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The Future for Research on Waterbirds in Rice Fields

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Abstract.—Considerable work has been done to investigate linkages between the production of rice (*Oryza sativa*) and bird ecology and conservation. Rice is an extremely important crop globally and affects waterbirds in diverse ways. Rice fields are not substitutes for natural wetlands but are used by many species and can help mitigate the loss of natural habitats in areas where agriculture dominates. Most birds use rice fields primarily for foraging, but some—including rare species—also nest in rice. Field management affects birds in numerous ways, some of which have been studied in detail, but most of which have not. Increasing collaboration between researchers, farmers and agronomists provides opportunities to better understand how field management can be modified to increase the conservation value of fields without compromising the economic viability of farming. Such research would facilitate the development of well-designed agri-environment schemes and provide a solid basis for marketing "wildlife-friendly" rice products. Other major topics where future research is needed include: nesting and post-fledging success; availability and value of foods other than rice grain that are found in fields; importance of field edges and water delivery infrastructure; influence of landscape features; effects of rice farming on population dynamics; experimental studies of management activities, especially at large spatial scales, in tropical regions, and during the breeding season; and an improved understanding of how socio-economic factors influence the ecology and conservation of the wetland birds that use rice fields. *Received 26 April 2010, accepted 20 May 2010.*

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The link between agriculture and wildlife management has become a central focus for applied ecological research, resulting in the creation of a distinct subfield centered on resolving conflicts between agronomic and conservation goals (McNeely and Scherr 2003; Ormerod *et al.* 2003). In particular, there has been an emphasis on the effects of agricultural practices on birds (e.g. Aebischer *et al.* 2000; Ormerod and Watkinson 2000; Vickery *et al.* 2004).

Our primary goal in compiling the set of papers in this volume was to provide a comprehensive review of what is known about the ecology and conservation of birds in areas where rice (*Oryza sativa*) is grown, in light of the global importance of this crop and its perceived value to wetland species (Fasola and Ruiz 1996; Lawler 2001; Czech and Parsons 2002; Elphick 2010). In this concluding paper, we aim to summarize the main findings of the volume, identify major gaps in current knowledge and challenges in filling those gaps, and examine some of the issues that researchers and land managers should consider in the future.

WHAT DO WE KNOW?

Collectively, the preceding papers establish the many ways in which rice farming influences birds, and the wealth of information that has been learned so far. The earliest research on birds in rice fields dates back more than a century, but the vast majority comes from the past three decades and the rate of interest in the topic continues to grow. Research topics have become increasingly diverse, moving beyond a strictly agronomic interest in the role of birds as grain predators (Beal 1900; Neale 1918) and potential pest control agents (McAtee 1923). The earliest detailed focus on avian ecology began with research in Italy, with subsequent studies conducted elsewhere in Europe, and then increasingly in other parts of world. These ecological studies began with a focus on the foraging ecology of herons and egrets in rice fields, especially as it related to successful breeding, and the first signs that rice fields could play an important role in waterbird conservation began to emerge (Fasola and Barbieri 1978; Fasola 1983).

As research interest has spread throughout the world, it has become clear that a broad array of species uses rice fields, often in regionally or globally important numbers. The papers in this volume document use of rice fields by hundreds of bird species from a wide range of families and orders. Undoubtedly, the list includes many species that use rice only under unusual circumstances or for which rice is not an especially important habitat. Additionally, some species are harmed by occurring in rice fields (Parsons *et al.* 2010). Nonetheless, for many of the species identified, rice habitats are extremely important, providing food, safe roosts, migratory stopovers and nest sites. Additionally, the number of species reported here is undoubtedly an underestimate as some parts of the world are not well covered in the volume (notably Southeast Asia, where much of the world's rice is grown), and others only sparsely so.

Many papers touch on the conservation importance of rice field habitats, and there is increasing recognition of this importance in conservation circles. For instance, areas of rice habitat have been designated as Important Bird Areas under BirdLife International's global scheme to recognize sites of high conservation value (e.g. Acosta *et al.* 2010), and the conservation role of rice fields has been the subject of a recent resolution under the Ramsar Convention on Wetlands of International Importance (Ramsar 2008; see also Kurechi 2007 for a specific application of the Convention to rice fields). Similarly, the Sacramento Valley in California, USA, has been incorporated into the Western Hemisphere Shorebird Reserve Network as a site of international importance based largely on the numbers of shorebirds that use rice fields (http://www.whsrn.org/). With this broader recognition of the habitat's role in conservation, the focus of much research has shifted back to a more explicit examination of agronomic issues. Rather than viewing birds purely as a farming problem, however, the modern focus is increasingly on identifying ways to reconcile the needs of wildlife with the demands of economically productive agriculture. Consequently, research is frequently centered on comparing the effects of different management practices on birds (Elphick *et al.* 2010; Ibáñez *et al.* 2010).

