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The Effects of Agricultural Management on Wetland Birds

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The Effects of Agricultural Management on Wetland Birds

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B.S., University of California, Davis, 2015

A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

At the

University of Connecticut

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APPROVAL PAGE

Master of Science Thesis

The Effects of Agricultural Management on Wetland Birds

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ABSTRACT

With the rapid growth of the human population, there is a need to balance biodiversity conservation with achieving food security. Increasing agricultural inputs has greatly augmented food production on smaller areas of land, but generally has negative effects on biodiversity. As natural wetlands decline worldwide, birds are increasingly using flooded agricultural land. The objectives of this thesis are (1) to determine what affects the use of flooded agriculture by waterbirds and (2) to determine what has been studied about the effects of agricultural intensification on wetland birds.

I examined the factors affecting the use of flooded agriculture by waterbirds by studying the abundance and species richness of waterbirds on rice fields during the growing season. I modeled bird abundance and species richness as a function of spatiotemporal variables, daily field conditions, and chemical management and compared a set of candidate models using subsets of these variables using an information theoretic approach. Abundance and species richness of waterbirds had a clear relationship with water management, but I found no evidence to suggest that they were influenced by chemical management factors.

To determine what has been studied about the effects of agricultural intensification on wetland birds, I created a systematic map to collate the available evidence on this topic. I conducted a systematic review for articles that included information on birds using flooded agriculture of differing levels of agricultural intensification. The systematic map consists of 102 studies that met my inclusion criteria. I found that the vast majority of the studies were conducted in rice fields and flooded wet meadows used for grazing and silage. A wide variety of methods of intensification were studied, but the majority of the studies only examined the effects of intensification on bird abundance. I suggest that more studies are needed on the effects of

intensification on bird survival and reproduction in order to determine the true habitat value of flooded agriculture for wetland birds. Overall, the results of this thesis suggest that the intensification of flooded agriculture cannot be universally described as beneficial or detrimental to wetland birds. Understanding the specific mechanisms through which agricultural inputs affect birds will be key in balancing conservation with food production.

General Introduction

The human population is expected to increase by two billion by the year 2050 (Cohen 2003, Bongaarts 2009, UN DESA 2019). As the human population grows, so does the need for food. In order to meet the food demand for over nine billion people, crop production is projected to increase 59-110% in the same time period (FAO 2009, Tilman et al. 2011, Valin et al. 2014). Massive increases in crop production can be achieved by intensifying agricultural production, as seen during the Green Revolution of the 1960s. Critical improvements in agricultural technology were developed during this time period, including new agro-chemicals, high-yielding crop varieties, and efficient management techniques, which are thought to have saved millions of people from starvation (Evenson and Gollin 2003, Borlaug 2007, Pingali 2012). Increasing agricultural inputs to boost agricultural outputs has been key in the challenge of providing food security for a burgeoning human population. This agricultural intensification, however, often has negative effects on ecosystems in the form of water pollution, loss of biodiversity, and wildlife population declines (Giller et al. 1997, Matson et al. 1997, Wilson et al. 1999, Chamberlain et al. 2000, Berka et al. 2001, Donald et al. 2001, Decaëns and Jiménez 2002). There is a growing concern about how biodiversity can be conserved while also providing food security for over nine billion people.

There are two general schools of thought on how to achieve this balance – land can be spared specifically for wildlife while intensifying production on existing agricultural land, or food can be produced less intensively over a larger area with the intention of sharing this land with wildlife (Green et al. 2005, Law and Wilson 2015). While the relationship between food production and species density is often complicated, theoretical assessments suggest that sparing tends to be the most effective strategy for achieving both goals (Ewers et al. 2009, Phalan et al.

2011, Balmford et al. 2018). In reality, deciding which strategy is best for an individual area is more complicated. For example, sparing land for wildlife is more difficult for habitats where there is not much land left to spare, such as wetlands.

Wetlands are disappearing across the world, and with them, wetland birds. Since 1900, 64-71% of wetlands have been lost worldwide (Davidson 2014). At the same time, 38% of the world's waterbird populations are in decline (Wetlands International 2012). Wetland birds are increasingly using artificial wetlands such as flooded agricultural fields as alternative habitat (Bellio et al. 2009, Toral and Figuerola 2010, Golet et al. 2018). As habitat to spare for wildlife is lost, it is worth looking into the conservation value of farmland. Intensive agriculture is often portrayed as the opposite of “wildlife friendly”, but not all methods of increasing crop production are equally detrimental to wildlife. It is important to understand what is actually known about the effects of intensification on wetland birds in order to make informed management decisions.

The main goal of this thesis is to examine factors affecting the use of flooded agriculture by wetland birds. This was accomplished with a field study and a literature search resulting in a systematic map. First, I examined waterbird abundance and species richness in relation to chemical management, spatiotemporal variables, vegetation height, and water presence in California rice fields. To get a broader view of what is known about the effects of the intensification of agricultural wetlands on birds, I created a systematic map – a collection of peer-reviewed and gray literature gathered with the intention of describing the state of knowledge on a subject. The systematic map I created documents where research on this topic is taking place, what methods of intensification and effects on birds have been studied, and what bird species and crops are represented in the literature. I seek to provide insight on how

agricultural management affects wetland birds and where major knowledge gaps on this subject exist, in order to suggest topics where meta-analyses are appropriate and to specify where more research needs to be done.

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Chapter 1 – Factors affecting the abundance and species richness of waterbirds in rice fields during the growing season

Wetland habitat is disappearing rapidly worldwide; since 1900, 64-71% of the world's wetland area has been lost (Davidson 2014). A large amount of this widespread wetland loss can be attributed to anthropogenic causes such as urban expansion and conversion to arable land (Hefner and Brown 1985, Nieuwenhuis and Schokking 1997, Drexler et al. 2009, van Asselen et al. 2013). As wetlands have declined in abundance, so have wetland birds (Peterjohn and Sauer 1997, Niemuth and Solberg 2003, Ma et al. 2009); 38% of waterbird populations are in decline, and 24% of waterbird species are listed as globally Threatened or Near Threatened under International Union for the Conservation of Nature Red List criteria (Wetlands International 2012). As natural wetland habitats are lost, birds are increasingly making use of artificial wetlands such as wastewater treatment facilities, reservoirs, salt ponds, and flooded agriculture – particularly rice (*Oryza sativa*) fields (Czech and Parsons 2002, Ma et al. 2004, Bellio et al. 2009, Hsu et al. 2011). Rice is a staple crop for more than half of the world's population and is grown on more than 167 million hectares worldwide (Van Nguyen and Ferrero 2006, FAO 2017). The decline of natural wetlands and the availability of rice fields suggest that agricultural wetlands may be a critical alternative habitat for wetland birds.

Numerous studies have been conducted on the value of rice fields as habitat for wild birds (Eadie et al. 2008, Acosta et al. 2010, Sundar and Subramanya 2010, Taylor and Schultz 2010, Wood et al. 2010, Wymenga and Zwarts 2010, Fasola and Brangi 2010, Fujioka et al. 2010, Ibáñez et al. 2010, King et al. 2010, Longoni 2010, Parsons et al. 2010, Pierluissi 2010, Stafford et al. 2010). Birds frequently use rice fields flooded post-harvest during the non-breeding season as a substitute for natural wetlands (Fasola and Ruiz 1996, Elphick 2000,

Pernollet et al. 2015, Sessler et al. 2018). There is relatively little data on factors affecting bird use of rice fields during the growing season, however, which has been specifically identified as a research priority (Elphick et al. 2010, Pierluissi 2010). The rice growing season overlaps with the breeding season for many wetland birds in temperate regions (GRiSP 2013) and many wetland bird species will use rice fields when breeding to varying degrees of success, depending on the intensity of field management (Fasola and Ruiz 1996, Pierluissi 2010, Xie et al. 2018). As the world moves towards more intensive farm management to feed a growing population, shifts in water and chemical management of rice fields have the potential to greatly impact wetland bird populations.

The goal of this study was to determine what factors affect waterbird abundance and species richness in rice fields during the growing season. I examined abundance and species richness in relation to date, site, presence of water, vegetation height, management regime (e.g. organically or conventionally managed), and historical pesticide use. I predicted that: (1) birds would be more abundant later in the season as young start fledging from nests, especially at sites closer to known nesting colonies; (2) waterbirds would be more abundant in flooded than unflooded fields due to the presence of aquatic prey; (3) bird abundance and species richness will be higher in shorter vegetation as high, dense vegetation may exclude certain types of birds such as shorebirds (Rottenborn 1996, Douglas and Pearce-Higgins 2014); and (4) fields that are organically managed or that have lower historical pesticide use will have greater bird abundance and diversity because herbicide and pesticide use will reduce invertebrate abundance and vegetation heterogeneity.

STUDY AREA

The conterminous USA has lost more than 53% of its natural wetlands since the 1780s, but in California the total loss is over 90% (Dahl 1990). At the same time, more than 25% of the area of rice harvested in the USA lies in the Sacramento Valley of northern California (USDA 2017). The availability of rice fields combined with the significant loss of natural wetlands make understanding the dynamics between wetland birds and rice management particularly important for this region. I conducted waterbird surveys in the southern part of the Sacramento Valley at two field sites, Conaway Ranch and Yolo Bypass Wildlife Area (Bypass), in Yolo County (Fig. 1.1).

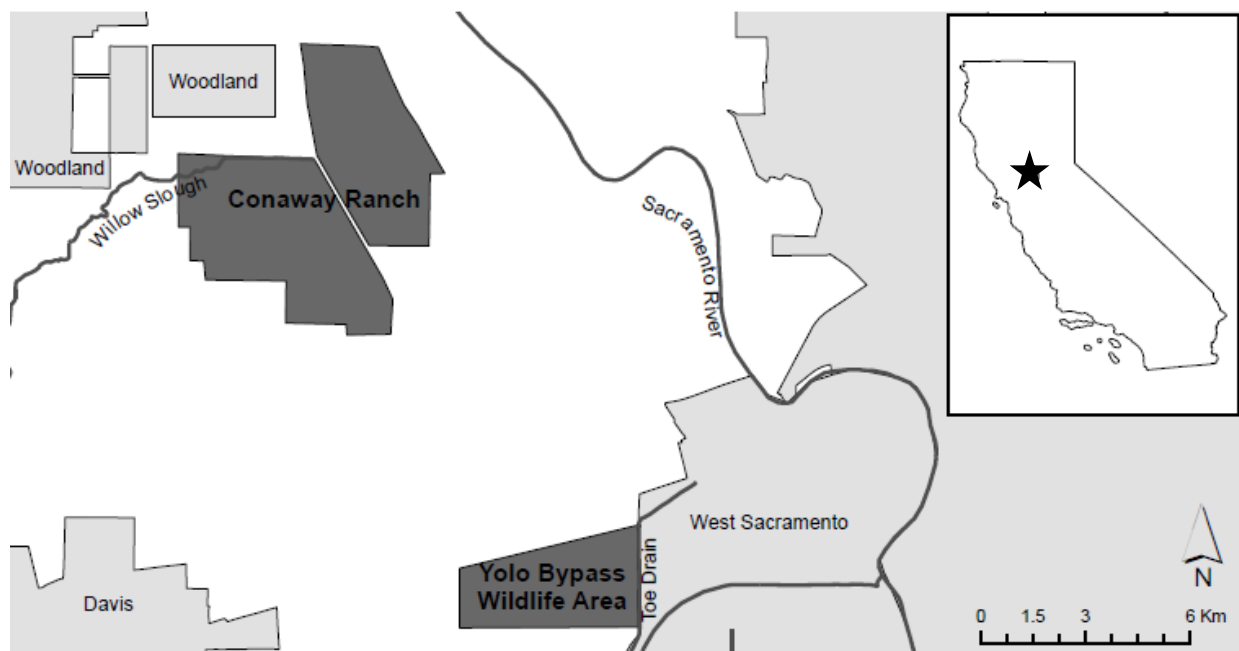


Figure 1.1 A map showing the two field sites within Yolo County. The inset map shows the location of the field site map within California, denoted by a star. Dark gray areas denote the field sites at which surveys were conducted. Light gray areas denote city limits.

