

11. ALL CROP SUMMARY

Our assessment of the literature strongly suggests that there is great variation among the nine focal WWL row crops in their use by waterbirds, the resources that fields planted to each crop provide to waterbirds, and the potential impacts that crop production methods have on waterbird populations. Equally variable is the level and distribution of effort (i.e., by crop, waterbird group, region) that researchers have undertaken to acquire this knowledge. In this chapter, we summarize what is known regarding waterbird use of row crop resources, and of the effects of crop production methods on waterbirds, drawing attention to the general trends across crops. We additionally encapsulate current knowledge of focal row crop landscape effects (impacts of row crops on surrounding habitats and waterbirds), as well as industry level changes and their potential impacts on waterbird populations. In the context of assessing current knowledge in light of the effort taken to acquire it, we also highlight where the major gaps in knowledge are, and provide recommendations for the most valuable future research that should close these gaps.

USE BY WATERBIRDS

Use of agricultural fields is not necessarily a sign that a crop is beneficial to a species, as habitat can sometimes be used by species that would fare better elsewhere. For instance, habitats can act as “sinks” if birds sustain high levels of reproductive failure (e.g., due to nests being crushed by farm machinery) or if mortality is high (e.g., due to pesticide use). Use of a crop, however, is the most basic prerequisite for identifying farming practices that benefit species. In this section, therefore, we describe the basic patterns of crop use by WWL waterbirds in focal row crops and BCRs.

Patterns in Waterbird Use Among Focal Row Crops – *Who, When, Where, Doing What?*

In North America, at least 120 of the 216 WWL waterbird species have been documented using agricultural lands planted to one or more of the nine WWL focal crops – 30 waterfowl species (25% of the total), 30 shorebird species (25%), 16 wading bird species (13%), 22 other waterbird species (18%), and 22 wetland-associated landbird species (18%). Waterbird use, however, varies greatly by crop type. Among the nine focal crops, over twice as many species have been reported in rice fields (104 species; 87% of the total number that occur in at least one crop) than in fields planted to any other crop type (Table 11-1). The number of species reported on land planted to corn (45 species; 33% of total), sorghum (37 species; 31%), and winter or spring wheat (31 species; 26%), however, is also noteworthy. Even excluding species that only use crops very rarely, the number of species reported in rice fields still exceeds any other crop, with roughly twice as many species in rice (78 species; 80% of the 98 species that occur in WWL row crops regularly) as in corn (41 species; 42% of total; see Table 11-1) sorghum (37 species; 38% of total), or winter/spring wheat (30 species; 31% of total). As many as 40 species (33%) have been documented in soybean fields, but given the low abundance and nutritional value of resources provided by soybean fields, and the presumed reduction in use in the past few years due to the introduction of genetically-modified (GM) varieties, this number should be interpreted with great caution (see **Resources** below). Inarguably, few species have been reported in cotton (9 species; 8% of total), peanuts (1; <1%), or tobacco (none). In general, from those studies that have evaluated preference for focal crops by quantifying the proportional use in relation to area availability of cropland across the landscape, rice, corn, and wheat are generally observed as

preferred (use > availability) by waterbirds, while sorghum and soybeans are used in proportion to availability, and cotton and sometimes soybeans are often avoided (use < availability).

Who? The principal waterbird groups observed using fields also differs among crop types (Table 11-1). Rice fields appear to attract a great diversity of waterbirds including waterfowl (swans, geese and ducks), shorebirds, wading birds, other waterbirds (primarily rails, gulls), and various WWL landbirds. For the remaining cereal crops of corn, wheat, and sorghum, the primary users include waterfowl (especially geese which may be abundant), a handful of shorebird species, an abundance of cranes, and a few species of landbirds (primarily blackbirds). Soybean fields are visited by a similar array of waterbirds as corn, wheat, and sorghum, but where flooded they can also attract a great diversity of shorebirds. The number and variety of species that have been documented using each crop, however, may have been influenced in part by the relative occurrence of multi- vs. single-species studies conducted in each crop (see **Level of Research Effort** below). Comprehensive multi-species surveys that are standardized across crops would allow one to evaluate the importance of this concern, and improve evaluations of the relative use of different crops by species.

Certain waterbird species could be considered highly associated with agricultural lands given their use of a number of focal row crops during various times of the year (Table 11-1). Of the total 120 species occurring on one or more of the nine WWL focal crops, 69 species have been observed in at least two crop types, and 43 species in three or more crops. Among those species documented using multiple crops, the most notable species (i.e., occurring on at least the five major crops of rice, corn, wheat, sorghum, soybean) are Snow Goose, Greater White-fronted Goose, Canada Goose, Mallard, Northern Pintail, Killdeer, Sandhill Crane, and Red-winged Blackbird. As these eight species have been observed in almost all of the nine focal row crops, they are especially likely to experience cumulative impacts from the positive or negative crop production practices that are common to all crops (see **Effects of Crop Production - Common Trends Across Crops**).

A total of 36 species considered to be of “Conservation Priority” by the National Audubon Society (e.g., because they are listed under the Endangered Species Act, on the Audubon WatchList, USFWS Birds of Conservation Concern, and/or exhibiting significant population declines according to Christmas Bird Count or Breeding Bird Survey data) have been documented in fields planted to one or more of the nine WWL focal crops (Table 11-2). While most of these species (30) have occurred in rice fields, and 17 solely in rice, there have also been 11 species documented in corn, 11 species in wheat, 9 species in sorghum, 7 species in soybean, 3 species in cotton, and one species in peanut fields. Conservation priority species that have been documented in more than two row crops include Northern Pintail (observed using all row crops except peanuts and tobacco), American Golden-Plover (rice, corn, soybeans), Mountain Plover (corn, wheat, sorghum), Long-billed Curlew (rice, wheat, sorghum), Upland Sandpiper (rice, corn, wheat, sorghum), American Woodcock (rice, corn, soybean, cotton), Sandhill Crane (all crops but tobacco), and Whooping Crane (corn, wheat, sorghum, soybean). Three of these eight species have been documented in multiple crop types solely during the nonbreeding season (American Golden-Plover, American Woodcock, Whooping Crane), four species (Northern Pintail, Long-billed Curlew, Upland Sandpiper, Sandhill Crane) during either the breeding or nonbreeding seasons, and Mountain Plover solely during the breeding season. Northern Pintail,

Mountain Plover, Long-billed Curlew, Upland Sandpiper, and American Woodcock have been known to nest in multiple crop types. As these conservation priority species are especially likely to occur on agricultural lands, they are potentially most vulnerable to any changes in agricultural practices. Proposed alterations in row crop production methods should be viewed as a potential threat to the population stability of these species. Equally, these species are those most likely to benefit from targeted attempts to alter farming practices with wildlife conservation in mind.

When? Most waterbird use of WWL focal row crops in North America has been documented during the nonbreeding periods, primarily winter, however some crops, principally rice, corn, and wheat, are also used during the breeding period for foraging and/or nesting (Table 11-1). Across row crops, swans, whistling-ducks, and geese have been documented using agricultural land primarily during the winter and migration periods; dabbling ducks additionally use fields (primarily corn and wheat) during the breeding period. Shorebirds have been observed in cropland during all seasons, but with numbers and diversity greatest during nonbreeding periods when rice and soybean fields are flooded. Shorebird use of row crops during the breeding period has primarily been in corn, wheat, sorghum, and rice fields. Wading birds have occurred in fields most often during winter and migratory periods, with fewer species observed during the breeding period in rice or wheat. Among other waterbirds, grebes, rails and gulls occur on cropland principally during nonbreeding periods, with a few species also using soybean and flooded rice fields during the breeding period; cranes use agricultural fields almost exclusively during nonbreeding periods. Finally, wetland-associated landbirds have been observed on cropland throughout the year, but during the breeding season primarily in corn, sorghum, and soybean fields.

Where? For each crop, the geographic source of information pertaining to waterbird use varies greatly. While a portion of documented cases of waterbird use has been from fields located within the focal BCRs, many records (a majority for rice, corn, soybean) are from non-focal regions in North America. Among focal BCRs, however, certain regions appear to receive disproportionate waterbird use of agricultural lands (Table 11-3). In terms of the total number of species documented, number of crop types used, and number of species reported for each crop, the highest use region is the **Mississippi Alluvial Valley** (BCR 26; 31 species observed; 5 crops used, primarily rice and flooded soybeans; species number varying from 1 in corn and cotton to 23 in rice). Moderately high use of agricultural lands was also found in the **Prairie Potholes** (BCR 11; 18 species; 4 crops, primarily wheat and corn; species number varying from 6 in soybeans to 16 in spring wheat), **Central Mixed-Grass Prairie** (BCR 19; 15 species; 4 crops, primarily wheat and corn; species number varying from 5 in sorghum and soybeans to 11 in winter wheat), **Eastern Tallgrass Prairie** (BCR 22; 13 species; 4 crops, primarily corn; species number varying from 3 in sorghum to 12 in corn), and in the **Shortgrass Prairie** (BCR 18; 12 species; 5 crops, primarily corn; species number varying from 1 in cotton and peanuts to 7 in corn). In contrast, little use has been documented for the **Central Hardwoods** (BCR 24; 6 species; 3 crops; species number varying from 3 in corn and winter wheat to 4 in soybeans) and **Prairie Hardwood Transition** (BCR 23; 4 species; 3 crops; species number varying from 1 in soybeans to 4 in corn).

