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Avian Foods, Foraging and Habitat Conservation in World Rice Fields

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Abstract.—Worldwide, rice (*Oryza sativa*) agriculture typically involves seasonal flooding and soil tillage, which provides a variety of microhabitats and potential food for birds. Water management in rice fields creates conditions ranging from saturated mud flats to shallow (<30 cm) water, thereby attracting different guilds of birds. Grain not collected during harvest (i.e. waste rice) is typically the most abundant potential food of birds in rice fields, with estimates of seed mass from North America ranging from 66-672 kg/ha. Although initially abundant after harvest, waste rice availability can be temporally limited. Few abundance estimates for other foods, such as vertebrate prey or forage vegetation, exist for rice fields. Outside North America, Europe and Japan, little is known about abundance and importance of any avian food in rice fields. Currently, flooding rice fields after harvest is the best known management practice to attract and benefit birds. Studies from North America indicate specific agricultural practices (e.g. burning stubble) may increase use and improve access to food resources. Evaluating and implementing management practices that are ecologically sustainable, increase food for birds and are agronomically beneficial should be global priorities to integrate rice production and avian conservation. Finally, land area devoted to rice agriculture appears to be stable in the USA, declining in China, and largely unquantified in many regions. Monitoring trends in riceland area may provide information to guide avian conservation planning in rice-agriculture ecosystems. *Received 17 October 2007, accepted 28 April 2009.*

Key words.—avian conservation, food resources, foraging habitat, invertebrates, plant seeds, rice, waste rice, waterbirds, waterfowl, wetlands.

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Rice (*Oryza sativa*) agriculture provides foraging and other habitats worldwide for breeding, migrating and wintering birds. Because rice farming typically involves soil disturbance from tillage, harvest and seasonal flooding, rice fields provide a variety of food resources for wetland-dependent birds, including grain and natural plant seeds, invertebrates, vertebrates and green forage. Additionally, physical infrastructure required to grow rice (e.g. levees, irrigation systems) often facilitates management of rice fields to make forage available for diverse guilds of birds. Herein, we review existing information pertaining to the value of rice fields as avian foraging habitat, management strategies designed to increase habitat quality and behavioral research relevant to understanding avian nutritional benefits of rice fields. Eadie *et al.* (2008) and Taft and Elphick (2007) summarized extensive information for North American rice fields. We benefited greatly from their reviews and extend our review to the global scale.

RICE SEEDS

Rice grain is an important food for many avian species. The majority of this food is in the form of grain spilled or not collected during harvest and commonly referred to as "waste rice" (Stafford *et al.* 2006). Additionally, many birds forage on recently-planted rice seeds, seedlings and grains maturing in seed heads before harvest. For example, Fulvous Whistling Ducks (*Dendrocygna bicolor*) feed on sown grain (Flicklinger and King 1972) and American Coots (*Fulica americana*) consume newly-planted rice and seedlings (van Way 1986). Farmers often consider Yellow-headed Blackbirds (*Xanthocephalus xanthocephalus*), Red-winged Blackbirds (*Agelaius phoeniceus*) and Wood Ducks (*Aix sponsa*) detrimental to rice yields because they commonly feed on growing rice prior to harvest, particularly in the Mississippi Alluvial Valley (MAV), USA. Similarly, the Bobolink (*Dolichonyx oryzivorus*) is considered an agricultural pest in Bolivia where they forage on rice seeds before harvest (Renfrew and Saavedra 2007). Farmers in Guyana also view Black-bellied Whistling Ducks (*Dendrocygna autumnalis*) as detrimental to rice agriculture, despite evidence the birds depredate ≤2.0% of sown grain (Bourne and Osborne 1978).

Waste rice appears the most abundant and important food for waterfowl (Anatidae) and many other waterbirds in rice fields. Eadie *et al.* (2008) and Remsen *et al.* (1991) reported that 15 species of waterfowl regularly used rice fields during the non-growing season in California and the Gulf Coast, USA, whereas at least nine species were commonly observed in MAV fields (Delnicki and Reinecke 1986; Reinecke *et al.* 1992; Twedt and Nelms 1999; Huner *et al.* 2002; Greer *et al.* 2009). Additionally, authors have reported that waterfowl using rice fields in winter feed heavily on waste rice (Singleton 1951; Reinecke *et al.* 1989; Miller and Newton 1999; Dabbert and Martin 2000; van Groenigen *et al.* 2003; Manley *et al.* 2004; Mugica *et al.* 2006a; Greer *et al.* 2009).

Most studies estimating the amount of waste rice remaining after harvest have been conducted in North America, where the primary rice-producing regions (California, MAV and Gulf Coastal prairies) are areas where natural wetlands and wintering waterfowl populations historically were abundant (Smith *et al.* 1989). Abundance of waste rice generally correlates positively with rice yields (Miller *et al.* 1989), which may vary considerably with factors such as weather, geography, rice variety and agricultural practices. Rice yield in the USA has increased 2.5-fold since 1950 (Abraham *et al.* 2005), but varies considerably by region. For example, in 2007 average rice yield was 7,991 kg/ha in Arkansas and 9,213 kg/ha in California (NASS 2008). In contrast, rice yield in Japan averaged 4,686 kg/ha in 2003 (Ministry of Agriculture, Forestry and Fisheries of Japan 2003). Eadie *et al.* (2008) reported the percentage of rice not collected during harvest of North American fields ranged from 3-6%. However, many factors influence rice loss during harvest (Elphick *et al.* 2010), including equipment operators (McNeal 1950), field condition (e.g. wetness and fallen rice plants; Miller and Street 2000:78), and type of header used on the harvester (i.e. stripper vs. conventional cutter-bar). Regarding the latter, Miller and Wylie (1996) documented less waste rice in California fields harvested with stripper-header equipped combines, whereas Stafford *et al.* (2006) and Kross *et al.* (2008) detected no difference in post-harvest abundance of waste rice in MAV fields harvested with the two equipment types. In Japan, Shimada (1999, 2006) estimated waste rice was at least 8.7 times more abundant in fields harvested by conventional combines compared to those harvested using a reaper-binder, a device that cuts and binds the stalks for field drying.

Although variable, most studies indicate waste rice is abundant in fields after harvest. In North America, rice seed dry mass in harvested fields ranged from 66-627 kg/ha (e.g. Smith and Sullivan 1980; Kross *et al.* 2008; reviewed by Eadie *et al.* 2008: Table 2) and averaged 315 kg/ha (SD = 133). In Japan, Amano *et al.* (2004, 2006) reported rice densities averaging 1,191-1,244 grains/m^2 ($\bar{x}$ = 1,223 grains/m^2) in 1999-2001 and 1,334 grains/m^2 (SE = 109) in 2001-2002. Assuming the dry mass of a rice seed is approximately 0.02 g (Delnicki and Reinecke 1986; Shimada 1999; Shimada and Mizota 2008c), seed mass per unit area reported by Amano *et al.* (2004, 2006) approximated 245 kg/ha in 1999-2001 and 267 kg/ha in 2001-2002. Three studies conducted in the Lake Izunuma-Uchinuma region of Japan reported estimates of rice seed mass during fall as 84-103 kg/ha in 1996 (Shimada 1999), 69-88 kg/ha in 2001 (Shimada 2002), and 56-78 kg/ha in 2007 (Shimada and Mizota 2008c). These authors documented a 75-95% decline in waste rice abundance between October and early-December 2007 (final density: $\bar{x}$ = 12 kg/ha). Nonetheless, post-harvest estimates of waste rice abundance in Japan generally were consistent with those from North America.

Although waste rice is abundant following harvest, evidence from North America suggests benefits of waste rice for wintering waterfowl vary geographically and reflect interactions among production systems, growing seasons and migration chronology. In the temperate climate of central California, rice is planted and harvested relatively late (e.g. mid- to late October; NASS 2008) and migrating waterfowl arrive early (e.g. early August; Bellrose 1980; Heitmeyer *et al.* 1989). Thus, waste rice has little time to deteriorate after harvest and provides an abundant food source for waterfowl such as Northern Pintail (*Anas acuta*) and other early migrant ducks (Heitmeyer *et al.* 1989). In contrast, the growing season in the subtropical climate of coastal Louisiana and Texas is long enough that rice farmers can produce two crops, although the majority produce and harvest only one crop (Hobaugh *et al.* 1989; Way *et al.* 2006: 1873). The first rice crop is often harvested in July or August and any resulting waste rice is gone long before waterfowl arrive. However, when a second or 'ratoon' crop is grown, harvest occurs in mid-autumn and creates a fresh source of waste rice when waterfowl arrive to winter. Further, yields in some fields growing ratoon rice are too low to justify harvesting, and these sites can be managed as winter food plots for waterfowl. Given these agronomic differences, we speculate that waste rice in the Gulf Coast region probably is less abundant but more spatially variable than in California.

The MAV produces more rice than any other region in the USA but probably provides the least waste rice for waterfowl. Climate in the MAV is intermediate between temperate central California and the subtropical Gulf Coast. Historically, rice farmers in the MAV grew one crop per year and harvested late enough in autumn to leave abundant waste rice for waterfowl (Reinecke *et al.* 1989). However, early planting, fast maturing varieties and increasingly efficient equipment have resulted in progressively earlier harvest dates (Manley *et al.* 2004). An interval of two-three months now occurs between harvest in August or early September and arrival of large numbers of wintering waterfowl in late November and December. Most waste rice is lost during this period to germination, decomposition and granivory (Stafford *et al.* 2006; Kross *et al.* 2008). For example, in Mississippi in 1995-1996, Manley *et al.* (2004) documented a mean decrease in waste rice of 79% from 492 kg/ha in August-September to <60 kg/ha in early December. Similarly, Stafford *et al.* (2006) reported that waste rice abundance in Arkansas, Louisiana, Mississippi and Missouri, declined an average of 71% from 271 kg/ha after harvest in early autumn to 78 kg/ha in early winter during 2000-2002. Because experimental evidence suggests that waterfowl cease foraging and depart rice fields when seed abundance decreases to a "giving-up" density of ~50 kg/ha (Reinecke *et al.* 1989; Greer *et al.* 2009), waste rice apparently contributes less to winter carrying capacity of waterfowl in the MAV than previously thought (Loesch *et al.* 1994; Stafford *et al.* 2006).

