a_{ij})}{A}(100) \tag{3.1}$$

where a_{ij} = maximum pond *ij* area (in m^2).
A = pond areas (in ha).

Level: CLASS, LANDSCAPE
Units: Percent
Range: 0 < LPI > 100

Description: LPI equals the pond area (m^2) divided by total pond areas, multiplied by 100 (to convert to a percentage).

2. Mean Pond Size, MPS.

MPS is the mean size of ponds (in ha.)

$$MPS = \frac{\sum_{j=1}^{n} a_{ij}}{n_i}\left(\frac{1}{10000}\right) \tag{3.2}$$

where a_{ij} =the area of pond *ij* (in m^2).
n_i = the number of the pond *ij*, a single pond size (PS) in this case equal to 1.

Level: CLASS, LANDSCAPE
Units: Ha
Range: MPS > 0, without limit.

Description: MPS equals the pond area (m^2) of all ponds of the corresponding patch type, divided by 10,000 (to convert to ha).

3. Number of Ponds, NP.

$$NP = n_i \tag{3.3}$$

Level: CLASS, LANDSCAPE
Units: None
Range: NP > 1, without limit.

Description: NP equals the number of ponds of the corresponding patch type (class).

4. Mean Pond Fractal Dimension, MPFD.

$$MPFD = \frac{\sum_{j=1}^{n}\left(\frac{2\ln p_{ij}}{\ln a_{ij}}\right)}{n_i} \tag{3.4}$$

where a_{ij} = the area of pond *ij* (in m^2).
n_i = the number of the pond *ij*.
p_{ij} = the perimeter of pond *ij* (in m).

Level: CLASS, LANDSCAPE
Units: None
Range: 1 < MPFD < 2

Description: MPFD reflects shape complexity across a range of pond size. It equals 2 times the logarithm of pond perimeter (m) divided by the logarithm of pond area (m^2) (Li and Reynolds 1994). MPFD approaches 1 for shapes with very simple perimeters such as circles or squares, and approaches 2 for shapes with highly convoluted and plane-filling perimeters.

5. Mean Shape Index, MSI.

$$MSI = \frac{\sum_{j=1}^{n} \frac{p_{ij}}{2\sqrt{\pi \times a_{ij}}}}{n_i} \qquad (3.5)$$

where a_{ij} = the area of pond *ij* (in m^2).
n_i = the number of the pond *ij*.
p_{ij} = the perimeter of pond *ij* (in m).

Level: CLASS, LANDSCAPE
Units: None
Range: MSI > 1, without limit.

Description: MSI equals the sum of the pond perimeter (m) divided by the square root of pond area (m^2), and divided by the number of ponds. MSI represents the mean shape pattern. If MSI = 1, the pond is circular and increases without limit as pond shape becomes more curvilinear.

6. Edge Density, ED.

$$ED = \frac{\sum_{k=1}^{n} e_{ik}}{A}(10000) \qquad (3.6)$$

where e_{ik} = the total parameters between pond$_i$ and landscape$_k$ (in m).
n = the number of the pond; a single pond in this case equal to 1.
A = pond area (in m^2).

Level: CLASS, LANDSCAPE
Units: None
Range: MSI > 1, without limit.

Description: Edge density (in m/ha) equals the pond perimeter (in m) divided by the pond area. Edge density is a measurement of the complexity of the shape of pond.

7. Total Edge, TE.

$$TE = \sum_{k=1}^{n} e_{ik} \tag{3.7}$$

where e_{ik} = the total perimeters between $pond_i$ and $landscape_k$ (in m).
n = the number of the pond; a single pond in this case equal to 1.

Level: CLASS, LANDSCAPE
Units: meters
Range: MSI > 0, without limit.

Description: Total Edge (TE) represents the total pond perimeters in meters.

Table 3-1. Definition and description of parameters used in the patch analysis of factors explaining remained/disappeared farm ponds and the influences on bird communities.

Types	Item Acronym	Pondscape Parameters (Metrics/Units)	Spatial Pattern
Micro-Scale	[b]PS	[2]Pond size	Pond size
	[b]LPI	[1, 2]Largest pond index (3.1)	Pond size
	[b]MPS	[1, 2]Mean pond size (ha) (3.2)	Pond size
	[b]NP	[1, 2]Numbers of pond (3.3)	Pond size
	[b]MPFD	[1, 2]Mean pond fractal dimension (3.4)	Pond shape
	[b]MSI	[1, 2]Mean shape index (3.5)	Pond shape
	[b]ED	[1, 2]Edge density (m/ha) of selected ponds (from TE) (3.6)	Pond shape
	[b]TE	[1, 2]Total parameters (in coverage units) of selected pond edge (3.7)	Pond shape
	[b]FCA	[2]Foliage canopy area next to waterfront edge of a pond (m^2)	Boundary delineation of disturbance
	[a,b]MUDA	[2]Mudflat area in a pond (m^2)	Boundary delineation of disturbance
	[a,b]WASA	[2]Water surface area in a pond (m^2)	Boundary delineation of disturbance
	[b]%FCA	[2]FCA ÷ PS	
	[b]%MUDA	[2]MUDA ÷ PS	
	[b]%WASA	[2]WASA ÷ PS	
	[a]ELVA	[2]Elevation (m)	

Table 3-1. Continued.

Types	Item Acronym	Pondscape Parameters (Metrics/Units)	Spatial Pattern
	[a]PERI	[2]Perimeter (m)	
	[a]TOPO	Waterfront topology (bold line represents pavement Raised:  Level: 	
	[b]D-U	[2, 3]Distance (m) to urban limit	Pond isolation from sources
	[b]D-C	[2,3]Distance (m) to coastline	Pondscape connectivity from sources
	[b]%FARM	[2, 3]The ratio of farmland areas within a radius of 100 ha from the pond's geometric center (m^2)/ha.	Pondscape isolation or connectivity from sources
Meso-scale	[b]%BUILD	[2, 3]The ratio of permanent building areas within a radius of 100 ha from the pond's geometric center (m^2)/ha.	Pondscape isolation from sources
	[b]%PONDS	[2, 3]The ratio of multiple pond areas within a radius of 100 ha from the pond's geometric center (m^2)/ha.	Pondscape connectivity from sources
Meso-scale	[b]%RIVER	[2, 3]The ratio of all watercourse areas covered by rivers, creeks, channels, and ditches within a radius of 100 ha from the pond's geometric center (m^2)/ha.	Pondscape connectivity from sources
	[b]%ROAD	[2, 3]The ratio of all road and trail areas within a radius of 100 ha from the pond's geometric center (m^2)/ha.	Pondscape isolation from sources

Notes:

[1] Metrics and units: calculation formulae see 3.1 to 3.7.
[2] The final results for explaining pond and avian losses were due to being: (1) highly correlated ($r \geq 0.5$), (2) moderately correlated ($0.5 > r \geq 0.25$), or (3) slightly or none correlated ($r < 0.25$) due to a badly located or dysfunctional pondscape, thus, the pond disappeared and/or the birds are gone.
[3] The mean values are expressed in percent. The different land use types were measured as a percentage area of a circle with an area of 100 ha (radius = 564.19 m) centered on each of the bird survey ponds ($n = 45$). The range of the percentage area of each land-use type is also given.
[a] Parameter measure obtained from field measurements.
[b] Parameter measure obtained from a geographic information system (GIS) and other sources (Department of Land Administration, Ministry of the Interior 2002; Agricultural and Forestry Aerial Survey Institute 2003).

<u>Pondscape Analysis</u>

In this section, two ArcView 3.2®-extended approaches were used (ESRI, Relands, CA 2004). First, I used FRAGSTATS®, a spatial pattern analysis program, to compute the pond metrics of the digital map patterns (McGarigal et al. 2002). This program was used for quantifying, analyzing, and interpreting the structure (i.e., area, shape, and edge) of a pondscape. Interpretation of pond changes from 1904 to 1999 was made when pond metrics were calculated from digital image files of the five periods. Second, I used logistic regression approaches (maximum likelihood estimates) to predict the likelihood of the occurrence of a pond remaining or disappearing using *Logit*. The *Logit* of a number *p* between 0 and 1 is the plot of *Logit* in the range 0 to 1, based on *e*. If the likelihood of a pond loss is *Pi,* then the probability of pond that remains is *(1 - Pi)*. *Pi*/(*1* − *Pi*) is the corresponding odds. Estimation and prediction by this method is described as (also see (2.1)~(2.4)):

$$Pi/(1-Pi)=e^{\beta_0+\beta iXi} \text{ or} \tag{3.8}$$

$$ln[Pi/(1-Pi)] =\beta_0+\beta iXi \tag{3.9}$$

where

ln is the natural logarithm, $\log_e$, where e = 2.71828…
Pi is the likelihood that pond-loss occurs,
Pi/(1-Pi) is the “odds ratio”,
ln[Pi/(1-Pi)] is the log odds ratio, or “*Logit*”,
all other components of the model are the same, such as:

$$\hat{P}_i = \frac{e^{\hat{y}_i}}{(1+e^{\hat{y}_i})} \tag{3.10}$$

while

$$yi = exp(\beta_0+\beta_1 x_1+\ldots+\beta_m x_m)/[1+exp(\beta_0 +\beta_1 x_1+\ldots+\beta_m x_m)]$$

$$\text{or} \quad \bar{y}_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \cdots + \beta_m x_{im} \qquad (3.11)$$

$x_{i1},....x_{im}$ are *m* parameters of the *i*th pond, and the likelihood is justified by internal driving forces m_s (i.e., the size, shape, etc). Logistic regression coefficients were interpreted when parameters were correlated to explain conditions which had vanished. I removed some parameters from this analysis because of their slight correlation. Some vulnerable parameters (i.e., highly correlated with ponds which had disappeared) were selected. Final parameter coefficients with a $p_{value} \leq 0.05$ were considered significant. The NCSS® 2004 Statistical Analysis System (NCSS, Kaysville, UT 2004) for Windows® statistical package was used for this analysis.

Patch analysis and regression approaches were not only calculated for the purposes of historical pond loss, but helped determine factors correlated with the distribution of avian communities. As previously stated, one of the study purposes was to examine the relationships between pondscapes and birds. Therefore, a field survey on the avian community was required. The next section provides an overview of the survey methods that were used to collect and analyze data. A general comparison of each survey's results, such as numbers of species and individuals, species richness, and diversity are described in detail below.

BIRD ANALYSIS

Two bird analyses are traditionally used for entire avian communities and specific avian groups by determining individuals, richness, and diversity. Differences in the characteristics of avian groups and pondscape configurations may cause species-area relationships to vary among regions. Therefore, to find differences in the response of species to habitat area and isolation, studies must include multiple analytical approaches to detect which analysis is better based on entire communities or on specific groups.

Community Analysis

Descriptive statistics for an entire community were used as the first stage of statistical avian data processing. The main aim was to conduct an initial analysis of the distribution of avian communities, such as average individual values; guild values were later described for specific groups. Afterwards, avian diversity was described by the results of diversity indices for single groups and for the entire community (Hill 1973; Hattori and Mai 2001). To determine species evenness and abundance, I used the Shannon-Wiener diversity index (H') (also named the Shannon index or Shannon-Weaver index) which provides a measure of the richness and relative density of a species as an indication of diversity (Shannon and Weaver 1949). This diversity measure, devised by Shannon and Weaver, originally came from information theory and measures the order observed within a particular system. In regard, to my studies, this order was characterized by the number of avian individuals observed for each species in the sampled ponds. The first step was to calculate P_i for each category (i.e., avian species), then I multiplied this number by the log of the number. The index was computed from the negative sum of these numbers. In short, the Shannon-Wiener index *(H')* is defined as equation 3.12, and is also described in (2.3) above:

$$H' = -\sum_{i=1}^{S} P_i \log_2 P_i \tag{3.12}$$

where *S* is the avian species richness and *Pi* is the percentage of the *i* species in an avian community. This index reflects the richness in species and evenness among an avian community. The benefits of *H'* are that it is more sensitive to changes in threatened birds in avian studies than is Simpson's diversity index (*D*) (Dean et al. 2002). If the value of *H'* is higher, it means that a species is abundant, or that the species distribution is even. However, with species diversity, it is sometimes difficult to see relationships with spatial heterogeneity using limited survey data. Grouping and classification are required as well as a reduction in spatial heterogeneity for the analyzed parameters. This is the main procedure in the methodology for analyzing avian groups with similar attributes of spatial behavior. The main approach in cluster analysis application is based on the idea of representing the grouping structure by avian data classification, based on the similarity of guilds between species as described in the pages below.

Cluster Analysis

Cluster analysis was used to identify relationships among attributes of multivariate samples and has been applied to many fields of scientific studies. First used by Tryon (1939), this analysis encompasses a number of algorithms which group parameters on the basis of similarities or distance (dissimilarities). The objective of cluster analysis was to group data into clusters such that the elements are within guilds (Root 1967; Recher and Holmes 1985; French and Picozzi 2002). These clusters have a high degree of "natural attributes" among themselves, while they are "relatively distinct" from others. To illustrate their relationships, many criteria have been described: partitioning methods, arbitrary origin methods, mutual similarity procedures, and hierarchical clustering methods. One of the most widespread hierarchical clustering methods is Ward's method (Ward 1963; Hair et al. 1998; McKenna 2003; Oppel et al. 2004).

Cluster analysis is very useful during the exploratory phase of examining large avian databases, especially when a prior hypothesis is lacking; nevertheless this is not a typical statistical procedure and a test for significance of avian groups is not available. Cluster analysis proceeds in two steps: a choice of a proximity measure and a choice of a group-building algorithm. I adopted a hierarchical clustering procedure that produces a series of data partitions. The first partition consists of *n* single-member groups, and the last consists of a single group with all *n* members. Differences between the procedures arise because of the different ways homogenous groups are defined.

In this project, avian groups were formed from individual taxonomies by merging the nearest neighbors by their habitat preferences, where the "nearest neighbors" denotes the smallest distance or largest similarity. Measuring the likelihood of species occurrence in anchoring microhabitats, I tried to find the smallest distance and merge the corresponding taxonomies according to their habitat selection. The term, "habitat selection", means the favorite locations which principally reflect species bio-choices to stay in the air, on the water surface, on mudflats or pond edges, or in trees, bushes, or wetland grasses, where they forage, nest, and roost. This anchoring preference can be calculated as the average likelihood of occurrence for all avian data from the surveys.

The clustering results can be graphically displayed in the form of a dendrogram, or a tree diagram representing clusters (Figure 3-4). Merging at nodes along a distance (dissimilarity) axis, clustering processes indicate the level at which avian grouping fusion occurs. In order to avoid "loss of information" from joining two avian groups, I adopted Ward's hierarchical clustering procedure, also known as the method of "minimum variance", which forms data partitions to minimize the loss of information associated with each grouping. The aim of Ward's procedure is to find those two clusters at each stage whose merger gives the minimum increase in the total within-group sum-of-the-squares error. In this case, information loss was defined in terms of a sum-of-the-squares error criterion. This method which uses loss of information as an increase in an error sum-of-the-squares criterion is represented by

$$ESS_i = \sum_{j=1}^{n_i} \sum_{k=1}^{p} (x_{ijk} - \overline{x_{ik}}) \qquad (3.13)$$

where x_{ijk} is the multivariate measurement associated with the *j*th item and $\overline{x_{ik}}$ is the mean of all items.

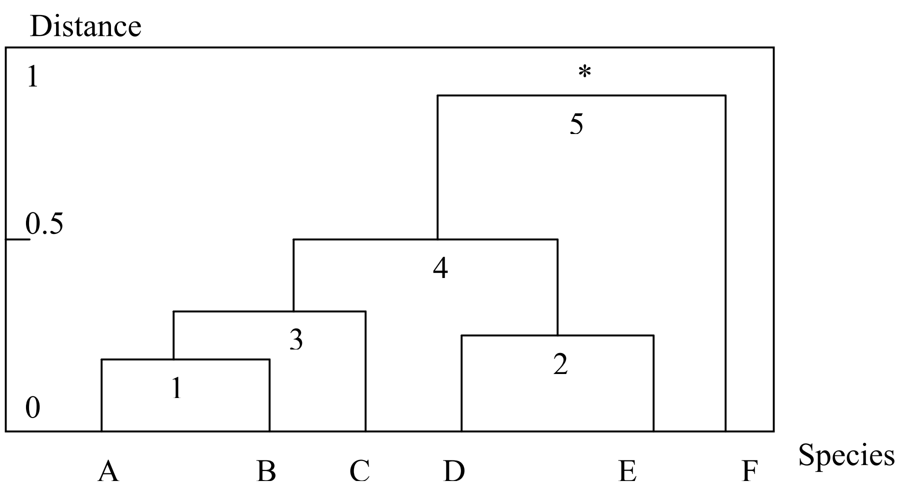


Figure 3-4. Dendrogram showing the classification of avian data. Letters along the x-axis identify individual species. The number below each linkage indicates the order in which each fusion occurred. Ward's method was applied with the distance (dissimilarities) index. The asterisk (*) identifies a linkage between two significantly different groups (α = 0.05).

Total within-group error sum-of-the-squares ESS_i is defined as one stage with k groups, j parameters, and n_i elements in each group. So, following the summation order, the first sum corresponds to the variability within a group for a given parameter, the second one sums up all parameters, and the last one is the total variability. The cluster analysis was performed with the computer package, SAS® 8.0 for Windows® (SAS Institute, Cary, NC 1999). The avian sample consisted of the 45 ponds with avian survey data available from winter 2003~2004.

BIRD-PONDSCAPE LINEAR RELATIONSHIP

Once parameters of the farm ponds were selected, the relationships of pond birds with pondscapes were analyzed. In general, wetland birds indicate the physical structure and land-use conditions of farm ponds (Rutschke 1987). Because of their sensitive behavior, it is possible in this case to correlate changes in the environment with bird communities. Because they are vulnerable to anthropogenic influences, there are two models to predict avian diversity as correlated with pondscape-associated land-use types. First, I calculated a regression model for wintering birds and pondscapes. The best fit line associated with the n points $(x_1, y_1), (x_2, y_2), \ldots, (x_n, y_n)$ had a linear form:

$$y = mx + b \quad \text{where}$$

$$m = \frac{n\left(\sum xy\right) - \left(\sum x\right)\left(\sum y\right)}{n\left(\sum x^2\right) - \left(\sum x\right)^2} \tag{3.14}$$

$$b = \frac{\sum y - m\sum x}{n}$$

The bird-diversity value, *y*, was justified by external anthropogenic driving force, *x*, (i.e., PS, TE, etc.). Interpretations of regression coefficients (*b*) were made when parameters were correlated to explain avian diversity. I removed some noisy parameters from this analysis because of their slight or lack of correlation ($r < 0.25$). Some parameters (i.e., those highly correlated ($r \geq 0.5$) or (2) moderately correlated ($0.5 > r \geq 0.25$) with bird diversity) were selected. Parameter coefficients with a $p_{value} \leq 0.05$ were considered significant. SPSS® 9.0 for Windows® (SPSS, Chicago, IL 1998) statistical package was used for this analysis. Therefore, the final simulated bird distributions by linear regression model should predict more-detailed contours of wintering bird diversity.

BIRD-PONDSCAPE NON-LINEAR RELATIONSHIP

Linear statistical models were used in the previous section. However, some authors have argued that regression models do not fit non-linear relationships and interactions among parameters. Virkkala (2004) confirmed that avian habitat selection is a dynamic and nonlinear process. Therefore, species-habitat relationships often yield skewed and bimodal data. There are also other complexities associated with fluctuating avian populations and hierarchical decision-making on different scales before final habitat selection. These highly complex relationships between birds and their microhabitats are inherently unpredictable. However, on a local scale, many habitat models for birds have achieved considerable success in predicting habitat selection. To deal with the complexities associated with habitat models, I used an artificial neural network (ANN) approach. An important advantage of using an ANN model is its non-parametric nature as suggested in Chapter Two. It is not necessary to transform data to match a certain distribution. ANN models can be non-linear and can model logical expressions such as “and”, “or”, “not”, and “exclusive of” as described below.

SIMULATION MODELS

A combination of GIS layers based on pondscape information for decision-making was developed in a previous study (Lin and Lin 1999; Lin et al. 2001). First, a diversity-based contour layer was created in ArcGIS® for the winter of 2003~2004. This base layer included the structural information on all farm ponds, such as area, shape, edge, connectivity, and clustering. Then, additional layers were created for vegetation, watercourse, transportation, urban, and demographic data compared against wintering bird distributions. These parameters focused on spatial relationships and attributes, such as: (1) area (efficient water volume and suitable water depth), (2) shape (curvilinear), (3) edge (rice fields and open spaces), (4) connectivity (adjacent to watercourses, rice fields, and open spaces), (5) clustering (stepping stones for bird dispersal), (6) socioeconomic parameters (anthropogenic disturbance from urbanization) and supported bird yields (i.e., crops, fruits, and cultured fish for their diets), and (7) socio-demography (low population density).

I analyzed the data sets with (1) the traditional method of multiple linear regression (MLR), to obtain a predictive model of reference and (2) an artificial neural network (ANN) method, to evaluate the performance of this recent method for non-linear modeling. To compare these two methods, the entire set of available data was used. To justify the predictive capacity of the MLR and ANN methods, modeling was carried out on a matrix (45 ponds with three to four pondscape parameters) in order to perform the MLR and ANN. The correlation coefficient (r) between observed and predicted values was used to quantify the capability of the models. These two methods are described below.

<u>Linear Model</u>

Based on logistic regression and criteria selection, I present three gradients of land development intensities as follows. The MLR model was:

$\bar{y}_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \cdots + \beta_m x_{im}$, for which $x_{i1},....x_{im}$ are *m* parameters of the *i*th pondscape, and the likelihood of pond loss (*yi*) was justified by m_s (i.e., size, shape, etc). All scenarios were divided into (1) scenario A of conservative land-use intensities; (2) scenario B of moderate land-use intensities; and (3) scenario C of intensive land-use intensities, as shown in Table 3-2.

Table 3-2. Strategic landscape scenarios for farm pond adjacent land-uses.

Scenarios of land-use intensities	Pond-Loss likelihood	Impacts on avian group diversity	Relative decisions for pondscape	Decision-making priority for units of land uses
A: Conservative	25%	Relatively low	Refuges designed for large Ponds	Pond, river, rice field, open space, road, and constructed areas, respectively.
B: Moderate	50%	Medium	Refuges designed for medium and large ponds	
C: Intensive	75%	Relatively high	Refuges designed for small, medium, and large ponds	

Since the simulation based on the gradients of land development intensities according to the maximum likelihood of pond loss was developed as a GIS model, this result also affected bird losses (Table 3-2). The MLR model was calculated again as the previous formula: $\bar{y}_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \cdots + \beta_m x_{im}$, where $x_{i1},\ldots x_{im}$ are m parameters of the ith pondscape, and the avian diversity (yi) was justified by m_s (i.e., size, shape, etc.). Therefore, both wintering bird distribution and the likelihood of pond loss were predicted. Final results of overlaying the GIS layers for setting priorities are illustrated for refuges in a given year to avoid pond and bird losses.

Non-linear Model

The MLR model is identical to a neural network with no hidden units. For hidden units of a neural network, each hidden unit computes a logistic regression (which differs for each hidden unit), and the output is therefore a weighted sum of the logistic regression outputs. Initially, artificial neural networks (ANN) were developed to provide simplified models of biological neural architecture. Each of these domains can be characterized as ones in which (1) multiple hypotheses need to be pursued in parallel, (2) enormous amounts of data need to be processed, and (3) the best current systems are far inferior to human performance.

The error back-propagation (BP) training algorithm has proven to be one of the most useful approaches developed for creating ANN. This algorithm adjusts the connection weights according to the back-propagated error computed between the observed and estimated results. This is a supervised learning procedure that attempts to minimize the error between the desired and predicted outputs. For this research, I chose a three-layered model with one input layer of three to four neurons (one for each input parameter), one hidden layer of two to eight neurons (a number which gave the best prediction result), and one output layer of one neuron which was the output parameter (Figure 3-5). Each neuron in the input layer was connected to all neurons in the hidden layer via adjustable weighted links, as was also true for the hidden layer and the output layer.

In the process of BP creation, the input data pattern is presented at the input neurons. These values are propagated through the network from the input to the hidden layer and then from the hidden layer to the output layer. At each stage, the values, i.e., the summed weighted inputs, are multiplied by the individual links for each connection. Then, the output layers are generated by the network based on the input data set. The errors, based on the differences between the "true" output and the "test" output, are fed back through the propagated loops. The individual weights associated with each of the connections to the hidden neurons are slightly adjusted to diminish the error.

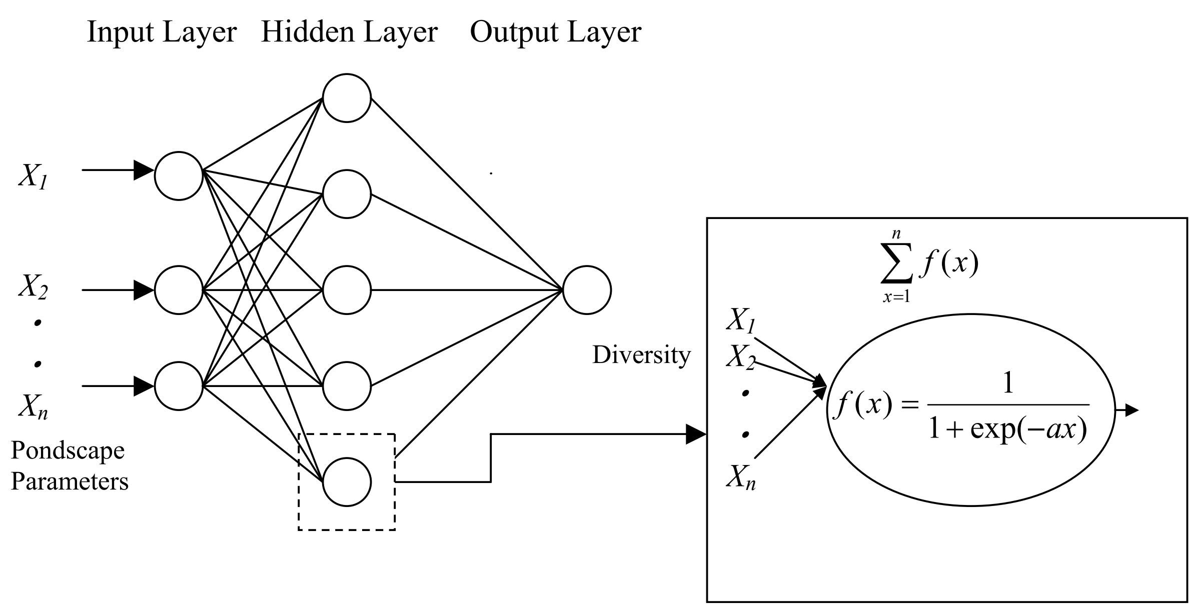


Figure 3-5. Structure of neural networks used in this study based on the error back-propagation (BP) training algorithm. Input layer of neurons comprising as many neurons as pondscape parameters at the entry of the system; hidden layer of neurons whose number is determined empirically; output layer of neurons with a single neuron (i.e., diversity) corresponding to the single dependent parameter.

Modeling was carried out in two phases to allow adjustment of the training set and then testing with the experimental set to determine the best ANN configuration. First, the model was tested to calibrate the model parameters. Second, to test and estimate the ANN models, I randomly selected a training set (80% of the pond records, i.e., 35), a validation set (20% of the pond records, i.e., 10), and an extrapolated set (i.e., 10 extra surrounding pond sites for estimation) (Palmer 1990). For each of the two sets, the model was determined with the training set and then validated with the test set. The quality of the model was judged through the correlation between observed and predicted values in the validation set. The ANN analysis was performed using the computer package, MATLAB 6.1 (MathWorks, Inc., Natick, MA 2001).

SUMMARY

Among the greatest threats to habitat persistence of farm ponds is loss-induced fragmentation leading to reduction of original pond size, severance of connections between adjacent pond connection, and decreased windbreak edges. For long-term sustainability, it is important that conservation efforts counter these effects of pond losses. To do so requires spatial targeting of farm-pond habitat studies. Herein I present a series of hypothetical conservation scenarios on a part of the Taoyuan Tableland, Taiwan, with the aim of countering the adverse effects of habitat loss. Scenarios were investigated, each with a different guild emphasis, reflecting the necessities of formulating multi-objective conservation strategies. These focused on pond size, pond shape, pond isolation, pond sustainability, and diversity for different bird groups. These aims centered on habitat patch size, woody patch (i.e., windbreaks) size, habitat patch isolation, avian diversity, and pond sustainability. Throughout the detailed survey over 4 months which focused on studies of pondscapes and bird materials, two methods were applied to detect the likelihood of pond and bird loss: (1) a linear regression and (2) a non-linear regression. The linear regression was first applied to predict the spatial diversity of wintering birds; then an artificial neural network was used to predict spatial diversity depending on the mechanisms of the error back-propagation processes. This network consisted of an input layer, hidden layer, and output layer. All neurons of each layer were connected by an axon to all neurons of the next layer. Based on self-adjustment of model training, errors computed between the observed and estimated results from layers were weighted and avoided. Therefore, the quality of the artificial neural network model was improved through a repeated validation process.

CHAPTER IV

RESULTS I

This chapter examines historical trends in land use transformation which have taken place in the farm-pond areas of the Taoyuan Tableland, Taiwan. It demonstrates that installation of irrigation systems and urbanization was the key factors undermining and catalyzing changes in pondscapes. Therefore, land transactions have increased the overall transformation of land use over the entire area. Unregulated urbanization has given rise to complex organic urban structures which have predominantly expanded horizontally. The emerging land use patterns indicate a mismatch with the formerly extensive pondscapes and farmlands. Land-use changes over two time periods, 1926 to 1960 and 1960 to 1999, were analyzed to demonstrate how enforcing land-use policies can influence the direction and magnitude of pondscape changes. First, adoption of a grand canal irrigation system resulted in the internal restructuring of agricultural land use from traditional farm-pond irrigation to more-diversified water sources, such as from ditches, canals, and reservoirs. Spatial dependency of pondscape changes could be identified between the northern irrigation system (Taoyuan Main Canal) from 1926 to 1960 and later, the southern irrigation system (Shihmen Main Canal) from 1960 to 1999. The relationship between pond area and pond losses was calculated and is illustrated and discussed herein.

PONDSCAPE CHANGES

Generally, the cases presented are based on pondscapes studied between 1904 and 2002 on the Taoyuan Tableland. The data covered four periods of land-use patterns and were obtained by examination of historical maps as well as recent aerial photographs. I produced land-use maps for several periods through aerial photographs of 2003 (obtained from the Agricultural and Forestry Aerial Survey Institute 2003), and interpreted and verified them by field surveys. Maps of land use were constructed by manually digitizing the boundaries of digital images of historical maps using ArcView® 3.2 software (ESRI, Redlands, CA 2004). First, old and new land-use maps of the entire study area were made from maps taken at 1:20,000 in 1904, at 1:25,000 in 1926, at 1:25,000 in 1960, at 1:25,000 in 1999, at 1:5000 in 2002, and aerial photos taken at approximately 1:5000 in 2003. Second, two contrasting historical periods of pondscape configurations occurred in 1926~1960 and 1960~1999. Because the digital maps of 1904 were at 1:20,000 and those of 2002 and 2003 were at 1:5000 and thus were scaled differently in the production process with those of the other periods, I did not compare each digital map in detail with them.

Between 1926 and 1960, the northern area was subject to irregular construction of irrigation systems with small irregularly shaped rice fields, and between 1960 and 1999, the southern area was subject to construction of irrigation systems with large rectangular rice fields. Both areas were being influenced by urbanization. The main process of classifying land-use categories was subdivision of the land into five types of areas with structures, farmland, farm ponds, roads, and watercourses (canals or rivers)(Table 4-1). The classification was based on field surveys and previous studies which are explained in Lin et al. (2001) and revealed detailed spatial development processes and patterns.

Table 4-1. Land-use categories on land-use maps.

Individual building	Land-use classification[1]
Areas with structures	Single houses, apartment buildings, villages, and high-density housing, commercial plots, and industrial plots
Farmlands	Plots of rice fields and open spaces
Farm ponds	Currently used as fishponds, and those remaining after excavation for irrigation
Roads	Transportation alignment from railways, freeways, and local transportation
Watercourses	Watercourses distinguished as rivers, ditches, and canals by a field survey

[1]Criteria classified from Lin (1996), Lin and Lin (1999), Lin et al. (2001), Fang and Chang (2004), and Fang et al. (2004a, 2004b).

Urbanization

The Taoyuan Tableland has led the nation in economic growth and urbanization processes since the 1960s. Unprecedented land-use changes were seen in the region in the last four decades. In particular, rapid urban expansion triggered the loss of large amounts of agricultural land and farm ponds. It is expected that similar land-use changes will soon be revealed because of the rapid urbanization process. Built-up area trends for the years 1904, 1926, and 1960 overlain on the 1999 map are shown in Figures 4-1, 4-2, and 4-3. By 1960, two eastern urban cores were almost completely covered by built-up areas, for which areas with structures and density had both increased by 1999. The reason for this tendency was that urbanization began near the old main railway running across the southeastern corner within the eastern portion of this area. Since the map of 1960 was first calibrated and created using aerial photographs at 1:5000 (The Combined Logistics Command, Ministry of National Defense 1960), areas with structures show a more-accurate digitized size in comparison with those of the 1904 and 1926. Since 1960, spatial variations in urbanized form changes were identified between cities. Cities undergoing economic development usually had large amounts of land-use changes. Taoyuan City (shape on the upper side of Figure 4-3) and Chungli City (shape on the lower side of Figure 4-3), situated in the eastern part of the tableland at a closer distance to Taipei, had significant percentages of built-up changes of the total land, respectively.

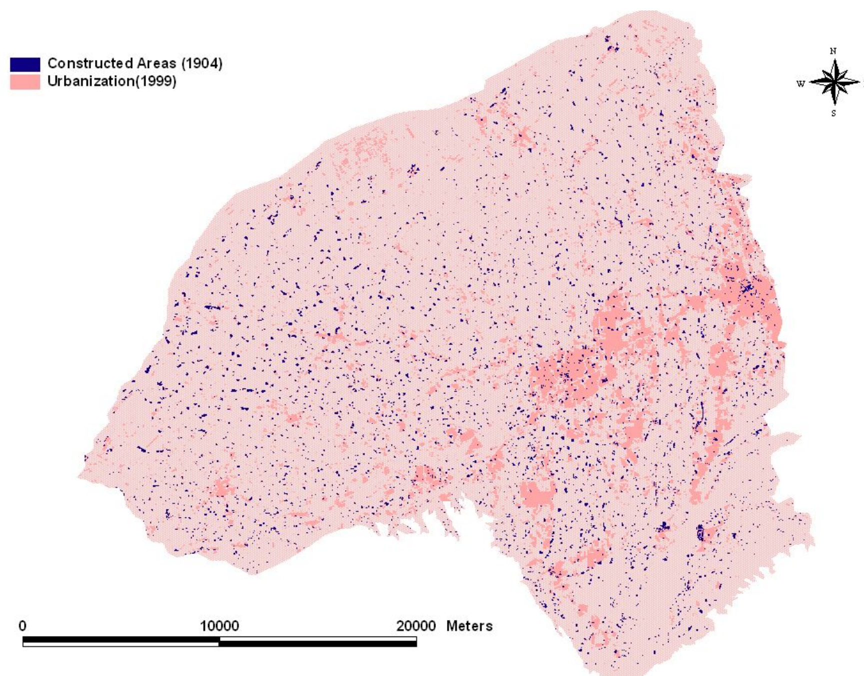


Figure 4-1. The trends of progressive constructed areas in 1904. [use: 10,000; 20,000 m; or 10 and 20 km; Urbanization (1999)]

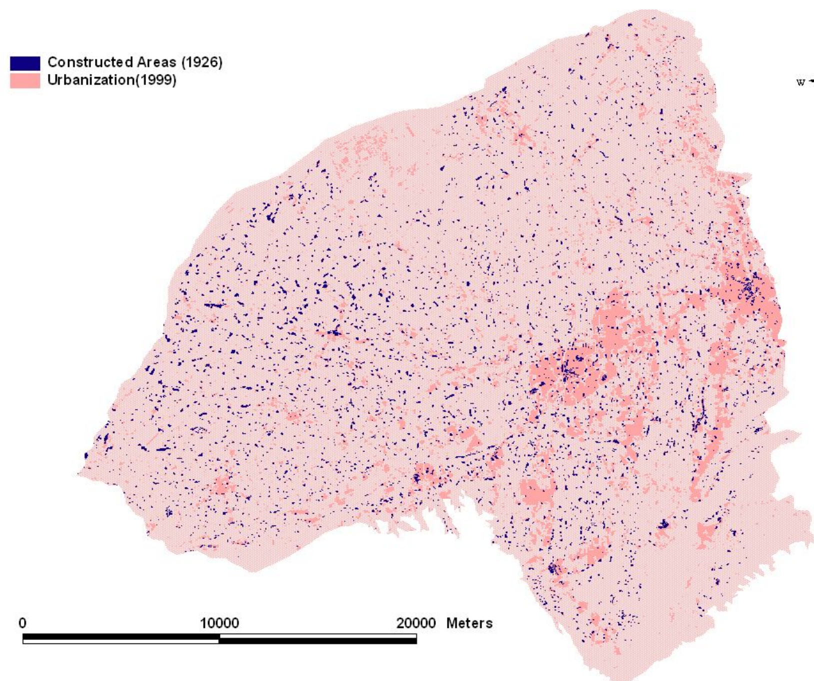


Figure 4-2. The trends of progressive constructed areas in 1926. [use 10,000; 20,000 m; or 10 and 20 km; Urbanization (1999)]

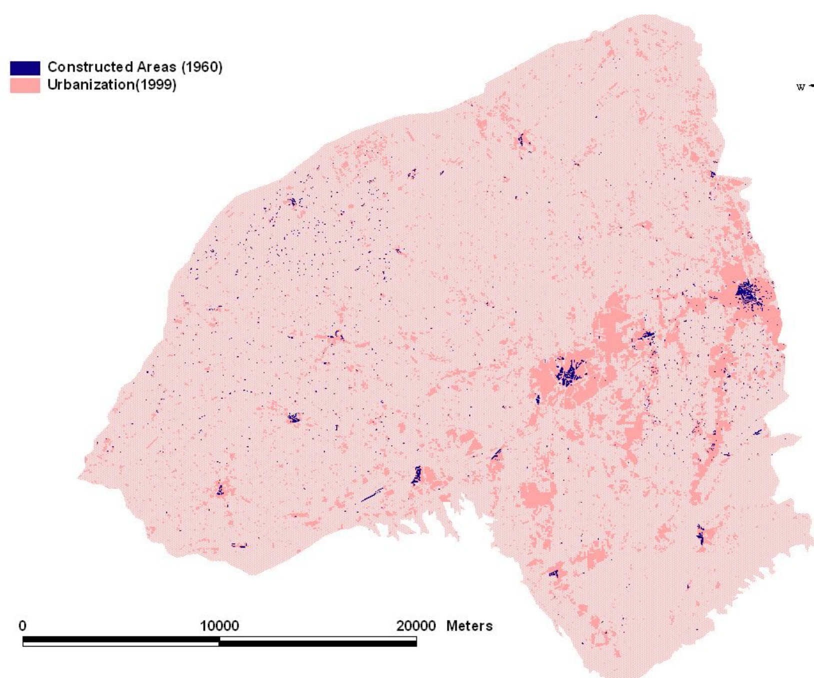


Figure 4-3. The trends of progressive constructed areas in 1960 (first calibrated by aerial photographs, identified precise sizes of constructed areas). [use 10,000; 20,000 m; or 10 and 20 km; Urbanization (1999)]

Farm Pond Trends from 1904 to 1999

Pond losses were partially triggered by urbanization, and partially by changes in irrigation systems. Pondscape and irrigation maps for 1904, 1926, 1960, and 1999 are shown in Figures 4-4, 4-5, 4-6, and 4-7, respectively. Farm ponds covered most of the study area except the southeastern corner since 1904, and an urbanized dendrogram had developed along the eastern corridors by 1999. The first period of 1926~1960 witnessed changes in the northern pondscapes based on irrigation systems. Originally, irrigated and irregularly shaped rice fields occupied this area, but this northern area experienced significant loss of farm ponds between 1926 and 1960, whereas in the southern part, consolidation into large rice fields reduced former farm ponds and watercourses between 1960 and 1999. This difference reflects variations in reclamation and consolidation times. The laterite loamy clay of the northern part was part of the large irrigation project of Japanese colonial rule in the early 20th century, whereas the southern part was gradually reclaimed and reconsolidated over time, chiefly for mechanized farming. Table 4-2 describes measurements of three types of ponds: those remaining, those lost, and those increasing in different periods on the tablelands.

Table 4-2. Pond trends from 1904 to 1999

	Status	No. of individual ponds	Area per pond (ha)	Perimeter per pond (m)
1904~1926[1]	Remaining	2847	2.11±2.51	578±390
	Lost	762	0.82±1.12	352±234
	Increased	1377	0.69±1.36	304±228
1926~1960	Remaining	2643	1.85±2.38	507±321
	Lost	1878	0.94±1.26	358±229
	Increased	488	0.53±1.08	254±284
1960~1999	Remaining	1159	2.68±3.06	627±367
	Lost	2045	0.91±1.27	353±236
	Increased	500	0.63±0.86	308±188

[1] Because the scale of the 1904 maps at 1:20,000 differed from those of other periods at 1:25,000, in my examined results, I did not address and compare the digital results of the period from 1904 to 1926 with that of other periods in the following sections.