Doing What? The behavioral activity most commonly observed by researchers has undoubtedly been that of waterbirds foraging on row crop resources within fields. This is not surprising given

that most use occurs during nonbreeding periods, but even during the breeding season, foraging is the predominant activity recorded. There are clearly fewer records of waterbirds using fields for breeding activities such as nesting or brood rearing. Accounts of waterbirds nesting in cropland are significant, however, as these species are especially vulnerable to crop production methods that may impact nest success. Among the nine focal row crops, more species have been confirmed to nest in wheat (17 species: seven waterfowl, eight shorebirds, two landbirds) and rice (13 species: four waterfowl, three shorebirds, one wading bird, four other waterbirds, one landbird) than in corn (Killdeer, Red-winged Blackbird, Common Yellowthroat), sorghum (Killdeer, Red-winged Blackbird), and soybeans (Killdeer). We found no accounts of waterbirds nesting in cotton, peanuts, or tobacco. Killdeer are a common cropland nesting species, as they have been documented to nest in rice, corn, wheat, sorghum, and soybean fields. Mallard (nesting in rice and wheat) and Red-winged Blackbird (nesting in rice, corn, and wheat) are species that are next most commonly observed breeding in focal row crops.

Pattern of Research Effort

Although the above summary is informative, it is important to recognize that it is necessarily influenced by the nature of the body of research that has been conducted. Whether the described patterns of waterbird use across crop types, species groups, and regions are an accurate and complete reflection of actual use depends on whether the studies conducted are truly representative of those that could have been conducted. A full interpretation of these patterns, therefore, must also consider the level of research effort undertaken to obtain our current knowledge. Assessing patterns in the research that has been conducted can help reveal potential biases in current knowledge, as well as identifying gaps in the research literature.

Our literature search yielded 349 documents related specifically to waterbird use of one or more of the nine focal row crops in North America. Examination of this research effort reveals that the proportion of studies conducted in each crop, on species in each waterbird group, and in each focal BCR, varies greatly (Figure 11-1; studies documenting use in multiple row crops, by multiple waterbird groups, or in multiple BCRs, were included in proportions by independently counting them for each crop, waterbird group, or BCR examined in the study, i.e., a given study may be included as a research effort more than once in a given chart). Most of the work in North America, by far, has occurred in rice, corn or wheat fields (Figure 11-1A), and has been clearly focused on waterfowl when viewed across all focal crops and BCRs (Figure 11-1B). The larger proportion of research conducted in the **Mississippi Alluvial Valley** (BCR 26), **Prairie Potholes** (BCR 11), **Eastern Tallgrass Prairie** (BCR 22), and **Central Mixed-Grass Prairie** (BCR 19; Figure 11-1C) is likely due to the prevalence of the production of these three main crops (rice in the **Mississippi Alluvial Valley**; corn and wheat elsewhere) in these regions.

The research effort (proportion of studies) for rice in North American is smaller than that for corn and similar to that for wheat (winter or spring; Figure 11-1A), yet the documented number of species observed in rice fields (104 species) is at least double that observed for corn (45 species) and wheat (31 species in winter or spring wheat). One possible explanation for this could be the higher number of multi-species studies in rice (9 North American studies) than in other crops (corn: 4 studies; wheat: 4; soybeans: 4; sorghum: 2; cotton, peanuts, tobacco: 0). Multi-species studies are more likely to document all species that use a crop, especially those

that occur only rarely, inflating species counts for crops like rice relative to other crops. Even with rare species excluded, however, the number of species in rice (78) remains almost double that of corn (41) and certainly that of wheat (30). This strongly suggests that the exceptionally high use of rice compared to corn and wheat is an accurate assessment of the relative use of these three crops. Similarly, while the research effort in sorghum has been relatively low compared to other crops, more waterbird species have been documented in sorghum than in wheat, and nearly as many species have been observed in sorghum as in corn. This high use of sorghum fields relative to the little effort that has been undertaken to document waterbird occurrence in the crop suggests that sorghum is highly used by waterbirds, perhaps even more than has been documented.

Although research in all crop types has been highly focused on waterfowl (Figure 11-1B), there has been at least moderate attention paid to all waterbird groups, especially in rice fields (Table 11-1). Shorebirds and landbirds are also well represented in studies from corn fields (Table 11-1), indicating that documented use of corn fields may not be biased by a disproportionate focus on waterfowl. Nonetheless, further work to document the full range of species using corn fields could reveal additional species, particularly nonbreeding shorebirds, using the crop. For wheat and sorghum fields, documented use by different taxonomic groups (Table 11-1) roughly matches the overall level of research effort on each group (Figure 11-1B), with twice as many waterfowl species documented as shorebird or landbird species. Although a direct correspondence would not necessarily be expected, this pattern raises the possibility that the documented patterns of use may in part reflect the taxonomic focus of research undertaken in row crops generally. As with corn, a greater research focus on non-waterfowl species, particularly shorebirds, may uncover the use of wheat and sorghum by a greater diversity of waterbirds. Unlike rice and soybeans, documented waterbird use in corn, wheat and sorghum fields is based largely on single-species studies that were not designed to record waterbird use comprehensively. It is quite possible, therefore, that our knowledge of waterbird use of these crops is incomplete.

Documented use of soybean fields is likely to be a close estimation of actual use, especially for fields that are purposely flooded and which have been the subject of multi-species studies. The number of shorebird species documented in soybeans is roughly twice the number of waterfowl species observed in fields, despite the greater focus on waterfowl in row crop studies. The primary cause of uncertainty concerning the data for this crop is the substantial change in production conditions that are thought to have occurred following the recent introduction of GM varieties. To our knowledge, none of the studies we reviewed involved GM varieties and it is uncertain whether the results from earlier studies apply under the new conditions.

It is plausible that the low numbers of species recorded in cotton, peanut and tobacco reflects a lack of attention to these crops (e.g., because waterfowl rarely use them), but the general lack of appropriate resources for waterbirds in these crops makes the result unsurprising.

In general, the recent description of substantial shorebird use of certain row crops (e.g., Braile 1999) indicates that there may be other gaps in our knowledge, especially for shorebirds that will use fields that are dry or rain-flooded. Additionally, because some waterbirds (especially rails) are secretive and typically occur in low abundances in any habitat type (especially during

nonbreeding periods), it is also possible that use of row crops by these species is underestimated. More comprehensive studies, especially for crops and regions where multi-species surveys have not been conducted would help clarify these issues.

The number of species documented in focal row crops for each focal BCR (Table 11-3) closely approximates the relative research effort (proportion of studies) conducted in each region (Figure 11-1C). Given the geographic placement of key research institutions and universities involved in the study of wildlife use of agricultural lands (e.g., Delta Waterfowl Foundation, Northern Prairie Wildlife Research Center, Institute for Wetlands and Waterfowl, Iowa State University, University of Nebraska, Mississippi State University), it is not surprising that much of the waterbird use of focal row crops has been documented for the **Mississippi Alluvial Valley** (BCR 26), **Prairie Potholes** (BCR 11), **Central Mixed-Grass Prairie** (BCR 19), and **Eastern Tallgrass Prairie** (BCR 22) regions. These regions also encompass the areas where much of North America's rice, corn and wheat are produced, and so it is also not unexpected that these regions are where most of the waterbird use has been documented, and most of the research focused. Given that the major row crops of corn, wheat, and soybeans are also produced in the **Prairie Hardwood Transition** (BCR 23) and **Central Hardwoods** (BCR 24) regions, it is perhaps surprising that more waterbird species have not been documented in these regions. The low use documented for these regions is potentially explained, at least in part, by the absence of research institutions focused on studying wildlife-agricultural interactions, as well as by the relatively smaller areas they encompass. Additional surveys of row crops in these regions would clarify whether the apparent differences in use among regions are real, or simply a by-product of differential research effort.

RESOURCES

Comparison of Crop Resources and Their Relative Value to Waterbirds

Although the resources provided by natural habitats such as wetlands or native grasslands are nearly always preferable to those found on agricultural lands, our literature review suggests that croplands can provide resources of value to waterbirds. The relative value of each crop, however, varies considerably. Although the number of species that have been documented in each crop may provide a sense of relative value, only by considering the specific characteristics of the resources provided by each crop – the energy content of waste grain, the diversity and abundance of other foraging resources in fields, the nature of nesting habitat and risk of nest failure – can we begin to assess the true value of each crop as nonnative habitat for waterbirds.

Foraging Resources. With the exception of shorebirds and insectivorous landbirds, most waterbirds appear to consume primarily those food resources provided by the crop itself – e.g., waste grain or green vegetation of the growing crop (Table 11-4). The caloric content of these resources, however, differs substantially among crops (Table 11-5). Corn kernels and sorghum grain have the highest energy content, followed by wheat seed and rice, whereas the green vegetation of wheat and soybeans provide the lowest energy content. Corn, sorghum, and rice are also more digestible than wheat green forage and soybeans. Although the green vegetation of wheat is low in caloric content and digestibility, it is high in protein and fiber content. This high nutritional content of wheat renders it of particular value to grazing waterbirds, such as swans and geese, especially during the pre-breeding phase of the annual cycle.