A number of general themes emerge from the papers included in this volume:

1. Global importance of rice. Rice production is a dominant land use in many regions and has broad influence on many aspects of human society. Some of these issues are obvious or well known, for example food security (Lobell *et al.* 2008), global and regional economics (Dawe 2002), water use (Gordon *et al.* 2008), pesticide production and use (Conway 1997; Wood *et al.* 2010), methane emissions (Neue 1993) and habitat conversion (Sundar and Subramanya 2010; Wood *et al.* 2010). Other factors are less obvious, but no less influential; for example, the roles that rice farming plays in livestock production (Devendra and Thomas 2002), harvest of wild species that use rice fields (Halwart 2006) or the risk of disease transmission (Lacey and Lacey 1990; Morse 1995; Muzaffar *et al.* 2010). Moreover, the area of rice habitat is considerably greater than the area of natural wetland habitat in many areas, and rice fields are frequently the dominant flooded habitat available to waterbirds (e.g. Longoni 2010; Wood *et al.* 2010; Wymenga and Zwarts 2010). These factors in combination make it inevitable that rice production will have considerable influence on biological diversity generally and wetland species in particular.

2. Comparisons of rice fields to natural wetlands. Surprisingly few studies have directly compared waterbird use of rice fields to more natural wetlands, and those that have, produced mixed results. Some studies have found lower bird numbers, species richness and species evenness in rice fields (Tourenq *et al.* 2001; Bellio *et al.* 2009; Taylor and Schultz 2010). Others have compared measures of foraging performance, finding little evidence for differences in capture success or time allocation (Elphick 2000), while studies comparing nesting performance have found different patterns for different species (Pierluissi 2010). Even though bird densities may be lower in rice fields than in natural wetlands, if the birds are faring adequately in terms of survival and reproduction, the conservation value of rice fields may be considerable due to the vast areas of habitat involved. For instance, the area of rice fields in California is similar to the area of other wetlands in the state. Hence, even if rice fields were used at only half the density of waterbirds as is found in managed wetlands, collectively they could still support a third of the potential population of a species in the region.

3. Value of rice fields relative to other land uses. Assessing the value of rice habitat to waterbirds depends on the alternative land management options and available habitats. Converting natural habitat to rice fields will nearly always impact waterbird communities negatively, causing the loss of specialist species and important wetland functions (Tourenq *et al.* 2001; Sundar and Subramanya 2010). Expanding the amount of rice habitat might also create indirect conflicts that negatively impact waterbirds, for example, by diverting water away from natural wetlands to irrigate the crop (King *et al.* 2010). Even management actions designed to benefit waterbirds in rice fields—such as flooding fields during the non-growing season (Elphick *et al.* 2010)—require careful consideration of both costs and benefits when they alter use patterns of limited resources such as water across landscapes. Although rice habitats cannot be expected to support the full complement of species found in natural wetlands, they compare favorably to many other human land uses, including most alternative crops (Taft and Elphick 2007; Longoni 2010; Sundar and Subramanya 2010).

4. Occurrence of birds in rice fields. Worldwide, rice fields are used by large numbers of a wide diversity of bird species. For example, over 30% of the bird species found in Japan and Korea occur in rice habitats (Fujioka *et al.* 2010), as do ~27% of the bird species in the Indian subcontinent (Sundar and Subramanya 2010) and over 20% of those found in California (Eadie *et al.* 2008). Both numbers and diversity are generally greater than in other crops, and many species of high conservation interest are included among those that use rice. Most regions have at least a few examples of globally-endangered species that use rice (Acosta *et al.* 2010; Fujioka *et al.* 2010; Wood *et al.* 2010), and Sundar and Subramanya (2010) identified 23 species of global conservation concern in the Indian subcontinent alone. Again, however, the situation can be complicated. Sometimes, conversion of natural habitat to rice has contributed to the declines of these species while at the same time the production of rice, rather than other crops, is the practice which helps to sustain remaining populations. Recognizing this apparent paradox, and both minimizing the negative effects of rice while enhancing the benefits, is a central challenge for future work.

