Wetland change through time and waterbird responses in two Chinese wetlands: implications for ecosystem function and wildlife conservation.

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Introduction

Wetlands occupy less than 9% of the world's surface, yet contain some of the highest primary productivity, biodiversity and economic value of any ecosystem on Earth (Costanza et al. 1997; Zedler and Kercher, 2005). Human communities have long targeted wetlands for their productivity, converting them to agriculture or settlements, impacting the biodiversity within these systems and compromising their function (Mitsch and Gosselink, 2000). Wetlands in China mirror these global trends, combining a long history of human modifications with new uses associated with recent, unprecedented socio-economic transformations (An et al. 2007). These new uses alter wetland function and these alterations directly affect the biodiversity that depend on these systems, such as waterbirds (Fiedler, 2009). Because waterbirds are easily observable and often closely linked to the ecological function of specific wetlands, they provide a useful indicator of change within wetlands (Weller, 1988; Ma et al., 2010). For example, researchers have documented a dramatic decline in waterbird populations wintering along the lower Yangtze River basin in China (Cao et al., 2008). This pattern of decline appears correlated to a reduction in the quality of foraging habitats for these species, as well as degradation of the overall quality of the freshwater wetland systems within this region due to novel human uses (Fox et al. 2011).

China's wetland decline is closely linked to the use patterns of the country's human communities, a relationship that extends back several millennia. Rice agriculture in China began over 9,000 years ago, placing wetlands at the center of southern China's agrarian society (Loewe and Shaughnessy, 1999; Jiang and Liu, 2006). Modifications to wetlands and freshwater systems for agriculture, expansion of trade networks and settlements benefitting the country's growing human population is a significant legacy of China's >4,000 year dynastic period (Elvin, 1998). Since 1950, when the country's government stabilized under the Chinese Communist Party, 20% of China's natural wetlands have been lost, and much more have been altered (Song and Dong, 2002). Rates of loss and modification appear to be accelerating as the country continues to rapidly develop. China lost an estimated 14% of its wetlands from 1990-2000 alone (Gong et al. 2010). Fundamental questions regarding this loss remain, however. For example, what is the rate of China's wetland ecosystem change through time (e.g. gradual over time or punctuated by rapid periods of alteration) and what do those changes mean for the biodiversity that depend on these systems? Understanding the pattern and consequences of wetland modification and loss in

China is important because these wetlands directly support hundreds of species and millions of people across the country.

China’s wetland biodiversity provides a tangible metric to document impacts and alterations to the country’s wetland and freshwater ecosystems. While cases such as the precipitous decline of the Chinese Sturgeon (*Acipenser sinensis*) and the extinction of the Yangtze River Dolphin (*Lipotes vexillifer*) have highlighted the loss within freshwater systems, these species were not studied in great detail until it was clear they were on the verge of extinction (Qiao et al. 2006; Turvey et al. 2007). A significant amount of work has focused on China’s migratory waterbird community over the last thirty years, however, and these records provide important information about the distribution and ecological function of wetland systems across the country. For example, waterbird declines in the middle and lower reaches of the Yangtze River basin mirror declines of other plant and animal species (Fang et al. 2006). The mechanisms driving these declines are not clear, however, and distinct gaps remain in our understanding of how these species respond to changing wetland conditions over time. Drivers of these changes likely involve a combination of new human uses of these systems with shifting hydrological and climate patterns that disrupt wildlife and humans uses alike (de Leeuw et al. 2009; Shankman et al. 2009; Fox et al. 2011). Impacts of altering these freshwater wetland systems extend beyond simple loss of habitat or the extinction of a species and can translate into significant cost to human communities. For example, in 2007, efforts to address degradation and loss of usable freshwater resources due to algae blooms on Lake Tai, near Shanghai, topped fourteen billion US dollars (AFP, 2007).

China’s recognition of the costs of wetland degradation has played a role in the development of policies that acknowledge the importance of these ecosystems, attempt to conserve their function and protect their biodiversity. Modern conservation efforts really began at a national scale in 1972 and centered on setting up protected areas and protection against illegal harvest of wild plants or animals (Harris, 2008). In 1992, China signed the Convention on Wetlands of International Importance, also known as the Ramsar Convention, signifying willingness to adhere to the convention’s requirements to designate important wetlands for conservation and implement wise use of these systems (Ramsar Convention Secretariat, 2011). Following the Yangtze River flood of 1998, China reversed decades of wetland reclamation efforts and implemented multiple policies aimed at protecting freshwater systems including the cessation of nearly all large-scale logging within the country in efforts to reduce runoff and siltation of the country's waterways (An et al. 2007). In 2003, China approved the National Wetland Conservation Action Plan, a program that includes, among many other ambitious goals, the objective of protecting 90% of the country's natural wetlands by 2030 (Wang et al. 2012). In spite of the success of programs that began in the late 1990's that pay local communities for sustainably managing ecosystems (payment for ecosystem services, or PES) dominated by forests and grasslands, a wetland PES program does not yet exist at the national level, although multiple provinces around the country have implemented PES programs for specific wetland systems (Zhen and Zhang, 2011). Due to their relatively recent implementation, however, the majority of these programs lack evaluation of whether they have made an impact on wetland loss or change patterns across the country or how they may affect wetland biodiversity.

My dissertation will address knowledge gaps that remain regarding Chinese wetland change over time and what these changes mean to waterbird biodiversity in those systems. I will do this by investigating change patterns at two Chinese wetlands important to waterbirds and that also supply local human populations with a variety of services. Napahai wetland, located in Yunnan Province is important to the central wintering population of the threatened Black-necked Crane (*Grus nigricollis*). Although global numbers of Black-necked Cranes show recent signs of increase, the population wintering at Napahai is declining, without a clear cause (Li, 2005).

The second wetland, Jiangxi Province's Poyang Lake, is one of the most important areas for waterbirds in China (Li et al, 2012). Over a dozen of Poyang's species are listed as threatened or endangered, and for six of these, more than half of their global populations winter at the lake, including over 98% of the world's critically endangered Siberian Cranes (*Leucogeranus leucogeranus*) (Barter et al., 2005). Despite the application of a great deal of money and effort by national and international agencies to understand and protect waterbirds in Poyang Lake, the processes driving waterbird use patterns within Poyang over time remain unclear (Ji et al., 2007). Understanding these processes will contribute to better management of protected areas established for the conservation of these species and assist in predicting how wintering waterbirds may respond to future changes to these systems.

The specific objectives of this proposal are to identify the patterns of wetland change within China, understand the processes that drive it and quantify the responses of waterbirds to that change. In chapter one, I will quantify how the Napahai wetland has changed since significant socio-economic reforms came to China in the early 1980's, employing new satellite imagery analysis methods in the process , and then I will examine whether these patterns are correlated to declines of wintering Black-necked Cranes. In chapter two, I will document never before seen foraging patterns and behaviors by Siberian Cranes, observed during two years of field work at Poyang Lake, compare these to established foraging patterns, and discuss the implications. In the third chapter, I will combine the remote sensing techniques with empirical knowledge of the area along with data documenting waterbird distributions across Poyang Lake for the last twelve years and develop explanatory models of waterbird distributions at four, hierarchical spatial scales.

I intend to make the outputs of this work available to local partners at Chinese universities, NGO's and nature reserves with whom I have developed a working relationship over the last eight years. This work could assist local managers and policy makers to improve protected area management, target conservation efforts, and inform economic development policies that affect Napahai and Poyang Lake. With information about change patterns within these systems and the responses by waterbird species indicative of broader ecosystem function in hand, managers and policy makers can evaluate and plan for impacts from future changes or modifications to these ecosystems. At a broader level, I hope this work will contribute to better management of other Chinese wetlands and provide insight into how wetlands may be affected by growing human pressures and new uses around the globe.

Chapter 1. Wetland change at China's Napahai wetland

Background

China offers unique opportunities to advance our understanding of the trajectory of wetland land cover changes over time, and to study what those changes mean for wetland-dependent species as well as human communities. Documenting long-term wetland change is a challenge, however, due to the seasonal and annual variability of multiple aspects of China's wetlands including climate and precipitation, water cycles, vegetation phenology and longer-term changes to surrounding upland characteristics such as topography or land cover. This variability combines with China's long history of anthropogenic modifications to wetlands that further complicate trends within land cover changes over time. The complexity and interactions of these drivers (biotic, abiotic and anthropogenic) obscure baseline function of wetlands and their distribution over space and through time (Lu et al., 2004). Recently, efforts using satellite imagery to better understand China's wetlands have shown promising results: wetlands have been identified across the country (Niu et al., 2009), regional wetland change patterns have been analyzed (Xu et al., 2011), and aspects of wetland function, such as hydrology have been mapped (Qi et al., 2009). Researchers have also analyzed Landsat satellite images nation-wide and determined that 14% of China's wetlands were lost between 1990 and 2000 (Gong et al., 2011).

In spite of these advancements, however, many knowledge gaps remain. For example we don't know how China's transition to market economy, which began in the early 1980's, affected wetlands. Additionally, previous analyses of change were conducted at relatively coarse temporal scales; 'before' and 'after' images were analyzed to quantify change between the two sets of images (Green et al., 1994). Unfortunately, this method is not ideal for capturing the fluctuating conditions present within many wetlands and may miss important patterns of shifting wetland conditions through time (Ozesmi and Bauer, 2002). To address some of these knowledge gaps, I will use newly-developed remote sensing and change detection methods to investigate change patterns at Napahai wetland in China's NW Yunnan Province near the county seat of Xiangelila (Figure 1) since China began its remarkable economic transformation in the early 1980's.

Napahai wetland is important to a range of waterbirds that depend on the area for wintering habitat (Chan et al, 2009). These birds breed across a wide swath of territory that stretches across the Tibetan/Qinghai plateau from southwestern Sichuan to the border of Xinjiang and Gansu provinces. Of the 31 species of waterbirds regularly found at Napahai, the wetland is critically important to one of three, distinct, wintering populations of the threatened Black-necked Crane (*Grus nigricollis*); the only crane species limited to alpine environments (Ramsar, 2004; Kong et al., 2011). In the non-breeding season Black-necked Cranes utilize both natural wetland vegetation and agricultural fields for their foraging needs where they consume a wide range of wetland plant, animal and grain items and roost in shallow-water wetlands (Bishop and Li, 2002). In spite of an overall increase in the number of Black-necked Cranes counted in surveys across the species' range, there has been a decline in wintering cranes use in the population that winters at Napahai (Li, 2005; Liu, et al., 2010). Other, nationally protected bird species that utilize habitats in and around Napahai include White-tailed Eagles (*Haliaeetus albicilla*), Black Storks (*Ciconia nigra*), White eared Pheasants (*Crossoptilon crossoptilon*) and Eurasian Spoonbills (*Platalea leucorodia*; Ramsar, 2004). In addition to the birds that depend on this system, several thousand human residents depend on the resources and services Napahai provides such as water and land for cultivation and grazing of domestic animals and, recently, eco-tourism activities (Lawrence et al, 2009).

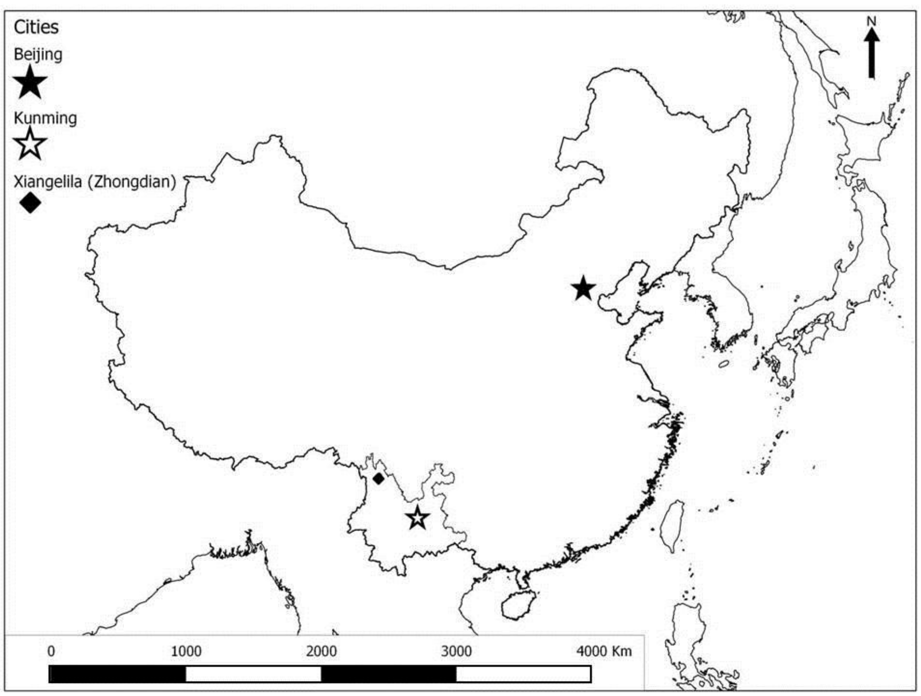

Figure1. Location of Xiangelila and Napahai wetland within China's Yunnan Province

The wetland of Napahai is located immediately adjacent to the county seat of Xiangelila (pronounced Shangri-La), renamed in 2001 to capitalize on the growing trends of ecotourism, specifically with the goal of attracting western tourists. Over the last twenty years, the national and provincial governments have made significant advances in developing infrastructure connections to this community located at an elevation of 3,300 meters above sea level, including constructing an airport in 1998 and remarkable widening and modernization of highways. At the moment a rail link is being constructed to connect the city to the line that currently ends at Lijiang, a major tourism destination for northwestern Yunnan. These infrastructure changes bring better access to markets for a variety of importing and exporting goods and increase the exposure of local residents to new crops, agricultural materials and methods, and provide greater access for tourists to visit Xiangelila and Napahai. All of these relatively recent developments mirror trends in other portions of China and appear to correlate to changes in agriculture patterns, rapidly expanding urban areas and new demands on natural resources such as local timber and freshwater.