In addition to the food resources provided by the planted crop, for some focal crops, other non-crop foraging resources such as the new shoots/seeds of weed species, and terrestrial or aquatic invertebrates, have been documented as available and important to a number of waterbirds, particularly non-waterfowl (Table 11-4). Crops vary from providing resources solely from the crop itself (e.g., the waste seed and green forage of wheat) to providing a wide gamut of resources including waste grain, weed seeds, invertebrates, amphibians, fish, birds, and small mammals (e.g., flooded rice fields). Intentionally flooded cropland, such as rice or soybean fields, are unusual among focal crops in that they support a community of aquatic prey that can attract a large number of wetland-associated waterbirds such as shorebirds, wading birds and dabbling ducks. Rice, corn, and flooded soybean fields appear to provide the most diverse food resources (Table 11-4), and not surprisingly, fields planted to these crops tend to attract the greatest diversity of waterbirds (Table 11-1). Flooded rice fields provide rice grain for granivorous waterfowl, cranes and blackbirds; green vegetation of sprouting rice and weed species for grazing species (geese, coots); weed seeds for cranes; benthic invertebrates for all waterbird groups (particularly shorebirds); crayfish (especially when farmed in rotation with rice) for wading birds and large shorebirds; and aquatic vertebrate prey (fish, amphibians, small birds and mammals) for wading birds. Corn fields have been recorded to provide waste corn to waterfowl and cranes; ripening corn, green vegetation of growing corn, and weed seeds to blackbirds; and terrestrial invertebrates to some shorebirds and landbirds. Soybean fields, when flooded, may support a high diversity and abundance of aquatic invertebrates important to shorebirds and other waterbirds. When unflooded, however, soybean fields generally offer only waste soybeans to waterfowl and cranes, and given the low nutritional value of soybeans as well as the risk of esophageal impaction, unflooded soybean fields may be detrimental to those waterbirds that are drawn to them. Wheat and sorghum fields appear to be less diverse in the foraging resources they provide to waterbirds. For these crops, however, the presence, abundance, and importance of weed seeds and terrestrial invertebrates have not been studied in detail (a data gap), and it is possible that these crops provide a greater variety of food resources than has been documented thus far. By all indications in the literature, cotton, tobacco and peanut fields provide minimal foraging resources for waterbirds.

Nesting Resources. More species appear to nest in wheat and rice fields than in the other focal row crops. The risks of nesting in cropland seem to be highest for corn, wheat, and soybeans because tillage, sowing, and pesticide applications for these crops tend to coincide closely with the timing of waterbird nesting activities. Thus, if we assess value using a combination of the degree of use, weighted by the relative risk of nest failure, rice fields appear to be of greatest value to waterbirds as nesting habitat. Clearly, however, this relationship is not well quantified. Moreover, detailed studies of nesting and, especially, fledging success of many species, however, are largely lacking. Waterbirds have not been recorded nesting in fields planted to cotton, peanuts, or tobacco, which further supports the view that these crops have low overall value to waterbirds.

Knowledge Gaps

The abundance and consumption of waste grain and growing crop vegetation have been assessed for virtually all focal crops except sorghum. For most crops, however, little is known regarding the abundance and relative importance of foraging resources other than those directly derived from the crop. For rice fields, variation among the major rice growing regions in the abundance

of aquatic invertebrates in fields has not been quantified, and an assessment of aquatic vertebrate prey and the importance of this resource to wading birds at all times of the year would also be helpful. Similarly, enumerating the abundance of aquatic invertebrates in flooded soybean fields would be a crucial step towards evaluating the degree to which winter flooding enhances the value of soybean fields for waterbirds. For most crops, particularly wheat, sorghum, and soybeans, the abundance and importance to waterbirds of the new shoots and seeds of weed species and of terrestrial invertebrates has not been thoroughly evaluated. Placing the use of crop resources into the broader context of other foraging resources used by waterbird populations would further extend current knowledge. Lastly, additional studies of the success of nesting attempts and post-fledging survival - especially relative to equivalent measures taken from more natural habitats - would clarify the value of crops to breeding waterbirds.

EFFECTS OF CROP PRODUCTION METHODS

Common Trends Across Crops

There are a number of common themes across crops in how production methods impact waterbirds (Table 11-6). Among the methods used to prepare the soil for new plantings, practices associated with conventional tillage have been shown to have both negative and positive effects on waterbird resources and habitats. In conventional tillage, plant residues are reduced in the fall either by burning or plowing; fields are then disked and harrowed in spring to create a smooth, residue-free surface for new plantings. For some crops (e.g., rice, corn) burning harvest residue may benefit granivorous waterbirds by increasing access to waste grain, but it may also reduce the total amount of grain. Similarly, plowing can increase access to invertebrates temporarily (demonstrated in corn and soybeans), but is also associated with a number of negative effects. For instance, plowing has been shown to bury waste grains (corn, sorghum) and soybeans (although for this last crop the effects may have benefits by protecting waterbirds from ingesting soybeans and causing esophageal compaction). Plowing can also lower the amount of vegetative nesting cover (corn, wheat), which can be important to cropland nesting birds. As a result, nest density, breeding success, or overall waterbird use of plowed fields tends to be low.

In contrast to the overall impacts of conventional tillage, the benefits of no or reduced tillage practices seem to far outweigh any negative impacts on waterbirds. Such ‘conservation tillage’ involves leaving the residue on the surface by not conducting any fall burning or plowing or any spring disking. Instead seeds are ‘slot planting’ directly into the soil through the previous crop’s residue, and herbicides are used in lieu of mechanical weeding. When compared to conventional methods, no and reduced tillage fields provide greater access and abundance of waste grains (corn), a higher abundance of terrestrial invertebrates (especially earthworms; corn, soybean, and cotton), and more nesting cover for waterbirds (corn, wheat). The potentially higher use of herbicides in conservation tillage fields, however, may diminish the abundance of foods provided by weedy species (new shoots, seeds), and this has been raised as a negative impact of concern by some researchers.

As for other crop production methods, impacts on waterbirds and their habitats are varied, but a number of consistent patterns are evident across focal crops (Table 11-6). In rice and soybean fields, the use of winter flooding as a management tool clearly benefits a number of waterfowl, shorebirds, wading birds, other waterbirds, and a select group of landbirds attracted to aquatic

habitats. Impacts of sowing practices on waterbirds depend on the method (for rice: dry/ground vs. wet/aerial seeding; for other crops: ground seeding using farm machinery) and timing of planting relative to the preferences and timing of waterbird nesting in row crop fields. For crops that are planted during the spring or summer (rice, corn, spring wheat, sorghum, soybeans), loss of nests from sowing activity has been documented only for waterbirds nesting in corn and wheat. No such impact has been documented in rice fields, likely because most ricefield-nesting waterbirds do so when fields are flooded and thus have been aerially seeded.

The use of pesticides (both insecticides and herbicides) has resulted in a number of negative consequences for waterbirds. Direct waterbird mortalities have been documented in fields planted to rice, corn, wheat, and cotton, and the indirect effects of diminished food resources (invertebrates; new shoots/seeds of weed species) have been documented for corn and soybean fields. The adoption of GM crops that enables more effective herbicide use likely exacerbates indirect effects (see also **Agricultural Industry Changes and Waterbird Conservation** below), but little research on this topic has been conducted that relates directly to waterbirds. Damage to waterbird nests from farm machinery passes to apply pesticides is likely for all crops with spring/summer growing seasons when pesticide applications are most intense.

Issues connected to harvest vary across crops. For rice, the introduction of more efficient harvesters appears to impact availability of waste grain to granivorous waterbirds such as geese. The newer stripper-header harvesters leave taller residual stalks than conventional harvesters, which might affect field access for many species. A recent trend in increased harvester efficiency has also resulted in a significant decrease in the abundance of waste corn for waterbirds. More generally, increasing harvester efficiency has potential to affect grain feeders in all crops, although commensurate increases in crop yields may compensate in some cases.

Finally, there are a few cases where the patterns of rotational cropping and fallowing of cropland influences waterbirds. Rotation of rice with crayfish farming has been illustrated to benefit most waterbirds, particularly wading birds. In contrast, for waterfowl that initiate nests in winter wheat stubble fields in the spring, which are then planted to a cover crop such as alfalfa instead of remaining fallow through one growing season ('summerfallow'), planting and/or late summer/fall haying-cutting of the rotation crop can be a major source of egg or hen mortality.

Knowledge Gaps

For a number of focal crops, there are gaps in our knowledge of the impacts on waterbirds of various crop production methods. The effects of tillage practices (conventional or conservation) on the abundance of waterbird foods (invertebrates, weed species) have not been documented for wheat, and impacts on breeding birds have not been studied for waterbirds nesting in fields planted to sorghum and soybeans. To some extent, these apparent gaps may simply reflect the limited use of these crops at particular times; more comprehensive surveys of crop use would clarify this issue. The effects of pesticide use on food resources in sorghum, cotton, and in new GM crops (especially rice, corn, soybeans and cotton) are unknown, and the rate of damage to nests from pesticide applications has not been evaluated for species breeding in corn, wheat, sorghum or soybeans. Finally, in fields planted to spring wheat and sorghum, it is likely that summer grain harvesting destroys those waterbird nests occurring in fields, but this has not been evaluated.

LANDSCAPE EFFECTS

Looking beyond the specific activities that take place in individual farm fields, it is clear that the collective agricultural enterprise has had substantial effects on wildlife at broader landscape levels (McNeely and Scherr 2003). Such large-scale impacts of agriculture on waterbird populations (primarily waterfowl) and waterbird habitats (wetlands, uplands) have been evaluated by a number of reviews, and we will only summarize some of the main issues here. In addition to the obvious loss of natural habitats through conversion to farmland, documented landscape-level impacts of agriculture include the effects of wetland deterioration in agricultural areas and cropland intensification on wetland and upland-breeding waterbirds (Trauger and Stoudt 1976, Miller 2000), changes in mammalian nest predator communities and nest predation rates in natural habitats (Cowardin et al. 1983, Klett et al. 1988), and shifts in waterfowl migration phenologies and geographic range as a result of landscape-level cropping patterns (Sutherland and Crockford 1993, Robertson and Slack 1995, Gauthier et al. 2005).

Studies of the specific effects of given cropping patterns at the landscape scale, particularly in relation to individual crops, however, are less common. Our literature search revealed only a few such studies that directly address the impacts of WWL focal row crops on the quality or use of adjacent and surrounding natural habitats important to waterbirds. Here, we have subdivided them into several broad classes in order to identify some of the key areas where additional investigation might be helpful.