Concern over decreasing availability of waste rice in the MAV has motivated experiments to evaluate field practices to conserve waste rice after harvest of the first crop or to grow ratoon crops to increase food available to waterfowl. Kross *et al.* (2008) compared waste rice abundance in undisturbed stubble and stubble that had been burned, rolled, disked or mowed. The authors recommended leaving stubble undisturbed or burned, as late-autumn rice seed in these treatments was greatest and exceeded 50 kg/ha (i.e. the giving-up density). K. J. Reinecke (unpublished data) collaborated recently with farmers in the MAV to plant rice in early April, harvest as soon as rice matured, and irrigate or fertilize fields to encourage ratoon growth. Results indicated that fields where planting, harvesting and irrigating was timely produced over 1,000 kg/ha of ratoon seed; fertilizer application did not increase production of ratoon crops. Thus, landowners willing to bear the cost of irrigation were able to increase rice available to waterfowl 20-fold compared to the amount in fields following harvest of first crops.

Our review indicated abundance of waste rice seeds in harvested fields was generally less than abundance of waste corn (*Zea mays*) in newly-harvested fields in Texas (343 kg/ ha; Baldassarre and Bolen 1984), soybeans (*Glycine max*) in Japan (290-355 kg/ha; Shimada and Mizota 2008a, b), or grain sorghum in Tennessee (391 kg/ha; M. A. Foster and M. J. Gray, unpublished data). Abundance of waste-rice was similar to post-harvest abundances of waste corn and soybean in Tennessee (239 kg/ha [corn], 117 kg/ha [soybean]) and late-fall estimates in Illinois (225 kg/ha [corn], 49 kg/ha [soybean]) (Warner *et al.* 1989). Moreover, waste rice abundance was typically less than that of natural seeds found in moist-soil wetlands. For example, recent studies in the USA reported moist-soil plant seed abundance estimates of 496 kg/ha in the MAV (Kross *et al.* 2008), 603 kg/ha in Mississippi (Reinecke and Hartke 2005), 790 kg/ha in Illinois (Bowyer *et al.* 2005) and 200-586 kg/ha in California (Naylor 2002). Finally, waste rice abundance was generally similar to average abundance of red oak (*Quercus* spp.) acorns in bottomland hardwood forests of Missouri (172 kg/ ha; McQuilkin and Musbach 1977).

Rice is a concentrated source of energy for waterbirds, but estimates of true metabolizable energy (TME) are only available for a few species. Greater White-fronted Geese (*Anser albifrons*) staging in Japan obtained about 2.95 kcal/g of metabolizable energy from waste rice (Amano *et al.* 2004) and the TME of rice for captive Canada Geese (*Branta canadensis*) was 2.81 kcal/g (Petrie *et al.* 1998). In contrast, Reinecke *et al.* (1989) reported a somewhat higher TME value of 3.34 kcal/g for captive Mallards (*Anas platyrhynchos*). These values compare favorably with agricultural seeds consumed by waterfowl but are generally greater than the TME of natural seeds. Kaminski *et al.* (2003) reviewed published TME estimates of waterfowl foods and reported mean values for natural plant seeds ranged from 2.30-2.47 kcal/ g for Mallards, Northern Pintails, Blue-winged Teal (*Anas discors*) and Canada Geese. Among agricultural seeds, Reinecke *et al.* (1989) reported TME was least for soybean (2.65 kcal/g; Mallards) and substantially greater for corn (3.67 kcal/g [Mallards; Reinecke *et al.* 1989]; 3.90 kcal/g [Canada Geese; Petrie *et al.* 1998]) and grain sorghum (3.49 kcal/g [Blue-winged Teal; Sherfy *et al.* 2001]; 3.76 kcal/g [Canada Geese; Petrie *et al.* 1998]).

Havera (1999: 543-546) summarized nutritional characteristics of 144 agricultural and natural plant seeds found in Mallard gizzards. Rice seeds contained high proportions (75-79%) of nitrogen-free extract (a measure of carbohydrate content) compared to most natural plant seeds ($\bar{x}$ = 49%; range: 33-84%). However, natural plant seeds were generally higher in protein ($\bar{x}$ = 9% [rice], 15% [natural]), fat ($\bar{x}$ = 2% [rice], 15% [natural]), potassium ($\bar{x}$ = 0.4% [rice], 0.8% [natural]), calcium ($\bar{x}$ = 0.1% [rice], 0.5% [natural]), and nitrogen ($\bar{x}$ < 0.1% [rice], 1.9% [natural]) than cultivated rice seeds. Havera (1999:550) also compiled nutritional composition for 30 categories of aquatic invertebrates, which contained considerably greater proportions of protein ($\bar{x}$ = 51%) and fat ($\bar{x}$ = 77%) than rice seeds. Although rice seeds are a good energy source for waterfowl, they may lack essential amino acids and other nutrients (e.g. lipids and protein) of natural plant seeds and aquatic invertebrates (Baldassarre *et al.* 1983; Delnicki and Reinecke 1986; Loesch and Kaminski 1989).

OTHER SEEDS

Native wetland grasses, sedges and forbs ("moist-soil" plants) that grow in rice fields are generally considered competing weeds by agronomists and farmers. Nonetheless, seeds from these plants provide important food sources for waterfowl and other waterbirds (Low and Bellrose 1944; Fredrickson and Taylor 1982; Smith *et al.* 1989). Unfortunately, few studies have quantified seed abundance of moist-soil or aquatic plants in rice fields and all existing estimates are from North America. Harmon *et al.* (1960) found an average of 38.5 kg/ha of other plant seeds in Louisiana rice fields in November, whereas Manley *et al.* (2004) estimated only 3.1-7.4 kg/ha of moist-soil plant seeds in Mississippi rice fields during winter. In their review, Eadie *et al.* (2008) reported estimates that ranged from 12-374 kg/ha. However, the greatest estimates came from a single rice field (Smith and Sullivan 1980) and a fallow field (Davis *et al.* 1961) and may not be representative of rice fields in general. Excluding these values, most estimates of moist-soil plant seed abundance ranged from 4-44 kg/ha (Eadie *et al.* 2008). Thus, fields left fallow for one or more years may produce abundant wetland vegetation and seeds because of persistent natural seed banks (van der Valk *et al.* 2000), but intensive mechanical and chemical weed control in North American rice fields generally limits yield of moist-soil plant seeds to less than 50 kg/ha.

Red Rice (*Oryza sativa* var.) is a naturalized moist-soil plant of great concern to rice farmers because it competes with commercial rice and its seeds are dark-colored and resemble rodent feces, thereby reducing commercial sale (Gealy *et al.* 2003). Widespread occurrence of Red Rice is problematic in the Americas, southern Europe and Asia (Gealy *et al.* 2003). Fortunately, Red Rice is readily consumed by waterbirds to the benefit of farmers (McAtee 1923). Moreover, Smith and Sullivan (1980) used exclosures to demonstrate feeding by wintering waterfowl decreased mass of Red Rice seeds in harvested fields in Arkansas by 97% (374 vs. 11 kg/ha). Nonetheless, rice producers are concerned that waterfowl may disperse Red Rice seeds within and among fields through foraging and incomplete digestion or by physically transporting seeds that adhere to their feet. Powers *et al.* (1978) examined excreta of captive Mallards, Mottled Ducks (*Anas fulvigula*) and Northern Pintails fed Red Rice and found no evidence of intact seeds, implying the ducks digested the seeds and precluded a possibility for seed dispersal. Waterfowl may disperse Red Rice seeds through physical transport but likely not through foraging and excretion.

The practice of flooding harvested fields in winter to attract foraging waterbirds affects dynamics of plant growth and economics of rice production in other ways. In Mississippi, Manley *et al.* (2005) demonstrated biomass of cool-season winter weeds decreased 83% when rice fields were flooded from November or December until early March. Similarly, biomass of graminoid weeds in California more than doubled in winter in the absence of foraging by waterfowl (open vs. exclosed plots; van Groenigen *et al.* 2003). Thus, winter flooding not only provided food for waterbirds, but reduced need for tillage or herbicides in preparation for spring planting and potentially decreased competition from weeds in the subsequent crops because the seed bank was diminished.

The only information regarding plant seeds potentially available to foraging waterfowl during the breeding season was an estimate of 1,014 kg/ha obtained during spring planting in Louisiana, where rice fields generally are left fallow in alternate years and develop dense stands of seed-producing annuals (Hohman *et al.* 1996). Seeds available in spring may be particularly important for Black-bellied and Fulvous Whistling Ducks breeding in the southern United States and South America (Bourne 1982; Hohman *et al.* 1996).

GREEN VEGETATION

Leaves, stems and roots of emerging rice and natural plants are consumed by some waterbirds, especially geese (Hobaugh 1984; Alisauskas *et al.* 1988; Day 1997), American Coots (van Way 1986), and blackbirds (Avery 1989). Although this vegetation provides high-protein forage, few studies have estimated its abundance in harvested rice fields. Hobaugh (1984) developed an index of availability of green forage in Texas rice fields, and reported use by geese correlated positively with index values during January to March. Similarly, Alisauskas *et al.* (1988) estimated Snow Geese (*Chen caerulescens*) feeding in harvested Texas rice fields consumed 98% green forage (comprised of 28% graminoids and 70% forbs) during three of four winter months.