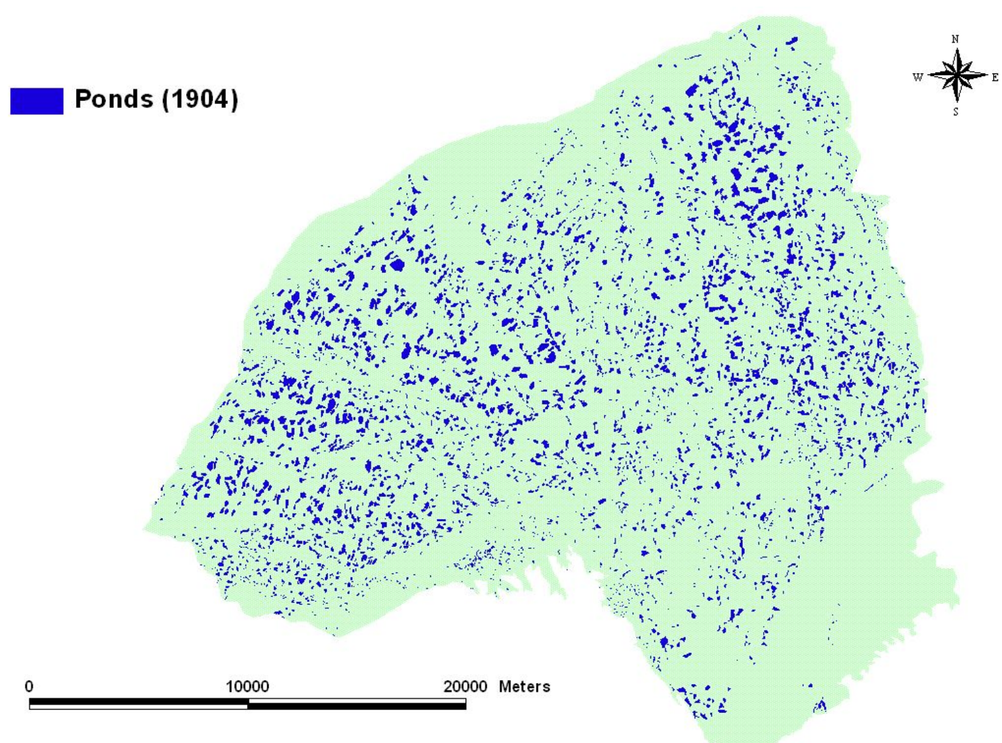


Figure 4-4. Pondscape in 1904.

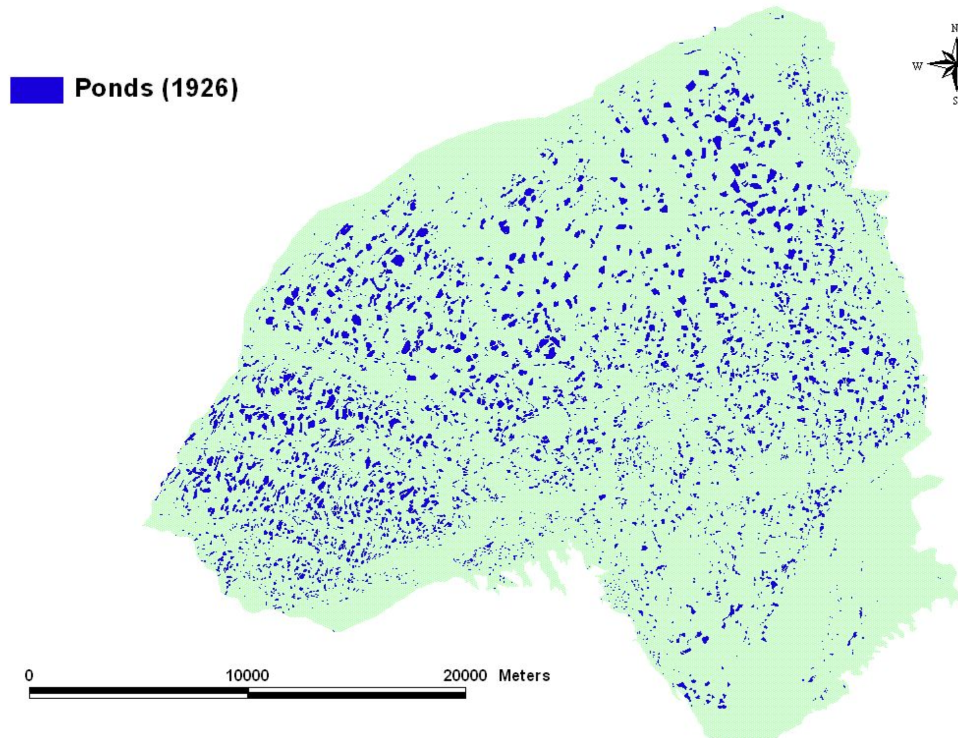


Figure 4-5. Pondscape in 1926.

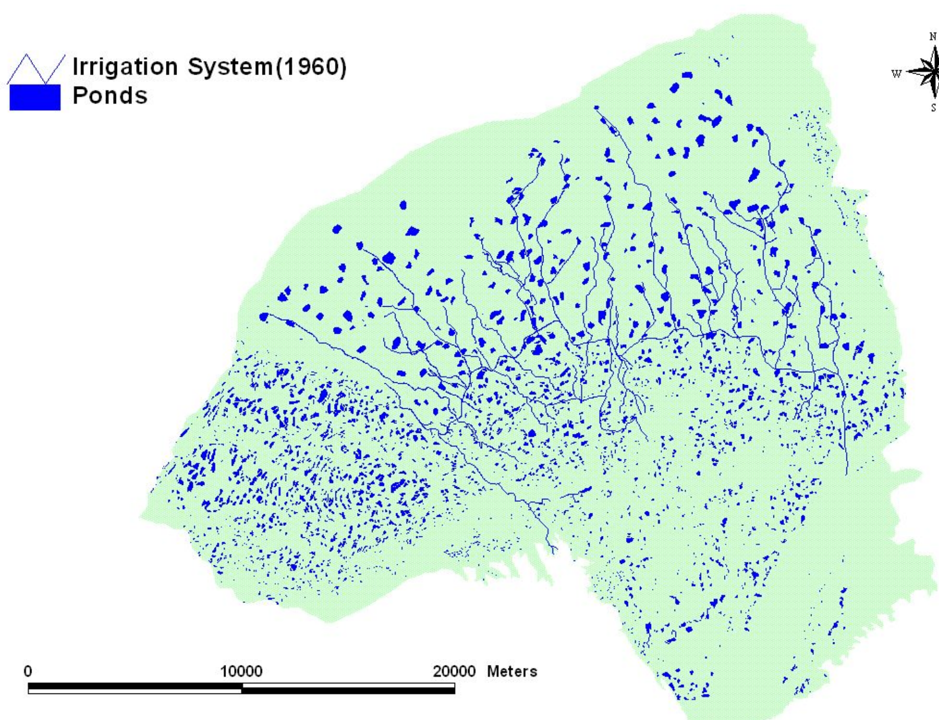


Figure 4-6. Pondscape with Taoyuan main canal system in 1960.

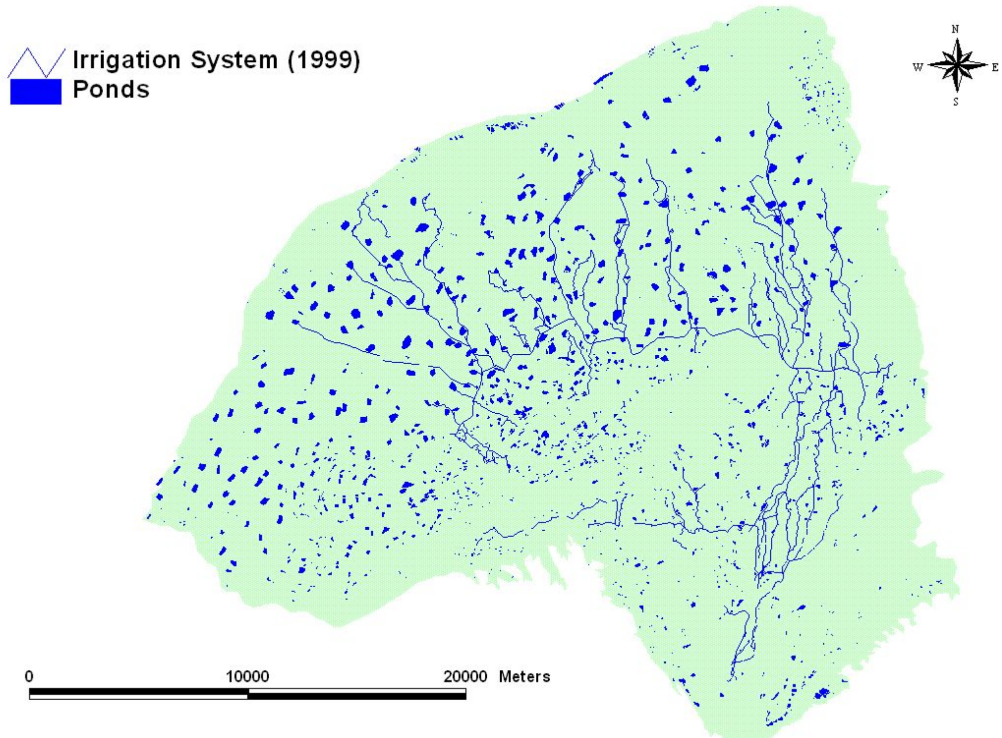


Figure 4-7. Pondscape with Taoyuan and Shihmen main canal systems in 1999.

Pondscape Changes between 1926 and 1960

The proportion of pond areas that underwent changes was as high as 25.3% among total ponds existing in 1926. There were two major types of land use changes: conversion from farm ponds to built-up areas and conversion from farm ponds to croplands. These two types of land use changes constituted about 56.1% of the total pond changes on the Taoyuan Tableland from 1926 to 1960. Pond loss occurred due to different types of changes during the period. The study area lost 3732 ha of ponds from 1926 to 1999, which was 4.9% of the total tableland (Figures 4-8 and 4-10). Smaller pond areas underwent changes from water surface to croplands and built-up areas, due to urban and transportation development.

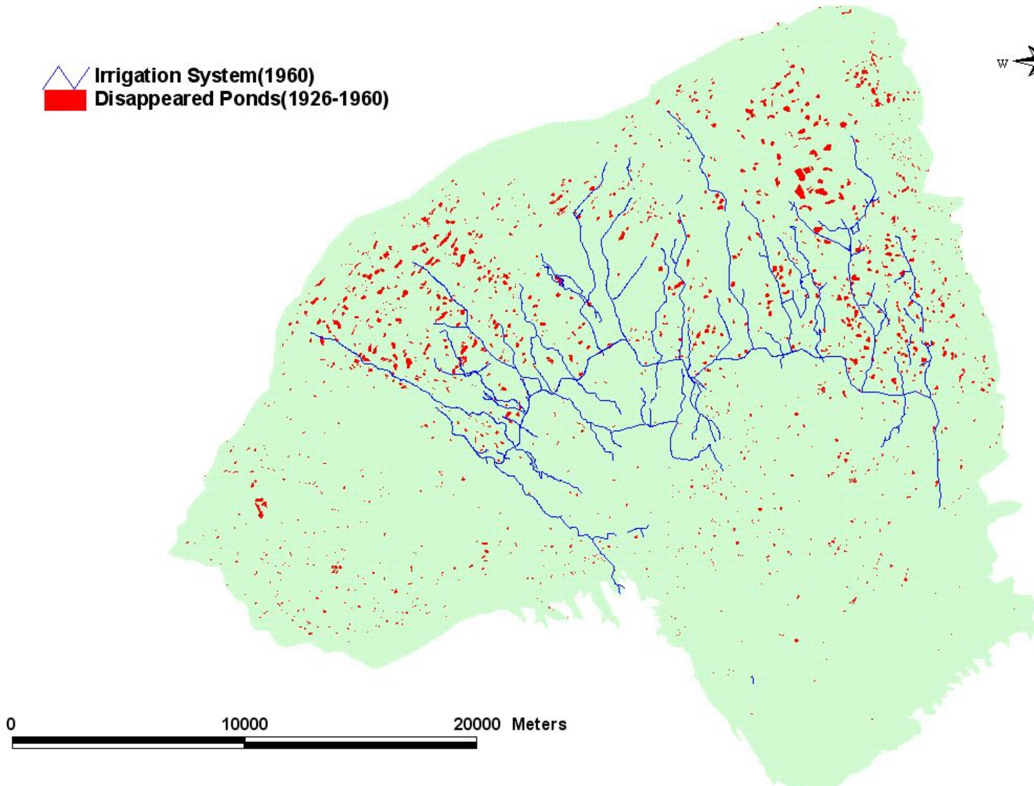


Figure 4-8. Pond losses between 1926 and 1960. [use: Irrigation system (1960); Ponds which disappeared (1926~1960); and either 10,000/20,000 m or 10/20 km]

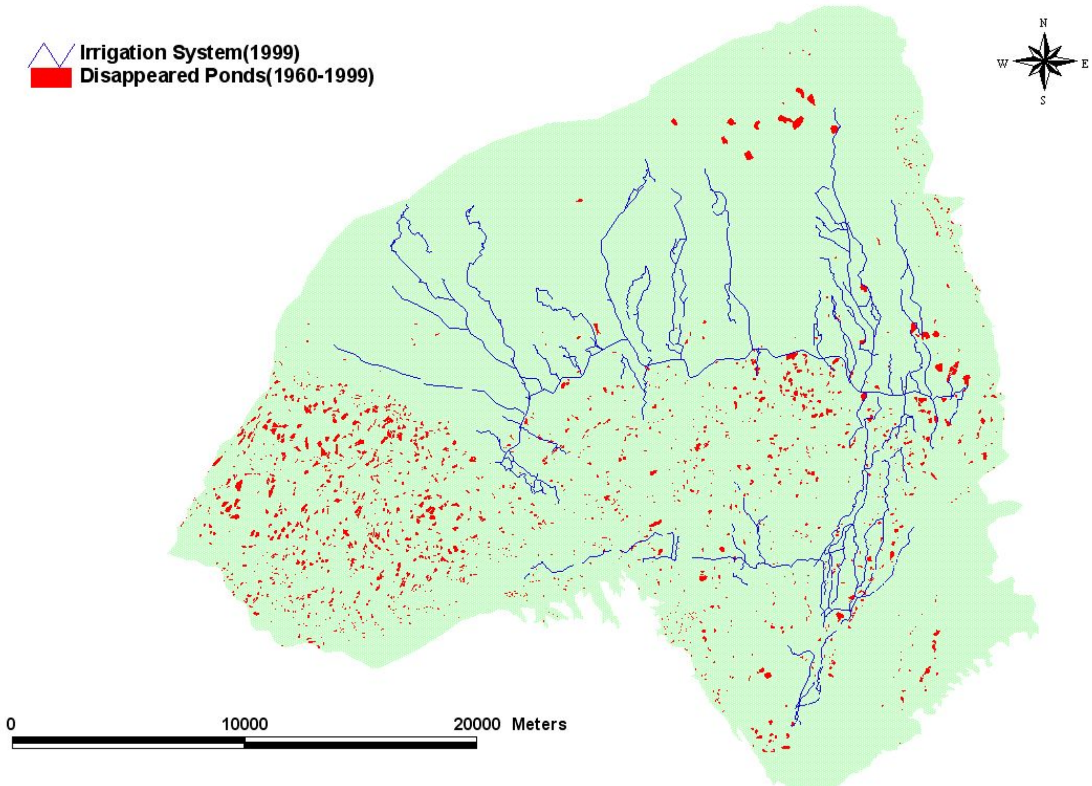
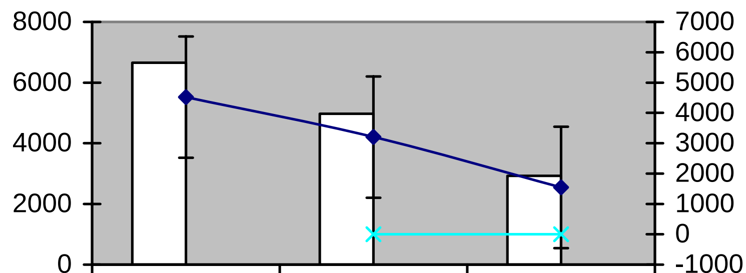


Figure 4-9. Pond losses between 1960 and 1999. [use: Irrigation system (1999); Ponds which disappeared (1960~1999); and either 10,000/20,000 m or 10/20 km]

Pondscape Changes between 1960 and 1999

In the second period of 1960~1999, 41.1% of the ponds underwent changes, but agricultural land losses significantly decreased compared to those of the first period. The region had a total of 2044 ha of farm-pond losses in 1960~1999, which was 2.7% of the total tableland area. The amount of ponds lost in 1960~1999 greatly increased to approximately 1.2 times that of 1926~1960 (Figures 4-8, 4-9, and 4-10). However, agricultural land losses did not completely stop, but took place on a smaller scale. A particular phenomenon was the existence of a large amount of urban lands in the entire region during the period of 1960~1999. Only a small proportion of the development sites in the early 1990s were further developed into built-up areas, while the rest was mostly urban sprawl. Excessive conversion of agricultural land was obvious because of the widespread existence of idle development sites. I, thus, confirmed that the present pattern of pondscapes has been profoundly influenced by past urbanization, which in turn was also adapted to the local environment. Areas subject to consolidation with canal systems possess few ponds, whereas areas subject to non-consolidation with curvilinear creeks and ditches possess clumped-type ponds.



	1926	1960	1999
Area_Ha.	6658	4970	2926
Area Loss Rate		25.30%	41.13%
No.	4521	3204	1545
No. Loss Rate		29.13%	51.78%

Figure 4-10. Farm pond changes on the Taoyuan Tableland (1926~1999) at the same 1:25,000 scale (left y-axis: areas of ponds (ha); right y-axis: individual ponds (no.)).

Sources: Calibrations in Figure 2-1 are from the Department of Survey, Great Japanese Imperial Service (1926), 1:25,000 scale; The Combined Logistics Command, Ministry of National Defense (1960), 1:25,000 scale; Department of Land Administration, Ministry of Interior (1999), 1:25,000 scale, personal digitized from paper maps. Loss ratios were calculated from the reduced areas within periods divided by the areas in previous years.

LOGISTIC REGRESSION

As described above, there were many target classes calculated from FRAGSTAT®, but for this model, the digital historical-map data were aggregated into three land uses, ponds, canal systems, and built-up areas, in order to develop a dataset for a simple binary choice model of "remaining ponds" and "lost ponds" (ponds changed into agricultural and urban land uses). One of the great strengths of modeling with historical records and GIS layers is that you are not simply dealing with the dependent parameter, but you also have the ability to generate other explanatory parameters from the data. Measures such as pond losses as well as other spatial indices of the pondscape determining the configuration of each pond were calculated. This was an attempt to go beyond simple one-dimensional measures of lost ponds, and try to understand more of the spatial reasons for pond losses in the model and to control for how they might have affected pond losses.

The parameters included in the model for each individual pond were PS, LPI, MPS, MPFD, MSI, ED, and TE. These parameters were considered in the model for two reasons: (1) it was indicated that pond size might have affected the anthropogenic choice for conversion into urban and agricultural uses; and (2) at this conversion stage, pond shape might also have been considered when choosing to convert land into urban and agricultural uses. In the logistical regression model, the predicted value for the dependent parameter is never less than or equal to 0, or greater than or equal to 1, regardless of the value of the independent parameters (pond configuration). This was accomplished by applying the following regression equation termed *Logit* (Berkson 1944):

$$yi = exp\ (\beta_0+\beta_1x_1+...+\beta_mx_m)/[1+exp\ (\beta_0+\beta_1x_1+...+\beta_mx_m)] \quad (4.1)$$

Regardless of the regression coefficients or the magnitude of the *x* values, one can easily recognize that this model produces predicted values of y in the range of 0 to 1. The name *Logit* stems from the fact that one can easily linearize this model via the *Logit* transformation. Separate *Logit* models for each of the two time periods (1926~1960 and 1960~1999) were performed for the entire farm pond area of the Taoyuan Tableland. A separate model for each time period was created in order to compare the estimated coefficients from the two time periods, so as to test if the effects of the internal parameters (i.e., pond size and shape) were consistent over time. As the two time period ranges were similar, one would expect the estimated coefficients to be consistent over the two time periods. The estimated coefficients from each of these models are given in Tables 4-3 and 4-4. As this was a discrete choice model, the signs on the coefficients were interpreted and given statistical significance such that a positive coefficient means an increase in the likelihood of pond loss and a negative sign means a decrease in the likelihood of pond loss.

Table 4-3. Binomial logit model of pond losses for the time period 1926~1960. Unit of observation: the individual ponds in 1960 (0: pond losses by 1960, n = 1878; 1: ponds remaining in 1960, n = 2643, p_{value} = **(0.005))

Parameter	Regression coefficient (β)	Wald Z-value (β = 0)	R^2
PS	-0.74	-3.55	0.37**
LPI	-49.05	-3.55	0.37**
MPS	-0.74	-3.55	0.37**
MPFD	80.20	2.71	0.40**
MSI	-0.06	-0.02	0
ED	0.03	0	0.50**
TE	0	-3.16	0.26**

Table 4-4. Binomial logit model of pond losses for the time period 1960~1999. Unit of observation: individual ponds in 1999 (0: pond losses by 1999, n = 2045; 1: ponds remaining in 1960, n = 1159, p_{value} = **(0.005))

Parameter	Regression coefficient (β)	Wald Z-value (β = 0)	R^2
PS	0.42	3.14	0.09**
LPI	20.90	3.14	0.09**
MPS	0.42	3.14	0.09**
MPFD	-26.15	-3.31	0.13**
MSI	-2.14	-1.31	0.02**
ED	0	-3.08	0.14**
TE	0	2.85	0.07**

The overall R^2 for the 1926~1960 model was calculated in Table 4-2, and for the 1960~1999 model was calculated in Table 4-3. Most of the signs on the coefficients remain consistent over time and meet the expectations for the 1926~1960 model: the larger the pond size, the less the likelihood of pond loss; the longer the perimeter of a pond, the less likelihood of pond loss. Pond size and pond perimeter were tested as important independent parameters in building a logistic regression model. To select the simple independent parameters (PS and TE) beyond other calculated synthetic parameters (i.e., LPI, MPS, MPFD, MSI, and ED) which combine the simple factors (PS and TE) as above, the estimated logistic regression model was calculated as:

$$Logit\ (Y) = 1.90 - 3.02PS + 0.01TE \quad (4.2)$$

Think of the binary dependent parameter, Y, in terms of an underlying continuous likelihood of pond-loss rate, Pi, ranging from 0 to 1. Then transform probability Pi by the aforementioned formula as

$$\hat{P}_i = \frac{e^{\hat{y}_i}}{(1+e^{\hat{y}_i})} \qquad (4.3)$$

I calculated Pi as the absence of each pond during the period range of 1926 to1960 using binomial errors and logit links. In this case, β for each model was estimated for a specific group (PS and TE), where:

$$Logit\ (Y) = 1.90 - 3.02PS + 0.01TE \qquad (4.2)$$

To calculate the likelihood, transform the logit using the following formula. The result is illustrated in Figure 4-11; the log likelihood and R^2 were calculated and are given in Table 4-5.

$$\begin{aligned} Pi &= \text{Likelihood of pond loss } (Y=group) \\ &= \exp(1.90 - 3.02PS + 0.01TE)/[1+\exp(1.90 - 3.02PS + 0.01TE)] \end{aligned} \qquad (4.4)$$

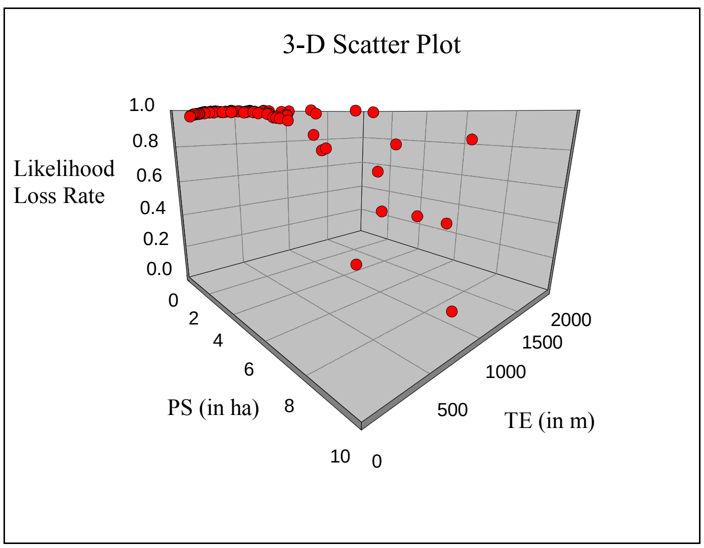


Figure 4-11. Graph showing the three-dimensional surface resulting from different values of the diagnostic scatter plots for the pond likelihood loss rate (0~1.0) from 1926 to 1960 (model $N = 4521$, $R^2 = 0.47$, d.f. = 3). Plots met the expectations for the 1926~1960 model: the smaller the pond size, the greater the likelihood of pond loss ($R^2_{PS} = 0.37$, α = 0.005, β = 0.003, power = 0.997); the shorter the perimeter of a pond, the greater the likelihood for pond loss ($R^2_{TE} = 0.26$, α = 0.005, β = 0.003, power = 0.997, p_{value} (**)).

Table 4-5. Log likelihood and R^2 section.

Terms	d.f.	Log likelihood	R^2 of remaining terms	Reduction from saturated R^2
All	1	-22.70	0	
PS	1	-16.88	0.26^{**}	0.74^{**}
TE	1	-14.28	0.37^{**}	0.63^{**}
None (model)	2	-11.87	0.47^{**}	0.52^{**}
None (saturated)	100	0	1.00	0

However, the overall R^2 for 1960~1999 was slightly statistically significant. This result was not consistent with that expected from pond losses; in most cases, they exhibited regional heterogeneity on the assigned lands. For example, larger pond losses in the northern region occurred from 1960 to 1999 because of construction of an international airport and associated urban development. Small ponds in the southern region disappeared because of farmland consolidation from 1960 to 1999. Therefore, results showed that losses of small ponds were more likely to occur in early agricultural periods (1926~1960) because of replacement by canal irrigation systems, capturing an important dynamic of the irrigated types in the region. However, while this land use from the surrounding pondscapes became diverse and heterogeneous, the configuration of lost ponds was not statistically significant. Therefore, further ecological field research on avian communities was necessary in order to more-completely interpret these pondscape dynamics.

SUMMARY

In summary, in this chapter (1) pondscape contours in the study areas were described; (2) vulnerable parameters, such as the configuration metrics to reduce farm ponds, were examined; (3) quantitative limitations of the vulnerable parameters were analyzed; and (4) pond trends in a historical time range were forecast.

In this chapter, a statistical model was designed to examine how the area-*per-se* effects of farm ponds have driven their loss on the Taoyuan Tableland. The study samples were focused on digital data of pond areas and pond parameters between 1926 and 1960. Regarding anthropogenic activities on the tableland, R^2 values (model N = 4521, $R^2 = 0.47$, d.f. = 3) indicated that significant increases in pond size occurred for remaining ponds. On the other hand, smaller ponds and those with shorter perimeters had significant relationships with pond losses except for the period of 1960~1999. However, the mean size of remaining ponds of 2.68 ha in 1999 was still larger than that of remaining ponds of 1.85 ha in 1960 (Table 4-2). Pond size trends suggest that smaller-sized ponds were lost. According to this result, a logistical regression model was created. On the basis of these findings, the next chapter discusses the results for avian communities, and provides further tests for the area-*per-se* hypothesis with keystone groups, as well as a summarized model which combines species-area and species-habitat relationships.

CHAPTER V

RESULTS II

Farm ponds generally represent a habitat condition somewhere on a continuum between natural and urban environments, and have great potential for supporting varied bird communities. This chapter characterizes the species richness and community structure over a habitat-scale gradient to a landscape-scale gradient of a farm-pond complex. In this study, 45 ponds were surveyed which ranged in area from 0.2 to 20.47 ha within a landscape complex on the Taoyuan Tableland. An avian survey conducted on four occasions between November 2003 and February 2004 detected 15,053 individuals of 94 species. Contrasting responses to pond configurations at the functional group level, and relationships between ponds and bird diversity (*H*') were calculated to assess the effects of pond size and shape within the complex on the species richness and community composition. Seven avian functional groups, representing farm pond species, were identified with respect to pond characteristics. This chapter deals with four main topics: (1) analysis of the results of a wintering bird survey on farm ponds; (2) calculation of coefficients correlating pondscape and anthropogenic influences with avian communities; (3) identification of the correlation coefficients; and (4) creation of a criterion selection model for wintering bird refuges.

AVIAN COMMUNITY

Species Richness

The avian survey detected 94 species at 45 point-count locations associated with line transects of this investigation. In Taoyuan County, 45 species (48%) were winter migrants, and 40 species (43%) were permanent residents. Five transient species (5%) were encountered on the farm-pond sites; one species (1%) was not present at the site previously, and was defined as "missing"; and three species (3%) were exotic species which had escaped from captivity. Total numbers of species in the winter season in the study area varied from a low in February 2004 to a high in December 2003 (Figure 5-1, Table 5-1). I found greater species richness in wintering migrants (48%) compared with permanent residents (45%). On the microhabitat scale, species of the water regime (vertical structure from water table to aerial space) and waterfront edge were encountered most frequently.

Table 5-1. Species richness and individuals of the avian community.

	November 2003	December 2003	January 2004	February 2004	Total counts
No. of species	60	67	62	59	94
No. of individuals	3,721	4,272	3,900	3,160	15,053

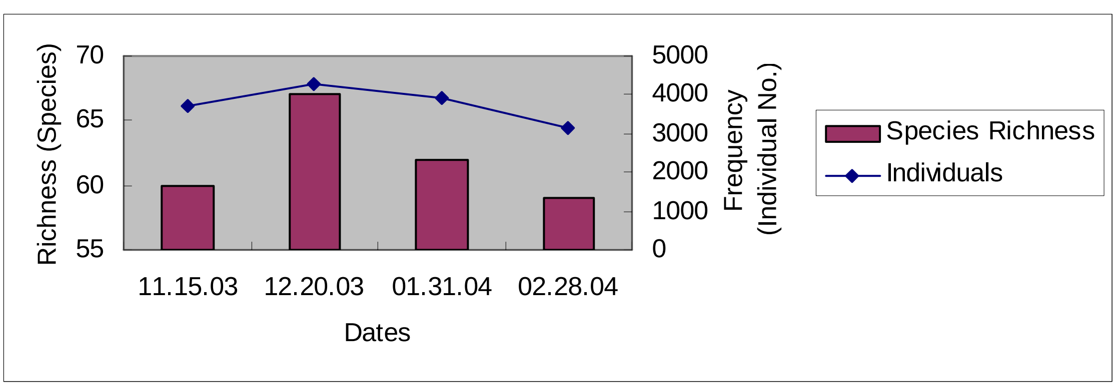


Figure 5-1. Chart of species richness and individuals of the avian community.

<u>Species Abundance</u>

Avian individual frequencies of occurrence were surveyed (Table 5-1, Figure 5-1). I found significantly higher abundances of ten species which accounted for 74% of the entire species abundance. These included the Black-crowned Night-Heron (*Nycticorax nycticorax*) (individual number, (IN) 2363; (OR) occurrence rate (OR), 15.7%; resident), Little Egret (*Egretta garzetta*) (IN, 1883; OR, 12.5%; resident), Grey Heron (*Ardea cinerea*) (IN, 1829; OR, 12.2%; wintering migrant), Light-vented Bulbul (*Pycnonotus sinensis*) (IN, 1575; OR, 10.5%; resident), Eurasian Tree Sparrow (*Passer montanus*) (IN, 1125; OR, 7.7%; resident), Great Egret (*Casmerodius alba*) (IN, 726; OR, 4.8%; wintering migrant), Red Collared-dove (*Streptopelia tranquebarica*) (IN, 509; OR, 3.4%; resident), Japanese White-eye (*Zosterops japonica*) (IN, 504; OR, 3.3%; resident), Little Ringed Plover (*Charadrius dubius*) (IN, 316; OR, 2.1%; wintering migrant), and Little Grebe (*Tachybaptus ruficollis*) (IN, 304; OR, 2%; resident). The 84 other species accounted for 26% of the total abundance. There were 23 species for which over 100 individuals were recorded in the entire survey record, while fewer than 10 individuals of 40 species were detected throughout the survey (Table 5-2).

Table 5-2. Individual number and their occurrence rate of the ten most-abundant species.

Rank	Common name	Scientific name	Individual number	Occurrence rate
1	Black-crowned Night-Heron	*Nycticorax nycticorax*	2,363	15.7%
2	Little Egret	*Egretta garzetta*	1,883	12.5%
3	Grey Heron	*Ardea cinerea*	1,829	12.2%
4	Light-vented Bulbul	*Pycnonotus sinensis*	1,575	10.5%
5	Eurasian Tree Sparrow	*Passer montanus*	1,125	7.5%
6	Great Egret	*Casmerodius alba*	726	4.8%
7	Red Collared-dove	*Streptopelia tranquebarica*	509	3.4%
8	Japanese White-eye	*Zosterops japonica*	504	3.4%
9	Little Ringed Plover	*Charadrius dubius*	316	2.1%
10	Little Grebe	*Tachybaptus ruficollis*	304	2.0%
Totals			11,134	74.1%

Species Diversity

Studies of variations in the numbers of individuals of species with relative abundances were conducted using species diversity. Although diversity may be measured most directly by numbers of individuals, it is usually expressed as an interplay of species richness and abundance into a single value (Shannon and Weaver 1949; MacArthur and MacArthur 1961; Dean et al. 2002). In this study, diversity was considered over a wide spectrum of spatial scales, from variations across a single pond to the entire region, where temporal patterns were consequences of individual habitat selection. The diversity was measured for all species recorded from November 2003 to February 2004. Four regional diversity variations were mapped for avian communities on contour maps (Figures 5-2, 5-3, 5-4, and 5-5). On these maps a successional gradient is indicated to document concentric rings in bird diversity for the spatial-temporal analysis. Indeed, 4-month surveys demonstrated such monthly diversity oscillations that horizontal heterogeneity might still occur in microhabitats. Species are able to select their proper habitats and then either over-winter or undertake long migrations according to different groups. I, thus, hypothesized that diversities on the meso-scale varied among different guilds of species due to habitat selection. The occurrence rates of avian communities detected by observers were broadly examined and classified into groups in the section that follows.

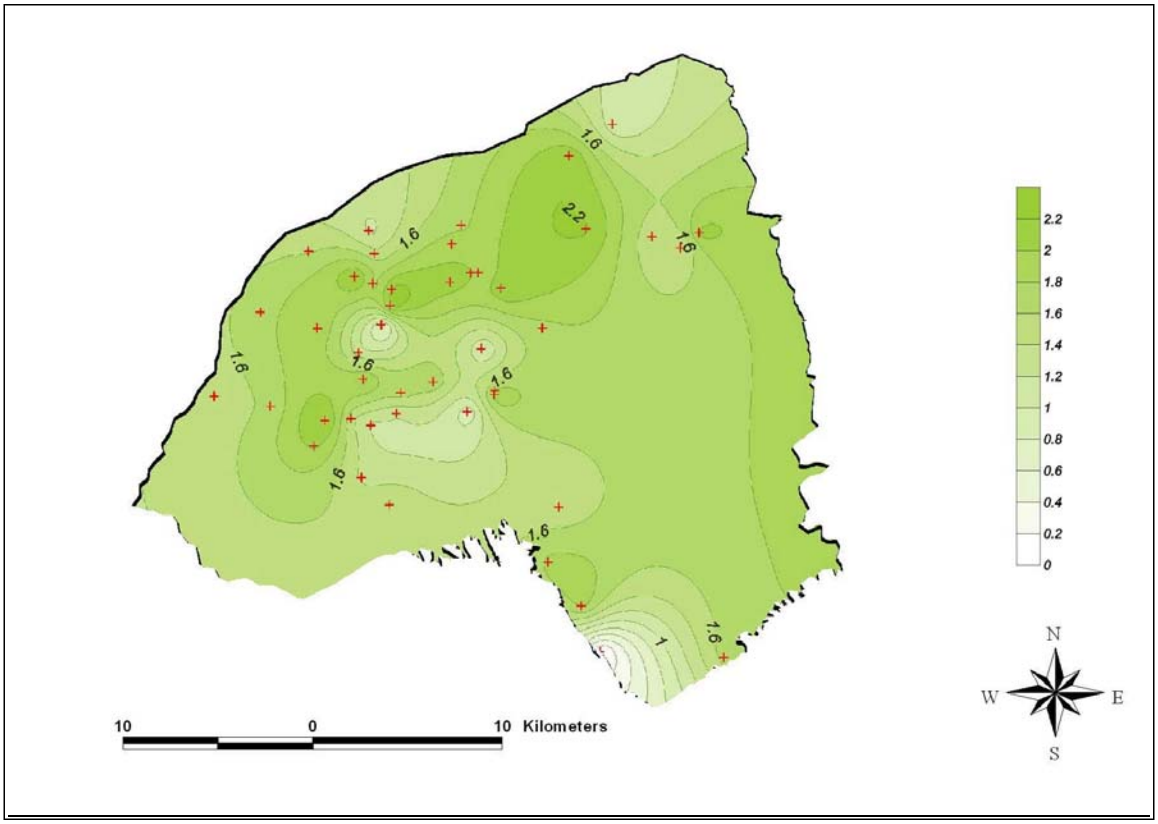


Figure 5-2. Variation in spatial diversity (*H'*) of wintering birds detected around farm ponds on the Taoyuan Tableland (data of 15 November 2003). [Diversity; 0~0.2; 0.2~0.4...; 2.2~]

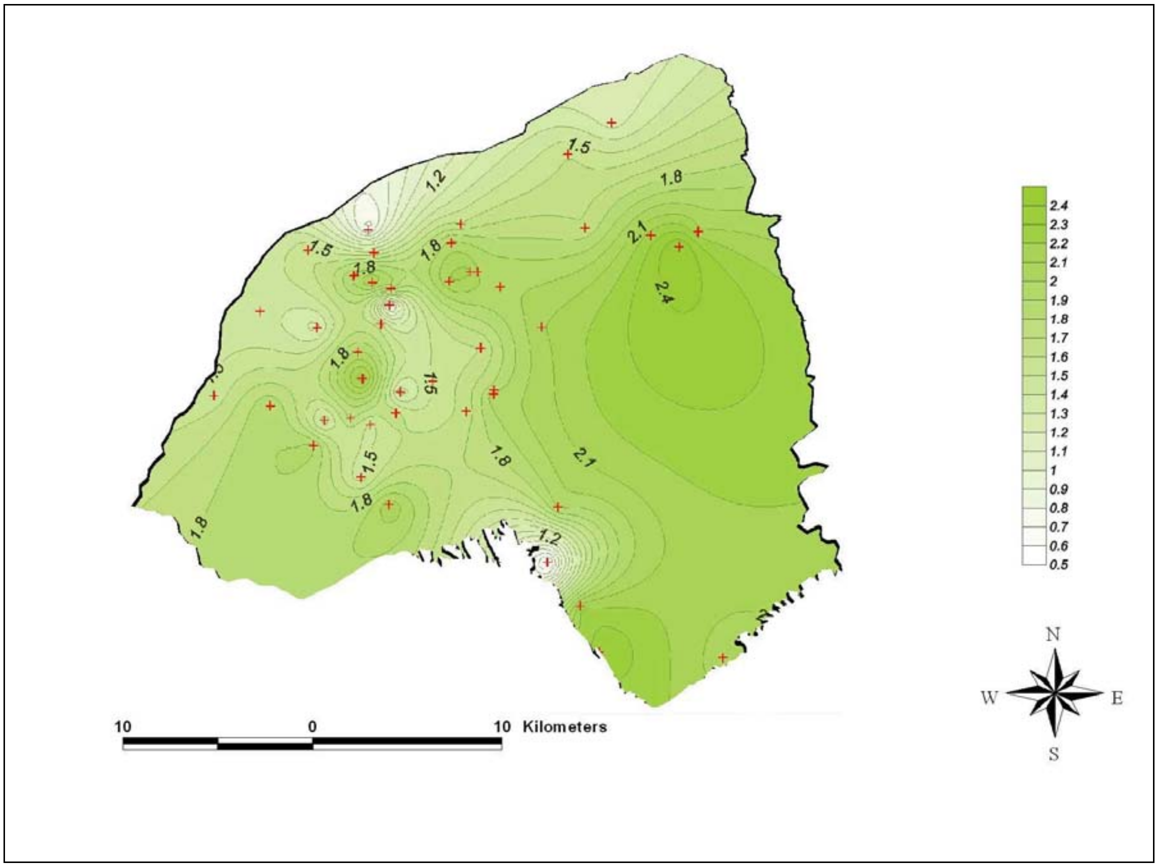


Figure 5-3. Variation in spatial diversity (*H'*) of wintering birds detected around farm ponds on the Taoyuan Tableland (data of 20 December 2003). [Diversity; 0.5~0.6; 0.6~0.7...; 2.4~]

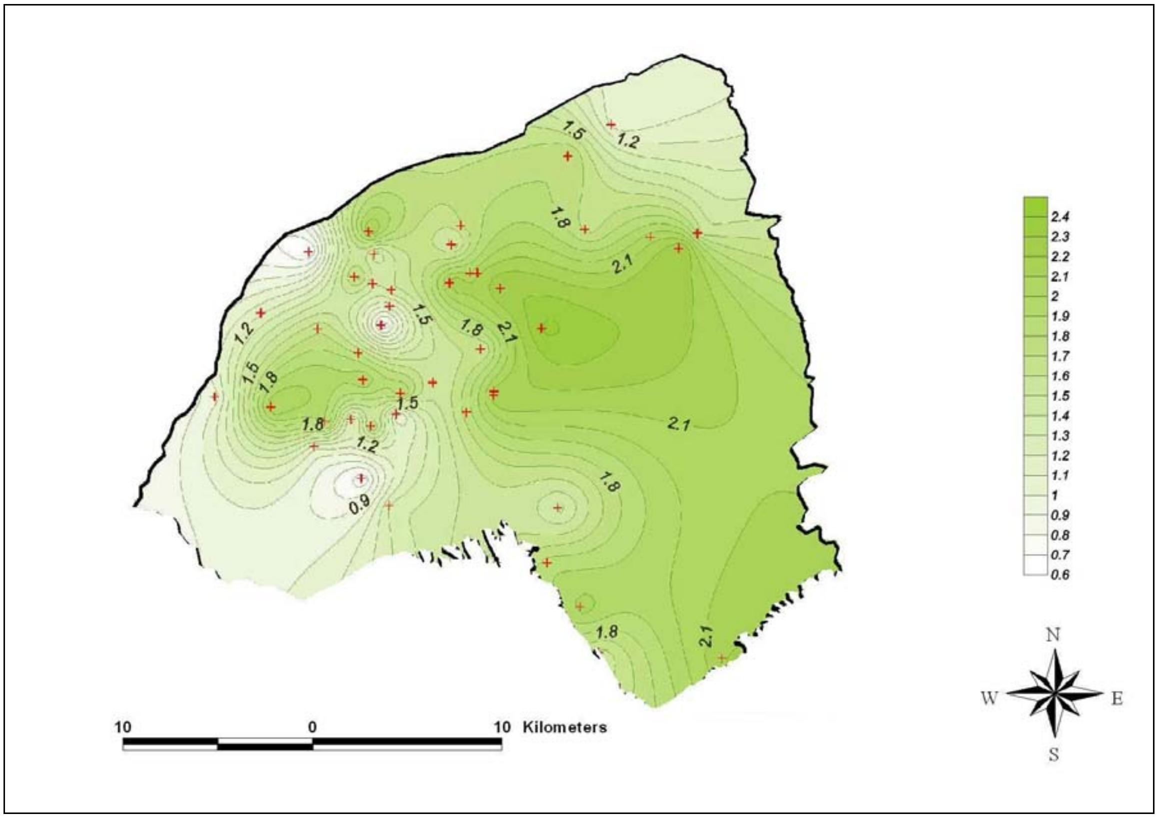


Figure 5-4. Variation in spatial diversity (*H'*) of wintering birds detected around farm ponds on the Taoyuan Tableland (data of 31 January 2004). [Diversity; 0.6~0.7; 0.7~0.8...; 2.4~]

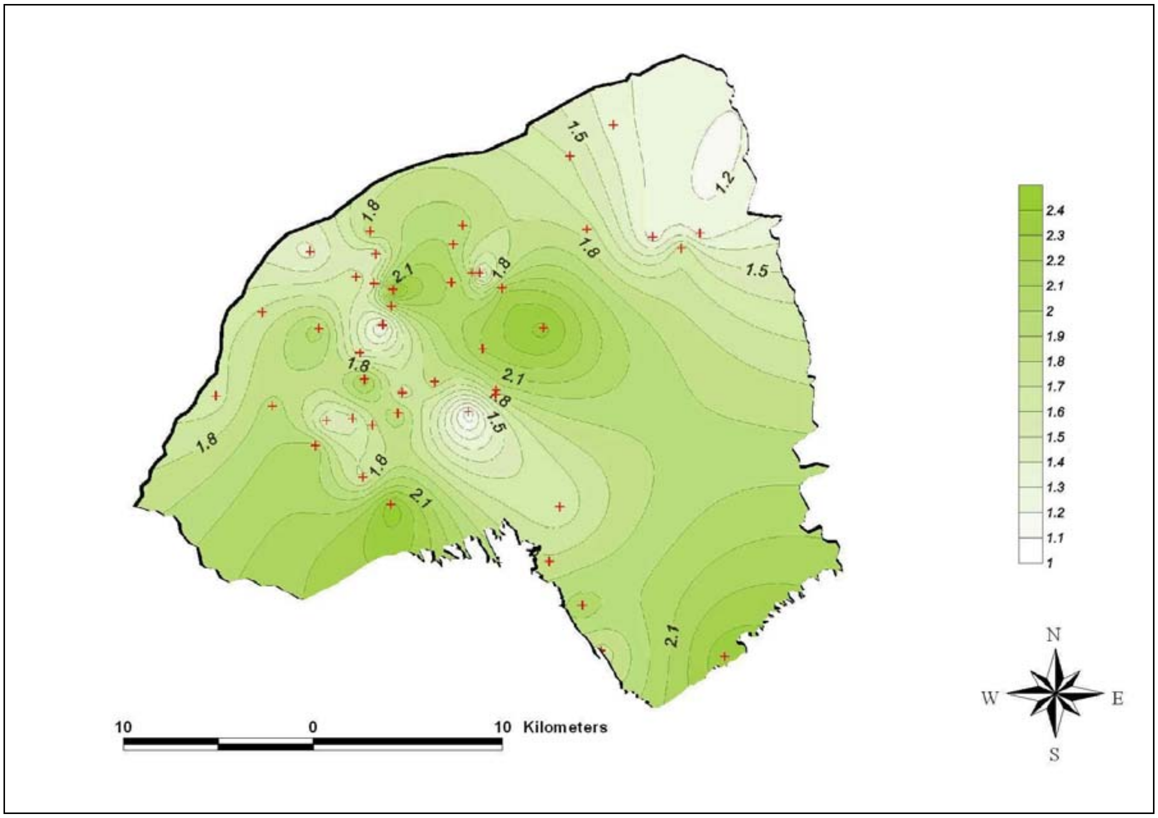


Figure 5-5. Variation in spatial diversity (*H'*) of wintering birds detected around farm ponds on the Taoyuan Tableland (data of 28 February 2004). [Diversity; 1~1.1; 1.1~1.2...; 2.4~]

GUILD CLASSIFICATION

Generally, farm ponds had the highest number of birds, and many species were restricted to this microhabitat type. Species were classified into broad categories based on microhabitat selection. They are described in functional terms, i.e., guilds, which are groups of species that use similar environmental resources during similar periods. Therefore, the occurrence rate of each species was obtained by dividing the number of microhabitats present by the total number of microhabitats at each pond in Table 5-3. This grouping was used for analyses because source pool sizes were represented by the total number of species found on the Taoyuan Tableland.