Water Quality and Consumption

In rice fields, concerns have been raised over the quality of water released from rice fields into neighboring wetlands or streams, including the chemical residues from insecticides, herbicides and fertilizers, as well as elevated water temperatures, salinities and concentrations of trace elements such as selenium (Cooper 1993, CH2M Hill 1996, Maul and Cooper 2000). All of these changes in water quality have the capacity to impact fish and other aquatic organisms downstream (Cooper 1993), many of which are important food resources for some waterbirds. Some contaminants, particularly selenium, also have potential to seriously impact the breeding success of birds nesting in wetlands that have received runoff water from agricultural habitats (Ohlendorf et al. 1986, Rubega and Robinson 1997).

A related concern is the water-consumptive nature of certain crops, especially cotton (Acquaah 2005), and the impact of this consumption on neighboring wetlands. Similar concerns arise for cotton as for rice fields, namely pesticide residues from heavily irrigated cotton fields entering other natural habitats and affecting the productivity of nesting birds such as American Avocets and Black-necked Stilts (Clark et al. 1995). Moreover, as cotton is typically grown in arid regions where the sufficient allocation of water among competing urban, agricultural and natural resource uses is significantly strained, the continued existence of natural and managed wetlands for waterbirds is often threatened by cotton agriculture (see also **Agricultural Industry Changes and Waterbird Conservation** below). Because cotton holds little value as waterbird habitat (see COTTON chapter), this is perhaps the gravest potential landscape effect currently exerted by any of the WWL focal row crops.

Predators

Agriculture has significantly altered the relationships between waterbirds and their predators. Row crop habitats are often very open (especially during the non-growing season), providing limited opportunities for birds to seek cover. Management activities that increase the amount of cover, as along field margins, might therefore have benefits for certain species. The structure of agricultural landscapes might also influence the behavior of individual predators. For example, in corn and wheat fields, Striped Skunks (*Mephitis mephitis*) – a principal mammalian predator of breeding waterfowl in the **Prairie Pothole** (BCR 11) region – have been shown to select wetland edges that are surrounded by fields planted to crops such as corn or wheat (Phillips et al. 2003). This result has clear ramifications for the breeding success of wetland-nesting waterbirds in this and other regions.

Shifts in Local Distribution Patterns

Lastly, the relative abundance and juxtaposition of agricultural and natural habitats within a landscape can affect the way in which the land is used by waterbirds. For example, wetlands used by spring-migrant Tundra Swans in southern Ontario, and roost sites used by migrant Whooping Cranes in Saskatchewan (**Prairie Potholes**; BCR 11), tended to be found in close proximity to agricultural fields where birds foraged (Johns et al. 1997, Petrie et al. 2002). A similar effect has been observed in Texas (**Shortgrass Prairie**; BCR 18), where the number of Sandhill Cranes wintering on pluvial wetlands increased with the amount of available sorghum stubble in surrounding fields (Iverson et al. 1985a). More generally, in California, the relative abundance of rice fields and natural habitats in the surrounding landscape appeared to influence the numbers of several waterbird groups that used individual fields (Elphick 1998).

AGRICULTURAL INDUSTRY CHANGES AND WATERBIRD CONSERVATION

For a number of focal row crops, there are ongoing industry-level changes that have the capacity to impact waterbird populations in various ways (primarily negative), and these are worth highlighting here. These examples illustrate the dynamic nature of modern agriculture and the need for conservation practitioners to constantly re-evaluate how changing industry practices are likely to affect wildlife conservation. Evaluating the consequences of these industry-level changes on waterbird population dynamics should be a high priority for future research.

Loss of Rice Lands

The greatest potential threat to waterbirds using rice fields is the replacement of flooded rice with other less beneficial forms of agriculture (e.g., cotton) or land development. Loss of active rice lands in areas of Louisiana and Texas, for example, present potential threats to the waterbird populations that occur in these regions, and conversion of rice fields to cotton is an ongoing threat in California.

Genetically Modified (GM) Crops

Over the last decade, there has been an increasing yearly trend in the area allocated to GM crops worldwide, including GM varieties of rice, corn, soybeans, and cotton (Krapu et al. 2004, Romeis et al. 2006b). By 2002, for example, 75% of the U.S. soybean crop was planted to GM types (Krapu et al. 2004), and in 2004, 32% of field corn and 46% of field cotton in the U.S. was planted to GM cultivars producing *Bt* toxins (Naranjo et al. 2005). This increase in the

production of GM crops is another industry-level practice that has the potential to significantly impact waterbirds in both positive and negative ways.

Potential benefits to waterbirds of GM crops include: 1) increases in the amount of waste grain left in fields, 2) an ability to more easily adopt reduced or no-till practices, and 3) an allowed presence of non-target terrestrial invertebrates in GM pest resistant (*Bt*) crops. Assuming yields are significantly greater in GM crops through improved pest control, and that spillage is a fixed percentage of total yield, GM cropping may mean more waste grain left in fields for foraging waterbirds. For rice and corn fields, where waste rice and corn kernels are foraging resources of high caloric value to waterbirds, such increases could contribute significantly to the overall resource value of croplands. Tandem increases in harvester efficiency, however, may counteract any effects of increased yield. Indeed, after accounting for a 20% increase in yield over a 20 year period (1978-1998), Krapu et al. (2004) documented an overall decline in the amount of waste corn available in Nebraska corn fields of up to 47% as a result of increased harvester efficiency. Next, according to a study conducted by the American Soybean Association, GM crops appear to encourage more widespread adoption of conservation tillage practices among growers, as GM crops enable more targeted herbicide (e.g., glyphosate) applications, decreasing the need for traditional weed control via plowing, disking, and cultivating activities (see <http://www.soygrowers.com/ctstudy/>). The potential benefits of reduced and no-till practices on GM crops would include greater access to waste grain, increased cover for nesting birds, and reduced nest disturbance. Finally, *Bt* transgenic crops may provide a promising alternative to the use of broad-spectrum insecticides that eradicate entire invertebrate communities in fields. Common in corn and cotton, this type of GM crop is genetically engineered to produce insecticidal proteins from *Bacillus thuringiensis* (*Bt*) which confers a built-in resistance to lepidopteran and coleopteran insect pests (Naranjo et al. 2005a, Romeis et al. 2006). Available evidence strongly suggests that densities of various terrestrial non-target arthropods and other insects are unaffected by the insecticidal properties of the *Bt* crop (Bitzer et al. 2005, Bhatti et al. 2005a, Bhatti et al. 2005b, Daly and Buntin 2005, Dively 2005, Head et al. 2005, Naranjo 2005b, 2005c, Pilcher et al. 2005, Torres and Ruberson 2005, Whitehouse et al. 2005). Depending on the extent to which terrestrial invertebrates are an important food resource for waterbirds in these crops (a significant knowledge gap for most focal row crops, see below), the adoption of *Bt* crops may benefit a number of waterbirds. Especially for crops of minimal use to waterbirds, such as cotton, adoption of *Bt* crops may be one of the only production practices enhancing cropland habitat for wildlife.

There is one negative effect of the production of GM crops, however, that may outweigh any of the potential benefits to waterbirds described previously. As glyphosate herbicides used for weed control in GM crops target all plant species except the crop, any weed species resources (new shoots, seeds) of value to waterbirds are significantly reduced, if not completely eradicated, in GM crop fields (Fawcett and Slife 1978, Peterson et al. 2002, Heard et al. 2003). This likely detracts from the overall resource value of these crops for grazing waterbirds such as geese, for seed-eating species such as waterfowl and certain landbirds (Chamberlain et al. 2007), and potentially also for waterfowl and shorebirds that feed on aquatic invertebrates that rely on decaying plant matter (detritus) from weed species in flooded fields. This loss may be particularly significant for crops such as soybeans and cotton, for which the food resources from

weed species are perhaps the only feature redeeming such cropland from not providing resources of value to waterbirds (see SOYBEAN, COTTON chapters).

Continuous Cropping

The incidence of continuous cropping, whereby fields are planted to another crop type immediately after harvest instead of being left fallow for a year, has steadily increased in regions such as the **Prairie Potholes** (Carlyle 1997). Under such continuous cropping practices, the waterfowl, shorebirds, and blackbirds that initiate nests in cropland stubble (such as in wheat) that is subsequently planted to another crop may suffer high rates of nest loss to tillage and sowing operations in the middle of the nesting season. This shift towards continuous cropping has been suggested as a cause for Northern Pintail population declines (Podruzny et al. 2002), and could contribute to other species' declines should this industry-level trend continue in the **Prairie Potholes** and elsewhere.

RESEARCH NEEDS AND RECOMMENDATIONS

Further Research on Waterbird Use

To date much research effort has focused on crops that are either very widespread or known to be used by large numbers of flocking waterbirds (Figure 11-1). Very little work has been conducted in cotton, peanut, or tobacco fields, and this is probably appropriate since there is little evidence that these crops are used by waterbirds, nor any reason to expect that they would be. Wheat, and especially sorghum, have perhaps received less attention from researchers than might be expected given their potential value to waterbirds. Corn and soybeans have been better studied, but are also undergoing important industry changes that warrant further work in order to better understand the long-term consequences of these changes.