My overarching goal in this chapter is to determine how wetland habitats at Napahai changed in distribution and area over the last twenty-five years and link those changes to wintering use patterns by Black-necked Cranes.

Within this goal, I have multiple objectives.

- First, I will document how Napahai's wetland area and configuration has changed over the last twenty-five years using time series stacks of Landsat satellite imagery.
- Second, I will identify potential drivers of change within Napahai by examining links between wetland change patterns and broader socio-economic policies such as changes in the land tenure system, infrastructure developments (e.g. the construction of large roads or other transportation links), changing agriculture patterns, and the establishment of protected areas.
- Third, I will use high-resolution satellite imagery to create fine-scale maps of Napahai's wetland land cover for the period of 2002-2010.
- Finally, I will assess whether wetland change patterns correlate with waterbird use over time, by comparing the distribution of Black-necked Cranes obtained from field surveys at specific times to wetland land cover maps for those times, and to habitat change maps over time. Doing this, I hope to show which drivers have the biggest effect on Black-necked Cranes wintering at Napahai.

Methods

To document wetland change patterns within China's Napahai wetland, I will focus on two major types of satellite imagery analysis: 1) Landsat time series stack (LTSS) analysis to document wetland change over time (Huang et al., 2010) and 2) digitizing fine scale imagery to identify important landscape features such as agriculture plots, settlements or impervious surfaces and wetland vegetation patterns (Rebelo et al., 2009). For the purposes of this work, I am defining fine scale imagery as imagery where the individual pixel in an image covers an area on the ground of less than $30m^2$ (30m X 30m). The strengths of these methods compliment the weaknesses that each method has alone. High resolution imagery is expensive and is only available for Napahai beginning in 2002, but I have obtained some imagery through a grant from the Planet Action partnership (Table 1). These finer scale resolution images are ideal for identifying and measuring smaller landscape features within satellite images such as wetland vegetation, or small agriculture plots. Outputs of these efforts will include maps showing important landscape features, summarization of land cover trends, and boxplots that indicate differences in pixel values distinguishing between land cover classes. Areas identified as different land cover classes in time series stack analysis will be calibrated with fine scale digitizing results during the years these data sets overlap to improve resolution of land cover classes, and to help inform results of time series stack analysis during years when fine scale data are not available. From these outputs, I will show how wetland areas within Napahai have changed since the early 1980's.

The Landsat archive is ideal for this use because it provides data going back to 1982. I will use a number of image transformations to enhance detection of changes in hydrology and vegetation, including the normalized difference vegetation index (NDVI) to provide a measure of vegetation vigor. Values for individual pixels from these transformations will be compared to determine whether they change over time and whether those changes have "trajectories." In other words, I will determine how a pixel value compares to other pixels at a given date, as well as how one pixel value may change over time. Pixel trajectories can be mapped and plotted as trend lines (Fig. 2), or represented as boxplots and compared to determine whether statistically significant differences exist in the values of pixels. Within a given time period, these differences in pixel values can be linked to different land cover classes of interest (e.g. forest with high NDVI versus water with low NDVI, Fig 3), or if over time any given pixel value consistently changes it can provide insight into a change from one land cover class to another (e.g. wetland vegetation with moderate NDVI to a road with very low NDVI). Time series stacks will be compiled first for the most recent years, so that the classifications they produce can be compared to the high-resolution imagery in hand.

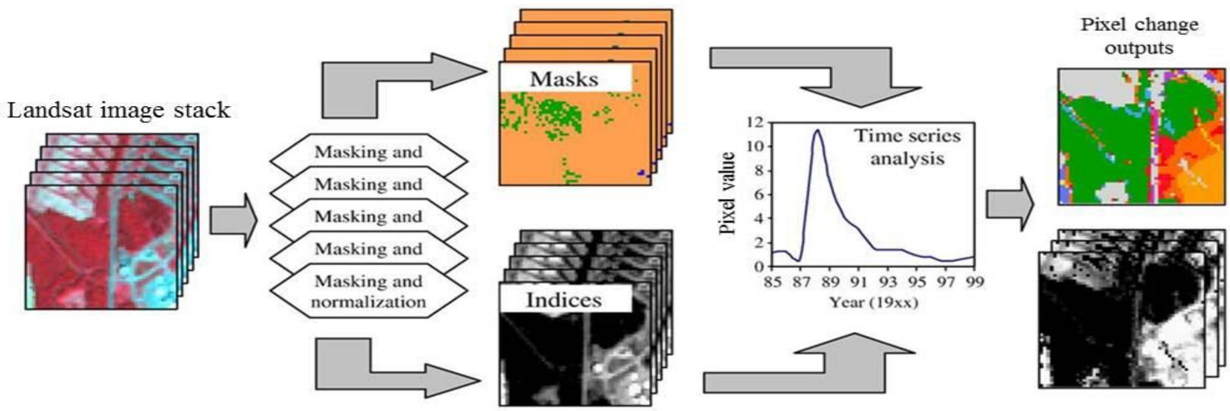

Fig.2. Data processing strategy for time series analysis (modified from Huang et al., 2010)

The Landsat archive provides a large amount of data covering the time period relevant to China's market reforms for free. To compare separate images to one another, each image will be corrected through the use of an automatic algorithm, the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS), to eliminate the effects of atmospheric and sensor discrepancies between images (Masek et al., 2006). Imagery dates will be partitioned into different time periods: 1985-1990, 1990-1995, 1995-2000, 2000-2005 and 2005-2010. This allows for comparisons of change between and within time periods. It also facilitates testing for whether policy or development events (e.g. changes to land tenure in China or the construction of the airport near Napahai) are correlated with wetland change patterns. Change maps generated from the Landsat imagery will be assessed by constructing validation point error matrices. These points will be distributed using a stratified random scheme with an equal numbers of points within each class and then visually assessed within the Landsat imagery, or when needed, high-resolution data from Google Earth or Quickbird data (Griffiths et al., 2012).

While the Landsat archive provides a great deal of potential for identifying areas of change within Napahai, it is not suitable for the mapping of landscape features that will be used to create habitat maps for wintering waterbirds. Because landscape features (e.g. agricultural plots) in Napahai can be smaller than individual Landsat pixels, finer-scale imagery is necessary to identify the boundaries of land cover classes of interest within the system (Jensen, 2005). Table 1 provides a list of these data, with their resolution, date of acquisition and their spectral bands. Table 2 shows landscape classes I believe are important in shaping habitat use of Black-necked Cranes. They will be hand-digitized from fine scale data sources. Many of these classes (e.g. urban, forest and water) are readily identifiable by visual assessment in fine scale imagery, and my multiple field visits to Napahai contribute to my awareness of important landscape features and relevant land cover classes (e.g. small agriculture plots or emergent wetland). In some instances of unfamiliar features or land cover, collaborators at the Kunming Institute of Zoology familiar with Napahai will provide their opinions and photographs so that correct identification of these areas is possible.

TABLE 1. Fine-scale imagery data available for land cover mapping of Napahai

Sensor	Date (YYYY-MM-DD)	Spatial Resolution (area^2/pixel)	Spectral Resolution
Quickbird	2002-11-17	.6m^2	B1: .45-.52 (Blue) B2: .52-.60 (Green) B3: .63-.69 (Red) B4: .76-.90 (Near IR)
ALOS-Avnir	2007-12-13	10m^2	B1: .42-.50 µm (Blue) B2: .52-.60 µm (Green) B3: .61-.69 µm (Red) B4: .76-.89 µm (Near IR)
SPOT4	2004-11-18 2009-01-16 2010-02-21	10m^2	B1: .50-.59 µm (Green) B2: .61-.68 µm (Red) B3: .79-.89 µm (Near IR) B4: 1.58-1.73 (Mid IR)
SPOT2	2008-11-20	10m^2	B1: .50-.59 µm (Green) B2: .61-.68 µm (Red) B3: .79-.89 µm (Near IR)
SPOT2	2006-03-09 2007-06-03	20m^2	B1: .50-.59 µm (Green) B2: .61-.68 µm (Red) B3: .79-.89 µm (Near IR)

Digitizing will be done using a mouse and multiple satellite imagery/geographic information system (GIS) software packages (e.g. ENVI, ArcGIS) to identify land cover classes of interest across multiple dates. I will draw polygons around individual land cover features. Once the polygons are created for each image, it will be possible to compare how the configuration and area of these polygons change over time. Polygons will be overlaid in a GIS, and analyzed for overlap or changes in configuration. Polygon areas or configurations that are not consistent over time will be identified as "areas of change" and evaluated as to whether they are true changes on the landscape or errors created during the digitizing process (an example of these errors could be edge effects or "slivers" created during the digitizing and overlay process that may not occupy the exact same space through time, but do not represent real change). Fine scale imagery for the region is only available after 2002 and is prohibitively expensive (up to $10,000 for a 60x60km scene; Astrium, 2012).

TABLE 2. Land cover classes of interest at Napahai

Land cover class	Relevance
Wetland bare	Waterbird foraging/roosting habitat
Seasonal agriculture	Potential waterbird foraging habitat
Wetland vegetation	Waterbird foraging/roosting habitat; Livestock grazing
Urban shadow	Shadow/confounding class
Shallow water	Waterbird foraging/roosting habitat; Livestock grazing
Deep water	Waterbird roosting habitat
Forest	Roads/human disturbance
Upland grassland	Potential waterbird foraging habitat/Livestock grazing
Urban	Human settlements/disturbance
Permanent agriculture	Potential waterbird foraging habitat
Bare	Potential waterbird foraging habitat/ Livestock grazing

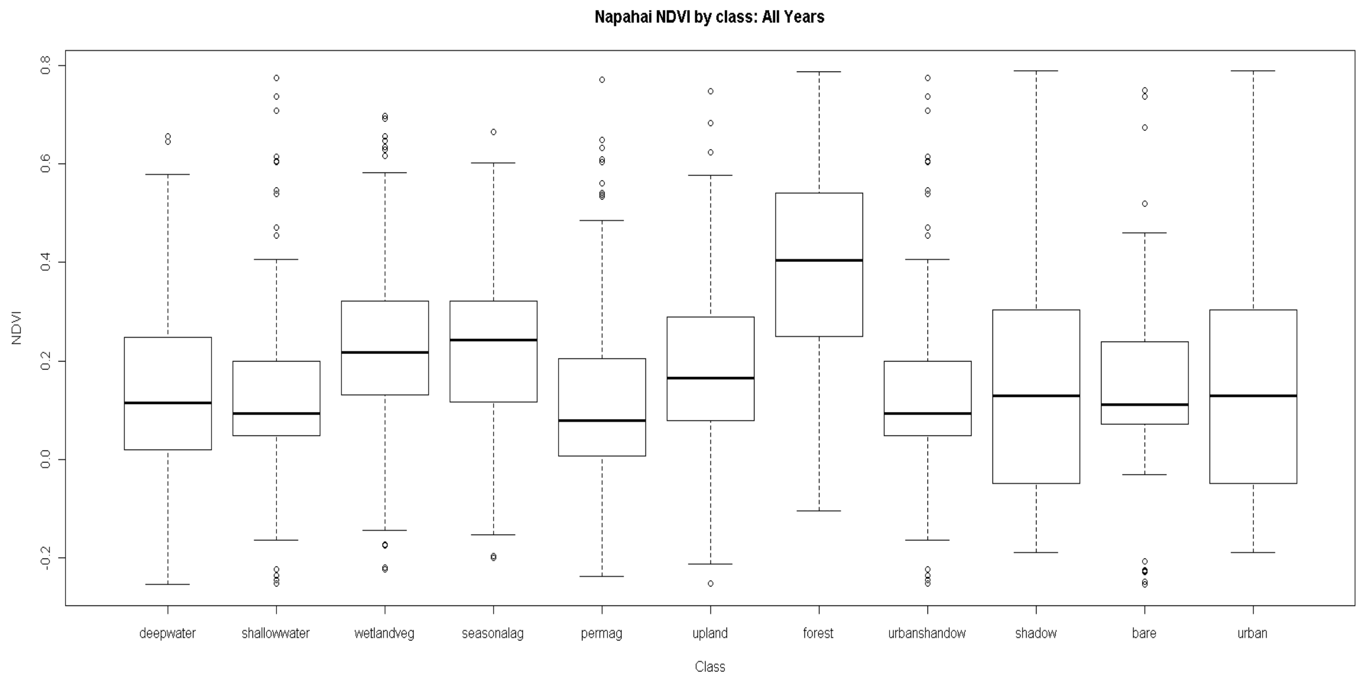

Fig.3. Boxplots of pixel NDVI values of different land cover classes at Napahai from 1990-2000