Studies investigating potential agronomic values of winter flooding of rice fields have provided data on abundance of green forage in harvested rice. Van Groenigen *et al.*

(2003) investigated development of winter weeds in California rice fields and reported graminoid weed biomass ranged from 44-204 kg/ha, depending on the extent of waterfowl foraging activity. In Mississippi, Manley *et al.* (2005) estimated biomass of winter weeds was ≤8 kg/ha in rice fields flooded throughout winter, whereas biomass in unflooded fields was 50-70 kg/ha. During spring in Japan, Iwabuchi (2004) estimated that there was 36 kg/ha and 171 kg/ha of the agricultural weeds *Alopecurus pratensis* and *Alopecurus aequalis* in winter-flooded and dry rice fields, respectively.

Some agricultural researchers investigating plants competing with rice during the growing season have estimated biomass of weeds and consequently assessed potential abundance of green forage for resident waterbirds. For example, weed biomass in rice fields sampled at approximately monthly intervals during the growing season in Côte d'Ivoire, Africa, varied with differing planting techniques (e.g. seeding vs. transplanting) and land development (e.g. with and without levees) in rice fields (range: 200-3,000 kg/ha; Becker and Johnson 2001). Some cultures use domestic waterfowl to reduce weed growth in rice fields. Tojo *et al.* (2007) reported domestic "Aigamo" ducks in rice fields in Japan controlled Heartshape False Pickerelweed (*Monochoria vaginalis*) better than manual weeding, but had little effect on barnyard grass (*Echinochloa* spp.). Domestic waterfowl are more likely to help rice farmers control weeds than wild waterbirds because they are non-migratory and bred to be highly selective foragers (Foley and Cork 1992). We are unaware of other estimates of green forage in rice fields but suggest further studies are needed to assess abundance of wetland plants and their importance to consumers in these habitats.

AQUATIC INVERTEBRATES

Aquatic invertebrates are an important source of protein and other nutrients for waterfowl and other waterbirds (Krapu and Reinecke 1992; Kosteke *et al.* 2005; Baldassarre and Bolen 2006; Sánchez *et al.* 2006). Harvested and flooded rice fields and natural wetlands contain large amounts of detritus that serve as important substrates for algae and diverse communities of aquatic invertebrates (Batema *et al.* 2005). Additionally, some farmers in North America use rice fields to produce crayfish (*Procambarus* spp.) for human consumption, thereby providing prey for waterbirds (Huner *et al.* 2002).

Several studies have estimated abundance of aquatic invertebrates in North American rice fields. Loughman and Batzer (1992) estimated densities (number/m^2) of several families of invertebrates in flooded rice fields in the Sacramento Valley, California, and reported densities of chironomid larvae increased from 50/m^2 in November to >400/m^2 in February. Hohman *et al.* (1996) reported 22 kg/ha of aquatic invertebrates in spring rice fields in coastal Louisiana, whereas McAbee (1994) estimated 7.0 kg/ha during winter in northern Louisiana. Manley *et al.* (2005) sampled invertebrate populations in Mississippi rice fields during winter and early spring 1995-1996 and reported invertebrate abundances increased during winter, with peak biomasses of 21.1-31.7 kg/ha in March and an overall mean of 6.3 kg/ha. In California, Lawler and Dritz (2005) sampled invertebrates during summers 1998-1999 in rice fields where straw had been burned or tilled the previous autumn and flooded or left dry during winter. Lawler and Dritz (2005) did not report biomass, but invertebrate densities peaked between mid-May and mid-June and consumer insects were most abundant in fields flooded the preceding winter. Abundance of aquatic invertebrates in North American rice fields in winter generally was similar to natural wetlands important to waterbirds (e.g. 9.8-40.6 kg/ha [forested wetlands; Batema *et al.* 2005]; 31.0 kg/ha [emergent wetlands; Gray *et al.* 1999]; 12.7 and 30.5 kg/ha [managed and unmanaged playa emergent wetlands; Anderson and Smith 2000]).

Some rice producers in North America, particularly in the coastal region of Louisiana, use rice fields to produce crayfish for commercial sale (Huner *et al.* 2002). This "double-cropping" of rice and crayfish provides additional income to farmers as well as abundant waterbird forage. Chien and Avault (1980) estimated mean biomass of crayfish was 1,059 kg/ha in fields managed to produce both rice and crayfish, whereas mean crayfish biomass was 800 kg/ha in ponds where rice was not grown. Fields managed as rice-crayfish complexes attract a diverse waterbird community and particularly benefit wading birds, including egrets and herons (Ardeidae), storks (Ciconiidae), ibis (Threskiornithidae) and Roseate Spoonbills (*Platalea ajaja*) (Huner *et al.* 2002: 69). The relationship between wading bird species in Louisiana and crayfish production in rice fields is one of the best documented examples of the rice industry benefiting avian populations. Correlational evidence suggested increased wading bird populations resulted, in part, from an increase in the area of rice fields producing crayfish, size of the commercial crayfish harvest, and coincidence of crayfish availability with breeding phenology (Fleury and Sherry 1995).

Estimates of aquatic invertebrate abundance in rice fields outside North America further attest to their importance as waterbird foods. Schoenly *et al.* (2003) reported densities of 318-747 individuals/m^2 during the early stages of plant growth and 256-490 individuals/m^2 when seed heads were forming, in rice fields of Laguna Province, Philippines. Mugica *et al.* (2006b) documented 14 families of invertebrates in rice fields of Sur del Jíbaro, Cuba, during the cultivation cycle, with crustaceans being most abundant (5 kg/ha). Gonzáles-Solís *et al.* (1996) investigated variation in waterbird prey in rice fields in the Ebro Delta, Spain, during May-December 1991. Converting density of aquatic coleopterans (beetles) reported by Gonzáles-Solís *et al.* (1996: 138) to dry mass indicated that four species averaged a total of 6.1 kg/ha and a fifth large adult beetle (*Hydrous pistaceus*) averaged 260.7 kg/ha. Richardson *et al.* (2001) reported the median number of Chironomidae captured in core and column samples (60 cm deep × 22.5 cm diameter) from rice fields in Australia during the 1998-1999 growing season declined from 4-15 in November to zero in January and February, whereas median abundance of Odonata larvae increased from zero to three during the same period.

AQUATIC VERTEBRATES

Most studies investigating avian food resources in rice fields have focused on plant foods and invertebrates; however, rice fields also harbor vertebrate prey. Although the abundance of many avian foods in rice fields has received the greatest attention in North America, most investigations of vertebrate prey in rice fields have been conducted elsewhere.

As with many plant and animal populations in dynamic wetlands, considerable seasonal variation likely characterizes vertebrate abundance in rice fields. In an evaluation of seasonal variation in waterbird prey in rice fields in the Ebro Delta, Gonzáles-Solís *et al.* (1996) reported fish (i.e. *Gambusia* spp., *Cyprinus* spp.) and frogs (*Rana* spp.) were relatively abundant and likely important foods of wading birds during autumn and winter, but were less abundant during other times of the year. Similarly, fish were important in the diet of six wading bird species that fed in rice fields in Cuba (Mugica *et al.* 2005); biomass of fishes in mature Cuban rice fields averaged 99.4 kg/ha (Mugica *et al.* 2006a). Fasola and Ruiz (1997) reported densities of amphibians in rice fields in southern Europe ranged from 0.1 to 9.3/100 m^2 for adults and 0.6-118/100 m^2 for tadpoles, whereas fish were present at densities averaging 4.8/100 m^2. Richardson *et al.* (2001) reported tadpoles (*Limnodynastes* spp.) were the primary prey of Eastern Great Egrets (*Ardea modesta*) and Intermediate Egrets (*Egretta intermedia*) in Australian rice fields and noted prey capture rates declined sharply between November and February. Also, egrets consumed adult frogs, but at considerably lower rates than tadpoles (Richardson *et al.* 2001). Lane and Fujioka (1998) reported frogs, tadpoles and fish were abundant in Japanese rice fields that were commonly used by foraging egrets and herons during the growing season.

Most information on vertebrate prey of birds in North American rice fields is anecdotal. Frogs, snakes, lizards, small granivorous rodents (e.g. Rice Rats [*Oryzomys palustris*]) and insectivorous shrews (Soricidae) were commonly observed in harvested rice fields of the MAV and may have been prey for wading birds and raptors (J. Stafford, personal observation). Eadie *et al.* (2008) reported Pacific Tree Frogs (*Hyla regilla*) and Bullfrogs (*Rana catesbeiana*) were common in California rice fields throughout the year, and Western Fence Lizards (*Sceloporus occidentalis*) and Western Spadefoot Toads (*Spea hammondii*) also occurred. Taft and Elphick (2007) reported herons and egrets consumed various species of fish, amphibians and small mammals in California fields.

BIRD USE OF FIELDS

Flooding rice fields makes food resources available to waterbirds, and an estimated 86% of ricelands worldwide are flooded during part of the year (Chang and Luh 1991). In central Japan, Maeda (2001) reported waterbirds used rice agriculture in the Kanto Plain primarily during the growing season because fields were typically left dry after harvest. Also in Japan, Shimada *et al.* (2000) reported use of rice fields by dabbling ducks (Anatini), Eastern Cattle Egrets (*Bubulcus coromandus*), Black-crowned Night Herons (*Nycticorax nycticorax*) and Black Kites (*Milvus migrans*) was significantly greater during a natural flood in 1998 compared to 1995-1997, when no floods occurred. Fujioka *et al.* (2001) reported more species, but similar densities (birds/ha/visit), of birds in flooded than dry rice fields in rural Japan during mid-summer, but dry fields attracted primarily passerines that exploited foods available on the ground.