5. Uses of rice fields by birds. Rice fields are primarily used by birds as foraging habitat (Fujioka *et al.* 2010; Stafford *et al.* 2010; Taylor and Schultz 2010), with relatively little use for nesting (Pierluissi 2010). Water depth within fields greatly influences foraging use by individual species, and both vegetation structure and field management can affect some species too (Elphick and Oring 1998; Lourenço and Piersma 2009; Taylor and Schultz 2010; Wymenga and Zwarts 2010). Although rice fields do not provide breeding habitat for many species, there are exceptions. Bitterns and rails of conservation interest have been found to use the dense vegetation of rice fields for nesting (Longoni *et al.* 2007; Pierluissi and King

2008) and various Charadriiformes may also benefit from breeding in rice habitats (Shuford *et al.* 2001, 2007). That said, relatively little is known about breeding success. Some species may experience reduced nest predation when using rice fields, while others may experience more (Pierluissi 2010). Some growing practices can be harmful to nesting birds, such as certain seeding methods (Kim *et al.* 2009) and temporarily drawing down water levels during the breeding season (Lee 1984; Longoni 2010). Similarly, harvest methods may cause widespread mortality of eggs, nestlings and perhaps adults. On the other hand, some birds apparently have the capacity to adjust their nesting behavior to match the constraints imposed by farming practices, for example by shifting the timing of nesting to match field conditions (Longoni *et al.* 2007).

6. Landscape conditions matter. When considering the importance of rice fields, it is necessary to look beyond the conditions in individual fields. Various studies suggest that birds respond to broader landscape conditions, both at local scales and at larger regional scales (King *et al.* 2010). Proximity of fields to natural wetlands, for example, influences bird use in numerous settings (Elphick 2008; Acosta *et al.* 2010; Taylor and Schultz 2010), often as a result of birds moving back and forth between habitats on a regular basis (King *et al.* 2010). Various authors have consequently emphasized the value of maintaining a mixture of habitats—both natural and agricultural—within the landscape (Fujioka *et al.* 2010; Longoni 2010) and considering landscape features that connect habitat patches (King *et al.* 2010). At larger spatial scales, patterns of rice field occurrence appear to influence species distributions and migration pathways. Also important is the amount of rice field habitat in a landscape relative to other habitats, such as more natural wetlands. For example, rice fields are apparently less important to waterbirds in the Rhône Delta, France, than in other parts of Europe, but this is perhaps because that region contains more extensive natural wetlands than do others (Longoni 2010). Just as the relative distributions over space can be important, so can changes in habitat availability over time. In the Sahel in Africa, for instance, rice fields are the main wetland habitat that remains at the end of the dry season, and so may be especially important to wetland birds at that time (Wymenga and Zwarts 2010).

7. Regional and species differences cause variable responses. To date, few questions have been studied in detail in multiple rice systems. Consequently, it remains hard to draw generalities across regions or species. Clearly, there are many similarities among the rice production systems and waterbird communities found in different regions (Elphick 2010), but there are also differences that could affect how conservation practitioners view certain practices. Some discoveries appear to be transferable across regions—for instance the importance of water depth and the potential for enhancing fields during the non-growing season through winter flooding (Elphick *et al.* 2010). In other cases, studies have produced quite different results. For example, Australian rice fields appear to provide very limited value during the breeding season (Taylor and Schultz 2010), perhaps even causing harm by attracting birds to nest in areas that do not support necessary prey populations for long enough to raise young (Richardson and Taylor 2001). In contrast, breeding populations of certain species elsewhere appear to rely greatly on rice field habitats (Shuford *et al.* 2001, 2007; Longoni 2010). In another example, the ploughing and flooding of rice fields in Portugal seems to increase the availability of spilled rice kernels to foraging waterbirds (Lourenço and Piersma 2008), yet similar activities elsewhere make grain less available (Kross *et al.* 2008). In most cases, we do not know enough about the demographic or behavioral responses of birds to rice habitats, or the underlying mechanisms influencing these responses, to fully understand the significance of documented differences. As the number of studies grows, with similar questions examined in different contexts, we can expect improvements in our ability to draw general inferences.

