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Can Aquaculture Ponds Be Managed as Foraging Habitats for Overwintering Water Birds? An Experimental Approach

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Received: 16 November 2020; Accepted: 7 December 2020; Published: 10 December 2020

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Abstract: Coastal wetlands have been gradually developed by aquaculture and other anthropogenic infrastructure, reducing the habitat for water birds. The traditional operation of shallow-pond milkfish (*Chanos chanos*) aquaculture in Taiwan may provide a model for aquaculture production that operates in harmony with overwintering water birds. The goal of this study was to test whether experimental water drawdown of aquaculture ponds, following the seasonal, traditional milkfish aquaculture, can create resource pulses that attract water birds in Tainan City in southern Taiwan. This experiment tested four types of aquaculture with potential for application: wild fish, no-feed tilapia, milkfish, and tilapia with feed. Ponds were surveyed every other day for water depth and water birds at least 37 times in four winters after water drawdown. In general, drawdown ponds created resource pulses that attracted higher feeding bird densities and numbers of species than control ponds in all aquaculture types. Milkfish ponds often had higher water birds in each year. Deep waders were sometimes the most abundant guild in the control, whereas shorebirds, shallow and deep waders were often higher in the drawdown treatment. Bird densities and numbers of species were correlated with water level, benthic biomass and water Chl *a*, but not with tilapia biomass. Species, such as Black-faced Spoonbills (*Platalea minor*), responded to water levels with the exception of Little Egrets (*Egretta garzetta*). The operation of seasonal, traditional shallow-pond milkfish aquaculture is suitable for foraging of water birds during the winter migratory bird season.

Keywords: aquaculture; Black-faced Spoonbill; drawdown; resource pulse; foraging habitat; shallow-pond milkfish aquaculture; water bird

1. Introduction

Coastal development, including aquaculture and mariculture development, has significantly changed wetland ecosystems around the world, consequently reducing habitats and affecting biotic communities [1–4]. Migratory water birds, relying on coastal wetlands, are among the most vulnerable groups of organisms in coastal areas and have continuously declined in numbers of species on the East Asian—Australasian Flyway [5,6]. To resolve conflicts between food production and biodiversity, the Convention of Biological Diversity declared that Satoyama landscapes are effective for keeping production in harmony with nature [7]. Many examples of traditional agriculture systems around the world not only provide food products but also maintain diverse landscapes and biodiversity [8,9]. Few examples, however, are present in the coastal aquacultural areas [10]. To facilitate the harmony between aquaculture and water birds, we need to find traditional and/or innovative solutions before formulating conservation policy.

In Southeast Asia, the alternate timing of fish cultivation and non-cultivation periods of traditional shallow-pond milkfish (*Chanos chanos*) aquaculture may help conserve migratory overwintering water birds. This 400-year traditional approach in Taiwan is gradually being replaced by either deep-pond aquaculture or common orient clam (*Meretrix lusoria*) aquaculture [11,12]. Traditionally, milkfish is cultivated from April through October because it is a tropical fish [13]. From November through the next March, the overwintering period of migratory water birds, ponds are exposed to drying and re-watering cycles in Taiwan [13]. During the drying phase, water birds can access these ponds and feed. About half the population of the endangered Black-faced Spoonbill (*Platalea minor*) [14] overwinters in Tainan city and its surroundings on the East Asian—Australasian Flyway [12,15]. This traditional operation of shallow ponds by milkfish aquaculture may serve as a conservation approach for migratory water birds, such as Black-faced Spoonbills, and can be used to restore a Satoumi aquaculture landscape (a coastal Satoyama) [16]. Experimental evidence of this operation, however, was lacking. This experiment adopted seasonality and operation of traditional milkfish aquaculture as guidelines to apply on different types of aquaculture.

Water bird usage of aquaculture ponds may be different from their usage in natural wetlands. In wetlands, size, water depth, and isolation are important factors affecting water bird usage of wetlands [17–19]. Shallow water depth usually attracts more species [17,20], whereas larger sized wetlands can have more types of species and higher densities [19,20]. Aquaculture ponds differ from wetlands in feed supply, topography, human activity and vegetation management. Whether the aforementioned factors are applicable to aquaculture ponds is not clear because there are few studies focusing on the ecology of water birds in aquaculture ponds. Abandoned aquaculture ponds, however, may be more similar to natural wetlands than production aquaculture, and may have similar usage of water birds to natural wetlands.

Food abundance also affects the habitat usage of water birds [21]. When reduced water in dry seasons forces concentrated prey densities as observed in the Everglades swamp (USA), these abundant accessible foods attract feeding of water birds [22]. This phenomenon, called resource pulse, is important to nutrition and reproduction of water birds [23,24]. Drawdown of aquaculture ponds may also create a resource pulse [25] because it can concentrate prey and make prey more vulnerable to predation, as in the natural wetlands. This resource pulse is an important food source for water birds in the Florida Everglades [22,26] and may also be an important food source for overwintering migratory water birds in coastal areas of Taiwan and adjacent regions. However, few studies have tested whether resource pulses created by water drawdown can attract water birds in different types of aquaculture.

