# Phase 1 Report
# How Development Projects May Impact Wintering Waterbirds at Poyang Lake

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**Introduction:**
Poyang Lake is a dynamic wetland system where water levels are often deep during the summer rainy season and shallow during the winter dry season. How deep and how shallow the water levels become varies greatly each year. Poyang Lake is also one of the largest wetlands in Asia and, because of its hydrological reverse flow system and its large yearly variation in water levels, Poyang Lake is unique in its ability to produce a large biomass of plant and animal food that many waterbird species, including the Siberian crane, depend on during winter. As a key winter area for waterbirds, the analysis of how various impacts from development can alter this ecosystem is important to consider and will be discussed in this brief assessment. The Phase 1 assessment is intended to generally describe how development projects may impact bird populations that winter at Poyang Lake. Specifically, this Phase 1 report will focus on 1) understanding how changes in the ecosystem may affect different foraging guilds of birds (see below for an explanation); 2) examining how direct and indirect impacts, within a foraging guild, may occur; and 3) identifying the degree to which annual variation in water levels may influence the above two conditions in some years but not others. This discussion focuses on birds inhabiting the Poyang Lake ecosystem. A following document (Phase 2) will quantify the degree to which impacts from a specific development proposal will affect wintering waterbirds.

**1. Foraging Guilds (groups of species that feed on similar foods in similar ways)**
Large variations of water in height, timing, permanence, and quality can influence the distribution and abundance of foods in Poyang Lake and subsequently determine a significant portion of habitat quality for over 250 bird species. When evaluating the impact of any proposed development on the range of bird species at Poyang Lake it is difficult to consider every individual species that uses the system. Instead, it is helpful to think of how different types of bird foraging guilds utilize the lake and then assess how impacts may affect representative species within that guild. Importantly, most of the endangered bird species at Poyang Lake fit within the six foraging guilds listed below. Though other foraging guilds exist at Poyang Lake in winter (e.g. upland seed gleaners) most bird species, where a significant proportion of their population winters at Poyang, are grouped within these six, distinct foraging guilds:

1. Tuber feeding birds (e.g. Siberian cranes)
2. Sedge/Grass eating birds (e.g. white-fronted geese)
3. Seed eating/dabbling birds (e.g. puddle ducks like spot-billed ducks)
4. Benthic insect larvae eating birds (e.g. spotted redshanks)
5. Large fish eating birds (e.g. oriental white storks)
6. Zooplankton eating birds (e.g. Eurasian spoonbills)

*Tuber feeding guild*
Tubers and winter buds are plant organs that store energy as starch. These organs are used to fuel growth of new plants after a period of stress (such as the winter draw down period) is over. For birds that feed on them, tubers provide good energy during a portion of the annual cycle where birds increase their fat stores in preparation for the long spring migration and breeding.

Some tuber feeders, like Siberian cranes, dig for tubers directly with their bills. Swan geese also dig extensively. For these birds to forage efficiently soil conditions must allow digging to occur and water cannot be so high as to prevent the benthic zone, where the tubers are, from being accessed by the birds. If standing water exists, water levels must be low enough (<40-60 cm) for cranes to wade in the water or for swan geese to float in the water and tip up so that they can reach the benthic zone with their extended necks. At the other extreme, when dry, the soil cannot be so hard that it becomes impossible to manipulate with the bird's bill. This sub-guild of shallow-water tuber feeders is represented by Siberian cranes, hooded cranes, white-naped cranes, Eurasian cranes and swan geese but also includes other bird species. Almost all of the world's wild Siberian cranes, approximately 60% of the world's white-naped cranes, and about 50% of the world's swan geese winter at Poyang Lake.

Tundra swans are also tuber feeders but can forage in deeper water than can the shallow water tuber feeders. Swans can feed in water as deep as 1.5 meters and reach the benthic zone with their long necks. They can also dig in deep water by creating erosive water currents. This behavior, called treading, is where the swans move their large webbed feet up and down in the water, creating convectional water currents. This water movement erodes the soil directly under the swan and allows tubers underneath to be exposed or to

float to the water surface and be eaten. Tundra swans represent a deep water tuber feeding sub-guild at Poyang Lake. About 1/3 of the world's Eurasian subspecies of tundra swan (*Olor columbianus bewickii*) winter at Poyang Lake.