The Bypass is a state wildlife management area located between the cities of Davis and West Sacramento. It is a part of the greater Yolo Bypass area designed to divert flood water from the Sacramento River and is managed to increase waterfowl and other bird populations. A small

proportion of this land is designated as agricultural land. Annual flooding restricts crops here to rice and wild rice (*Zizania* spp.). No organically grown rice is cultivated at the Bypass. Conaway Ranch is located just north of the Bypass, between the cities of Woodland, Davis, and West Sacramento. Land on the ranch is leased to farmers, and rice is the primary crop. A combination of organic and conventionally grown rice is grown at Conaway Ranch, along with wild rice, tomatoes (*Solanum lycopersicum*), sunflowers (*Helianthus annuus*), and other field crops.

In this region, rice planting typically begins in April or May. Due to the fact that rice can germinate under relatively anoxic conditions (Smith and Fox 1973), water is often present on the fields during or shortly after they are seeded in order to reduce competition from weed plants. Occasionally fields will be drained for a period of time after the seedlings have germinated to allow the young plants to secure their roots in the soil and protect them from aquatic invertebrate pests. Fields are then generally reflooded for the majority of the growing season. Different rice varieties grow at different rates, leading to variation in vegetation height and water presence across different fields, even on the same day. Fields are drained of water again before harvest begins, typically in late September to October.

During these rice growing months, waterbirds are breeding and raising young. Notably, there was a White-faced Ibis (*Plegadis chihi*) nesting colony located just 3 km north of Conaway Ranch during the months in which surveys were conducted, where about 2000 breeding pairs of ibis reared young.

METHODS

Waterbird Observations. Bird surveys were conducted from June to August 2018 using binoculars along regular routes accessible by farm access roads. Surveys were not conducted on

a field if heavy machinery or crop dusters were in use nearby due to the tendency of the machinery to cause birds to flush from the fields. California rice fields are subdivided by dirt levees into subsections called “checks” to facilitate water depth management (Fig. 1.2). Long-legged waders, shorebirds, rails, waterfowl, grebes, and cormorants were counted separately in each check. Disturbed birds leaving a check were counted, but birds simply flying over the field were not. White-faced Ibis were much more abundant than other species and were counted three times for each check, with the maximum count used for analysis. Other birds were counted once for each check.



Figure 1.2 A rice field subdivided by dirt levees into sections called “checks”. Dirt levees combined with rice boxes, or small weirs, allow consistent water depth across all sections of a field. Photo credit: Chris Elphick

Field Characteristics. Presence of water and vegetation height class were estimated for each check every time bird observations were made (Table 1.1). Water was recorded as present, absent, or present in parts of the check but not others. Vegetation height was divided into five classes, from no visible vegetation to taller than 60 cm.

Table 1.1 Description of variables recorded at California rice checks between June and August, 2018.

Variable	Description
Day	Day of the year the observation was recorded. Relationships with day were expected to be highly nonlinear, so day was fitted as a natural spline with 5 degrees of freedom.
Site	Site at which the observation was recorded: Conaway Ranch or Yolo Bypass Wildlife Area. Yolo Bypass Wildlife Area was the reference category for site.
Water Presence	Qualitative assessment of water presence on a check. Water presence was recorded as not flooded, partially flooded, or entirely flooded. Fully flooded was the reference variable for water presence.
Vegetation Height	The height of the rice, broken into 5 classes: Veg 0: No growth, no rice visible above the water. Veg 1: Fresh growth, rice visible, but <15 cm in height. Wading birds easily visible. Veg 2: Short growth, rice 15-30 cm in height. Long-legged waders visible, but difficult to see when foraging. Height class 2 was the reference variable for vegetation height. Veg 3: Medium growth, rice 31-60 cm in height. Wading birds difficult to see unless flushing or in front of vegetation. Veg 4: Tall growth, rice \geq 60 cm in height. Wading birds impossible to see unless flushing or in front of vegetation.
Management	Crop management type; organic or conventional. Conventional was the reference category for management.
Pesticide	Cumulative pesticide density (kg/ha) for the 5 years previous to the field season (2013-2017).

Farm plan maps were used to determine which fields were organically or conventionally managed. Organic agriculture differs from conventional agriculture in many ways, but most of the differences are in the types of agro-chemicals allowed on the fields. Historical pesticide data were retrieved from the California Pesticide Use Reporting database (CDPR 2017). Historical pesticide data were recorded as the cumulative kilograms of pesticide applied to rice fields over the 5 years previous to field observations (2013-2017) in each Public Land Survey System

(PLSS) section. Historical pesticide pounds applied for each PLSS section were divided by the section area (typically one square mile) to get the average pesticide application density for that section. This historical pesticide density was then assigned to each field within each PLSS section. Fields that spanned multiple sections were assigned a pesticide density weighted by the amount of the field in each pesticide block. Spatial analyses were conducted in ArcMap v. 10.6 (ESRI 2017). Rice check area was determined by retrieving field check outlines from aerial imagery of fields in ArcMap (ESRI 2019).

Analysis. Waterbird abundance, species richness, and the abundance of the two most commonly seen species – White-faced Ibis and Great Egret (*Ardea alba*) – were modeled with generalized linear mixed models. Date, site, water presence category, vegetation height class, management type, and cumulative historical pesticide density (Table 1.1) were treated as fixed effects, with checks nested within fields added as normally distributed random effects. Models used the log of check area as an offset to model bird density independent of field size. Initial models assumed a Poisson error distribution with a log link function, but diagnostic tests showed that the count data were overdispersed. Consequently, final models assumed a negative binomial error distribution. All models were implemented using the R package glmmTMB v 0.2.3 (Brooks et al. 2017). I used variance inflation factors to identify and eliminate highly collinear variables in my candidate models. Models were compared using Akaike’s information criterion with a correction for small sample size (AIC_c) to select the best performing model within the candidate model set (Anderson and Burnham, 2002; Table 1.2). If more than one model had a ΔAIC_c of 2 or less, the simpler of the two models was selected. To examine if vegetation height systematically affected detection based on a species’ size I plotted average height (Cornell Lab of Ornithology 2020) against number of individuals counted for each species. I conducted linear

regression analysis to determine if there was a strong correlation between height and number of individuals counted for each species.

Table 1.2 Candidate model set for waterbird abundance, White-faced Ibis abundance, Great Egret abundance, and species richness in California rice fields during June-August 2018. Descriptions of parameters and reference variables can be found in Table 1.1.

Model	Model Parameters
Model 1: Intercept only null model	Intercept only
Model 2: Waterbirds are only affected by spatiotemporal variables	Day + Site
Model 3: Waterbirds are affected by all measured variables	Day + Site + Water Presence + Vegetation Height + Management + Pesticide
Model 4: Spatiotemporal and chemical management practices are the factors affecting waterbird use	Day + Site + Management + Pesticide
Model 5: Chemical management practices are the predominant determinants of waterbird use	Management + Pesticide
Model 6: Spatiotemporal variables and daily field conditions are the predominant determinants of waterbird use	Day + Site + Water Presence + Vegetation Height
Model 7: All measured variables except for date affect bird use of fields	Site + Water Presence + Vegetation Height + Management + Pesticide

RESULTS

I observed 6821 waterbirds from 25 species spanning nine families and six orders (Table 1.3). Out of 1155 observations of rice field checks, 36% contained waterbirds. The most commonly observed species was White-faced Ibis, which was counted in 19% of all observations, followed by Great Egret (18%) and Snowy Egret (*Egretta thula*) (5%). The most commonly observed bird family was Ardeidae, which was seen in 24% of observations. The most abundant birds for individual fields were White-faced Ibis and Western Sandpiper (*Calidris mauri*), which had as many as 800 and 157 individuals in a single check, respectively.

The model that contained date, site, water presence, and vegetation height (model 6) was the best supported model for waterbird abundance, White-faced Ibis abundance, Great Egret abundance, and species richness, with Akaike weights (w_i) > 0.5 and lower AIC_c values for this model than for all other models (Table 1.4). Models focused on chemical management (models 4 and 5) performed much less well, and the addition of chemical management to all other variables (model 3) also reduced model performance.

I found that waterbird abundance, Great Egret abundance, and species richness were all higher in partially flooded fields than in fully flooded fields. Additionally, waterbird abundance, White-faced Ibis abundance, and species richness were all lower in unflooded fields than in fully flooded fields (Table 1.5, 1.6, Fig. 1.4). Waterbird abundance and White-faced Ibis abundance (Fig. 1.5) both varied with date, with increases during the periods of the season when fields were being reflooded and around the time juvenile White-faced Ibis began fledging from the nesting colony in late July. Vegetation height class did not have a positive or negative effect on waterbird abundance, White-faced Ibis, or species diversity, but Great Egrets were negatively associated with vegetation 30-60 cm in height (Table 1.5, 1.6, Fig. 1.3). There was a low correlation between species height and number of observations ($R^2 = 0.001$), so I did not suspect that vegetation height systematically affected detection based on a species' size.

Table 1.3 Waterbirds counted during surveys of California rice fields during June-August, 2018. Total percentage of observations the species or family was recorded during are listed, along with the mean number of individuals in a check when that species was present, and maximum number of individuals from that species or family seen in a single check.

Family	Species	% of Obs.	Mean Count	Max Count
Anatidae		1.35%	3	12
	Canada Goose (<i>Branta canadensis</i>)	0.10%	4	4
	Wood Duck (<i>Aix sponsa</i>)	0.10%	2	2
	Cinnamon Teal (<i>Spatula cyanoptera</i>)	0.19%	1	1
	Northern Shoveler (<i>Spatula clypeata</i>)	0.10%	3	3
	Gadwall (<i>Mareca strepera</i>)	0.19%	1	1
	Mallard (<i>Anas platyrhynchos</i>)	0.87%	2	8
	Green-winged Teal (<i>Anas crecca</i>)	0.10%	3	3
	Unknown dabbling duck (<i>Anas</i> spp.)	0.10%	6	6
Rallidae		0.29%	1	1
	Sora (<i>Porzana carolina</i>)	0.10%	1	1
	American Coot (<i>Fulica americana</i>)	0.19%	1	1
Podicipedidae	Pied-billed Grebe (<i>Podilymbus podiceps</i>)	0.10%	3	3
Charadriidae	Killdeer (<i>Charadrius vociferous</i>)	0.10%	1	1
Recurvirostridae		0.97%	21	41
	Black-necked Stilt (<i>Himantopus mexicanus</i>)	0.97%	20	41
	American Avocet (<i>Recurvirostra americana</i>)	0.29%	1	2
Scolopacidae		2.03%	28	160
	Western Sandpiper (<i>Calidris mauri</i>)	1.25%	32	157
	Dowitcher spp. (<i>Limnodromus</i> spp.) *	0.48%	32	100
	Yellowlegs spp. (<i>Tringa</i> spp.) **	0.87%	2	6
	Wilson's Phalarope (<i>Phalaropus tricolor</i>)	0.10%	1	1

(continued on next page)

Table 1.3 (cont.) Waterbirds counted during surveys of California rice fields during June-August, 2018. Total percentage of observations the species or family was recorded during are listed, along with the mean number of individuals in a check when that species was present, and maximum number of individuals from that species or family seen in a single check.