For all crops but rice, there have been relatively few studies that have attempted to document the full range of bird species using fields (e.g., our survey found no studies in cotton and only 4 in each of corn, wheat, and soybeans), with most research focusing on individual species of special interest. In particular, there has been a clear emphasis on species that occur in dense concentrations, especially waterfowl, and to some extent also cranes. When multi-species studies have been conducted in a crop, they often are not repeated throughout the large area over which the crop occurs. Recent discoveries indicate that shorebird use of row crop fields may be more extensive than previously assumed, and highlight the fact that there are knowledge gaps, even for species that occur in farm fields in conspicuously large flocks. Detailed knowledge of crop use by species that are common, but sparsely distributed, also is likely to be much less complete. Overall, the relatively small number of studies focusing on the entire assemblage of waterbirds using row crops suggests that the diversity of species using some crops may be underestimated. Moreover, the lack of a systematic approach to quantifying species richness and abundance across crops makes comparisons among regions, crops, and production practices difficult.

We believe that the most efficient approach to improving our understanding of the relative use of these crops to waterbirds would be to initiate a volunteer-based, citizen-science project centered around the goal of collecting comprehensive information on the numbers and species of birds using fields planted to these crops. Such a program would have the additional benefits of galvanizing interest in the potential for agricultural habitats to contribute to meeting conservation

goals, and would provide a potential mechanism for long-term monitoring of bird numbers in farmland.

Research Needs Common to All Crops

In general, across the WWL focal row crops in North America, the gaps in our knowledge of waterbird use, crop resources, and the effects of crop production methods are quite similar, and consequently, many of the research questions of highest priority transcend all crop types.

Nocturnal foraging and cumulative use across landscapes: With respect to waterbird use, two topics are of considerable interest for a number of crops – nocturnal habitat use, and estimating cumulative use across space by species that are widespread but occur at low densities. For crops in which recreational hunting is common (e.g., rice, corn, wheat, soybean) and thus where nocturnal use may be high, there has been little quantification of use at night. Such information would provide a more comprehensive assessment of the relative use of crop types by waterbirds. Second, for certain species that are widespread in their use of a crop but that occur in small numbers in any particular field (e.g., Killdeer), estimating the cumulative abundance across fields would provide a valuable landscape perspective on the overall importance of a crop to that species. The ability to obtain such landscape-level estimates of abundance is another possible advantage of instigating a broad-scale citizen-science based program to describe bird use of agricultural fields.

Tillage practices: Common gaps across crop types also exist in our understanding of the effects of crop production methods on waterbirds, while in other cases there is potential to bridge knowledge gaps by extrapolating across crops. To resolve more fully whether conventional or conservation tillage most benefit waterbird communities using row crop fields, we need to evaluate the positive and negative effects of all phases of both practices on more species and during all phases of the annual cycle. Ultimately, decisions need to be weighted by the overall diversity, abundance, and perceived conservation value of those species affected by each method. Additionally, it is quite possible that there will be no simple prescription and that some combination of methods is preferred in order to benefit the full suite of target species.

Impact of genetically modified (GM) crops: The direct impacts of the production of GM varieties on waterbirds using focal row crops are virtually unknown, as we know of no studies that have explicitly examined this topic. Understanding the overall impact of GM crops on waterbirds will require a balanced evaluation of how GM crop-associated changes in the foraging (i.e., increases in waste grain or terrestrial invertebrates; decreases in new shoots/seeds of weed species or in aquatic invertebrates) or nesting resources (i.e., increased nesting cover from the adoption of conservation tillage) affect the various different waterbird species using crop fields. Depending on how species use a particular crop, some species may benefit (e.g., species that forage primarily on terrestrial invertebrates), while others may be adversely affected (e.g., grazers and seed-eating species). At the very least, such an evaluation will require improving our knowledge of the relative importance of weed species and aquatic and terrestrial invertebrates as foraging resources for the suite of waterbirds using a crop. To this end, we first need to quantify better the resources available in each focal row crop for which GM varieties have been introduced, and to study the typical consumption and use of these resources by waterbirds in these crops. Most valuable will then be to conduct a series of well-designed

experimental studies that test whether changes in waterbird use of fields are linked to changes in the availability or abundance of resources that result from the introduction of GM varieties.

Resource use and demography: As with much wildlife management, one of the biggest challenges to researchers is to go beyond simply describing use patterns and actually connect those patterns to demographic processes that influence population size. Unless one knows how resources limit populations of waterbirds using row crop fields, it will remain difficult to fully assess how changing management practices might affect species abundance. For virtually all crops, we need to quantify the available food resources and their consumption by waterbirds better, especially the invertebrates (aquatic for rice and soybean fields; terrestrial otherwise) and new shoots and seed of weed species present in fields. Further work in this area will allow an assessment of the potential role that waterbirds can play in the biological control of crop pests and in lessening a traditional dependence on pesticide use. Moreover, wherever possible we need to link any information on food availability with information on predation risk and other in-field factors influencing survival to assess the demographic consequences of different farm management methods. In a similar vein, we need to document the breeding success of species that nest in row crops better. Importantly, we need to do more to extend this work beyond the nest phase by better addressing the much harder-to-study topics of post-fledging survival and subsequent recruitment. Explicitly relating these demographic measures to quantified assessments of food and nesting resource availability will make it easier to identify specific practices of conservation value.

Rates of nest success and waterbird mortality related to various crop production techniques (e.g., tillage, sowing, and pesticides) have been quantified for only some species in some crop types. Beyond quantifying these demographic parameters for a broader range of conditions, a key area of future research will be to assess how specific practices combine to contribute to the overall stability of waterbird populations, especially for Conservation Priority Species. This work will be particularly challenging because most of the focal waterbirds are migratory and do not occur in agricultural habitats year-round. Consequently, researchers will need to look beyond the crop systems themselves, and evaluate the how impacts of production methods during the phase of the annual cycle when a species uses agricultural land relate to events during the rest of the year.

Pesticide use and pest bird management: Impacts of pesticides on non-target invertebrate and plant food resources have yet to be documented in detail for many crops, and taking the next step to assess any subsequent impacts on the birds that eat these foods will be important. Continued research on alternatives to pesticide use including use of low toxicity chemicals or crop management practices (e.g., integrated pest management, organic farming) that reduce the need for chemical control will be immensely valuable. For all crops in which crop damage is an issue (particularly rice, corn, and wheat), a better understanding of the cost-effectiveness of the various alternatives to lethal control of bird pests (e.g., blackbirds) will be necessary before such practices are widely adopted. Equally, assessments of the economic impact of pest species have not been conducted in all crops, and this information may better inform debates over whether control is necessary.

Trade-offs between waterbird conservation goals and economics: Finally, investigating the trade-offs between the benefits and costs of various crop production methods to the conservation

of waterbirds and the economics of crop production will be a vital focus for future research for all crop types. Specifically, better integration of conservation activities within the framework of farm economics could help resolve certain, very particular, conservation concerns. For example, recent work has been conducted in California to protect Tricolored Blackbirds nesting in farm fields by compensating farmers for their lost crop. Bringing ecologists together with agro-economists might provide fruitful research that would identify additional cases where a similar approach is a cost-effective conservation strategy. More generally, combining ecological and economic information will ultimately be needed if we are to design sustainable conservation-oriented agronomic practices.

CONCLUSIONS

To summarize, our survey of the research literature on waterbirds in row crop fields demonstrates that there is a great deal that we know, but also highlights a number of key areas where additional research would be valuable. Not surprisingly, many of the gaps in knowledge involve studies that would be technically or logistically difficult to implement. At the same time, however, agricultural systems provide many advantages to researchers. They are relatively simple systems, without much of the habitat diversity that generally characterizes natural systems. Fields are “replicated” across the landscape, at very large scales. System dynamics – such as the timing and spatial pattern of disturbance, chemical and water inflows, etc. – are relatively predictable and – because they are largely determined by land owners – can often be anticipated precisely. Lastly, given the ubiquity of many crops, the results of well designed studies are potentially relevant to very large areas of land. Collectively, these features provide the hallmarks of an ideal setting in which to conduct rigorous and moderately well controlled, large-scale, experimental studies that could directly inform future field management, while also providing insights into the management of more natural habitats. By recognizing farmland as an inherently experimental setting, researchers are well placed to start filling these gaps by directly comparing management alternatives, which in turn should allow practitioners to better identify areas where it is possible to reconcile the needs of wildlife with those of growers, and thereby provide conservation gains in the vast area of agricultural habitat in North America.

References

- Acquaah, G. 2005. Principles of crop production: theory, techniques, and technology. Pearson Prentice Hall, Upper Saddle River, New Jersey.
- Bhatti, M. A., J. Duan, G. Head, C. Jiang, M. J. McKee, T. E. Nickson, C. L. Pilcher, and C. D. Pilcher. 2005a. Field evaluation of the impact of corn rootworm (Coleoptera: Chrysomelidae)-protected *Bt* corn on ground-dwelling invertebrates. *Environmental Entomology* **34**:1325-1335.
- Bhatti, M. A., J. Duan, G. P. Head, C. Jiang, M. J. McKee, T. E. Nickson, C. L. Pilcher, and C. D. Pilcher. 2005b. Field evaluation of the impact of corn rootworm (Coleoptera: Chrysomelidae)-protected *Bt* corn on foliage-dwelling arthropods. *Environmental Entomology* **34**:1336-1345.
- Bitzer, R. J., E. R. Marlin, C. D. Pilcher, C. L. Pilcher, and W.-K. F. Lam. 2005. Biodiversity and community structure of epedaphic and euedaphic springtails (Collembola) in transgenic rootworm *Bt* corn. *Environmental Entomology* **34**:1346-1376.