Table 5-3. Occurrence rate of avian species in different microhabitats.

ID	Code	Common name	Scientific name	Air	Water surface	Mud-flat	Bank & edge	Grass-land	Brush-land	Wood-land
2	1402	Northern Pintail	*Anas acuta*	0.00	1.00	0.00	0.00	0.00	0.00	0.00
3	1403	Northern Shoveler	*Anas clypeata*	0.00	1.00	0.00	0.00	0.00	0.00	0.00
4	1404	Common Teal	*Anas crecca*	0.00	1.00	0.00	0.00	0.00	0.00	0.00
5	1408	Eurasian Wigeon	*Anas penelope*	0.00	1.00	0.00	0.00	0.00	0.00	0.00
6	1410	Spot-billed Duck	*Anas poecilorhyncha*	0.00	1.00	0.00	0.00	0.00	0.00	0.00
7	1419	Common Pochard	*Aythya ferina*	0.00	1.00	0.00	0.00	0.00	0.00	0.00
8	1523	Black-eared Kite	*Milvus migrans lineatus*	1.00	0.00	0.00	0.00	0.00	0.00	0.00
9	2102	Common Coot	*Fulica atra*	0.00	0.00	1.00	0.00	0.00	0.00	0.00
10	2106	Ruddy-breasted Crake	*Porzana fusca*	0.00	0.00	1.00	0.00	0.00	0.00	0.00
11	2608	Grey-headed Lapwing	*Vanellus cinereus*	0.00	0.00	1.00	0.00	0.00	0.00	0.00
12	2609	Pacific Golden-Plover	*Pluvialis fulva*	0.00	0.00	1.00	0.00	0.00	0.00	0.00
13	2738	Common Redshank	*Tringa totanus*	0.00	0.00	1.00	0.00	0.00	0.00	0.00
14	2801	Black-Winged Stilt	*Himantopus himantopus*	0.00	0.00	1.00	0.00	0.00	0.00	0.00
15	2802	Pied Avocet	*Recurvirostra avosetta*	0.00	0.00	1.00	0.00	0.00	0.00	0.00
16	4002	Fork-tailed Swift	*Apus pacificus*	1.00	0.00	0.00	0.00	0.00	0.00	0.00
17	4903	Striated Swallow	*Hirundo striolata*	1.00	0.00	0.00	0.00	0.00	0.00	0.00
18	4905	Plain Sand Martin	*Riparia paludicola*	1.00	0.00	0.00	0.00	0.00	0.00	0.00
19	6701	Red-throated Pipit	*Anthus cervinus*	0.00	0.00	1.00	0.00	0.00	0.00	0.00
20	2735	Common Greenshank	*Tringa nebularia*	0.00	0.00	0.97	0.03	0.00	0.00	0.00
21	1421	Greater Scaup	*Aythya marila*	0.00	0.95	0.00	0.00	0.00	0.00	0.05
22	205	Little Grebe	*Tachybaptus ruficollis*	0.00	0.94	0.00	0.06	0.00	0.00	0.00
23	2104	Common Moorhen	*Gallinula chloropus*	0.00	0.00	0.89	0.08	0.03	0.00	0.01
24	1409	Mallard	*Anas platyrhynchos*	0.00	0.88	0.00	0.12	0.00	0.00	0.00
25	4001	House Swift	*Apus nipalensis*	0.81	0.00	0.00	0.19	0.00	0.00	0.00

Table 5-3. Continued.

ID	Code	Common name	Scientific name	Air	Water surface	Mud-flat	Bank & edge	Grass-land	Brush-land	Wood-land
26	2731	Wood Sandpiper	*Tringa glareola*	0.00	0.00	0.80	0.20	0.00	0.00	0.00
27	3207	Common Black-headed Gull	*Larus ridibundus*	0.75	0.00	0.00	0.25	0.00	0.00	0.00
28	2601	Kentish Plover	*Charadrius alexandrinus*	0.00	0.00	0.73	0.27	0.00	0.00	0.00
29	4904	Pacific Swallow	*Hirundo tahitica*	0.73	0.00	0.00	0.19	0.01	0.00	0.07
30	2611	Northern Lapwing	*Vanellus vanellus*	0.00	0.00	0.72	0.28	0.00	0.00	0.00
31	2603	Little Ringed Plover	*Charadrius dubius*	0.00	0.00	0.77	0.17	0.06	0.00	0.00
32	1108	Great Egret	*Casmerodius alba*	0.00	0.59	0.00	0.34	0.00	0.00	0.07
33	4101	Common Kingfisher	*Alcedo atthis*	0.55	0.00	0.00	0.25	0.02	0.11	0.08
34	4902	Barn Swallow	*Hirundo rustica*	0.53	0.00	0.00	0.47	0.00	0.00	0.00
35	1706	Common Kestrel	*Falco tinnunculus*	0.50	0.00	0.00	0.00	0.00	0.00	0.50
36	1111	Intermediate Egret	*Mesophoyx intermedia*	0.00	0.47	0.00	0.45	0.00	0.00	0.08
37	1110	Little Egret	*Egretta garzetta*	0.00	0.54	0.00	0.28	0.01	0.04	0.13
38	2733	Common Sandpiper	*Tringa hypoleucos*	0.00	0.00	0.43	0.51	0.04	0.03	0.00
39	1101	Grey Heron	*Ardea cinerea*	0.00	0.34	0.00	0.46	0.02	0.01	0.17
40	901	Common Cormorant	*Phalacrocorax carbo*	0.00	0.32	0.00	0.64	0.00	0.00	0.04
41	2703	Dunlin	*Calidris alpina*	0.00	0.00	0.28	0.72	0.00	0.00	0.00
42	1121	Black-crowned Night-Heron	*Nycticorax nycticorax*	0.00	0.23	0.00	0.59	0.01	0.07	0.10
43	6707	White Wagtail	*Motacilla alba*	0.00	0.22	0.00	0.27	0.51	0.00	0.00
44	5410	Black-billed Magpie	*Pica pica*	0.20	0.00	0.00	0.07	0.00	0.10	0.63
45	1601	Osprey	*Pandion haliaetus*	0.17	0.00	0.00	0.00	0.00	0.00	0.83
46	5914	Rufous-capped Babbler	*Stachyris ruficeps*	0.00	0.14	0.00	0.14	0.00	0.00	0.71
47	3509	Red Collared-dove	*Streptopelia tranquebarica*	0.00	0.13	0.00	0.19	0.01	0.02	0.66
48	6710	Yellow Wagtail	*Motacilla flava*	0.00	0.11	0.00	0.22	0.64	0.02	0.01

Table 5-3. Continued.

ID	Code	Common name	Scientific name	Air	Water surface	Mud-flat	Bank & edge	Grass-land	Brush-land	Wood-land
49	5403	Large-billed Crow	*Corvus macrorhynchos*	0.00	0.11	0.00	0.28	0.00	0.00	0.60
50	6708	Grey Wagtail	*Motacilla cinerea*	0.00	0.11	0.00	0.63	0.22	0.03	0.01
51	5913	Steak-breasted Scimitar Babbler	*Pomatorhinus ruficollis*	0.00	0.05	0.00	0.16	0.00	0.68	0.11
52	5103	Black Drongo	*Dicrurus macrocercus*	0.00	0.05	0.00	0.29	0.19	0.14	0.34
53	6313	Daurian Redstart	*Phoenicurus auroreus*	0.00	0.04	0.00	0.21	0.38	0.13	0.25
54	6422	Plain Prinia	*Prinia inornata*	0.00	0.04	0.00	0.36	0.08	0.47	0.05
55	7201	Japanese White-eye	*Zosterops japonica*	0.00	0.03	0.00	0.03	0.01	0.10	0.84
56	3507	Spotted Dove	*Streptopelia chinensis*	0.00	0.02	0.00	0.21	0.08	0.00	0.68
57	1105	Cattle Egret	*Bubulcus ibis*	0.00	0.02	0.00	0.21	0.00	0.01	0.77
58	7012	White-vented Myna	*Acridotheres grandis*	0.00	0.02	0.00	0.53	0.00	0.00	0.45
59	6003	Light-vented Bulbul	*Pycnonotus sinensis*	0.00	0.01	0.00	0.14	0.02	0.14	0.69
60	7601	Eurasian Tree Sparrow	*Passer montanus*	0.00	0.01	0.00	0.23	0.04	0.21	0.51
61	1119	Yellow Bittern	*Ixobrychus sinensis*	0.00	0.00	0.00	0.00	1.00	0.00	0.00
62	1802	Chinese Bamboo-Partridge	*Bambusicola thoracica*	0.00	0.00	0.00	0.00	1.00	0.00	0.00
63	2101	White-breasted Waterhen	*Amaurornis phoenicurus*	0.00	0.00	0.00	1.00	0.00	0.00	0.00
64	2707	Rufous-necked Stint	*Calidris ruficollis*	0.00	0.00	0.00	1.00	0.00	0.00	0.00
65	2709	Temminck's Stint	*Calidris temminckii*	0.00	0.00	0.00	1.00	0.00	0.00	0.00
66	2713	Common Snipe	*Gallinago gallinago*	0.00	0.00	0.00	1.00	0.00	0.00	0.00
67	2729	Grey-tailed Tattler	*Tringa brevipes*	0.00	0.00	0.00	1.00	0.00	0.00	0.00

Table 5-3. Continued.

ID	Code	Common name	Scientific name	Air	Water surface	Mud-flat	Bank & edge	Grass-land	Brush-land	Wood-land
68	3508	Eastern Turtle Dove	*Streptopelia orientalis*	0.00	0.00	0.00	0.05	0.00	0.03	0.91
69	3512	White-bellied Green-pigeon	*Treron sieboldii*	0.00	0.00	0.00	0.00	0.00	0.00	1.00
70	3601	Lesser Coucal	*Centropus bengalensis*	0.00	0.00	0.00	1.00	0.00	0.00	0.00
71	4501	Black-browed Barbet	*Megalaima oorti*	0.00	0.00	0.00	0.00	0.00	0.00	1.00
72	5407	Grey Tree-pie	*Dendrocitta formosae*	0.00	0.00	0.00	0.00	0.43	0.43	0.14
73	5502	Vinous-throated Parrotbill	*Paradoxornis webbianus*	0.00	0.00	0.00	0.21	0.00	0.65	0.14
74	6002	Black Bulbul	*Hypsipetes leucocephalus*	0.00	0.00	0.00	1.00	0.00	0.00	0.00
75	6307	Siberian Rubythroat	*Luscinia calliope*	0.00	0.00	0.00	0.33	0.00	0.67	0.00
76	6317	Orange-flanked Bush-robin	*Tarsiger cyanurus*	0.00	0.00	0.00	0.00	0.00	1.00	0.00
77	6321	Brown-headed Thrush	*Turdus chrysolaus*	0.00	0.00	0.00	1.00	0.00	0.00	0.00
78	6325	Dusky Thrush	*Turdus naumanni*	0.00	0.00	0.00	1.00	0.00	0.00	0.00
79	6402	Great Reed-Warbler	*Acrocephalus arundinaceous*	0.00	0.00	0.00	0.00	1.00	0.00	0.00
80	6406	Japanese Bush-Warbler	*Cettia diphone*	0.00	0.00	0.00	0.33	0.00	0.00	0.67
81	6407	Brownish-flanked Bush-Warbler	*Cettia fortipes*	0.00	0.00	0.00	1.00	0.00	0.00	0.00
82	6410	Zitting Cisticola	*Cisticola juncidis*	0.00	0.00	0.00	0.00	0.00	1.00	0.00
83	6421	Yellow-bellied Prinia	*Prinia flaviventris*	0.00	0.00	0.00	0.22	0.12	0.56	0.10
84	6703	Olive-backed Pipit	*Anthus hodgsoni*	0.00	0.00	0.00	1.00	0.00	0.00	0.00
85	6902	Brown Shrike	*Lanius cristatus*	0.00	0.00	0.00	0.22	0.03	0.39	0.36
86	6904	Long-tailed Shrike	*Lanius schach*	0.00	0.00	0.00	0.00	0.00	0.63	0.38

Table 5-3. Continued.

ID	Code	Common name	Scientific name	Air	Water surface	Mud-flat	Bank & edge	Grass-land	Brush-land	Wood-land
87	7001	Crested Myna	*Acridotheres cristatellus*	0.00	0.00	0.00	0.89	0.00	0.00	0.11
88	7002	Common Myna	*Acridotheres tristis*	0.00	0.00	0.00	0.31	0.00	0.23	0.46
89	7005	White-cheeked Starling	*Sturnus cineraceus*	0.00	0.00	0.00	0.00	1.00	0.00	0.00
90	7007	White-shouldered Starling	*Sturnus sinensis*	0.00	0.00	0.00	0.00	0.00	1.00	0.00
91	7008	Red-billed Starling	*Sturnus sericeus*	0.00	0.00	0.00	1.00	0.00	0.00	0.00
92	7302	Scaly-breasted Munia	*Lonchura punctulata*	0.00	0.00	0.00	0.15	0.26	0.48	0.11
93	7303	White-rumped Munia	*Lonchura striata*	0.00	0.00	0.00	0.00	0.14	0.86	0.00
94	7511	Black-faced Bunting	*Emberiza spodocephala*	0.00	0.00	0.00	0.20	0.20	0.54	0.07
95	9902	Rose-ringed Parakeet	*Psittacula krameri*	0.00	0.00	0.00	0.50	0.00	0.00	0.50

A cluster analysis was used to establish a classification of guilds according to the occurrence rate of each species. In this case, ninety-four species were recorded by measuring characteristics of microhabitats that could be broadly classified as the occurrence rate of detected areas, such as air, water surface, mudflats, trail and edge, grassland, scrubland, and woodland. I used Ward's method to merge clusters of all 94 species, when the nearest neighbor distance reached seven. The dendrogram picturing the hierarchical clustering conducted is shown in Figure 5-6. The grouping and the value of the error of the sum of the squares (ESS) of the vertical axis at which the mergers occur are clearly illustrated. The equation was given in the previous chapter as

$$ESS_i = \sum_{j=1}^{n_i} \sum_{k=1}^{p} (x_{ijk} - \overline{x_{ik}}) \tag{3.2}$$

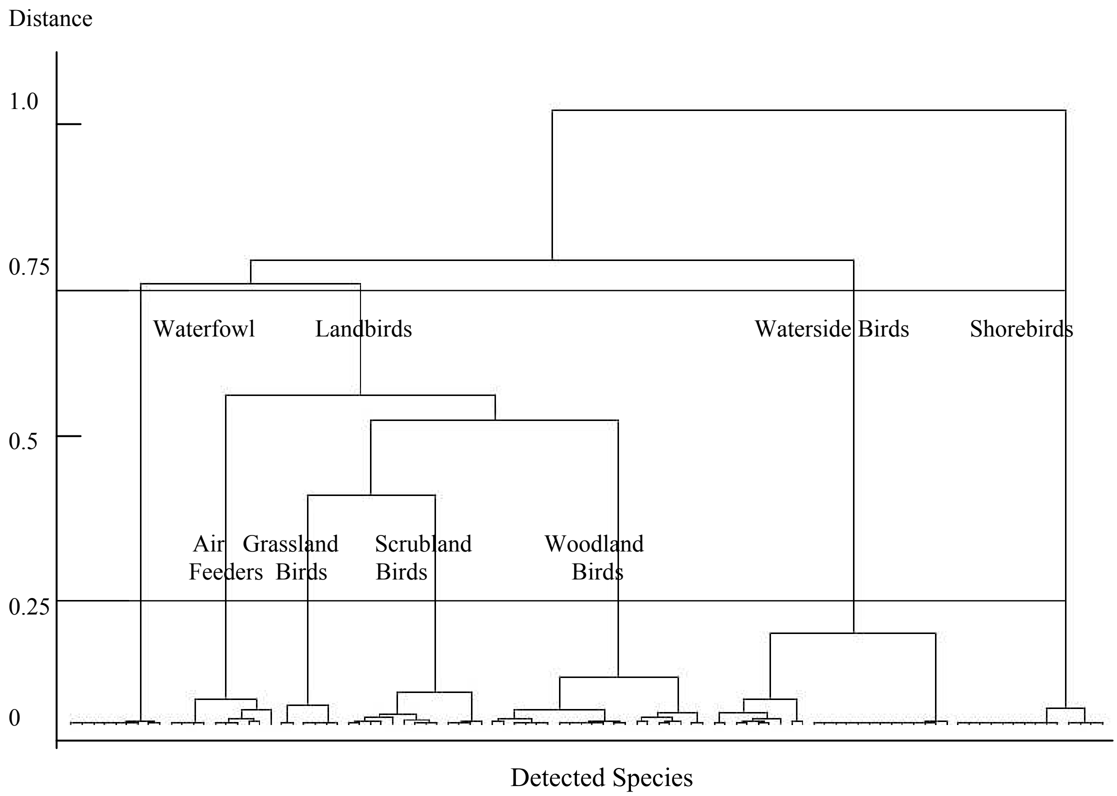


Figure 5-6. Dendrogram of dissimilarities between 94 species in the study area.

Note:

According to the dendrogram for 94 species, microhabitats were categorized into seven guilds: air feeders (ten species), waterfowl (nine species), shorebirds (14 species), waterside birds (22 species), woodland birds (20 species), scrubland birds (13 species), and grassland birds (six species) (Figure 5-6 and Appendix A). The value of dissimilarities was divided in accordance with distance (marked at a distance of 0.25) into seven guilds. If this classification was adopted, the low similarities (marked at a distance of 0.75) could be divided into four guilds: waterfowl (nine species), shorebirds (14 species), waterside birds (22 species), and land birds (49 species), respectively. The likelihood of species occurrence was surveyed and categorized into a concentric pattern, such that the gradients run from the pond's core to its edge: (1) interior pond species comprised of waterfowl (families Anatidae and Podicipedidae) and shorebirds (families Charadriidae and Scolopacidae); (2) waterside species (families Ardeidae et al.); and (3) external pond species of land birds (i.e., species detected in such microhabitats as grasslands, scrublands, and woodlands; of families Corvidae, Frigillidae, Laniidae, Passeridae, Pycnonodidae, Sylviidae, and Zosteropidae, et al.) which were dominant in their respective microhabitats (Figure 5-7).

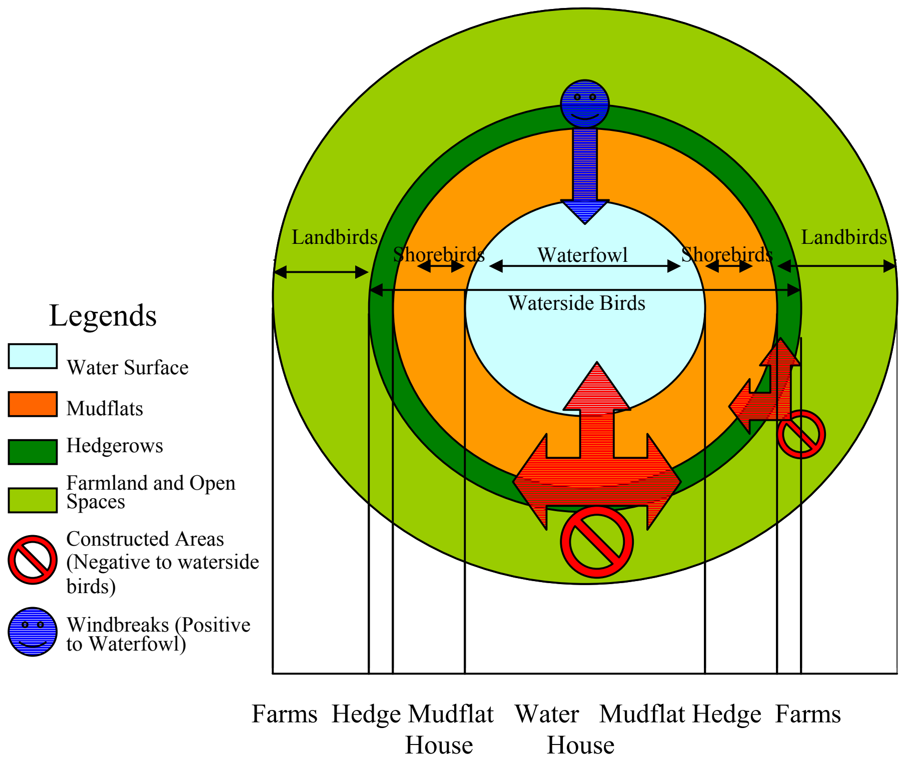


Figure 5-7. Concentric patterns of the relative dominance of bird species in pond habitats arrayed on a successional sequence from the pond's core to its surroundings on a habitat scale.

I then proposed that waterfowl, shorebirds, and waterside birds (families Anatidae, Charadriidae, Scolopacidae, and Ardeidae) in microhabitats were associated with distribution patterns of "interior species-edge species". Therefore, pond areas mainly provide shelter and foraging for wintering migrants and residents. Microhabitat structural influences on bird distribution patterns can be classified into pond core, edge, and surrounding land uses (Fang 2004b; Fang et al. 2004a). On farm ponds, I detected more than half of the species richness of land birds, and species of land birds did not change much among the 4 months (Table 5-4). However, the species abundance of land birds was less than that of wetland birds (i.e., waterfowl, shorebirds, and waterside birds). According to the bird classification, waterfowl (families Anatidae and Podicipedidae) and shorebirds (families Charadriidae and Scolopacidae) are distributed in a narrow range limited by water regimes. For example, waterfowl were detected with an approximate likelihood rate of 0.97 on water surfaces, while shorebirds were found to have a likelihood rate of 0.92 on mudflats. The two groups were less likely to appear in other microhabitats (Table 5-5).

However, waterside birds (families Ardeidae, et al.) were detected over a broad habitat range with a likelihood rate of 0.15 on water areas, and a likelihood rate of 0.75 at waterfronts (i.e., banks, levies, and embankments with footpaths, trails, or vegetative cover). This group was detected engaging in such behaviors as forging and roosting with highest abundances in aquatic areas to terrestrial areas.

Land birds, such as grassland birds, scrubland birds, and woodland birds were detected with probabilities of 0.86, 0.69, and 0.64 in the microhabitats of wet meadows, bushes, and trees, with equal probabilities of being present in the respective locations in which they were detected. From a morphological analysis of bird communities, the Plain Sand Martin *(Riparia paludicola)* (10 cm) was the shortest species, while the Grey Heron *(Ardea cinerea)* (93 cm) was the tallest; the lightest species were sorted to three land birds: Zitting Cisticola (*Cisticola juncidis*) (7 g), Plain Prinia (*Prinia inornata*) (7 g), and Yellow-bellied Prinia *(Prinia flaviventris)* (7 g). The heaviest species was found to be a waterside species: Common Cormorant (*Phalacrocorax carbo)* with a mean weight of 2.11 kg, approximately 300-fold that of the lightest land birds (i.e., Zitting Cisticola, Plain Prinia, and Yellow-bellied Prinia) (Figure 5-8).

The mean weight (biomass) of waterfowl was measured, and the heaviest were waterside birds followed by waterfowl. Bird biomass and length presented a positive relationship (R^2 = 0.75, n = 94) (Figure 5-8) (sources: Dunning 1993; The Sample Hall of Department of Animal Studies in Academia Sinica, Taipei, Taiwan).

Table 5-4. Number individuals detected and species richness of avian guilds by month.

Guild/Dates	11.15.2003	12.20.2003	01.31.2004	02.28.2004
Air feeders	96(5)	248(7)	90(6)	79(4)
Waterfowl	85(6)	209(6)	157(7)	132(5)
Shorebirds	240(6)	261(10)	212(10)	94(6)
Waterside birds	2192(10)	1776(14)	1775(11)	1465(15)
Grassland birds	31(4)	127(3)	9(2)	12(4)
Scrubland birds	233(11)	213(9)	354(9)	296(8)
Woodland birds	844(18)	1438(18)	1303(17)	1082(17)
No. of individuals (Species richness)	3721(60)	4272(67)	3900(62)	3160(59)

Notes:

Number of individuals detected in each group; the value in parentheses is species richness.

Table 5-5. The occurrence rate of avian guilds in different microhabitats.

	Water cover	Waterfront edge	Grasslands	Scrublands	Woodlands
Air feeders	**0.79** [1]	0.14	0	0.01	0.06
Waterfowl	**0.97** [2]	0.02	0	0	0.01
Shorebirds	**0.92** [3]	0.07	0.01	0	0.00
Waterside birds	0.15	**0.75**	0.01	0.01	0.08
Grassland birds	0.06	0.08	**0.86**	0.00	0.00
Scrubland birds	0.01	0.12	0.10	**0.69**	0.08
Woodland birds	0.05	0.20	0.04	0.07	**0.64**

Notes:

[1]： Vertical space over water surface.
[2]： Water surfaces.
[3]： Mudflat surfaces after drawdown.

Guild	Mass (g)	Length (cm)
Air Feeders	147.4±256.5	23.8±14.1
Waterfowl	778.6±339.6	48.8±11.8
Shorebirds	199.7±211.9	27.9± 9.1
Waterside Birds	336.3±543.4	36.7±26.0
Grassland Birds	82.5± 96.8	23.0± 7.2
Scrubland Birds	26.0± 27.9	17.1± 6.9
Woodland Birds	187.5±329.6	28.8±13.8
Average	247 ±387.8	30.0±17.8

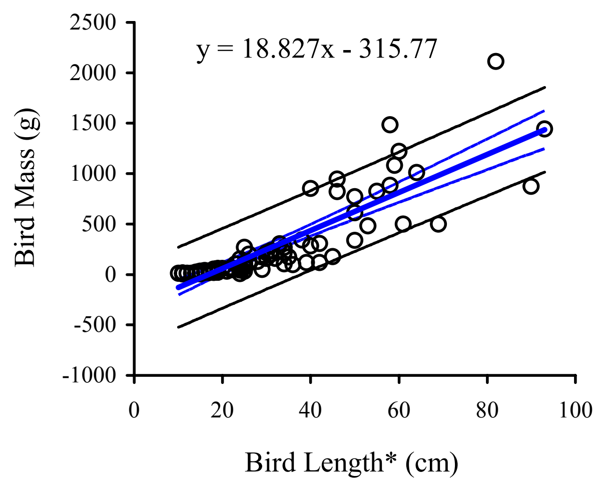


Figure 5-8. Correlation between avian mass and length of guilds (R^2 = 0.75, N = 94).

Note:

Bird length*, The asterisk (*) identifies the average length measured from the beak to tail of a single species (cm).[in the Figure use: Bird mass (g) and Bird length* (cm)]

ENVIRONMENTAL CORRELATION

To relate the richness, abundance, and diversity of guilds to environmental variables, correlation analyses were carried out. This involved correlating guild data with measured environmental variables. When determining how guild abundance, richness, and diversity responded to environmental changes, I first calculated the total abundance, richness, and diversity (columns of data matrices) at each pond (rows of data matrices). For the abundance of each guild, I carried out similar analyses. First, the number of each shorebird species in each month was calculated, because they might respond to a change in mudflat area due to drawdown effects. Then, the entire abundance of species in addition to shorebirds belonging to the same guild in each pond was summed because their microhabitats did not change during this winter season.

Second, eighteen environmental factors were considered: pond size (PS), largest pond index (LPI), mean pond fractal dimension (MPFD), mean shape index (MSI), edge density (ED), pond parameter (TE), foliage canopy area (FCA), mudflat area (MA), water surface area (WASA), elevation (ELVA), distance to urban limits (D-U), distance to the coastline (D-C), the ratio of farmland area (%FARM), the ratio of the area with permanent structures (%BUILD), the ratio of multiple pond areas (%PONDS), the ratio of all watercourse areas covered by rivers, channels, and ditches (%RIVER), the ratio of all road and trail areas (%ROAD) within a radius of 100 ha from the pond's geometric center, and the ratio of unconsolidated/consolidated areas (UCON/CON). I did not consider other variables related to the degree of urbanization (i.e., human density, transportation flow rate, automobile occupancy rate, tall building rate, etc.), as they mostly influence species breeding in the urban matrix (e.g., Eurasian Tree Sparrow *Passer montanus*, Light-vented Bulbul *Pycnonotus sinensis,* Japanese White-eye

Zosterops japonica, etc.) but not specialists within water-surface cores of ponds and the surrounding farm areas. Pond size was determined from the last edition of the official digital maps of the Department of Land Management, Ministry of the Interior (Department of Land Management, Ministry of the Interior 2002). The variables of LPI, MPFD, MSI, ED, D-U, D-C, %FARM, %BUILD, %PONDS, %ROAD, and UCON/CON were measured and calculated on a 1:5000 scale digital map (Appendix B). The mudflat area (MA) and water surface area (WASA) were measured using aerial photographs (1:5000) (Agricultural and Forestry Aerial Survey Institute 2003) and calibrated by field surveys; these were considered representative of the migrating stopover indices of species in farm ponds, and thus a possible source of colonizing species. I also assessed the foliage canopy area (FCA), which might function as corridors or stopovers, by contouring plots around each pond and counting the size of wooded areas on a 1:5000 scale map (Agricultural and Forestry Aerial Survey Institute 2003). Each variable was then calculated for the 45 pond samples.

<u>Guild Species Richness</u>

Shorebirds, comprising 14 species, showed an increasing trend of guild species richness with increasing mudflat area (MUDA) (r = 0.36) (Table 5-6 and Appendix C-2). The microhabitat choices showed that the guild richness of waterfowl increased with increasing pond size (PS) (r = 0.40) and mudflat area (MUDA) (r = 0.41), but this needs to be interpreted with care since the guild was made up of only nine species. The guild species richness of waterside birds, comprised of 22 species, was partially negatively associated with (1) elevation (m) (r = -0.43), (2) mean pond fractal dimension (MPFD) (r = -0.32), (3) the ratio of the area with permanent structures within a radius of 100 ha from the pond's geometric center (m^2/ha) (%BUILD) (r = -0.48)(Appendix C-4), and (4) distance to the coastline (D-C) (r = -0.41); and partially positively associated with (1) pond size (PS) (r = 0.27), (2) the ratio of farmland areas within a radius of 100 ha from the pond's geometric center (m^2/ha) (r = 0.40) (Appendix C-5), and (3) distance (m) to urban limits (r = 0.40). By comparing their relative relationships described by the distance to urban limits (D-U), I found that the richness of waterside guilds had a moderate correlation (r = 0.40) with this variable compared to the other guilds. Guild richness of air-feeders decreased with increasing distance (m) to urban limits (D-U) (r = -0.32), but this also requires careful interpretation since the guild was made up of only ten species, most of whom belong to the families Apodidae (swifts) and Hirundinidae (swallows). When comparing wetland birds (i.e., waterfowl, shorebirds, and waterside birds) and land birds (i.e., woodland birds, scrubland birds, and grassland birds) by describing the relationships with the internal and external variables of ponds, wetland birds had a stronger correlation with those variables than did land birds. For wetland bird species to persist in the agricultural pondscape, large areas should occur in fields to ensure many different wetland bird species.

Table 5-6. Pearson product moment correlation coefficients indicating the coefficients between guild species richness and pondscape variables (significant at the 0.05 level for the two-tailed test).

	Air Feeders	Waterfowl	Shorebirds	Waterside birds	[2]Land birds
[1]PS	0.04	**0.40**	0.22	**0.27**	-0.12
MPFD	-0.02	-0.10	-0.16	**-0.32**	0.14
MSI	0.10	-0.02	-0.17	-0.24	0.23
ED	-0.11	-0.02	-0.04	-0.23	-0.03
TE	0.15	0.23	0.03	0.10	0.11
FCA	-0.01	**0.30**	0.13	0.06	0.02
MUDA	-0.08	**0.41**	**0.36**	0.02	0
%FCA	-0.14	0.05	0.02	-0.23	-0.09
ELVA	0.01	-0.13	-0.24	**-0.43**	0.20
D-U	**-0.32**	0.06	0.21	**0.40**	-0.21
D-C	0.09	-0.04	-0.21	**-0.41**	**0.25**
%FARM	-0.07	-0.05	0.06	**0.40**	0.18
%BUILD	0.10	-0.11	-0.12	**-0.48**	-0.07
%PONDS	-0.15	**0.37**	0.17	0.22	-0.21
%RIVER	0.21	0.04	0	-0.23	0.12
%ROAD	0.06	-0.15	-0.14	-0.09	**-0.28**

Notes:

[1]PS: The values of calculated results are the same values as LPI and MPS in this case
[2]Landbirds: This group included grassland, scrubland, and woodland birds, but air feeders are not included.

Guild Species Abundance

As to the abundances of guild species, the environmental variables that correlated well were (1) foliage canopy area next to waterfront edges (FCA), and (2) mudflat area (MUDA). In general, the number of individuals of waterfowl species increased with increasing (1) foliage canopy area next to waterfront edge of a pond (m^2) (FCA) (r = 0.68), (2) the ratio of mudflat size divided by pond size (%MUDA) (r = 0.40), (3) total edge (TE) (r = 0.37), (4) mudflat area in a pond (MUDA) (r = 0.35), and (5) pond size (PS) (r = 0.26). The number of individuals of shorebird species increased as MUDA (r = 0.29) and %MUDA (r = 0.37) did, but the number stabilized for other variables (Table

5-7)(Appendix C-1), while the opposite was true for the number of waterside species around %BUILD (r = -0.36).

Table 5-7. Pearson product moment correlation coefficients indicating the correlation between the number of individuals of guild species and pondscape variables (significant at the 0.05 level for the two-tailed test).

	Air Feeders	Waterfowl	Shorebirds	Waterside birds	[2]Land birds
[1]PS	-0.10	**0.26**	0.16	**0.41**	-0.09
MPFD	0.18	-0.01	-0.13	-0.27	**0.27**
MSI	**0.31**	0.21	-0.12	-0.11	**0.41**
ED	0.01	-0.13	-0.03	-0.25	0.03
TE	0.15	**0.37**	0.03	**0.29**	0.22
FCA	0	**0.68***	0.01	**0.31**	0.21
MUDA	-0.05	**0.35**	**0.29**	0.11	0
WASA	-0.04	0.06	-0.02	**0.25**	0
%FCA	-0.03	-0.05	0	-0.12	-0.02
%MUDA	-0.02	**0.40**	**0.37**	0.18	-0.02
ELVA	0.17	0.17	-0.23	-0.21	**0.29**
D-U	-0.21	-0.16	0.07	**0.33**	-0.18
D-C	0.17	**0.26**	-0.14	-0.18	**0.33**
%FARM	-0.16	-0.01	0.02	**0.26**	0.11
%BUILD	0.17	-0.09	-0.07	**-0.36**	-0.01
%PONDS	-0.16	0.23	0.14	**0.29**	-0.11
%RIVER	**0.45**	0.13	-0.03	-0.18	-0.05
%ROAD	0.06	-0.20	-0.12	-0.17	**-0.29**

Notes:

[1] PS: The values of calculated results are the same values as LPI and MPS in this case.
[2] Land birds: This group included grassland, scrubland, and woodland birds, but not air feeders in this case.
*Indicates that a high correlation occurred.

The cumulative number of individuals of waterside species dramatically declined as the amount of built-up areas in the environment increased. However, the cumulative number of individuals of waterside guilds increased with (1) pond size (PS) (r = 0.41), (2) distance to urban limits (m) (D-U) (r = 0.33), (3) foliage canopy area next to the waterfront edge of a pond (m^2) (FCA) (r = 0.31), (4) total edge (TE) (r = 0.29), (5) the ratio of multiple pond areas within a radius of 100 ha from the pond's geometric center (m^2/ha) (%PONDS) ($r = 0.29$), (6) the ratio of farmland areas within a radius of 100 ha from the pond's geometric center (m^2/ha) (%FARM) ($r = 0.26$), and (7) water surface area in a pond (WASA) ($r = 0.25$). Guild abundance of land birds other than air feeders decreased with the increasing ratio of all road and trail areas within a radius of 100 ha from the pond's geometric center (m^2/ha) (%ROAD) ($r = -0.29$), but increased with increasing (1) mean shape index (MSI) ($r = 0.41$), (2) distance to the coastline (m) (D-C) ($r = 0.33$), (3) elevation (ELVA) ($r = 0.29$), and (4) mean pond fractal dimension (MPFD) ($r = 0.27$), respectively.

When comparing wetland birds (i.e., waterfowl, shorebirds, and waterside species) and land birds (i.e., woodland birds, scrubland birds, and grassland birds) by describing their relationships with the internal and external variables of ponds, the number of individuals of wetland birds had a stronger correlation with variables than did that of land birds. Guild analyses suggested that the availability of microhabitats was the principal factor affecting bird individuals. The potential for environmental impact on the bird community was hence particularly high for wetland species, especially waterside birds. For individuals of wetland birds to persist in the agricultural pondscape, large pond areas as well as well-designed adjacent landscape should occur in fields to ensure individual numbers.

Guild Species Diversity

Relationships between each wetland guild and pondscape configurations were moderate, and some of them were slightly moderate in the micro- and meso-habitat scale studies (Table 5-8). Repeated 4-month measurements on individual ponds are required to evaluate avian variation in guilds and therefore inter-individual variation when the 45 ponds were measured. They do not represent pseudo-replication when data from different individual ponds are not pooled. The mean of the individual means is the most reliable estimate of avian communities because it prevents repeated measurements of one or more individuals from distorting the species' mean, that is, it avoids pseudo-replication.

At best, the mean is as reliable as the mean of the individual means, a condition that occurs either by chance or by making an equal number of measurements on each individual. Since microhabitats, besides mudflat areas, did not change in any month during this winter survey, then the entire abundance of species other than shorebirds belonging to the same guild in each pond was calculated. This approach was used to examine relationships between guilds and microhabitats, especially for waterfowl and waterside species. By comparing their correlation coefficients (*r*), I found that the correlation of guilds and habitats calculated using species means in each pond throughout months had stronger correlations with higher correlation coefficients.