Collectively, tuber feeders utilize the areas of lowest elevation at Poyang Lake and follow the receding or moving water so that new tuber resources are exploited over winter.

The plant species that create tubers are submerged aquatic macrophytes. These plants root in the benthic zone and grow to the water surface where their flowers then open above the water. These plants are adapted to changing water levels and grow as water levels increase. Unlike the birds that feed on their tubers, these plants are influenced by water in both winter and summer. The level, quality, timing, permanence, and movement (horizontally and vertically) of water all influence the abundance, productivity and distribution of these plants. These aquatic plants need sufficient sunlight in order to survive and store their energy in tubers. Hence the turbidity of water, and the water levels over the year, are important factors that determine the amount of reserves that are being stored and also partly influence their spatial distribution. Further, with large variations in these water characteristics occurring annually, the plants must be highly mobile within the system to survive within large extremes of water conditions that occur. Thus, locations where tubers occur at high density in any one year vary considerably. For example, Da Hu Chi may have high tuber densities in some years and almost no tubers in other years.

*Sedge/grass eating birds*

Birds that graze on the sedges and grasses at Poyang Lake utilize a zone that is at a higher elevation than the tuber zone but still at a relatively low elevation when compared to the rest of the basin. In contrast to the tuber zone, where plant abundance varies greatly in any one location among years and can occur across wide expanses of the lake basin, the sedge/grass zone is often relatively narrow in width and it varies little in spatial distribution from one year to the next. The plant community in this zone is dominated by sedges that grow in cool weather and by some grasses. As such, this plant community is short in stature and produces the highest growth rates and flowers during autumn, winter, or spring.

Bird species that graze on vegetation in this zone require rapidly growing, short plants that are rich in nitrogen during winter and that are accessible because of their short stature. Short, actively growing vegetation and no (or very low) water is important for the birds to have access to this food, for providing high nutrition to grazing birds and for birds to be able to feed while maintaining vigilance to predators. Tall vegetation and high biomass are not preferred by these species as nitrogen content is too low and the food intake by birds is reduced in areas of tall vegetation. Typical species in this foraging guild include greater white-fronted geese, lesser white-fronted geese, graylag geese, bean geese, Eurasian wigeon, and often swan geese as well. Of these species, a large proportion of Asia's bean goose, swan goose, white-fronted goose and lesser white-fronted goose populations winter at Poyang Lake.

This more permanent zone of vegetation is very susceptible to changes in water level during winter because it cannot tolerate deep inundation during the winter growing season. At the other end of the gradient, shallow summer inundations may also cause greater competition from grasses that dominate vegetation zones at higher elevation. The grass/sedge zone thus occurs between submerged aquatic and grass zones and presumably requires moderate water levels during summer as well as low water levels during winter to persist. Given that many of the sedge species in this zone are long-lived, the sedge/grass zone does not shift very rapidly in response to changing conditions as do submerged aquatic species like wild celery; the sedges lack a rapid means of colonizing new substrates. Short-term annual fluctuations in water level from one year to the next may not alter this zone dramatically whereas longer-term changes in water level will.

*Seed eating/dabbling birds*

The seed eating and dabbling species are represented by birds that forage along the water surface on foods that are floating or found just beneath the water surface. Often the foraging areas that are best for these species occur at, or near, the edge where open water ends and mudflats begin because seeds and invertebrates are concentrated there. The foods eaten can be plant (primarily seeds) or animal (e.g. insects or benthic organisms). Generally these foods have been produced elsewhere in the system and are concentrated along edges of water by water currents or wind.