Family	Species	% of Obs.	Mean Count	Max Count
Phalacrocoracidae	Double-crested Cormorant (<i>Phalacrocorax auritus</i>)	0.10%	1	1
Ardeidae		24.23%	3	49
	American Bittern (<i>Botaurus lentiginosus</i>)	0.97%	1	1
	Great Blue Heron (<i>Ardea herodias</i>)	3.09%	1	1
	Great Egret (<i>Ardea alba</i>)	18.24%	3	31
	Snowy Egret (<i>Egretta thula</i>)	4.92%	3	31
	Cattle Egret (<i>Bubulcus ibis</i>)	0.29%	2	4
	Black-crowned Night-Heron (<i>Nycticorax nycticorax</i>)	1.45%	1	2
Threskiornithidae	White-faced Ibis (<i>Plegadis chihi</i>)	18.63%	27	800

* Most assumed to be Long-billed Dowitchers (*L. scolopaceus*), but may have included Short-billed Dowitchers (*L. griseus*)

** Likely a mix of Greater Yellowlegs (*T. melanoleuca*) and Lesser Yellowlegs (*T. flavipes*)

Table 1.4 Akaike information criterion (AIC_c) results for all candidate models for waterbird abundance, White-faced Ibis abundance, Great Egret abundance, and species richness from observations in California rice fields between June-August 2018. Models with $\Delta AIC_c < 2$ are shown in bold type. Number of parameters (K), log likelihood ($\log(L_i)$), and Akaike weight (w_i) are also presented for each model.

Model	K	Waterbird abundance ^a			White-faced Ibis abundance ^b			Great Egret abundance ^c			Species richness ^d		
		$\log(L_i)$	ΔAIC_c	w_i	$\log(L_i)$	ΔAIC_c	w_i	$\log(L_i)$	ΔAIC_c	w_i	$\log(L_i)$	ΔAIC_c	w_i
1: Intercept only	1	-1734.6	38.9	0.000	-1104.6	27.1	0.000	-808.7	16.5	0.000	-1000.8	52.5	0.000
2: Date and site	3	-1720.2	22.2	0.000	-1092.7	15.5	0.000	-796.4	3.9	0.111	-976.2	15.6	0.000
3: Full model	15	-1702.9	4.1	0.115	-1078.7	3.9	0.125	-788.2	4.1	0.099	-960.2	0.1	0.486
4: Date, site, and chemical management	9	-1720.1	26.3	0.000	-1092.5	19.3	0.000	-796.3	7.9	0.015	-974.2	15.6	0.000
5: Chemical management	3	-1734.5	42.8	0.000	-1104.5	30.9	0.000	-808.4	19.9	0.000	-997.7	50.3	0.000
6: Date, site, and daily field variables	13	-1702.9	0	0.885	-1078.8	0	0.874	-788.2	0	0.775	-962.3	0	0.506
7: Full model without date	10	-1718.3	24.7	0.000	-1093.6	23.4	0.000	-797.9	13.2	0.001	-969.6	8.5	0.007

^a Minimum AIC_c score = 3438.3

^b Minimum AIC_c score = 2190.1

^c Minimum AIC_c score = 1609.0

^d Minimum AIC_c score = 1957.1

Table 1.5 Parameter estimates with standard error and lower and upper 95% confidence interval bounds for models of waterbird abundance and species richness as a function of date, site, water presence, and vegetation height (model 6). Parameter estimates where the confidence intervals do not cross zero are shown in bold type. Day parameters correspond to degrees of freedom for the natural spline fit to the day variable. The reference categories were the Bypass for site, fully flooded for water presence, and Veg2 for vegetation height class. Vegetation height classes are defined in Table 1.1.

Parameter	Waterbird Abundance				Species Richness			
	Estimate	Std. Error	Lower CI	Upper CI	Estimate	Std. Error	Lower CI	Upper CI
Intercept	1.635	0.916	-0.160	3.430	-1.499	0.419	-2.320	-0.679
Day (1)	-0.607	0.614	-1.811	0.597	-0.036	0.294	-0.611	0.540
Day (2)	-3.280	0.770	-4.790	-1.770	-0.902	0.374	-1.636	-0.168
Day (3)	-0.403	0.636	-1.650	0.844	0.491	0.307	-0.111	1.093
Day (4)	-4.482	1.137	-6.710	-2.254	-0.575	0.545	-1.643	0.493
Day (5)	0.946	0.628	-0.284	2.176	0.803	0.294	0.226	1.380
Site	-0.924	0.813	-2.518	0.669	-0.843	0.380	-1.588	-0.097
Partial Flooding	2.650	1.001	0.687	4.613	1.034	0.310	0.046	1.451
No Flooding	-2.261	0.518	-3.277	-1.246	-0.748	0.358	-1.641	-0.426
Veg0	0.673	1.225	-1.729	3.074	-0.172	0.564	-1.277	0.933
Veg1	0.035	0.891	-1.711	1.781	0.220	0.401	-0.566	1.006
Veg3	-0.396	0.385	-1.150	0.358	-0.206	0.194	-0.585	0.173
Veg4	0.474	0.728	-0.953	1.901	0.313	0.340	-0.354	0.980

Table 1.6 Parameter estimates with standard error and lower and upper 95% confidence interval bounds for models of White-faced Ibis abundance and Great Egret abundance as a function of date, site, water presence, and vegetation height (model 6). Parameter estimates where the confidence intervals do not cross zero are shown in bold type. Day parameters correspond to degrees of freedom for the natural spline fit to the day variable. The reference categories were the Bypass for site, fully flooded for water presence, and Veg2 for vegetation height class. Vegetation height classes are defined in Table 1.1.

Parameter	White-faced Ibis Abundance				Great Egret Abundance			
	Estimate	Std. Error	Lower CI	Upper CI	Estimate	Std. Error	Lower CI	Upper CI
Intercept	1.212	1.287	-1.311	3.734	-1.959	0.740	-3.410	-0.509
Day (1)	-0.480	1.063	-2.563	1.603	1.035	0.647	-0.232	2.302
Day (2)	-5.773	1.303	-8.327	-3.218	-1.602	0.847	-3.262	0.058
Day (3)	0.411	1.047	-1.641	2.464	1.408	0.684	0.067	2.749
Day (4)	-6.278	1.854	-9.911	-2.644	0.441	1.211	-1.932	2.814
Day (5)	1.777	0.987	-0.157	3.712	2.186	0.632	0.947	3.424
Site	-0.035	1.095	-2.162	2.091	-1.182	0.537	-2.235	-0.129
Partial Flooding	2.904	1.717	-0.461	6.269	1.783	0.833	0.150	3.416
No Flooding	-3.476	0.901	-5.242	-1.710	-0.923	0.542	-1.985	0.140
Veg0	-3.027	2.139	-7.220	1.166	-1.712	1.430	-4.514	1.091
Veg1	0.275	1.222	-2.120	2.669	-0.405	0.685	-1.747	0.937
Veg3	-0.982	0.629	-2.214	0.250	-0.930	0.413	-1.740	-0.121
Veg4	0.235	1.180	-2.077	2.547	-1.222	0.761	-2.713	0.269

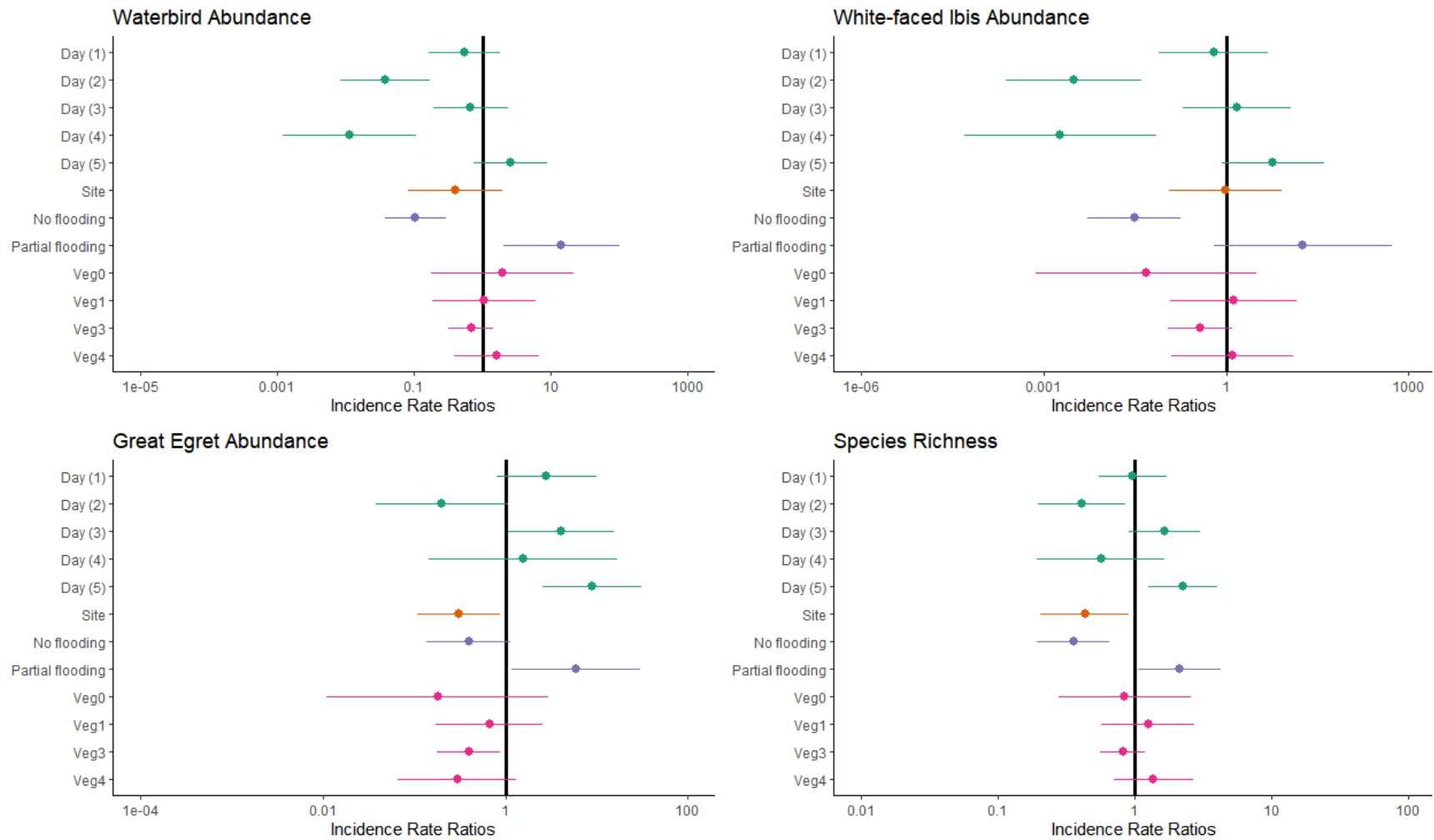


Figure 1.3 Forest plots showing incidence rate ratios with 95% confidence intervals for parameters in the best performing models for waterbird abundance, White-faced Ibis abundance, Great Egret abundance, and species richness. Day parameters correspond to degrees of freedom for the natural spline fit to the day variable. The reference categories were the Bypass for site, fully flooded for water presence, and Veg2 for vegetation height class. Vegetation height classes are defined in Table 1.1. Green bars indicate parameters related to date, orange bars indicate parameters related to site, purple bars indicate parameters related to water presence, and pink bars indicate parameters related to vegetation height class.