Finally, Once I have identified wetland change patterns I will work with local partners at the Kunming Institute of Zoology (KIZ) to determine whether these outputs correlate with changes in waterbird use over time, which addresses my third objective. KIZ has records of waterbird use at Napahai going back to the early 1980's (Dr. Wu Heqi, KIZ, personal communication), consisting of location data of Black-necked Cranes and other waterbirds drawn on maps. A second set of data on this species comes from two cohorts of Black-necked Cranes fitted with satellite telemetry devices during 2005 and 2009. Previous attempts using Landsat imagery to identify habitat selection preferences of wintering Black-necked Cranes were limited in their efficacy (Dr. Wu Heqi, KIZ, personal communication). By using fine scale satellite imagery to distinguish between habitats, I believe habitat selection patterns may be easier to discern through the use of neutral models in which random points are compared to observed locations of Black-necked Cranes obtained from collected field data (Urban, 2005). If differences exist between the locations of Black-necked Cranes to points randomly distributed across the landscape within a GIS platform, we can infer that cranes are not randomly distributed and that they are selecting for used habitats compared to all available habitats across the landscape (Gardner and Urban, 2007).

Significance and Applications

I expect that the combined image classification methods of this chapter will result in improved identification of how wetland patterns within Napahai change over time compared with either method gives alone. Additionally, the method will result in more information about the process of wetland change than established "before/after" change detection methods (Huang et al., 2010; Kennedy et al., 2010). I expect that these methods will better differentiate between anthropogenic long term shifts in land cover and seasonal, or annual, changes stemming from variability in vegetation activity, hydrological fluctuations, sun angle, cloud, cloud shadow or scan-line errors. Making these distinctions will make it possible to alleviate issues of error propagation through multiple land cover classifications including a "change class" (Dai and Khorram, 1998; Ozesmi and Bauer, 2002; Lu et al., 2004; Kennedy et al., 2010).

Combining fine-scale satellite imagery work and field data, I will use neutral models to detect whether Black-necked Cranes are exhibiting non-random habitat selection patterns across Napahai. I believe that previous work trying to link Black-necked crane habitat selection to specific habitats within Napahai failed because the data that was being used was from the Landsat archive (Dr. Wu Heqi, KIZ, personal communication), with pixel resolution too coarse to distinguish between relevant habitat types present within Napahai. Combining these two types of data, fine-scale remotely sensed imagery and field data from telemetry devices attached to Black-necked Cranes has long been a goal of researchers at KIZ (Professor Xiaoping Yang, KIZ, personal communication) and I hope that these techniques pave the way for future crane/habitat analyses.

In summary, I will produce wetland change maps for Napahai, as well as change trajectories of pixels within important landscape features to show how this system changes over time and determine which landscape features are most important to wintering Black-necked Cranes. It is my intention to use the digitizing of fine scale satellite imagery to create land cover maps of areas that are important to a declining wintering population of Black-necked Cranes. These outputs will be used with colleagues within the Kunming Institute of Zoology (KIZ) to look at how wetland change patterns within Napahai are related to survey data for wintering Black-necked Crane numbers and spatial patterns. Ultimately, I hope this work helps clarify whether wetland change patterns within Napahai help explain declines in Black-necked Crane numbers and help identify where actions can be taken to slow, or reverse this trend. I also hope that the products of this chapter can be used to evaluate whether wetland conservation policies are effective at protecting Napahai and its surrounding area.

The outputs of this chapter will reveal whether wetland change patterns are related to declining Black-necked Cranes wintering at Napahai. This knowledge will contribute to management planning for Napahai, and may contribute to broader discussions regarding the basin's economic and ecotourism development. Napahai will continue to change as new transportation corridors (e.g. high-speed roads and rail links) and economic opportunities arrive at the nearby county seat of Xiangelila. These developments will likely increase the number of people visiting Napahai and could further alter how local communities utilize Napahai's resources. By understanding how Napahai has changed since China's economic reforms began in 1982, I hope to gain insight into how future changes to this region will affect the wetlands and the Black-necked Cranes that depend on them and contribute to the development of strategies that will ensure their continued access to this wintering site.

Chapter 2. Novel foraging patterns and behaviors of Siberian Cranes wintering at Poyang Lake, China

Background

Poyang Lake is a large, dynamic wetland system located in south-eastern China's Jiangxi Province. Home to over 300 bird species, the lake hosts a number of migratory waterbirds that depend on a variety of habitats available for their wintering needs (Ji et al., 2007). While over a dozen threatened or endangered waterbirds use the system, it is of particular importance to the critically endangered Siberian Crane because nearly all of world's wild Siberian Cranes depend on Poyang during the winter months (Barter et al., 2004; Barter et al., 2005; Li et al., 2012). Over the last decade, increasing pressures from the lake's ten million human residents and changing hydrology patterns has caused concern about the continued existence of the species as well as raised questions about how best to mitigate these pressures and manage protected areas established for the conservation of Siberian Cranes and other migratory waterbirds. A flood event in the summer of 2010 clearly illustrated these increasing pressures and changing hydrological patterns. Following this flood, I observed Siberian Cranes foraging in grasslands, habitats never before documented as used by Siberian Cranes wintering at Poyang. In this chapter, I compare the foraging behaviors of flocks and individuals foraging in wetland and grassland habitats, link novel foraging areas with Siberian Crane reproductive recruitment following the flood, as measured by juvenile to adult ratios, and discuss what these novel foraging areas may mean for the future of conservation and management efforts at Poyang.

Poyang Lake covers approximately 4,000km^2 of northern Jiangxi Province and during the summer high-water period is China's largest freshwater lake (Zhang et al., 2011). The system is heavily influenced by dramatic hydrological variation, however, and during the winter low-water period the surface area of the lake shrinks to <1,000Km^2 (Shankman and Liang, 2003; Figure 1). This hydrological variation is driven by sub-tropical monsoonal rain patterns that affect all of south-eastern China and the five, primary tributaries that drain >98% of Jiangxi Province. These tributaries empty into Poyang Lake before draining out of the single outlet at Hukou to the Yangtze River and on to the East China Sea. Poyang is typically a south-to-north flowing system, but when the Yangtze experiences periods of high surface elevation, or flooding, the large river can reverse the normal flow of Poyang and back-flow into the lake basin (Shankman et al., 2006). The magnitude of these fluctuations can exceed ten meters in portions of the lake basin during extreme flood events (Figure 2) and they directly influence the vegetation, wildlife and human communities that call the lake home (Yesou et al., 2011).

Poyang's dramatic hydrological fluctuations and sub-tropical location combine to produce a range of vegetation communities at different times in the calendar year. During the hot, humid summers reeds and other grasses dominate the shallow water and adjacent saturated areas (de Leeuw et al., 2006).

As waters recede in the fall they leave behind vast mudflats and extensive sedge and forb meadows intermixed with small pothole lakes and river channels (Yesou et al., 2011). These seasonal changes produce a complex patchwork of different habitat types, which are used by a wide range of migratory birds, many of whom breed in northern China, southern Russia or Siberia. In spite of the large distances that many species have to travel to get to Poyang, over 5,000Km in the case of arctic breeders, Poyang's wetlands are the closest which are reliably unfrozen during the winter months.

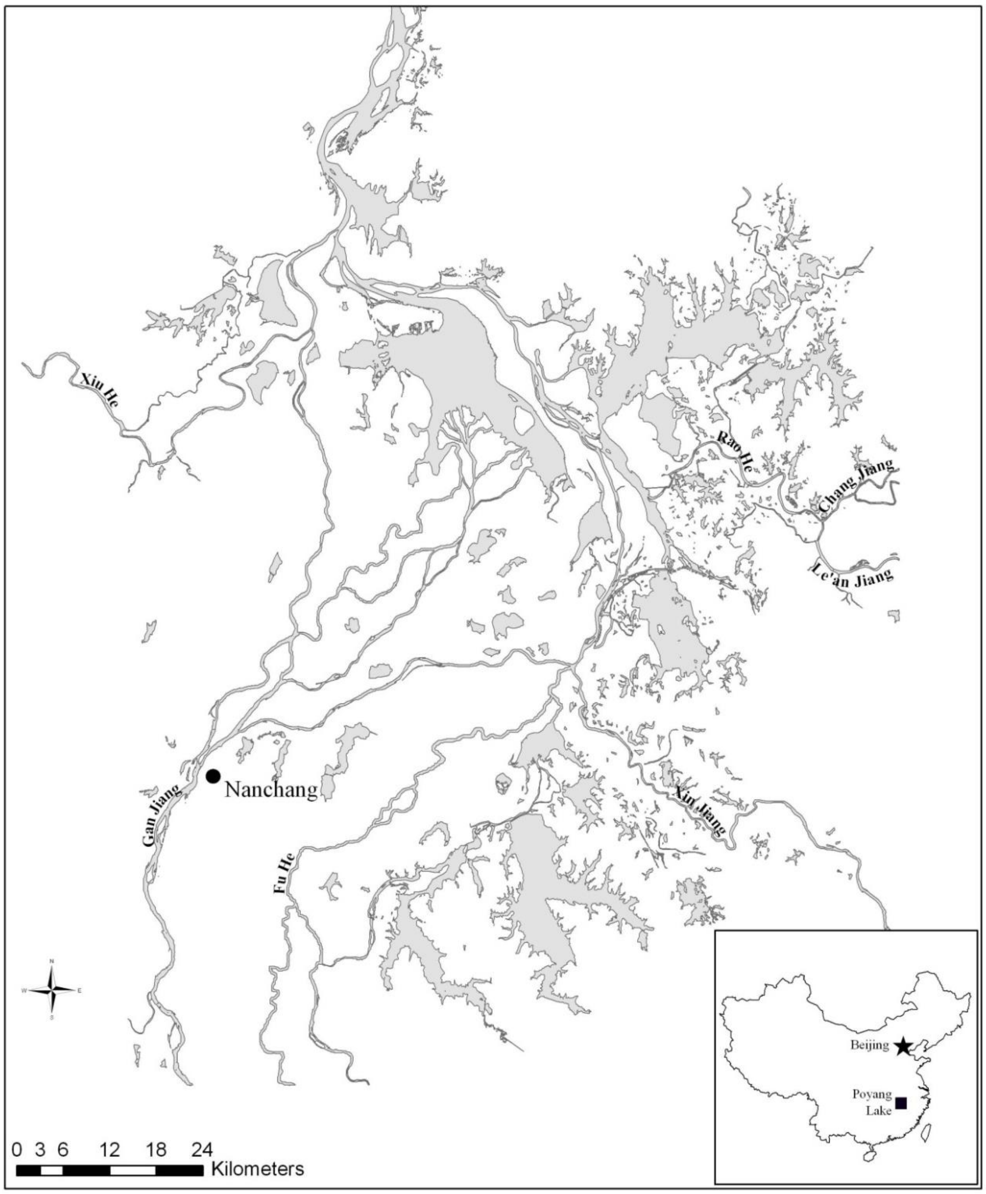

Figure 1. Poyang Lake at typical winter low water levels and principal tributaries

Every winter hundreds of thousands of migratory birds travel to Poyang to spend all or part of the non-breeding season at the lake. Over a dozen of the migrants are species of concern, categorized as threatened or endangered (Barter et al., 2004; Barter et al., 2005). For approximately half of the species of concern that winter at Poyang, significant proportions of the global population of these species reside at Poyang during winter. For example, over half of the world's Swan Geese (*Anser cygnoides*) and Hooded Cranes (*Grus monacha*) winter at Poyang, over 60% of the world's Tundra Swans (*Cygnus columbianus*) and White-naped Cranes (*Grus vipio*) rely on the system, and over 98% of the world's Oriental White Storks (*Ciconia boyciana*) and Siberian Cranes (*Leucogeranus leucogeranus*) depend on Poyang for wintering habitat (Li, 2001; Cao et al., 2008). The number of species found at Poyang, in addition to the system's importance for threatened or endangered bird species, makes Poyang one of the most important wetland systems in East Asia.