8. Field management affects use and value of rice fields. Essentially all aspects of rice field management, from field preparation and sowing to harvest and winter field management, have the potential to influence the birds that use fields (Elphick *et al.* 2010; Ibáñez *et al.* 2010; Taylor and Schultz 2010). Even minor differences in the timing of activities can have important effects. For instance, shortening the growing season could affect the chance of successful breeding (Pierluissi 2010), and increasing the period between harvest and the arrival of winter migrants can affect food abundance (Stafford *et al.* 2010). The effects of many management activities, however, remain poorly-known, even for activities where the outcome may seem straightforward. Hunting, for example, adds to mortality in numerous bird populations and causes disturbance to non-target species. Simultaneously, however, in some places it has also resulted in the creation of managed wetlands in rice field landscapes and field flooding during nongrowing periods (Elphick *et al.* 2010). Exactly how these costs and benefits trade-off is unclear, but carefully managed hunting appears to be compatible with meeting bird conservation goals in farming landscapes.

Pesticide use is a major concern in many places where rice is grown, because of both direct and indirect effects (Longoni 2010; Sundar and Subramanya 2010; Wood *et al.* 2010). A vast array of different pesticides is used in rice fields, but their effects on wild bird populations are often poorly-known (Parsons *et al.* 2010). Organic rice farming occurs as an alternative in some areas, with various effects on prey communities that potentially translate into effects on bird populations (O'Malley 1999; Wilson *et al.* 2008; Ibáñez *et al.* 2010). Organic production, however, is unlikely to become a dominant form of rice farming, and if it resulted in lower or less consistent yield it might cause more land to be converted to farmland. Alternative agri-environment schemes that provide wildlife benefits within the constraints of conventional rice production, in contrast, are widely recognized as being an important mechanism for improving the conservation value of ricelands over large areas (Fujikoa *et al.* 2010; Ibáñez *et al.* 2010; Stafford *et al.* 2010; Wood *et al.* 2010).

9. Birds can provide economic benefits to farmers. Waterbirds have long been recognized to have the potential to benefit farmers through weed and pest control. Additional ways in which they may have benefits include aiding nutrient cycling, straw decomposition, ecotourism and hunting revenue. Few studies have quantified these economic benefits, but those that have suggest that this potential is realized in at least some settings (Stafford *et al.* 2010).

WHAT IS NOT KNOWN?

Although the primary intent of this volume was to summarize what we do know, we also asked authors to identify areas where there are clear knowledge gaps. In addition to the specific topics identified within each paper, there are some larger holes in what we know that are most easily identified by the papers that we were unable to include. Probably the most conspicuous is the lack of a review on bird use of rice fields in Southeast Asia. Although scattered information exists for this region, we failed to find an expert who felt confident that they could usefully review the topic. With much of the world's rice grown in this part of the world, studies of birds in the rice paddies of countries such as Indonesia, Vietnam, Thailand, Myanmar and the Philippines are clearly warranted.

Even in those regions for which we do include reviews, there are vast areas where little is known. For example, the papers on China (Wood *et al.* 2010) and Africa (Wymenga and Zwarts 2010) focus on relatively small areas within the larger regions, and work in the Indian subcontinent is limited to certain regions (Sundar and Subramanya 2010). These examples further illustrate a lack of even basic information for large portions of the world's ricelands. Even in the Americas, where bird use of rice fields has been studied in at least ten countries (Acosta *et al.* 2010), current knowledge for many places is limited to species lists and estimates of relative abundance, rather than a detailed understanding of species ecology. In short, the literature on birds in rice fields is disproportionately represented by studies from Mediterranean Europe and the USA, which collectively contain a mere 1% of the world's rice fields (IRRI World Rice Statistics 2009). Detailed work in Asia, where most rice is grown, is largely limited to Japan and the Republic of Korea (Fujioka *et al.* 2010).

Even in relatively well-studied areas, much remains to be learned. In addition to geographic biases in past research, there have been clear emphases on certain taxonomic groups. In most regions, long-legged wading birds and waterfowl have received the most attention, although shorebirds are increasingly becoming the focus of more detailed research (e.g. Lourenço *et al.* 2010). With the exception of crop pests, research on passerines has been very limited (Acosta *et al.* 2010) despite the diversity and numbers of birds that use fields (e.g. Elphick 2004; Sundar and Subramanya 2010). Similarly, raptors, which are ubiquitous and common in many rice growing regions, have received little study (Elphick 2004; Lourenço 2009).