With increasing demand for aquaculture production [27], reduced habitats in coastal areas are envisioned for water birds, especially migrants. Thus, we applied the operational seasonality of traditional shallow-pond milkfish aquaculture as a guideline for this aquaculture experiment. We tested the following hypotheses: (1) whether experimental water drawdown of aquaculture ponds that created a resource pulse of food concentration could increase feeding usage of water birds; (2) whether water birds responded differently to different types of aquaculture; (3) whether the usage patterns of water birds are related to food abundance. We also examined responses of guilds of water birds in abundance and numbers of species and evaluated the relationships between water depths and bird guilds and selected bird species. We predicted that water drawdown would increase water bird densities and the numbers of different species because prey would be concentrated and become more vulnerable to predation, which is a resource pulse that attracts usage by water birds. We also predicted that guilds of water birds would respond differently in control and drawdown because of the different requirements of water birds. In addition, water birds would positively respond to food abundance in general. Results of this study may demonstrate that the operation of aquaculture ponds following this seasonality can serve as a way to conserve migratory water birds in subtropical/tropical regions while maintaining fish production.

2. Materials and Methods

2.1. Study Area

The study area is located in the Cigu region of Tainan City, southern Taiwan. This area harbors the estuary of Tzeng-Wen creek and the Black-faced Spoonbill protection area (Figure 1). The regional weather is subtropical. The average monthly temperature is highest in July (27.8 ± 0.6 °C; 2011–2016 data of the Cigu weather station of the Central Weather Bureau of Taiwan) and the lowest is in January (17.1 ± 0.9 °C). The wet season usually lasts from April through September in this part of Taiwan, whereas the dry season extends from October to March. The study area is on the East Asia-Australasian migratory flyway [28]. Migratory birds, including Black-faced Spoonbill, Pied avocet (*Recurvirostra avosetta*), Red-necked Stint (*Calidris ruficollis*) and Eurasian Wigeon (*Anas penelope*), overwinter in this area from September through the next April [29].

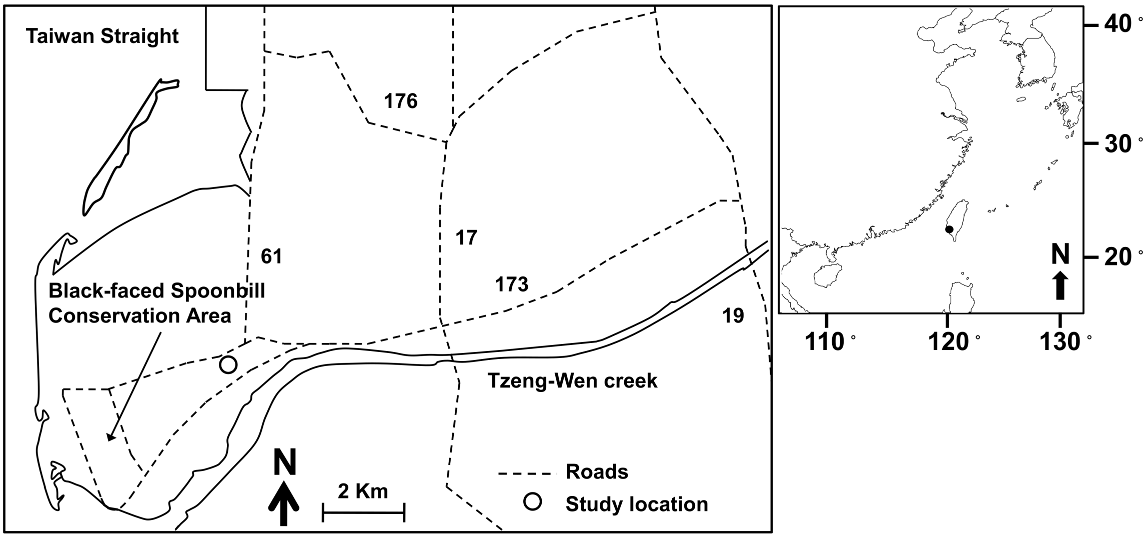

Figure 1. The study location is in the Cigu region of Tainan City, Taiwan.

The studied aquaculture ponds are in the western section of the Cigu campus of the National University of Tainan. The western section of the Cigu campus at about 80 ha is mostly wetlands that were restored from aquaculture ponds by removing banks and reconnecting ponds to tidal canals. The studied aquaculture ponds had relatively intact earthen banks and were rehabilitated for aquaculture functions before this experiment. The water sources of these ponds were from the tidal canals and rainfall. The water in tidal canals had to be pumped into aquaculture ponds because these ponds were disconnected to canals by banks.