Reinecke *et al.* (1992) reported 21-39% of Mallards in the MAV during winter used flooded rice fields, and Tamisier (1976) reported Green-winged Teals (*Anas carolinensis*) and Northern Pintails fed primarily in flooded rice fields in southern Louisiana. More recently, Pearse (2007) estimated that flooded rice fields constituted 4.6% of wetland habitat for waterfowl in the MAV of Mississippi during winters 2003-2005, and reported Mallards generally used these fields in greater proportion than available. In the Central Valley (CV) of California, Miller and Newton (1999) indicated populations of wintering Northern Pintails, and consumption of foods in harvested rice fields, were greater in wet than dry winters. Similarly, shorebird use of rice fields in the CV increased when rainfall or wetland management practices expanded the area of shallow water and mudflats (Shuford *et al.* 1998). Ackerman *et al.* (2006) reported Greater White-fronted Geese wintering in the CV primarily roosted (43%) and fed (34%) in burned rice fields during 1987-1990, but shifted the majority of these activities (78% roost, 64% feed) to flooded fields during 1998-2000. Overall, 24 of 31 waterbird species using rice fields in the CV were more abundant in flooded than dry fields, and the greatest species diversity occurred when water depths were 10-20 cm (Elphick and Oring 1998, 2003). Fasola and Ruiz (1996) reported 25-50% of wading birds in rice fields of the Ebro Delta fed in rice fields with water depths of <8 cm. Clearly, the presence, extent, depth and related hydrologic proximate factors influence avian use of rice fields worldwide.

Although flooding generally correlates with abundance and diversity of birds foraging in rice fields, Maeda (2001) reported Little Egrets (*Egretta garzetta*) and Common Snipes (*Gallinago gallinago*) occurred in rice fields in Japan during the dry season, although foraging was concentrated in ditches retaining water. Similarly, Elphick and Oring (1998) documented significantly greater use of unflooded than flooded rice fields by Great Blue Herons (*Ardea herodias*) and Sandhill Cranes (*Grus canadensis*) in central California. Finally, Guzmán *et al.* (1999) showed spatial and temporal changes in migration of Common Cranes (*Grus grus*) wintering in the Iberian Peninsula of Europe reflected the area of dry rice fields available as foraging habitat.

Agronomic practices other than flooding also influence use of rice fields by birds. In the Camargue, France, increased spring use by foraging waterbirds of rice fields farmed fewer than four years and of those that were wet-sown rather than dry-sown indicated intensive or repetitive crop production reduced availability of waterbird foods (Tourenq *et al.* 2003). In Arkansas, Havens (2007) evaluated winter waterbird use of harvested and flooded rice fields relative to different post-harvest management practices designed to facilitate rice straw decomposition. Mean density of Mallards was greatest in paddies with rolled rice straw (4.2 birds/ha/survey; SE = 0.4), whereas mean densities of other dabbling ducks (2.3 birds/ha/survey; SE = 0.5) and geese (2.9 birds/ha/survey; SE = 1.0) were greatest in burned-straw paddies (Havens 2007). Further, mean aggregate density of rails, shorebirds and wading birds was 33 times greater in rolled-straw paddies (1.0 birds/ha/survey; SE = 0.3) than in paddies with standing rice stubble (Havens 2007). Generally, shorebirds avoid fields with tall or dense vegetation, but such conditions may attract other species, such as American Bitterns (*Botaurus lentiginosus*; Eadie *et al.* 2008). In spring, most shorebirds (70%) and wading birds migrating north from coastal Louisiana, were observed in rice fields with <50% vegetation cover, even though only 19% of fields occurred in this category (Rettig 1994).

Central Hokkaido, Japan is an important migration staging area for Greater White-fronted Geese that forage on waste rice and emerging winter wheat (Amano *et al.* 2004). In a study of factors associated with crop use and depredation of winter wheat, Amano *et al.* (2004) found consumption of waste rice was lower when fields were closer to houses, roads and windbreaks. Because landscape context may have influenced use of rice fields by foraging geese, the authors recommended locating winter wheat fields near roads or other structures to decrease crop depredation by geese (Amano *et al.* 2004).

WATERBIRD FORAGING BEHAVIOR

Waterbird activity budgets have been studied extensively in ricelands. Rave and Cordes (1993) investigated time-activities of Northern Pintails in non-hunted rice fields in southwest Louisiana. During winter 1988-1989, mean diurnal activities included 21% feeding, 52% resting, 16% comfort movements and 4% courtship. Further, Rave and Cordes (1993) reported most feeding occurred in early morning, and Northern Pintails increased time allocated to foraging from 6% in November to 33% in February. Northern Pintails using rice fields in California's Sacramento Valley also increased time allocated to foraging from ~15% in August-September and ~10% in December to ~35% in February-March (Miller 1985). The importance of ricelands as foraging habitat in late winter also was supported by data indicating Northern Pintails needed less time to obtain food from rice fields than natural marshes (Miller 1985:63). Finally, Havens (2007) compared behaviors and densities of Mallards using winter-flooded rice fields in Arkansas during 2004-2006. Density of feeding Mallards in paddies with rolled stubble was 2.8 times greater than paddies where rice stubble was burned and 10.4 times greater than paddies with standing stubble. Rolled paddies may have afforded greater visibility than those with standing stubble and the decreased requirement for vigilance may have enhanced their value as foraging sites (Guillemain *et al.* 2001, 2002; Havens 2007).

Jónsson and Afton (2006) compared time and energy budgets of Snow Geese in coastal marshes and rice prairies in southwest Louisiana. Because the estimated gross energy concentration (kJ/g) in diets of geese was less in rice prairies than coastal marshes, the authors predicted geese would spend more time feeding in rice prairies. However, geese actually spent more time feeding in coastal marshes, and the authors hypothesized this difference probably was related to greater fiber content, lower metabolizable energy and greater effort needed to harvest rhizomes and tubers in coastal marshes. Time spent feeding by adults was similar between habitats, but juveniles fed more in rice prairies, where they largely grazed on green vegetation, than in coastal marshes where exploitation of subterranean foods may be more difficult.

Although many studies of foraging waterbirds in rice fields have focused on waterfowl, some researchers have investigated foraging behavior of wading birds. Lombardini *et al.* (2001) reported foraging success (biomass/min) of Western Cattle Egrets in the Camargue was greatest during winter, whereas foraging success of Little Egrets was greatest during the breeding season. Richardson *et al.* (2001) presented detailed comparative data on foraging behaviors of Eastern Cattle, Eastern Great, and Intermediate Egrets in rice fields in southern Australia. Eastern Cattle Egrets fed on insects and apparently were successful in all capture attempts. In contrast, Eastern Great and Intermediate Egrets captured tadpoles successfully in 69-85% of attempts and insects in only 15-31% of attempts. Capture attempts by Eastern Great and Intermediate Egrets declined from November to January, but Eastern Cattle Egrets did not exhibit significant temporal variation in capture attempts. Richardson *et al.* (2001) concluded that foraging profitability of rice fields declined seasonally when wading birds required maximal energy to feed young and, thus, that fields were likely less valuable to egrets than natural wetlands (Richardson *et al.* 2001).

Elphick (2000) conducted a comprehensive investigation of waterbird behavior in rice fields in California. He compared foraging and other activities in flooded and unflooded rice fields and semi-natural wetlands. Successful foraging attempts per unit time did not differ between flooded rice fields and wetlands, although attack rates were greatest for five bird species in flooded rice fields, perhaps indicating relatively abundant prey (Elphick 2000). However, attack and capture rates of Western Great Egrets were significantly less in dry than flooded rice fields and wetlands, although waterbirds generally acquired more prey per attack in wetlands than in rice fields. Models explaining variation in foraging behavior of waterbirds indicated risk of predation, water depth, time of day and date were important predictors of prey attack and capture rates. Elphick (2000) also investigated time allocation among behaviors of several waterbird species and reported few differences among habitats. However, Western Great Egrets spent more time sleeping in unflooded rice fields, whereas Long-billed Dowitchers (*Limnodromus scolopaceus*) spent more time sleeping in wetlands. Greater Yellowlegs (*Tringa melanoleuca*) and Long-billed Dowitchers fed most in flooded rice fields. Elphick (2000) concluded that flooded rice fields likely provided foraging habitats for the studied waterbirds functionally equivalent to wetlands, and suggested increased flooding of rice fields could result in valuable contributions to waterbird habitat in California.

Spatial distribution of foods within rice fields may influence foraging behavior of waterbirds. Manley (1999) documented variation in abundance of waste rice in and among Mississippi rice fields in early winter. Specifically, ~58% of rice fields and ~66% of soil samples from rice fields contained less than 50 kg/ha (i.e. the presumed foraging giving-up density; Reinecke *et al.* 1989; Greer *et al.* 2009). At the scale of the MAV, results from Stafford (2004) supported Manley's (1999) findings, documenting 76% of fields and 80% of soil samples within fields contained less than 50 kg/ha of available waste rice in early winter. Given the heterogeneous distribution of waste rice seeds, Stafford (2004) hypothesized that waterfowl foraging in rice fields may use "area-restricted" search tactics (Wood 1985; Tome 1989) to locate and exploit food patches and follow a theoretical "giving-up time" rule when foraging (i.e. leave after a period of unsuccessful searching; Iwasa *et al.* 1981). In a controlled experiment that provided differently-scaled heterogeneous food distributions, Klaassen *et al.* (2006) concluded Mallards employed area-restricted searches when forage was patchy. A separate experiment revealed that Mallards spent less time in empty patches when the previously visited patch was empty and moved longer distances when starting in empty than full patches, thereby indicating Mallards used prior information about spatial patterns of food distribution when foraging (Klaassen *et al.* 2007).