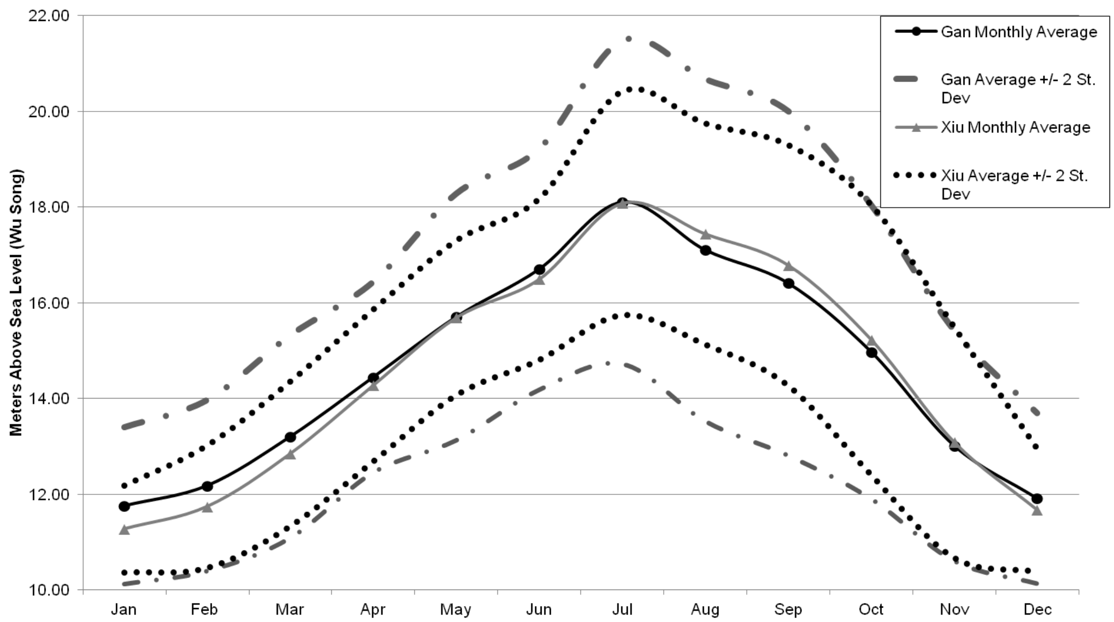

Figure 2. Variability at Poyang measured by two tributaries: Gan and Xiu River average monthly elevation: 1955-2008. Dashed lines indicate two standard deviations of the

Among the waterbirds that winter at Poyang, Siberian Cranes garner particular attention. Siberian Cranes are critically endangered and breed in northern Siberia. Historically, the species wintered in northern Iran, central India and southeastern China. Today, only the eastern population wintering in southeastern China remains viable (Birdlife International, 2012). Of the globally estimated 3,800 individuals, >98% of these spend the majority of their winter at Poyang (Li, 2001; Li et al., 2012). Siberian Cranes, like other members of the crane family are omnivorous on their breeding grounds, but appear to rely heavily on plant material for their wintering forage requirements (Meine and Archibald, 1996). Early records of the species foraging on vegetation on wintering grounds comes from the central population in India where Hume (1868) identified the contents of "stomachs" of 20 birds shot there as consisting almost entirely of vegetation material. Later, close-proximity observations by Spitzer (1979) and Sauey (1985) documented Siberian Cranes foraging exclusively on the below-ground tubers of emergent wetland vegetation at India's Koleado National Park.

At Poyang, observations of Siberian Cranes foraging in shallow-water and mudflats were first documented in 1991, and observations over two winters revealed that >90% of the identifiable food items consumed by Siberian Cranes consisted of stems and roots of submerged aquatic vegetation, or SAV (Liu and Bin, 1991)) . Later observations documented that Siberian Cranes also foraged on leaves of *Polygonum*, *Eleocharis* and *Myriophyllum* (Zeng et al., 2002; Wu, 2005). One of the few gut content analyses of the species at Poyang was obtained from a Siberian Crane "stomach" examined in 1986 that contained 27g tubers, 9g mud, 5g sand, 2g snails (Zeng et al., 2002). Siberian Cranes foraging at Poyang is highly correlated with below-ground productivity of *Vallisneria* combined with water depth that allows access to SAV tubers (Burnham, 2007). In summary, from all that has been documented about the diet and foraging behavior of wintering Siberian Cranes, they were thought to be completely dependent on wetlands while wintering at Poyang Lake (Barzen et al., 2009).

Following a summer flood in 2010, however, I observed Siberian Cranes foraging in upland areas. To my knowledge this is the first time upland foraging has been observed in this species. Floods are a regular feature of the hydrology at Poyang, and an important driver of wetland vegetation distribution across the lake basin (Cui et al., 2000). Following previous floods (e.g. 1998), Siberian Cranes remained feeding in wetland areas (Li, 2000), but approximately halfway through the winter season of 2010-2011, Siberian Cranes shifted their foraging to upland areas and consumed items never before described as used by wintering Siberian Cranes while at Poyang.

In this chapter I document novel foraging patterns exhibited by Siberian Cranes following the summer flood of 2010, and attempt to explain why this pattern occurred and what these novel patterns may mean for the population as a whole. I describe the use of novel foraging areas during the winters of 2010-2011 and 2011-2012 and compare behaviors between traditional (wetland) foraging areas and novel (upland) areas. I will answer the following three questions. One, are there differences in flock behaviors and foraging intensity, as measured by swallowing success, in Siberian Cranes observed in wetlands and uplands at China's Poyang Lake? And two, do these novel foraging patterns have any impact on the population that winters at Poyang Lake?

Methods

Submerged aquatic vegetation sampling

Data for submerged aquatic vegetation (SAV) distribution and productivity, as measured by biomass/1m^2, were obtained from long term ecological monitoring efforts performed by Poyang Lake National Nature Reserve and the International Crane Foundation. These data are available for all years for four study lakes within the Poyang Lake basin going back to 1998. SAV sampling for the fall of 2010, after the summer flood, came up with almost no SAV in any of the four study lakes (International Crane Foundation, unpublished data). Following my arrival at Poyang in the fall of 2010, I had multiple conversations with fishermen in the field at other locations of the lake basin who all confirmed that there was a distinct lack of SAV in other portions of the lake basin. These anecdotes are supported by Diemos 1 satellite imagery taken in November 2010 that shows very blue, clear water throughout most of the sub-lakes across Poyang with very little indication of the vegetation signature these sub-lakes have in prior, or following, years.

Field observations of Siberian Cranes

Observations of flock size and foraging behaviors were conducted in February and March of 2011, November and December of 2011, and February and March of 2012. Two observers conducted two types of data: flock scans and focal individual observations. Observers used spotting scopes of 60x magnification were used for all observations. Due to Poyang's large size, the logistical challenges moving around in the lake basin, and the ability for flocks of wintering Siberian Cranes to quickly move large distances, it was not feasible to set up an a priori sampling location grid. Therefore flocks were opportunistically sampled, using information from local protected area workers and local fishermen, as well as random searches of areas with historic use by Siberian Cranes across Poyang to find flocks. I attempted to sample an equal number of wetland foraging flocks and upland foraging flocks, with priority going to the largest flocks observable. As the winter season advanced, and birds began to stage for migration in March, the frequency of encountering large flocks in either wetlands or uplands declined and a greater proportion of smaller groups were included in observations.

The field protocol was as follows: upon identification of a flock of Siberian Cranes, observers traveled by foot to get as close as possible without flushing the birds, typically between 600-1000m. The location of each observation point was recorded using a Garmin GPS V. Observers recorded three bearings for each flock: leading edge, middle of flock and trailing edge. Observers estimated distance to the flock along those bearings to the nearest ten meters. Observers checked estimated distances with laser rangefinders.

Flock Scans: To test whether flocks of Siberian Cranes in uplands behaved differently from those observed in wetlands, observers conducted flock scans in both habitat types. The same observer conducted all flock scans, while the other observer conducted all focal bird observations. Once bearings were recorded for the flock, the observation bout commenced at the leading edge of flocks, scanning toward the trailing edge. The behavior of each individually distinguishable bird was recorded in one of six predetermined behavior categories, using a voice recorder. Behavior categories and their descriptions are listed in TABLE 1. The recording of data for all observable birds in one flock is defined as an observation bout. At the end of each observation bout, the observer rewound the voice recorder and played it back, tallying behaviors on a data sheet. Additional data recorded for each observation bout included weather conditions, observation location (lat, long), and water or substrate depth as observed on foraging bird's bodies.

TABLE 1. Flock Scan Behavior Categories and description

Categories	Description
1.Foraging	Probing, gleaning, digging, or excavating food from substrate, feeding juveniles, handling food in mandibles and swallowing.
2. Socializing	Any inter- or intra-specific interactions, excluding provisioning juveniles. Includes unison calling, dancing, drop-wing threats or physical conflict with others.
3. Locomotion	Any movement, walking or flying into or out of the flock.
4. Comfort	Loafing, sleeping, resting, preening, stretching
5. Alert	Heads up posture, guard calling, pre-flight body posturing
6. Unknown	Any behavior or individual that could not be seen clearly, either due to observation conditions or position of the individual within the flock (e.g. blocked by another bird)

For each bout, all behaviors were recorded on data sheets, sub tallies were made for each behavior category to determine the number of individuals engaged in each behavior category. These categories were then summed to get the total number of individuals observed in the flock. Observers monitored flocks throughout the morning or afternoon with periods of 30-40 minutes between observation bouts. This method was a compromise between maximizing the ability to document behavior differences associated with time of day while minimizing time spent searching for flocks.

Focal observations: To understand whether amount of time spent foraging and foraging success rates of individuals differ in uplands versus wetlands, one observer conducted focal individual observations concurrent with flock scans. The observer randomly chose a bearing that fell between the leading edge and trailing edge of a flock and selected the first individual observed actively foraging as the focal individual. The observer recorded the start time of the observation bout and began a stopwatch to record the amount of time focal individuals actively foraged for food. When focal individuals stopped actively foraging (i.e. to walk to a new area, interact with another bird, or begin comfort behaviors), the stop watch was paused. Every time the focal individual swallowed a food item, the observer clicked a four-digit hand-held tally clicker. Because the goal of this observation method was to quantify differences in foraging rate, I needed to be sure that observed individuals were intent on foraging. Therefore observations were only counted if focal individuals actively foraged between five and twenty minutes. In addition, active foraging behaviors were subdivided into three different categories, (Table 2). At the end of each observation the observer recorded the total number of food items swallowed, the total time spent actively foraging and the total time of the observation bout.

TABLE 2. Focal Individual Foraging Behaviors

Foraging Behavior	Description
1.Glean	Slow to moderate rate of handling of food item from the surface of a substrate (i.e. grass, water or mud)
2. Jab	Quick handling of food from a surface/substrate or, in the case of flying insects, from the air
3.Probe/Dig	Use of bill/mandibles to dig in soil or mud, excavate a food item and consume it.

Index of global Siberian Crane population

To answer the question of whether novel foraging patterns will have any impact on the Siberian Crane population that winters at Poyang I will look at juvenile to adult ratios following the flood year and subsequent years when more normal conditions at Poyang existed. Cranes appear to be capital breeders; they carry the energy that will fuel reproduction back from the wintering areas (Jönsson, 1997). Because of this, I interpret the ratio of juveniles to adults as an index of habitat quality at Poyang. The more juvenile produced per adult, the higher the habitat quality. If adults arrive at the breeding grounds energetically depleted, or arrive later than optimal, due to low quality forage on the nonbreeding grounds for example, they are likely to have lower reproductive success, which will be reflected in the ratio of juveniles to adults throughout the subsequent year.

I will obtain data on juvenile-to-adult ratios of Siberian Cranes at fall and spring migratory staging areas in northeast China (H. Jiang, China National Bird Banding Center, unpublished data). These staging areas concentrate birds into a small area, making it logistically feasible to obtain an index of the total population size. Data on Siberian Cranes, by age class, is available from 2011 to 2013 for the spring and fall migratory period.

Statistical analysis

Flock foraging behavior and focal bird observations-- To test for differences between flock behaviors in wetlands versus uplands, I calculated the percentage of observed birds engaged in each of the six behavior types listed in Table 1, during each observation bout. I used quantile-quantile (qq) plots to assess whether the data were normally distributed, and used boxplots to visually assess differences among time spent in different behaviors. For data whose qq plots indicated a normal distribution, I tested whether there was a significant difference in the proportion of time spent in different behaviors in wetlands versus uplands using t-tests. For data that did not appear normally distributed, I used Wilcoxon rank-sum tests (Mann-Whitney) to test for differences in proportion of individuals engaged in each behavior. I used the statistical package R for all comparisons (R Development Core Team, 2008). Tests of focal individual foraging rates between wetlands and uplands followed these same methods.