The shape of wetland basins that produce good quality habitat for these species are areas where the basin slope is very shallow (a profile of 100:1 or more). With gently sloping surfaces subtle changes in water level during winter can create large new foraging areas for the birds. As wind direction and speed vary through the winter, these habitats can shift dramatically throughout the basin. With this guild, habitat quality within the year is highly variable and determined by minute changes in water level. Open systems, such as at the inland delta found at Nanjishan, are areas where these habitat conditions occur in great abundance and at large scale. Ecologically, broad open areas differ in quality for species in the seed eating/dabbling guild from the more closed sub-lake basins like Da Hu Chi.

Characteristic species within this foraging guild include mallard, gadwall, spot-billed duck and common teal.

Areas where these habitats occur at Poyang Lake are variable both within and among years but are similar to the submerged aquatic plant zone except that birds in this guild need shallower water levels (e.g. < 30 cm) than do tuber feeding birds.

*Benthic insect larvae eating birds*

The habitats utilized by shorebirds in this foraging guild are similar to seed eating/dabbling birds but their range of water conditions is likely narrower. The maximum water depth for tall foraging shorebirds like black-winged stilts is approximately 20 cm whereas maximum water depth for medium foraging shorebirds like redshanks is around 7 cm. Smaller shorebirds (e.g. little ringed plover) have

maximum foraging depths of about 3 cm. In most cases, optimal foraging depths are 30% lower than maximum foraging depths.

Most of these species can also feed on mudflats but are less likely to feed in these areas as they dry out. Foods of benthic feeders consist of invertebrates (usually insect larvae, crustaceans or gastropods) where the birds probe to capture them, thus the inability to forage on dry soils. Factors that influence productivity of invertebrates are not well understood but are likely improved by having occasional dry periods which allow aerobic decomposition (relatively fast) to occur compared to slow decomposition rates under anaerobic conditions (caused by water inundation). Thus, though dry conditions can often prevent foraging, they may be necessary to maintain high productivity. In the Poyang system the variable nature for water levels, and the large spatial scales over which these variable water levels occur, allows a heterogeneous system of both wet and dry systems to occur simultaneously.

As with the seed eating/dabbling guild, these habitats occur in the same, low elevation areas but birds in this guild cannot feed in water as deep as the seed eating/dabbling guild members and tuber feeders.

Thousands of shorebirds utilize Poyang Lake each winter but estimates of their numbers are poor because the many, relatively small species are difficult to count over such broad and variable areas.

*Fish eating birds*

There are two basic groups of fish eating birds, those that forage on predominantly live, unstressed fish (e.g. herons, egrets, bitterns), or large crustaceans like crayfish and crabs, and those that feed on dead or stressed fish (e.g. storks). Herons, egrets and bitterns feed by stealth, standing in water and waiting for animals to come to them. These birds are able to feed on large expanses of water as long as water levels are not so deep as to prevent wading. Maximum water levels that birds could forage in would range from approximately 15 cm for small bitterns like the little bittern to 40 cm for larger birds like grey herons. For this group, areas of suitable water can be large. Important habitats are also not as sensitive to change as are habitats for tuber feeders (for example) because they only require standing water of variable quality and animal prey densities. Prey species can be produced anywhere and migrate to feeding areas. Abundant presence of several egret species in both summer (when water levels are high) and winter (when water levels are low) illustrate the flexible habitat requirements of members of this sub-guild.

No species of heron, egret or bittern that utilize Poyang Lake is endangered and no major concentration of a population for any heron, egret, or bittern resides at Poyang Lake.

For storks that feed on dead fish or fish that are incapacitated or stressed in some way, the habitat requirements differ from herons, egrets and bitterns. Storks can physically forage in deeper water but require water areas to be more segregated and shallow so that they can seek out prey species rather than waiting for fish to swim near them as egrets and

herons do. Though physical maximum water levels are likely 60 cm for storks in this sub-guild, the normal foraging depth is less than 30 cm.

Approximately 90% of the world's oriental white storks winter at Poyang Lake. Other birds that belong to this group include black storks.