Amano *et al.* (2004) used optimal foraging models to investigate factors affecting habitat selection by Greater White-fronted Geese during fall and spring migration near Lake Miyajimanuma, Japan. Components of the foraging models included daily energy and nitrogen requirements, digestive capacity, daily maximum foraging time, and energy content and abundance of rice seeds and alternate foods (i.e. shoots of winter wheat). Habitat use was best predicted by models where the foraging strategy was to maximize energy intake. Further, models indicated geese made limited use of wheat fields during fall to meet protein requirements when rice abundance decreased and used wheat fields increasingly in spring to maximize energy intake when rice was nearly depleted (Amano *et al.* 2004). The analysis yielded important insights regarding waterfowl feeding ecology and science-based options for reducing depredation on wheat. We suggest future studies of waterbird foraging in rice fields will be more productive when explicitly integrating optimal foraging theory (Schoener 1971; Stephens and Krebs 1986).

CONSERVATION AND RESEARCH IMPLICATIONS

Rice production frequently involves hydro-infrastructures to distribute and retain water (i.e. canals, pumps, levees) and fields often can be flooded actively or passively in the growing and non-growing seasons. Rice fields not flooded after harvest provide foraging habitat for various bird species, but fields flooded post-harvest attract a greater abundance and species diversity of waterbirds (Reinecke *et al.* 1989; Elphick and Oring 1998). Currently, post-harvest flooding is most widespread in areas where large numbers of migrating and wintering waterfowl occur and landowners accrue recreational and economic benefits from hunting leases. However, flooding fields after harvest also provides environmental and agronomic benefits. Manley (2009: 62) reported export of suspended solids from Mississippi rice fields tilled after harvest and allowed to drain during winter was 32 times greater than from fields left in stubble and flooded. Further, Manley *et al.* (2005) reported straw biomass decreased 43-68% and winter weed biomass declined 24-83% when fields were flooded in winter. Use of winter flooding, to decompose rice straw and control competing weeds, saved farmers the equivalent of $22-63/ha (USD, 2002) in preparing fields for planting. In Japan, Yamamoto *et al.* (2003) also found that profits were greater on winter-flooded rice fields where ducks fed than on fields left dry, and attributed the difference to lower pesticide and herbicide costs. Further, intensive foraging by birds may increase straw decomposition. In California, Bird *et al.* (2000) reported straw biomass decreased 27-41% in small plots where waterfowl were prevented from feeding and 72-76% in plots where waterfowl were present. Van Groenigen *et al.* (2003) used entire fields to replicate this experiment and reported decomposition of straw in flooded fields where waterfowl foraged was at least double that of fields where no foraging occurred.

Management of rice stubble also may increase attractiveness, suitability and amount of forage available to avifauna (Elphick *et al.* 2010). Stafford *et al.* (2006) reported a 71% decline in waste rice abundance between harvest and early winter in MAV rice fields. Their conclusion prompted investigations of management practices that might retain rice seed for waterbirds in the region. Studies by Stafford *et al.* (2005) in Mississippi and a large-scale study by Kross *et al.* (2008) in Mississippi and Arkansas suggested waste rice abundance in early winter was greatest in fields where stubble was left untreated, intermediate in burned fields and least in fields where stubble was tilled or rolled. In contrast, bird use generally seems greater when farmers manipulate rice straw post-harvest to facilitate decomposition by increasing contact between straw and soil, and Havens' (2007) study in Arkansas indicated greatest densities of waterbirds occurred in rice fields with rolled or burned stubble. Apparently, many waterbirds seek open water areas in rice fields to land and initiate foraging. Thus, we concur with the recommendation of Kross *et al.* (2008) to conduct incomplete burns (where permissible) in harvested fields prior to flooding as a compromise that maintains a relatively high abundance of waste rice and creates mosaics of stubble and open water similar to the vegetative structure of "hemi-marshes" (Weller and Spatcher 1965; Kaminski and Prince 1981; Smith *et al.* 2004). This recommendation is consistent with Loughman and Batzer's (1992) data indicating fields burned and flooded after harvest in California contained the greatest densities of aquatic invertebrates.

Generally, ratoon rice crops are grown only in regions with subtropical or tropical climates. In North America, ratoon crops are rare outside of Texas and Louisiana. However, rice varieties that are cold tolerant and mature rapidly are being developed and will increase the frequency of ratoon crops in regions with shorter growing seasons. This development should increase foraging habitat available to wetland birds because fields will be flooded more days each year and waste rice from ratoon crops harvested late in the growing season will have less time to decompose or germinate before migrating and wintering birds arrive. Further, where ratoon crops can be grown in areas important to migrating and wintering waterfowl, landowners have the opportunity to produce abundant rice for waterfowl provided they are willing to pay the cost of irrigation. Conservation organizations should encourage farmers to implement this practice and request government farm programs to support the effort with financial or other incentives.

Wildlife managers in North America occasionally plant rice crops specifically to provide food plots for waterbirds. When flooded during fall and winter, this strategy may provide areas rich in high-carbohydrate forage, especially if crops are left unharvested. However, agricultural monocultures may not provide the variety of habitat types needed to attract and sustain abundant and diverse waterbird communities. Therefore, we suggest efforts to grow and flood harvested and unharvested rice crops to attract waterbirds should be considered in the context of wetland complexes that promote availability of diverse food sources and vegetation structures (e.g. moist-soil, bottomland forest and naturally flooded wetlands; Reinecke *et al.* 1989). Accordingly, Pearse (2007) reported that the greatest abundances of dabbling ducks in the MAV of Mississippi during winter were associated with landscapes composed of complexes of flooded cropland (including rice), seasonally-flooded emergent and forested wetlands, and permanent wetlands (e.g. rivers, ponds). Thus, habitat conservationists should use available scientific evidence to implement landscape scale conservation of wetlands and flooded agricultural lands for waterbirds.

Considerable work remains to obtain precise estimates of food abundance for birds in rice fields. Abundance of waste rice and its relation to agricultural practices has received considerable study in North America, and similar investigations should be conducted in other regions where waste rice is important to bird populations (e.g. Guzmán *et al.* 1999; Amano *et al.* 2004, 2006; Stafford *et al.* 2006). Similarly, estimates of moist-soil and aquatic plant seed abundance in rice fields are needed for regions outside North America, especially where control of wetland weeds is expensive and their seeds provide abundant food sources for birds. We concur with Taft and Elphick (2007) that investigation of the abundance and importance of rice, invertebrates and other plant seeds to breeding birds are especially needed. Little is known about abundance or use of green forage in most rice-growing regions despite its importance to migrating and wintering geese. Further, most estimates of invertebrate biomass in rice fields are from North America, whereas abundance of vertebrate prey has received most study elsewhere and merits additional attention in North America (Gonzáles-Solís *et al.* 1996; Fasola and Ruiz 1997; Richardson *et al.* 2001). Understanding and managing rice fields as avian foraging habitats also will benefit from further research on factors affecting spatial and temporal variation in use of rice fields by foraging waterbirds, especially studies relating field use to covariates such as food abundance, vegetation cover and juxtaposition, landscape context and weather (King *et al.* 2010). Finally, we especially recommend studies integrating food abundance and exploitation in the context of foraging theory, demographics and conservation planning for priority species (Fleury and Sherry 1995; Miller and Newton 1999; Amano *et al.* 2004; Stafford *et al.* 2006; Greer *et al.* 2009).

Farmers may be more likely to manage rice fields as foraging habitat for birds if they expect to increase or at least maintain profitability (Zekor and Kaminski 1987). We are encouraged that recent studies have demonstrated certain management practices enhance foraging habitat and potentially benefit rice farmers (e.g. Havens 2007). In North America, flooding rice fields after harvest benefits numerous types of birds (Elphick and Oring 1998) and, by efficiently decomposing rice straw and controlling growth of winter weeds, may decrease costs of preparation for spring planting (Bird *et al.* 2000; Manley *et al.* 2005). Understanding how Greater White-fronted Geese in Japan used waste rice and wheat sprouts to obtain energy and protein identified management practices that were likely to increase farm income by reducing depredation on wheat and increasing yields (Amano *et al.* 2004, 2006). Overall, we believe progress in avian conservation in rice-producing areas will require integrating knowledge of food abundance and exploitation by birds with innovative management practices that increase foraging opportunities while maintaining or increasing farm income.

The ability of ricelands to provide foraging habitat for waterbirds in the future will largely depend on changes in commodity prices, management practices and area of land in production. In the USA, area of rice planted is projected to remain relatively stable through 2016 (~1.2 Mha/yr; Interagency Agricultural Outlook Board 2007: 45), although global population growth undoubtedly will stimulate worldwide rice production. We expect future changes in rice production will affect avian foraging habitat primarily at regional scales, especially where changes in rice production and bird populations of conservation concern co-occur. For example, over the past 50 years, the area of rice harvested has increased by more than 50% in the USA but decreased by at least 50% in coastal Texas (NASS 2008) where over 1,000,000 waterfowl winter (Hobaugh *et al.* 1989). Northern Pintail populations are a special concern in North America (Miller and Duncan 1999) and decreased access to food in rice fields may have contributed to reduced winter body mass and survival of this species (Ballard 2007). Indeed, dynamic commodity markets worldwide may influence the availability of ricelands for waterbird use. In attempts to compensate in part for possible declines in waste grain abundance, scientists and conservationists in the USA are working with habitat managers to increase moist-soil plant management on lands that are not in commercial crop production (Stafford *et al.* 2006; Kross *et al.* 2008).

Although rice acreage may decrease in some regions, average rice yields in the USA are predicted to increase by about 13% by 2016, from ~7,400 kg/ha to ~8,400 kg/ha, perhaps indicating increased abundance of waste rice for waterbirds (Interagency Agricultural Outlook Board 2007). Conversely, previous estimates of the land area in rice-wheat rotation in China ranged from 10.5-13.0 Mha, but recent analyses (e.g. remote sensing) indicated an average area of 4.6 Mha during 1990-1995 and only 3.4 Mha in 2001 (Dawe *et al.* 2004). Apparently, land area planted in rice-wheat rotation in China was previously overestimated and has declined sharply in recent years (Dawe *et al.* 2004). Because rice fields provide valuable habitats for foraging avifauna, we suggest it is critical that researchers employ modern tools, such as remote sensing, to investigate trends in rice agriculture worldwide (sensu Fleskes *et al.* 2005). Such research would provide information to guide future conservation planning and implementation in rice-agriculture ecosystems.