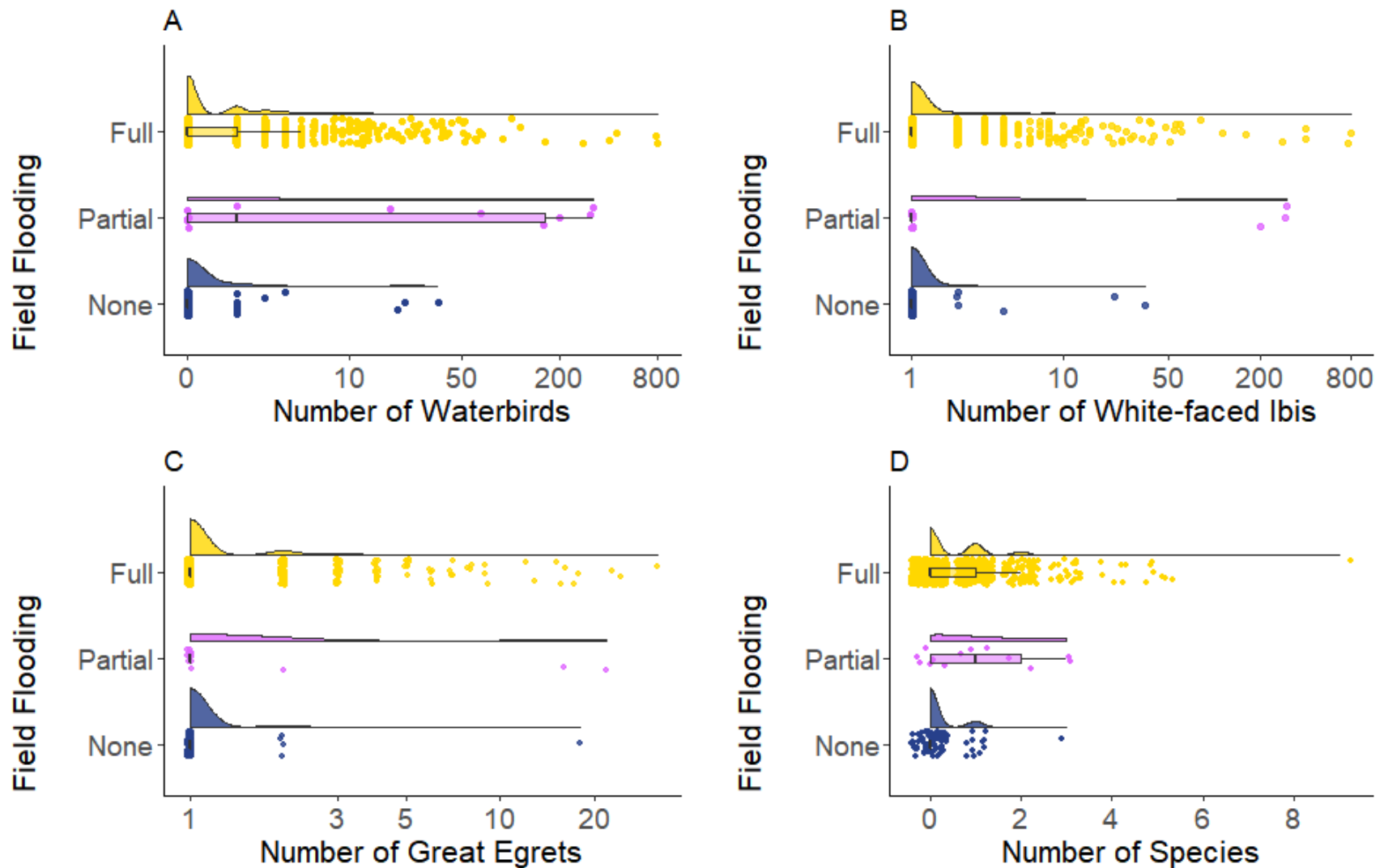


Figure 1.4 Number of (A) waterbirds, (B) White-faced Ibis, (C) Great Egrets, and (D) species in California rice checks with no, partial, or complete flooding during June – August, 2018. Number of waterbirds, White-faced Ibis, and Great Egrets are plotted on a log scale and have had one added to all counts to facilitate the visualization of zero counts. Plots show a density distribution above the central line, and the actual data points with an overlaid box plot below; box represents central 50% of data bisected at the median, and whiskers represent 95% of the data.

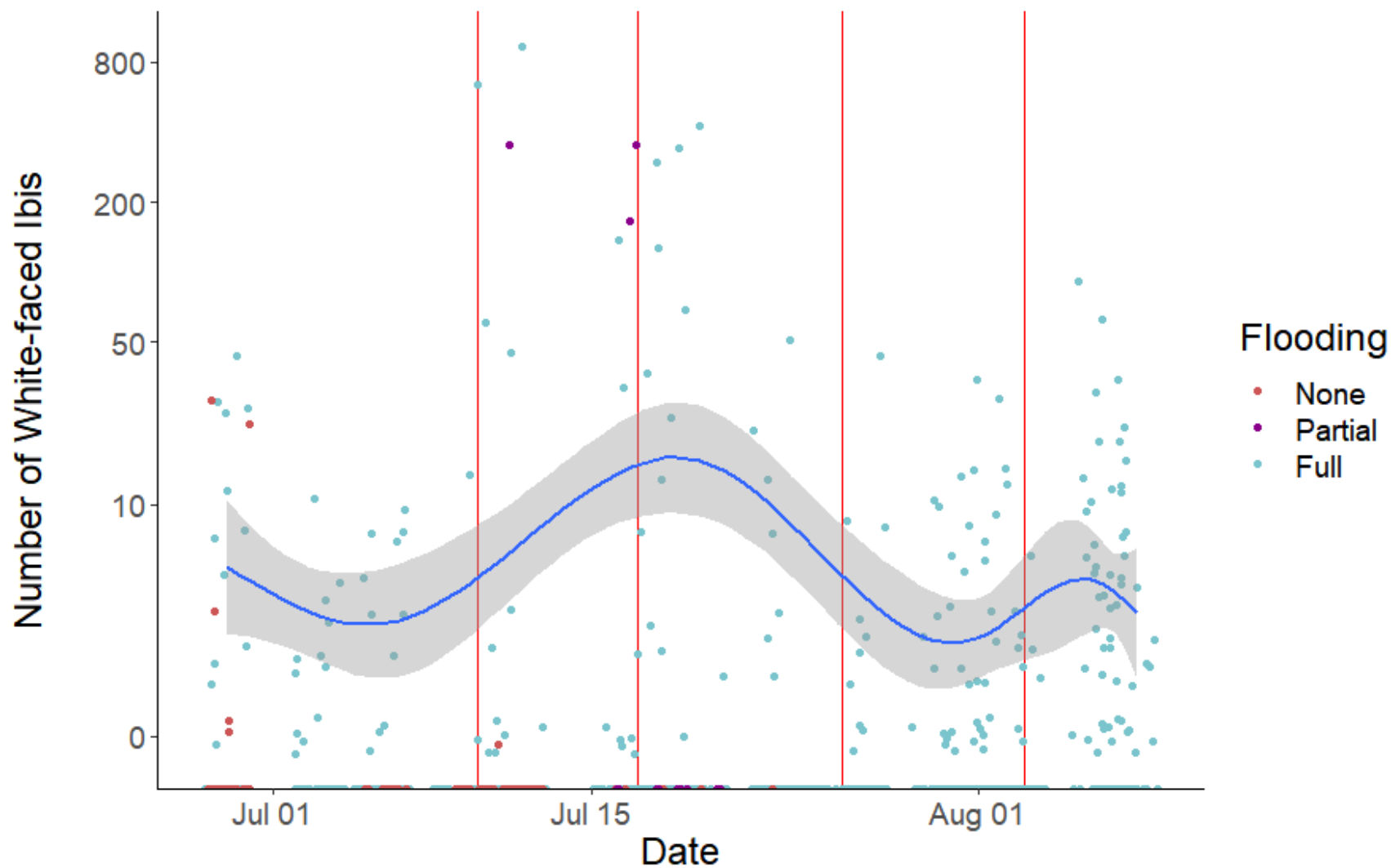


Figure 1.5 Number of White-faced Ibis observed in California rice fields June-August 2018, by date. Individual observations are plotted as points, which have been jittered for increased visibility. A LOESS curve has been fitted as a natural spline with five degrees of freedom to visualize the spline fit to day used in the model. Red vertical lines denote location of knots, and occur at July 10th, July 17th, July 26th, and August 3rd. Points are colored by water presence category they occurred in. Dry rice fields were reflooded between July 10th and July 26th. White-faced Ibis were the dominant species seen on rice fields, so the pattern for all waterbird abundance looks similar.

DISCUSSION

Chemical use on farmland is widely thought to affect biodiversity adversely and result in reduced field use by wildlife (Chamberlain et al. 2000, Freemark and Kirk 2001, Donald et al. 2001). Consequently, I predicted that waterbird abundance and species richness would decrease as chemical management of fields increased. However, models that included chemical management variables were poorly supported. In fact, the model that included just chemical management factors as explanatory variables (model 5) performed worse than the intercept only (null) model (model 1) for waterbird, White-faced Ibis, and Great Egret abundance, and was at best only marginally better for species richness (Table 1.4). While organically managed fields are often found to have higher species richness and abundance than conventionally managed fields (Mäder et al. 2002, Bengtsson et al. 2005), management of different organic fields can vary considerably (Hole et al. 2005, Quinn et al. 2012). Guidelines for organic agriculture largely consist of prohibiting substances and practices rather than laying out specific management actions that should be taken. Organically managed fields, therefore, can still be intensively managed along axes unrelated to chemical use. Additionally, while low pesticide use is often associated with higher bird abundance and diversity, this association is complicated by the fact that low pesticide use is often combined with other beneficial management practices such as crop rotation and heterogenous landscapes (Henderson et al. 2009, Chiron et al. 2014). Further research is perhaps needed to better distinguish what aspects of organically-farmed fields are beneficial to biodiversity and abundance of birds.

Of the variables in the top models, the clearest patterns were associated with water management. As expected, birds were more abundant in flooded fields than unflooded fields; however, both bird abundance and species richness were highest in fields that were in the process

of being reflooded. This pattern indicates that flooding makes aquatic prey available immediately after the water flows onto a field, either through movement from irrigation ditches or emergence from the soil (Lane and Fujioka 1998, Anderson and Smith 2000, Fraser et al. 2012). This association with reflooding also accounted for some of the fluctuations in abundance observed through time. Increases in field use were also seen when young were fledging in late July, suggesting that rice fields are an important foraging habitat for ibis post-nesting.