*Zooplankton eating birds*
Represented by Eurasian spoonbills and avocets, members of this foraging guild have very specialized feeding habits. They sift through water, and perhaps benthic materials, for zooplankton like ostracods and daphnia while opportunistically feeding on small fish found in isolated pools. Maximum water levels are not known but likely do not exceed 40-50 cm and are considerably less for avocets (e.g. < 20 cm). Typically spoonbills forage in water levels that are 20-30 cm deep. As with benthic systems mentioned above, little is known about what factors influence the abundance or distribution of prey species for this guild but overall primary wetland productivity may play an important role.

No species in this foraging guild is endangered but a significant proportion of Eurasian spoonbills in the Asian Flyway utilize Poyang Lake.

**2. Indirect versus Direct Impacts**
Since changes to the foraging conditions for various guilds of waterbirds may cause changes in the distribution and abundance of individual species, understanding the requirements of foraging birds at Poyang Lake allow us to determine the manner in which impacts may occur. These impacts can be broken down into two categories: impacts that indirectly affect birds by altering the production and distribution of their food and impacts that directly affect a bird's access to food once it is produced.

*Indirect Impacts*
Foods of the six foraging guilds include tubers of submerged aquatic plants, sedges for grazing, seeds, and benthic invertebrates, as well as animals living in the water column such as fish, crayfish and zooplankton. These foods are produced in a naturally dynamic ecosystem that is characterized by large fluctuations in water level from summer highs to winter lows. Altering the hydrological regime changes production and distribution of these foods and varies as weather patterns shift among years. Impacts due to human development may also affect hydrological variables. If these alterations occur outside of the hydrological ranges that characterize the conditions at Poyang Lake, or if they reduce variations within the system, they will then alter the distribution, composition or productivity of freshwater plants and animals that are adapted to these conditions. If bird species are limited by food in winter, and these species cannot switch to new habitats if food sources decline, then a decline in food abundance will result in a decline in the species dependent upon those foods. Some species have alternative foods and habitats that can be used if such impacts occur whereas other species (e.g. Siberian crane) do not.

Depending upon if the food is plant or animal, impacts from changes to the ecosystem on the foods that birds consume will differ. Indirect impacts can also be measured by the manner in which changes to the wetland affect people and their use of the wetland. If

development impacts do not change wetland productivity, for example, but do change people's fishing patterns in the wetland, then foods such as fish can still be affected even though wetland productivity is not. Indirect impacts by development projects on plant foods, animal foods and human use of these habitats will be discussed in turn.

A. Plants

Submerged aquatic macrophytes

Submerged aquatic macrophytes are adapted to variable water conditions. They grow and extend as water levels rise in summer and they float as water levels drop in winter. Maintaining higher water levels in winter can increase the growing season of plants but may decrease their propensity to produce tubers because the plants do not go through a period of stress. In the wet season, increasing water levels when water temperatures are too cool for plant growth can also disrupt the life cycle of this plant species. For example, if high water from the Yangtze River occurred in April or May rather than June or July then plant growth may not occur fast enough in cooler waters to keep up with rising water levels. As a result, the plants are not able to access enough light in the rapidly rising water and die because they are unable to photosynthesize.

Water depths of 1-2 meters in the lake and sub-lake basins result in high turbidity because waters are shallow enough for wind to re-suspend sediments in the system. Historically, highly turbid conditions exist until water levels at Poyang Lake become high enough that sub-lakes in the system are no longer hydrologically isolated. When waters of Poyang Lake merge with the waters of the sub-lakes during summer, water clarity increases and light becomes available to the macrophytes adapted to growing at deeper depths (e.g. *Vallisneria*). Maintaining higher water levels in winter may increase the growing season for some plants, as mentioned above, but the water quality may be poor, because of re-suspension of sediments, and negate any increased growth period.