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LITERATURE CITED

Abraham, K. F., R. L. Jefferies and R. T. Alisauskas. 2005. The dynamics of landscape change and Snow Geese in mid-continent North America. Global Change Biology 11: 841-855.

Ackerman, J. T., J. Y. Takekawa, D. L. Orthmeyer, J. P. Fleskes, J. L. Yee and K. L. Kruse. 2006. Spatial use by wintering Greater White-fronted Geese relative to a decade of habitat change in California's Central Valley. Journal of Wildlife Management 70: 965-976.

Alisauskas, R. T., C. D. Ankney and E. E. Klaas. 1988. Winter diets and nutrition of midcontinental Lesser Snow Geese. Journal of Wildlife Management 52: 403-414.

Amano, T., K. Ushiyama, G. Fujita and H. Higuchi. 2004. Factors affecting rice grain density unconsumed by White-fronted Geese in relation to wheat damage. Agriculture, Ecosystems and Environment 102: 403-407.

Amano, T., K. Ushiyama, G. Fujita and H. Higuchi. 2006. Foraging patch selection and departure by non-omniscient foragers: a field example in White-fronted Geese. Ethology 112: 544-553.

Anderson, J. T. and L. M. Smith. 2000. Invertebrate response to moist-soil management of Playa wetlands. Ecological Applications 10: 550-558.

Avery, M. L. 1989. Experimental evaluation of partial repellent treatment for reducing bird damage to crops. Journal of Applied Ecology 26: 433-440.

Baldassarre, G. A., R. J. Whyte, E. E. Quinlan and E. G. Bolen. 1983. Dynamics and quality of waste corn available to postbreeding waterfowl in Texas. Wildlife Society Bulletin 11: 25-31.

Baldassarre, G. A. and E. G. Bolen. 1984. Field-feeding ecology of waterfowl wintering on the Southern High Plains of Texas. Journal of Wildlife Management 48: 63-71.

Baldassarre, G. A. and E. G. Bolen. 2006. Waterfowl Ecology and Management, Second edition. Krieger Publishing Company, Malabar, Florida.

Ballard, B. M. 2007. Linking waterfowl ecology and management: a Texas coast perspective. Pages 95-108 *in* Wildlife Science: Linking Ecological Theory and Management Applications (T. E. Fulbright and D. G. Hewitt, Eds.). CRC Press, Boca Raton, Florida.

Batema, D. L., R. M. Kaminski and P. A. Magee. 2005. Wetland invertebrate communities and management of hardwood bottomlands in the Mississippi Alluvial Valley. Pages 173-190 *in* Ecology and Management of Bottomland Hardwood Systems: The State of Our Understanding (L. H. Fredrickson, S. L. King and R. M. Kaminski, Eds.). University of Missouri-Columbia. Gaylord Memorial Laboratory Special Publication No. 10. Puxico, Missouri.

Becker, M. and D. E. Johnson. 2001. Improved water control and crop management effects on lowland rice productivity in West Africa. Nutrient Cycling in Agroecosystems 59: 119-127.

Bellrose, F. C. 1980. Ducks, geese, and swans of North America. Third edition. Stackpole Books, Harrisburg, Pennsylvania.

Bird, J. A., G. S. Pettygrove and J. M. Eadie. 2000. The impact of waterfowl foraging on the decomposition of rice straw: mutual benefits for rice growers and waterfowl. Journal of Applied Ecology 37: 728-741.

Bourne, G. R. 1982. Food habits of Black-bellied Whistling Ducks occupying rice culture habitats. Wilson Bulletin 93: 551-554.

Bourne, G. R. and D. R. Osborne. 1978. Black-bellied Whistling Duck utilization of a rice culture habitat. Interciencia 3: 152-159.

Bowyer, M. W., J. D. Stafford, A. P. Yetter, C. S. Hine, M. M. Horath and S. P. Havera. 2005. Moist-soil plant seed production for waterfowl at Chautauqua National Wildlife Refuge, Illinois. American Midland Naturalist 154: 331-341.

Chang, T. and B. S. Luh. 1991. Overview and prospects of rice production. Pages 1-11 *in* Rice Production (B. S. Luh, Ed.). Van Nostrand Reinhold, New York, New York.

Chien, Y.-H. and J. W. Avault, Jr. 1980. Production of crayfish in rice fields. The Progressive Fish-Culturalist 42: 67-71.

Dabbert, C. B. and T. E. Martin. 2000. Diet of Mallards wintering in greentree reservoirs in southeastern Arkansas. Journal of Field Ornithology 71: 423-428.

Davis, J. P., C. H. Thomas and L. L. Glasgow. 1961. Foods available to waterfowl in fallow ricefields of southwestern Louisiana, 1960-1961. Proceedings of the Annual Conference Southeastern Association of Game and Fish Commissions 15: 60-66.

Dawe, D., S. Frolking and C. Li. 2004. Trends in rice-wheat area in China. Field Crop Research 87: 89-95.

Day, J. H. 1997. Fall and winter use of harvested rice fields by Pacific Flyway White-fronted Geese (*Anser albifrons*). Unpublished M.Sc. Thesis, Humboldt State University, Arcata, California.

Delnicki, D. and K. J. Reinecke. 1986. Mid-winter food use and body weights of Mallards and Wood Ducks in Mississippi. Journal of Wildlife Management 50: 43-51.

Eadie, J. M., C. S. Elphick, K. J. Reinecke and M. R. Miller. 2008. Wildlife values of North American ricelands. Pages 7-90 *in* Conservation in Ricelands of North America (S. W. Manley, Ed.). The Rice Foundation, Stuttgart, Arkansas.

Elphick, C. S. 2000. Functional equivalency between rice fields and seminatural wetland habitats. Conservation Biology 14: 181-191.

Elphick, C. S. and L. W. Oring. 1998. Winter management of Californian rice fields for waterbirds. Journal of Applied Ecology 35: 95-108.

Elphick, C. S. and L. W. Oring. 2003. Conservation implications of flooding rice fields on winter waterbird communities. Agriculture, Ecosystems and Environment 94: 17-29.

Elphick, C. S., O. Taft and P. M. Louenço. 2010. Management of rice fields for birds during the non-growing season. Waterbirds 33 (Special Publication 1): 181-192.

Fasola, M. and X. Ruiz. 1996. The value of rice fields as substitutes for natural wetlands for waterbirds in the Mediterranean region. Colonial Waterbirds 19: 122-128.

Fasola, M. and X. Ruiz. 1997. Rice farming and waterbirds: integrated management in an artificial landscape. Pages 210-235 *in* Farming and Birds in Europe: the Common Agricultural Policy and its Implications for Bird Conservation (D. J. Pain and M. W. Pienkowski, Eds.). Academic Press, San Diego, California.

Fleskes, J. P., W. M. Perry, K. L. Petrik, R. Spell and F. Reid. 2005. Change in area of winter-flooded and dry rice in the northern Central Valley of California determined by satellite imagery. California Fish and Game 91: 207-215.

Fleury, B. E. and T. W. Sherry. 1995. Long-term population trends of colonial wading birds in the southern United States: the impact of crayfish aquaculture on Louisiana populations. Auk 112: 613-632.

Flickinger, E. L. and K. A. King. 1972. Some effects of aldrin-treated rice on Gulf Coast wildlife. Journal of Wildlife Management 36: 706-727.

Foley, W. J. and S. J. Cork. 1992. Use of fibrous diets by small herbivores: how far can the rules be "bent"? Trends in Ecology and Evolution 7: 159-162.

Fredrickson, L. H. and T. S. Taylor. 1982. Management of seasonally flooded impoundments for wildlife. U.S. Fish and Wildlife Service Resource Publication 148. Washington, D.C.

Fujioka, M., J. W. Armacost, Jr., H. Yoshida and T. Maeda. 2001. Value of fallow farmlands as summer habitats for waterbirds in a Japanese rural area. Ecological Research 16: 555-567.

Gealy, D. R., D. H. Mitten and J. N. Rutger. 2003. Gene flow between red rice (*Oryza sativa*) and herbicide-resistant rice (*O. sativa*): implications for weed management. Weed Technology 17: 627-645.

González-Solís, J., X. Berandí and X. Ruiz. 1996. Seasonal variation of waterbird prey in the Ebro Delta rice fields. Colonial Waterbirds 19 (Special Publication 1): 135-142.

Gray, M. J., R. M. Kaminski, G. Weerakkody, B. D. Leopold and K. C. Jensen. 1999. Aquatic invertebrate and plant responses following mechanical manipulations of moist-soil plants. Wildlife Society Bulletin 19: 770-779.

Greer, D. M., B. D. Dugger, K. J. Reinecke and M. J. Petrie. 2009. Depletion of rice as a food of waterfowl wintering in the Mississippi Alluvial Valley. Journal of Wildlife Management 73: 1125-1133.

Gullemain, M., P. Duncan and H. Fritz. 2001. Switching to a feeding method which obstructs vision increases head-up vigilance in dabbling ducks. Journal of Avian Biology 32: 345-350.

Guillemain, M., G. R. Martin and H. Fritz. 2002. Feeding methods, visual fields and vigilance in dabbling ducks (Anatidae). Functional Ecology 16: 522-529.

Guzmán, J. M. S., A. S. García, C. C. Amado and A. Muñoz del Viejo. 1999. Influence of farming activities in the Iberian Peninsula on the winter habitat use of Common Crane (*Grus grus*) in areas of its traditional migratory routes. Agriculture, Ecosystems and Environment 72: 207-214.