Conceptually, research questions have also remained quite narrowly focused. General topics that clearly warrant more attention include:

(1) More studies of rice fields as breeding habitat, especially those that focus on nesting success and fledgling survival, are greatly needed (Pierluissi 2010), with those that compare rice fields to other habitats or that compare different rice management methods (cf. Kim *et al.* 2009; Ibáñez *et al.* 2010) of greatest value. Understanding the causes of nest failure and mortality is also important because this knowledge would allow researchers to determine whether problems are inherently related to rice farming or not, with implications for management. For instance, the recent release of the catfish *Claria gariepinus* in Cuba is suspected to have increased predation on waterbirds in both rice fields and natural wetlands (Mugica *et al.* 2006).

(2) Research on the abundance of rice-field foods other than spilled grain, and more detailed information on intake rates and nutritional value for all foods would be helpful (Stafford *et al.* 2010). Data on foraging during the breeding season in particular are lacking, as are detailed analyses of the benefits of growing a second, ratoon, crop late in the season (Elphick *et al.* 2010). Placing data collection on foraging behavior in a broader theoretical context would also provide important insights (e.g. Amano *et al.* 2006a, 2006b; Lourenço *et al.* 2010), especially if linked directly to measures of body condition or survival.

(3) Use and value of field edges, irrigation canals and other water features that form part of the rice infrastructure have all received little research attention (Elphick *et al.* 2010; King *et al.* 2010; Longoni 2010). Even basic descriptive information is largely lacking from most areas. More detailed studies of habitat quality would be especially useful in light of the loss of some of these habitats (e.g. field edges) with agricultural intensification (Ibáñez *et al.* 2010), and the habitats' likely importance for breeding (Pierluissi 2010). Studies of how management changes affect these habitats are also warranted and largely lacking (see Lane and Fujioka 1998 for a rare exception).

(4) That landscape affects waterbird use of rice fields is reasonably well established, but we remain a long way from understanding exactly what features affect which species and in what ways (King *et al.* 2010). Consequently, current understanding remains no more specific than the fact that it is good for landscapes to contain a mixture of habitats. Better data on how birds perceive and respond to rice landscapes would allow a more sophisticated assessment and lead to specific recommendations as to how landscapes can be managed to maximize conservation value. The advent of telemetry methods has allowed some advances (e.g. Fleskes *et al.* 2002; Ackerman *et al.* 2006), and with ever-better radio-transmitters and geolocators, considerable improvements should be possible in the future.

(5) Estimating the total numbers of birds, and what proportion of each species' population, depend on rice fields is important in evaluating the conservation contribu-

tions of the crop, but has been done in only a few cases (e.g. Shuford *et al.* 2001, 2007). Perhaps most important, however, is an explicit focus on the quality of rice habitats and the population-level consequences for bird species using them. One concern is that, although fields are used by large numbers of birds, they could effectively be ecological traps that attract birds to unsuitable areas. For example, if birds choose to nest in rice fields, but suffer frequent nest loss as a result, then fields might operate as "sink" habitat (sensu Pulliam 1988). Similarly, if birds suffer high levels of mortality or sublethal effects due to pesticide use in fields (Parsons *et al.* 2010), then the apparent benefits of those fields might be very misleading.

Fasola and Brangi (2010) take the first steps towards identifying population-level consequences of rice agriculture for birds. Taking research from its current state of largely-descriptive documentation of bird use patterns to a deeper understanding of the demographic consequences of birds using rice fields would advance research in the field considerably. Detailed work on this topic will require a greater focus on vital rates, but other approaches may also be fruitful. For instance, increased winter flooding in California is thought to benefit many species of waterbirds, but this hypothesis only holds if one assumes that populations are somehow limited by conditions on the wintering grounds (Elphick and Oring 1998). As winter flooding has increased, therefore, population increases would be expected in species thought to be limited by winter conditions, but not in those thought to be limited by other factors. Testing hypotheses such as this one might be possible with existing data. For instance, in the Guadalquivir Marshes, Spain, waterbirds that use rice and other artificial wetlands have increased in numbers locally, while those that rely more on natural wetlands have not (Rendón *et al.* 2008). Perhaps more importantly, this pattern seems to translate into population changes at a continental flyway scale (Toral and Figuerola, unpublished data).