Since submerged aquatic plants are highly mobile within the system, given enough time these plants could likely migrate to higher elevation areas if water levels were altered on a more permanent basis by development. These areas, if they would go dry during winter, would persist in producing tubers. Areas of suitable habitat, however, would be dramatically reduced because the lower elevations within Poyang are flatter and have a greater spatial extent for plants to grow whereas higher elevation areas have a steeper transition along the elevation gradient and provide restricted growth zones for plants. How much area would be available for submerged aquatic plants would depend upon how much water elevations changed. Soil type may also influence how well species might shift to higher elevation areas and what types of species will migrate. With submerged plants, soils that submerged aquatic plants grow in range from sand to silt. These plant species might reasonably adapt to available soils if increasing water levels caused them to shift up the elevation gradient.

In summer, water quality is influenced by interactions with the Yangtze River and can be improved when reverse flow conditions occur, thereby raising water levels in Poyang above the shallower, heavily turbid winter water conditions. Even under good water quality conditions, however, once water depths surpass 4-6 meters deep, submerged

aquatic plants cannot gather enough light to grow because of the light absorption and scattering characteristics of water prevents enough light from reaching young plants.

Sedges

Sedges in the zone adjacent to the mud zone at Poyang Lake occur in direct relation to specific elevations that, in turn, relate to specific water levels. Since sedges grow most actively in the cool season (fall through spring) water levels that are important to this species likely occur in winter. If winter water levels are increased and reach the current sedge zone, these species would decline. Water levels could change gradually enough to allow sedges to shift up the elevation gradient enough to survive but how quickly these long-lived perennial plants would take to move and recover fully is unknown. As a minimum, full recovery would take more than two years. Multi-year development of new sedge zones would require bird species using these habitats to shift forage in alternative places during the transition phase and, if alternative habitats were unavailable, would lead to population declines. Evidence of the slow change by sedges to water levels is seen in the mud zone that exists between the end of the sedge zone and the beginning of the submerged aquatic macrophyte zone. This mud area is exposed each year but sedges do not shift into it to any appreciable extent in low water years because they are not able to respond quick enough to colonize these ephemeral border zones.

How much sedges could move up the elevation gradient would depend upon soil type, the steepness of the elevation gradient and how rapidly changes in water level occurred. Sandy soils would not be as suitable a substrate for sedges to grow on as would silt and clay dominated soils. Conversely, sandy soils occur in the high elevation areas of natural levees that are found along river and lake banks whereas the clay and silt soils are located at lower elevations in lake basins. Forcing sedges to move to soils at higher elevations would force them to grow in unsuitable habitat where they might persist but not at high enough density to serve as habitat for grazing birds.

As with submerged aquatic plants in the Poyang Lake system, soil elevation affects vegetation coverage. Low elevation areas are much more abundant than are high elevation areas, and plants that occur at low elevation areas will likely decrease in distribution if water levels are increased sufficiently to force plants to move up the elevation gradient.

Changing the boundaries of the sedge and grass zones would also likely have an additional indirect impact to the system as a whole. Currently, these extensive areas stabilize soils so that deep inundation periods result in relatively clear water. Re-suspension of sediments that occur at lower water levels do not occur under slightly higher water conditions. If the location and area of these sedge/grass areas are significantly decreased, it is possible that water quality, even at higher water levels, would be dramatically reduced. A reduction in water quality can decrease the ability of plants to grow, especially in deep waters (i.e. 2-6 meters). Over longer periods of time, stream bank stability can be reduced sufficiently, once vegetation is removed, to completely erode away.

These shifting zones would also greatly affect direct and indirect use of the system by people. Winter grazing areas for water buffalo and domestic ducks would be reduced substantially. Reducing the grasses will decrease reed-harvesting and hay-making operations by local communities as well.

Seeds

Seeds produced by many plant species come from throughout the Poyang Lake system because the high summer floods allow produced seeds to be transported throughout the entire system. If high water conditions in winter bring water edges up to steep basin edges (e.g. levees) then this foraging habitat can be negatively affected. Likewise, high water in winter, if it reduces seed production from sedges, may also reduce reproductive capability of the plants and food amounts available to birds. Currently no data exist that indicate the relative importance of sedge seeds versus other plant species in the diet of seed eating guild members.