- Braile, T. M. 1999. Migration studies of shorebirds in west-central Indiana. M.S. thesis. Purdue University, West Lafayette, Indiana.
- Carlyle, W. J. 1997. The decline of summerfallow on the Canadian prairies. *Canadian Geographer* **41**:267-280.
- CH2M Hill. 1996. Environmental and conservation balance sheet for the California Rice Industry. California Rice Commission, Sacramento.
- Chamberlain, D. E., S. N. Freeman, and J. A. Vickery. 2007. The effects of GMHT crops on bird abundance in arable fields in the UK. *Agriculture, Ecosystems & Environment* **118**:350-356.
- Clark, D. R., Jr., E. L. Flickinger, D. H. White, R. L. Hothem, and A. A. Beilsle. 1995. Dicofol and DDT residues in lizard carcasses and bird eggs from Texas, Florida and California. *Bulletin of Environmental Contaminants and Toxicology* **54**:817-824.
- Cooper, C. M. 1993. Biological effects of agriculturally derived surface water pollutants on aquatic systems – a review. *Journal of Environmental Quality* **22**:402-408.
- Cowardin, L. M., D. H. Johnson, A. M. Frank, and A. T. Klett. 1983. Simulating results of management actions on mallard production. *Transactions North American Wildlife Conference* **48**:257-272.
- Daly, T., and G. D. Buntin. 2005. Effect of *Bacillus thuringiensis* transgenic corn for lepidopteran control on nontarget arthropods. *Environmental Entomology* **34**:1292-1301.
- Dively, G. P. 2005. Impact of transgenic VIP3A x Cry1Ab lepidopteran-resistant field corn on the nontarget arthropod community. *Environmental Entomology* **34**:1267-1291.
- Fawcett, R. S., and F. W. Slife. 1978. Effects of 2,4-D and dalapon on weed seed production and dormancy. *Weed Science* **26**:543-547.
- Gauthier, G., J. F. Giroux, A. Reed, A. Bechet, and L. Belanger. 2005. Interactions between land use, habitat use, and population increase in greater snow geese: what are the consequences for natural wetlands? *Glob. Change Biol.* **11**:856-868.
- Head, G., W. Moar, M. Eubanks, B. Freeman, J. Ruberson, A. Hagerty, and S. Turnipseed. 2005. A multiyear, large-scale comparison of arthropod populations on commercially managed *Bt* and non-*Bt* cotton fields. *Environmental Entomology* **34**:1257-1266.
- Heard, M. S., C. Hawes, G. T. Champion, S. J. Clark, L. G. Firbank, A. J. Haughton, A. M. Parish, J. N. Perry, P. Rothery, R. J. Scott, M. P. Skellern, G. R. Squire, and M. O. Hill. 2003. Weeds in fields with contrasting conventional and genetically modified herbicide-tolerant crops I: Effects on abundance and diversity. *Philosophical Transactions of the Royal Society of London B* **358**:1819-1832.
- Iverson, G. C., P. A. Vohs, and T. C. Tacha. 1985a. Habitat use by Sandhill Cranes wintering in western Texas. *Journal of Wildlife Management* **49**:1074-1083.
- Johns, B. W., E. J. Woodsworth, and E. A. Driver. 1997. Habitat use by migrant Whooping Cranes in Saskatchewan. *Proceedings of the 7th North American Crane Workshop* **7**:123-131.
- Klett, A. T., T. L. Shaffer, and D. H. Johnson. 1988. Duck nest success in the Prairie Pothole Region. *Journal of Wildlife Management* **52**:431-440.
- Maul, J. D., and C. M. Cooper. 2000. Water quality of seasonally flooded agricultural fields in Mississippi. *Agriculture Ecosystems & Environment* **81**:171-178.
- McNeely, J. A., and S. J. Scherr. 2003. *Ecoagriculture: strategies to feed the world and save wild biodiversity*. Island Press, Washington, D.C.

- Miller, M. W. 2000. Modeling annual mallard production in the prairie-parkland region. *Journal of Wildlife Management* **64**:561-575 | 561.
- Naranjo, S. E. 2005b. Long-term assessment of the effects of transgenic *Bt* cotton on the abundance of nontarget arthropod natural enemies. *Environmental Entomology* **34**:1193-1210.
- Naranjo, S. E. 2005c. Long-term assessment of the effects of transgenic *Bt* cotton on the function of the natural enemy community. *Environmental Entomology* **34**:1211-1223.
- Naranjo, S. E., G. Head, and G. P. Dively. 2005a. Field studies assessing arthropod nontarget effects in *Bt* transgenic crops: introduction. *Environmental Entomology* **34**:1178-1180.
- Ohlendorf, H. M., R. L. Hothem, C. M. Bunck, T. Aldrich, and J. F. Moore. 1986. Relationships between selenium concentrations and avian reproduction. *Transactions of the North American Wildlife and Natural Resources Conference* **51**:330-342.
- Peterson, D., J. Scursoni, and F. Forcella. 2002. Weed diversity and yield in glyphosate-tolerant soybean from Minnesota to Louisiana. *North Central Weed Science Society Abstracts* **57**:129.
- Petrie, S. A., S. S. Badzinski, and K. L. Wilcox. 2002. Population trends and habitat use of Tundra Swans staging at Long Point, Lake Erie. *Waterbirds* **25**:143-149.
- Phillips, M. L., W. R. Clark, M. A. Sovada, D. J. Horn, R. R. Koford, and R. J. Greenwood. 2003. Predator selection of prairie landscape features and its relation to duck nest success. *Journal of Wildlife Management* **67**:104-114.
- Pilcher, C. D., M. E. Rice, and J. J. Obrycki. 2005. Impact of transgenic *Bacillus thuringiensis* corn and crop phenology on five nontarget arthropods. *Environmental Entomology* **34**:1302-1316.
- Podruzny, K. M., J. H. DeVries, L. M. Armstrong, and J. J. Rotella. 2002. Long-term response of northern pintails to changes in wetlands and agriculture in the Canadian Prairie Pothole Region. *Journal of Wildlife Management* **66**:993-1010.
- Robertson, D. G., and R. D. Slack. 1995. Landscape change and its effects on the wintering range of a Lesser Snow Goose *Chen caerulescens caerulescens* population: a review. *Biological Conservation* **71**:179-185.
- Romeis, J., M. Meissle, and F. Bigler. 2006. Transgenic crops expressing *Bacillus thuringiensis* toxins and biological control. *Nature Biotechnology* **24**:63-71.
- Rubega, M. A., and J. A. Robinson. 1997. Water salinization and shorebirds: emerging issues. Pages 45-54 in J. M. Reed, N. Warnock, and L. W. Oring, editors. *Conservation and Management of Shorebirds in the Western Great Basin, International Wader Studies*.
- Sutherland, W. J., and N. J. Crockford. 1993. Factors affecting the feeding distribution of red-breasted geese *Branta ruficolis*. *Biological Conservation* **63**:61-65.
- Torres, J. B., and J. R. Ruberson. 2005. Canopy- and ground-dwelling predatory arthropods in commercial *Bt* and non-*Bt* cotton fields: patterns and mechanisms. *Environmental Entomology* **34**:1242-1256.
- Trauger, D. L., and J. H. Stoult. 1976. Trends in waterfowl populations and habitats on study areas in Canadian parklands. *Transactions North American Wildlife Conference* **43**:187-205.
- Whitehouse, M. E. A., L. J. Wilson, and G. P. Fitt. 2005. A comparison of arthropod communities in transgenic *Bt* and conventional cotton in Australia. *Environmental Entomology* **34**:1224-1241.

Table 11-1. Waterbird species found in or in association with fields planted to each of the nine focal row crops in North America during winter, migration, and/or breeding seasons. Use by landbirds presented only for species on the Waterbird on Working Lands (WWL) species list. W = winter; S/F = spring migration/fall migration, B = breeding season, B-f = Breeding season, foraging, B-n = Breeding season, nesting, (r) = (rare).

GROUP	Conservation Priority Species	Crops								
		Rice	Corn	Winter Wheat	Spring Wheat	Sorghum	Soybean	Cotton	Peanut	Tobacco
WATERFOWL										
		W	W, S/F	W, S/F			W, S/F			
			W, B-f	W		W, B-f				
		F, B-f,n	W			B-f				
		W, S/F	W, S/F	W, S/F		W	W, S/F	W, F		
		W, S/F	W	W		W				
		W, S/F	W, S	W, S		S	W, S	W, F		
		W, S/F	W, S/F	W, S/F		W, S/F	W, S/F, B-f	W, F		
		W, S/F	W	W, S						
		W & S/F (r)								
	X	W & S/F (r)								
	X	W & S/F (r)								
		W & S/F (r)								
		W & S/F (r)								
	X	W & S/F (r)								
					B-n (r)					
		W & S/F (r)								
		W (r)								
		W & S/F (r)								
		W, F					W			
	X		W, F, B-f							
		W, S/F, B-f,n	W, S/F, B-f	B-f, n	F, B-f	W	W, F, B-f			
	X	W, F, B-f,n				W, F	F, B-f			
	X	W, S/F	W, F, B-f	W, F, B-n	F, B-f,n	W, F	W, S	W		

Table 11-1. Continued.

GROUP	Conservation Priority Species	Crops								
		Rice	Corn	Winter Wheat	Spring Wheat	Sorghum	Soybean	Cotton	Peanut	Tobacco
WATERFOWL										
		W, S/F		B-n	B-n		W			
		W, S/F								
		W, S/F	W, F		B-n	W, F				
		W, S/F	F, B-f	B-n	B-n	W, F				
		W, S/F	W, F		B-n	W, F				
		W								
		W, S/F		B-n	B-n	W, F				
SHOREBIRDS										
		W, S/F	F			W, F	W			
	X	S	S				W, S			
		S/F								
		W, S/F, B-f,n	W, S/F, B-f,n	B-f	B-n	B-f,n	W, F, B-f,n			
	X		B-f,n	B-f,n		B-f,n				
		W, S/F, B-f,n								
		W, S/F, B-f,n								
		W, S/F					W			
	X	W, S/F	F (r)				W			
	X	W, S		B-n		W, F				
	X	S								
	X			B-n	B-n					
		S			B-n					
	X	S/F (r)								

Table 11-1. Continued.