Waterfowl Shannon-Wiener diversity *(H')* appeared to show a preference for a detected single pond area (PS) ($r = 0.27$) and the ratio of multiple pond areas within a radius of 100 ha from the pond's geometric center (%POND) ($r = 0.35$), while waterside birds were more commonly recorded with the existence of external farmland areas (%FARM) ($r = 0.40$). However, no preference for either areas with structures (%BUILD) ($r = -0.31$) or highly convoluted pond shapes (mean pond fractal dimension, MPFD) ($r = -0.28$) was shown by waterside birds. Shorebirds appeared to show a preference for (1) pond size (PS) ($r = 0.31$), (2) mudflat area in a pond (m^2) (MUDA) ($r = 0.46$), (3) the ratio of mudflat size divided by pond size (%MUDA) (*r* = 0.48), and (4) distance to urban limits (m) (D-U) (*r* = 0.35). This result is not surprisingly as the first two groups, waterfowl and shorebirds, use a narrow range of habitats as interior pond species, while waterside birds use a broader range from the internal water surface to external pond-edge areas. Results from this study show that farm ponds provide these species with habitat requirements that are adequate to attract residents and migrants. Species that prefer big farm ponds or show preference for either pondscape configuration are likely to have benefited from widespread development according to this pondscape simulation model. It is important to note that pond type was interchangeable with the preference for these functional groups. Regional (matrix) studies suggested that there is a range of biotic and abiotic differences between consolidated areas and unconsolidated areas on the tablelands. Characteristics such as distances to borders, road ratio, farm ratio, and watercourse ratio in these ranges all warrant further attention in understanding how avian species may respond to differences between natural and mechanized croplands.

Table 5-8. Pearson product moment correlation coefficients indicating the coefficients between guild diversity *(H')* and pondscape variables (significant at the 0.05 level for the two-tailed test).

	Air Feeders	Waterfowl	Shorebirds	Waterside birds	[2]Land birds
[1]PS	0.17	**0.27**	**0.31**	0.22	-0.21
MPFD	-0.16	0.01	-0.11	**-0.28**	0.15
MSI	-0.03	0.03	-0.11	-0.23	0.14
ED	-0.19	0.10	0.02	-0.20	0.07
TE	0.19	0.13	0.09	0.06	-0.07
FCA	0.04	0.23	0.16	0.18	-0.15
[3]MUDA	-	-	**0.46**	-	-
[3]WASA	-	-	-0.03	-	-
%FCA	-0.21	0.15	0.09	-0.18	0
[3]%MUDA	-	-	**0.48**	-	-
ELVA	-0.12	-0.08	**-0.27**	-0.20	0.24
D-U	-0.13	0.10	**0.35**	**0.30**	**-0.26**
D-C	-0.04	0	-0.23	**-0.26**	**0.25**
%FARM	-0.07	-0.05	0.06	**0.27**	0.11
%BUILD	0.02	-0.09	-0.14	**-0.31**	0.02
%PONDS	-0.04	**0.35**	0.18	0.15	-0.12
%RIVER	0.07	-0.04	-0.04	-0.19	-0.01
%ROAD	0.06	-0.16	-0.06	-0.21	-0.21

Notes:

[1] The values of calculated results are the same values as LPI and MPS in this case.
[2] This group included grassland, scrubland, and woodland birds, but not air feeders in this case.
[3] To avoid pseudo-replication from temporal variations in diversity *(H')* each month, some variables were not calculated in the rows of data matrices, e.g., temporal mudflat values, such as MUDA, WASA, and %MUDA, were only calculated for shorebirds.

LINEAR MODELING

This study shows that different avian guilds respond differently to environmental changes. In general, ponds with a larger available size for wetland birds and wintering migratory birds have the capacity for sustained population increases. The individual numbers ($r = 0.32$, $n = 94$, $p < 0.001$) and species richness ($r = 0.18$, $n = 94$, $p < 0.001$) of a pond were moderately and slightly related to the population sizes of entire species, with possible exceptions being ponds supporting large concentrations of, for example, air-feeders and land birds. However, the point at which a pond is regarded by a single species as saturated may also be determined by the population sizes of other species wintering on those ponds. Given that several species share similar habitat requirements, then this was likely to some extent to be true of wetland birds. Therefore, a significant positive correlation was calculated between species richness, abundance, and diversity in several guilds of wetland birds. In the following sections, responses of guilds to pondscape changes are indicated for variables that were selected in correlation to avian communities.

Species-area Relationships

Species-area relationships were compared between ecological groups with similar source pool sizes. Such analyses restricted to pooled guild sizes to reduce confounding with habitat effects. I found that the lack of suitable microhabitat size was likely to be key to the poor responses of some species when selecting their wintering ponds. The entire microhabitats included the water surface, mudflats, and foliage canopy areas. Wetland birds that depend on a larger microhabitat size have increased in more spatially heterogeneous areas probably for refuge safety and food supply.

Waterfowl individuals vs. foliage canopy area next to the waterfront edge

First, the number of individuals of waterfowl had a high correlation (r = 0.68) (Table 5-7) (Appendix C-1) with the foliage canopy area next to the waterfront edge of a pond (FCAx), because these specialists or interior species are more sensitive to disturbance than are generalists or edge species. The linear regression was used to calculate as follows:

$$Waterfowl\ Individuals\,(Y) = -7.8266 + 1.504 \times 10^{-3}\,(FCAx) \qquad (5\text{-}1)$$

The equation of the straight line relating *Waterfowl Individuals* and *FCAx* was estimated as equation 5-1 using the 45 ponds studied. The y-intercept, the estimated value of Waterfowl Individuals when FCAx is zero, was -7.8266 with a standard error of 4.1207. The slope, the estimated change in *Waterfowl Individuals* per unit change in *FCAx*, was 0.0015 with a standard error of 0.0002. The value of R^2, the proportion of the variation in *Waterfowl Individuals* that could be accounted for by variations in *FCAx*, was 0.4583. The correlation between *Waterfowl Individuals* and *FCAx* was 0.6770. A significance test that the slope is zero resulted in a *t*-value of 6.032. The 95% confidence interval for the slope was 0.001~0.0020. The estimated intercept was -7.8266. The 95% confidence interval for the intercept was -16.1368~0.4836.

Migrants (family Anatidae) and residents (family Podicipedidae) tended sensitive to proximity to roads, farms, or other non-water surfaces. They were clearly intolerant and seemed to respond to obvious disturbances by human visitation levels by selecting suitable pond sizes, windbreak areas, and pond edges.

Shorebird diversity vs. the mudflat area of a pond

Second, shorebird diversity *(H')* was positively correlated to pond size and human disturbance, especially as to mudflat area of a pond (m^2) (MUDA) ($r = 0.46$) and percentage of mudflats (%MUDA) ($r = 0.48$) (Table 5-8)(Appendix C-2). The linear regression was used to calculate an estimated model as follows:

$$Shorebird\ Diversity\ H'(Y) = 6.1035 \times 10^{-2} + 7.0338 \times 10^{-6}\,(MUDAx) \qquad (5\text{-}2)$$

The equation of the straight line relating *Shorebird Diversity H'* and *MUDAx* was estimated as equation 5-2 using 99 observations in these ponds. Some ponds without mudflats as well as those without shorebirds were not used in this analysis. The y-intercept, the estimated value of *Shorebird Diversity H' (Y)* when *MUDAx* is zero, was 6.1035×10^{-2} with a standard error of 0.0241. The value of R^2, the proportion of the variation in *Shorebird Diversity H' (Y)* that could be accounted for by variation in *MUDAx*, was 0.2746. The correlation between *Shorebird Diversity H' (Y)* and *MUDA* was 0.5240. The 95% confidence interval for the intercept was 0.0132~0.1089.

This relationship refers to how the size of a mudflat due to drawdown influences its sediment characteristics, which likely influences invertebrate prey, and consequently, the diversity of feeding shorebirds. Higher mudflat coverage on the pond margins also contributed to increased species richness (r = 0.36) (Table 5-6)(Appendix C-4); this may be related to food availability but also to a low anthropogenic disturbance level due to reduced accessibility. This disturbance factor for waterside birds is described in detail below.

Waterside bird individuals vs. pond size

Third, the species richness (r = 0.27) and abundance (r = 0.41) of waterside birds were related to pond size (Tables 5-6 and 5-7). Total species richness and numbers of individuals of waterside birds increased with pond size (PS). The linear regression was calculated as follows:

$$Waterside\,Bird\ Indivuduals\,(Y) = 69.6039 + 1.0818 \times 10^{-3}\,PSx \qquad (5\text{-}3)$$

The equation of the straight line relating *Waterside Bird Individuals (Y)* and *PSx* was estimated as equation 5-3 using data from the 45 observed ponds. The y-intercept, the estimated value of *Waterside Bird Individuals (Y)* when *PSx* is zero, was 69.6039 with a standard error of 35.5207. The slope, the estimated change in *Waterside Bird*

Individuals per unit change in pond size, was 0.0011 with a standard error of 0.0004. The value of R^2, the proportion of the variation in *Waterside Bird Individuals* that could be accounted for by variation in *PSx*, was 0.1700. The correlation between *Waterside Bird Individuals* and *PSx* was 0.4123. A significance test that the slope is zero resulted in a *t*-value of 2.9675. The significance level of this *t*-test was 0.0049. Since 0.0049 < 0.0500, the hypothesis that the slope is zero was rejected. The estimated slope was 0.0011. The 95% confidence interval for the slope was 0.0003~0.0018. The estimated intercept was 69.6039. The 95% confidence interval for the intercept was -2.0303~141.2381.

Species-pondscape Relationship

The species-pondscape relationships were investigated between ecological groups and areas surrounding the ponds. Such analyses restricted to pooled guild data to reduce confounding area effects. Parameters found to be important as local determinants of community structures were the amount of farmland and amount of urban environment. Specific land uses found to be important were low-rise residential houses and high-density apartments.

Waterside bird richness vs. ratio of area with permanent structures

First, *Waterside Bird Richness* had a moderate correlation (*r* = -0.48) (Table 5-6)(Appendix C-4) with the ratio of areas with permanent structures within a radius of 100 ha from the pond's geometric center (*%BUILDx*), because specialists which were detected from the pond's core to the waterfront are more sensitive to anthropogenic disturbance than other generalists (i.e., land birds). The linear regression was calculated using the 45 observed ponds in this dataset as follows:

$$Waterside\ Bird\ Richness\,(Y) = 6.4037 - 6.2857 \times 10^{-6} (\%BUILDx) \quad (5\text{-}4)$$

The y-intercept, the estimated value of *Waterside Bird Richness* when *%BUILDx* is zero, was 6.4037 with a standard error of 0.2786. The slope, the estimated change in *Waterside Bird Richness* per unit change in *%BUILD*, was 6.2857×10^{-6}. The value of R^2, the proportion of the variation in waterside bird richness that could be accounted for by variation in *%BUILDx*, was 0.2280. The correlation between waterside bird richness and *%BUILDx* was -0.4775. A significance test that the slope is zero resulted in a *t*-value of -3.5636. The significance level of this *t*-test was 0.0009. Since 0.0009 < 0.0500, the hypothesis that the slope is zero was rejected.

Waterside bird richness vs. the ratio of farmland areas

Second, *Waterside Bird Species* had a moderate correlation ($r = 0.40$) (Table 5-6)(Appendix C-5) with the ratio of farmland areas within a radius of 100 ha from the pond's geometric center (*%FARMx*). The linear regression was calculated using data from the 45 observed ponds in this dataset as follows:

$$Waterside\ Bird\ Richness(Y) = 2.0933 + 4.9597 \times 10^{-6} (\%FARMx) \quad (5\text{-}5)$$

The y-intercept, the estimated value of *Waterside Bird Richness* when *%FARMx* is zero, was 2.0933 with a standard error of 1.2815. The value of R^2, the proportion of the variation in *Waterside Bird Richness* that could be accounted for by variation in *%FARMx*, was 0.1581. The correlation between *Waterside Bird Richness* and *%FARM* was 0.3976. A significance test that the slope was zero resulted in a *t*-value of 2.8412. The significance level of this *t*-test was 0.0068. Since 0.0068 < 0.0500, the hypothesis that the slope is zero was rejected. The richness of the waterside bird guild was negatively correlated with increased urbanization (indicated by %BUILD), but the richness was positively correlated with increased green spaces (i.e., farmlands, open spaces). Because I combined water and edge species of different sizes, foraging modes, and vertical roosting zones from the pond's core to the waterfront, it was likely that an increase in areas with anthropogenic construction was the main reason for their decline. Further, farmlands associated with green spaces, which might translate into greater insect abundances, were strongly correlated with waterside bird abundance.

FINDINGS AND DISCUSSION

Some of the significant findings came from the regression models. One such finding was land use of urban development in the surrounding farm-pond areas might pose a threat to the waterside bird distributions. Second, the cumulative effects on pond area and shape were those that resulted from the interaction of anthropogenic influences, and they were statistically significant for the waterside group. Studies conducted in other farm-pond locations also found that waterside species were more sensitive to human disturbances, reserve isolation, and fragmentation than other guilds (i.e., air feeders and land birds).

In this case, guild studies provide insights into resource-related mechanisms that underlie changing waterbird communities. Since avian species in a guild are using the same type of microhabitats and may competitively substitute for one another, overall guild structure can be a more-reliable indicator of habitat availability. However, overall guild studies have several shortcomings. First, overall guild responses to environmental variations can be biased if generalists numerically dominate a guild. These generalists in a guild might not respond in the same fashion to changes to microhabitat variations (e.g., some air feeders can use human structures while other species cannot). Second, environmental trends associated with the guild approach can be masked by a single abundant species (e.g., some land birds may account for large amounts, thus masking the overall guild's abundance). Third, some rare species in a functional group may be counted as zero, thus it is difficult to compare their differentiations in response to microhabitat variations (e.g., some waterfowl and shorebirds were absent or rare in ponds).

The air feeder and land bird guilds indicated very few relationships with pondscape areas for the first two above-mentioned exceptions from the habitat relationships. The guilds contained species that exploit anthropogenic sources of food, thus the guilds did not significantly increase or decrease in diversity in areas with greater amounts of permanent structures. Numerically, the guilds were dominated by generalists, such as Eurasian Tree Sparrow (*Passer montanus*), Light-vented Bulbul (*Pycnonotus sinensis*), Japanese White-eye (*Zosterops japonica*), Large-billed Crow (*Corvus macrorhynchos*), Scaly-breasted Munia (*Lonchura punctulata*), Barn Swallow (*Hirundo rustica*), etc. Because these species utilize different aspects of urban environments, the guild as a whole did not show a strong correlation with the environmental variables.

Waterfowl abundance increased with increasing foliage canopy area next to the waterfront edge of a pond (*FCAx*), probably because these canopies contain more food and shelter. In addition, shorebird diversity increased with increasing mudflat area in a pond (*MUDAx*), probably because these mudflats contain an abundant and stable supply of food due to bottom exposure by seasonal drawdown from full water regimes. However, it is possible that no waterfowl or shorebirds occurred due to a lack of mudflats and sufficient windbreaks in several study pond sites. Under such circumstances, loss of numerical details in all avian groups associated with their microhabitats such as air feeders, land birds, waterfowl, and shorebirds is inevitable if I want to make generalized statements for both area effects and habitat effects.

Beyond the above-mentioned functional groups, the waterside bird guild appeared to be favored by both habitat and area relationships, such as (1) increases in high-density green spaces (i.e., farmlands and open spaces), (2) increases in low-density housing development, (3) increases in larger pond size, and (4) increases in regular pond shape (e.g., like a circle or square instead of a curvilinear shape). The greater numbers of small-fruiting windbreak species (i.e., families Casuarinaceae and Meliaceae), anthropogenic crops, and fragmented woodland covers (i.e., families Moraceae and Euphorbiaceae) in low-density housing estates might benefit some waterside species.

With regard to both the richness and abundance ordinations, the waterside birds were differentiated by their responses to urbanization. The reduction in richness and abundance of waterside birds in more-disturbed parts could be due to the lack of good-quality roost sites. The tree-roosting waterside guild more consistently avoided urbanization probably because its roost sites are less protected from disturbances due to a lack of the tall height of tree canopies. Overall waterside species richness dropped off across the gradient described by %BUILD. Increases in the amount of anthropogenic structures imply an irreversible reduction and conversion in the amount of natural greenery spaces and farmland that many native species depend on.

According to records of the canopy, many of the open country species in the pondscape areas of the Taoyuan Tableland are originally exotic species, probably because these habitats resemble coastal scrub canopies (i.e., beefwood) for economic growth in that they are floristically poor and structurally simple relative to inland forests. Therefore, to attract many of the waterside species, preservation of large-sized ponds is still necessary. Once a waterside species has colonized a pond, pond size may still affect its establishment by such local mechanisms as availability of and competition for resources. However, equipped with ecological knowledge, environmental planners can now understand how to achieve a suitable habitat for adaptable species. In the linear regression analysis, areas surrounding pondscapes were measured to determine their effects on the avifauna composition, and this was confounded by non-linear correlations with pond size and shape. For example, in each regression analysis at least one measure, either %FARM or %BUILD, explained significantly more of the variation in the waterside bird's diversity than either measure of pond size (PS) or shape (MPFD), indicating that species-area relationships within the complex is of secondary importance for avian spatial distribution. This is the major conflict between the species-habitat hypothesis and species-area hypothesis. However, the linear regression relationships of area and species might not have indicated non-linear relationships, if they occur, between environmental factors (i.e., pond size and shape) and avian diversity. Therefore, simultaneously achieving the objectives of conducting linear regression models and improving the quality of simulation models with non-linear models for seeking precise prediction results are required through increased use of advanced simulation skills.

SUMMARY

In addition to their agribusiness value, farm ponds appear to have great influences on the make-up of avian communities, especially for the waterside avian community. I compared the following community characteristics against the corresponding ratio of constructed area values associated with pond configurations at each site for all functional groups: cumulative counts of waterfowl, shorebirds, land birds, air feeders, and waterside species. Pondscape was a strong and/or moderate correlate for all of the wetland birds (i.e., waterside birds, shorebirds, and waterfowl), but not land birds or air feeders. The presence of adjoining natural and/or farmland habitats was probably the most important determinant of wetland avifauna in farm-pond areas. Regarding this detailed study, there may be a number of reasons why some farm ponds do not become refuges for more-sensitive species. First, there is too little of the ornamental vegetation cover found on the surrounding areas, and it may support a small insect population. Second, anthropogenic structures are usually made of concrete with no native trees, and this may make such areas unattractive to waterside species that require an intact shrub layer, dead wood, or generally undisturbed microhabitats. Third, the small pond size associated with a curvilinear shape is not optimal to support, preserve, and attract waterside birds and other avifauna.

CHAPTER VI

MODELING AND EVALUATION

Modeling was applied to the avian assemblage of the Taoyuan Tableland, Taiwan. One parameter was selected to describe its structure: Shannon-Wiener's diversity index (*H*') of the same waterside bird guild. Four environmental parameters were selected as explanatory parameters: pond size (PS), pond shape (MPFD), proportion of farmland area in peripheral areas (%FARM), and proportion of areas with structures in peripheral areas (%BUILD). Correlations between observed values and values estimated by ANN models of the four dependent parameters were moderately significant. The ANN models were developed from 35 of the 45 sampled farm ponds chosen at random and were validated using the 10 remaining sampled farm ponds. The role of each parameter was evaluated by inputting fictitious configurations of independent parameters and by checking the response of the model. The resulting habitat profiles depict the complex influence of each environmental parameter on the biological parameters of the assemblage, and the non-linear relationships between the dependent and independent parameters. The main results and the potential for the use of ANNs to predict biodiversity and structural characteristics of species assemblages are discussed.

LOGISTIC MODELING

Based on logistic regression and criteria selection, I proposed three gradients of land development intensities as follows. The multiple linear regression (MLR) model is described by equation (4.1) and the developed advanced *Logit* model is described by equation (3.4):

$$\text{Logit}(Y) = 1.90 - 3.02PS + 0.01TE \qquad (4.2)$$

and

$$MPFD = \frac{\sum_{j=1}^{n}\left(\frac{2\ln p_{ij}}{\ln a_{ij}}\right)}{n_i} = 1.5; \tag{3.4}$$

where p_{ij} is the perimeter of pond *ij* (m) = total edge = 1000TE_{km} (km),
a_{ij} is the area of pond *ij* (m^2) = pond size = 10000*PS* (in ha), and
n_i is the number of pond *ij* = 1.

The MPFD's value is equal to 1.5, while the MPFD is given the value of the mean number between [1, 2] (1 < the range of MPFD < 2):

$$\frac{\ln[1000(TE_{km})]^2}{\ln(10000PS)} = 1.5\,, \tag{6.1}$$

$$TE_{km} = PS^{\frac{3}{4}}\,, \tag{6.2}$$

$$Logit(Y) = \ln\frac{p}{1-p} = 1.90 - 3.02PS + 0.1PS^{\frac{3}{4}}, \tag{6.3}$$

and

$$Logit(Y) = \ln\frac{p}{1-p} = 1.90 - 3.02(TE_{km})^{\frac{4}{3}} + 0.01TE_{km}\,, \tag{6.4}$$

where TE_{km} is the total edge (km), and PS is the pond size (ha).

The likelihood of pond loss (*p*), *Logit* (*Y*), *PS,* and TE_{km} were calculated and values are given in Table 6-1. According to Table 3-3, the gradients of land development intensities for land uses adjacent to farm ponds were divided into: (1) scenario A with conservative land use, (*p* = 0.25); (2) scenario B with moderate land use (*p* = 0.50); and (3) scenario C with intensive land use (*p* = 0.75) for waterside bird refuges in the text that follows Table 6-1 and Figures 6-1, 6-2, 6-3, and 6-4.

Table 6-1. Pond-loss likelihood rate and logit functions for pairs of PS and TE.

Land-use scenario	Pond-loss likelihood *(p)*	*PS* (ha)	TE_{km} (km)	*Logit (Y) = ln(p/1-p)*
Extremely conservative	0.05	1.6087	1.4284	-2.9444
Highly conservative	0.10	1.3609	1.2600	-2.1972
Conservative	0.25	0.9962	0.9971	-1.0986
Moderate	0.50	0.6310	0.7080	0
Intensive	0.75	0.2666	0.3710	1.0986

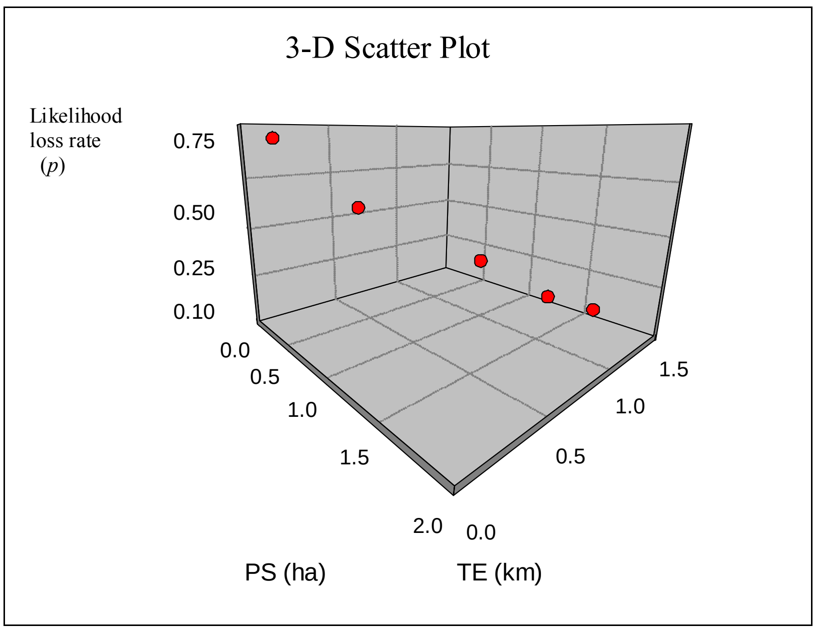


Figure 6-1. Graph showing the three-dimensional surface resulting from different values of scatter plots for a pond likelihood loss rate (0.05~0.75) from the five different land-use intensities. Plots were calculated using expectations of the 1926~1960 model: the smaller the pond size, the greater likelihood of pond loss; and the shorter a parameter of a pond, the greater likelihood of pond loss (revised from Figure 4-11).

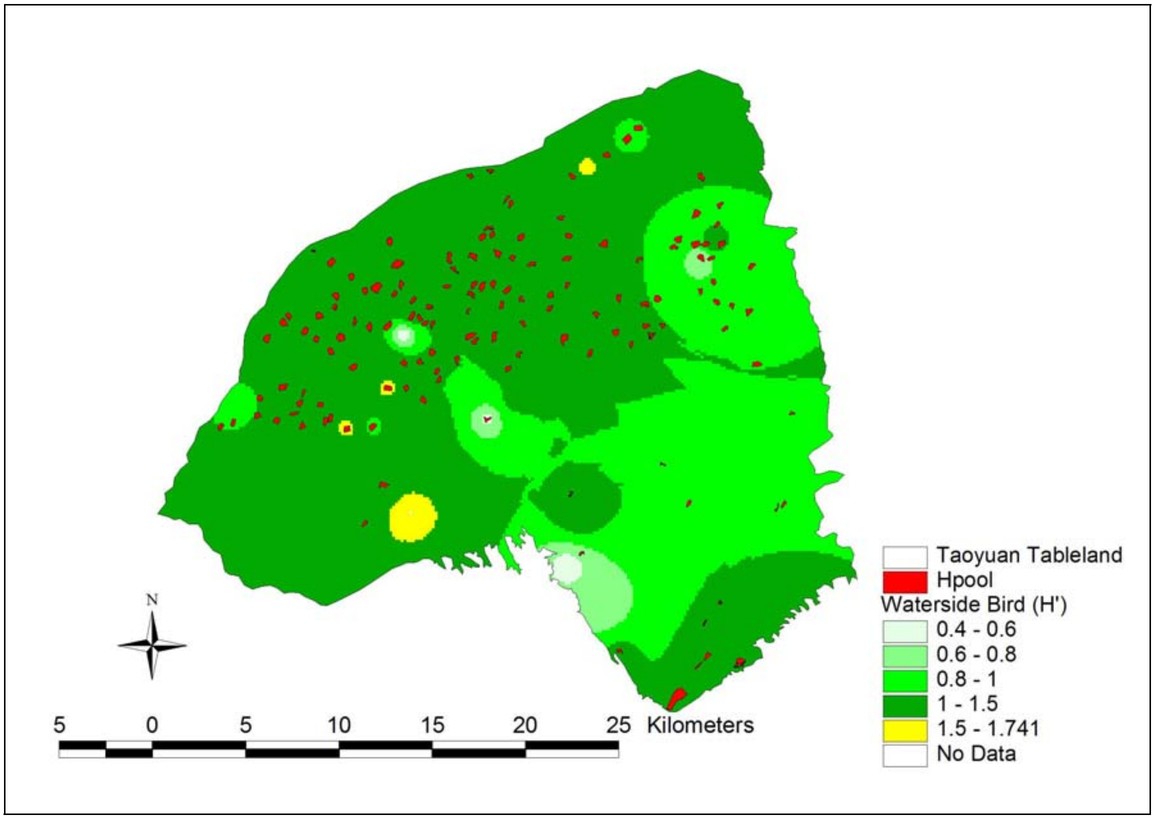


Figure 6-2. Scenario A for conservative land use. If the lower value of the likelihood of pond loss is equal to 0.25, overall ponds noted as threatened red spots (pond size > 0.996 ha, TE_{km} > 0.997 km) need to be conservatively protected due to the slight likelihood of their loss. The base map of waterside bird diversity *H'* suggests designating waterside bird refuges in gradients of patches (decided by *H'*) against the potential pond-loss rate overlaid by threatened spots shown in red (Hpool: pond size > 0.996 ha, TE_{km} > 0.997 km). [diversity *H'*: 0.4~0.6; 0.6~0.8; 0.8~1.0; 1.0~1.5; and 1.5~1.741; distance (km), 12].

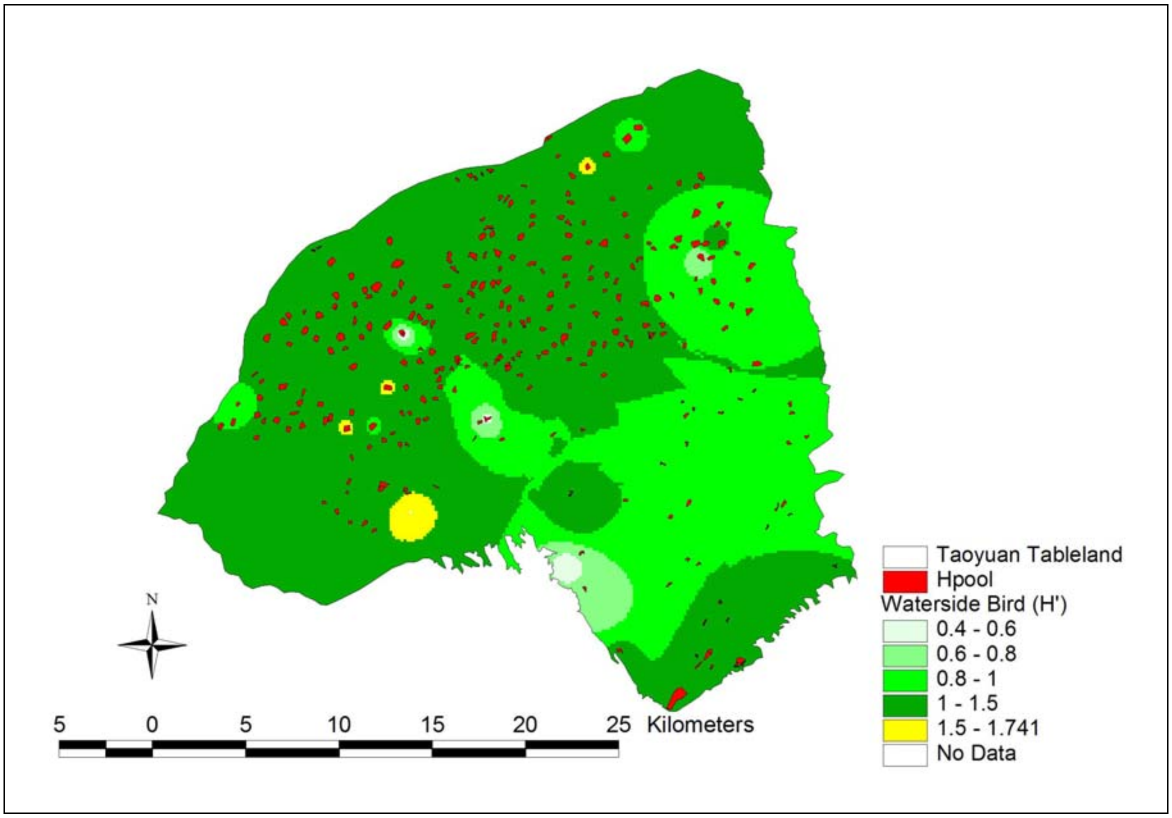


Figure 6-3. Scenario B for moderate land use. If a moderate value for the likelihood of a pond being lost is equal to 0.50, overall ponds noted as threatened by red spots (pond size > 0.631 ha, TE_{km} > 0.708 km) need to be moderately protected due to the likelihood of their loss. The base map of waterside (or water-edge) bird diversity *H'* suggests designating waterside bird refuges in gradients of patches (decided by *H'*) against potential pond-loss rates overlaid by threatened spots shown in red (Hpool: pond size > 0.631 ha, TE_{km} > 0.708 km). [diversity *H'*: 0.4~0.6; 0.6~0.8; 0.8~1.0; 1.0~1.5; and 1.5~1.741; distance (km), 12].

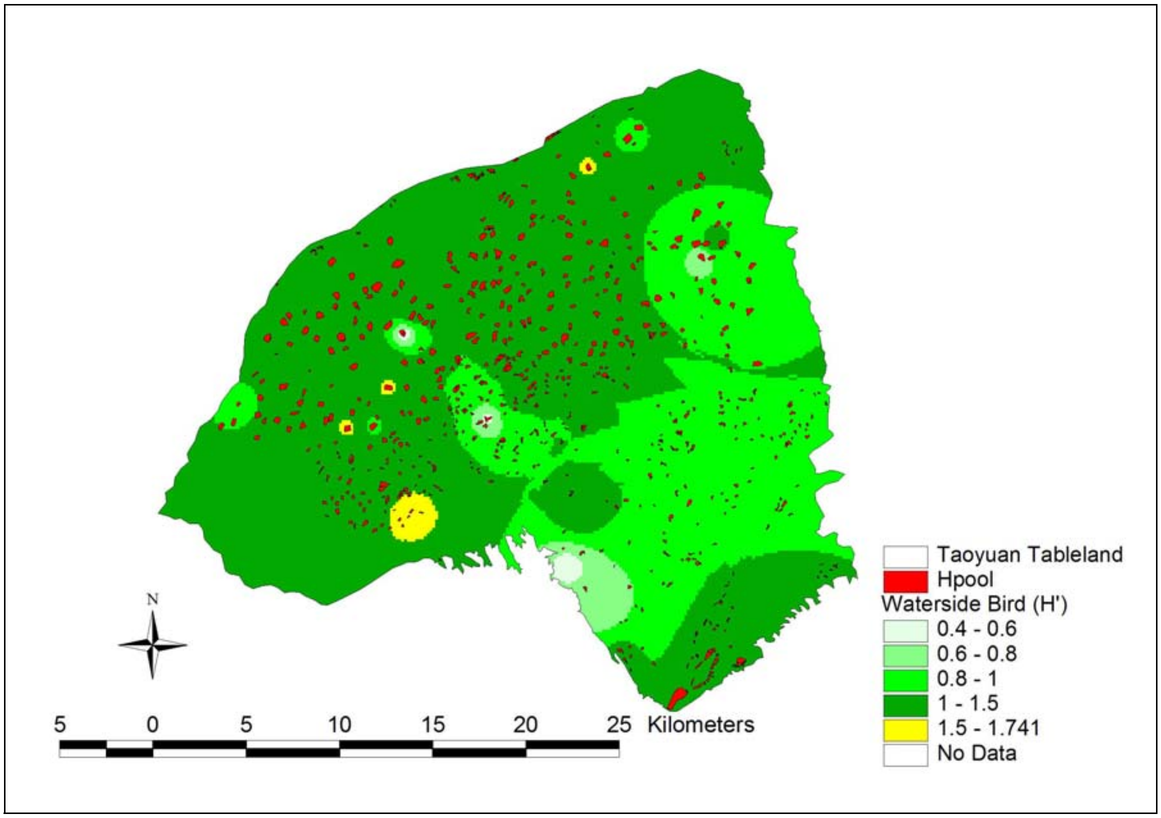


Figure 6-4. Scenario C for an intensive land-use pattern. If a high value for the likelihood of a pond being lost is equal to 0.75, overall ponds which would be threatened as shown in red (pond size > 0.2666 ha, TE_{km} > 0.371 km) would require intensive protection due to the likelihood of their loss. The base map of waterside bird diversity *H'* suggests designating waterside bird refuges in gradients of patches (decided by *H*) against the potential pond-loss rate overlaid by threatened spots shown in red (Hpool: pond size > 0.2666 ha, TE_{km} > 0.371 km). [diversity *H'*: 0.4~0.6; 0.6~0.8; 0.8~1.0; 1.0~1.5; and 1.5~1.741; distance (km), 12].

MODEL CRITIQUE

On the basis of the results of this study, there were limitations for use of bird diversity in the linear model simulation. First, the linear relationship is so simple that it cannot indicate all of the non-linear relationships. Second, the number of pond sites, which ranged from 1 to 45, affected the precision of the simulation results of bird distribution. These limitations to the linear regression and the model valuation are detailed below.

Linear Regression

Linear regression is the most commonly used method to analyze ecological data. It has been thoroughly statistically tested and is universally known. Its success comes from its ease of use and its capacity to provide predictive and explanatory results. However, this approach is incapable of accounting for non-linear relationships between the dependent parameter and each independent parameter. For example, for the 45 pond samples based on waterside bird diversity (*H'*), the linear regression procedure using the four environmental parameters gave the following correlation coefficients (*r*): with *%BUILD* (r = -0.31, R^2 = 0.09, significance level of the *t*-test = 0.0396 < α = 0.0500, power = 0.5458); with *%FARM* (r = 0.27, R^2 = 0.08, significance level of the *t*-test = 0.0679 > α = 0.0500, power = 0.4488); with *PS* (r = 0.22, R^2 = 0.05, significance level of the *t*-test = 0.1451 > α = 0.0500, power =0.3057); and with *MPFD* (r = -0.28, R^2 = 0.08, significance level of the *t*-test = 0.0640 > α = 0.0500, power = 0.4598). The low correlation coefficients (*r*) reflect the low percentages of the explained variance (less than 28% for all studied parameters). The calculated results remain insufficient with a low percentage of variance explained. This is another drawback of using linear regression. It only gave a coefficient with a sign and values for each independent parameter, which can be translated by a direction of the relationship with the dependent parameter, but no more information can be extracted from the results. That is why the use of artificial neural networks (ANN) is wholly justified in avian ecology where relationships among parameters are non-linear.

Artificial Neural Networks

The diversity of waterside birds was predicted throughout the exercise using the back-propagation (BP) algorithm with a three-layered neural network. The first layer, called the input layer, was comprised of four cells representing each of the environmental parameters. The second layer, or hidden layer, was composed of a further set of neurons whose number depends on the best-calculated unbiased results. Since the BP algorithm was trained by the least mean square method, the least mean square training could reduce the error or distance between the actual output and the desired output, by adjusting the weightings. Training cases were presented sequentially, and the weightings were adjusted. I determined the number of second-layer neurons through a serious of iterations which varied from two and four to eight neurons (Tables 6-2 to 6-4). In each case, I calculated the correlation coefficients between true values of *H*' and the predicted value of *H'* from the ANN (Figures 6-5 to 6-10). In my study, a network with one hidden layer of four neurons was selected. It emphasized a stable fit which avoided overtraining.

Table 6-2. Determination of the number in the hidden layer for two neurons (2^1). The correlation coefficient (*r*) was detected to differ between the training set ($r = 0.686382$, $n = 35$) and validation set ($r = 0.702283$, $n = 10$). ANN was unable to obtain the underlying rules embedded in the true *H*'.

True *H'*	ANN's *H'*	Error	%Error
0.187446	0.332273	0.144827	77.26%
0.260985	0.264444	0.003459	1.33%
0.539752	0.505032	0.03472	6.43%
0.596994	0.498332	0.098662	16.53%
0.428046	0.391391	0.036655	8.56%
0.627509	0.534325	0.093184	14.85%

Table 6-2. Continued.

True H'	ANN's H'	Error	%Error
0.676667	0.533938	0.142729	21.09%
0.479812	0.4668	0.013012	2.71%
0.437183	0.475328	0.038145	8.73%
0.525698	0.528713	0.003015	0.57%
0.394329	0.383462	0.010867	2.76%
0.616483	0.472067	0.144416	23.43%
0.508955	0.464275	0.04468	8.78%
0.3686	0.468286	0.099686	27.04%
0.517141	0.464745	0.052396	10.13%
0.496184	0.497274	0.00109	0.22%
0.531822	0.465075	0.066747	12.55%
0.402353	0.33943	0.062923	15.64%
0.511992	0.502332	0.00966	1.89%
0.209802	0.22506	0.015258	7.27%
0.532727	0.478609	0.054118	10.16%
0.439588	0.468216	0.028628	6.51%
0.40717	0.428007	0.020837	5.12%
0.516359	0.475853	0.040506	7.84%
0.411911	0.536471	0.12456	30.24%
0.328685	0.495674	0.166989	50.81%
0.337185	0.510684	0.173499	51.46%
0.419735	0.367255	0.05248	12.50%
0.455566	0.444234	0.011332	2.49%
0.417423	0.468759	0.051336	12.30%
0.338905	0.468501	0.129596	38.24%
0.434793	0.47389	0.039097	8.99%
0.491163	0.464692	0.026471	5.39%
0.526723	0.470573	0.05615	10.66%
0.448619	0.470273	0.021654	4.83%
0.514072	0.464002	0.05007	9.74%
0.251645	0.47273	0.221085	87.86%
0.459589	0.459636	4.7E-05	0.01%
0.54215	0.570131	0.027981	5.16%
0.536566	0.4721	0.064466	12.01%
0.36816	0.432755	0.064595	17.55%
0.419471	0.469732	0.050261	11.98%
0.465609	0.489365	0.023756	5.10%
0.225209	0.134077	0.091132	40.47%
0.43893	0.475755	0.036825	8.39%

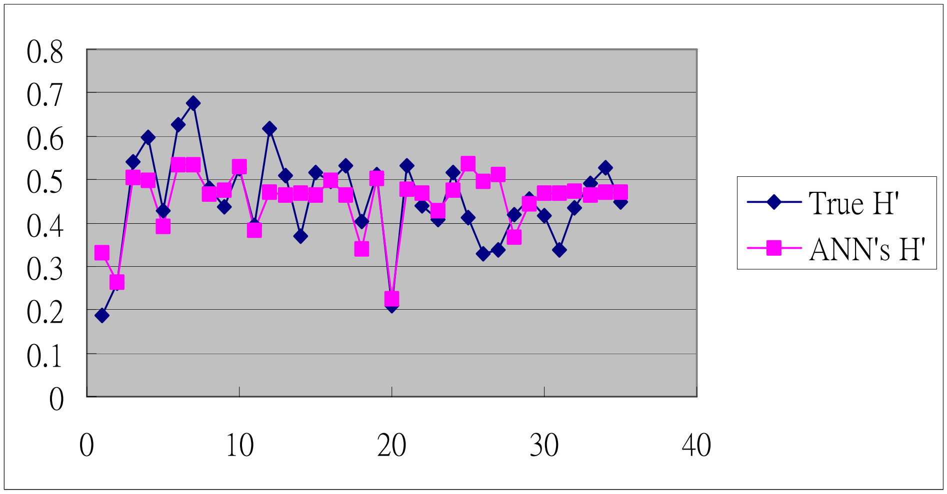


Figure 6-5. Correlation trends between the true *H'* and ANN's predicted *H'* in the training set underfit for two neurons. (correlation coefficient (r) = 0.686382 < 0.702283, n = 35).