(6) There is also a wide variety of management questions that warrant investigation, many of which are discussed in detail elsewhere in this volume. Research on management to date has focused on non-growing periods, with considerably less research on how management affects breeding. Similarly, management research has been disproportionately focused in temperate rice growing regions, with very little from the tropical areas where most rice is grown. More systematic experimental studies of all management activities are also warranted.

As a guiding principle, research on management activities should explicitly consider links between ecological and agro-economic factors (Stafford *et al.* 2010). Doing so would improve the likelihood that management changes suggested by ecologists recognize the constraints that farmers face and direct attention towards those practices most likely to be adopted. Similarly, investigating the economic impacts of management changes, as well as ecological ones, would facilitate the development of economic incentives or compensation schemes, which might be required to ensure grower participation in agri-environment schemes. Broader societal issues also need to be considered, especially in developing countries where issues such as food security and human health are more directly linked to rice production.

(7) Developing a deeper understanding of the economics of bird activity in rice fields extends beyond just the costs of particular management options. Better financial quantification of the value of birds in terms of aspects such as pest control, nutrient cycling, straw decomposition and hunting revenue are required. Similarly, there is a need for better estimates of the value of yield losses due to bird activity. Only with both types of data can the economic trade-offs of bird activity be accounted for properly (Elphick 2010).

(8) Finally, rice fields offer various opportunities to test basic ecological questions (Elphick 2010). Studies of species richness, occurrence and abundance have been conducted in a sufficient number of different countries for researchers to begin to examine biogeographic questions about waterbird community structure (e.g. Acosta *et al.*

2010). Many individual species also occur in multiple rice-growing regions, providing opportunities to examine how their responses compare. For example, Glossy Ibis (*Plegadis falcinellus*) rarely use West African rice fields (Wymenga and Zwarts 2010), but this species and its close congener the White-faced Ibis (*Plegadis chihi*) are common in rice fields elsewhere. Additionally, where *Plegadis* ibises commonly use rice, the habitat appears to be beneficial in some cases (Eadie *et al.* 2008) but not in others (Taylor and Schultz 2010). Determining the reasons for apparent differences such as these could provide insights into both the ecology of the species involved and into potential ways that the value of fields could be enhanced via management. More generally, a better understanding of how rice fields in different places function as wildlife habitat would improve the potential for effectively transferring beneficial management actions between regions.

IMPEDIMENTS TO RESEARCH

Increased research in rice fields is constrained in various ways, but to some extent those impediments are declining. Perhaps the biggest problems facing researchers are access to fields and influence over the way they are managed, both of which limit experimental control. Because the primary function of fields is agronomic, research activities need to be conducted in a way that does not decrease yield. This condition is presumably one reason why relatively little work has been conducted in fields during the growing season, when entry into fields to search for and monitor nests could cause crop damage. An increased ability to monitor nests remotely (cf. Hartman and Oring 2006; Gjerdrum *et al.* 2008) may help reduce the need for repeated visits into fields and thus make studies of nesting behavior easier to conduct. Increased cooperation between rice growers and conservation groups also is making it easier for researchers to influence exactly how fields are managed. For instance, conservation partners in California have sought to obtain grower input on the types of research that would be most fruitful in designing voluntary conservation practices, and growers are allowing researchers to experiment with these practices on their land.

The large scales at which much research on birds in rice fields needs to take place poses additional constraints. Because many of the birds that use fields move around the landscape at large spatial scales (King *et al.* 2010), and because field management occurs at the scale of entire fields (which can be tens of hectares in size), sample units tend to be large and much research needs to take place over big areas. These factors place logistical limits on the number of fields that can be sampled, and on just how independent, spatially, they can be from one another. Additionally, many of the birds that use rice fields have highly clustered distributions, which for studies of field use creates statistical problems because distributions tend to be highly non-normal and often zero-inflated (Zuur *et al.* 2010). Although these factors have limited the types of analyses that can be conducted in the past, the development and increased availability of newer statistical methods (e.g. mixed-modelling; Elphick *et al.* 2007) is making it much easier for ecologists to overcome the problems and address more sophisticated questions.