Harmon, B. G., C. H. Thomas and L. L. Glasgow. 1960. Waterfowl foods in Louisiana ricefields. Transactions of the North American Wildlife and Natural Resource Conference 25: 153-161.

Havens, J. H. 2007. Winter abundance of waterfowl, waterbirds, and waste rice in managed Arkansas rice fields. Unpublished M.Sc. Thesis, Mississippi State University, Mississippi State, Mississippi.

Havera, S. P. 1999. Waterfowl of Illinois: status and management. Illinois Natural History Survey Special Publication 21, Urbana, Illinois.

Heitmeyer, M. E., D. P. Connelly and R. L. Pederson. 1989. The Central, Imperial, and Coachella Valleys of California. Pages 475-505 *in* Habitat Management for Migrating and Wintering Waterfowl in North America (L. M. Smith, R. L. Pederson and R. M. Kaminski, Eds.). Texas Tech University Press, Lubbock, Texas.

Hobaugh, W. C. 1984. Habitat use by Snow Geese wintering in Southeast Texas. Journal of Wildlife Management 48: 1085-1096.

Hobaugh, W. C., C. D. Stutzenbaker and E. L. Flickinger. 1989. The rice prairies. Pages 367-384 *in* Habitat Management for Migrating and Wintering Waterfowl in North America (L. M. Smith, R. L. Pederson and R. M. Kaminski, Eds.). Texas Tech University Press, Lubbock, Texas.

Hohman, W. L., T. M. Stark and J. L. Moore. 1996. Food availability and feeding preference of breeding Fulvous Whistling-Ducks in Louisiana ricefields. Wilson Bulletin 108: 137-150.

Huner, J. V., C. W. Jeske and W. Norling. 2002. Managing agricultural wetlands for waterbirds in the coastal regions of Louisiana, U.S.A. Waterbirds 25 (Special Publication 2): 66-78.

Interagency Agricultural Outlook Board. 2007. USDA Agricultural Projections to 2016. Office of the Chief Economist, World Agricultural Outlook Board, U.S. Department of Agriculture. Long-term Projections Report OCE-2007-1.

Iwabuchi, S. 2004. Restoration of biodiversity and improvement in agricultural land resource quality through winter-flooded rice fields (WfRF). Page 68 *in* Proceedings of the World Rice Research Conference, 4-7 November 2004, Tsukuba, Japan.

Iwasa, Y., M. Higashi and N. Yamamura. 1981. Prey distribution as a factor determining the choice of optimal foraging strategy. American Naturalist 117: 710-723.

Jónsson, J. E. and A. D. Afton. 2006. Different time and energy budgets of Lesser Snow Geese in rice-prairies and coastal marshes in Southwest Louisiana. Waterbirds 29: 451-458.

Kaminski, R. M. and H. H. Prince. 1981. Dabbling duck and aquatic macroinvertebrate responses to manipulated wetland habitat. Journal of Wildlife Management 45: 1-15.

Kaminski, R. M., J. B. Davis, H. W. Essig, P. D. Gerard and K. J. Reinecke. 2003. True metabolizable energy for Wood Ducks from acorns compared to other waterfowl foods. Journal of Wildlife Management 67: 542-550.

King, S., C. S. Elphick, D. Guadagnin, O. Taft and T. Amano. 2010. Effects of landscape management on waterbird use of rice fields. Waterbirds 33 (Special Publication 1): 151-159.

Klaassen, R. H. G., B. A. Nolet and J. de Fouw. 2006. Intake rate at differently scaled heterogeneous food distributions explained by the ability of tactile-foraging Mallard to concentrate foraging effort within profitable areas. Oikos 112: 322-331.

Klaassen, R. H. G., B. A. Nolet and C. H. A. Van Leeuwen. 2007. Prior knowledge about spatial patterns affects patch assessment rather than movement between patches in tactile-feeding Mallard. Journal of Animal Ecology 76: 20-29.

Kostecke, R. M., L. M. Smith and H. M. Hands. 2005. Macroinvertebrate response to cattail management at Cheyenne Bottoms, Kansas, USA. Wetlands 25: 758-763.

Krapu. G. L. and K. J. Reinecke. 1992. Foraging ecology and nutrition. Pages 1-29 *in* Ecology and Management of Breeding Waterfowl (B. D. J. Batt, A. D. Afton, M. G. Anderson, C. D. Ankney, D. H. Johnson, J. A. Kadlec and G. L. Krapu, Eds.). University of Minnesota Press, Minneapolis, Minnesota.

Kross, J. P., R. M. Kaminski, K. J. Reinecke and A. T. Pearse. 2008. Conserving waste rice for wintering waterfowl in the Mississippi Alluvial Valley. Journal of Wildlife Management 72: 1383-1387.

Lane, S. J. and M. Fujioka. 1998. The impact of changes in irrigation practices on the distribution of foraging egrets and herons (Ardeidae) in the rice fields of central Japan. Biological Conservation 83: 221-230.
Lawler, S. P. and D. A. Dritz. 2005. Straw and winter flooding benefit mosquitoes and other insects in a rice agroecosystem. Ecological Applications 15: 2052-2059.
Loesch, C. R. and R. M. Kaminski. 1989. Winter bodyweight patterns of female Mallards fed agricultural seeds. Journal of Wildlife Management 53: 1081-1087.
Loesch, C. R., K. J. Reinecke and C. K. Baxter. 1994. Lower Mississippi Valley Joint Venture Evaluation Plan. North American Waterfowl Management Plan, Vicksburg, Mississippi.
Lombardini, K., R. E. Bennetts and C. Tourenq. 2001. Foraging success and foraging habitat use by Cattle Egrets and Little Egrets in the Camargue, France. Condor 103: 38-44.
Loughman, D. L. and D. P. Batzer. 1992. Assessments of rice fields as habitat for ducks wintering in California. Final Report FG 1359, California Department of Fish and Game, Sacramento, California.
Low, J. B. and F. C. Bellrose, Jr. 1944. The seed and vegetative yield of waterfowl food plants in the Illinois River valley. Journal of Wildlife Management 8: 7-22.
Maeda, T. 2001. Patterns of bird abundance and habitat use in rice fields of the Kanto Plain, central Japan. Ecological Research 16: 569-585.
Manley, S. W., R. M. Kaminski, K. J. Reinecke and P. D. Gerard. 2004. Waterbird foods in winter-managed ricefields in Mississippi. Journal of Wildlife Management 68: 74-83.
Manley, S. W., R. M. Kaminski, K. J. Reinecke and P. D. Gerard. 2005. Agronomic implications of waterfowl management in Mississippi ricefields. Wildlife Society Bulletin 33: 981-992.
Manley, S. E., R. M. Kaminski, P. B. Rodriguez, J. C. Dewey, S. H. Schoenholtz, P. D. Gerard and K. J. Reinecke. 2009. Soil and nutrient retention in winter-flooded ricefields with implication for watershed management. Journal of Soil and Water Conservation 64: 173-182.
McAbee, W. C. 1994. Waterfowl use and food availability on flooded croplands in northeast Louisiana. Louisiana Tech University, Ruston, Louisiana.
McAtee, W. L. 1923. Ducks useful in Arkansas as scavengers of red rice. Auk 40: 527-528.
McNeal, X. 1950. Effect of combine adjustment on harvest losses in rice. Bulletin 500. Cooperative Extension Service University of Arkansas, Fayetteville, Arkansas.
McQuilkin, R. A. and R. A. Musbach. 1977. Pin oak acorn production on green tree reservoirs in Southeastern Missouri. Journal of Wildlife Management 41: 218-225, 597.
Miller, M. R. 1985. Time budgets of Northern Pintails wintering in the Sacramento Valley, California. Wildfowl 36: 53-64.
Miller, M. R., D. E. Sharp, D. S. Gilmer and W. R. Mulvaney. 1989. Rice available to waterfowl in harvested fields in the Sacramento Valley, California. California Fish and Game 75: 113-123.
Miller, M. R. and G. D. Wylie. 1996. Preliminary estimate of rice present in strip-harvested fields in the Sacramento Valley, California. California Fish and Game 82: 187-191.
Miller, M. R. and D. C. Duncan. 1999. The Northern Pintail in North America: status and conservation needs of a struggling population. Wildlife Society Bulletin 27: 788-800.
Miller, M. R. and W. E. Newton. 1999. Population energetics of Northern Pintails wintering in the Sacramento Valley, California. Journal of Wildlife Management 63: 1222-1238.
Miller, T. C. and J. E. Street. 2000. Mississippi's rice growers guide. Mississippi State University Extension Service publication 2255, Mississippi.
Ministry of Agriculture, Forestry and Fisheries of Japan. 2003. Preliminary Statistical Report on Agriculture, Forestry and Fisheries: Production of Paddy Field Rice and Upland Rice, 2003. http://www.maff.go.jp/esokuhou/index.html, accessed 21 July 2007.
Mugica, L., M. Acosta, D. Denis and A. Jiménez. 2005. Variación estacional en la dieta de seis especies del gremio zancudas (Aves: Ciconiiformes) en dos arroceras Cubanas. Revista Biología 19: 40-49.
Mugica, L., M. Acosta, D. Denis and A. Jiménez. 2006a. Disponibilidad de presas par alas aves acuáticas en los campos inundados de la arrocera Sur del Jíbaro durante el ciclo de cultivo del arroz. Journal of Caribbean Ornithology 19: 97-103.
Mugica, L., M. Acosta, D. Denis, A. Jiménez, A. Rodriguez and X. Ruiz. 2006b. Rice culture in Cuba as an important wintering site for migrant waterbirds from North America Pages 172-176 *in* Waterbirds Around the World (G. C. Boere, C. A. Galbraith and D. A. Stroud, Eds.). The Stationery Office, Edinburgh, UK.
National Agricultural Statistics Service (NASS). 2008. National Agricultural Statistics Service Website. U.S. Department of Agriculture, National Agricultural Statistics Service, Agricultural Statistics Board, Washington, D.C., USA. http://www.nass.usda.gov, accessed 11 August, 2008.
Naylor, L. W. 2002. Evaluating moist-soil seed production and management in Central Valley wetlands to determine habitat needs for waterfowl. Unpublished M.Sc. Thesis, University of California, Davis, California.
Pearse, A. T. 2007. Design, evaluation, and applications of an aerial survey to estimate abundance of wintering waterfowl in Mississippi. Unpublished Ph.D. Dissertation, Mississippi State University, Mississippi.
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.
Powers, K. D., R. E. Noble and R. H. Chabreck. 1978. Seed distribution by waterfowl in southwestern Louisiana. Journal of Wildlife Management 42: 598-605.
Rave, D. P. and C. L. Cordes. 1993. Time-activity budget of Northern Pintails using nonhunted rice fields in Southwest Louisiana. Journal of Field Ornithology 64: 211-218.
Reinecke, K. J., R. M. Kaminski, D. J. Moorehead, J. D. Hodges and J. R. Nassar. 1989. Mississippi Alluvial Valley. Pages 203-248 *in* Habitat Management for Migrating and Wintering Waterfowl in North America (L. M. Smith, R. L. Pederson and R. M. Kaminski, Eds.). Texas Tech University Press, Lubbock, Texas.
Reinecke, K. J., M. W. Brown and J. R. Nassar. 1992. Evaluation of aerial transects for counting wintering Mallards. Journal of Wildlife Management 56: 515-525.
Reinecke, K. J. and K. M. Hartke. 2005. Estimating moist-soil seeds available to waterfowl with double sampling for stratification. Journal of Wildlife Management 69: 794-799.
Remsen, J. V., M. M. Swan, S. W. Cardiff and K. V. Rosenberg. 1991. The importance of the rice-growing region of south-central Louisiana to winter populations