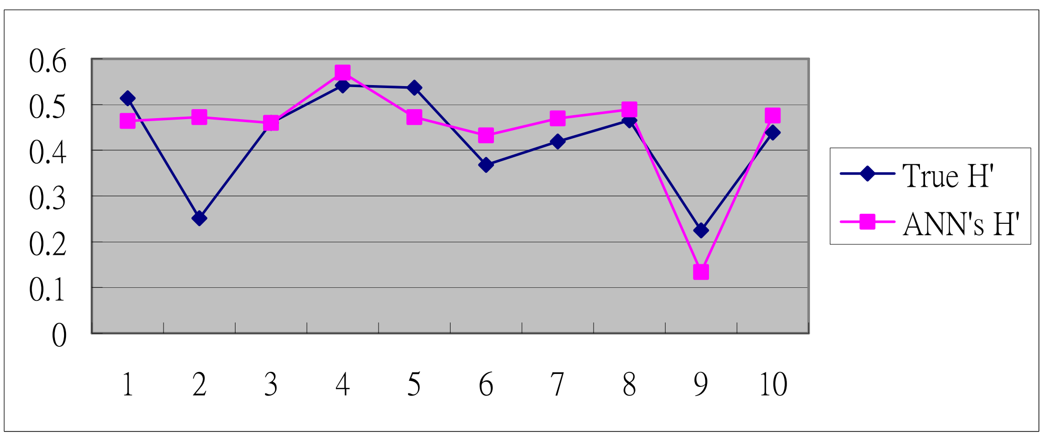


Figure 6-6. Correlation trends between the true *H'* and ANN's predicted *H'* in the validation set for two neurons. (correlation coefficient (r) = 0.702283, n = 10).

Table 6-3. Determination of the number in the hidden layer for four neurons (2^2). The correlation coefficient (r) was detected to differ between the training set (r = 0.725537, n = 35) and the validation set (r = 0.722752, n = 10). The *H'* predicted by the ANN was able to meet the underlying rules embedded in the true *H'*.

True H'	ANN's *H'*	Errors	%Errors
0.187446	0.321635	0.134189	71.59%
0.260985	0.270458	0.009473	3.63%
0.539752	0.48322	0.056532	10.47%
0.596994	0.488195	0.108799	18.22%
0.428046	0.400301	0.027745	6.48%
0.627509	0.569665	0.057844	9.22%
0.676667	0.506622	0.170045	25.13%
0.479812	0.480475	0.000663	0.14%
0.437183	0.460412	0.023229	5.31%
0.525698	0.556084	0.030386	5.78%
0.394329	0.396859	0.00253	0.64%
0.616483	0.466228	0.150255	24.37%
0.508955	0.494652	0.014303	2.81%
0.3686	0.431709	0.063109	17.12%
0.517141	0.514715	0.002426	0.47%
0.496184	0.481721	0.014463	2.91%
0.531822	0.561988	0.030166	5.67%
0.402353	0.340692	0.061661	15.33%
0.511992	0.492565	0.019427	3.79%
0.209802	0.211101	0.001299	0.62%
0.532727	0.481507	0.05122	9.61%
0.439588	0.484536	0.044948	10.23%
0.40717	0.419575	0.012405	3.05%
0.516359	0.455931	0.060428	11.70%
0.411911	0.521107	0.109196	26.51%
0.328685	0.468543	0.139858	42.55%
0.337185	0.50566	0.168475	49.97%
0.419735	0.382099	0.037636	8.97%
0.455566	0.446861	0.008705	1.91%
0.417423	0.422844	0.005421	1.30%
0.338905	0.479862	0.140957	41.59%

Table 6-3. Continued.

True H'	ANN's *H'*	Errors	%Errors
0.434793	0.454446	0.019653	4.52%
0.491163	0.456215	0.034948	7.12%
0.526723	0.482599	0.044124	8.38%
0.448619	0.446258	0.002361	0.53%
0.514072	0.543711	0.029639	5.77%
0.251645	0.471911	0.220266	87.53%
0.459589	0.447477	0.012112	2.64%
0.54215	0.546492	0.004342	0.80%
0.536566	0.471146	0.06542	12.19%
0.36816	0.40313	0.03497	9.50%
0.419471	0.489098	0.069627	16.60%
0.465609	0.47727	0.011661	2.50%
0.225209	0.116435	0.108774	48.30%
0.43893	0.445361	0.006431	1.47%

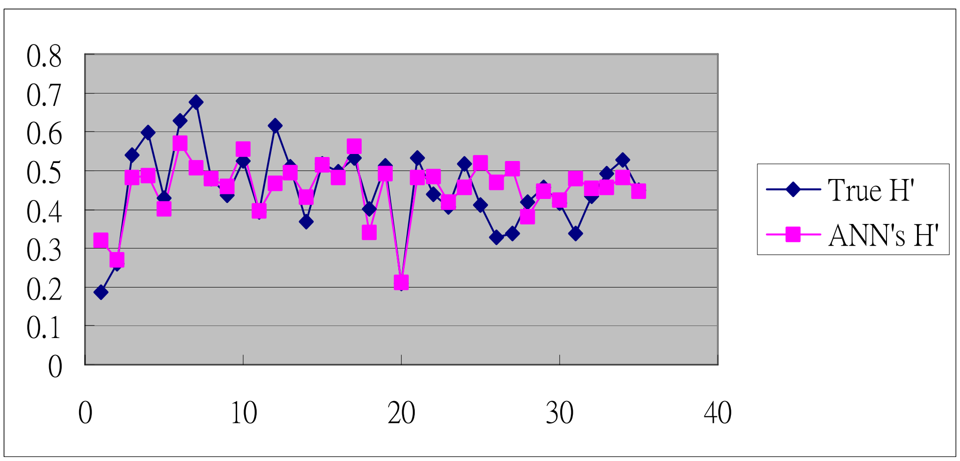


Figure 6-7. Correlation trends between the true *H'* and *H'* predicted by the ANN in the training set for four neurons. (correlation coefficient (r) = 0.725537 > 0.722752, n = 35).

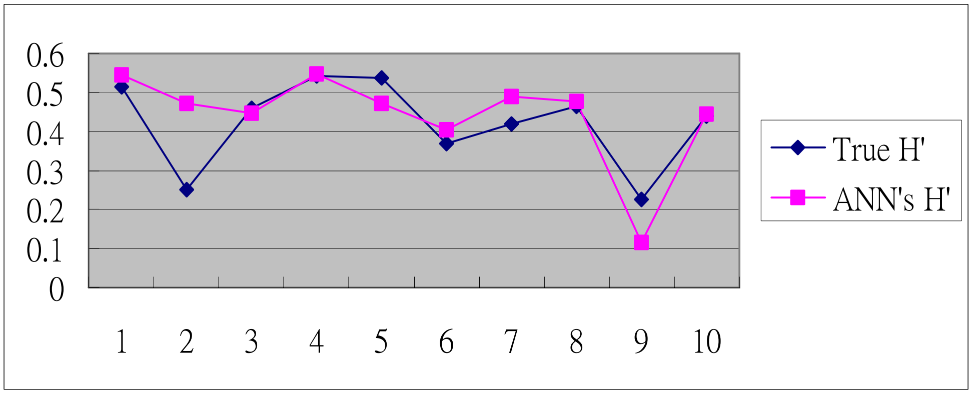


Figure 6-8. Correlation trends between the true *H'* and *H'* predicted by the ANN in the validation set fit to four neurons. (correlation coefficient (r) = 0.722752 < 0.725537, n = 10).

Table 6-4. Determination of the number in the hidden layer for eight neurons (2^3). The correlation coefficient (r) was detected to differ between the training set (r = 0.735429, n = 35) and the validation set (r = 0.651899, n = 10). The *H'* predicted by the ANN was unable to obtain the underlying rules embedded in the true *H'*.

True H'	ANN's *H'*	Errors	%Errors
0.187446	0.275367	0.087921	46.90%
0.260985	0.268591	0.007606	2.91%
0.539752	0.481917	0.057835	10.72%
0.596994	0.491778	0.105216	17.62%
0.428046	0.406655	0.021391	5.00%
0.627509	0.557321	0.070188	11.19%
0.676667	0.514813	0.161854	23.92%
0.479812	0.478036	0.001776	0.37%
0.437183	0.453056	0.015873	3.63%
0.525698	0.532488	0.00679	1.29%
0.394329	0.441207	0.046878	11.89%
0.616483	0.460536	0.155947	25.30%
0.508955	0.486689	0.022266	4.37%
0.3686	0.427333	0.058733	15.93%
0.517141	0.502539	0.014602	2.82%
0.496184	0.477907	0.018277	3.68%
0.531822	0.553899	0.022077	4.15%
0.402353	0.3364	0.065953	16.39%
0.511992	0.501078	0.010914	2.13%

Table 6-4. Continued.

True H'	ANN's *H'*	Errors	%Errors
0.209802	0.199458	0.010344	4.93%
0.532727	0.489226	0.043501	8.17%
0.439588	0.486095	0.046507	10.58%
0.40717	0.403708	0.003462	0.85%
0.516359	0.464963	0.051396	9.95%
0.411911	0.493226	0.081315	19.74%
0.328685	0.484116	0.155431	47.29%
0.337185	0.523756	0.186571	55.33%
0.419735	0.383715	0.03602	8.58%
0.455566	0.455206	0.00036	0.08%
0.417423	0.42896	0.011537	2.76%
0.338905	0.479666	0.140761	41.53%
0.434793	0.469748	0.034955	8.04%
0.491163	0.464623	0.02654	5.40%
0.526723	0.491248	0.035475	6.74%
0.448619	0.466519	0.0179	3.99%
0.514072	0.528054	0.013982	2.72%
0.251645	0.470845	0.2192	87.11%
0.459589	0.463008	0.003419	0.74%
0.54215	0.456747	0.085403	15.75%
0.536566	0.470909	0.065657	12.24%
0.36816	0.412461	0.044301	12.03%
0.419471	0.500922	0.081451	19.42%
0.465609	0.46492	0.000689	0.15%
0.225209	0.18114	0.044069	19.57%
0.43893	0.413555	0.025375	5.78%

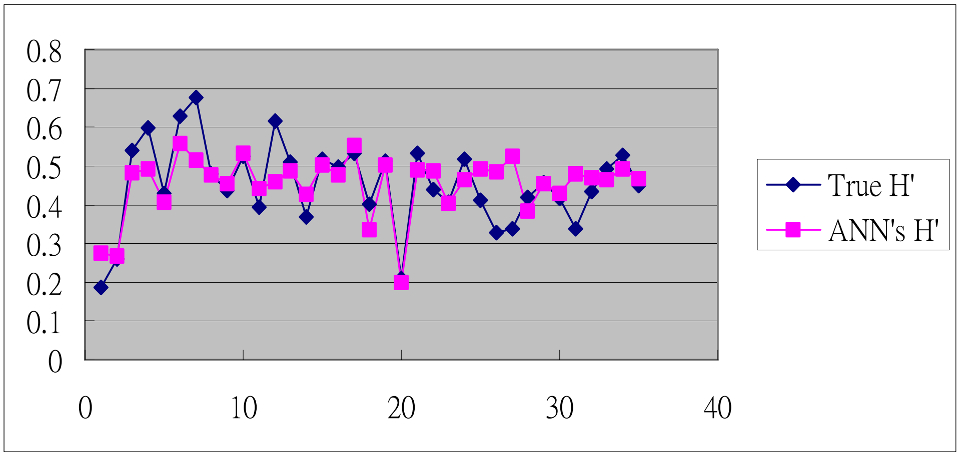


Figure 6-9. Correlation trends between the true *H'* and *H'* predicted by the ANN in the training set overfit to eight neurons. (correlation coefficient (r) = 0.735429 > 0.651899, n = 35).

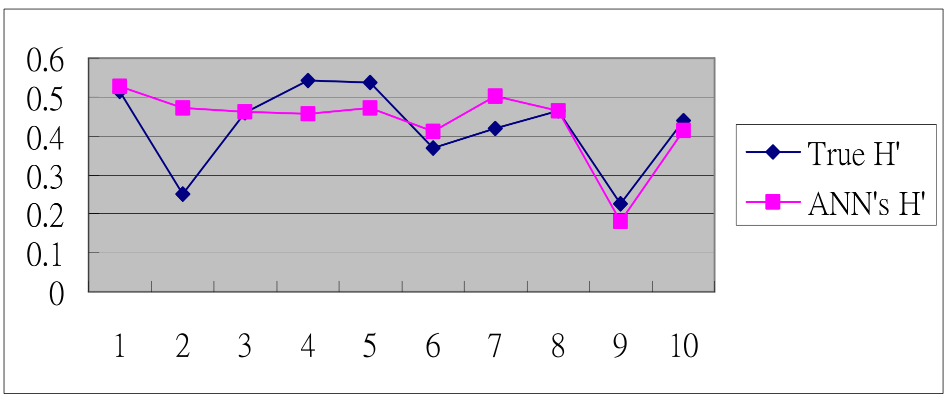


Figure 6-10. Correlation trends between the true *H'* and *H'* predicted by the ANN in the validation set for eight neurons. (correlation coefficient (r) = 0.651899, n = 10).

<u>Refining the Model</u>

In this study, the back-propagation (BP) neural network architecture is shown in Figure 6-11, and consists of four layers of neurons connected by weightings.

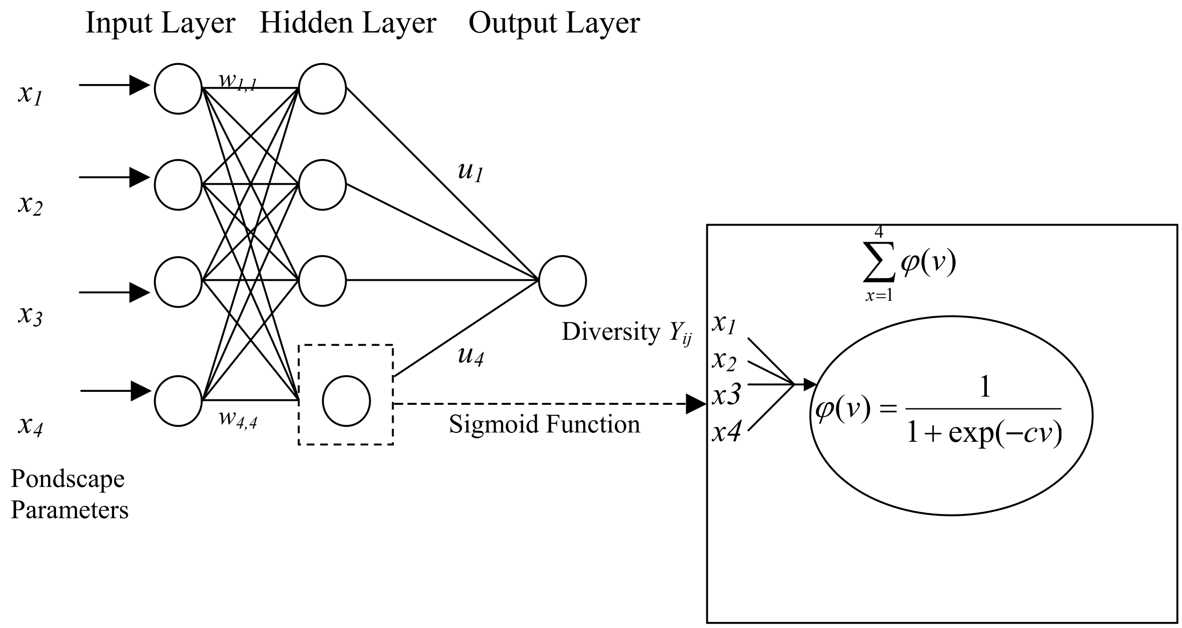


Figure 6-11. Structure of the neural network used in this study. The input layer was comprised of four cells representing each of the four pondscape parameters *Xi* (i = 1, 4). The hidden layer was comprised of four neurons which calculated the dot products between its vector with weightings $w_j = [w_{ji,}\ i = 1,4]$ and $x = [x_{i,}\ i=1,4]$ from MATLAB 6.1.

I used MATLAB 6.1 (MathWorks, Natick, MA 2001) to calculate a refining simulation model for ten extra values of *H*' (for a total (n) of 55). The information was captured by the network when input data passed through the hidden layer of neurons to the output layer. The weightings connecting from neuron one to neuron four were denoted as w_{ji}. The output of each neuron was calculated based on the amount of stimulation it received from the given input vector, x_i, where x_i was the input of neuron i. The net input of a neuron was calculated as the weights of its inputs, and the output of the neuron was based on some sigmoid function which indicated the magnitude of this net input. So the net output, u_j, from a neuron can be indicated as

$$u_j = \sum_{i=1}^{p} w_{ji} x_i \tag{6-5}$$

and

$$y_j = \varphi(u_j - \theta_j) \tag{6-6}$$,

where

w_{ji} is the incremental change in the weighting from x_i to u_j,

θ_j is a threshold to be passed through by the non-linear activation function, $\varphi(\cdot)$,

x_i is the *ith* pondscape parameter,

u_j is the *jth* neuron from an outgoing signal to the magnitude of all observations,

$\varphi(\cdot)$ is the activation function, and

y_j is the output of *jth* neuron in any layer.

For this research, I chose the continuous sigmoid as the basic function:

$$\varphi(v) = \frac{1}{1 + \exp(-cv)} \tag{6.7}$$,

where v is the net effect, and c is a constant.

For a given input set, the network produces an output, and this response is compared to the known desired response for each neuron. The weightings of the network were then changed to correct or reduce the error between the output of the neuron and the desired response. This iterative process was continued with the weightings being changed until the total error of all training set was reduced below an acceptable value for the sum of the errors. The BP algorithm for determining the optimal weights from the training sets is similar to any function approximation technique like the least squares regression. But BP has an improved function to handle highly complex and non-linear data (for calculation results see Appendices 3 and 4).According to the BP simulation, gradients of land development intensities for land uses adjacent to farm ponds were refined as (1) scenario A with conservative land use, ($p = 0.25$); (2) scenario B with moderate land use ($p = 0.50$); and (3) scenario C with intensive land use ($p = 0.75$) for the priorities of waterside bird refuges as described in the pages that follow Figures 6-12, 6-13, and 6-14. The simulation with scenario B (with moderate land use) (Figure 6-13) showed an increase of one priority of the patches ($H' > 1.5$) for potential waterside bird refuges by overlaying extrapolated estimation of pond sites ($r = 0.72$, $n = 55$) compared with that before the estimation in Figure 6-3; and the simulation of scenario C (with intensive land use) (Figure 6-14) showed an increase of two priorities of the patches ($H' > 1.5$) as potential waterside bird refuges ($r = 0.72$, $n = 55$) by overlaying the extrapolated estimate compared with that before the estimation in Figure 6-4.

SUMMARY

ANN is one of the tools that can resolve prediction problems, and this ANN property is now well understood. First, the validation results were satisfactory with a four-neuron model, confirming the non-linearity of the relationship among the parameters. The training set ($r = 0.725537$, n = 35) and validation set ($r = 0.722752$, $n = 10$) were surprisingly close in meeting the underlying rules embedded in the real values of the true H'.

Second, the pondscape configuration was in fact a very relevant factor in avian diversity. In this study, the pond fractal dimension (MPFD) was the most significant parameter for waterside birds in the non-linear model in comparison to the other factors (the calculation process of the factor elimination approach is given in Appendix D-1, D-2, and D-3). The one-row factor elimination approach (FEA) determined that the MPFD is the crucial factor affecting waterside bird diversity. The mean H' predicted error of the MPFD in the four-neuron simulation model was slight (mean H' predicted error =

0.0827 ±1.16432E-05, *n* = 45). Rather, the relationship between the values of the MPFD (range = [1, 2]) and waterside bird *H*' was negative (Appendix D-4, tested by a 4-neuron model, with test samples at a ±10% range). The precise results and the ANN potential to predict waterside bird *H'* were significant from the MPFD.

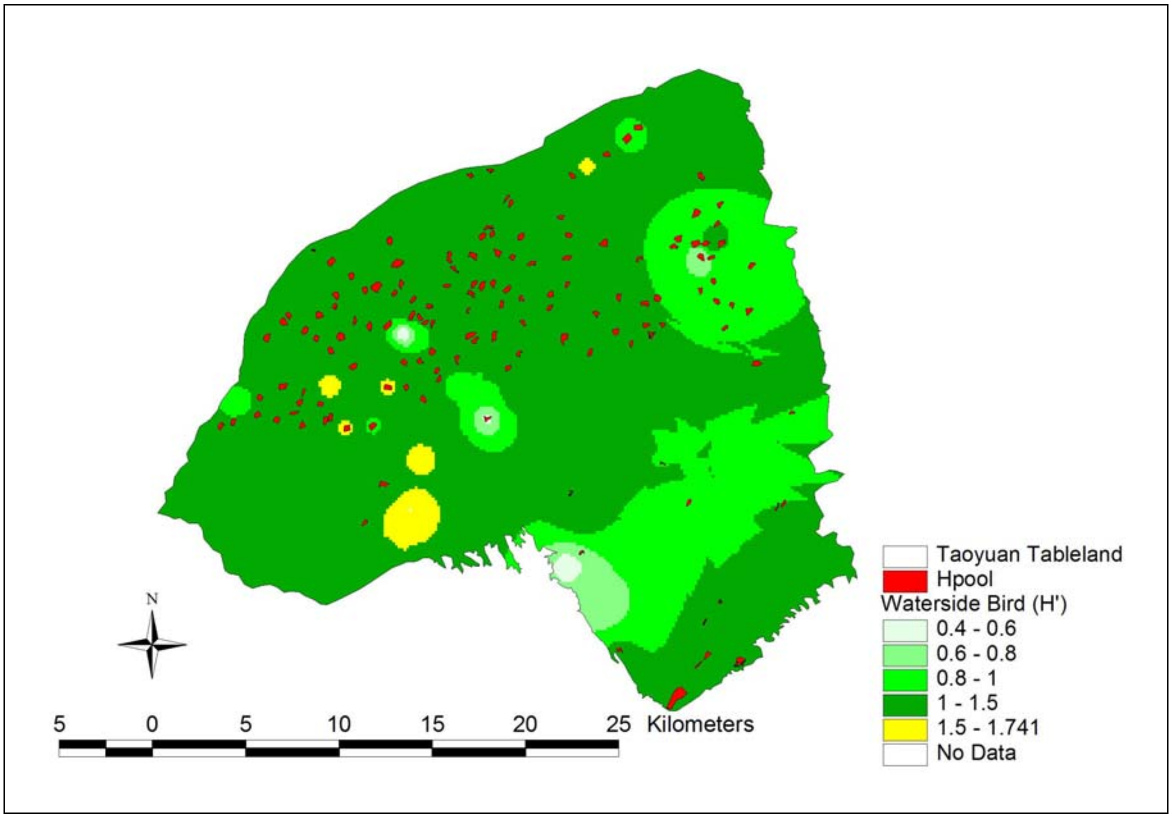


Figure 6-12. Scenario A refined by the ANN model for conservative land use. If the lower value of the likelihood of pond loss was equal to 0.25, overall ponds noted as threatened as red spots (pond size > 0.996 ha, TE_{km} > 0.997 km) need to be conservatively protected due to the slight likelihood of their loss. The extrapolated map (r = 0.72, n = 55) of waterside bird diversity *H'* suggests raising the priority of designating waterside bird refuges in patches against the potential pond-loss rate overlaid by threatened red spots (Hpool: pond size > 0.996 ha, TE_{km} > 0.997 km) [diversity *H'*: 0.4~0.6; 0.6~0.8; 0.8~1.0; 1.0~1.5; and 1.5~1.741; distance (km), 12] (r = 0.72).

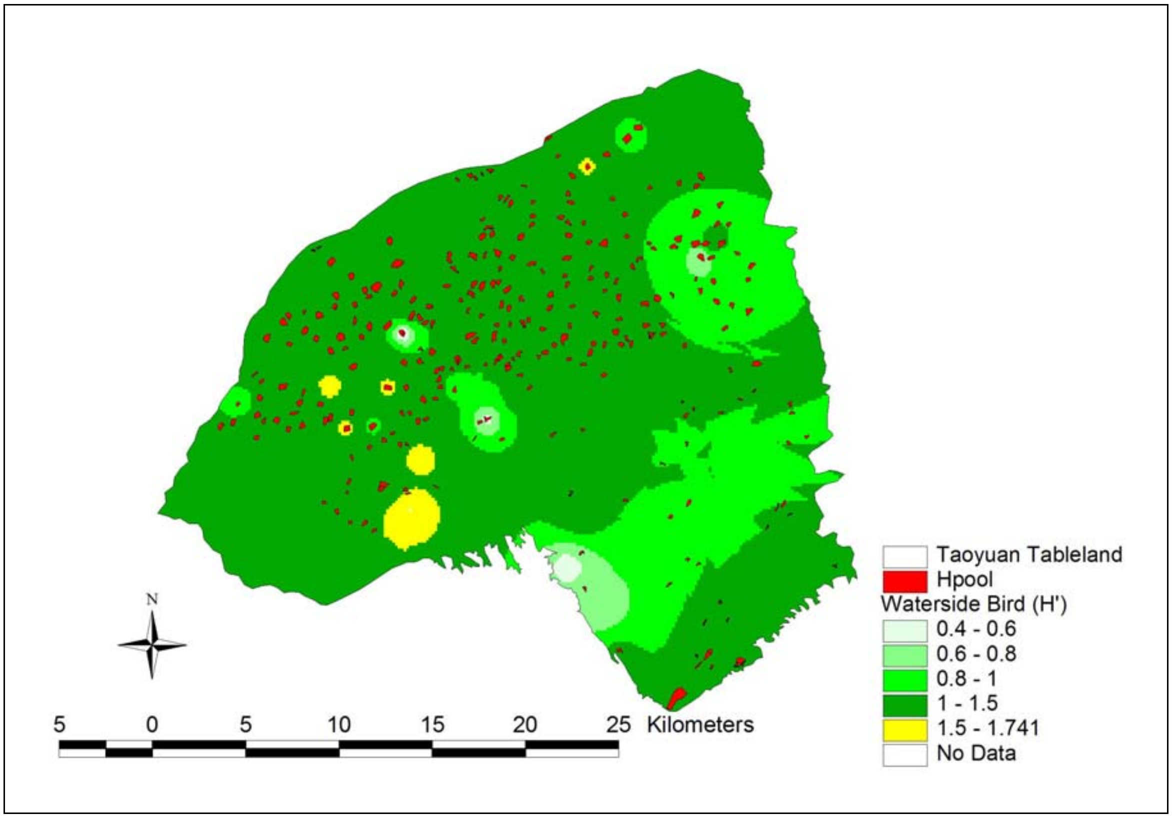


Figure 6-13. Scenario B refined by the ANN model for moderate land use. If the moderate value of the likelihood of pond loss was equal to 0.50, overall ponds noted as threatened by red spots (pond size > 0.631 ha, TE_{km} > 0.708 km) need to be moderately protected due to the likelihood of their loss. The extrapolated map (r = 0.72, n = 55) of waterside bird diversity *H'* suggests raising the priority of designating waterside bird refuges in patches against potential pond-loss rate overlaid by threatened red spots (Hpool: pond size > 0.631 ha, TE_{km} > 0.708 km) [diversity *H'*: 0.4~0.6; 0.6~0.8; 0.8~1.0; 1.0~1.5; and 1.5~1.741; distance (km), 12].

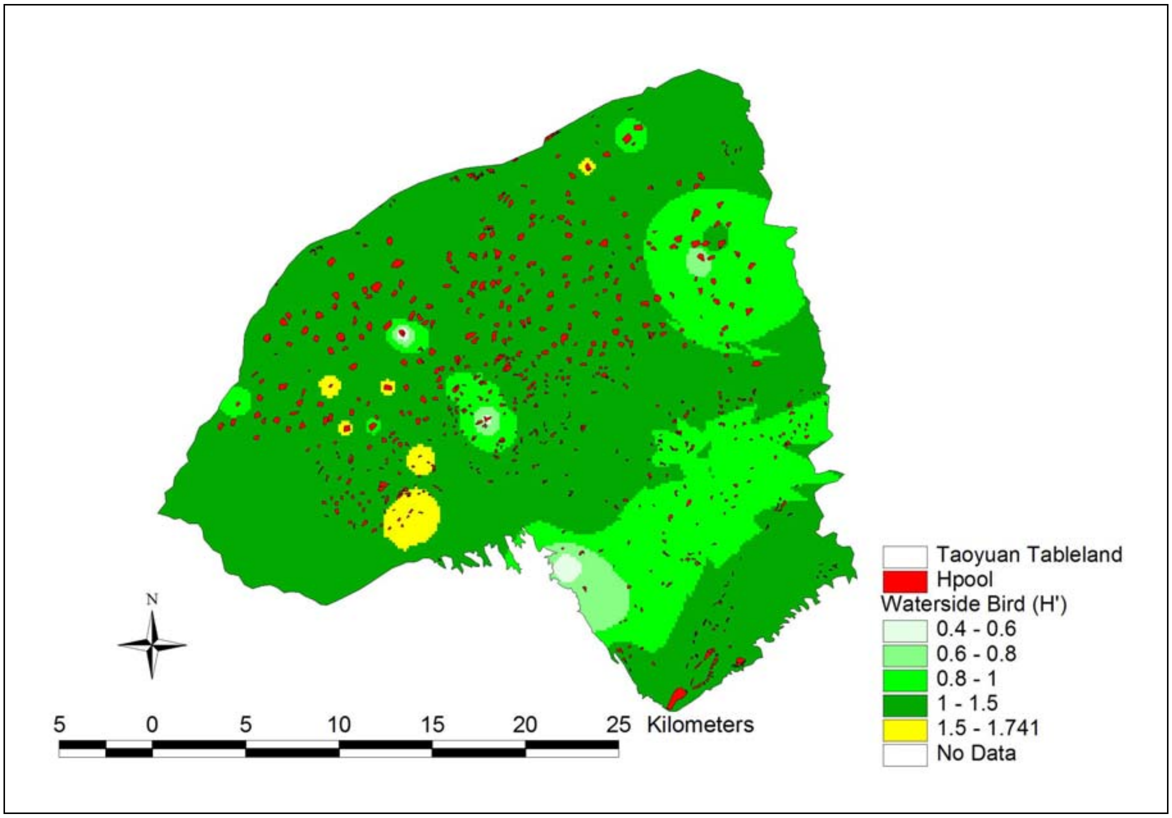


Figure 6-14. Scenario C refined by the ANN model for an intensive land-use pattern. If the high value of the likelihood of pond loss was equal to 0.75, all ponds noted as threatened by the red spots (pond size > 0.2666 ha, TE_{km} > 0.371 km) need to be intensively protected due to the likelihood of their loss. The extrapolated map (r = 0.72, n = 55) of waterside bird diversity *H'* suggests raising the priority of designating waterside bird refuges in patches against potential pond-loss rate overlaid by threatened red spots (Hpool: pond size > 0.2666 ha, TE_{km} > 0.371 km) [diversity *H'*:0.4~0.6; 0.6~0.8; 0.8~1.0; 1.0~1.5; and 1.5~1.741; distance (km), 12] (r = 0.72).

CHAPTER VII
CONCLUSIONS

To analyze the results of this study, GIS pondscape data were coded, calculated, and compared with data on avian communities. A modified simulation model was developed to describe the cumulative influences of species-area and species-habitat relationships and to produce a detailed simulation map for the distribution of waterside bird diversity (*H'*). This chapter discusses the study results and model application, and offers recommendations for better management practices for wintering bird refuges in Taiwan.

FINDINGS AND DISCUSSION

Some of the most significant findings came from the artificial neural network (ANN) model. The ANN model suggests that small and curvilinear ponds together with urban development associated with landscapes possessing high-density rural populations adversely affect waterside bird diversity. To some extent, increased heterogeneity of microhabitats within these pond units would result in promoting species diversity. For example, drawdown can be beneficial to shorebirds; foliage buildup at the waterfront can be beneficial to waterfowl. There is clearly some mechanism responsible for variations in avian communities across the pond size gradient. According to MacArthur and Wilson (1967), the nature of this mechanism is interesting as the island biogeographic concept predicts that smaller microhabitats should contain fewer species due to the effects of reduced immigration rates. The incidence of area-sensitive species, i.e., waterfowl, is expected to increase as pond size increases. In addition, a larger pond is also more likely to contain at least one individual of a species, especially an uncommon or rare one.

Another important finding is that pond shape (i.e., MPFD) within a pondscape might tremendously influence waterside bird diversity. The ANN method provides a good indication of the cumulative influences of other environmental factors: such as %BUILD and %FARM. The cumulative influences were those that resulted from anthropogenic influences, and became statistically significant for waterside bird diversity. The above-mentioned environmental factors were selected from the correlation analysis associated with the linear regression model, and the impact trend of each factor was detected by the ANN testing model. Finally, the impact trends were calculated as the respective sequence of MPFD, %FARM, PS, and %BUILD (for the overall calculation processes see Appendix D).

Model Application

Determining and controlling environmental parameters such as MPFD, %FARM, PS, and %BUILD between ponds should, in theory, allow waterside birds to stop in and colonize ponds. In accordance with the island biogeographic concept (MacArthur and Wilson 1967), this should result in increased diversity with pond size. According to my final findings, other factors especially a circular pond shape should also result in increased diversity on the habitat scale (Figure 7-1).

On the Taoyuan Tableland, all ponds are similarly isolated. Within the complex pondscape, ponds are similarly isolated from each other, and if steppingstone colonization takes place, then species are able to become established throughout the complex (Forman 1995).

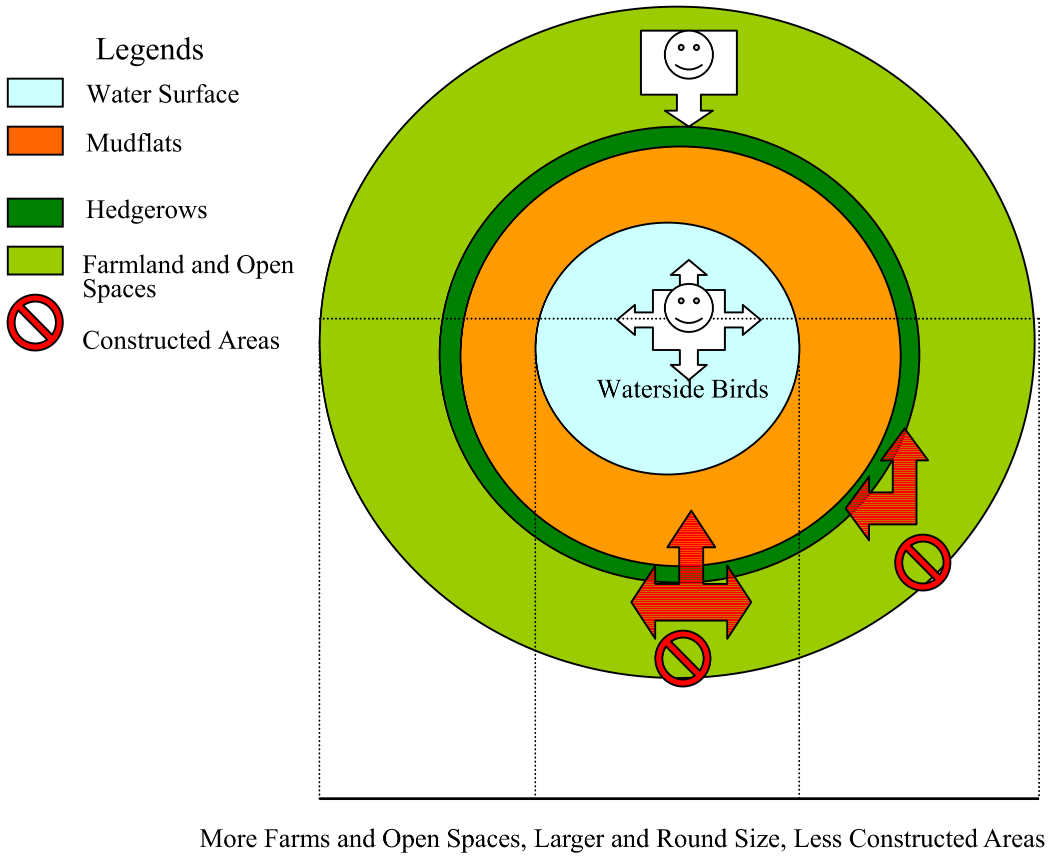


Figure 7-1. Refinement of the concentric patterns of the dominance of waterside diversity of pond microhabitats arrayed on a successional sequence from the pond core to the surroundings on a habitat-stand scale.

All or part of a population may move to surrounding ponds due to stochastic or deterministic mechanisms, and steppingstone recolonization might then ensure the persistence of a population among wintering stopovers. This is effectively the colonization effect where functional groups are continuously moving by colonization from and into nearby neighboring ponds.

Because there are many ponds within the tableland and they are spatially close together, vulnerable avian populations are likely to be enhanced by immigrants from multiple neighboring populations during migration. Stable microhabitats are also likely to receive immigrants from several neighboring populations. Movements among farm ponds are thus likely to be high, and therefore the entire pond complex is likely to respond as a multifaceted community. There is likely to be a concentric gradient in pond systems between waterside species and habitat “islands”.

I confirmed that due to similar mechanisms operating in all ponds and the high connectivity among them, farm ponds correspond very closely to the environmental gradients. Given the wide range of ponds examined in my study, it is quite possible that predicted group diversities exist at different positions along this gradient. Therefore, an extrapolation approach due to the colonization effect can be helpful for predicting waterside bird diversity (*H*’) in surrounding study ponds. Throughout the study, values of pondscape parameters were input into the ANN algorithm; I then determined detailed regional contour maps surrounded by urbanized areas (Figure 7-3 with an extrapolated approach compared to Figure 7-2 with current data sets).

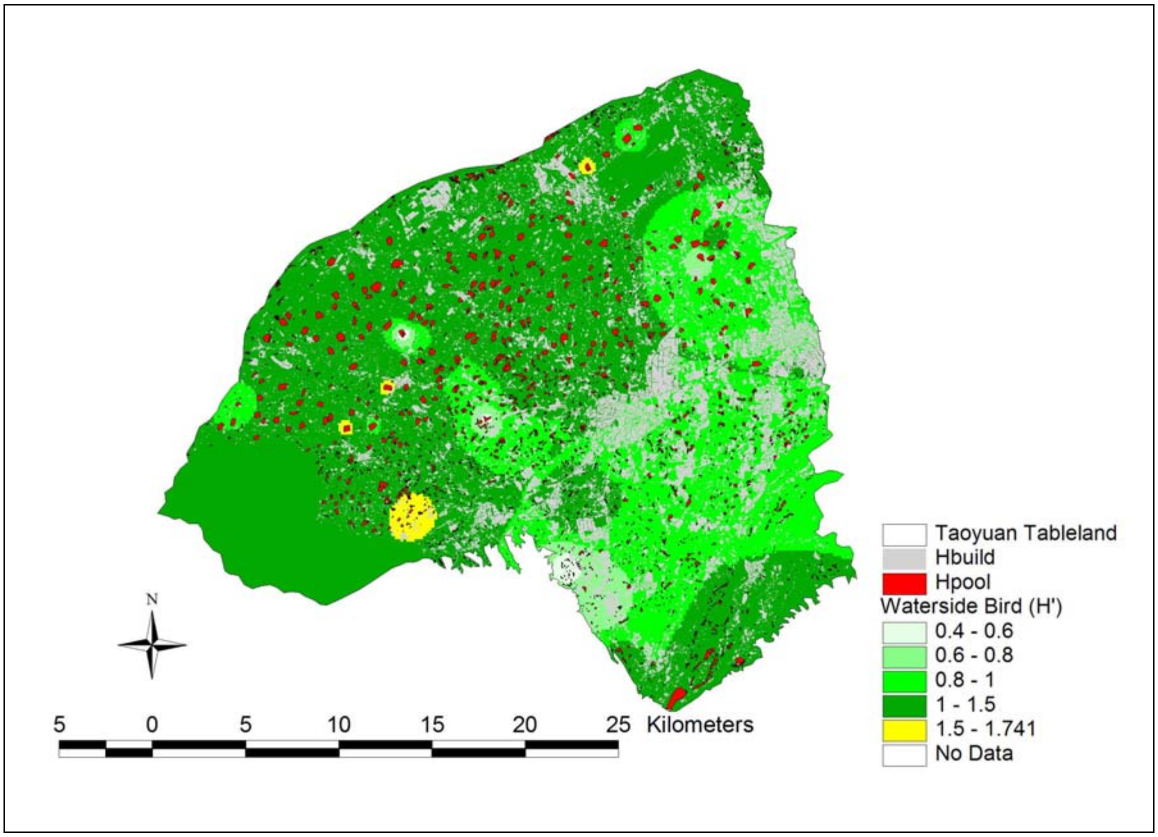


Figure 7-2. Scenario C designed for an intensive urbanized gradient pattern (right spotted areas) using the current survey data. The simulation did not cover the pond areas in the southwestern portion adjacent to the Houkuo Tableland located in Hsinchu County. According to Figure 6-4, potential waterside bird refuges were determined from priorities of gradients with the references of pond-loss likelihood overlaid by threatened red spots (Hpool, pond size > 0.2666 ha, TE_{km} > 0.371 km) [diversity H': 0.4~0.6; 0.6~0.8; 0.8~1.0; 1.0~1.5; and 1.5~1.741; distance (km), 12].