I will relate observations of crane age ratios at spring and fall staging area before and after the 2010 summer flood to foraging behavioral patterns. This analysis will provide an indication of whether the observed shift in foraging patterns corresponds with changes in recruitment of juveniles into the population. I expect that if the novel foraging behaviors and upland diet are not optimal, there will be a decline in breeding productivity by Siberian Cranes, and that it will be apparent in ratio of juveniles to adults at migration staging areas.

Preliminary Results

Preliminary results are for data collected from flock scans for nine flocks over six days between March 02, 2011 and March 12, 2011. The largest flocks were located in wetland habitats, and ranged from 25-1126, while flock size ranged from 6-95 in uplands (Figure 3). Twenty-three observations occurred in wetland habitats, of which 21 included fewer than 1000 individuals, and 17 observations occurred in uplands. The behavior exhibited most frequently within flocks in both habitat types was foraging (Figure 4). On average, over 75% of the individuals scanned in wetland flocks and over 55% of the individuals scanned in upland flocks were foraging ($p < .000001$). Comfort and alert behaviors were the next most frequently observed behaviors in uplands, although a higher percentage of individuals in upland flocks engaged in both comfort and alert behaviors than the percentage of individuals in wetland flocks exhibiting these behaviors ($p < .05$, $p < .01$, respectively, Table 3). Social interaction behaviors were exhibited by a higher percentage of individuals in wetlands than in uplands ($p < .01$). The frequency of locomotion and unknown behaviors did not differ between habitat types.

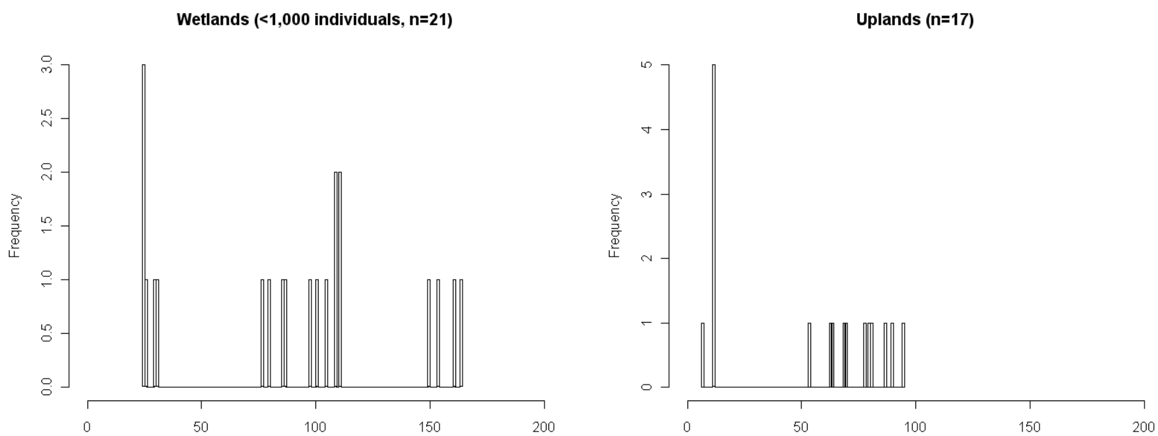

Figure 3. Number of individuals in flocks observed.

Preliminary data for focal individual data were collected for thirty individuals during the same time period as flock scans data were collected. Two individuals were removed from data analysis because they did not meet the criteria of actively foraging for at least five and no more than twenty minutes. Nineteen observations occurred in wetland habitats and nine observations occurred in uplands (Figure 5). There was no difference in the total number of minutes per observation bout that focal individuals spent actively foraging in either habitat type (Table 4). Both total number of swallows per bout and swallows per minute were significantly higher in uplands (Table 4, Figure 6).

Table 3. Results of comparison of effect of habitat type (wetland versus upland) on proportion of observed Siberian Cranes engaged in six behaviors

Behavior	Habitat w/ higher mean	Test/s Used	Results
1.Foraging	Wetland	t-test	$p < .000001$
2. Comfort	Upland	t-test	$p < .05$
3. Alert	Upland	Wilcoxon	$p < .01$
4. Social	Wetland	Wilcoxon	$p < .01$
5. Locomotion	N/A	t-test/Wilcoxon	No significant difference
6. Unknown	N/A	t-test/Wilcoxon	No significant difference

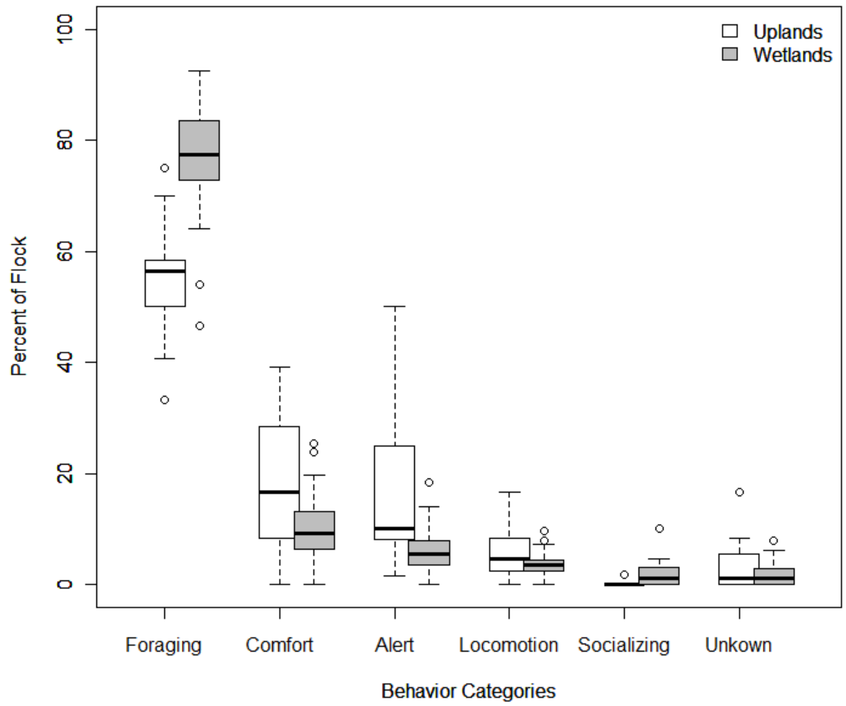

Figure 4. Percentage of behaviors recorded in flock observations by habitat type

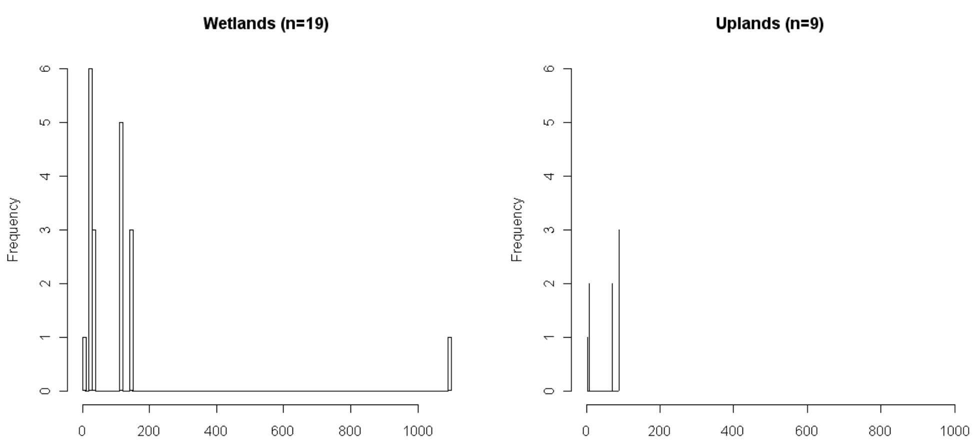

Figure 5. Number of Individuals in flocks during focal individual observations

Table 4. Amount of time spent foraging, and foraging success rate, as indicated by number of swallows, im wetland and upland habitat

Comparison	Habitat with higher mean	Test Used	Results
1.Total minutes per bout	N/A	t-test	No significant difference
2. Total foraging minutes	N/A	t-test	No significant difference
3. Total swallows per bout	Upland	Wilcoxon	$p < .05$
4. Swallows per minute	Upland	t-test	$p < .005$

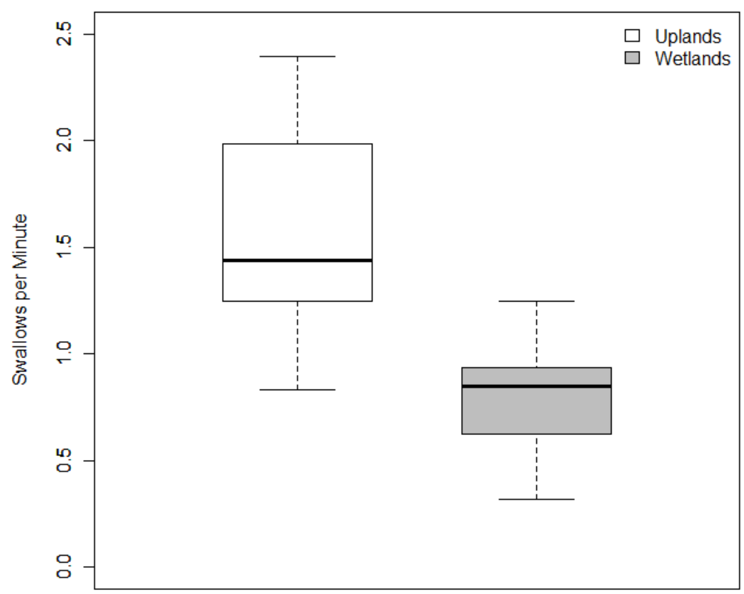

Figure 6. Foraging success (swallows per minute) of focal individuals by habitat type

Based on visual observations of upland areas utilized by foraging Siberian Cranes, it was apparent that birds were probing into the soil, consuming the below-ground roots of a species of cinquefoil, *Potentilla limprichtii*, leaving behind the above-ground leaves and shoots of individual plants (J. Burnham and B.T. Sun, professor of Botany at Nanchang University, personal observations; Figure 7). Visual analysis of fecal samples from upland flocks of Siberian Cranes contained remnants of both the black, epidermal tissue of *Potentilla* taproots, as well as undigested material that appeared to be the starchy white interior of the taproot. These *Potentilla* roots can be >20cm long and have been consumed by humans in periods of famine (B.T. Sun, personal communication). Additional items in fecal samples included very fine, white hair-like structures that appear to come from the bulb of an iris in the uplands, *Tulipa edulis* that grows intermixed with *P. limprichtii* (B.T. Sun and J. Burnham, personal observation).

Figure 7. Probe holes (red circles) Siberian Crane feces and discarded leaves and shoots of *Potentilla* (white circles). Length of pliers is 20cm. Photo: J. Burnham. February, 2011.

I also consistently found small (< 3-5 mm dia.) pieces of gastropod shell or operculum in the fecal samples, although the total amount of these items represented less than 10% of the total sample. Small (2mm x 7mm) snails in the *Oncomelania* genus, a primary vector of the Schistosomiasis blood parasite, are widespread across Poyang and their shells are readily visible at the water's edge when water levels drop in the winter (Seto et al., 2002). Other snails in the *Bellamya*, *Parafossarulus*, and *Semisulcospira* genera are also frequently encountered at Poyang (Wu et al., 2008). Many snails spend portions of the winter buried in soil or sediment and it is unclear whether snails in Siberian Crane feces is evidence that they were consumed intentionally, or if they were unintentionally consumed as birds excavated below-ground tubers and taproots and incidentally ingested mud that contained snails.

Discussion

Siberian Cranes wintering at Poyang typically forage in shallow water and wet mud (Liu and Bin, 1991; Wu, 2005). During the winter of 2010-2011, however, I observed Siberian Cranes foraging in upland areas. In February and March of 2011 a higher proportion of Siberian Crane flocks observed in wetlands were foraging and socially interacting than of flocks observed in uplands (Figure 4), yet higher foraging success, in the form of swallows per minute (Figure 6), were observed in upland areas.

One explanation to these patterns could be that the flood of 2010 reduced food resources in wetland areas (e.g. tubers of *Vallisneria*). With reduced tuber density, birds had to spend more time searching for food, and higher incidents of conflict over scarce food resources. The observation of more comfort behavior in upland birds may be attributable to higher rates of food consumption and shorter search times in uplands with a correspondingly greater number of sated birds, in upland flocks (J. Burnham, personal observation). Alternatively, it may have been easier to identify comfort behaviors in upland flocks than in wetland flocks, because their body is fully observable. In six different instances, I saw Siberian Cranes in upland flocks exhibiting extreme comfort behaviors such as hock-sitting, or sitting completely on the ground and tucking their head in apparent sleep postures (J. Burnham, personal observation). Neither I nor my assistants recorded these behaviors in wetlands.