Summer water levels, outside of the effect they may have on submerged aquatic vegetation (see above), would have an unknown impact on seed production.

B. Animals

Our knowledge of the factors that influence productivity of fish, insects, zooplankton and crustaceans in lake systems such as Poyang Lake is limited. Generally, variable water levels create greater productivity because soils are exposed to air during some parts of the year and also guarantee prolonged productivity. The presence of air allows for decomposition to occur under relatively fast aerobic conditions. Decomposition recycles nutrients into the wetland system where they can be utilized by plants and animals. When water levels cover substrates more consistently over the entire annual cycle, decomposition must occur in the absence of oxygen and does so at much slower rates so nutrient cycling is much slower. Invertebrate productivity is especially sensitive to rates of nutrient cycling and declines under conditions dominated by constant water levels.

Fish productivity may also be affected by nutrient cycling but this linkage is poorly understood. Fish migration in and out of the lake system is also likely important, especially in a reverse flow system such as Poyang Lake. In the only other known reverse flow system in Asia (the Great Lake in Cambodia), the ability of fish to migrate in and out of the Great Lake is key to maintaining the enormous productivity of the entire ecosystem. Any structure that interferes with fish migration could have a serious impact on overall fish productivity in the Poyang Lake system. Importantly, fish migration occurs at specific times of the year so barriers are sensitive to seasonality. If fish migration occurs in April or May but water does not flow over barriers in the system until June or July then fish migration is still greatly affected.

Other impacts to fish would occur in relation to spawning habitat. Reducing the spatial coverage of emergent plants could likely greatly alter spawning habitat for local fish species. Overall fish productivity is important to endangered fish eating species that winter at Poyang Lake such oriental white storks.

C. Changes in Poyang Lake that affect human behavior

Important changes may result from development projects that are hard to predict because they influence what people do as the system changes rather than affecting the food more directly. Predicting human behavior is often difficult but it cannot be discounted. In essence, development impacts can cause a change in human behavior which, in turn, causes a change in food abundance. Three potential examples are explored here: control of water levels, aquaculture, and sand mining.

Controlling water levels

If winter water levels are maintained at a high elevation, controlling water in sub-lakes like Da Hu Chi will be difficult. Sub-lakes cannot be drained if water levels in discharge rivers are higher than lake water levels in the system. This reduction on control of water levels alters management flexibility in the overall system as well as impacting family-based fishing methods within the system. With a reduction in control of water it becomes difficult to allow water to vary subtly throughout the year in the whole lake basin. Reducing water level variability in the system greatly impacts the primary abiotic (i.e. non-living) ecological driver for the Poyang Lake system and is likely to have a large, negative effect on its role in sustaining waterbirds.

Aquaculture

Fishing and crab farming are two examples arising from within the Poyang Lake system and that interact with water management techniques in unpredictable ways.

For example, Poyang Lake Nature Reserve leases the use-rights to control water resources in the Sha Hu sub-lake basin. Their management goal was to allow water levels to drop slowly throughout the year as opposed to draining the lake over a few days to catch all fish in the basin; as was the custom of local fishermen who previously managed water levels in Sha Hu. When the nature reserve implemented their water management plan, people changed their fishing strategy from capturing fish as they leave Sha Hu through the drainage canal to seining fish in the open water. This new fish capture technique disturbed the benthic layer as seines were drawn along the lake basin and may have actually caused a decline in *Vallisneria*, a submerged aquatic plant that produces tubers, even though longer winter inundation periods caused this plant species to increase in Sha Hu and tuber feeders to have better habitat.

Young crabs are stocked into lakes such as Mei Xi Hu after the high water season. Stocked crabs feed on natural animals and plants within the lake and are then harvested before floods return. In this scenario crabs either feed directly on wild celery or they so disturb the lake bottom through their movement that water quality declines enough to prevent the plant from growing. In either case, wild celery disappears quickly after crabs are introduced to a lake. In this example, water management is not changed but resource extraction techniques are. The decline in the wetland's ability to produce food for foraging birds, however, is significantly negatively affected.