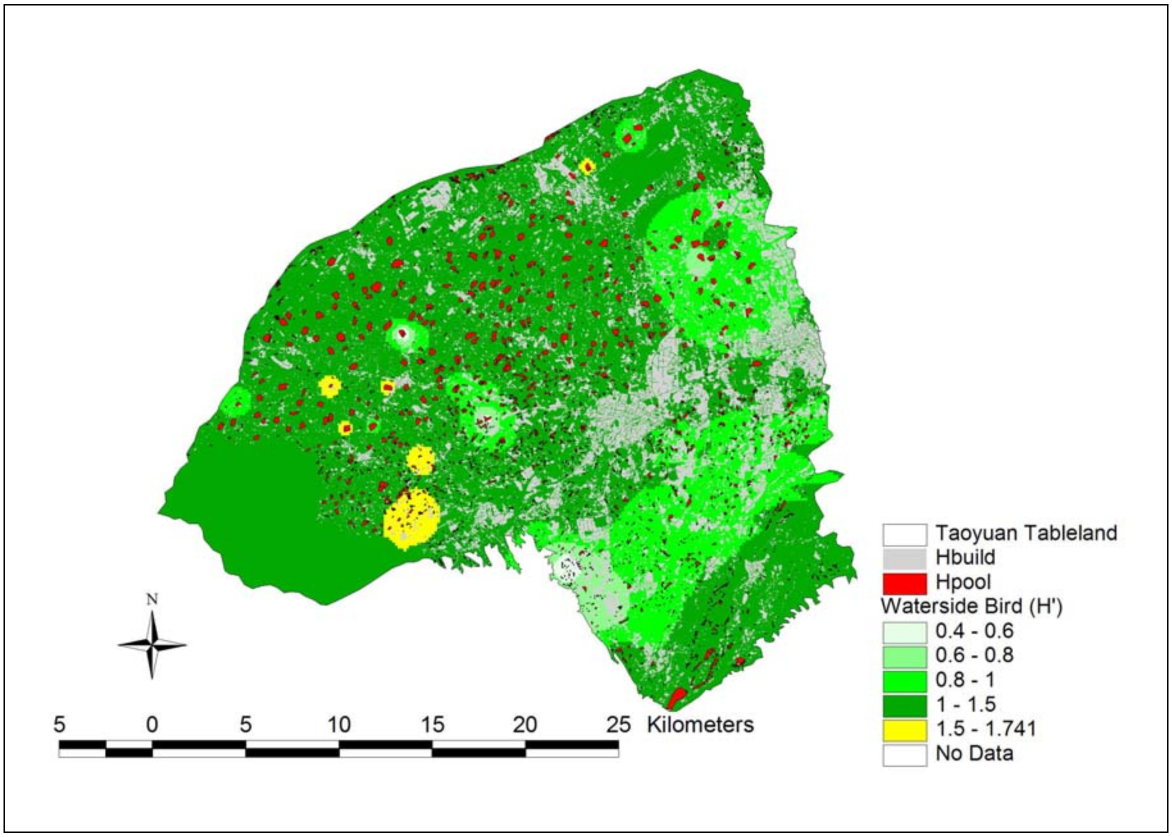


Figure 7-3. Scenario C designed for an intensive urbanized gradient pattern (right spotted areas) refined using the ANN model ($r = 0.72$, $n = 55$). The simulation did not cover the pond areas in the southwestern portion adjacent to the Houkuo Tableland located in Hsinchu County. According to Figure 6-10, potential waterside bird refuges were determined from priorities of gradients with the references of pond-loss likelihood overlaid by threatened red spots. [diversity *H'*: 0.4~0.6; 0.6~0.8; 0.8~1.0; 1.0~1.5; and 1.5~1.741; distance (km), 12].

RECOMMENDATIONS

The species-area hypothesis and species-habitat hypothesis have been debated for about 30 years in landscape studies. This is an important ecological issue not only for those who are concerned with rangeland ecology, but also generally for ecological practitioners, such as officials, designers, planners, and managers. Regarding some controversial issues, I am reminded of the old Buddhist story about the blind scholars and the elephant. Asked to describe the elephant, the first scholar, touching the massive side, stated, “It is like a wall”. The second scholar, holding the tail, said, “No, it is like a piece of rope”. The third, holding the trunk, insisted,” You are totally wrong. It is like a snake”. Due to limited experience of the scale of the study data and frame of reference, the blind scholars only acknowledged superficial segments to describe an entire picture. Nevertheless, current scholars, who see a tree without regarding the forest, may commit these same errors. Whereas some scholars who study a single habitat cannot see the forest for the trees, others cannot even see the trees without habitat studies. Those scholars who support the species-area hypothesis or species-habitat hypothesis constantly take risks because of a partial understanding of landscape-complex phenomena. In this dissertation, I tried to provide a general sketch of the entire elephant to illustrate a clear image of farm-pond studies. This research is not only a valuable study of avian communities found in the area, but also provides a useful reference for future studies of other similar sites. Based on the results of this research, several recommendations are suggested for improving pondscape management and for protecting wintering birds. The local planning authorities could implement and promote some or all of these strategies.

1. Although an integrated pondscape analysis is not easy, this analysis presents a rationale for such integration, based partly on an advanced ANN analysis. This dissertation can help the agencies responsible for planning pondscape management to better promote use of ecological simulation skills and, thereby, to assess pond-loss likelihood more effectively as well as bird diversity in farm-pond areas.

2. Farm-pond protection evolving from land-use analysis requires government action, but cooperation with stakeholders (i.e., birdwatchers, inhabitants, farmers, irrigation associations, and ranching enterprises) is necessary to effectively manage the pondscape. For example, extensive agricultural practices associated with ranching enterprises appear to maintain windbreaks with native plant communities adjacent to ponds which are essential for maintaining bird communities. In addition, aquaculture as well as drawdown practices continue to be applied during winter seasons. Therefore, biologists and conservationists should focus their rangeland programs on maintaining avian species.
3. Integrated pondscape research must be a long-term project. It is necessary to build a time frame of 10 to 20 years. For example, to undertake evaluations of pondscape changes requires avian data of long-term losses or increases of richness and abundance from year to year. This consideration would help make the simulation and evaluation model more precise in continuing this work over the long run.

SUMMARY

Pondscape microhabitats contain major factors of stability, but they are by no means static within a biotope. Land-use changes are a normal part of pondscapes, and pondscapes are remarkably restless. Historically within the past 100 years, the area of farm ponds accounted for 11.8% by area of the Taoyuan Tableland comprising a maximum extent of 8900 ha; however, by 2002 the area of farm ponds only accounted for 3.8% of the land area (2898 ha) (Taiwan Geographic Map, 1: 5000) (Department of

Land Administration, Ministry of the Interior 1999). Due to human alterations, approximately 6000 ha of farm ponds have disappeared. If a pond area of 1 ha can support seven wintering birds, those that comprised habitats of wintering birds were thus estimated to support 42,000 individuals in the entire area (Environmental Protection Administration 2004). According to avian community counts, only a little over 22,000 wintering birds simultaneously occurred on the Taoyuan Tableland. Some 94 species, or about one-fifth of the bird species in Taiwan, were recorded in Taoyuan's farm-pond areas. Loss of farm ponds could drastically affect birds in Taiwan due to loss of habitat.

Several things were noted about pondscape changes on the Taoyuan Tableland. (1) Recently there has been an increasing number of reports warning about pond losses. (2) A circular pond shape is the major factor promoting an increase in waterside bird diversity. (3) Pond size associated with various microhabitats in surrounding areas exerts a beneficial effect on increasing wetland bird diversity. (4) As rural human populations increase, residential areas are resulting in fewer waterside birds.

The purposes of this dissertation were to assess and simulate the relationships between pondscape parameters and avian communities, especially as to the aspect of waterside species from pond cores to waterfronts. My research has focused on refining the simulation skills for evaluating land uses. After studying the results of the correlation analysis associated with validation of the artificial neural network, it was further confirmed that a curvilinear pond shape, sprawling housing, and small pond size have significant influences on avian declines. The approach presented in this dissertation dealt with construction of pondscape evaluation and simulation criteria. The final significant results can promote precise simulation capabilities using the concept of island biogeography ($r = 0.72$), advancing a way by the back-propagation process of data training, validation, and extrapolation to form a landscape approach.

Trade-offs between urban development and pondscape conservation should be considered. All future urban development should include a restoration project for farm ponds which would primarily involve planting appropriate native vegetation as well as supporting ecologically beneficial water regimes for wetland birds. On the basis of a holistic framework of analysis, this study provides a potential approach for in-site refuge planning and design in Taoyuan, Taiwan.

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APPENDICES

Appendix A. Birds Detected Name Lists in Taoyuan Farm Ponds (November 2003~December 2004).

ID	Chinese name	No.	Scientific name	Common name	Length (cm)	Weight (g)	[1]Status	[2]Guild
1402	尖尾鴨	2	Anas acuta	Northern Pintail	64	1010	W	W
1403	琵嘴鴨	3	*Anas clypeata*	Northern Shoveller	50	613	W	W
1404	小水鴨	4	*Anas crecca*	Common Teal	38	341	W	W
1408	赤頸鴨	5	*Anas penelope*	Eurosian Wigeon	50	772	W	W
1410	花嘴鴨	6	*Anas poecilorhyncha*	Spot-billed Duck	60	1220	W	W
1419	紅頭潛鴨	7	*Aythya ferina*	Common Pochard	46	823	W	W
1523	黑鳶	8	*Milvus migrans lineatus*	Black-eared Kite	55	827	R	A
2102	白冠雞	9	*Fulica atra*	Common Coot	40	853	W	M
2106	緋秧雞	10	*Porzana fusca*	Ruddy-breasted Crake	19	60	R	M
2608	跳行鳥	11	*Vanellus cinereus*	Grey-headed Lapwing	34	270	T	M
2609	金斑行鳥	12	*Pluvialis fulva*	Pacific Golden-Plover	24	153	W	M
2738	赤足鷸	13	*Tringa totanus*	Common Redshank	28	129	T	M
2801	高蹺行鳥	14	*Himantopus himantopus*	Black-Winged Stilt	32	161	W	M
2802	反嘴行鳥	15	*Recurvirostra avosetta*	Pied Avocet	42	306	W	M
4002	叉尾雨燕	16	*Apus pacificus*	Fork-tailed Swift	22	45	W	A
4903	赤腰燕	17	*Hirundo striolata*	Striated Swallow	19	22	R	A
4905	棕沙燕	18	*Riparia paludicola*	Plain Sand Martin	10	13	R	A
6701	赤喉鷚	19	*Anthus cervinus*	Red-throated Pipit	14	20	W	M
2735	青足鷸	20	*Tringa nebularia*	Common Greenshank	35	174	W	M
1421	斑背潛鴨	21	*Aythya marila*	Greater Scaup	46	945	W	W
205	小鷿鷈	22	*Tachybaptus ruficollis*	Little Grebe	26	201	R	W
2104	紅冠水雞	23	*Gallinula chloropus*	Common Moorhen	33	303	R	M
1409	綠頭鴨	24	*Anas platyrhynchos*	Mallard	59	1082	W	W
4001	小雨燕	25	*Apus nipalensis*	House Swift	15	24	R	A
2731	鷹斑鷸	26	*Tringa glareola*	Wood Sandpiper	22	68	W	M
3207	紅嘴鷗	27	*Larus ridibundus*	Common Black-headed Gull	40	284	W	A
2601	東方環頸行鳥	28	*Charadrius alexandrinus*	Kentish Plover	18	41	W	M
4904	洋燕	29	*Hirundo tahitica*	Pacific Swallow	13	13	R	A
2611	小辮行鳥	30	*Vanellus vanellus*	Northern Lapwing	34	219	W	M
2603	小環頸行鳥	31	*Charadrius dubius*	Little Ringed Plover	16	39	W	M
1108	大白鷺	32	*Casmerodius alba*	Great Egret	90	874	W	WS

Appendix A. Continued.

ID	Chinese name	No.	Scientific name	Common name	Length (cm)	Weight (g)	[1]Status	[2]Guild
4101	翠鳥	33	*Alcedo atthis*	Common Kingfisher	16	27	R	A
4902	家燕	34	*Hirundo rustica*	Barn Swallow	17	18	R	A
1706	紅隼	35	*Falco tinnunculus*	Common Kestrel	31	201	W	A
1111	中白鷺	36	*Mesophoyx intermedia*	Intermediate Egret	69	500	W	WS
1110	小白鷺	37	*Egretta garzetta*	Little Egret	61	500	R	WS
2733	磯鷸	38	*Tringa hypoleucos*	Common Sandpiper	18	52	W	WS
1101	蒼鷺	39	*Ardea cinerea*	Grey Heron	93	1443	W	WS
901	鸕鷀	40	*Phalacrocorax carbo*	Common Cormorant	82	2111	W	WS
2703	黑腹濱鷸	41	*Calidris alpina*	Dunlin	19	58	W	WS
1121	夜鷺	42	*Nycticorax nycticorax*	Black-crowned Night-Heron	58	883	R	WS
6707	白鶺鴒	43	*Motacilla alba*	White Wagtail	19	21	W	H
5410	喜鵲	44	*Pica pica*	Black-billed Magpie	45	178	R	T
1601	魚鷹	45	*Pandion haliaetus*	Osprey	58	1486	W	T
5914	山紅頭	46	*Stachyris ruficeps*	Rufous-capped Babbler	24	10	R	T
3509	紅鳩	47	*Streptopelia tranquebarica*	Red collared-dove	23	104	R	T
6710	黃鶺鴒	48	*Motacilla flava*	Yellow Wagtail	17	18	W	H
5403	巨嘴鴉	49	*Corvus macrorhynchos*	Large-billed Crow	53	483	R	T
6708	灰鶺鴒	50	*Motacilla cinerea*	Grey Wagtail	18	18	W	WS
5913	小彎嘴	51	*Pomatorhinus ruficollis*	Steak-breasted Scimitar Babbler	21	32	R	S
5103	大卷尾	52	*Dicrurus macrocercus*	Black Drongo	29	50	R	T
6313	黃尾鴝	53	*Phoenicurus auroreus*	Daurian Redstart	15	15	W	T
6422	褐頭鷦鶯	54	Prinia inornata	Plain Prinia	15	7	R	S
7201	綠繡眼	55	*Zosterops japonica*	Japanese White-eye	11	10	R	T
3507	斑頸鳩	56	*Streptopelia chinensis*	Spotted Dove	30	159	R	T
1105	黃頭鷺	57	*Bubulcus ibis*	Cattle Egret	50	338	W	T
7012	白尾八哥	58	*Acridotheres grandis*	White-vented Myna	25	90	V	T
6003	白頭翁	59	*Pycnonotus sinensis*	Light-vented Bulbul	18	27	R	T
7601	麻雀	60	*Passer montanus*	Eurasian Tree Sparrow	14	22	R	T
1119	黃小鷺	61	*Ixobrychus sinensis*	Yellow Bittern	36	98	R	H
1802	竹雞	62	*Bambusicola thoracica*	Chinese Bamboo-Partridge	25	270	R	H
2101	白腹秧雞	63	*Amaurornis phoenicurus*	White-breasted Waterhen	29	173	R	WS
2707	紅胸濱鷸	64	*Calidris ruficollis*	Rufous-necked Stint	15	34	T	WS
2709	丹氏濱鷸	65	*Calidris temminckii*	Temminck's Stint	15	23	W	WS
2713	琵嘴鷸	66	*Gallinago gallinago*	Common Snipe	26	122	V	WS
2729	黃足鷸	67	*Tringa brevipes*	Grey-tailed Tattler	25	107	T	WS
3508	金背鳩	68	*Streptopelia orientalis*	Eastern Turtle Dove	30	215	R	T

Appendix A. Continued.

ID	Chinese name	No.	Scientific name	Common name	Length (cm)	Weight (g)	[1]Status	[2]Guild
3512	綠鳩	69	*Treron sieboldii*	White-bellied Green-pigeon	31	235	R	T
3601	番鵑	70	*Centropus bengalensis*	Lesser Coucal	39	120	R	WS
4501	五色鳥	71	*Megalaima oorti*	Black-browed Barbet	20	59	R	T
5407	樹鵲	72	*Dendrocitta formosae*	Grey Tree-pie	34	104	R	S
5502	粉紅鸚嘴	73	*Paradoxornis Webbianus*	Vinous-throated Parrotbill	12	11	R	S
6002	紅嘴黑鵯	74	*Hypsipetes leucocephalus*	Black Bulbul	24	42	R	WS
6307	野鴝	75	*Luscinia calliope*	Siberian Rubythroat	16	19	W	S
6317	藍尾鴝	76	*Tarsiger cyanurus*	Orange-flanked Bush-robin	14	12	W	S
6321	赤腹鶇	77	*Turdus chrysolaus*	Brown-headed Thrush	22	63	W	WS
6325	斑點鶇	78	*Turdus naumanni*	Dusky Thrush	25	72	W	WS
6402	大葦鶯	79	*Acrocephalus arundinaceus*	Great Reed-Warbler	17	27	W	H
6406	短翅樹鶯	80	*Cettia diphone*	Japanese Bush-Warbler	15	14	W	T
6407	台灣小鶯	81	*Cettia fortipes*	Brownish-flanked Bush-Warbler	14	10	R	WS
6410	棕扇尾鶯	82	*Cisticola juncidis*	Zitting Cisticola	11	7	R	S
6421	灰頭鷦鶯	83	*Prinia flaviventris*	Yellow-bellied Prinia	14	7	R	S
6703	樹鷚	84	*Anthus hodgsoni*	Olive-backed Pipit	15	19	W	WS
6902	紅尾伯勞	85	*Lanius cristatus*	Brown Shrike	18	28	T	T
6904	棕背伯勞	86	*Lanius schach*	Long-tailed Shrike	25	34	R	S
7001	八哥	87	*Acridotheres cristatellus*	Crested Myna	26	113	R	WS
7002	家八哥	88	*Acridotheres tristis*	Common Myna	25	110	V	T
7005	灰椋鳥	89	*Sturnus cineraceus*	White-cheeked Starling	24	61	W	H
7007	灰背椋鳥	90	*Sturnus sinensis*	White-shouldered Starling	24	61	W	S
7008	絲光椋鳥	91	*Sturnus sericeus*	Red-billed Starling	24	61	W	WS
7302	斑文鳥	92	*Lonchura punctulata*	Scaly-breasted Munia	11	14	R	S
7303	白腰文鳥	93	Lonchura striata	White-rumped Munia	11	12	R	S
7511	黑臉鵐	94	*Emberiza spodocephala*	Black-faced Bunting	15	18	W	S
9902	紅領綠鸚鵡	95	*Psittacula krameri*	Rose-ringed Parakeet	42	117	V	T
3512	綠鳩	69	*Treron sieboldii*	White-bellied Green-pigeon	31	235	R	T
3601	番鵑	70	*Centropus bengalensis*	Lesser Coucal	39	120	R	WS
4501	五色鳥	71	*Megalaima oorti*	Black-browed Barbet	20	59	R	T
5407	樹鵲	72	*Dendrocitta formosae*	Grey Tree-pie	34	104	R	S

Appendix A. Continued.

ID	Chinese name	No.	Scientific name	Common name	Length (cm)	Weight (g)	[1]Status	[2]Guild
5502	粉紅鸚嘴	73	*Paradoxornis Webbianus*	Vinous-throated Parrotbill	12	11	R	S
6002	紅嘴黑鵯	74	*Hypsipetes leucocephalus*	Black Bulbul	24	42	R	WS
6307	野鴝	75	*Luscinia calliope*	Siberian Rubythroat	16	19	W	S

Notes:

[1]Status R: Resident, T: Transit, V: Escape, W: Wintering Migrant
[2] Guild A: Air Feeder, H: Herb (Grassland) Species, M: Mudflat Species, S: Shrub (Shrublands) Species, T: Tree (Woodland) Species, W: Waterfowl, WS: Waterside's Species.

Appendix B. Factors in Pondscape.

***Appendix B-1*. Environmental factors in pondscape.**

ID	Name	X_Coord	Y_Coord	Elevation (m)	PS (ha)	Foliage Canopy Area (m^2)	TE (Perimeter) (m)	FCA Ratio
					(2)	FCA		FCA/(2)/10000
01	Lo-Tso	268,315	2,765,170	95	14.77	18479	1816	0.13
02	Cha-Liao	266,027	2,767,377	81	5.63	16343	1102	0.29
03	Ching-Pu-Tzu	264,790	2,768,225	78	5.17	21713	954	0.42
04	Pi-Nei	264,480	2,768,155	73	8.47	18623	1178	0.22
05	Hsueh-Hsiao	263,309	2,767,611	69	8.18	12495	1696	0.15
06	Pu-Ting	258,956	2,770,460	28	9.90	8781	1180	0.09
07	Ta-Pi-Chiao	259,361	2,769,253	39	20.22	16064	1851	0.08
08	Chiu-Pi	263,373	2,769,638	51	11.06	7803	1725	0.07
09	Po-Kua-Tzu	263,933	2,770,699	56	10.28	11487	1280	0.11
10	Hu-Ti	269,578	2,774,459	13	6.18	2134	989	0.03
11	Hou-Hu-Tang	258,450	2,764,000	67	18.68	25780	1725	0.14
12	Feng-Tien	256,326	2,765,320	47	14.98	14960	1423	0.10
13	Hou-Hu-Chih	253,263	2,766,142	18	12.24	16828	1335	0.14
14	Lin-Wu	255,820	2,769,339	18	12.58	8982	1374	0.07
15	Hung-Tang	258,229	2,767,980	41	20.47	19944	1830	0.10
16	Liao-Wu	258,854	2,762,597	75	10.04	21251	1356	0.21
17	Ta-Po	253,834	2,761,225	45	5.85	15431	1139	0.26
18	Lu-Wu	256,666	2,760,433	75	9.66	9622	1219	0.10
19	Fu-Lien	256,100	2,759,100	104	1.01	3864	452	0.38
20	Wang-Wu	250,826	2,761,709	20	3.59	10017	735	0.28
21	Han-Pi	264,924	2,764,212	102	4.05	14003	905	0.35
22	Liu-Liu	259,707	2,765,463	66	2.44	5496	779	0.23
23	Tu-Lung-Kou	260,145	2,766,455	64	9.58	16400	1340	0.17
24	Keng-Wu	260,205	2,767,318	58	7.28	12706	1127	0.17
25	Keng-Wei	259,198	2,767,662	51	6.60	16980	1008	0.26
26	Tsao-Pi	265,671	2,761,796	117	2.40	9069	677	0.38
27	Kuo-Ling-Li	265,660	2,761,998	117	1.33	4251	495	0.32
28	Pei-Shih	262,415	2,762,501	104	4.99	8489	974	0.17

***Appendix B-1*. Continued.**

ID	Name	X_Coord	Y_Coord	Elevation (m)	PS (ha)	Foliage Canopy Area (m^2)	TE (Perimeter) (m)	FCA Ratio
					(2)	FCA		FCA/(2)/10000
29	Shih-Pi-Hsia	260,748	2,761,961	93	8.68	23279	1183	0.27
30	Mei-Kao-Lu	264,191	2,760,924	115	5.00	17876	1201	0.36
31	Pa-Chang-Li	268,476	2,752,997	228	0.20	5222	179	2.58
32	Lung-Tan	270,250	2,750,700	230	10.15	20486	2763	0.20
33	Feng-Kuei-Kou	271,250	2,748,300	248	4.68	1193	1158	0.03
34	Tou-Liao	277,778	2,747,897	245	12.45	52905	2594	0.42
35	Sha-Lun	275,500	2,769,500	15	9.18	5454	1203	0.06
36	2_18	276,500	2,770,300	65	9.68	6943	1288	0.07
37	2_2-1	274,175	2,770,158	58	8.21	9658	1223	0.12
38	2_1-2	270,398	2,770,362	53	12.60	13402	1421	0.11
39	Heng-Shan	271,672	2,775,953	52	15.74	36950	1633	0.23
40	Po-Kung-Kang	258,646	2,757,445	139	9.63	12917	1460	0.13
41	Chang-Pi	260,088	2,755,995	159	2.49	4472	676	0.18
42	Yuan-Pen	259,121	2,760,179	92	3.15	9189	763	0.29
43	Hung-Wa-Wu	260,475	2,760,784	94	6.16	10201	947	0.17
44	Hsia-Yin-Ying	258,061	2,760,530	84	10.92	15926	1317	0.15
45	Pa-Chiao-Tan	269,064	2,755,889	166	0.21	7889	322	3.75

Notes:

X_Coord : X coordination
Y_Coord: Y coordination
Elevation (m)
Perimeter (m)
FCA, Foliage Canopy Area (m^2)
PS, Pond Size (Ha)
FCA Ratio, FCA/PS/10000

***Appendix B-2*. Environmental parameters in pondscape.**

ID	Name	X_Coord	Y_Coord	Farms (m^2)/ha	Builds (m^2)/ha	Ponds (m^2)/ha	Rivers (m^2)/ha	Roads (m^2)/ha	Distance to coastal line (m)	Distance to city limit (m)
01	Lo-Tso	268,315	2,765,170	728489	90394	159248	0	21869	9841	3838
02	Cha-Liao	266,027	2,767,377	786565	73050	101208	5560	33617	7315	6711
03	Ching-Pu-Tzu	264,790	2,768,225	725907	66117	174844	0	33132	6192	8075
04	Pi-Nei	264,480	2,768,155	699376	70371	197644	0	32610	6222	8386
05	Hsueh-Hsiao	263,309	2,767,611	581657	245555	136140	3391	33257	6692	8804
06	Pu-Ting	258,956	2,770,460	865373	16564	98974	0	19089	1816	14073
07	Ta-Pi-Chiao	259,361	2,769,253	613178	118431	202606	0	65786	2999	12858
08	Chiu-Pi	263,373	2,769,638	844617	10012	110637	2056	32678	4650	10235
09	Po-Kua-Tzu	263,933	2,770,699	689493	92309	171671	0	46527	3732	10702
10	Hu-Ti	269,578	2,774,459	766943	92751	71702	21266	47338	2405	6527
11	Hou-Hu-Tang	258,450	2,764,000	764020	38372	186705	0	10902	7131	9644
12	Feng-Tien	256,326	2,765,320	789556	25803	158661	8434	17547	4369	11579
13	Hou-Hu-Chih	253,263	2,766,142	712475	15459	235931	0	36134	1367	14326
14	Lin-Wu	255,820	2,769,339	681772	147799	125813	0	44617	1324	15178
15	Hung-Tang	258,229	2,767,980	706106	29566	232710	2177	29441	3434	12458
16	Liao-Wu	258,854	2,762,597	625262	216765	103992	8984	44997	7963	7783
17	Ta-Po	253,834	2,761,225	869158	31631	68151	7554	23506	3484	10827
18	Lu-Wu	256,666	2,760,433	820059	50538	100967	0	28436	6370	8053
19	Fu-Lien	256,100	2,759,100	805635	126333	46001	0	22031	6577	7873
20	Wang-Wu	250,826	2,761,709	857952	46790	42557	7727	44973	819	13856
21	Han-Pi	264,924	2,764,212	709546	48762	213700	6221	21772	10436	6667
22	Liu-Liu	259,707	2,765,463	778978	70572	81179	4051	65221	6338	9726
23	Tu-Lung-Kou	260,145	2,766,455	772795	28012	153954	5758	39481	5686	10244
24	Keng-Wu	260,205	2,767,318	820261	68659	72833	0	38246	5071	11076
25	Keng-Wei	259,198	2,767,662	868093	24729	98355	0	8823	4174	12103
26	Tsao-Pi	265,671	2,761,796	702379	180332	94549	2237	20503	12792	3732
27	Kuo-Ling-Li	265,660	2,761,998	756011	138896	85899	2237	16958	12584	3684
28	Pei-Shih	262,415	2,762,501	704298	86424	147942	6103	55233	11118	5585
29	Shih-Pi-Hsia	260,748	2,761,961	688797	182989	89472	12664	26079	9912	6586
30	Mei-Kao-Lu	264,191	2,760,924	424734	379157	131790	0	64319	12541	3287
31	Pa-Chang-Li	268,476	2,752,997	763904	177152	41979	0	16965	20369	1397
32	Lung-Tan	270,250	2,750,700	351370	464034	10857	101761	71979	23148	269

***Appendix B-2*. Continued.**

ID	Name	X_Coord	Y_Coord	Farms (m^2)/ha	Builds (m^2)/ha	Ponds (m^2)/ha	Rivers (m^2)/ha	Roads (m^2)/ha	Distance to coastal line (m)	Distance to city limit (m)
33	Feng-Kuei-Kou	271,250	2,748,300	860699	44805	78481	0	16016	25045	881
34	Tou-Liao	277,778	2,747,897	722022	113701	158527	0	5750	29508	3611
35	Sha-Lun	275,500	2,769,500	632011	139736	179469	1543	47241	2175	2802
36	2_18	276,500	2,770,300	810541	47320	129035	0	13104	8728	1558
37	2_2-1	274,175	2,770,158	783159	69387	105553	18719	23181	8323	2300
38	2_1-2	270,398	2,770,362	624982	178180	166138	4869	25832	6184	6070
39	Heng-Shan	271,672	2,775,953	779071	42809	128150	29083	20886	2162	5053
40	Po-Kung-Kang	258,646	2,757,445	755033	61549	163445	0	19974	9619	5156
41	Chang-Pi	260,088	2,755,995	812892	74782	70638	0	41687	11659	3016
42	Yuan-Pen	259,121	2,760,179	800921	38888	141945	0	18246	8758	5873
43	Hung-Wa-Wu	260,475	2,760,784	449183	416572	105239	4141	24864	9921	5398
44	Hsia-Yin-Ying	258,061	2,760,530	924773	40389	10163	0	24675	7666	7278
45	Pa-Chiao-Tan	269,064	2,755,889	525204	395050	45467	4010	30269	19557	318
33	Feng-Kuei-Kou	271,250	2,748,300	860699	44805	78481	0	16016	25045	881
34	Tou-Liao	277,778	2,747,897	722022	113701	158527	0	5750	29508	3611
35	Sha-Lun	275,500	2,769,500	632011	139736	179469	1543	47241	2175	2802
36	2_18	276,500	2,770,300	810541	47320	129035	0	13104	8728	1558

***Appendix B-3*. Environmental parameters in pondscape.**

ID	Name	X_Coord	Y_Coord	Consolidated Area	LPI (3.1)	MPS (3.2)	MPFD (3.4)	MSI (3.5)	ED (3.6)
01	Lo-Tso	268,315	2,765,170	NO	3.92	14.77	1.26	1.33	122.91
02	Cha-Liao	266,027	2,767,377	NO	1.50	5.63	1.28	1.31	195.56
03	Ching-Pu-Tzu	264,790	2,768,225	NO	1.37	5.17	1.26	1.18	184.60
04	Pi-Nei	264,480	2,768,155	NO	2.25	8.47	1.25	1.14	138.98
05	Hsueh-Hsiao	263,309	2,767,611	NO	2.17	8.18	1.31	1.67	207.40
06	Pu-Ting	258,956	2,770,460	NO	2.63	9.90	1.23	1.06	119.24
07	Ta-Pi-Chiao	259,361	2,769,253	YES	5.37	20.22	1.23	1.16	91.53
08	Chiu-Pi	263,373	2,769,638	NO	2.94	11.06	1.28	1.46	155.89
09	Po-Kua-Tzu	263,933	2,770,699	NO	2.73	10.28	1.24	1.13	124.53
10	Hu-Ti	269,578	2,774,459	YES	1.64	6.18	1.25	1.12	159.84
11	Hou-Hu-Tang	258,450	2,764,000	NO	4.96	18.68	1.23	1.13	92.35
12	Feng-Tien	256,326	2,765,320	YES	3.98	14.98	1.22	1.04	95.04
13	Hou-Hu-Chih	253,263	2,766,142	YES	3.25	12.24	1.23	1.08	109.04
14	Lin-Wu	255,820	2,769,339	NO	3.34	12.58	1.23	1.09	109.19
15	Hung-Tang	258,229	2,767,980	YES	5.43	20.47	1.23	1.14	89.38
16	Liao-Wu	258,854	2,762,597	YES	2.66	10.04	1.25	1.21	135.04
17	Ta-Po	253,834	2,761,225	YES	1.55	5.85	1.28	1.33	194.62
18	Lu-Wu	256,666	2,760,433	YES	2.56	9.66	1.24	1.11	126.25
19	Fu-Lien	256,100	2,759,100	NO	0.27	1.01	1.33	1.27	447.03
20	Wang-Wu	250,826	2,761,709	YES	0.95	3.59	1.26	1.09	204.44
21	Han-Pi	264,924	2,764,212	NO	1.08	4.05	1.28	1.27	223.30
22	Liu-Liu	259,707	2,765,463	YES	0.65	2.44	1.32	1.41	319.45
23	Tu-Lung-Kou	260,145	2,766,455	YES	2.54	9.58	1.26	1.22	139.90
24	Keng-Wu	260,205	2,767,318	YES	1.93	7.28	1.26	1.18	154.75
25	Keng-Wei	259,198	2,767,662	YES	1.75	6.60	1.25	1.11	152.80
26	Tsao-Pi	265,671	2,761,796	NO	0.64	2.40	1.29	1.23	281.70
27	Kuo-Ling-Li	265,660	2,761,998	NO	0.35	1.33	1.31	1.21	371.46
28	Pei-Shih	262,415	2,762,501	NO	1.32	4.99	1.27	1.23	195.35
29	Shih-Pi-Hsia	260,748	2,761,961	NO	2.30	8.68	1.24	1.13	136.29
30	Mei-Kao-Lu	264,191	2,760,924	NO	1.33	5.00	1.31	1.52	240.39

***Appendix B-3*. Continued.**

ID	Name	X_Coord	Y_Coord	Consolidated Area	LPI (3.1)	MPS (3.2)	MPFD (3.4)	MSI (3.5)	ED (3.6)
31	Pa-Chang-Li	268,476	2,752,997	NO	0.05	0.20	1.36	1.12	884.38
32	Lung-Tan	270,250	2,750,700	NO	2.69	10.15	1.37	2.45	272.18
33	Feng-Kuei-Kou	271,250	2,748,300	NO	1.24	4.68	1.31	1.51	247.42
34	Tou-Liao	277,778	2,747,897	NO	3.30	12.45	1.34	2.07	208.40
35	Sha-Lun	275,500	2,769,500	YES	2.44	9.18	1.24	1.12	131.07
36	2_18	276,500	2,770,300	NO	2.57	9.68	1.25	1.17	133.10
37	2_2-1	274,175	2,770,158	NO	2.18	8.21	1.26	1.20	148.96
38	2_1-2	270,398	2,770,362	NO	3.34	12.60	1.24	1.13	112.79
39	Heng-Shan	271,672	2,775,953	NO	4.18	15.74	1.24	1.16	103.71
40	Po-Kung-Kang	258,646	2,757,445	YES	2.56	9.63	1.27	1.33	151.56
41	Chang-Pi	260,088	2,755,995	YES	0.66	2.49	1.29	1.21	271.81
42	Yuan-Pen	259,121	2,760,179	NO	0.84	3.15	1.28	1.21	242.30
43	Hung-Wa-Wu	260,475	2,760,784	NO	1.64	6.16	1.24	1.08	153.71
44	Hsia-Yin-Ying	258,061	2,760,530	YES	2.90	10.92	1.24	1.12	120.66
45	Pa-Chiao-Tan	269,064	2,755,889	NO	0.06	0.21	1.51	1.98	1533.82

Notes:

(1) LPI, Largest Pond Index.
(2) MPS, Mean Pond Size (PS in this case, if n = 1).
(3) NP, Number of Ponds (in this case equal to 45).
(4) MPFD, Mean Pond Fractal Dimension.
(5) MSI, Mean Shape Index.
(6) ED, Edge Density.
(7) TE, Total Edge (in this case equal to 54,994 m).

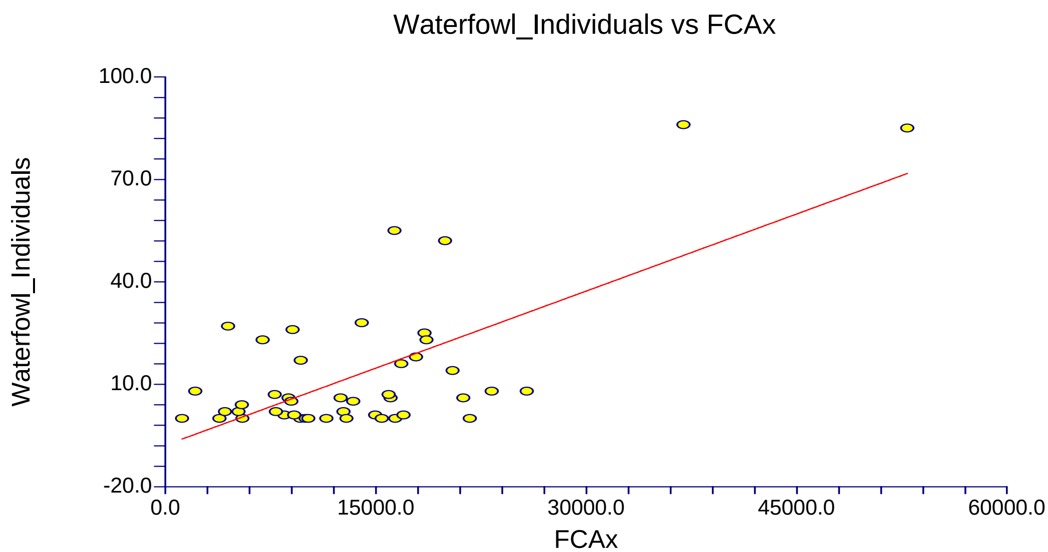
Appendix C. Results of the Regression Models.

Appendix C-1. **The regression model of waterfowl individuals and foliage canopy area next to waterfront edge of a pond (FCA)(m^2)**

Database

Y = Waterfowl Individuals   X = FCAx

Linear Regression Plot Section



Run Summary Section

Parameter	**Value**	**Parameter**	**Value**
Dependent Variable	Waterfowl Individuals	Rows Processed	100
Independent Variable	FCAx	Rows Used in Estimation	45
Frequency Variable	None	Rows with X Missing	0
Weight Variable	None	Rows with Freq Missing	0
Intercept	-7.8266	Rows Prediction Only	55
Slope	0.0015	Sum of Frequencies	45
R-Squared	0.4583	Sum of Weights	45.0000
Correlation	0.6770	Coefficient of Variation	1.1705
Mean Square Error	229.9428	Square Root of MSE	15.16387

Linear Regression Report

Database

Y = Waterfowl Individuals   X = FCAx

Summary Statement

The equation of the straight line relating Waterfowl Individuals and FCAx is estimated as: *Waterfowl Individuals (Y)* = (-7.8266) + (0.0015) *FCAx* using the 45 observations in this dataset. The y-intercept, the estimated value of *Waterfowl Individuals (Y)* when *FCAx* is zero, is -7.8266 with a standard error of 4.1207. The slope, the estimated change in *Waterfowl Individuals* per unit change in *FCAx*, is 0.0015 with a standard error of 0.0002. The value of R-Squared, the proportion of the variation in *Waterfowl Individuals* that can be accounted for by variation in *FCAx*, is 0.4583. The correlation between *Waterfowl Individuals* and *FCAx* is 0.6770. A significance test that the slope is zero resulted in a t-value of 6.0320. The significance level of this t-test is 0.0000. Since 0.0000 < 0.0500, the hypothesis that the slope is zero is rejected.

The estimated slope is 0.0015. The lower limit of the 95% confidence interval for the slope is 0.0010 and the upper limit is 0.0020. The estimated intercept is -7.8266. The lower limit of the 95% confidence interval for the intercept is -16.1368 and the upper limit is 0.4836.

Descriptive Statistics Section

Parameter	**Dependent**	**Independent**
Variable	Waterfowl Individuals	FCAx
Count	45	45
Mean	12.9556	13821.2667
Standard Deviation	20.3682	9170.6217
Minimum	0.0000	1193.0000
Maximum	86.0000	52905.0000

Linear Regression Report

Database
Y = Waterfowl Individuals   X = FCAx

Regression Estimation Section

Parameter	**Intercept B (0)**	**Slope B (1)**
Regression Coefficients	-7.8266	0.0015
Lower 95% Confidence Limit	-16.1368	0.0010
Upper 95% Confidence Limit	0.4836	0.0020
Standard Error	4.1207	0.0002
Standardized Coefficient	0.0000	0.6770
T Value	-1.8993	6.0320
Prob. Level (T Test)	0.0642	0.0000
Reject H0 (Alpha = 0.0500)	No	Yes
Power (Alpha = 0.0500)	0.4590	1.0000
Regression of Y on X	-7.8266	0.0015
Inverse Regression from X on Y	-32.3874	0.0033
Orthogonal Regression of Y and X	-7.8267	0.0015

Estimated Model
*(-7.82663192598266) + (1.50363841337781E-03) * (FCAx)*

Analysis of Variance Section

Source	**DF**	**Sum of Squares**	**Mean Square**	**F-Ratio**	**Power (5%)**
Intercept	1	7553.089	7553.089		
Slope	1	8366.37	8366.37	36.3846	1.0000
Error	43	9887.541	229.9428		
Adj. Total	44	18253.91	414.8616		
Total	45	25807			

S = Square Root (229.9428) = 15.16387

Notes:
The above report shows the F-Ratio for testing whether the slope is zero, the degrees of freedom, and the mean square error. The mean square error, which estimates the variance of the residuals, is used extensively in the calculation of hypothesis tests and confidence intervals.

Linear Regression Report

Database
Y = Waterfowl Individuals   X = FCAx

Tests of Assumptions Section

Assumption/Test	**Test Value**	**Prob. Level**	**Is the Assumption Reasonable at the 0.2 Level of Significance?**
Residuals follow Normal Distribution?			
Shapiro Wilk	0.9399	0.021294	No
Anderson Darling	0.8413	0.030312	No
D'Agostino Skewness	2.3578	0.018381	No
D'Agostino Kurtosis	0.9900	0.322196	Yes
D'Agostino Omnibus	6.5395	0.038017	No
Constant Residual Variance?			
Modified Levene Test	3.7662	0.058873	No
Relationship is a Straight Line?			
Lack of Linear Fit F (0, 0) Test	0.0000	0.000000	No

Notes:
A 'Yes' means there is not enough evidence to make this assumption seem unreasonable. This lack of evidence may be because the sample size is too small, the assumptions of the test itself are not met, or the assumption is valid.
A 'No' means that the assumption is not reasonable. However, since these tests are related to sample size, you should assess the role of sample size in the tests by also evaluating the appropriate plots and graphs. A large dataset (say N > 500) will often fail at least one of the normality tests because it is hard to find a large dataset that is perfectly normal.

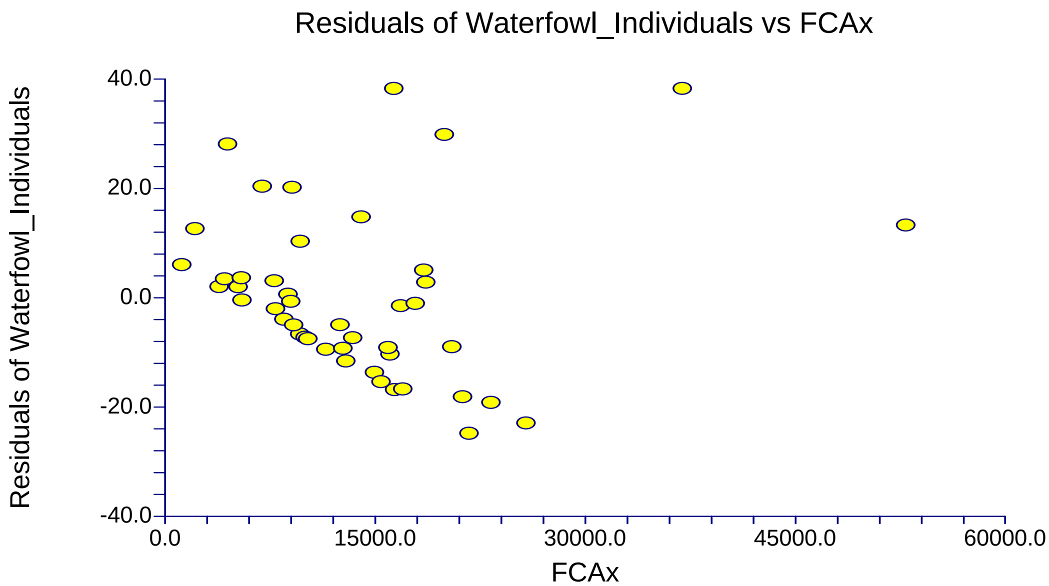
Normality and Constant Residual Variance:
Possible remedies for the failure of these assumptions include using a transformation of Y such as the log or square root, correcting data-recording errors found by looking into outliers, adding additional independent variables, using robust regression, or using bootstrap methods.