From focal data, it is apparent that individuals in uplands swallowed more food items, and swallow at higher rates than individuals in wetlands. More swallows per minute could occur because it was easier for individuals to find food items in uplands than in wetlands. Increased swallowing rates could be due to greater difficulty manipulating upland forage items than aquatic items, resulting in a multiple swallows for one food item (e.g. a taproot of *Potentilla* breaks into multiple pieces that has to be extracted from the soil). Greater foraging success could result in less time spent foraging and more time engaged in comfort and alert behaviors by flocks in uplands. And while intake rates by individuals in uplands were higher than by individuals in wetlands, flock sizes were higher in wetlands than in uplands. If foraging success was greater in uplands, this suggests that, Siberian Cranes still preferred to stay in wetlands, perhaps because the food items in wetlands are preferable to those in uplands, or because the wetland environment provides a buffer against disturbance that is lacking in uplands (e.g. cattle flocks, people travelling across the roads in the wet meadows are all more frequently encountered in uplands).

Currently, the nutritional value of *Potentilla* or *Tulipa* is unknown. In spite of the scarcity of *Vallisneria* following the flood of 2010, Siberian Cranes still appeared to prefer to forage in wetlands, as evidenced by larger flock sizes in wetland areas and by the fact that even when upland flocks were being encountered, there were still large flocks foraging in wetlands. I suspect that *Vallisneria* is a better forage item than *Potentilla* or *Tulipa*, but that these two upland plants are the best available forage options when *Vallisneria* is scarce in the Poyang system.

Behavior exhibited by Siberian Cranes from January-March of 2011 is novel to the species. Multiple times during these months, observers watched individual Siberian Cranes follow con-specifics (White-naped Cranes, Hooded Cranes and Eurasian Cranes) while they were foraging. The Siberian

Cranes would then harass the conspecifics by aggressive posturing, biting motions and jumping in the air while raking their feet towards the foraging con-specific. These actions typically resulted in retreat by the con-specific, and the Siberian Crane would begin foraging in the area where the con-specific had just previously foraged (J. Burnham, personal observation). These aggressive interactions rarely led to physical contact because the targeted con-specific usually moved out of the striking distance of the aggressive Siberian Crane and continued to forage in the upland areas. This sort of apparent learned inter-specific foraging behavior has been observed in Whooping Cranes (*Grus americana*), where aviculturists involved in a re-introduction program observed juvenile Whooping Cranes in North America following Wild Turkey (*Meleagris gallopavo*) and mimicking them as the latter foraged on oak acorns (M. Wellington, Aviculturist at the International Crane Foundation, personal communication).

The decision by Siberian Cranes to forage in uplands or wetlands is likely motivated by a combination of tradeoffs between energy intake, energy expenditure, and exposure to disturbances or threats. I expect wetlands have the preferred food items (*Vallisneria*) and it appears that wetlands offer more refuge from disturbance. Prior to the winter of 2010-2011, it appears that enough *Vallisneria* was accessible in Poyang for Siberian Cranes to successfully employ a blind search strategy for the relatively abundant food resources. This strategy paid off, as long as *Vallisneria* densities were high enough. Siberian Cranes may have had a competitive advantage against other species through morphological adaptations that allowed them to exploit *Vallisneria* resources including feet that retain partial webbing between their toes and serrations on the tips of their upper mandibles, which may assist in manipulating slippery forage items (Johnsgard, 1983). Historical patterns of Siberian Cranes foraging at Poyang fit with the observation that given abundant resources specialists, such as Siberian Cranes, outperform generalists, such as other crane species, in exploiting those resources (Rosenzweig and Lomolino, 1997).

Following the summer flood event of 2010, there was a precipitous decline in *Vallisneria* densities recorded in long-term monitoring performed along established transects in Poyang Lake National Nature Reserve (International Crane Foundation, unpublished data). *Vallisneria* apparently became scarce enough that it fell below a 'giving-up density' threshold, triggering a switch to alternative forage items (Charnov, 1976; Brown et al. 1997). Upland food items may not be as preferred as wetland food items as evidenced by the large flocks that remained in wetlands, but upland forage items such as *Potentilla* and *Tulipa* were widespread across the basin in 2010-2011 and readily visible. The negatives of foraging in uplands may include lower quality forage items in *Potentilla* and *Tulipa* root structures. Also, while I did not quantify this, I can anecdotally say that the there appear to be much higher rates of disturbance in upland settings, as evidenced by the majority of flocks in uplands getting flushed from their foraging areas by people, cattle and dogs (J. Burnham, personal observation). It could be important for future management efforts to quantify these tradeoffs and calculating the SAV density that triggers the switch between wetland and upland foraging.

When novel foraging patterns were initially observed in January of 2011, there was much concern by local protected area staff and internationally-based conservationists that the birds were reacting to a dramatic food shortage. Three scenarios were proposed as responses by the birds: starvation at Poyang Lake, an inability to accumulate enough calories to fuel the return migration to the migratory stopover sites in northeastern China, or an impact on the following reproductive season. It was apparent that Siberian Cranes did not starve while at Poyang, and during the subsequent counts at the spring migration staging area in northeastern China the expected numbers of Siberian Cranes were observed (H. Jiang, personal communication). If new forage items consumed at Poyang are shown to correlate to trends in breeding success, it could provide insight into longer-term population trends and how they are affected by ongoing activities at Poyang. If, for example, Siberian Cranes are forced to continue to rely on novel upland forage items either from a loss of *Vallisneria* or from water depths that make this plant inaccessible (i.e. if high water levels are imposed to favor human activities), it may mean that while Siberian Cranes will not starve at Poyang, it could lead to reduced numbers of juveniles produced on the breeding grounds and contribute to a longer-term population decline.

Poyang is a very important wetland system and to date most of the conservation efforts exerted by local, national and international groups have focused on securing protected areas across the lake basin. For example, Poyang Lake National Nature Reserve (PLNR) is the lake's oldest national nature reserve, includes 5% of the lake basin, and has long been the primary protected area in the lake. Most of PLNR's jurisdiction is restricted to individual sub-lakes and surrounding uplands are often not included in the reserve's territory. The results presented in this chapter suggest that conservation efforts may need to expand to focus on including upland areas adjacent to existing protected lake and mudflat areas where alterative forage items for Siberian Cranes such as *Potentilla* and *Tulipa* exist. These areas may take on increasing importance and significance to Siberian Cranes and other migratory waterbirds as the system at Poyang continues to change and evolve, and may provide a critical a buffer against future shortages in *Vallisneria*. Siberian Cranes exhibited never-before seen flexibility in their foraging during the winter of 2010-2011. Expansion into new foraging areas raises many questions about what these patterns will mean for the long-termed survival of the birds at Poyang.

Chapter 3: Modeling waterbird responses to a dynamic wetland system at different spatial scales

Background

The ecological changes that alter or compromise the function of wetlands around the world are clearly present in China's Poyang Lake, the country's largest freshwater body (Chapter 2, figure 1). A dynamic wetland system with dramatic seasonal and annual water fluctuations, Poyang has a long history of use by human residents with cultivated rice agriculture going back approximately 9,000 years (Jiang and Liu, 2006). Poyang's ten million human residents have a long history of altering the flow of water into the lake, which been reduced in area by approximately half since the 1950's (Shankman and Liang, 2003). The lake's perimeter has been converted into other uses such as agriculture and settlements through the construction of levees and canals (Shankman et al., 2009). Since the late 1990's, human uses within Poyang are shifting to more intensive agriculture practices powered by newly available heavy farm machinery, novel crab farming aquiculture, intensified sand dredging and mining activities and increased pollution from a growing manufacturing base in the nearby provincial capital of Nanchang (de Leeuw et al., 2009, Yesou et al., 2011). The construction of thousands of water control structures (dams, sluice gates, etc.) within Poyang, its tributaries, and along Poyang's only outlet, the Yangtze River, also dramatically affect water flow into and out of the system (Harris and Hao, 2010). All of these modifications combine with shifting climate and weather patterns to create significant changes to Poyang's ecology, and likely will alter its future functionality.

Poyang Lake provides a wide range of ecosystem services beneficial to the large human population in the lake basin, from providing fish to helping control floods, to providing habitat to hundreds of plant and animal species across the lake basin (Barzen et al., 2009). Poyang's dramatic hydrological fluctuations help create a high degree of habitat heterogeneity and influence the types of human activities that can occur in the non-dyked portions of the lake. These patterns are readily apparent during the fall and winter, when water levels at Poyang drop and reveal a complex patchwork of braided river channels, vast mudflats, seasonally wet meadows dominated by sedges and forbs, and small sub-lakes whose water levels are controlled by outlet sluice gates (Harris and Hao, 2010). This heterogeneity of features creates critically important wintering habitat to some of China's most endangered waterbird species, with multiple species exhibiting precipitous population declines in recent years (Cao et al., 2008). In spite of

Poyang's value to people, plants and animals, however, few studies have looked at how this wetland system has changed over time in a systematic way, the effects those changes have on wildlife and what that change means for the future of the system.

The migratory waterbirds that depend on Poyang for wintering habitat provide a powerful lens through which to observe broader ecological trends in the system. Hundreds of thousands of individual waterbirds from 19 families and over 125 species are regularly found at the lake (Ji, et al. 2007). Among these annual visitors, over a dozen species are considered threatened or endangered and at least half of those the majority of the population rely on Poyang for winter, or non-breeding, habitat, including over 98% of the world's critically endangered Siberian Cranes (*Leucogeranus leucogeranus*) (Li et al., 2012). Poyang's importance to these species makes it a hotspot for national – and international – conservation efforts and it is arguably the most important wetland for migratory birdlife in Asia (Barter et al., 2004; Barter et al., 2005). The dependence of the birds on productive foraging habitats combined with a variety of water depths that permit foraging, in addition to their sensitivity to humans make these species a useful barometer of ecological conditions and disturbances.

Identifying which aspects of Poyang's ecology, human use or hydrology drive waterbird use at different spatial scales, and determining how those drivers interact within and between spatial scales, would be a valuable contribution to the development of management tools to address the needs of Poyang's human and wildlife communities. I hope to develop a model of waterbird resource use at Poyang that will contribute to a better understanding of how these species use the system through time which can inform local land managers and conservationists in ongoing efforts to ensure Poyang remains usable habitat for waterbirds. I also hope to provide insight into the system's broader ecological patterns and identify trends and relationships that can be useful to help predict how Poyang's ecology may respond to future changes in hydrology, ecology, human uses, or combinations of all three.

In this chapter I propose to investigate the distribution of wintering waterbirds within Poyang from 1999-2011 in relation to distributions of landscape features, hydrological patterns, plant productivity and human uses. I will investigate these relationships at four hierarchical spatial scales to determine which of those drivers act on birds within and between spatial scales. **The goal of this chapter is to identify the independent and combined contribution of landscape features, hydrological patterns, plant productivity and human impacts to wintering**

waterbird distributions between 1999 and 2011. Additionally, I will determine the scales at which these factors are most important in shaping bird distributions over time. I expect that different variables within different spatial scales will best explain waterbird use patterns over time and I also expect that relationships will exist between variables across spatial scales. I believe that by better understanding how wintering waterbirds respond to these factors, we will gain insight into broader ecological patterns within the lake.

Methods

The data I will analyze will come from multiple sources, including field-based and remotely sensed observations. Field-based data include long-term ecological monitoring within Poyang Lake National Nature Reserve (PLNR) beginning in 1999, secondary monitoring at PLNR from 2005-2008, twelve separate basin-wide surveys for waterbirds within Poyang Lake from 1999-2012 and recent winter field observations from 2010-2012. Individual field data sets, and the types of observations they contain are provided in Table 1. Remotely sensed imagery will include Landsat, European and Chinese satellite imagery. Landsat imagery is freely available online through the USGS and European and Chinese imagery is from European Space Agency (ESA) archives made available through an ongoing collaboration with the University of Louis Pasteur's SErvice Régional de Traitement d'Image et de Télédétection (SERTIT) research institute in Strasbourg, France. Figure 1 shows the number of scenes available for these analyses and their temporal overlap with field data.

The four different spatial scales I will analyze represent different levels at which wintering waterbirds select habitats at Poyang. Listed in table 2 they are, in descending order of spatial extent, the entirety of the lake basin, sub-basins within the lake, sub-lakes with these different sub-basins and patches within the individual sub-lakes (Figure 2). From my experiences with the system and data provided from over a decade of satellite imagery analysis, these four scales represent the boundaries where Poyang's hydrology and ecology operate in distinct ways relative to adjacent scales.