GROUP	Conservation Priority Species	Crops								
		Rice	Corn	Winter Wheat	Spring Wheat	Sorghum	Soybean	Cotton	Peanut	Tobacco
SHOREBIRDS										
Dunlin		W, S/F								
Least Sandpiper		W, S/F					W			
Western Sandpiper		W, S/F				W, F	W			
Semipalmated Sandpiper		S/F					W			
Buff-breasted Sandpiper	X	S	S							
White-rumped Sandpiper		S					W			
Pectoral Sandpiper		S/F	F (r)				W			
Spotted Sandpiper		S/F (r)	F (r)			W, F	F (r)			
Upland Sandpiper	X	S/F (r)	S/F, B-f	B-n	B-n	F				
Stilt Sandpiper	X	S/F								
Long-billed Dowitcher		W, S/F					W			
Short-billed Dowitcher	X						W			
Wilson's Snipe		W, S/F	S			W, F	W			
American Woodcock	X		W, F	W			W	W		
Wilson's Phalarope	X	S/F			B-n					
Red-necked Phalarope	X	S								
WADING BIRDS										
Wood Stork	X	F (r)								
Roseate Spoonbill		F (r)								
White-faced Ibis		W, B-f	W	B-f						
Glossy Ibis		W								
White Ibis		W, F				W, F				
Great Egret		W, F, B-f				W, F	B-f (r)			
Great Blue Heron		W, F, B-f	F							

Table 11-1. Continued.

GROUP	Conservation Priority Species	Crops								
		Rice	Corn	Winter Wheat	Spring Wheat	Sorghum	Soybean	Cotton	Peanut	Tobacco
WADING BIRDS										
			W, F, B-f			W, F				
	X		W, F, B-f			W, F				
			F (r)			W, F				
			W, F, B-f			W, F		B-f		
	X		W, F (r), B-f							
			B-f,n							
			W, F (r), B-f	F						
			W (r)							
			F (r)							
OTHER WATERBIRDS										
			W							
			W (r)							
	X		W (r)							
			W							
			W							
			W			W, F		B-f		
			W & F (r)	B-f						
	X		W, F (r),							
			B-f,n							
	X		W							
	X		F (r)							
			W, F					B-f		
			W, F (r),							
			B-f,n							

Table 11-1. Continued.

GROUP	Conservation Priority Species	Crops								
		Rice	Corn	Winter Wheat	Spring Wheat	Sorghum	Soybean	Cotton	Peanut	Tobacco
OTHER WATERBIRDS										
			B-f,n							
	X		W, S/F	W, S/F, B-f	W, S/F, B-f	S/F, B-f	W, S	S/F	W	W, S
	X			W, S/F	S/F	S/F	S/F	S/F		
			W	F, B-f						
			W							
			W							
									B-f	
	X		B-f,n							
			W (r)							
	X		W							
LANDBIRDS										
	X		W							
			W (r)							
			W							
			W							
			W (r)							
			W (r)	F, B-f			W, F	F, B-f		
				F, B-f				F, B-f		
				F, B-f			W, F	F, B-f		
				F, B-f				F, B-f		
	X		W (r)				W, F			
			W							
				F				F (r)		
				F (r)				F (r)		

Table 11-1. Continued.

GROUP Species	Conservation Priority Species	Crops								
		Rice	Corn	Winter Wheat	Spring Wheat	Sorghum	Soybean	Cotton	Peanut	Tobacco
LANDBIRDS										
Common Yellowthroat		W	F, B-f,n	W			W, F (r)			
Lincoln's Sparrow		W	F, B-f (r)			W, F	F (r)			
Swamp Sparrow			F, B-f				F (r), B-f (r)			
LeConte's Sparrow	X	W (r)								
Red-winged Blackbird		W, S/F B-f,n	W, S/F, B-f,n	W, B-f,n	S/F, B-f,n	W, S/F, B-f	W, F, B-f,n?	W, S/F, B-f		
Rusty Blackbird	X		W, F (r)	W						
Yellow-headed Blackbird		W	S/F, B-f	B-f		F, B-f	B-f			
Tricolored Blackbird	X	W, B-f		B-n						
Boat-tailed Grackle		W	W, F			W, F				
TOTAL # Species										
ALL	36	104	45	26	16	37	40	9	1	0
Excluding Rare Species	27	78	41	26	15	37	34	9	1	0

Table 11-2. Conservation Priority Species found in or in association with fields planted to each of the nine focal crops in North America during winter, migration, and/or breeding seasons. W = winter; S/F = spring migration/fall migration, B = breeding season, B-f = Breeding season, foraging, B-n = Breeding season, nesting.

GROUP Species	Crops								
	Rice	Corn	Winter Wheat	Spring Wheat	Sorghum	Soybean	Cotton	Peanut	Tobacco
WATERFOWL									
Canvasback	W, S/F (rare)								
Redhead	W, S/F (rare)								
Greater Scaup	W, S/F (rare)								
American Black Duck		W, F, B-f							
Mottled Duck	W, F, B-f,n				W, F	F, B-f			
Northern Pintail	W, S/F	W, F, B-f	B-n	F, B-f	W, F	W, S	W		
SHOREBIRDS									
American Golden Plover	S	S				W, S			
Mountain Plover		B-f,n	B-f,n		B-f,n				
Lesser Yellowlegs	W, S/F	F (rare)				W			
Long-billed Curlew	W, S		B-n		W, F				
Whimbrel	S								
Marbled Godwit			B-n	B-n					
Solitary Sandpiper	S/F (rare)								
Buff-breasted Sandpiper	S	S							
Upland Sandpiper	S/F (rare)	S/F, B-f	B-n	B-n	W, F				
Stilt Sandpiper	S/F								
Short-billed Dowitcher						W			
American Woodcock	W, F	B-n			W	W			
Wilson's Phalarope	S/F			B-n					
Red-necked Phalarope	S								

Table 11-2. Continued.

GROUP Species	Crops								
	Rice	Corn	Winter Wheat	Spring Wheat	Sorghum	Soybean	Cotton	Peanut	Tobacco
WADING BIRDS									
Wood Stork	F (rare)								
Little Blue Heron	W, F, B-f				W, F				
American Bittern	W, F (rare), B-f								
OTHER WATERBIRDS									
Clark's Grebe	W (rare)								
King Rail	W, F (rare), B-f,n								
Yellow Rail	W								
Clapper Rail	F (rare)								
Sandhill Crane	W, S/F	W, S/F, B-f	W, S/F, B-f	S/F, B-f	W, S	S/F	W	W, S	
Whooping Crane		W, S/F	S/F	S/F	S/F	S/F			
Black Tern	B-f,n								
Forster's Tern	W								
LANDBIRDS									
Bald Eagle	W								
Sedge Wren	W (rare)				W, F				
LeConte's Sparrow	W (rare) B-f,n?								
Rusty Blackbird		W, F (rare)	W						
Tricolored Blackbird	W, B-f		B-n						

Table 11-3. Summary of the number of waterbird species observed in each focal Bird Conservation Region (BCR) by focal row crop and totaled across crops in North America. WF = waterfowl; SB = shorebirds; WB = wading birds; OW = other waterbirds; LB = landbirds. Gray indicates crop not typically grown in region.

Crop	Prairie Potholes (BCR 11)					Prairie Hardwood Transition (BCR 23)					Eastern Tallgrass Prairie (BCR 22)					Shortgrass Prairie (BCR 18)				
	WF	SB	WB	OW	LB	WF	SB	WB	OW	LB	WF	SB	WB	OW	LB	WF	SB	WB	OW	LB
Rice																				
Corn	4	2	0	1	2	2	1	0	1	0	5	2	0	2	3	5	2	0	0	0
Winter Wheat	6	2	0	0	0	1	0	0	1	0	2	1	0	1	1	1	1	0	1	2
Spring Wheat	8	5	0	2	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Sorghum	.	.	.	.	.	.	.	.	.	.	2	1	0	0	0	0	2	0	1	1
Soybean	2	0	0	2	2	1	0	0	0	0	2	2	0	2	1	.	.	.	.	.
Cotton																0	0	0	1	0
Peanut																0	0	0	1	0
Tobacco																.	.	.	.	.
All Crops	5	6	0	5	2	2	1	0	1	0	5	2	0	3	3	6	2	0	2	2
Total Species in BCR	18					4					13					12				

Crop	Central Mixed-Grass Prairie (BCR 19)					Central Hardwoods (BCR 24)					Mississippi Alluvial Valley (BCR 26)				
	WF	SB	WB	OW	LB	WF	SB	WB	OW	LB	WF	SB	WB	OW	LB
Rice											9	5	0	5	4
Corn	2	3	0	1	2	1	1	0	0	1	1	0	0	0	0
Winter Wheat	6	2	0	2	1	1	0	0	0	2	.	.	.	.	.
Spring Wheat															
Sorghum	1	1	0	2	1	.	.	.	.	.	1	0	0	0	1
Soybean	3	0	0	2	0	2	1	0	0	1	4	12	0	0	0
Cotton											0	0	0	0	1
Peanut															
Tobacco															
All Crops	7	4	0	2	2	2	1	0	0	3	9	13	0	5	4
Total Species in BCR	15					6					31				

Table 11-4. Summary of current knowledge regarding the foraging resources provided by the major WWL focal row crops in North America, including timing of consumption (NB = nonbreeding period; B = breeding period) by waterbird groups. Gray shaded boxes indicate not applicable, i.e., resource is not available in fields planted to the crop.