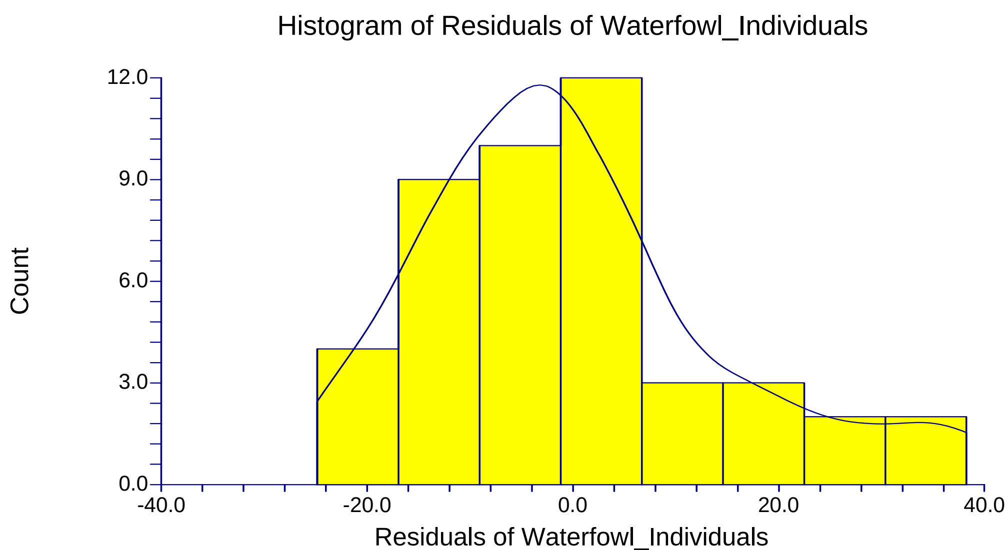
Straight-Line:
Possible remedies for the failure of this assumption include using nonlinear regression or polynomial regression.

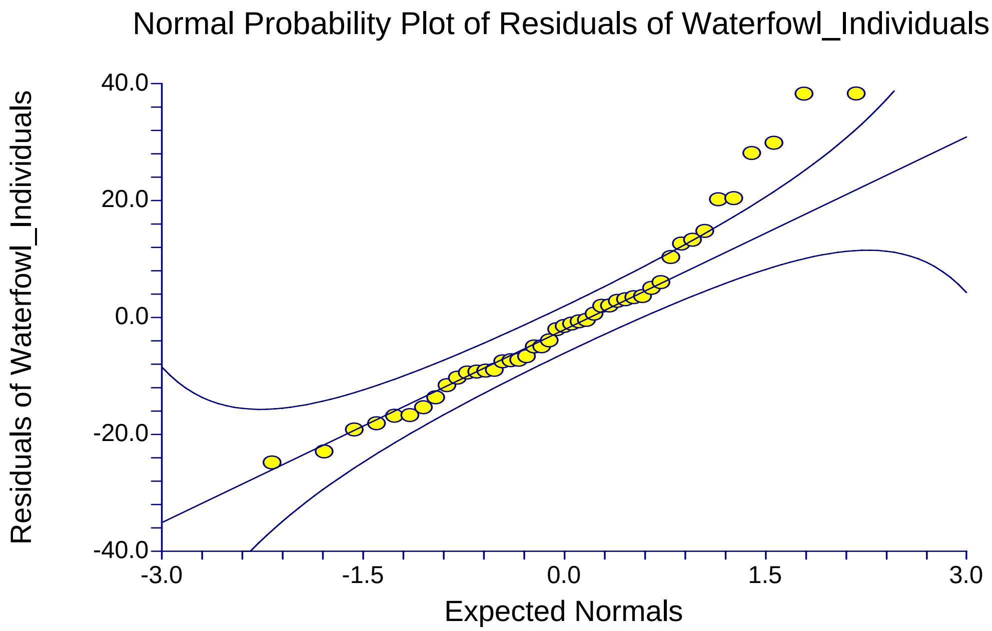
Linear Regression Report

Database
Y = Waterfowl Individuals   X = FCAx

Residual Plots Section







Normal Probability Plot of Residuals of Waterfowl_Individuals
Residuals of Waterfowl_Individuals
40.0
20.0
0.0
-20.0
-40.0
-3.0
-1.5
0.0
1.5
3.0
Expected Normals

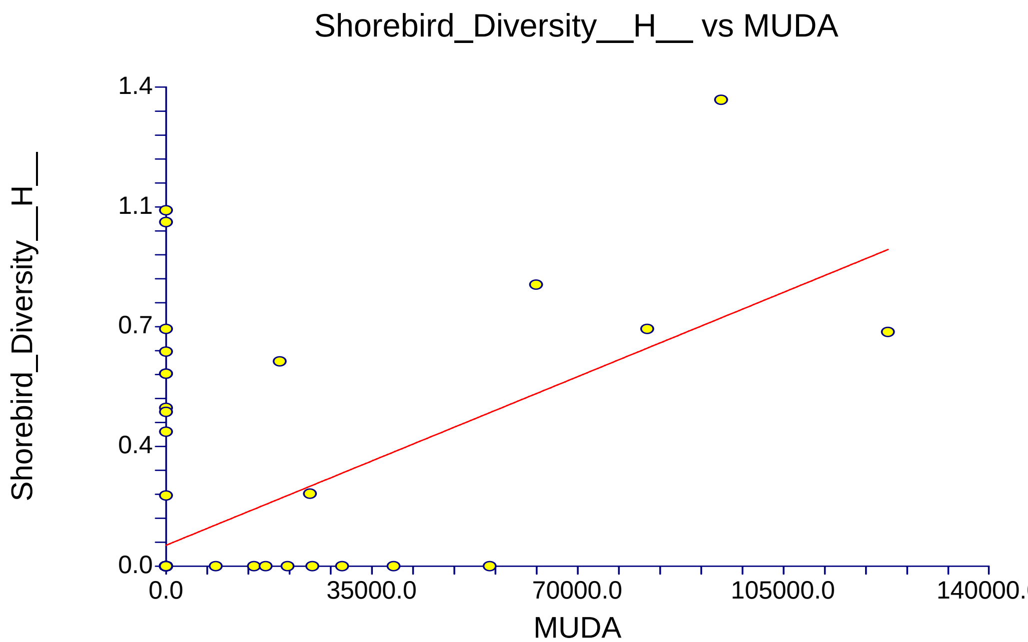
***Appendix C-2*. The regression model of shorebird diversity (*H'*) and mudflat area in a pond (m^2).**

Linear Regression Report

Database

Y = Shorebird Diversity (H') X = MUDAx

Linear Regression Plot Section



Run Summary Section

Parameter	Value	Parameter	Value
Dependent Variable	Shorebird Diversity	Rows Processed	10
Independent Variable	MUDA	Rows Used in Estimation	99
Frequency Variable	None	Rows with X Missing	1
Weight Variable	None	Rows with Freq Missing	0
Intercept	0.0610	Rows Prediction Only	0
Slope	0.0000	Sum of Frequencies	99
R-Squared	0.2746	Sum of Weights	99
Correlation	0.5240	Coefficient of Variation	2.1849
Mean Square Error	5.241032E-02	Square Root of MSE	0.228933

Linear Regression Report

Database

Y = Shorebird Diversity (H')   X = MUDAx

Summary Statement

The equation of the straight line relating Shorebird Diversity (*H*') and MUDA is estimated as: $Shorebird\ Diversity\ H'(Y) = 6.1035 \times 10^{-2} + 7.0338 \times 10^{-6}(MUDAx)$ using the 99 observations in this dataset. The y-intercept, the estimated value of Shorebird Diversity (*H'*) when MUDA is zero, is 6.1035×10^{-2} with a standard error of 0.0241. The slope, the estimated change in Shorebird Diversity (*H'*) per unit change in MUDA, is 7.0338×10^{-6} with a standard error of 0.0000. The value of R-Squared, the proportion of the variation in Shorebird Diversity (*H'*) that can be accounted for by variation in MUDA, is 0.2746. The correlation between Shorebird Diversity (*H'*) and MUDA is 0.5240.

A significance test that the slope is zero resulted in a t-value of 6.0589. The significance level of this t-test is 0.0000. Since 0.0000 < 0.0500, the hypothesis that the slope is zero is rejected.

Descriptive Statistics Section

Parameter	**Dependent**	**Independent**
Variable	Shorebird Diversity (*H'*)	MUDA
Count	99	99
Mean	0.1048	6219.5051
Standard Deviation	0.2674	19920.4706
Minimum	0.0000	0.0000
Maximum	1.3624	122839.0000

Linear Regression Report

Database
Y = Shorebird Diversity (H') X = MUDAx

Regression Estimation Section

Parameter	**Intercept B(0)**	**Slope B(1)**
Regression Coefficients	0.0610	0.0000
Lower 95% Confidence Limit	0.0132	0.0000
Upper 95% Confidence Limit	0.1089	0.0000
Standard Error	0.0241	0.0000
Standardized Coefficient	0.0000	0.5240
T Value	2.5310	6.0589
Prob. Level (T Test)	0.0130	0.0000
Reject H0 (Alpha = 0.0500)	Yes	Yes
Power (Alpha = 0.0500)	0.7074	1.0000
Regression of Y on X	0.0610	0.0000
Inverse Regression from X on Y	-0.0546	0.0000
Orthogonal Regression of Y and X	0.0610	0.0000

Estimated Model
*(6.10348280556879E-02) + (7.03381879341286E-06) * (MUDAx)*

Linear Regression Report

Database
Y = Shorebird Diversity (H') X = MUDAx

Tests of Assumptions Section

Assumption/Test	Test Value	Prob. Level	Is the Assumption Reasonable at the 0.2 Level of Significance?
Residuals follow Normal Distribution?			
Shapiro Wilk	0.5710	0.000000	No
Anderson Darling	20.3696	0.000000	No
D'Agostino Skewness	6.6816	0.000000	No
D'Agostino Kurtosis	4.7129	0.000002	No
D'Agostino Omnibus	66.8545	0.000000	No
Constant Residual Variance?			
Modified Levene Test	4.4050	0.038430	No
Relationship is a Straight Line?			
Lack of Linear Fit F(13, 84) Test	2.2123	0.015538	No

Notes:
A 'Yes' means there is not enough evidence to make this assumption seem unreasonable. This lack of evidence may be because the sample size is too small, the assumptions of the test itself are not met, or the assumption is valid.
A 'No' means the that the assumption is not reasonable. However, since these tests are related to sample size, you should assess the role of sample size in the tests by also evaluating the appropriate plots and graphs. A large dataset (say N > 500) will often fail at least one of the normality tests because it is hard to find a large dataset that is perfectly normal.

Normality and Constant Residual Variance:
Possible remedies for the failure of these assumptions include using a transformation of Y such as the log or square root, correcting data-recording errors found by looking into outliers, adding additional independent variables, using robust regression, or using bootstrap methods.

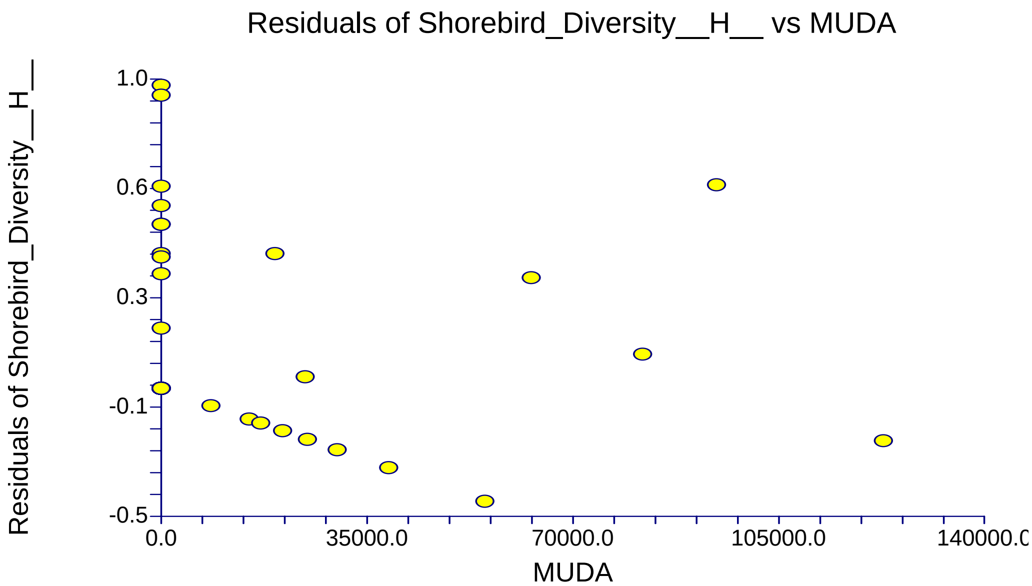
Straight-Line:
Possible remedies for the failure of this assumption include using nonlinear regression or polynomial regression.

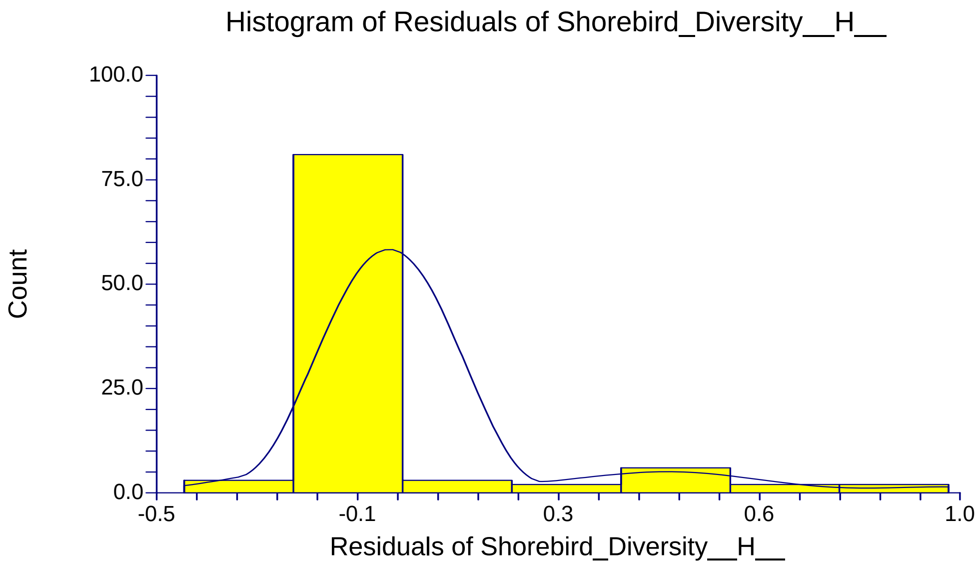
Linear Regression Report

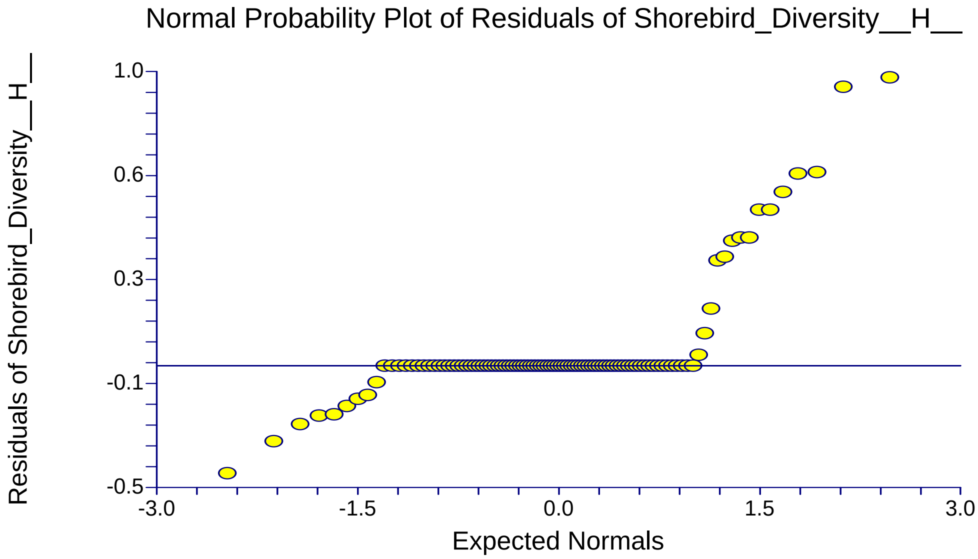
Database

Y = Shorebird Diversity (H') X = MUDAx

Residual Plots Section







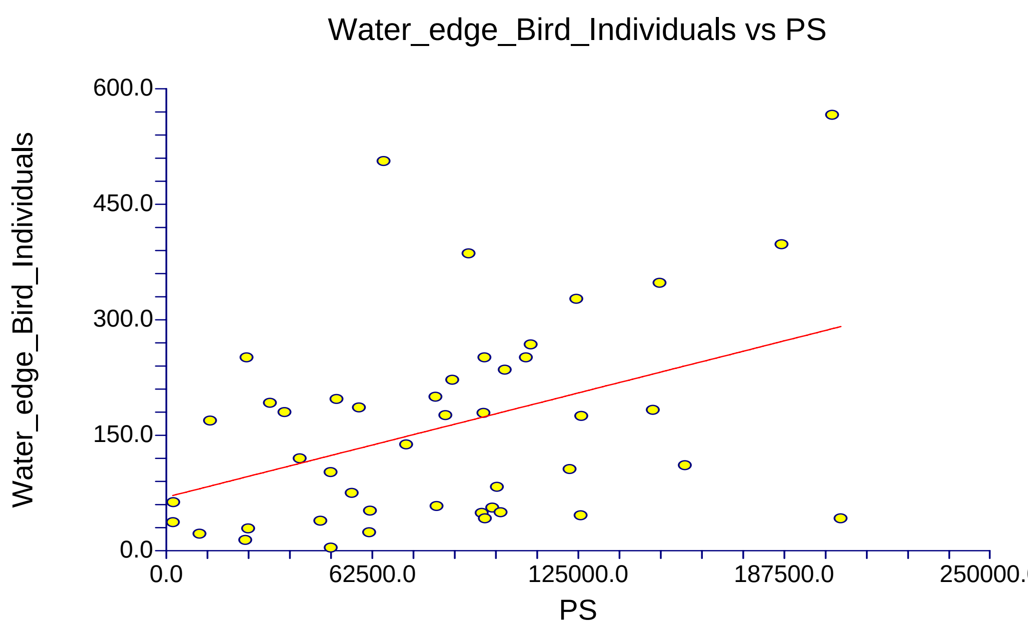
Normal Probability Plot of Residuals of Shorebird_Diversity__H__
Residuals of Shorebird_Diversity__H__
1.0
0.6
0.3
-0.1
-0.5
-3.0
-1.5
0.0
1.5
3.0
Expected Normals

***Appendix C-3*. The regression model of waterside (water edge) bird individuals and pond size (PS)(m^2).**

Linear Regression Report

Database
Y = Waterside Bird Individuals   X = PSx

Linear Regression Plot Section



Run Summary Section

Parameter	Value	Parameter	Value
Dependent Variable	Waterside Bird Individuals		
Independent Variable	PS	Rows Used in Estimation	45
Frequency Variable	None	Rows with X Missing	0
Weight Variable	None	Rows with Freq Missing	0
Intercept	69.6039	Rows Prediction Only	0
Slope	0.0011	Sum of Frequencies	45
R-Squared	0.1700	Sum of Weights	
	45.0000		
Correlation	0.4123	Coefficient of Variation	
	0.7609		
Mean Square Error	14855.44	Square Root of MSE	
	121.8829		

Linear Regression Report

Database

Y = Waterside Bird Individuals   X = PSx

Summary Statement

The equation of the straight line relating Waterside Bird Individuals and PS is estimated as: *Waterside Bird Individuals* = (69.6039) + (0.0011) *PS* using the 45 observations in this dataset. The y-intercept, the estimated value of *Waterside Bird Individuals* when *PS* is zero, is 69.6039 with a standard error of 35.5207. The slope, the estimated change in Waterside Bird Individuals per unit change in PS, is 0.0011 with a standard error of 0.0004. The value of R-Squared, the proportion of the variation in *Waterside Bird Individuals* that can be accounted for by variation in PS, is 0.1700. The correlation between *Waterside Bird Individuals* and *PS* is 0.4123.

A significance test that the slope is zero resulted in a t-value of 2.9675. The significance level of this t-test is 0.0049. Since 0.0049 < 0.0500, the hypothesis that the slope is zero is rejected. The estimated slope is 0.0011. The lower limit of the 95% confidence interval for the slope is 0.0003 and the upper limit is 0.0018. The estimated intercept is 69.6039. The lower limit of the 95% confidence interval for the intercept is -2.0303 and the upper limit is 141.2381.

Descriptive Statistics Section

Parameter	**Dependent**	**Independent**
Variable	Waterside Bird Individuals	PS
Count	45	45
Mean	160.1778	83727.0889
Standard Deviation	132.2533	50404.4108
Minimum	4.0000	2026.0000
Maximum	566.0000	204732.0000

Linear Regression Report

Database
Y = Waterside Bird Individuals   X = PSx

Regression Estimation Section

Parameter	**Intercept B(0)**	**Slope B(1)**
Regression Coefficients	69.6039	0.0011
Lower 95% Confidence Limit	-2.0303	0.0003
Upper 95% Confidence Limit	141.2381	0.0018
Standard Error	35.5207	0.0004
Standardized Coefficient	0.0000	0.4123
T Value	1.9595	2.9675
Prob. Level (T Test)	0.0566	0.0049
Reject H0 (Alpha = 0.0500)	No	Yes
Power (Alpha = 0.0500)	0.4824	0.8266
Regression of Y on X	69.6039	0.0011
Inverse Regression from X on Y	-372.6719	0.0064
Orthogonal Regression of Y and X	69.6034	0.0011

Notes:
The above report shows the least squares estimates of the intercept and slope followed by the corresponding standard errors, confidence intervals, and hypothesis tests. Note that these results are based on several assumptions that should be validated before they are used.

Estimated Model
*(69.603919723589) + (1.08177483842041E-03) * (PSx)*

Linear Regression Report

Database
Y = Waterside Bird Individuals   X = PSx

Analysis of Variance Section

Source	**DF**	**Sum of Squares**	**Mean Square**	**F-Ratio**	**Power (5%)**
Intercept	1	1154561	1154561		
Slope	1	130816.8	130816.8	8.8060	0.8266
Error	43	638783.8	14855.44		
Adj. Total	44	769600.6	17490.92		
Total	45	1924162			

s = Square Root(14855.44) = 121.8829

Notes:
The above report shows the F-Ratio for testing whether the slope is zero, the degrees of freedom, and the mean square error. The mean square error, which estimates the variance of the residuals, is used extensively in the calculation of hypothesis tests and confidence intervals.

Linear Regression Report

Database
Y = Waterside Bird Individuals   X = PS   x

Tests of Assumptions Section

Assumption/Test	**Test Value**	**Prob. Level**	**Is the Assumption Reasonable at the 0.2 Level of Significance?**
Residuals follow Normal Distribution?			
Shapiro Wilk	0.9563	0.087965	No
Anderson Darling	0.5800	0.131535	No
D'Agostino Skewness	2.0719	0.038271	No
D'Agostino Kurtosis	1.3924	0.163786	No
D'Agostino Omnibus	6.2319	0.044337	No
Constant Residual Variance?			
Modified Levene Test	3.0485	0.087954	No
Relationship is a Straight Line?			
Lack of Linear Fit F(0, 0) Test	0.0000	0.000000	No

Notes:
A 'Yes' means there is not enough evidence to make this assumption seem unreasonable. This lack of evidence may be because the sample size is too small, the assumptions of the test itself are not met, or the assumption is valid.
A 'No' means the that the assumption is not reasonable. However, since these tests are related to sample size, you should assess the role of sample size in the tests by also evaluating the appropriate plots and graphs. A large dataset (say N > 500) will often fail at least one of the normality tests because it is hard to find a large dataset that is perfectly normal.

Normality and Constant Residual Variance:
Possible remedies for the failure of these assumptions include using a transformation of Y such as the log or square root, correcting data-recording errors found by looking into outliers, adding additional independent variables, using robust regression, or using bootstrap methods.

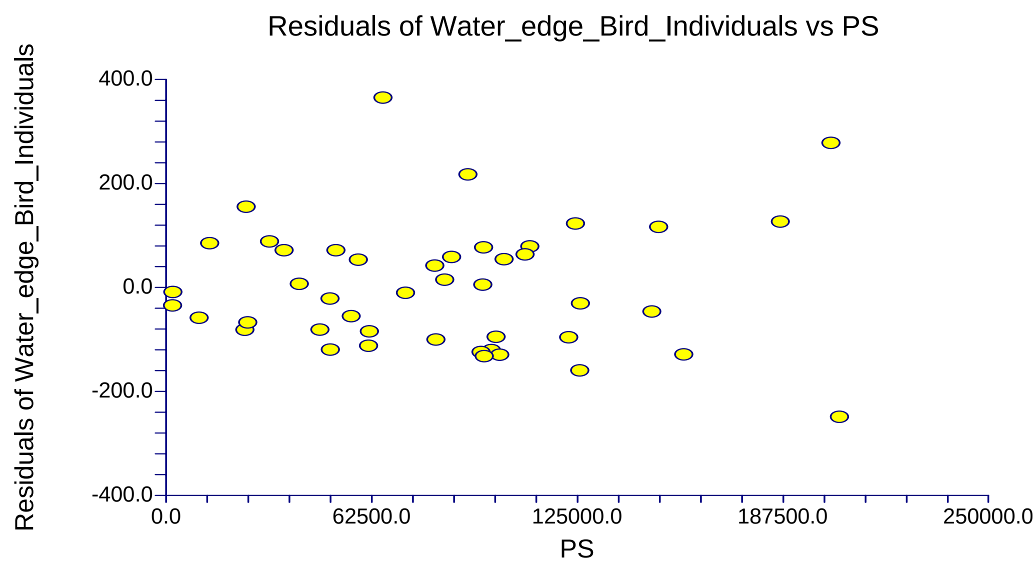
Straight-Line:
Possible remedies for the failure of this assumption include using nonlinear regression or polynomial regression.

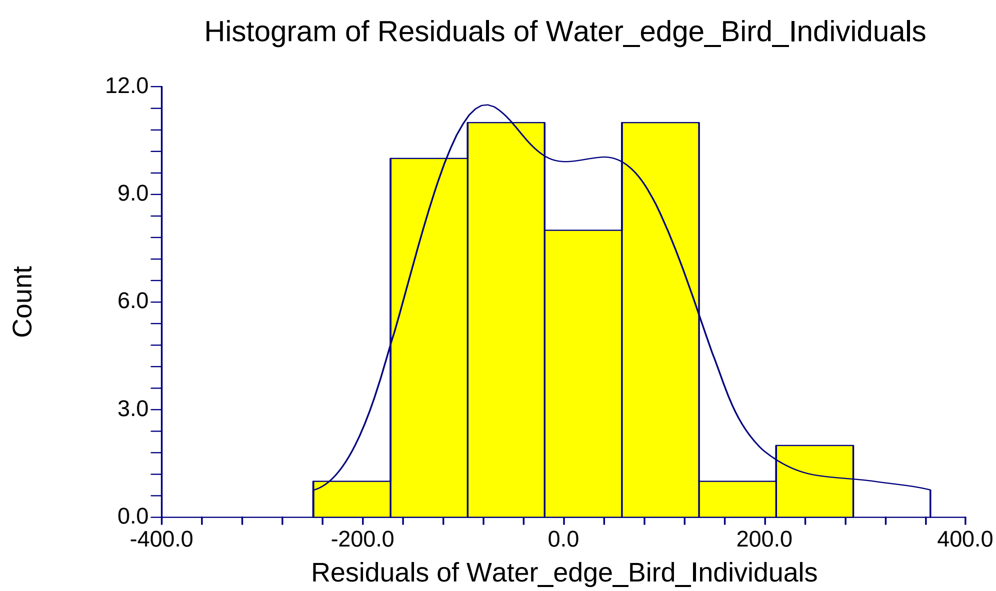
Linear Regression Report

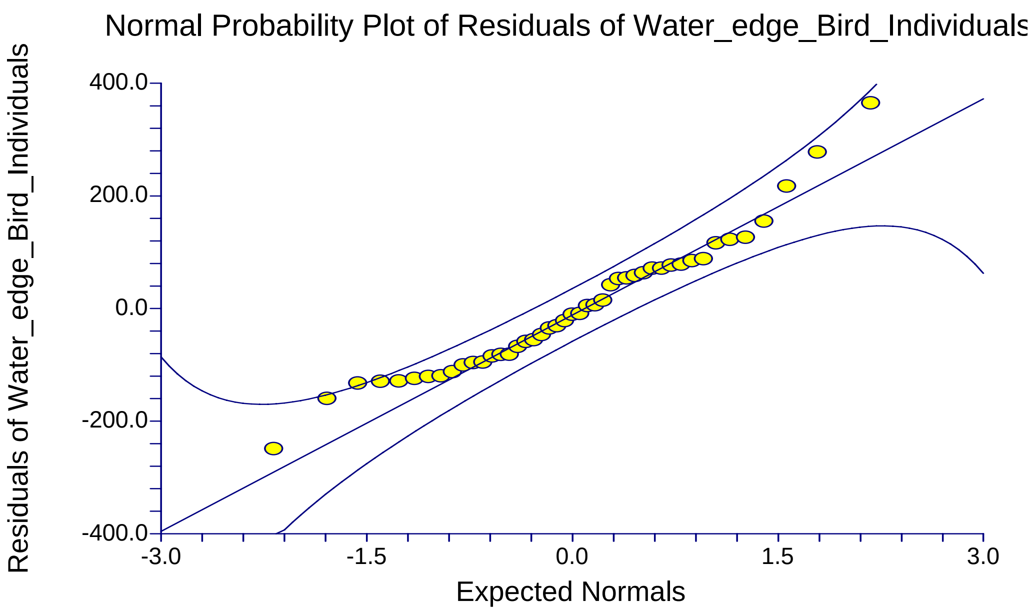
Database

Y = Waterside Bird Individuals   X = PSx

Residual Plots Section





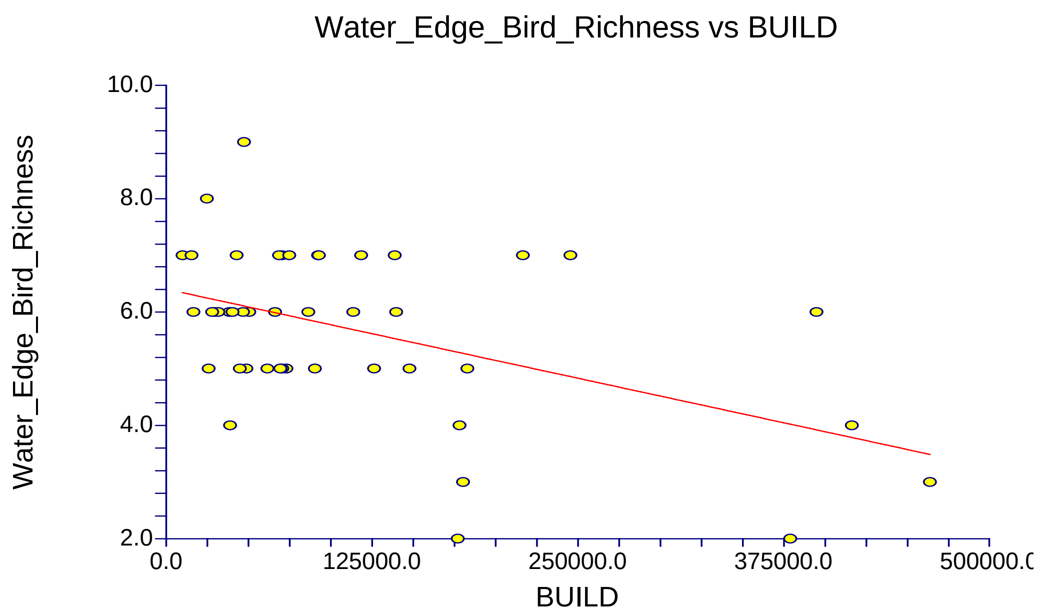

Normal Probability Plot of Residuals of Water_edge_Bird_Individuals
Residuals of Water_edge_Bird_Individuals
400.0
200.0
0.0
-200.0
-400.0
-3.0
-1.5
0.0
1.5
3.0
Expected Normals

Appendix C-4**. The regression model of waterside (water edge) bird richness and the ratio of permanent building areas within a circle of 100 hectares from pond geometric center (%BUILD).**

Linear Regression Report

Database
Y = Waterside Bird Richness   X = %BUILDx

Linear Regression Plot Section



Run Summary Section

Parameter	**Value**	**Parameter**	**Value**
Dependent Variable	Waterside Bird Richness	Rows Processed	45
Independent Variable	BUILD	Rows Used in Estimation	45
Frequency Variable	None	Rows with X Missing	0
Weight Variable	None	Rows with Freq Missing	0
Intercept	6.4037	Rows Prediction Only	0
Slope	0.0000	Sum of Frequencies	45
R-Squared	0.2280	Sum of Weights	45
Correlation	-0.4775	Coefficient of Variation	0.2279
Mean Square Error	1.681245	Square Root of MSE	1.2966

Linear Regression Report

Database
Y = Waterside Bird Richness   X = %BUILDx

Summary Statement
The equation of the straight line relating Waterside Bird Richness and BUILD is estimated as: $Water-edge\,Bird\,Species\,(Y) = 6.4037 - 6.2857 \times 10^{-6}\,(\%BUILDx)$ using the 45 observations in this dataset. The y-intercept, the estimated value of Waterside Bird Richness when %BUILD is zero, is 6.4037 with a standard error of 0.2786. The value of R-Squared, the proportion of the variation in Waterside Bird Richness that can be accounted for by variation in %BUILD, is 0.2280. The correlation between Waterside Bird Richness and BUILD is -0.4775.

A significance test that the slope is zero resulted in a t-value of -3.5636. The significance level of this t-test is 0.0009. Since 0.0009 < 0.0500, the hypothesis that the slope is zero is rejected.

Descriptive Statistics Section

Parameter	**Dependent**	**Independent**
Variable	Waterside Bird Richness	%BUILD
Count	45	45
Mean	5.6889	113722.1333
Standard Deviation	1.4589	110822.1594
Minimum	2.0000	10012.0000
Maximum	9.0000	464034.0000

Linear Regression Report

Database
Y = Waterside Bird Richness   X = %BUILDx

Regression Estimation Section

Parameter	**Intercept B(0)**	**Slope B(1)**
Regression Coefficients	6.4037	0.0000
Lower 95% Confidence Limit	5.8419	0.0000
Upper 95% Confidence Limit	6.9655	0.0000
Standard Error	0.2786	0.0000
Standardized Coefficient	0.0000	-0.4775
T Value	22.9884	-3.5636
Prob. Level (T Test)	0.0000	0.0009
Reject H0 (Alpha = 0.0500)	Yes	Yes
Power (Alpha = 0.0500)	1.0000	0.9361
Regression of Y on X	6.4037	0.0000
Inverse Regression from X on Y	8.8241	0.0000
Orthogonal Regression of Y and X	6.4037	0.0000

Estimated Model
*(6.40371457368543) + (-6.2857217310662E-06) * (%BUILDx)*

Linear Regression Report

Database
Y = Waterside Bird Richness   X = %BUILDx

Analysis of Variance Section

Source	**DF**	**Sum of Squares**	**Mean Square**	**F-Ratio**	**Power (5%)**
Intercept	1	1456.356	1456.356		
Slope	1	21.3509	21.3509	12.6995	0.9361
Error	43	72.29354	1.681245		
Adj. Total	44	93.64445	2.128283		
Total	45	1550			

s = Square Root(1.681245) = 1.296628

Notes:
The above report shows the F-Ratio for testing whether the slope is zero, the degrees of freedom, and the mean square error. The mean square error, which estimates the variance of the residuals, is used extensively in the calculation of hypothesis tests and confidence intervals.

Linear Regression Report

Database
Y = Waterside Bird Richness   X = %BUILDx

Tests of Assumptions Section

Assumption/Test	**Test Value**	**Prob. Level**	**Is the Assumption Reasonable at the 0.2 Level of Significance?**
Residuals follow Normal Distribution?			
Shapiro Wilk	0.9883	0.924382	Yes
Anderson Darling	0.2507	0.742326	Yes
D'Agostino Skewness	-0.2552	0.798569	Yes
D'Agostino Kurtosis	0.3904	0.696219	Yes
D'Agostino Omnibus	0.2176	0.896927	Yes
Constant Residual Variance?			
Modified Levene Test	2.4851	0.122261	No
Relationship is a Straight Line?			
Lack of Linear Fit F(0, 0) Test	0.0000	0.000000	No

No Serial Correlation?
Evaluate the Serial-Correlation report and the Durbin-Watson test if you have equal-spaced, time series data.

Notes:
A 'Yes' means there is not enough evidence to make this assumption seem unreasonable. This lack of evidence may be because the sample size is too small, the assumptions of the test itself are not met, or the assumption is valid.
A 'No' means the that the assumption is not reasonable. However, since these tests are related to sample size, you should assess the role of sample size in the tests by also evaluating the appropriate plots and graphs. A large dataset (say N > 500) will often fail at least one of the normality tests because it is hard to find a large dataset that is perfectly normal.

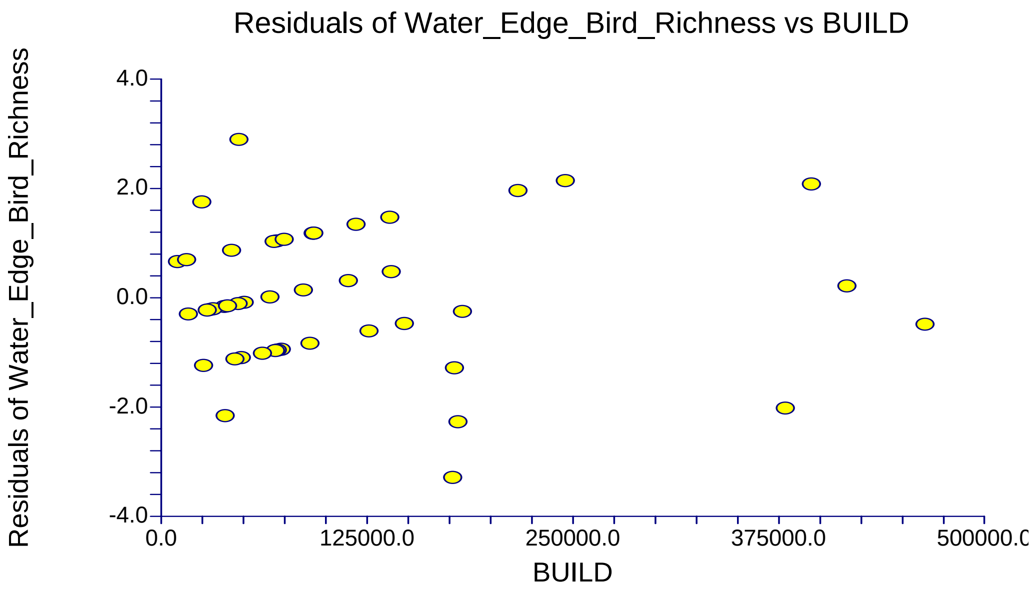
Normality and Constant Residual Variance:
Possible remedies for the failure of these assumptions include using a transformation of Y such as the log or square root, correcting data-recording errors found by looking into outliers, adding additional independent variables, using robust regression, or using bootstrap methods.

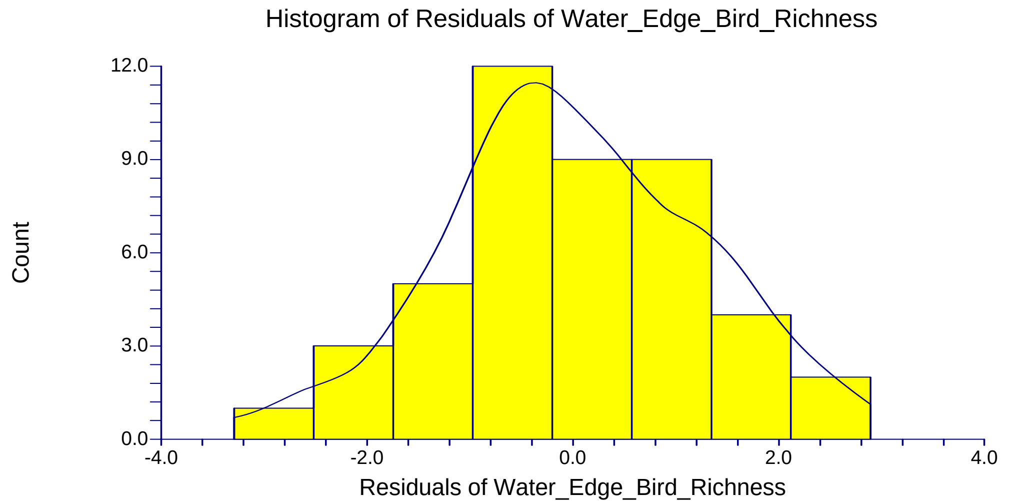
Straight-Line:
Possible remedies for the failure of this assumption include using nonlinear regression.