Table 1. Field data available for analysis

Data	Variables	Years Available	Extent
PLNR Long-term monitoring	SAV density/distribution/productivity; summer turbidity; sub-lake water levels; weather; waterbird presence	1999-2012	4 study lakes within PLNR
PLNR Secondary monitoring (higher sampling intensity to long-term monitoring)	SAV density/distribution/productivity; sub-lake water levels; waterbird presence, habitat observations	2005-2008	2 study lakes within PLNR
Waterbird Surveys	Waterbird presence at sub-lake locations	1999, 2000, 2004, 2005, 2006, 2007, 2008, 2010, 2011, 2012	Full basin
Field observations	Waterbird presence, behavior observations, foraging habitat observations	2010-2012	Three sub-basins

Table 2. Spatial scales at which waterbird habitat selection will be analyzed within Poyang Lake

Extent	Scale	Definition
Broadest	Lake Basin	The entirety of the system. Habitats beyond a xx m bufferperimeter of the maximum high-water mark will not be considered part of Poyang Lake
↓	Sub-basin	Eight, distinct regions within Poyang defined by different hydrological patterns during seasonal filling and draining.
	Sub-lake	Seasonal, contiguous bodies of water that remain within grasslands or mudflats after water levels recede in the fall
Finest	Patch	Areas within sub-lakes that correspond to different physical characteristics of the sub-lake (e.g. shallows or edge, deeper water, etc.)

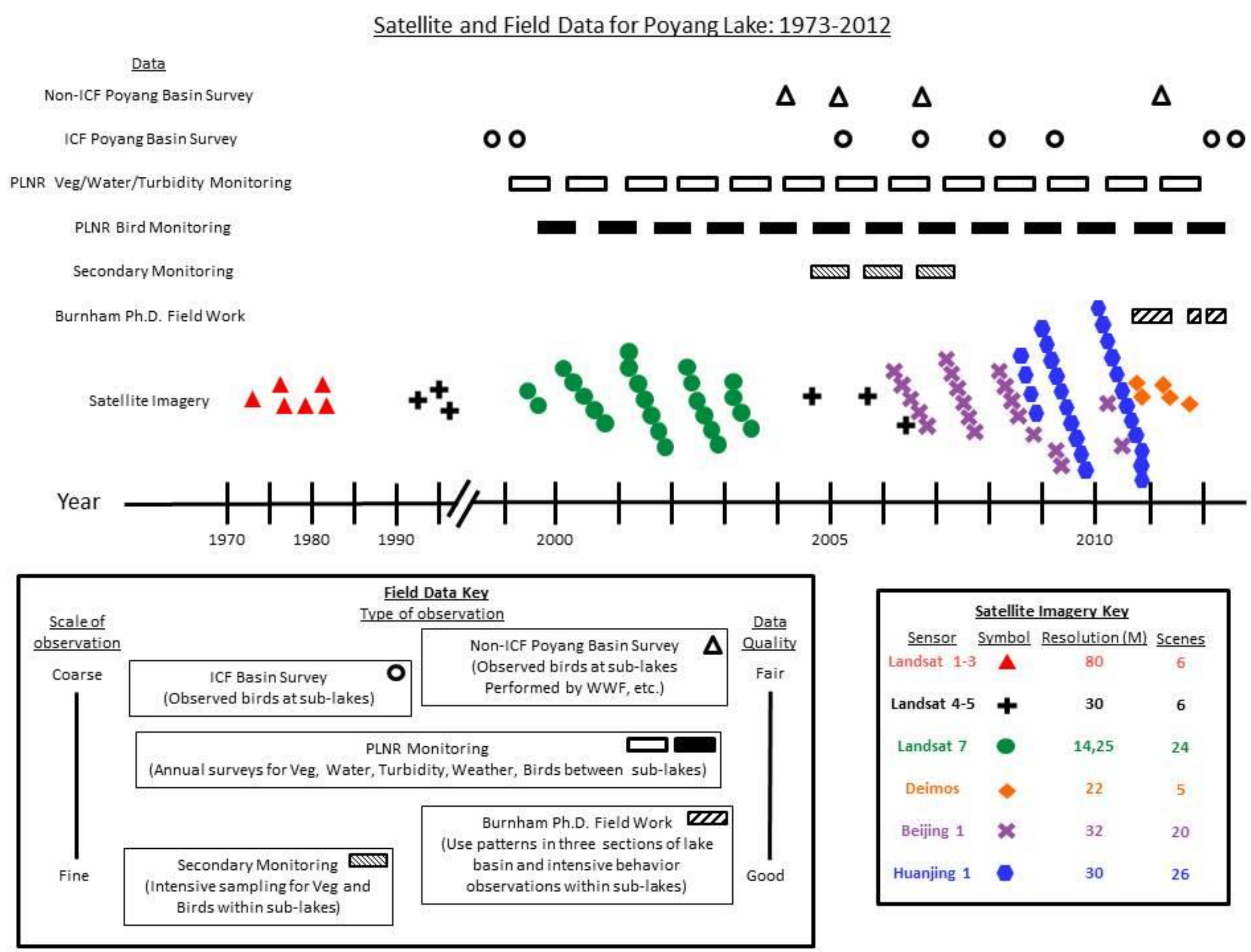

Figure 1. Temporal overlap between different variables with data explanations

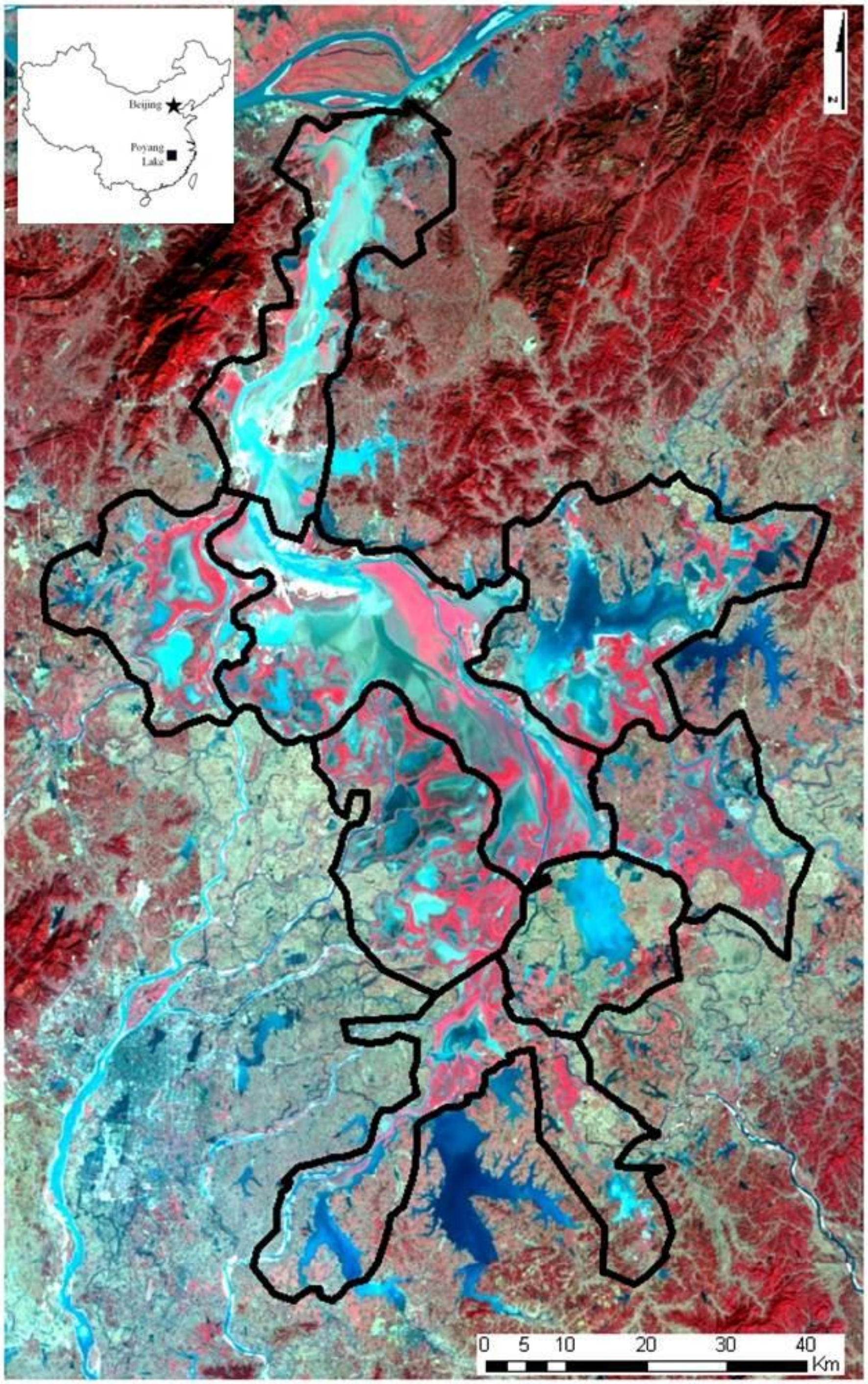

Figure 2. Location of Poyang Lake with hydrologically distinct sub-Basins identified. These sub-basins are defined as regions of the lake that exhibit distinct infilling and draining patterns over time. Deimos I image date Dec. 04, 2012 courtesy of SERTIT.

Within these spatial scales, I will determine which variables best explain different measures of waterbird use through time including number of individuals, abundance by species and community diversity measures (e.g. species richness, evenness). A list of common waterbirds that winter at Poyang is given in table 7. While analysis may extend to species not in this list, I expect to find that the number of observations and sampling intensity for these 20 species is consistent between years and observers over the time period I will analyze.

I will obtain landscape metrics from a variety of sources including remotely sensed imagery (e.g. Landsat images), products of satellite imagery (e.g. water inundation maps), land cover maps, human use maps (e.g. fishing nets and/or road maps), water gauge data, metrics of turbidity and wetland plant productivity and distribution across sub-lakes, where available. I will treat these different landscape metrics as independent variables in my analysis of waterbird habitat use patterns. Measures of waterbird use through time at the lake basin, sub-basin and sub-lake scales will be determined from basin-wide counts done at regular intervals from 1999-2012. Data obtained from a long-term ecological monitoring program put in place by the International Crane Foundation and Poyang Lake Nature Reserve will be used to look at sub-lake and patch scales. The different independent and dependent variables for the separate spatial scales are listed in Tables 3-6. I expect that different families, species, and foraging guilds will respond to different variables within and between spatial scales over time. To account for this variability, I will guild waterbirds according to taxonomic (i.e., family), foraging strategy and dominant diet to analyze waterbird responses to the different variables within and between spatial scales.

Table 3. Lake Basin Scale: variables and data sources

Independent Variable	Driver Category	Data type, Source/Status
Surrounding upland slope/topography	Landscape	Available through SRTM or ASTER DEM, online
Surrounding upland land cover/land use	Landscape	Derived from Landsat imagery, in hand
Flood inundation	Hydrology	Map SERTIT, in hand
Roads and settlements	Human Use	Derived from Landsat/finer scale imagery, in hand
Fishing net	Human Use	Map, SERTIT, in hand
Sand Dredging	Human Use	Map, Derived from Landsat/finer scale imagery, in hand
Interaction terms of the above	Interaction	Data in hand

Dependent Variable	Data Source/Status
Species Richness (number of species)	ICF Basin-wide survey, in hand/ Non-ICF surveys
Abundance (individuals/species)	ICF Basin-wide survey, in hand/ Non-ICF surveys
Diversity Indices	ICF Basin-wide survey, in hand/ Non-ICF surveys

Table 4. Sub-basin Scale

Independent Variable	Driver Category	Data Source/Status
Sub-basin water area	Hydrology	Landsat/finer scale imagery/SERTIT data, in hand
Sub-basin average flood inundation	Hydrology	SERTIT, in hand
Sub-basin slope/topography	Landscape	Available through SRTM or ASTER DEM, online
Sub-basin patch (water): configuration/orientation/shape/edge	Landscape	Landsat/finer scale imagery/SERTIT data, in hand
Sub-basin land cover composition	Landscape	Derived from Landsat/finer scale imagery, in hand
Sub-basin road density/settlement density	Human Use	Derived from Landsat/finer scale imagery, in hand
Sub-basin fishing net density	Human Use	Derived from Landsat/finer scale imagery, in hand
Sand Dredging map/density/sub-basin	Human Use	Derived from Landsat/finer scale imagery, in hand
Interaction terms of the above	Interaction	Data in hand

Dependent Variable	Data Source/Status
Species Richness (number of species)/sub-basin	ICF Basin-wide survey, in hand/ Non-ICF surveys
Abundance (individuals/species)/sub-basin	ICF Basin-wide survey, in hand/ Non-ICF surveys
Diversity Indices (Shannon, α,β,γ-level) between sub-basin	ICF Basin-wide survey, in hand/ Non-ICF surveys