Sand dredging

Sand dredging in Poyang Lake dramatically increases turbidity. With increases in turbidity, portions of the lake are unable to produce tubers that constitute the wintering diet of many waterbirds. Productivity of invertebrates or sedges can also be influenced by changes in water quality but this has not been studied as of yet.

Importantly, if water levels in autumn, winter or spring are increased, the extent of sand dredging that occurs in Poyang Lake can increase as more areas have sufficient water to float dredges and sand transport ships. Increasing winter water levels, for example, can allow for more sand dredging to occur which will then increase turbidity in the lake system which can then influence aquatic plants or animal productivity.

*Direct Impacts*

Direct impacts of water development projects to foraging water bird species would be caused primarily through altering water levels during winter when most bird species would be present. As defined in the section describing bird foraging guilds, water levels can either benefit or inhibit access to food by waterbirds but the water level at which an impact occurs for any one foraging guild differs.

Maintaining water depths of over 1.5 meters in winter would directly eliminate most foraging habitat for all 6 foraging guilds that currently utilize the Poyang Lake ecosystem extensively. Other foraging guilds, such as deep water tuber feeders like diving ducks, and deep water fish eaters like grebes or cormorants, would likely retain access to foods with these water depths. Water levels of 0.6-1.5 meters would enable primarily swans (tuber feeders) to feed. Below 0.6 meters of water depth most other guilds begin to have access to food but still at various depths. Cranes can begin feeding in water of 0.6 meters whereas other species, such as little ringed plovers, cannot begin to feed until water depths are 0.03 m or below.

At the other end of the water gradient, conditions that are too dry will also create habitats that are difficult for birds to forage in because dry soils are too hard to probe and find animal or plant food in. The current condition, with considerable short-term fluctuation in water, creates extensive and ever changing areas of wet mud or shallow water accessible to foraging birds across a large area. Historically, portions of the lake where soil conditions were not ideal for foraging during any one year were productive foraging sites in other years.

Through its size, through its gradually varying topography and through its interaction with wind and water, Poyang Lake produces a wide variety of water depths that change on a daily basis during winter. This heterogeneity in space and time is a critical component of maintaining the current diversity and abundance of water bird guilds at Poyang Lake. Development projects that alter these conditions significantly will directly impact these foraging guilds, particularly the species within those foraging guilds that exhibit little to no ability to shift their winter foraging requirements.

As with indirect impacts (above) there may also be an interaction between changes in human behavior that result from a development project and the ability of birds to directly access their food. If, for example, water levels are raised and birds become concentrated near the higher elevation areas of Poyang Lake, this is also where people are concentrated as well. People use these higher elevation areas for farming and housing because these are the places that flood less deeply than other areas. If, under scenarios where water elevations are increased, food plants and animals may be able to adjust to the environmental changes, creating good foraging habitat, but the presence of people could still prevent birds from using these good habitats because many species will not use areas that have many people present.

**3. The Influence of Annual Variation in Water Conditions**

At Poyang Lake variability in the system is important within the year (as described above) but it is also important among years. From peak to minimum water level within an annual hydrological cycle, changes in water level have ranged from as much as eleven meters to as little as four meters over the last 9 years of monitoring. These fluctuations are not easily controllable as they are determined by water cycles that are far larger than any one development project can manage.

During different annual water level regimes, habitats within Poyang Lake for each of the foraging guilds have varied dramatically. For example, in nine years of monitoring, tuber abundance at Da Hu Chi has averaged from as high as 18.316 $g/m^2$ (2003) to as low as 0.105 $g/m^2$ (2006). When tuber production has been high at Da Hu Chi many tuber feeding birds have used the sub-lake but in other years, when tuber production was low, use of Da Hu Chi by tuber feeding birds was low. Though data on movements of tuber feeding birds throughout the entire Poyang Lake ecosystem is sparse, in years where tuber production is low at sub-lakes like Da Hu Chi, it is possibly higher elsewhere within Poyang and birds utilize these resources.