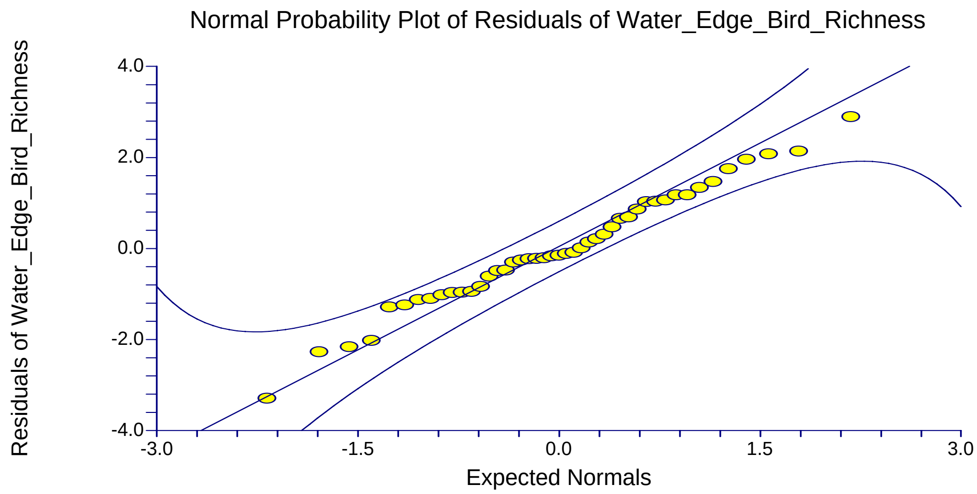
Linear Regression Report

Database
Y = Waterside Bird Richness   X = %BUILDx

Residual Plots Section





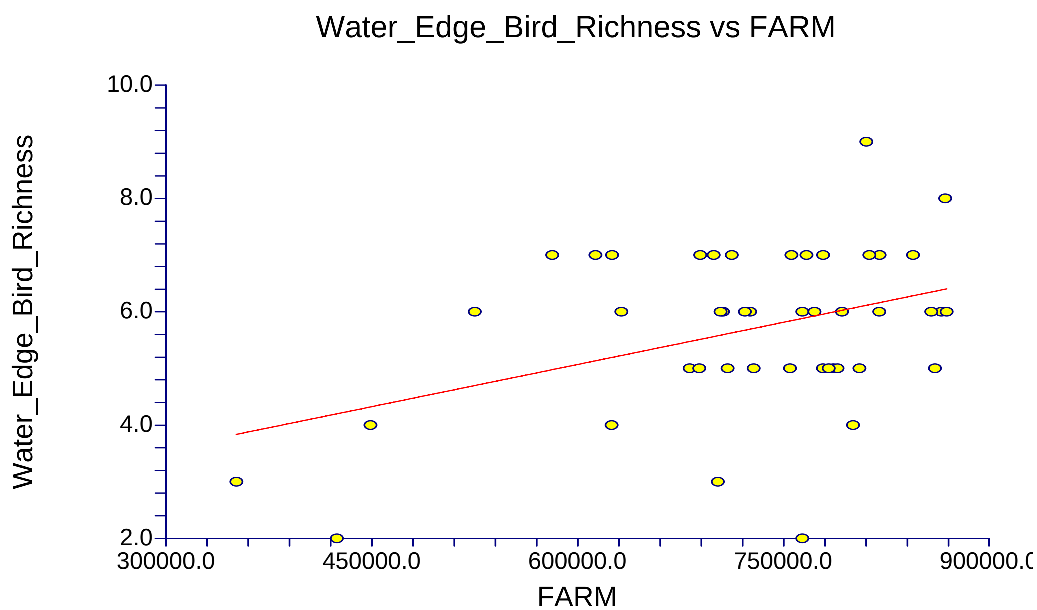

Normal Probability Plot of Residuals of Water_Edge_Bird_Richness
Residuals of Water_Edge_Bird_Richness
4.0
2.0
0.0
-2.0
-4.0
-3.0
-1.5
0.0
1.5
3.0
Expected Normals

Appendix C-5. **The regression model of waterside (water edge) bird richness and the ratio of farmland areas within a circle of 100 hectares from pond geometric center (%FARM).**

Linear Regression Report

Database
Y = Waterside Bird Richness   X = %FARMx

Linear Regression Plot Section



Run Summary Section

Parameter	**Value**	**Parameter**	**Value**
Dependent Variable	Waterside Bird Richness	Rows Processed	45
Independent Variable	FARM	Rows Used in Estimation	45
Frequency Variable	None	Rows with X Missing	0
Weight Variable	None	Rows with Freq Missing	0
Intercept	2.0933	Rows Prediction Only	0
Slope	0.0000	Sum of Frequencies	45
R-Squared	0.1581	Sum of Weights	45
Correlation	0.3976	Coefficient of Variation	0.238
Mean Square Error	1.8335	Square Root of MSE	1.354

Linear Regression Report

Database
Y = Waterside Bird Richness   X = %FARMx

Summary Statement
The equation of the straight line relating Waterside Bird Richness and FARM is estimated as: $Water-edge\,Bird\,Richness(Y) = 2.0933 + 4.9597 \times 10^{-6}(\%FARMx)$ using the 45 observations in this dataset. The y-intercept, the estimated value Waterside Bird Richness when FARM is zero, is 2.0933 with a standard error of 1.2815. The value of R-Squared, the proportion of the variation in Waterside Bird Richness that can be accounted for by variation in FARM, is 0.1581. The correlation between Waterside Bird Richness and %FARM is 0.3976.

A significance test that the slope is zero resulted in a t-value of 2.8412. The significance level of this t-test is 0.0068. Since 0.0068 < 0.0500, the hypothesis that the slope is zero is rejected.

Descriptive Statistics Section

Parameter	**Dependent**	**Independent**
Variable	Waterside Bird Richness	%FARM
Count	45	45
Mean	5.6889	724961.1778
Standard Deviation	1.4589	116941.2063
Minimum	2.0000	351370.0000
Maximum	9.0000	869158.0000

Linear Regression Report

Database
Y = Waterside Bird Richness   X = %FARMx

Regression Estimation Section

Parameter	**Intercept B(0)**	**Slope B(1)**
Regression Coefficients	2.0933	0.0000
Lower 95% Confidence Limit	-0.4911	0.0000
Upper 95% Confidence Limit	4.6777	0.0000
Standard Error	1.2815	0.0000
Standardized Coefficient	0.0000	0.3976
T Value	1.6335	2.8412
Prob. Level (T Test)	0.1097	0.0068
Reject H0 (Alpha = 0.0500)	No	Yes
Power (Alpha = 0.0500)	0.3585	0.7931
Regression of Y on X	2.0933	0.0000
Inverse Regression from X on Y	-17.0597	0.0000
Orthogonal Regression of Y and X	2.0933	0.0000

Notes:
The above report shows the least squares estimates of the intercept and slope followed by the corresponding standard errors, confidence intervals, and hypothesis tests. Note that these results are based on several assumptions that should be validated before they are used.

Estimated Model
*(2.09330450951941) + (4.95969231123658E-06) * (FARM)*

Linear Regression Report

Database
Y = Waterside Bird Richness   X = %FARMx

Analysis of Variance Section

Source	**DF**	**Sum of Squares**	**Mean Square**	**F-Ratio**	**Power (5%)**
Intercept	1	1456.356	1456.356		
Slope	1	14.80121	14.80121	8.0724	0.7931
Error	43	78.84323	1.833564		
Adj. Total	44	93.64445	2.128283		
Total	45	1550			

s = Square Root(1.833564) = 1.354091

Notes:
The above report shows the F-Ratio for testing whether the slope is zero, the degrees of freedom, and the mean square error. The mean square error, which estimates the variance of the residuals, is used extensively in the calculation of hypothesis tests and confidence intervals.

Linear Regression Report

Database
Y = Waterside Bird Richness   X = %FARMx

Tests of Assumptions Section

Assumption/Test	Test Value	Prob. Level	Is the Assumption Reasonable at the 0.2 Level of Significance?
Residuals follow Normal Distribution?			
Shapiro Wilk	0.9806	0.644821	Yes
Anderson Darling	0.2769	0.654764	Yes
D'Agostino Skewness	-1.1666	0.243390	Yes
D'Agostino Kurtosis	0.9288	0.352984	Yes
D'Agostino Omnibus	2.2236	0.328974	Yes
Constant Residual Variance?			
Modified Levene Test	0.0058	0.939636	Yes
Relationship is a Straight Line?			
Lack of Linear Fit F(0, 0) Test	0.0000	0.000000	No

Notes:
A 'Yes' means there is not enough evidence to make this assumption seem unreasonable. This lack of evidence may be because the sample size is too small, the assumptions of the test itself are not met, or the assumption is valid.
A 'No' means the that the assumption is not reasonable. However, since these tests are related to sample size, you should assess the role of sample size in the tests by also evaluating the appropriate plots and graphs. A large dataset (say N > 500) will often fail at least one of the normality tests because it is hard to find a large dataset that is perfectly normal.

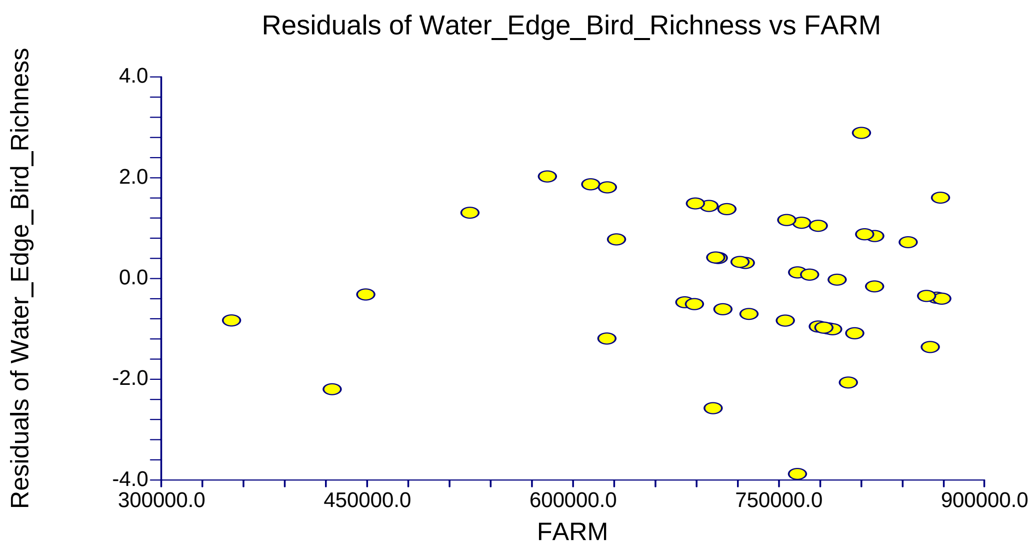
Normality and Constant Residual Variance:
Possible remedies for the failure of these assumptions include using a transformation of Y such as the log or square root, correcting data-recording errors found by looking into outliers, adding additional independent variables, using robust regression, or using bootstrap methods.

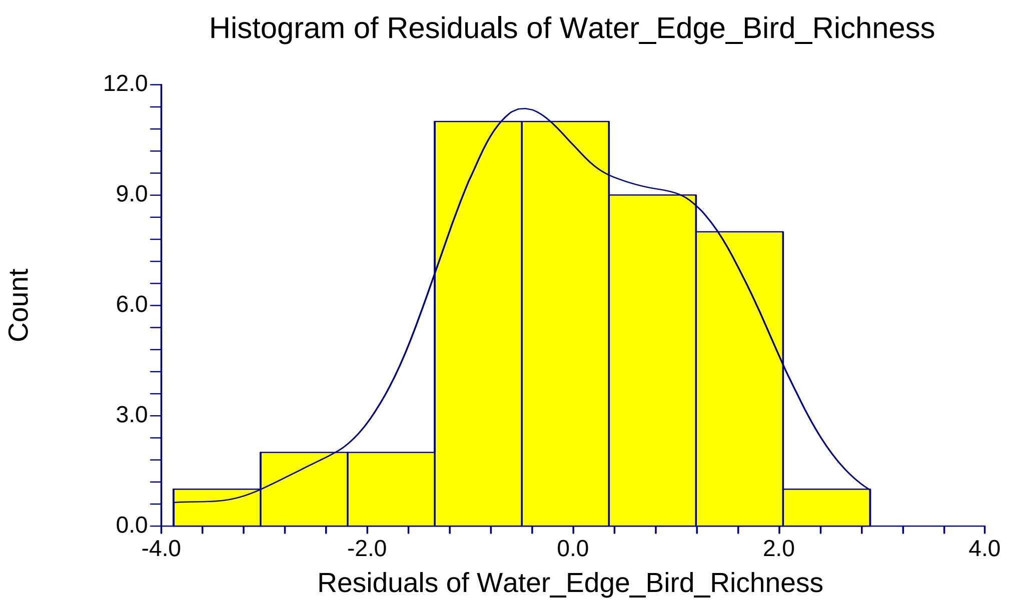
Straight-Line:
Possible remedies for the failure of this assumption include using nonlinear regression or polynomial regression.

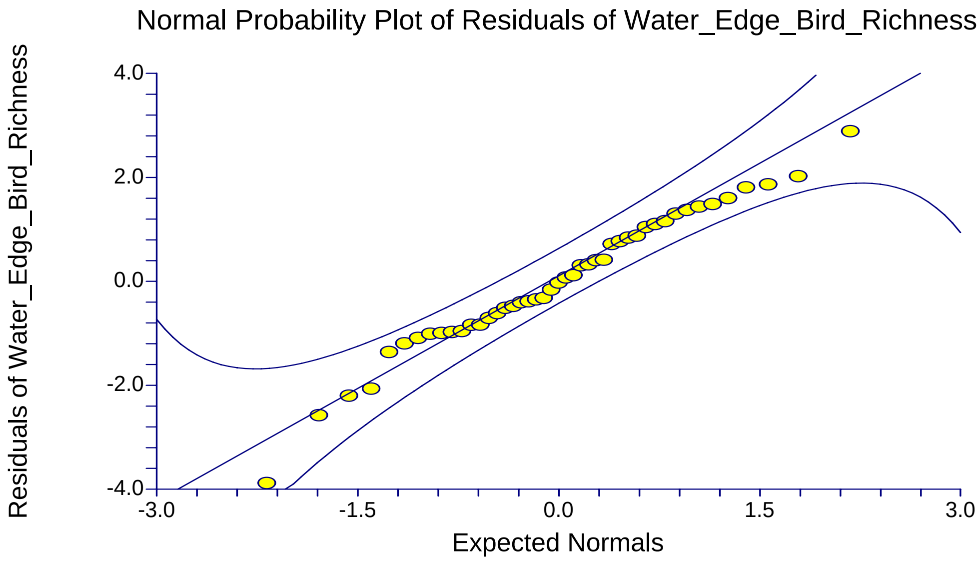
Linear Regression Report

Database
Y = Waterside Bird Richness   X = %FARMx

Residual Plots Section







Normal Probability Plot of Residuals of Water_Edge_Bird_Richness
Residuals of Water_Edge_Bird_Richness
4.0
2.0
0.0
-2.0
-4.0
-3.0
-1.5
0.0
1.5
3.0
Expected Normals

Appendix D. Results of the Non-linear Regression Models (Factor Elimination Approach).

The structure of the neural network used by the package of MATLAB 6.1. The input layer comprises four cells representing each of the four-pondscape parameters *Xi* (*%BUILD, %FARM, PS,* and *MPFD*). The hidden layer comprises four neurons which calculate the dot products between its vector of weights w_j =[$w_{ji,}$ *i* =1,4] and *x* = [$x_{i,}$ *i*= *%BUILD, %FARM, PS, and MPFD*]. The factor elimination approach (FEA) was used to determine which factors *xi* ; [$x_{i,}$ *i* = *%BUILD, %FARM, PS,* and *MPFD*] are causally major influences on waterside bird's diversity (*H'*) in a respective sequence. Data input by a one-row, two-row, and three-row elimination was tested and simulated the final output to find differentiations between an original model and some elimination models.

***Appendix D-1*. One-row factor elimination approach[1].**

	If data input while %BUILD = 0, then output	If data input while %FARM = 0, then output	If data input while PS = 0, then output	If data input while MPFD =0, then output
	Error for model (%BUILD)	Error for model (%FARM)	Error for model (PS)	Error for model (MPFD)
	0.717988	0.717987	0.717982	0.082728
	0.717952	0.71799	0.717968	0.082715
	0.717988	0.717987	0.717976	0.082736
	0.717988	0.717988	0.717975	0.082741
	0.717987	0.71799	0.717971	0.082729
	0.717988	0.71799	0.717968	0.08274
	0.717988	0.717987	0.717982	0.082734
	0.717987	0.717987	0.717963	0.082743
	0.717988	0.717987	0.717969	0.082741
	0.717988	0.717989	0.71797	0.082742
	0.717988	0.717989	0.717982	0.082734
	0.717987	0.717986	0.717969	0.082743
	0.717987	0.717988	0.717951	0.082744
	0.717988	0.717989	0.717957	0.082743
	0.717987	0.717987	0.717958	0.082745
	0.717987	0.717985	0.717976	0.082735
	0.717987	0.717989	0.717964	0.082744
	0.717987	0.717989	0.717979	0.082735
	0.717988	0.717988	0.717963	0.082723

***Appendix D-1*. Continued.**

	If data input while %BUILD = 0, then output	If data input while %FARM = 0, then output	If data input while PS = 0, then output	If data input while MPFD =0, then output
	Error for model (%BUILD)	Error for model (%FARM)	Error for model (PS)	Error for model (MPFD)
	0.717988	0.717988	0.717986	0.082718
	0.717987	0.717985	0.717974	0.082741
	0.717987	0.717985	0.717968	0.082744
	0.717967	0.71799	0.717975	0.082742
	0.717988	0.717988	0.717969	0.082738
	0.717987	0.717985	0.717978	0.08273
	0.717988	0.71799	0.717971	0.08274
	0.717987	0.717985	0.71798	0.08274
	0.717988	0.717988	0.717984	0.082731
	0.717972	0.71799	0.717986	0.082675
	0.717988	0.717988	0.717959	0.082739
	0.717987	0.717987	0.717966	0.082743
	0.717987	0.717987	0.71798	0.082736
	0.717988	0.71799	0.717948	0.082744
	0.717988	0.717989	0.717971	0.082741
	0.717987	0.717986	0.717966	0.082735
	0.717987	0.717989	0.717947	0.082744
	0.717987	0.717987	0.717969	0.082742
	0.717988	0.717988	0.717977	0.082739
	0.717988	0.717987	0.717984	0.082727
	0.717988	0.717989	0.717967	0.082742
	0.717988	0.717989	0.717977	0.082737
	0.717987	0.717988	0.717969	0.08274
	0.717988	0.717986	0.717973	0.08274
	0.717975	0.71799	0.717977	0.08273
	0.717988	0.717989	0.717963	0.082744
Total *H'* predicted error	32.30936	32.30946	32.30869	3.723117
[2] Mean *H'* predicted error	0.717986	0.717988	0.717971	0.082736

Note:

[1] One-row factor elimination approach (FEA) determined that the MPFD is the major factor to affect waterside bird's diversity.

[2] Mean *H'* predicted error from MPFD = 0.082736 ± 1.16432E-05, n = 45.

Non-linear Model Report

***Appendix D-2*. Two-row factor elimination approach[2].**

Model for four variables (1)	If data input while %BUILD = 0 and MPFD = 0, then output (2)	∣(1) - (2)∣	Mean∣(1) - (2)∣
0.187446	0.082705	0.104741	0.359866
0.260985	0.122874	0.138111	
0.539752	0.082714	0.457038	
0.596994	0.082716	0.514278	
0.428046	0.082662	0.345384	
0.627509	0.082675	0.544834	
0.676667	0.082712	0.593955	
0.479812	0.082733	0.397079	
0.437183	0.082724	0.354459	
0.525698	0.082688	0.44301	
0.394329	0.082676	0.311653	
0.616483	0.082731	0.533752	
0.508955	0.082735	0.42622	
0.3686	0.082705	0.285895	
0.517141	0.08274	0.434401	
0.496184	0.082726	0.413458	
0.531822	0.08274	0.449082	
0.402353	0.082721	0.319632	
0.511992	0.082683	0.429309	
0.209802	0.082662	0.12714	
0.532727	0.082735	0.449992	
0.439588	0.08274	0.356848	
0.40717	0.082834	0.324336	
0.516359	0.082721	0.433638	
0.411911	0.082715	0.329196	
0.328685	0.082686	0.245999	
0.337185	0.082727	0.254458	

***Appendix D-2*. Continued.**

Model for four variables (1)	If data input while %BUILD = 0 and MPFD = 0, then output (2)	∣(1) - (2)∣	Mean∣(1) - (2)∣
0.419735	0.082685	0.33705	
0.455566	0.171857	0.283709	
0.417423	0.082714	0.334709	
0.338905	0.082733	0.256172	
0.434793	0.082724	0.352069	
0.491163	0.082713	0.40845	
0.526723	0.082724	0.443999	
0.448619	0.082731	0.365888	
0.514072	0.082737	0.431335	
0.251645	0.082731	0.168914	
0.459589	0.082721	0.376868	
0.54215	0.082683	0.459467	
0.536566	0.082719	0.453847	
0.36816	0.082712	0.285448	
0.419471	0.082733	0.336738	
0.465609	0.082722	0.382887	
0.225209	0.082919	0.14229	
0.43893	0.082704	0.356226	

Model for four variables (1)	If data input while %FARM = 0 and MPFD = 0, then output (3)	∣(1) - (3)∣	Mean∣(1) - (3)∣
0.187446	0.119762	0.067684	0.190609
0.260985	0.082665	0.17832	
0.539752	0.295036	0.244716	
0.596994	0.408341	0.188653	
0.428046	0.08274	0.345306	
0.627509	0.0982	0.529309	
0.676667	0.327516	0.349151	
0.479812	0.481802	0.00199	
0.437183	0.446435	0.009252	
0.525698	0.238242	0.287456	

***Appendix D-2*. Continued.**

Model for four variables (1)	If data input while %FARM = 0 and MPFD = 0, then output (3)	∣(1) - (3)∣	Mean∣(1) - (3)∣
0.394329	0.096696	0.297633	
0.616483	0.506644	0.109839	
0.508955	0.493653	0.015302	
0.3686	0.141107	0.227493	
0.517141	0.535493	0.018352	
0.496184	0.452838	0.043346	
0.531822	0.408257	0.123565	
0.402353	0.115738	0.286615	
0.511992	0.08366	0.428332	
0.209802	0.083815	0.125987	
0.532727	0.511091	0.021636	
0.439588	0.530891	0.091303	
0.40717	0.082839	0.324331	
0.516359	0.270776	0.245583	
0.411911	0.346511	0.0654	
0.328685	0.094077	0.234608	
0.337185	0.488498	0.151313	
0.419735	0.117446	0.302289	
0.455566	0.082659	0.372907	
0.417423	0.250451	0.166972	
0.338905	0.487894	0.148989	
0.434793	0.326796	0.107997	
0.491163	0.12676	0.364403	
0.526723	0.257555	0.269168	
0.448619	0.412632	0.035987	
0.514072	0.393359	0.120713	
0.251645	0.493673	0.242028	
0.459589	0.222926	0.236663	
0.54215	0.139283	0.402867	
0.536566	0.270283	0.266283	
0.36816	0.13834	0.22982	

***Appendix D-2*. Continued.**

Model for four variables (1)	If data input while %FARM = 0 and MPFD = 0, then output (3)	∣(1) - (3)∣	Mean∣(1) - (3)∣
0.419471	0.39382	0.025651	
0.465609	0.464695	0.000914	
0.225209	0.082681	0.142528	
0.43893	0.310171	0.128759	
Model for four variables (1)	**If data input while PS = 0 and MPFD = 0, then output (4)**	**∣(1) - (4)∣**	**Mean∣(1) - (4)∣**
0.187446	0.082728	0.104718	0.361753
0.260985	0.082715	0.17827	
0.539752	0.082737	0.457015	
0.596994	0.082743	0.514251	
0.428046	0.08273	0.345316	
0.627509	0.082751	0.544758	
0.676667	0.082735	0.593932	
0.479812	0.082792	0.39702	
0.437183	0.082751	0.354432	
0.525698	0.082749	0.442949	
0.394329	0.082734	0.311595	
0.616483	0.082755	0.533728	
0.508955	0.086509	0.422446	
0.3686	0.082994	0.285606	
0.517141	0.083064	0.434077	
0.496184	0.082736	0.413448	
0.531822	0.082797	0.449025	
0.402353	0.082736	0.319617	
0.511992	0.082727	0.429265	
0.209802	0.082718	0.127084	
0.532727	0.082744	0.449983	
0.439588	0.082762	0.356826	
0.40717	0.082745	0.324425	
0.516359	0.082743	0.433616	

***Appendix D-2*. Continued.**

Model for four variables (1)	If data input while PS = 0 and MPFD = 0, then output (4)	∣(1) - (4)∣	Mean∣(1) - (4)∣
0.411911	0.08273	0.329181	
0.328685	0.082744	0.245941	
0.337185	0.08274	0.254445	
0.419735	0.082731	0.337004	
0.455566	0.082675	0.372891	
0.417423	0.082804	0.334619	
0.338905	0.082764	0.256141	
0.434793	0.082736	0.352057	
0.491163	0.09757	0.393593	
0.526723	0.082748	0.443975	
0.448619	0.082742	0.365877	
0.514072	0.106905	0.407167	
0.251645	0.082752	0.168893	
0.459589	0.08274	0.376849	
0.54215	0.082727	0.459423	
0.536566	0.082758	0.453808	
0.36816	0.082738	0.285422	
0.419471	0.082748	0.336723	
0.465609	0.082743	0.382866	
0.225209	0.08273	0.142479	
0.43893	0.082802	0.356128	

Note:

[2] The smaller value between Mean∣(1) - (2)∣, Mean∣(1) - (3)∣, and Mean∣(1) - (4)∣ is Mean∣(1) - (3)∣, 0.190609. It means that %FARM is the major factor to affect waterside bird's diversity second to MPFD.

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Appendix D-3. **Three-row factor elimination approach[3].**

Model for four variables (1)	If data input while PS = 0, then output (5)	∣(1) - (5)∣	Mean∣(1) - (5)∣
0.187446	0.133191	0.054255	0.177395
0.260985	0.36112	0.100135	
0.539752	0.311963	0.227789	
0.596994	0.394981	0.202013	
0.428046	0.088134	0.339912	
0.627509	0.101445	0.526064	
0.676667	0.398676	0.277991	
0.479812	0.442911	0.036901	
0.437183	0.4224	0.014783	
0.525698	0.266918	0.25878	
0.394329	0.137559	0.25677	
0.616483	0.490963	0.12552	
0.508955	0.449274	0.059681	
0.3686	0.101951	0.266649	
0.517141	0.506424	0.010717	
0.496184	0.48638	0.009804	
0.531822	0.375387	0.156435	
0.402353	0.104514	0.297839	
0.511992	0.086163	0.425829	
0.209802	0.180751	0.029051	
0.532727	0.510508	0.022219	
0.439588	0.521787	0.082199	
0.40717	0.151181	0.255989	
0.516359	0.239217	0.277142	
0.411911	0.436041	0.02413	
0.328685	0.089211	0.239474	
0.337185	0.512409	0.175224	
0.419735	0.202116	0.217619	
0.455566	0.448426	0.00714	
0.417423	0.207832	0.209591	

***Appendix D-3.* Continued.**

Model for four variables (1)	If data input while PS = 0, then output (5)	∣(1) - (5)∣	Mean∣(1) - (5)∣
0.338905	0.456638	0.117733	
0.434793	0.321924	0.112869	
0.491163	0.095369	0.395794	
0.526723	0.19056	0.336163	
0.448619	0.414597	0.034022	
0.514072	0.340959	0.173113	
0.251645	0.47338	0.221735	
0.459589	0.180769	0.27882	
0.54215	0.387556	0.154594	
0.536566	0.188782	0.347784	
0.36816	0.116483	0.251677	
0.419471	0.363481	0.05599	
0.465609	0.486035	0.020426	
0.225209	0.139851	0.085358	
0.43893	0.229862	0.209068	
Model for four variables (1)	**If data input while %BUILD = 0, then output (6)**	**∣(1) - (6)∣**	**Mean∣(1) - (6)∣**
0.187446	0.274949	0.087503	0.117559
0.260985	0.082704	0.178281	
0.539752	0.490462	0.04929	
0.596994	0.538866	0.058128	
0.428046	0.232105	0.195941	
0.627509	0.589941	0.037568	
0.676667	0.446631	0.230036	
0.479812	0.548573	0.068761	
0.437183	0.535868	0.098685	
0.525698	0.577974	0.052276	
0.394329	0.215564	0.178765	
0.616483	0.527835	0.088648	
0.508955	0.564772	0.055817	
0.3686	0.616616	0.248016	
0.517141	0.56208	0.044939	

***Appendix D-3.* Continued.**

Model for four variables (1)	If data input while %BUILD = 0, then output (6)	∣(1) - (6)∣	Mean∣(1) - (6)∣
0.496184	0.478083	0.018101	
0.531822	0.589654	0.057832	
0.402353	0.399068	0.003285	
0.511992	0.441631	0.070361	
0.209802	0.084544	0.125258	
0.532727	0.504365	0.028362	
0.439588	0.513029	0.073441	
0.40717	0.135948	0.271222	
0.516359	0.522604	0.006245	
0.411911	0.460899	0.048988	
0.328685	0.562533	0.233848	
0.337185	0.505554	0.168369	
0.419735	0.199027	0.220708	
0.455566	0.082656	0.37291	
0.417423	0.545984	0.128561	
0.338905	0.54011	0.201205	
0.434793	0.464991	0.030198	
0.491163	0.629243	0.13808	
0.526723	0.571718	0.044995	
0.448619	0.462239	0.01362	
0.514072	0.594199	0.080127	
0.251645	0.529846	0.278201	
0.459589	0.511951	0.052362	
0.54215	0.213175	0.328975	
0.536566	0.586547	0.049981	
0.36816	0.476408	0.108248	
0.419471	0.531681	0.11221	
0.465609	0.513163	0.047554	
0.225209	0.082793	0.142416	
0.43893	0.600789	0.161859	

Note:

[3] The smaller value between Mean∣(1) - (5)∣ and Mean∣(1) - (6)∣ is Mean∣(1) - (6)∣, 0.117559. It means that PS is the major factor compared with %BUILD to affect waterside bird's diversity next to MPFD, %FARM, respectively.

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***Appendix D-4*. Testing for MPFD's trends with waterside bird's diversity (neurons = 4, testing at a ±10% range)[4,5].**

+10%	Model for four variables (real value)	Model for four variables (value +10% for MPFD)	Error	%Error	Absolute Error	%Absolute Error
	0.187446	0.086846	-0.1006	-53.67%	0.1006	53.67%
	0.260985	0.419103	0.158118	60.59%	0.158118	60.59%
	0.539752	0.241327	-0.29843	-55.29%	0.298425	55.29%
	0.596994	0.409666	-0.18733	-31.38%	0.187328	31.38%
	0.428046	0.126446	-0.3016	-70.46%	0.3016	70.46%
	0.627509	0.478065	-0.14944	-23.82%	0.149444	23.82%
	0.676667	0.121843	-0.55482	-81.99%	0.554824	81.99%
	0.479812	0.418704	-0.06111	-12.74%	0.061108	12.74%
	0.437183	0.507477	0.070294	16.08%	0.070294	16.08%
	0.525698	0.62896	0.103262	19.64%	0.103262	19.64%
	0.394329	0.113587	-0.28074	-71.19%	0.280742	71.19%
	0.616483	0.499311	-0.11717	-19.01%	0.117172	19.01%
	0.508955	0.363725	-0.14523	-28.53%	0.14523	28.53%
	0.3686	0.442154	0.073554	19.95%	0.073554	19.95%
	0.517141	0.392819	-0.12432	-24.04%	0.124322	24.04%
	0.496184	0.547495	0.051311	10.34%	0.051311	10.34%
	0.531822	0.397962	-0.13386	-25.17%	0.13386	25.17%
	0.402353	0.083391	-0.31896	-79.27%	0.318962	79.27%
	0.511992	0.449082	-0.06291	-12.29%	0.06291	12.29%
	0.209802	0.243291	0.033489	15.96%	0.033489	15.96%
	0.532727	0.5219	-0.01083	-2.03%	0.010827	2.03%
	0.439588	0.454133	0.014545	3.31%	0.014545	3.31%
	0.40717	0.27637	-0.1308	-32.12%	0.1308	32.12%
	0.516359	0.39338	-0.12298	-23.82%	0.122979	23.82%
	0.411911	0.343719	-0.06819	-16.56%	0.068192	16.56%
	0.328685	0.120889	-0.2078	-63.22%	0.207796	63.22%
	0.337185	0.482327	0.145142	43.05%	0.145142	43.05%
	0.419735	0.107504	-0.31223	-74.39%	0.312231	74.39%

***Appendix D-4*. Continued.**

+10%	Model for four variables (real value)	Model for four variables (value +10% for MPFD)	Error	%Error	Absolute Error	%Absolute Error
	0.455566	0.477773	0.022207	4.87%	0.022207	4.87%
	0.417423	0.477161	0.059738	14.31%	0.059738	14.31%
	0.338905	0.437777	0.098872	29.17%	0.098872	29.17%
	0.434793	0.100243	-0.33455	-76.94%	0.33455	76.94%
	0.491163	0.361597	-0.12957	-26.38%	0.129566	26.38%
	0.526723	0.225592	-0.30113	-57.17%	0.301131	57.17%
	0.448619	0.465423	0.016804	3.75%	0.016804	3.75%
	0.514072	0.379417	-0.13466	-26.19%	0.134655	26.19%
	0.251645	0.483704	0.232059	92.22%	0.232059	92.22%
	0.459589	0.096827	-0.36276	-78.93%	0.362762	78.93%
	0.54215	0.138836	-0.40331	-74.39%	0.403314	74.39%
	0.536566	0.352103	-0.18446	-34.38%	0.184463	34.38%
	0.36816	0.087037	-0.28112	-76.36%	0.281123	76.36%
	0.419471	0.38156	-0.03791	-9.04%	0.037911	9.04%
	0.465609	0.581141	0.115532	24.81%	0.115532	24.81%
	0.225209	0.286337	0.061128	27.14%	0.061128	27.14%
	0.43893	0.562228	0.123298	28.09%	0.123298	28.09%

Mean Absolute Error = 0.160848
%Mean Absolute Error = 37.20%
Mean Error = -0.09954
% Mean Error = -18.83%

-10%	Model for four variables (real value)	Model for four variables (value -10% for MPFD)	Error	%Error	Absolute Error	%Absolute Error
	0.187446	0.535527	0.348081	185.70%	0.348081	185.70%
	0.260985	0.465616	0.204631	78.41%	0.204631	78.41%
	0.539752	0.549607	0.009855	1.83%	0.009855	1.83%
	0.596994	0.561024	-0.03597	-6.03%	0.03597	6.03%
	0.428046	0.531174	0.103128	24.09%	0.103128	24.09%

***Appendix D-4*. Continued.**

-10%	Model for four variables (real value)	Model for four variables (value -10% for MPFD)	Error	%Error	Absolute Error	%Absolute Error
	0.627509	0.495453	-0.13206	-21.04%	0.132056	21.04%
	0.676667	0.545614	-0.13105	-19.37%	0.131053	19.37%
	0.479812	0.614344	0.134532	28.04%	0.134532	28.04%
	0.437183	0.575875	0.138692	31.72%	0.138692	31.72%
	0.525698	0.507576	-0.01812	-3.45%	0.018122	3.45%
	0.394329	0.553225	0.158896	40.30%	0.158896	40.30%
	0.616483	0.588588	-0.0279	-4.52%	0.027895	4.52%
	0.508955	0.630609	0.121654	23.90%	0.121654	23.90%
	0.3686	0.568743	0.200143	54.30%	0.200143	54.30%
	0.517141	0.637883	0.120742	23.35%	0.120742	23.35%
	0.496184	0.555125	0.058941	11.88%	0.058941	11.88%
	0.531822	0.659972	0.12815	24.10%	0.12815	24.10%
	0.402353	0.601145	0.198792	49.41%	0.198792	49.41%
	0.511992	0.463043	-0.04895	-9.56%	0.048949	9.56%
	0.209802	0.663442	0.45364	216.22%	0.45364	216.22%
	0.532727	0.591605	0.058878	11.05%	0.058878	11.05%
	0.439588	0.611965	0.172377	39.21%	0.172377	39.21%
	0.40717	0.725582	0.318412	78.20%	0.318412	78.20%
	0.516359	0.578344	0.061985	12.00%	0.061985	12.00%
	0.411911	0.526542	0.114631	27.83%	0.114631	27.83%
	0.328685	0.525251	0.196566	59.80%	0.196566	59.80%
	0.337185	0.569102	0.231917	68.78%	0.231917	68.78%
	0.419735	0.547502	0.127767	30.44%	0.127767	30.44%
	0.455566	0.319199	-0.13637	-29.93%	0.136367	29.93%
	0.417423	0.559975	0.142552	34.15%	0.142552	34.15%
	0.338905	0.610003	0.271098	79.99%	0.271098	79.99%
	0.434793	0.581464	0.146671	33.73%	0.146671	33.73%
	0.491163	0.606986	0.115823	23.58%	0.115823	23.58%
	0.526723	0.611576	0.084853	16.11%	0.084853	16.11%
	0.448619	0.584086	0.135467	30.20%	0.135467	30.20%

***Appendix D-4*. Continued.**

-10%	Model for four variables (real value)	Model for four variables (value -10% for MPFD)	Error	%Error	Absolute Error	%Absolute Error
	0.514072	0.654742	0.14067	27.36%	0.14067	27.36%
	0.251645	0.593954	0.342309	136.03%	0.342309	136.03%
	0.459589	0.5942	0.134611	29.29%	0.134611	29.29%
	0.54215	0.569574	0.027424	5.06%	0.027424	5.06%
	0.536566	0.597571	0.061005	11.37%	0.061005	11.37%
	0.36816	0.576004	0.207844	56.45%	0.207844	56.45%
	0.419471	0.617513	0.198042	47.21%	0.198042	47.21%
	0.465609	0.556435	0.090826	19.51%	0.090826	19.51%
	0.225209	0.255199	0.02999	13.32%	0.02999	13.32%
	0.43893	0.541991	0.103061	23.48%	0.103061	23.48%

Mean Absolute Error = 0.142779

%Mean Absolute Error = 40.03%

Mean Error = 0.119205

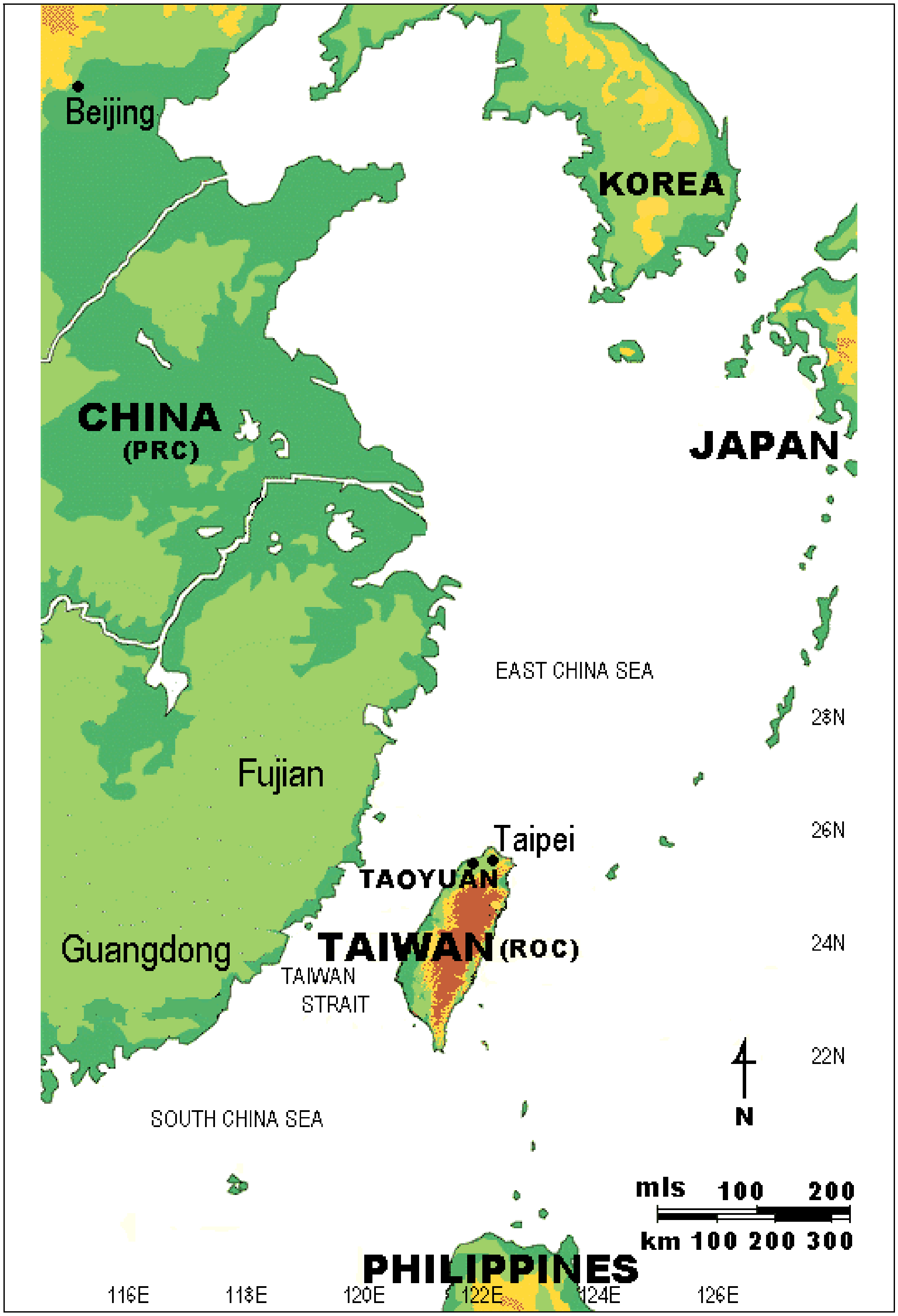
% Mean Error = 35.86%

Note:

[4] The value of MPFD (range = [1, 2]) has a strongly negative relationship with waterside bird's diversity. MPFD approaches 1 for shapes with very simple perimeters such as circles or squares, then waterside bird's diversity increases; and approaches 2 for shapes with highly convoluted and plane-filling perimeters, then waterside bird's diversity declines. If the value of added +10% occurs, the value of mean error (= -0.09954) reduces, and vice versa.

[5] The training sets (r = 0.725537, n = 35) and validated sets (r = 0.722752, n = 10) were able to meet the underlying rules embedded for real values in the true *H*'.

Appendix E. The Location of Taiwan.



VITA

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