WILDLIFE-FRIENDLY RICE

Simultaneous with the growing research interest in conservation on farmland that has occurred in recent years, in many parts of the world there have also been policy shifts to emphasize agricultural practices designed to benefit wildlife (Kleijn and Sutherland 2003; Whittingham 2007). Although work in rice fields has not been at the forefront of this development, growing attention is being paid in many places to identifying ways that the conservation benefits obtained from rice field management can be increased, and to explore the potential for promoting rice as a "wildlife-friendly" crop. Examples are diverse. At one end of the spectrum growers are using organic farming methods to reduce chemical inputs onto the land and are explicitly managing rice fields with the intent of providing bird habitat. For instance, in the Ebro Delta of Spain, the Sociedad Española de Ornitología (SEO/BirdLife) operates a 52 ha wildlife sanctuary and rice farm using organic practices (Ibáñez *et al.* 2010; http://www.rietvell.com/). Rice from this farm is sold under the Riet Vell brand, which has existed since 2001, and which markets its products on the basis of the conservation benefits that the company's farming practices provide for birds. Organic rice production also occurs in other countries, and is generally seen as a way to benefit birds by reducing pesticide use (Parsons *et al.* 2010). With the exception of work in Spain (Ibáñez *et al.* 2010), however, studies have not explicitly tested whether such benefits accrue.

Instead of focusing on organic production methods as a basis for marketing, some growers have used specific benefits to particular species of conservation interest to promote their crops. For instance, some Korean growers get higher prices for "Cheolwan Crane Rice," which is grown in an area where endangered species occur, and it has been suggested that this approach could be used as a basis for promoting beneficial conservation practices (Lee *et al.* 2007). Similarly, in Cambodia, Ibis Rice™—named for the critically-endangered Giant Ibis (*Pseudibis gigantea*)—is marketed by growers who agree to limit practices such as wetland conversion and waterbird hunting in an effort to protect rare waterbirds (http://www.wildlifefriendly.org/ibis-rice).

In some ways the most exciting developments are occurring in conventional rice production. Although the wildlife benefits in these systems may be lower on a per area basis than in organically farmed systems, the cumulative effect of smaller changes over very large areas could have substantial impacts. Beneficial though organic production might be, it is unlikely to serve more than a specialty niche market, especially given the food security demands of a growing human population and the importance of rice in developing countries. Consequently, production changes that occur on conventionally farmed land—which occupies vastly greater acreages than organically farmed rice—have potential to be enormously influential. Identifying features of organic farming that can aid farmers when incorporated into conventional practice, such as integrated pest management as a means of pesticide reduction (Parsons *et al.* 2010), is one option for benefitting wildlife.

The long-standing interactions between California rice growers and conservation organizations, dating back to the 1990s when post-harvest straw management practices started to change in response to air pollution legislation (Brouder and Hill 1995), provides another example. In this situation, growers were unable to freely burn crop residues and began to flood fields to enhance rice straw decomposition, prompting the recognition that winter-flooded fields might provide important habitat for waterbirds. Initially, much of the conservation focus was from waterfowl hunting groups, such as Ducks Unlimited, but rapidly it became apparent that many other species might benefit from winter flooding (Elphick and Oring 1998; Elphick 2004). Recently these interactions have strengthened with joint workshops between rice growers, members of conservation groups affiliated with the California Migratory Bird Conservation Partnership, representatives of government agencies and academic researchers working in both agronomy and conservation biology. The goal of these workshops has been to collaboratively identify management practices that are expected to benefit birds without serious economic impacts to farmers, and to identify potential mechanisms for compensating growers for any lost productivity caused by conservation actions. As a result, several practices are now being field-tested to examine the practicality of implementing them at large scales, and to quantify the degree to which they actually provide conservation benefits.

The successful marketing of agricultural products based on their sustainable production or benefits to wildlife has been demonstrated in various settings. Shade-grown coffee, for instance, has a history of being marketed for its benefits to birds (Perfecto *et al.* 1996; Sherry 2000), and the development of certification schemes (e.g. see http://nationalzoo.si.edu/SCBI/MigratoryBirds/Coffee/) could provide a useful model for the rice industry. For such approaches to be successful, however, there needs to be a clear market where people are prepared to pay a premium for a product produced in a specific way, and those economic benefits must outweigh the costs of meeting certification criteria (Gobbi 2000). “Bird-friendly” coffee has been economically viable largely because much of the crop is exported to wealthy countries where people are both willing and able to pay such premiums. A better understanding of such economic conditions would help guide those working on birds in rice fields. Unlike coffee, rice is grown largely for domestic markets in many countries (Dennis *et al.* 2007), so wildlife-friendly rice farming is likely to be an option only in countries where export is important or where a sizable portion of the populace is wealthy enough to pay a premium. Identifying situations where economic factors make wildlife-friendly marketing most plausible would be a useful step forward in furthering waterbird conservation on agricultural lands.