Waterbird abundance and diversity were lowest in dry rice fields, with only three species observed using unflooded fields: Great Egrets, White-faced Ibis, and Snowy Egret. This pattern is consistent with findings on bird use of rice fields during the non-growing season (Elphick and Oring 1998, Strum et al. 2013). Unlike during the growing season, however, post-harvest unflooded fields are still regularly used by waterbirds (Elphick and Oring 2003). This difference can be attributed to the fact that waterbirds are able to feed on leftover grain in dry post-harvest fields, as well as the fact that increased rainfall during the winter months leads to shallow puddling where birds can feed on invertebrates. The observation that few waterbirds use dry fields was offset by a surge in bird numbers in freshly reflooded fields suggests that if fields are allowed to dry for short periods of time, the lack of birds using the fields while they are dry may be counterbalanced by the value of the freshly flooded fields. Extended dry periods, however, will likely hamper the ability of waterbirds to use rice fields for foraging. This is troubling because in order to continue rice production in the face of growing global water scarcity (Hoekstra et al. 2012), there have been efforts to grow rice using less water (Tuong and Bouman 2001, Tuong et al. 2005). Although using less water for agriculture could leave more water for natural wetlands, dry field cultivation of rice could also be devastating for wetland birds (Fasola

et al. 1996). As water use is a critical management factor affecting birds in rice fields, a better way to assess the tradeoffs between water savings and bird conservation is needed.

I did not see an effect of vegetation height on bird abundance or richness. High vegetation may exclude shorebird species and decrease feeding efficiency (Butler and Gillings 2004, Wilson et al. 2005), but it also provides shelter from nest predators (Whittingham and Evans 2004, Whittingham et al. 2006, Gillis et al. 2012). Many bird species are known to nest in rice fields or use them post-fledging (Earl 1950, Cirne and López-Iborra 2005, Pierluissi and King 2008, Pierluissi 2010), and I often observed juvenile ducks and herons sheltering near the edges of fields with high vegetation. The change in vegetation height throughout the growing season does not appear to have a direct relationship with bird abundance or diversity, but it allows species with different habitat requirements to use rice fields at different growth stages for breeding and foraging.

Although I found no evidence that bird abundance or species richness varied with chemical management, many pesticides used in rice fields are known to be highly toxic to birds. Birds using fields with higher pesticide density may be at risk for negative effects associated with pesticide use, including reproductive harm and death (Flickinger and King 1972, Flickinger et al. 1980, Parsons et al. 2010, De Almeida and De Almeida 2011). Harm to birds from pesticides has historically been a problem in California. The White-faced Ibis, for example, experienced a steep decline in population between the 1940s and 1970s in California, to the point that no known breeding occurred in the state between 1965 and 1977 (Remsen 1978). This decline is largely attributed to the loss of natural wetlands and DDT contamination. The population of White-faced Ibis in California began to rebound after DDT was banned, and they are now common in rice fields year-round (Shuford et al. 1996). The fact that I found no clear

effect of chemical use on waterbirds perhaps suggests that improved pesticide management practices in California have alleviated the problems of pesticides seen in the past.

Pesticides may also reduce the abundance of aquatic invertebrate prey available to waterbirds. Ibáñez et al. (2010) also found no correlation between management type and waterbird density, but noted that the organic fields they studied contained higher prey biomass than conventionally managed fields. Waterbird abundance alone may not accurately indicate habitat quality, as it does not directly indicate how well birds are faring in the fields. Ideally, further research would focus on recording metrics of foraging success and relating them to the survival and reproductive success of birds foraging in fields.

Understanding how agricultural management affects the habitat quality of rice fields for breeding waterbirds, especially in areas where natural wetlands are scarce, is vital to balancing bird conservation and food production. Determining why some populations respond strongly to pesticide use and management type while others do not will give valuable insight into specific management actions that can be taken to aid bird conservation. Additionally, water management may be the most critical factor to consider when considering the value of rice fields for waterbirds as natural wetlands continue to decline.

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Chapter 2 – Intensification of agricultural wetlands and its effects on birds: a systematic map

1. Introduction

1.1 Background

As the human population grows, so does demand for food. To keep up with the needs of a burgeoning human population, global crop production is projected to increase 59-110% by 2050 (Tilman et al. 2011, Valin et al. 2014). There has been much debate about how to preserve biodiversity while also achieving food security. One proposed solution to the biodiversity/food security problem is to spare preserves for wildlife while intensifying agriculture on existing farmland (Green et al. 2005, Phalan et al. 2011). Agricultural intensification is defined by the United Nations Food and Agriculture Organization as increases in agricultural yield per unit time or area (FAO, 2004), but is often discussed in terms of agricultural inputs (e.g. pesticides, fertilizers, water) rather than outputs. Intensified agricultural management can lead to massive increases in food production, as seen during the Green Revolution of the 1950s and 60s (Evenson and Gollin 2003), but land with intensive agriculture can be of lower quality to the wildlife living on it and activities associated with intensification often have negative effects on natural ecosystems nearby (Matson et al. 1997, Donald et al. 2001, Kremen et al. 2002). Intensification of existing agricultural lands with the intention of sparing other land for wildlife preservation may be an effective conservation approach for habitats that are still plentiful enough to have significant spared patches (Green et al. 2005, Phalan et al. 2011). Sparing land for wildlife may be more difficult for more endangered habitats, such as wetlands, because of the risk that small

habitat patches and fragmentation pose to biodiversity and population persistence (Fahrig 1997, Krauss et al. 2010).

Since 1900, 64-71% of wetland area has been lost worldwide, with higher rates in some regions (e.g. 83% in Asia; Davidson, 2014). As wetland habitats become increasingly scarce, wild animals are becoming more dependent on agricultural wetlands – areas of farmland that are flooded, intentionally or unintentionally, at any point in the year. The use of agricultural wetlands – particularly rice – as surrogate wetland habitat has been well documented in birds (Fasola and Ruiz 1996, Maeda 2001, Eadie et al. 2008, Elphick 2010). There are numerous studies on the effects of intensification on biodiversity, but many of these studies focus on grassland and woodland species and do not address flooded fields (e.g. Chamberlain et al., 2000; Stanton et al., 2018). Understanding the dynamics of wildlife in flooded field agriculture is vital, as agricultural wetlands are economically important worldwide, particularly in Asia where rice is a major food source (Maclean et al. 2002).

1.2 Objectives

In this study, I created a systematic map of what is known about the effects of intensifying management of agricultural wetlands on birds. Systematic maps are a type of evidence synthesis that aim to gather all available evidence for a research question with the objective of describing the state of knowledge on a certain subject (James et al. 2016, Livoreil et al. 2017). Unlike traditional narrative reviews, systematic maps are conducted using rigorous, reproducible literature searches structured to reduce researcher bias and to capture the maximum amount of literature available on a particular subject. Instead of aiming to answer a specific research question, this type of evidence synthesis is meant to gather and describe the evidence available on a particular topic. The systematic map I created is a collection of peer-reviewed and gray

literature gathered with the intention of documenting where research on the effects of intensification of agricultural wetlands on birds is taking place, what types of intensification and effects on birds have been studied, and what bird species and crops are represented in the literature.

To catalog the available literature, I conducted a systematic search for articles containing information on birds, flooded agriculture, comparisons of multiple levels of intensification, and any effects on birds. This search was conducted in multiple publication databases using pre-determined search terms identified via a semi-automated process that used a keyword co-occurrence network analysis to reduce the risk that important terms were omitted (Grames et al. 2019). Using the resulting information, I identify areas where quantitative synthesis (e.g., meta-analysis) is plausible and major gaps in knowledge that warrant further investigation.

2. Methods

2.1 Database Searches

To create a comprehensive, unbiased search string, I first identified an initial set of search terms by performing a preliminary search of the literature in a subset of potential databases that I expected to contain a majority of key papers. Terms for the preliminary search (Table 2.1) were selected to return papers in four concept groups that consisted of birds, agriculture, various forms of intensification, and measured effects on birds. Terms categorized within these four concept groups were connected by the Boolean OR operator, and the concept groups were connected by the AND operator, enabling me to search for any combination that includes one term from each of the four concept groups. I conducted the preliminary searches in January 2019 in the BIOSIS

Citation Record (1926-2019), Zoological Record (1864-2019), and Scopus (1788-2019) databases.

Table 2.1 Search terms used in the preliminary search. Returned papers from the preliminary search were used to find additional important search terms for our full search. Search terms were used in the form [Taxa] AND [System] AND [Intensification] AND [Effect]. Wildcards () were used in all databases to return results with the same root, but containing different word beginnings or endings.*

Concept Group	Terms
Taxa	*bird* OR Aves OR avian OR *fowl*
System	agricultur* OR crop* OR rice OR taro OR lotus* OR cranberr* OR flood* field* OR pasture*
Intensification Type	agric* intens* OR land use intens* OR pesticide* OR fertilizer* OR irrigat* OR agricultur* yield OR crop yield* OR crop rotation OR increased yield OR straw manipulation* OR flood* OR water level* OR water depth*
Effect	prey availability OR food availability OR forag* OR water availab* OR habitat use OR habitat selection OR habitat suitability OR population size* OR abundance OR species diversit* OR hatch success OR reproductive success

I used the beta version of the R package litsearchr to import the results of the preliminary search and identify a more comprehensive set of keywords using the recommended litsearchr method (Grames et al. 2019). I used litsearchr to build a keyword co-occurrence network of important words and phrases from the preliminary search results and suggest keywords based on their connectivity within the network. Within litsearchr, I fit a spline with three knots to identify rapid-change points in the importance of keywords within the co-occurrence network. Keywords with weights above the third knot were manually categorized into the same concept groups used for the preliminary search. I combined the preliminary search terms with the terms identified using litsearchr to create a final set of search terms (Table 2.2).

Table 2.2 Search terms used in the full literature search. Search terms were used in the form [Taxa] AND [System] AND [Intensification] AND [Effect]. Wildcards () were used in all databases to return results. containing different word beginnings or endings.*

Group	Terms
Taxa	*bird* OR Aves OR avian* OR *fowl*
System	crop* OR rice* OR taro* OR lotus* OR cranberr* OR flood* field* OR agro* ecosystem* OR farming OR farmland OR cultiv* land* OR oryza sativa OR paddy* OR arable field* OR arable land* OR cereal field* OR pasture* OR livestock* graze*
Intensification	agriculture* chang* OR agricultur* manag* OR agricultur* polic* OR agricultur* practic* OR agricultur* product* OR agricultur* intens* OR agricultur* yield* OR crop* rotat* OR crop* yield* OR crop product* OR crop divers* OR conventional farm* OR environment schem* OR farm* manag* OR farm* practic* OR flood* OR fertilizer* OR intens* agricultur* OR intens* farm* OR increas* yield* OR irrigat* OR land use intens* OR low* intens* OR organ* farm* OR organ* field* OR pest* control* OR pesticid* OR pest* manag* OR straw* manipul* OR water* avail* OR water* manag* OR water* level* OR water* depth* OR water qualit* OR weed control*
Effect	abund* OR avian* divers* OR bird* densiti* OR bird commun* OR bird* divers* OR bird* rich* OR breed* densiti* OR breed* perform* OR breed* success* OR brood* size* OR chick* surviv* OR clutch* size* OR feed* behavior* OR fledg* success* OR food* avail* OR forag* OR farmland biodivers* OR food abund* OR habitat* prefer* OR habitat* util* OR habitat* use* OR habitat* select* OR hatch* success* OR mortal* rate* OR nesting bird* OR nest* success* OR nest* surviv* OR nest* habitat* OR nest* site* OR occuranc* OR population dens* OR prey* avail* OR reproduct* output* OR reproduct* success* OR site* select* OR speci* divers* OR speci* rich* OR surviv* rate* OR species composit* OR species dens* OR water* avail* OR bod* condit* OR bod* mass* OR population declin*

Searches using this final set of terms were conducted during January 2019 in the databases BIOSIS Citation Index (1926-2019), Zoological Record (1864-2019), MEDLINE (1950-2019), Scopus (1788-2019), Academic Search Premier (1887-2019), Agricola (1970-2019), GreenFILE (1898-2019), OpenDissertations (1597-2019), and CAB Abstracts (1973-2019) to retrieve both published and gray literature. I searched for the terms in the title, abstract,

and keyword fields with no date restrictions. Searches were conducted in English only, but no restrictions were made on languages returned. I used the “quick” version of the deduplicate function in litsearchr to detect and remove papers that were retrieved by multiple databases.