Table 5. Sub-lake Scale

Independent Variable	Driver Category	Data Source/Status
Sub-lake water area	Hydrology	Landsat/finer scale imagery/SERTIT data, in hand
Sub-lake average flood inundation	Hydrology	SERTIT, in hand
Sub-lake surrounding slope/topography	Landscape	Available through SRTM or ASTER DEM, online
Sub-lake surrounding land cover	Landscape	Landsat/finer scale imagery/SERTIT data, in hand
Sub-lake composition: configuration/orientation/shape/edge	Landscape	Landsat/finer scale imagery/SERTIT data, in hand
Sub-lake edge proximity to road/settlement	Human Use	Derived from Landsat/finer scale imagery, in hand
Sub-lake fishing net density	Human Use	Derived from Landsat/finer scale imagery, in hand
Sub-lake neighbor effect (e.g. lake/landcover)	Landscape	Derived from Landsat/finer scale imagery, in hand
Sub-lake aquatic vegetation productivity	Vegetation	ICF long term monitoring, where available
Interaction terms of the above	Interaction	Data in hand

Dependent Variable**	Data Source/Status
Species Richness I (number of species)/sub-lake	ICF Basin-wide survey, in hand/ Non-ICF surveys
Species Richness II (number of species)/sub-lake	ICF long-term monitoring
Abundance I (individuals/species)/sub-lake	ICF Basin-wide survey, in hand/ Non-ICF surveys
Abundance II	ICF long-term monitoring
Diversity Indices I (Shannon, α,β,γ-level) between sub-basin	ICF Basin-wide survey, in hand/ Non-ICF surveys
Diversity Indices II (Shannon, α,β,γ-level) between sub-basin	ICF Long Term Monitoring

** Dependent variables I and II separated to control for potential differences in methodology and observation bias

TABLE 6. Patch Scale

Independent Variable	Driver Category	Data Source/Status
Neighborhood size/area	Landscape	Landsat/finer scale imagery/SERTIT data, in hand
Neighborhood surrounding slope/topography	Landscape	Available through SRTM or ASTER DEM, online
Neighborhood surrounding land cover	Landscape	Landsat/finer scale imagery/SERTIT data, in hand
Neighborhood composition: configuration/orientation/shape/edge	Landscape	Landsat/finer scale imagery/SERTIT data, in hand
Neighborhood edge proximity to road/settlement	Human Use	Derived from Landsat/finer scale imagery, in hand
Neighborhood water depth	Hydrology	ICF secondary monitoring
Neighborhood average flood inundation	Hydrology	SERTIT, in hand
Neighborhood neighbor effect (e.g. lake/landcover type)	Landscape	Derived from Landsat/finer scale imagery, in hand
Sub-lake aquatic vegetation applied to neighborhood	Vegetation	ICF long-term monitoring
Neighborhood aquatic vegetation density	Vegetation	ICF secondary monitoring
Interaction terms of the above	Interaction	Data in hand

Dependent Variable	Data Source/Status
Species Richness (number of species)/neighborhood	ICF long-term monitoring/ICF secondary monitoring
Abundance (individuals/species)/sub-lake	ICF long-term monitoring/ICF secondary monitoring
Diversity Indices (Shannon) of neighborhoods	ICF long-term monitoring/ICF secondary monitoring

Table 7. Common wintering waterbirds at Poyang Lake (from Ji et al., 2007)

Family	Species	Scientific Name	Forage type	Foraging style
Gruidae	Siberian Crane	*Leucogeranus leucogeranus*	SAV tubers	Probing
Gruidae	White-naped Crane	*Grus vipio*	SAV tubers/ upland roots	Probing
Coconiidae	Oriental White Stork	*Ciconia boyciana*	Large fish	Stalking/ scavenging
Threskiornithidae	Eurasian Spoonbill	*Paltalea leucorodia*	Small fish/ crustaceans	Flock feeding
Anatidae	Tundra Swan	*Cygnus columbbianus*	SAV tubers	Upending/ grubbing
Anatidae	Swan Goose	*Anser cygnoides*	SAV tubers	Upending/ grubbing
Anatidae	White-fronted Goose	*Anser albifrons*	Sedge	Grazing
Anatidae	Bean Goose	*Anser fabalis*	Sedge	Grazing
Anatidae	Spot-billed duck	*Anas poecilorhyncha*	Phytoplankton	Dabbling
Anatidae	Mallard	*Anas platyrhynchos*	Phytoplankton	Dabbling
Anatidae	Common Teal	*Anas crecca*	Phytoplankton	Dabbling
Anatidae	Northern Pintail	*Anas acuta*	Phytoplankton	Dabbling
Anatidae	Widgeon	*Anas penelope*	Phytoplankton	Dabbling
Charadriidae	Northern Lapwing	*Vanellus vanellus*	Invertebrates	Probing
Laridae	Black-headed Gull	*Larus ridibundus*	Generalist	Surface feeding
Recurvirostridae	Pied Avocet	*Recurvirostra avosetta*	Invertebrates	Probing
Scolopacidae	Spotted Redshank	*Tringa erythropus*	Invertebrates	Probing
Scolopacidae	Black-tailed Godwit	*Limosa limosa*	Invertebrates	Probing
Scolopacidae	Dunlin	*Calidris alpina*	Invertebrates	Probing
Ardeidae	Grey Heron	*Ardea cinerea*	Large fish	Stalking/ scavenging

Analyses between dependent and independent variables, or metrics, will include multiple statistical techniques to determine what relationships exist within or between separate scales. I expect that many of the relationships between independent and dependent variables may exhibit similar patterns at different spatial scales. I also expect that multiple instances of autocorrelation between independent and dependent variables will exist (Koenig, 1999). I will use ordination methods (e.g. Principal Components Analysis) to reduce the dimensionality of predictive variables at each scale and compare these results to regression analyses to determine the most important variables contributing to selection at each spatial scale (González-Gajardo et al., 2009; Beale et al. 2010).

Significance and application

The outputs of this chapter will be wintering waterbird distribution maps from 1999 to 2012 at four scales within Poyang Lake. I will also determine which drivers are most strongly associated with waterbird distribution at each scale. I hope that as a result of identification of these drivers, a decision support tool can be put in place that managers can use to prioritize management actions for increased effectiveness of conservation efforts within Poyang Lake. For example if basin-wide hydrological factors are revealed as the greatest negative driver, then management efforts and solutions need to focus at this scale. Furthering the example, if factors at the patch or sublake scale have positive effects on waterbird distribution, local reserve managers can use this information in formulating their management goals and activities. Ultimately, I want to use knowledge gained through modeling relationships between waterbirds and environmental factors to help predict how future waterbird use may respond to ongoing changes within the Poyang Lake system.

China's Poyang Lake provides essential ecosystem services such as water resources, soil nutrient cycling and providing fish and plant species to over ten million people and hundreds of thousands of migratory waterbirds. If it is clear that waterbird populations have declined over the 12 years of my study, or that waterbird use patterns have changed in a way that shows a negative trend over time, it will not only be bad for the birds, but for the human communities that also depend on Poyang. Without understanding the response of wintering waterbirds to recent changes, it will be impossible to make educated predictions on how these species will respond to future changes. Within Poyang Lake, this knowledge could inform a variety of management initiatives within fifteen different protected areas, multiple national and international conservation efforts targeting the endangered wildlife at Poyang, as well as the socio-economic policies that shape the development of the lake.

Beyond the boundaries of Poyang Lake, it is my intention that the methods and techniques I develop in this chapter can be adapted to work with other dynamic wetland systems around the globe. These dynamic systems remain poorly understood precisely because of the high degree of land cover heterogeneity, their complicated hydrology and the human uses that rapidly alter how water, energy and nutrients flow through these systems. I feel that by looking at indicators of ecosystem function, such as waterbirds, and looking at what drives their use patterns at distinct scales within the system it will be possible to account for the high degree of variability that characterizes these systems. Once significant drivers of waterbird use are identified, this knowledge can help inform conservation, management and development efforts, hopefully ensuring the function and future use of these systems, for both bird and human communities.

Overall summary and applications

The world's wetlands hold a disproportionately high amount of the planet's biodiversity given the small amount of area they occupy on the Earth's surface (Gopal, 2009). This biodiversity, and the inherent variability of these ecosystems that transition between upland habitats and open water, greatly contribute to the exceptionally valuable ecosystem services wetlands provide to a variety of plant, animal and human communities around the world (Costanza et al., 1997; Zedler and Kercher, 2005). In spite of their value and utility, wetlands face growing pressures from human activities and shifting climate patterns that threaten the very biodiversity and variability that fuels the function of these systems. International agreements such as the Ramsar Convention on Wetlands and the Bonn Convention on Migratory Species recognize the importance of wetlands at the ecosystem and continental scale, and attempt to mitigate some of the human pressures on these systems, with limited success in preventing loss of wetland function. The efficacy of these international agreements are limited due to a variety reasons, but a major contributor is that the scientific community still does not fully understand how multiple drivers of change, such as increasing human pressures and shifting climate patterns, interact to affect these systems and their biodiversity over time (Erwin, 2009).

In my PhD I seek to address some of these gaps by documenting wetland change over time, documenting how those changes affect biodiversity and contextualizing what those changes may mean for the future of these wetland systems. I will do this by looking at two wetland systems within China that exemplify challenges affecting wetlands globally. These wetlands are particularly relevant because of their large human populations, long histories of modifications for human benefit and the rapid economic transformation China experienced in the 1980s which was accompanied by novel and increased resource extraction and farming activities. I expect that my analysis will result in better understanding of the mechanisms behind the changes I find, and that the knowledge gained will be used to improve management of wetlands.

In my first chapter I intend to show how wetland vegetation patterns have changed since the early 1980's at Napahai wetland and whether those changes explain declining population trends of wintering Black-necked Cranes using the wetland. From a methodological perspective, the work at Napahai uses novel change detection methods and a unique combination of satellite data sources to document change within Napahai since open market reforms swept the country and link those changes to trends observed in wintering Black-necked Crane observations.

Anticipated products from this chapter include a land cover change map covering the mid-1980s to present as well as detailed maps of wetland habitats. I will integrate these maps with survey data of Black-necked Cranes at Napahai to determine whether the trends of wetland change are correlated with numbers of observed cranes over time. I also intend to work with partners at KIZ to determine whether the fine-scale habitat maps generated from Quickbird and SPOT satellite imagery can be used to determine whether Black-neck Cranes fitted with satellite telemetry devices in 2005 and 2009 exhibited discernible habitat selection patterns within the Napahai system. These outputs will be useful in prioritizing management of Napahai National Nature Reserve, and to focus conservation efforts to ensure that Napahai remains a viable wintering location for Black-necked Cranes.

In my second chapter, focused on Poyang Lake, I will make advances in our collective understanding of avian ecology. I will describe and quantify novel foraging behavior and novel diet in the critically endangered Siberian Crane following a flood event in 2010. I will examine population count data for evidence that the novel diet did or did not affect a demographic rate (the ratio of juveniles to adults) that can provide insight into potential longer-term effects on the Siberian Crane population, if they continue to forage in these new habitats.

In my third chapter, I will construct models to identify which drivers best explain waterbird use over time and whether drivers at different spatial scales are correlated to one another. Ultimately, I want to use these models to help identify actions that could be implemented by partners at local nature reserves to better manage waterbird habitat.

It is my intention that this work advance multiple aspects of methodology, ecological knowledge and management efforts targeting dynamic wetland systems in China and the migratory waterbirds that depend on them. I believe that wetland change patterns and how they affect waterbird species that depend on these systems are good indicators of broader ecosystem function. I intend to produce outputs that span the range from individual waterbirds selecting foraging habitat to hierarchical species distributions to ecosystem-level change detection and habitat maps. I will work with colleagues at international NGO's, collaborators at Chinese research institutions and universities, as well as partners at protected areas within these wetlands to use these outputs in ways that inform management decisions, focus future conservation efforts, and contribute to discussions that center on improved economic development policies that take wetland function into account. By understanding the way these systems change over time, and how species respond to these changes, I hope to provide a quantifiable measure of the changes these systems have experienced to researchers, conservationists and management practitioners.

As the 21st century advances, the global human population will only continue to expand and exert new, and more intensive, pressure on the planet's natural resources. Under these pressures, effective biodiversity conservation by managers and conservationists requires new tools and models. These models will have to account for historical human uses of ecosystems as well as novel uses that, in combination with shifting climate patterns and weather events will likely produce novel impacts on these systems. China offers a unique opportunity to study how changes within wetlands occur at a rapid rate and learn from these changes in order to anticipate future changes in other freshwater systems around the globe. Patterns that are currently occurring within Napahai and Poyang will be repeated in other freshwater systems that have a large human population such as Cambodia's Tonle Sap or Africa's Lake Chad. China's socio-economic transformation over the last thirty years has completely altered how communities around the country utilize a wide range of natural resources. These patterns mirror global patterns, except at an accelerated rate. This work will provide researchers, managers and policy makers with advances in methods and knowledge useful for anticipating and mitigating negative impacts of changing freshwater ecosystems for the benefit of wildlife and human communities alike.

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