DYNAMISM OF RICE INDUSTRY

Like much of modern agriculture, many changes are occurring within the rice industry, and it is possible that these changes will influence rice habitats in ways that affect waterbirds. A full evaluation of the industry changes that are likely to occur in the near future is beyond the scope of this paper, but if rice fields are to be a part of the waterbird conservation equation, ecologists will need to monitor and understand the industry and assess how its development will alter the conclusions drawn throughout this volume. Plant breeding and genetic-modification of crops (Qiu 2008) are especially likely to be influential, with some changes beneficial to waterbirds and others not. Development of faster-growing varieties, for example, may increase the period between harvest and the arrival of migrant waterfowl, which could either result in less spilled grain when the migrants arrive or to increased opportunities to grow ratoon crops that produce extra grain (Stafford *et al.* 2010). Similarly, altering vegetative characteristics such as decreasing plant height may make rice fields less suitable as nesting habitat for birds that need to conceal their nests or themselves (Pierluissi 2010).

Perhaps the greatest concerns center around drought-tolerant crops that can be grown with less water or under dry conditions (Fasola and Ruiz 1996; Longoni 2010). As water shortages become more common in rice growing regions such as the Murray-Darling Basin, Australia (Chambers *et al.* 2005), or as rice cultivation spreads in arid regions (Wymenga and Zwarts 2010), new varieties or cultivation methods that use less water will grow more attractive (Sahrawat 2006; Burton 2008). Growing rice with less water could provide a number of advantages to society, and could advantage waterbirds, but only if this method makes more water available to flood natural wetlands rather than allowing an expansion of agricultural land (cf. Ewers *et al.* 2009). A move away from irrigation also would remove the primary advantage that rice provides over other grain crops and could eliminate the extent to which rice can mitigate for wetland losses. This problem will be especially acute in situations where rice is the dominant habitat available to wetland birds as alternative habitats for conserving wetland species may not exist.

Climate change could also create major shifts in the effects of rice farming on waterbirds. Changes in global water resources may exacerbate existing water shortages and create new ones (Oki and Kanae 2006; World Water Assessment Programme 2009), increasing interest in rice that will grow with less water (Sahrawat 2006). More generally, increasing temperatures and changing rainfall patterns are projected to have far-reaching consequences for human food security in many parts of the world, with subsequent effects on crop production (e.g. Peng *et al.* 2004; Lobell *et al.* 2008). Similarly, sea-level rise will likely impact rice production in low-lying coastal zones. These agricultural changes will presumably coincide with changing conditions in natural wetlands, although just how these will interact to affect wetland species is unknown. Ultimately, the study of how birds can benefit from, or be harmed by, rice agriculture will increasingly need to address socio-economic factors that impact the industry. Global food security will not only affect methods of agricultural production and intensification, but will likely also lead to shifts in where crops are grown, as indicated by recent moves by wealthy countries to buy or lease farmland in poorer countries to ensure a reliable food supply (Cotula *et al.* 2009). Recent shifts in which crops are grown and in global food prices, in response to increased enthusiasm for biofuels (spurred by government subsidies) also indicate the speed and extent to which markets can change (Searchinger *et al.* 2008).

To conclude, although we know a great deal about the birds that occur in rice fields, it is clear that much research is still warranted. Moreover, a full accounting of the conservation costs and benefits of rice agriculture will require that we go beyond simply describing the ecology of the system. As for many applied topics, bringing together researchers and approaches from diverse disciplines is key. In addition to experts in economics, agronomics, marketing and the like, there is a critical need to involve rice growers in future conversations. Farmers know their land and their industry better than most, and many have a strong interest in conservation. Frequently, however, they are not aware of the conservation value of their land, or of what can be done to enhance it. By obtaining a better understanding of the multitude of issues that affect the interactions between birds and rice farming, wetland bird ecologists will become better equipped to inform farmers of these factors and to take advantage of the opportunities provided on the ~1% of the world's land where rice is grown.

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