Variability in food resources among years can be extensive. In a complex ecosystem such as Poyang Lake, however, the lake system has provided habitat throughout the historical variation that has occurred, including the winter after floods in 1998 as well as the low waters and cold of 2008. Development projects, if they reduce the ability of the hydrology to fluctuate in time or in space, they may not affect a particular foraging guild in an average year. In contrast, development projects can still have significant long-term impact if they remove foraging habitats in non-average years. For example, if tuber feeders need to find tubers in the deepest portions of Poyang lake during droughts, these areas may no longer be available if water levels in winter are maintained at a higher elevation. If species in the affected guilds have no alternative habitats outside of Poyang Lake they will then decline each time abnormal years occur. These declines, if not offset by above-normal productive years, can cause a slower, but still certain, extirpation of a species.

With migrant species such as those that winter at Poyang Lake, breeding occurs in northern areas and can be linked with winter habitat conditions. Fat, or other reserves that are acquired in winter habitats, can be carried to breeding grounds by birds and used

to produce eggs or fuel incubation. Declines in winter foods can thus affect productivity, further exasperating population declines.

*How much can birds adjust to changes in the Poyang Lake Ecosystem?*
Within Poyang Lake bird species appear to shift habitats readily as conditions change. This is true within years as well as between years. We have less data on the ability of birds to shift among major wetland ecosystems within the central Yangtze basin but some movement between these areas likely occurs. How much change can occur to the system before birds become unable to adapt? This is a difficult question for which we have few data.

Some bird species can likely shift habitats in these extreme, or abnormal years. Others, likely cannot. Siberian cranes, for example, have not been seen outside the Poyang Lake ecosystem in significant numbers during winter in any of the last 15 years. Other tuber feeders such as swan geese (tuber feeding guild), lesser white fronted geese (sedge eating guild), and oriental white storks (fish eating guild) do use other habitats but Poyang Lake is where the greatest concentrations for their species occur. For other species, like shorebirds (invertebrate feeding guild) or Eurasian spoonbills (zooplankton feeding guild), we do not have enough information to know if birds will successfully find other habitats should Poyang Lake become unsuitable.

Poyang Lake is a wetland ecosystem found no where else in Asia. This ecosystem is also populated by bird species that are either endangered or have major proportions of their populations concentrated at Poyang Lake. Given the overall declining status of wetlands that remain in China, and throughout Asia, species that currently depend upon Poyang Lake as winter habitat may have few other likely habitats to utilize should conditions at Poyang Lake decline precipitously. This would be especially true in the future if declines in wetland habitats continue. Further research on how much habitat and where those habitats should be located is critically needed.

Within Poyang lake, should moderate changes occur that cause vegetation zones to shift, it is difficult to predict how successfully bird populations will adjust to these shifts in food availability. Plant population shifts can often occur spatially with changing wetland conditions but these shifts usually take several years. Importantly, during transition times, plant population will decline dramatically until they stabilize under the new conditions. Bird populations during transition periods of food plants would likely decline dramatically.

Further, though tuber producing plants change in abundance with great rapidity in deep water zones during dry years, they do not respond in the same way within shallow water zones in wet years. Historically, tuber producing plants have not colonized in the sedge zones or the higher grassland zones during wet years. Sedges are longer lived perennial species and shift locations even slower than do submerged aquatic plants. Even in extreme water years, sedges have moved little along moisture or elevation gradients.

Finally, if food plants are able to adjust to changing environmental conditions, their productivity may not respond at the level in which foraging guilds that rely on plants require. These species will decline if food is insufficient. It is unlikely that transitioning plant communities will be productive enough to provision the large numbers of birds dependent upon them given a dramatic alteration of the Poyang Lake hydrology. Population declines as a result of insufficient food can lead to extirpation of bird populations before plant populations fully stabilize to new environmental conditions caused by development impacts or other changes in the ecosystem.