2.3 Study Inclusion

In order to be considered for inclusion in the systematic map, papers needed to meet certain selection criteria regarding relevant taxa, study locations, appropriate exposures and comparators, and outcomes. Articles had to include wild birds as a study taxon; articles that only studied domestic birds or poultry were not included. Study locations had to include land on which crops were grown or livestock were allowed to graze, and that had intentional or unintentional flooding, not including aquaculture. I did not place any geographic restrictions for study locations. To meet inclusion criteria for appropriate exposures and comparators, studies had to measure some aspect of intensifying agricultural management – including but not limited to pesticide use, fertilizer use, irrigation, or planting density – and comparisons had to be made between these different levels of intensity. Papers that only compared agriculture to non-agriculture were not considered for inclusion. Relevant types of outcome studied had to be some aspect of bird biology, including but not limited to abundance, species richness, foraging behavior, or reproductive activity. Articles that did not have a comparative study design, including review articles, were excluded.

Studies were reviewed by screening article titles, abstracts, and full text in an iterative process for relevance (Fig. 2.1). Paper titles were initially screened for irrelevant topics, followed by a review of paper abstracts for all papers that passed the initial screening. Full text review was conducted on all papers that remained after abstract review. At each stage of review, studies

were excluded from analysis if they clearly did not meet criteria regarding appropriate taxa, study location, exposures and comparators, outcomes, and type of article.

2.4 Systematic Map Database

After final review, data were extracted from the text and entered into a searchable relational database (see Supplemental Information). Data extracted included full citation information, publication type (e.g. journal article, dissertation), language of the article, location of the study sites, crops studied, bird species or groups studied, type and measurement of agricultural intensity, type and measurement of the effect on birds, and agencies that funded the study. If parts of a study fell outside the scope of our inclusion criteria, data were only extracted for the parts of the study that matched the inclusion criteria.

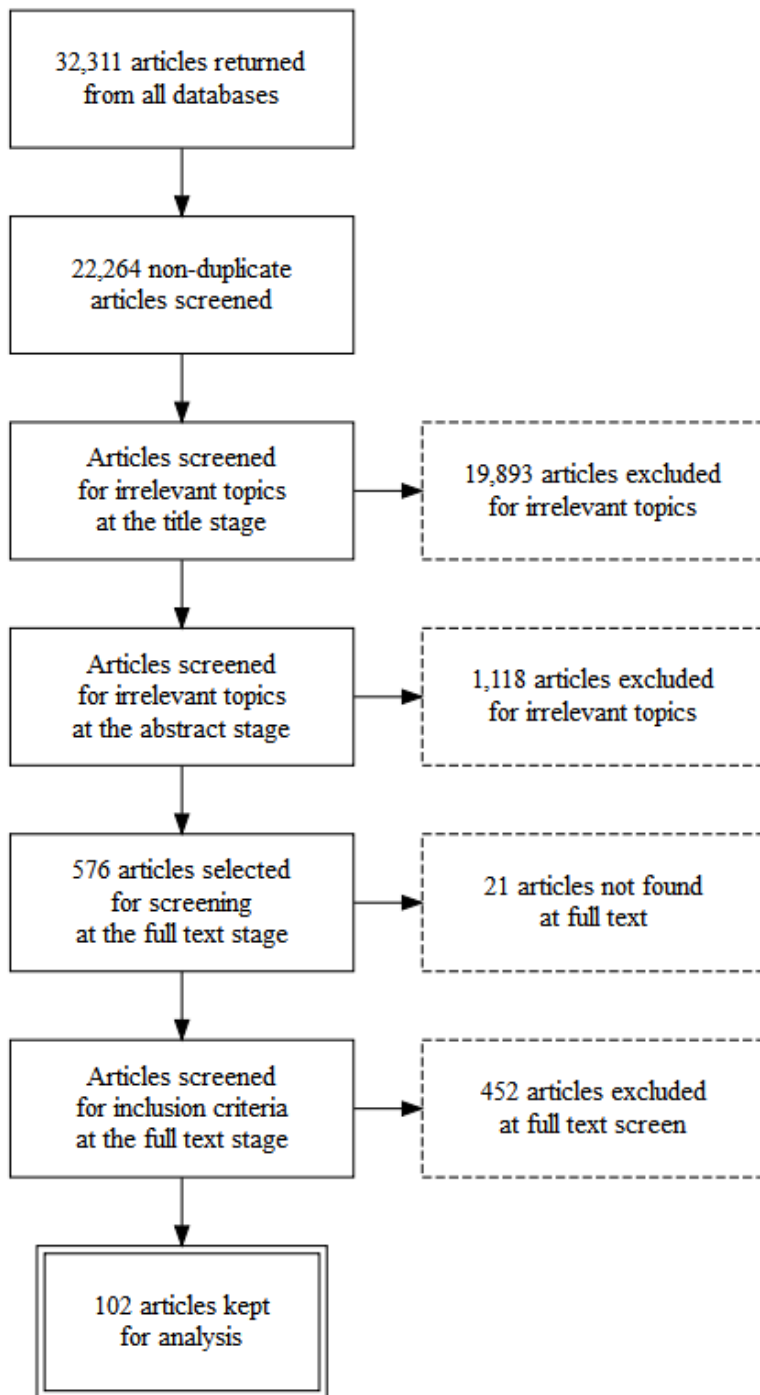


Figure 2.1 An overview of the iterative article screening process. Articles were screened for irrelevant topics and presence of inclusion criterion at each stage of the screening process. Solid boxes represent the papers at each stage of review. Dashed outline boxes represent articles excluded from the systematic map. The double bordered box represents articles kept for inclusion in the systematic map.

3. Results

3.1 Literature Search and Screening

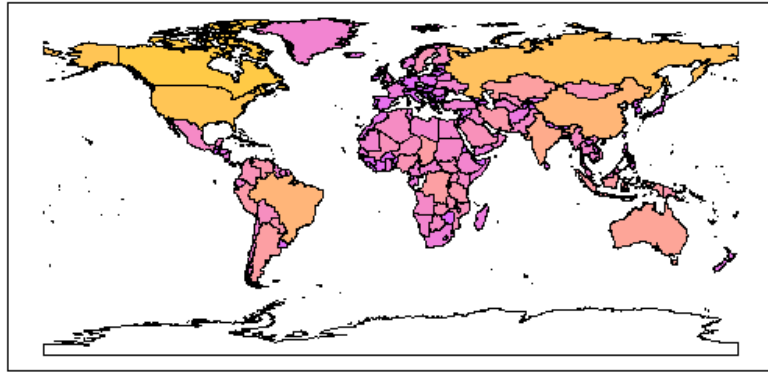
Using important keywords extracted from this preliminary search, the full literature search returned 32,311 records (Fig. 2.1). Removing duplicates resulted in 22,264 unique papers, 576 of which remained after title and abstract review for evaluation at the full text stage. After the iterative review process, 102 papers remained that met all inclusion criteria.

3.2 Geographical Distribution and Crops

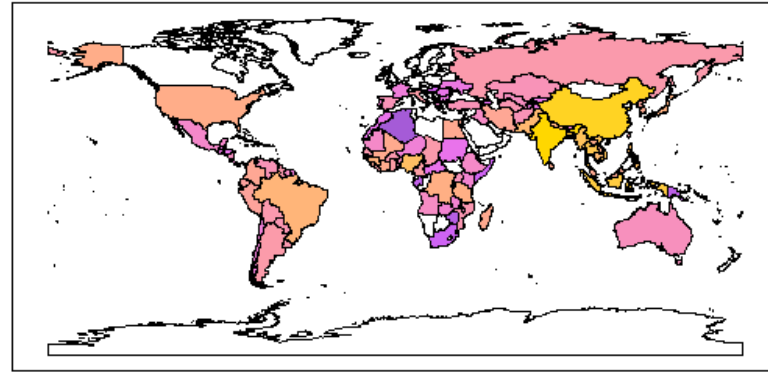
Articles included study locations across 27 countries and five continents (Fig. 2.2). Most studies included in our systematic map were conducted in Europe (49%), North America (28%), and Asia (18%), with South America (3%) and Africa (2%) having a much lower percentage of studies. The USA (21%), Netherlands (17%), and France (10%) were the countries best represented in the literature.

Across all studies, 17 agricultural products were studied (Fig. 2.3). Rice (45%), livestock (38%), and silage/hay (20%) were the most commonly represented, with most of the other agricultural products found only in a single study each.

A) Wetland area by country

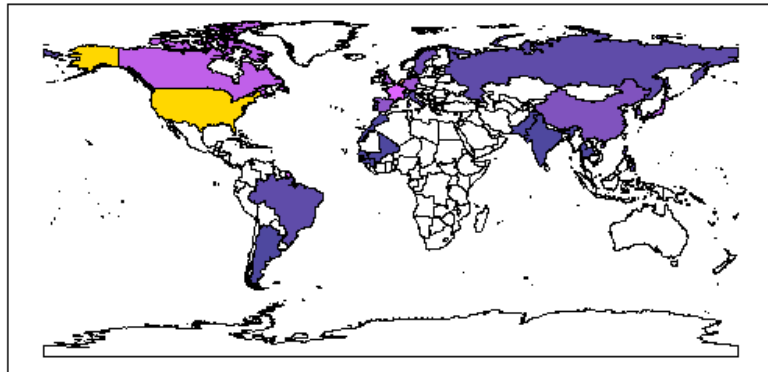


C) Area of rice harvested by country

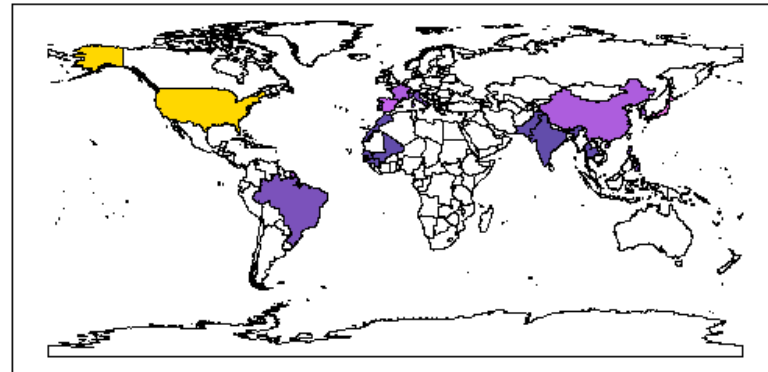


Log Area (ha) 8 12 16

B) Number of papers by country



D) Number of papers studying rice by country



Papers 5 10 15 20

Figure 2.2 World maps showing (A) the area of wetlands found in each country (Lehner and Döll 2004), (B) the number of papers included in our final review from each country, (C) the area of harvested rice for each country (FAOSTAT 2017), and (D) the number of studies conducted in rice fields included in our final review from each country.