of shorebirds, raptors, waders, and other birds. Journal of Louisiana Ornithology 1: 35-47.

Renfrew, R. B. and A. M. Saavedra. 2007. Ecology and conservation of Bobolinks (*Dolichonyx oryzivorus*) in rice production regions of Bolivia. Ornitologia Neotropical 18: 61-73.

Rettig, V. E. 1994. Use of agricultural fields by migrating and wintering shorebirds in southwest Louisiana. Unpublished M.Sc. Thesis. Louisiana State University, Baton Rouge, Louisiana.

Richardson, A. J., I. R. Taylor and J. E. Growns. 2001. The foraging ecology of egrets in rice fields in southern New South Wales, Australia. Waterbirds 24: 255-264.

Sánchez, M. I., A. J. Green and R. Alejandre. 2006. Shorebird predation affects density, biomass, and size distribution of benthic chironomids in salt pans: an exclosure experiment. Journal of the North American Benthological Society 25: 9-18.

Schoener, T. W. 1971. Theory of feeding strategies. Annual Review of Ecology and Systematics 2: 369-404.

Schoenly, K. G., I. T. Domingo and A. T. Barrion. 2003. Determining optimal quadrat sizes for invertebrate communities in agrobiodiversity studies: a case study from tropical irrigated rice. Environmental Entomology 32: 929-938.

Sherfy, M. H., R. L. Kirkpatrick and K. E. Webb, Jr. 2001. Nutritional consequences of gastrolith ingestion in Blue-winged Teal: a test of the hard-seed-for-grit hypothesis. Journal of Wildlife Management 65: 406-141.

Shimada, T. 1999. Comparison of the food abundance for wintering geese of different harvesting methods in rice fields near Lake Izunuma-Uchinuma. Strix 17: 111-117.

Shimada, T. 2002. Daily activity pattern and habitat use of Greater White-fronted Geese wintering in Japan: factors of the population increase. Waterbirds 25: 371-377.

Shimada, T. 2006. Wintering strategy and conservation of Greater White-fronted Goose *Anser albifrons* in rice agriculture and ecosystem in Japan. Unpublished Ph.D. Dissertation, Iwate University, Iwate, Japan.

Shimada, T. and C. Mizota. 2008a. Waste soybean as a potential food resource for wintering geese in northern Miyagi Prefecture. Japanese Journal of Ornithology 57: 20-24.

Shimada, T. and C. Mizota. 2008b. Significance of wheat and barley shoots for wintering geese in northern Miyagi Prefecture. Japanese Journal of Ornithology 57: 25-29.

Shimada, T. and C. Mizota. 2008c. Temporal and spatial changes in foraging distribution of an increasing population of wintering Greater White-fronted Geese over one decade: a case study for an area around Lake Izunuma-Uchinuma. Japanese Journal of Ornithology 57: 122-132.

Shimada, T., A. Bowman and M. Ishida. 2000. Effects of flooding on a wetland bird community. Ecological Research 15: 229-235.

Shuford, W. D., G. W. Page and J. E. Kjelmyr. 1998. Patterns and dynamics of shorebird use of California's Central Valley. Condor 100: 227-244.

Singleton, J. R. 1951. Production and utilization of waterfowl food plants on the east Texas Gulf Coast. Journal of Wildlife Management 15: 46-56.

Smith, L. M., R. L. Pederson and R. M. Kaminski (Eds.). 1989. Habitat Management for Migrating and Wintering Waterfowl in North America. Texas Tech University Press, Lubbock, Texas.

Smith, L. M., D. A. Haukos and R. M. Prather. 2004. Avian response to a vegetative pattern in playa wetlands during winter. Wildlife Society Bulletin 32: 474-480.

Smith, R. J. and J. D. Sullivan. 1980. Reducing red rice grain in rice fields by winter feeding of ducks. Arkansas Farm Research 29: 3.

Stafford, J. D. 2004. Abundance and conservation of waste rice for wintering waterfowl in the Mississippi Alluvial Valley. Unpublished Ph.D. Dissertation, Mississippi State University, Starkville, Mississippi.

Stafford, J. D., R. M. Kaminski, K. J. Reinecke, M. E. Kurtz and S. W. Manley. 2005. Post-harvest field manipulations to conserve waste rice for waterfowl. Proceedings of the Annual Conference of Southeastern Association of Fish and Wildlife Agencies 59: 151-163.

Stafford, J. D., R. M. Kaminski, K. J. Reinecke and S. W. Manley. 2006. Waste rice for waterfowl in the Mississippi Alluvial Valley. Journal of Wildlife Management 70: 61-69.

Stephens, D. W. and J. R. Krebs. 1986. Foraging Theory. Princeton University Press, Princeton, New Jersey.

Taft, O. W. and C. S. Elphick. 2007. Waterbirds on working lands: literature review and bibliography development. Technical Report, National Audubon Society. http://www.audubon.org/bird/waterbirds/downloads.html, accessed 10 June 2008.

Tamisier, A. 1976. Diurnal activities of Green-winged Teal and Pintail wintering in Louisiana. Wildfowl 27: 19-32.

Tojo, S., M. Yoshizawa, T. Motobayashi and K. Watanabe. 2007. Effects of loosing Aigamo Ducks on the growth of rice plants, weeds, and the number of arthropods in paddy fields. Weed Biology and Management 7: 38-43.

Tome, M. W. 1989. Search-patch characteristics of foraging Ruddy Ducks. Auk 106: 42-48.

Tourenq, C., N. Sadoul, N. Beck, F. Mesléard and J.-L. Martin. 2003. Effects of cropping practices on the use of rice fields by waterbirds in the Camargue, France. Agriculture, Ecosystems and Environment 95: 543-549.

Twedt, D. J. and C. O. Nelms. 1999. Waterfowl density on agricultural fields managed to retain water in winter. Wildlife Society Bulletin 27: 924-930.

van der Valk A. G., H. R. Murkin and J. A. Kadlec. 2000. The drawdown and reflooding years. Pages 75-97 *in* Prairie Wetland Ecology: The Contribution of the Marsh Ecology Research Program (H. R. Murkin, A. G. van der Valk and W. R. Clark, Eds.). Iowa State University Press, Ames, Iowa.

van Groenigen, J. W., E. G. Burns, J. M. Eadie, W. R. Horwath and C. van Kessel. 2003. Effects of foraging waterfowl in winter flooded rice fields on weed stress and residue decomposition. Agriculture, Ecosystems and Environment 95: 289-296.

van Way, V. 1986. Approaches to coot management in California. Proceedings of the Vertebrate Pest Conference 12: 292-294.

Warner, R. E., S. P. Havera, L. M. David and R. J. Siemers. 1989. Seasonal abundance of waste corn and soybeans in Illinois. Journal of Wildlife Management 53: 142-148.

Way, M. O., F. P. F. Reay-Jones and T. E. Reagan. 2006. Resistance to stem borers (Lepidoptera: Crambidae) among Texas rice cultivars. Journal of Economic Entomology 99: 1867-1876.

Weller, M. W. and C. S. Spatcher. 1965. Role of habitat in the distribution and abundance of marsh birds. Iowa State University Agriculture and Home Economics Experiment Station Special Report 43, Ames, Iowa.

Wood, C. C. 1985. Food-searching behaviour of the Common Merganser (*Mergus merganser*) II: choice of foraging location. Canadian Journal of Zoology. 63: 1271-1279.

Yamamoto, H., K. Oohata and K. Yamamoto. 2003. The effects of water flooding and provision of the food for wintering ducks on rice fields - A preliminary study for establishing a stable wintering duck population in Katano-kamoike. Strix 21: 111-123.

Zekor, D. T. and R. M. Kaminski. 1987. Attitudes of Mississippi Delta farmers toward private-land waterfowl management. Wildlife Society Bulletin 15: 346-354.