RESOURCES	RICE	CORN	WHEAT	SORGHUM	SOYBEAN	COTTON
Waste Grain	waterfowl – NB, B cranes – NB blackbirds – NB	waterfowl – NB cranes – NB blackbirds – NB, B	waterfowl – NB, B (dabbling ducks) cranes – NB, B blackbirds – NB, B	waterfowl – NB cranes – NB, B blackbirds – NB, B	waterfowl (esp. geese) – NB cranes – NB	cranes – NB
Ripening Grain	<i>data gap</i>	blackbirds – B	waterfowl (swans, geese) – NB blackbirds – NB	blackbirds - B		
Green Forage of Crop	geese – NB coots – NB blackbirds - B	blackbirds – NB	waterfowl (swans, geese) – NB cranes – NB blackbirds – NB	<i>data gap</i>	<i>data gap</i>	
Weed Species – New Shoots	waterfowl – NB, B	<i>data gap</i>	<i>data gap</i>	<i>data gap</i>	geese – NB	prob. Northern Pintail - NB prob. blackbirds - NB
Weed Species – Seeds	cranes – NB	blackbirds – NB	<i>data gap</i>	<i>data gap</i>	blackbirds – NB	<i>data gap</i>
Terrestrial Invertebrates		shorebirds – NB, B landbirds – NB, B	<i>data gap</i>	prob Fulvous Whistling-Duck – B	shorebirds – NB landbirds – NB	prob Northern Pintail – NB
Aquatic Invertebrates	benthic/nektonic: waterfowl – NB, B shorebirds – NB wading birds – NB other waterbirds – NB crayfish: shorebirds – NB, B wading birds – NB, B				flooded soybean only: waterfowl (dabbling ducks) – NB shorebirds – NB	

Table 11-5. Summary of the estimated caloric content (kcal/g) of row crop grains and green forage (for wheat) from assays with Canada Geese, Mallard and other waterbirds (Sugden 1971, Storey and Allen 1982, Joyner et al. 1987, Reinecke et al. 1989, Petrie et al. 1998). Energy Content Ranking summarizes relative differences in AME and TME values among crops.

	Rice Seed	Corn Kernels	Wheat Grain	Wheat Forage	Sorghum Grain	Soybeans
Energy Content Ranking	4	1	3	6	2	5
Apparent Metabolizable Energy ¹⁻³ TME (kcal/g)	3.53	3.97	3.85	2.54	3.96	3.03
True Metabolizable Energy ⁴⁻⁵ AME (kcal/g)	2.82 – 3.34	3.67 – 3.90	3.38	2.40	3.78	2.65 – 3.55
Digestibility (%) ⁴	67	88	not available	55	87	63
Fiber (% dry weight) ⁶	not available	2	not available	17	2	not available
Protein (% dry weight) ⁶	not available	10	not available	27	11	not available

References:

- 1 Joyner, D. E., B. N. Jacobson, and R. D. Arthur. 1987. Nutritional characteristics of grains fed to Canada Geese. *Wildfowl* **38**:89-93.
- 2 Storey, M. L., and N. K. Allen. 1982. Apparent and true metabolizable energy of feedstuffs for mature, nonlaying female Embden geese. *Poultry Science* **61**:739-745.
- 3 Sugden, L. G. 1971. Metabolizable energy of small grains for mallards. *Journal of Wildlife Management* **35**:781-785.
- 4 Petrie, M. J., R. D. Drobney, and D. A. Graber. 1998. True metabolizable energy estimates of Canada goose foods. *Journal of Wildlife Management* **62**:1147-1152.
- 5 Reinecke, K. J., R. M. Kaminski, D. J. Moorehead, J. D. Hodges, and J. R. Nassar. 1989. Mississippi Alluvial Valley. *in* L. M. Smith, R. L. Pederson, and R. M. Kaminski, editors. *Habitat management for migrating and wintering waterfowl in North America*. Texas Tech University Press, Lubbock, TX.
- 6 Ensminger, M. E., J. E. Oldfield, and W. W. Heinemann. 1990. *Feeds and Nutrition*. Ensminger Publishing, Clovis, CA.
- 7 Gates, R. J., D. F. Caithamer, W. E. Moritz, and T. C. Tacha. 2001. Bioenergetics and nutrition of Mississippi Valley population Canada geese during winter and migration. *Wildlife Monographs*:1-65.

Table 11-6. Continued.

Crop Production Methods	Rice	Corn	Wheat (Winter and Spring)	Sorghum	Soybean	Cotton
Sowing	0 no effect of timing of sowing on nesting birds, effects of sowing method (wet vs. dry) unknown	— farm machinery destroys nests	— farm machinery destroys nests	0 occurs during nonbreeding period	?? farm machinery may destroy nests	
Pesticide Use	— waterbird mortalities	— waterbird mortalities; new shoots/seed of weeds, invertebrates reduced; ?? damage to nests from applications	— waterbird mortalities; ?? damage to nests	— waterbird mortalities not documented; ?? reduction in foods of weed species; ?? damage to nests	— waterbird mortalities not documented; new shoots/seeds of weeds reduced; ?? damage to nests	— waterbird mortalities ?? effects on food resources unknown
Harvesting	+/- for method of harvest: conventional: + stripper-header: —	— increased harvest efficiency decreases abundance of waste corn	— in spring wheat: likely that harvesting destroys nests	?? may destroy nests, but unstudied		
Crop Rotation	+ increases abundance of moist soil plants; crayfish as interim flooded habitat		— continuous cropping of winter with spring wheat may negatively impact nesting birds			

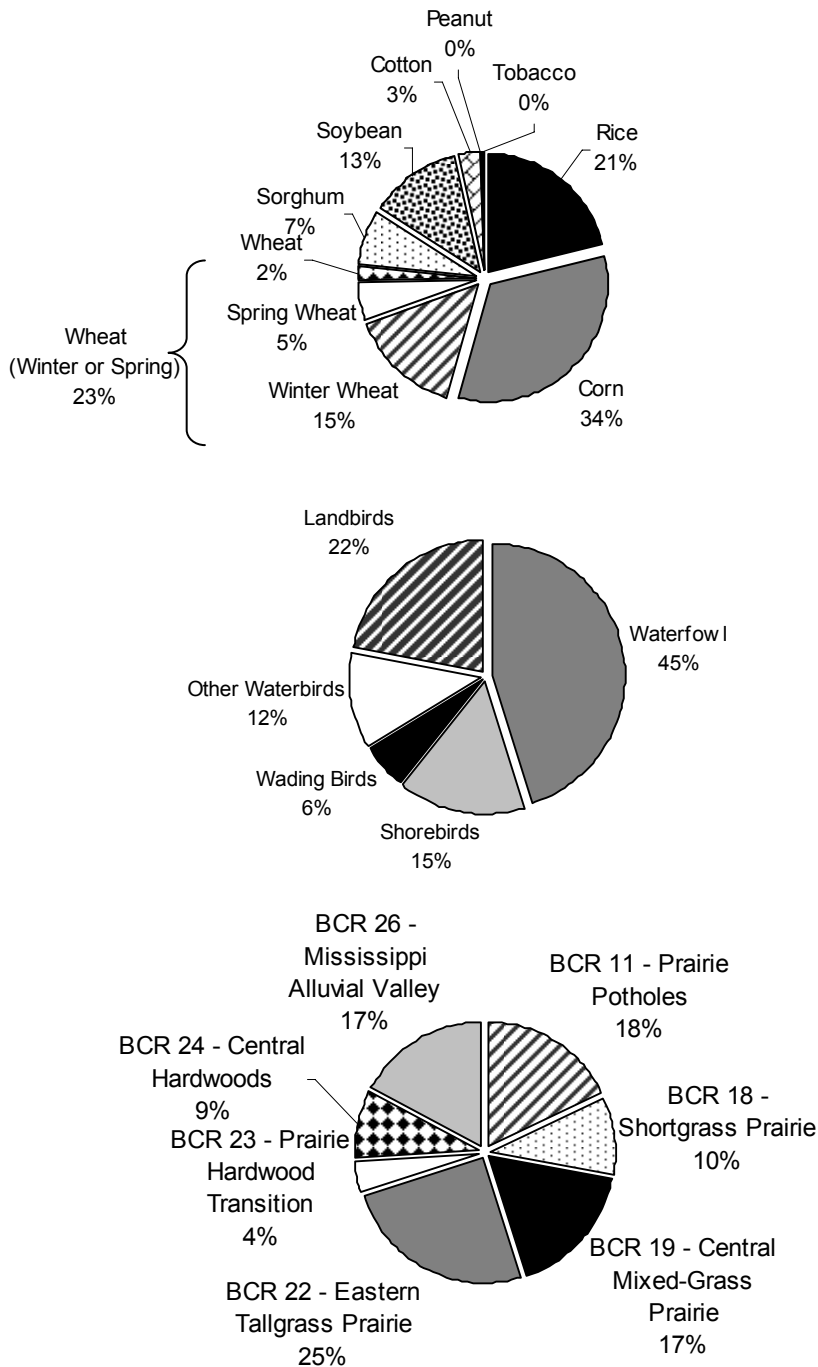


Figure 11-1. Summary of the research effort that supports the current documented waterbird use of nine WWL focal row crops in North America. Relative effort measured as the proportion of studies* conducted in each focal row crop (A), on each waterbird group (B), and in each focal BCR (C).

*Studies documenting use in multiple row crops, by multiple waterbird groups, or in multiple BCRs, were included in proportions by independently counting them for each crop, waterbird group, or BCR examined in the study, respectively, i.e., a given study may be included as a research effort more than once in a given pie chart.