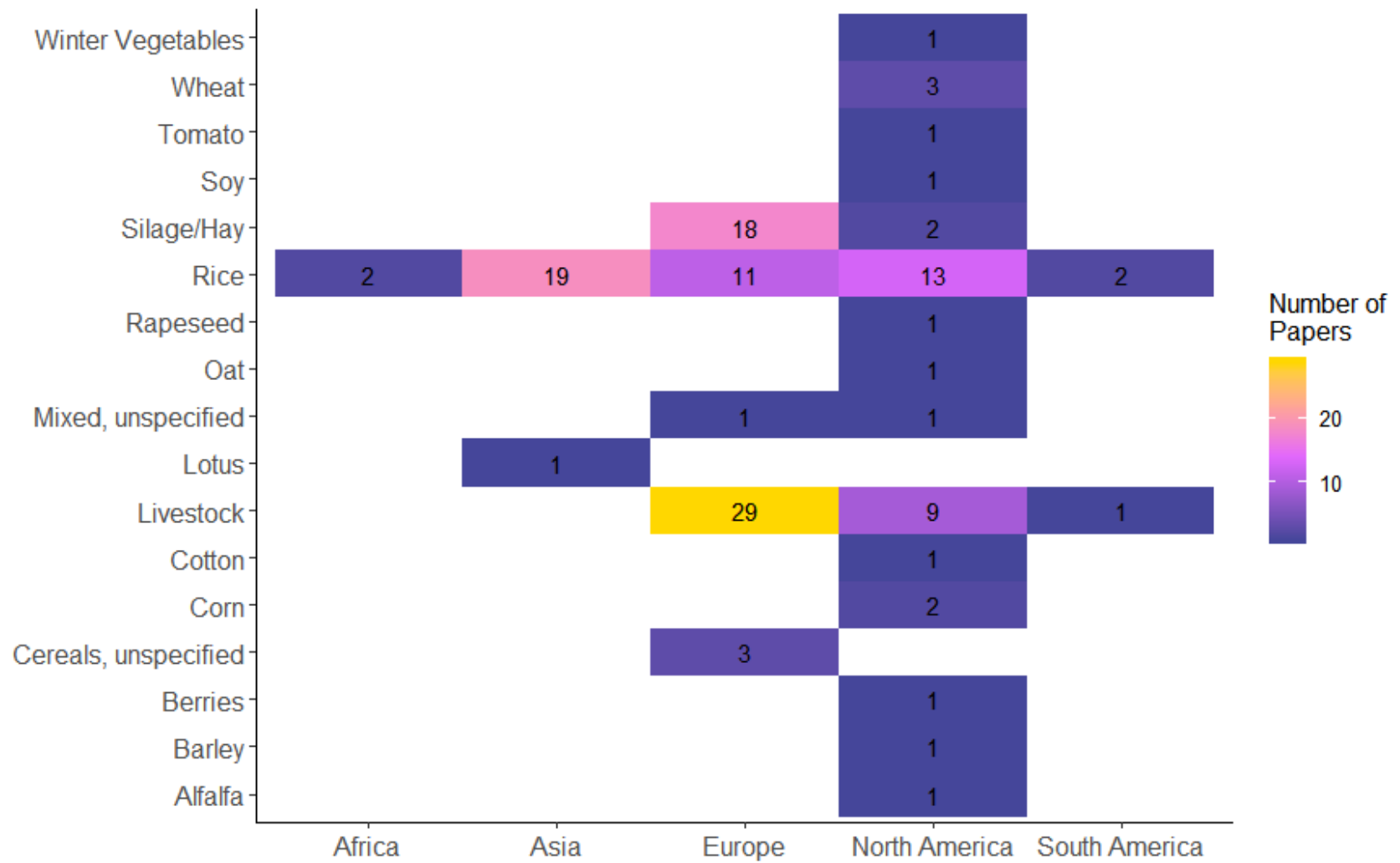


Figure 2.3 A heatmap table showing the number of articles addressing the effects of agricultural intensification on wetland birds, organized by agricultural product and by continent.

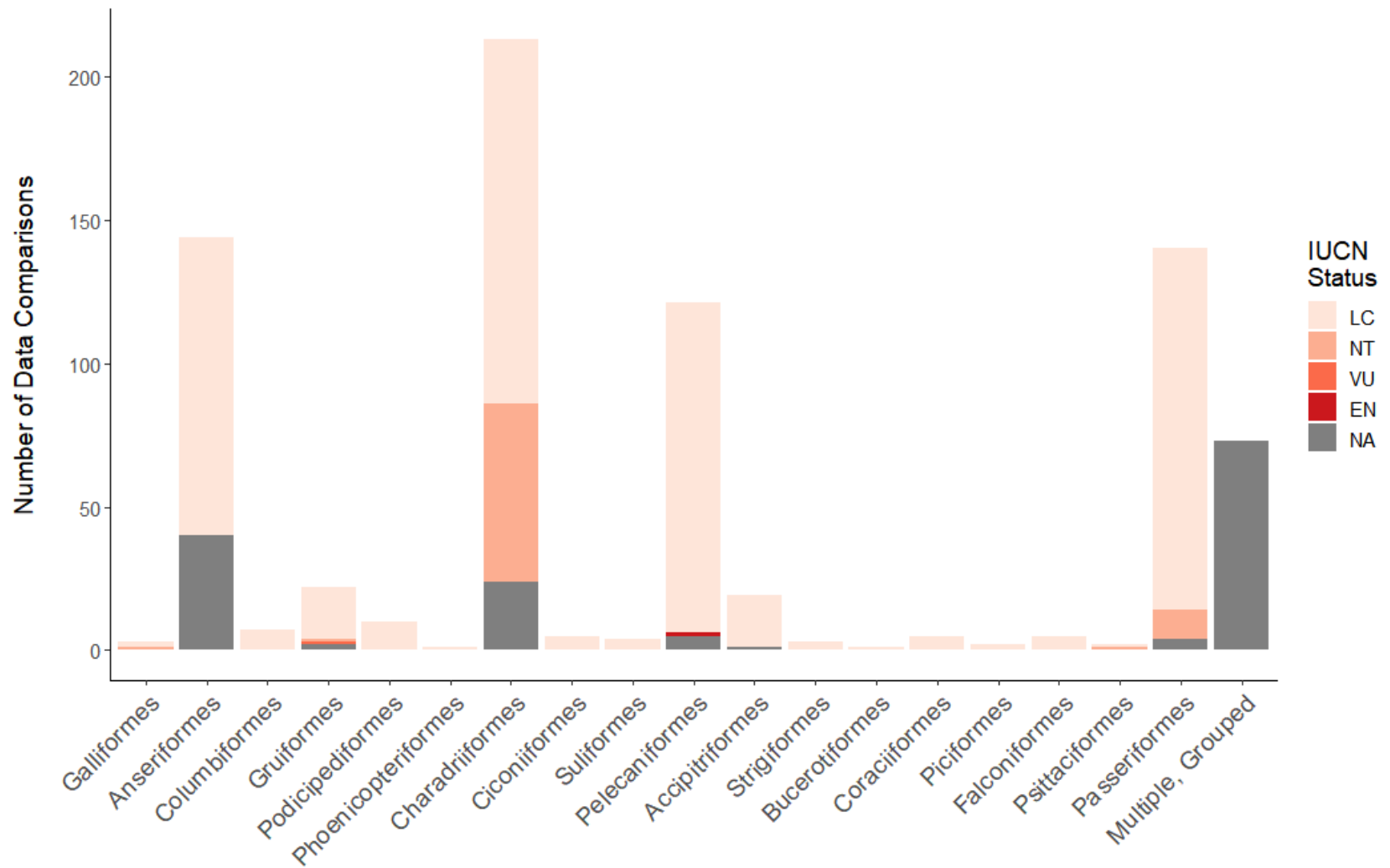


Figure 2.4 Number of distinct comparisons between different levels of intensification by bird order. The number distinct comparisons from birds of each IUCN status are denoted by color. LC: Least Concern; NT: Near Threatened; VU: Vulnerable; EN: Endangered; NA: data from multiple species, grouped.

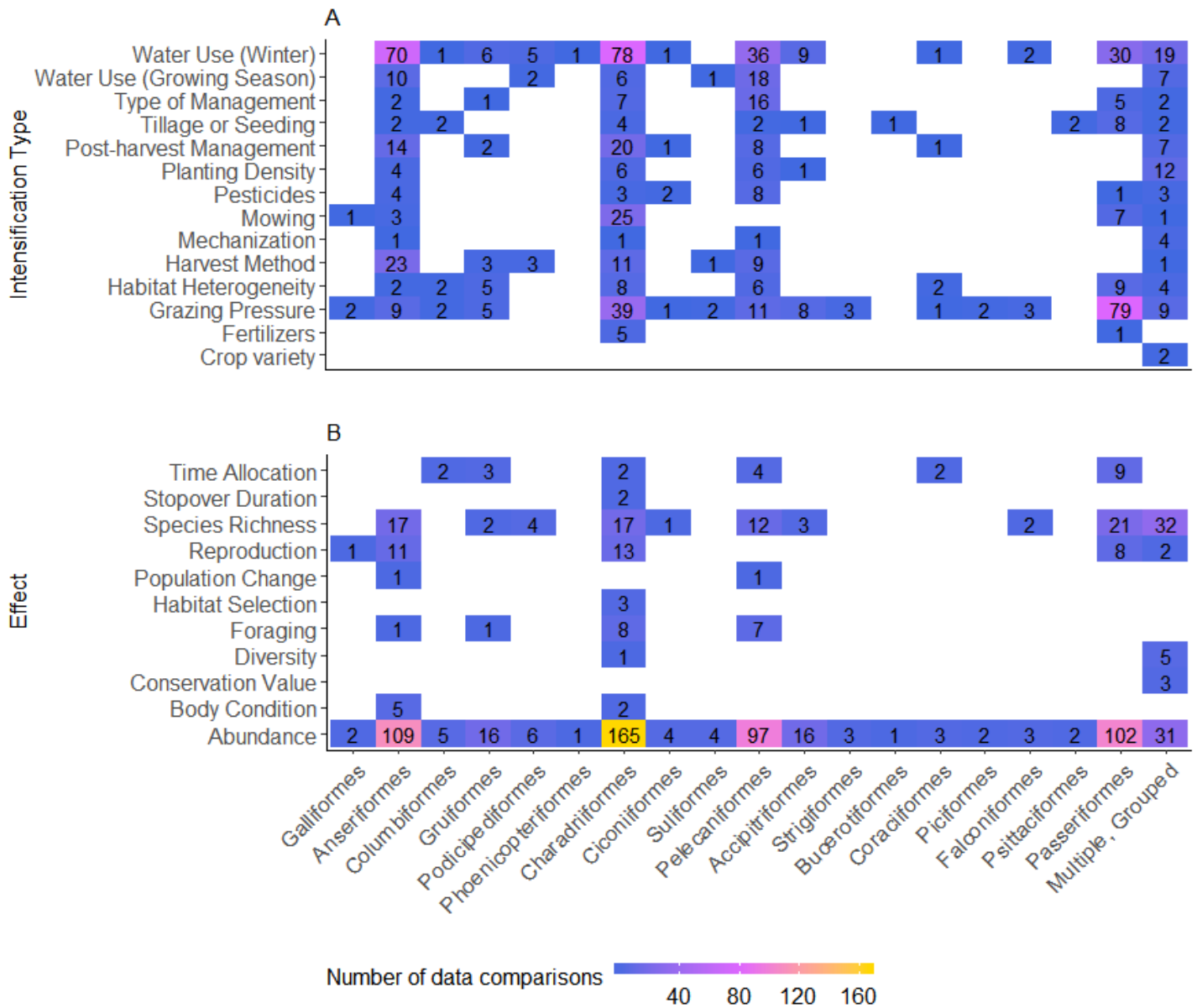


Figure 2.5 Heatmap tables showing the number of distinct comparisons between different levels of intensification conducted for each bird order organized by (a) agricultural intervention and (b) biological outcome examined.

3.3 Birds Studied

A total of 259 bird species across 18 orders were represented in the literature (Fig. 2.4). Charadriiformes were represented in the greatest number of papers (59%), followed by Anseriformes (37%) and Pelecaniformes (24%). When we quantified the total number of distinct comparisons between different levels of intensification, Charadriiformes remained the best represented group (27% of comparisons), followed by Anseriformes (18%), Passeriformes (18%), and Pelecaniformes (15%). 73 comparisons (9%) were attributed to grouped data rather than individual species.

3.4 Intensification and Effects

Fifteen types of intensified agricultural practices were examined across studies (Fig. 2.5). Grazing regime (e.g. density of livestock, proportion of the year the land was grazed) was the most commonly examined type of management (21% of papers), followed by water use during the non-growing season (e.g. comparisons of flooding versus non-flooding, depth of flooding, and length of time water was left on the field; 20%), mowing regime (e.g. date of first mow, number of mows per year; 11%), and post-harvest management (e.g. standing stubble versus burning or plowing; 11%). Other types of agricultural intensification studied included water use during the growing season, tillage and seeding, pesticide use, planting density, fertilizer use, crop variety (e.g., high yielding versus low yielding varieties), amount of mechanization, harvest method, and type of field management (e.g., organic versus conventional management).

Seven types of effects on birds were examined by the selected studies (Fig. 2.5). Bird abundance was most commonly studied (53% of studies) followed by species richness (16%) and reproduction (16%). Other types of effects studied included differences in time allocation (i.e.

number of perching or foraging activities per hour), body condition, conservation value (as derived from a species' density in a particular field, its relative abundance across its range, and its population trend), foraging ability, habitat selection, and population change.

3.5 Funding Agencies

Funding for studies included in the systematic map came from 134 distinct sources. The agencies that funded the most studies included Ducks Unlimited (8%) and the Central Valley Joint Venture (7%). Information about funding agencies was not provided for 32% of studies. The most common source of funding was governmental, which included federal government (26%) and sub-federal government (e.g. state, province; 10%) sources of funding. Non-governmental organizations provided funding for 32% of studies.

4. Discussion

The vast majority of the studies included in our systematic map were conducted in rice fields and on flooded grazing land in Europe and North America. Rice and lotus were the only crops traditionally grown under flooded conditions for which there were studies that matched all of our inclusion criteria. While there are a wide variety of bird orders and types of intensification studied, there are significant gaps in knowledge for certain areas of the world, crops, and types of effects seen on birds.

4.1 What has been studied?

The effects of agricultural intensification on waterbirds have been primarily studied in Europe and North America, with more studies from the USA than any other country. A large percentage of studies from Europe and North America involved wet meadows for grazing and silage. In northern Europe in particular, many of the studies focused on Black-tailed Godwits

(*Limosa limosa*) and Northern Lapwings (*Vanellus vanellus*), which are declining species that nest in wet meadows (Schekkerman et al. 2009). Most studies on agriculture other than rice and wet meadow grazing were from the USA, partially due to a single study examining the effects of post-harvest flooding on five crops not traditionally grown in flooded conditions (e.g. tomatoes (*Solanum lycopersicum*), cotton (*Gossypium* spp.); Fleskes et al., 2012).

Waterbirds including shorebirds, waterfowl, and long-legged waders were all well represented in the literature (Fig. 2.4). These groups include many species that will readily use shallowly flooded fields which are characteristic of agricultural wetlands. The order Passeriformes was also well represented in the studies. Many papers reported data for groups of species rather than individual species. Species were often grouped by functional group (e.g. “shorebirds”, “waterbirds”, “long-legged waders”), feeding type (e.g. “aerial insectivores”, “herbivores”), or by habitat preference (e.g. “woodland species”, “edge species”). While there was a wide variety of ways in which intensification has been examined in at least some species, few effects on birds other than changes in abundance and species richness have been examined.

Meta-analyses should be conducted on topics that are more heavily researched in order to inform management decisions. For example, more quantitative evidence synthesis should be conducted to examine the effects of all types of agricultural intensification on bird abundance. This research would give insight into which aspects of agricultural intensification should be seen as a conservation concern.

4.2 Knowledge Gaps

Based on the papers selected during our search, most studies are not conducted in the areas we would expect to receive most attention based on the distribution of flooded crops

worldwide. Most notably, Asia and Africa are the continents that produce the most of the world's rice (87% and 8%, respectively), but 19% of the studies conducted in rice were from Asia, and only 2% were from Africa (Fig. 2.2).

Over 1,724,000 ha of taro (*Colocasia esculenta*) and 41,000 ha of cranberries (*Oxycoccus palustris*) are grown worldwide (Food and Agriculture Organization of the United Nations 2017) and traditionally grown in flooded conditions, but we found no studies of the effects of intensification in these crops on waterbirds. In fact, very little is known about bird use of taro or cranberries at all (Czech and Parsons 2002). Similarly, we found only one study from lotus (*Nelumbo nucifera*) fields (Maeda and Yoshida 2009). Additional crops grown in flooded conditions but not found in any study in our systematic map include watercress (*Nasturtium officinale*) and wild rice (*Zizania* spp.).

Data for effects on birds other than abundance and species richness are extremely limited. While these are commonly used metrics for quantifying habitat use, they do not necessarily correlate with measures of reproduction and survival that are key to understanding habitat quality (Van Horne 1983).

4.3 Study Limitations

While we found studies from across the world in multiple languages, our search only returned papers in which some component was written in English (e.g. abstract, figure labels, or keywords). As such, some areas of the world may be under-represented. This is a widespread problem for ecological evidence syntheses, as up to half of all non-English scientific papers may be unsearchable using English search terms (Amano et al. 2016). Papers included in the systematic map were in eight languages; English (84%) was the most common, followed by

Dutch (4%), French (4%), German (4%), Japanese (2%), simplified Chinese (2%), Portuguese (1%), and Catalan (1%). Amano et al. (2016) found that the most common languages after English for scientific manuscripts on biodiversity conservation included Spanish, Portuguese, simplified Chinese, and French. We suspect, therefore, that additional information may be found if searches were also conducted for scientific literature in these languages.

Similarly, while gray literature – such as reports or government documents – was not excluded from our search, we did not conduct an exhaustive search for it specifically. Despite these limitations, the use of litsearchr allowed me to conduct a much broader search than would have been possible by traditional methods.

4.4 Conclusions

More quantitative forms of evidence synthesis, such as meta-analyses, should be conducted on the effects of agricultural intensification on the abundance of birds. Significant gaps in knowledge exist, however, for intensification of agricultural wetland crops besides rice and for effects on birds beyond effects on abundance. Further research should be done on bird use of cranberries and taro, which are widespread crops and are likely to provide quality habitat to wetland birds, similar to rice. The creation of this systematic map will allow policy makers to more easily make evidence-based decisions about which management techniques can be used to increase crop production while minimizing harm to birds.

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General Discussion

Flooded agricultural fields have the potential to provide habitat to wetland birds as natural habitat declines. The value of these artificial wetlands, however, is heavily influenced by field management (Fasola and Ruiz 1996, Pierluissi 2010). Understanding which aspects of agricultural management affect birds and how they affect them is critical to balancing bird conservation with achieving food security for a growing population. Overall, I sought to study how conditions in flooded agriculture affect wetland birds. I approached this subject at two scales: a fine scale field study and a global systematic map. The field study was developed to gain insight about the effects of growing season rice management on waterbirds, a topic that is relatively poorly understood compared to the effects of post-harvest management on waterbirds. The global systematic map sought to investigate more broad questions about what is known about birds using all types of flooded agriculture.

Rice is a staple crop for more than 50% of the world's population and is grown on every continent except Antarctica (Van Nguyen and Ferrero 2006, FAOSTAT 2017), making it a promising source of artificial habitat for wetland birds. To better understand how management of rice fields affect birds during the growing season, I looked at the abundance and species richness of waterbirds in relation to spatiotemporal variables, daily field conditions, and chemical management variables. While the best supported models I examined showed a strong relationship with water presence, they did not include measures of chemical management. Reducing chemical management through lowering pesticide use or organically managing fields is largely thought to be associated with higher biodiversity and abundance (Chamberlain et al. 2000, Freemark and Kirk 2001, Donald et al. 2001). I did not find evidence to support this idea, which suggests that more research is needed to fully understand what aspects of organic

management cause increases in abundance and biodiversity. Additionally, pesticides are known to have systemic effects on birds, including reproductive harm and death (Flickinger et al. 1980, Parsons et al. 2010, De Almeida and De Almeida 2011). If birds are foraging in high pesticide areas indiscriminately, they may be at higher risk of ingesting pesticides and suffering adverse reactions. Conversely, pesticides used in my study area on conventionally managed fields may not necessarily be more detrimental to birds than pest management tactics used in organic agriculture.

Water management seems to have a strong effect on waterbird use of fields. As predicted, waterbirds were more commonly found and more diverse in flooded fields than in unflooded fields. Birds were much more abundant, however, in fields that were in the process of being reflooded. The value of recently reflooded fields may offset the loss of abundance and diversity seen in dry fields. However, this also suggests that dry-field management of rice – a strategy recommended to grow rice in the face of water scarcity – could be devastating to wetland birds if the value of natural wetlands is not restored.

Agricultural wetlands produce a variety of agricultural products, but crops other than rice are relatively poorly studied. Flooded pastures are the second most studied type of agricultural land used by birds, but they have almost exclusively been examined in Europe and North America. Additionally, we know virtually nothing about bird use of several other crops grown in flooded conditions, such as cranberries, taro, or lotus (Czech and Parsons 2002). A more thorough examination of wetland bird use of all types of agricultural wetlands worldwide is needed to fully understand their value for wetland bird conservation. This is especially true for regions such as Asia which has lost over 80% of its natural wetlands in the last hundred years, but where over 145 million hectares of rice is harvested annually (Davidson 2014, FAOSTAT 2017).

Additionally, most known effects of agricultural intensification are on bird abundance or diversity. While these two metrics are useful, they do not give very much insight into habitat quality (Van Horne 1983). Researching foraging rates and reproductive success will give a more complete view of how valuable these habitats are. Meta-analysis on well researched topics, such as the effect of non-growing season water use on bird abundance, should be conducted to clarify which aspects of intensification are detrimental to bird abundance, and which might have a neutral affect.

Overall, very little is known about the fine-scale spatial use of rice fields and other agricultural wetlands by waterbirds. Determining where waterbirds are foraging during the day and how long they spend in each location could be used to understand the relative importance of agricultural wetlands as habitat compared to other available habitats. Additionally, foraging rates of birds in fields with different types of chemical management could give valuable insight into the habitat quality of fields of differing management regimes.

While sparing land for wildlife may be the ideal strategy to conserve biodiversity, this will be a challenge as habitats like wetlands decline. It is usually assumed that agricultural intensification in all of its forms is bad for wildlife, but agriculture can be intensified in various ways which can affect different taxa differently. Understanding this will be key in maximizing the conservation value of agriculture for wildlife.

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