2.2. Experiments

In this experiment, we controlled for 2 variables: water-level manipulation and aquaculture type. The experiment had four types of aquaculture: abandoned pond with wild fish (type A), no-feed tilapia (type B), milk fish with feed (type C) and tilapia with feed (type D). The two ponds in each group were side-by-side and similar in size. The areas of ponds A1, A2, B1, B2, C1, C2, D1 and D2 were 5.09, 4.95, 5.47, 5.09, 14.35, 18.6, 7.56 and 7.82 ha, respectively. Abandoned ponds, which are scattered in the region, have the potential to cultivate wild fish or tilapia for water bird usage and to serve as a roosting habitat. Invasive tilapia, which is widely cultivated in this region, is prevalent in canals of this region [30]. Though feeding water birds with tilapia is an aggressive conservation method, this may be necessary when conserved populations are under a major threat [31]. Shallow pan milk fish ponds often have large areas in this region. Following the seasonality of shallow-pond milkfish cultivation, we cultivated these four types of aquaculture ponds, but only harvested milkfish around the end of

October. Fish feed contained only grain protein and had no protein from the ocean bottom trawl. This experiment was conducted from October to January during the years 2012 to 2015. After milk fish harvest, we started the water-level manipulation, which involved drawdown and control.

The number of tilapia and benthic organisms in ponds, which are food sources for water birds, were estimated before drawdown. Tilapia populations were estimated by using mark-recapture. Captured tilapia were weighed and measured in length. Population estimation used the bias-adjusted Lincoln–Peterson estimator [32]. The number of benthic organisms, including fish, shrimps, snails and crabs, was estimated with a bottom trawl. This trawl had a trawling width of 2.6 m and a mesh size of 0.7 cm. We pulled the trawl net for 10 m to make a sampling area of 26 m^2. We separated organisms into fish, shrimp and crab as well as snail groups, absorbed their water with towels and weighed them. We then estimated the total benthic animal biomass in each pond based on the trawling data and the area ratio (pond area/trawl area).

After the milkfish harvest, we left the remaining organisms in ponds. We started drawdown for only 1 pond in each type. When the average water level of the pond reached 20 cm, we stopped drawdown. The 2nd pond usually had a water depth of above 60 cm. Water in ponds would gradually dry out depending on weather conditions, such as rain, wind and humidity. After the 1st drawdown, we waited at least 20 days before the 2nd drawdown of the 2nd pond to a 20 cm depth because the evaporation rate was around 1 cm per day. Water meters were set-up at the positions of average depths in ponds, usually close to the center of ponds. The shape of each pond was like a shallow dish with a relatively flat bottom and gradually elevating ground around edges. Depths of ponds were calculated from measurements along X-shaped transects for each pond before drawdown. Water depth of each ponds was recorded to the nearest 5 cm mark during every bird survey.

The bird survey for each pond was conducted every other day after drawdown began. The survey started at about 6 a.m. and lasted 2 to 3 h. Ponds were generally not affected by tides because banks were large and were much higher than high tide flows. We recorded numbers and species of water birds inside banks of each pond. The number of surveys was 37 times for 2012, 50 times for 2013 and 2014 and 40 times for 2015. The survey durations were from November to the next January.

2.3. Data Analysis

Foraging guilds of water bird were assigned in accordance with Ma et al. [18] and our observations [30] (Table 1). Common Greenshank (*Tringa nebularia*), Common Redshank (*Tringa tetanus*) and Marsh Sandpiper (*Tringa stagnatilis*), commonly assigned as shorebirds, were classified as shallow waders because they use shallow water rather than mudflats in our observations. We separated long-legged waders from waders as deep waders because they were often observed in deeper waters. Based on the evaluation of the International Union for Conservation of Nature, the Red-necked Stint is near threatened and the Black-faced Spoonbill is endangered.

We evaluated foraging guilds by comparing densities and the number of species in each foraging guild in different water depth ranges (≤5, >5 to ≤20, >20 to ≤40 and >40 cm) with one-way analysis of variance (ANOVA) in each aquaculture type. These data were from this experiment and were log-transformed to reach normality. For all cases, the assumption of homogeneity of variance of variables was violated; therefore, Welch's statistics were adopted [33]. When ANOVA reached significance using Welch's statistics, we used the Games-Howell multiple comparison to separate groups of means [33]. For statistical analyses, we used SPSS 21.0 (IBMTM, Armonk, NY, USA).

To compare the effects of drawdown, aquaculture type as well as the year on density and number of species, we used three-way ANOVA to test these variables and interactions among them with 4-year data. We used Duncan tests for post-hoc analyses. These water bird data were from 10 consecutive surveys after the water level of the drawdown ponds reached 20 cm. We used data from this period because it represented higher usage by water birds. For results with interaction effects, we first analyzed effects of the aquaculture type and water level on densities and the numbers of species for each year with two-way ANOVA. Then, we compared densities and numbers of species of different types in the control and drawdown separately in each year with one-way ANOVA. Additionally, we analyzed effects of water level treatment for each aquaculture type in each year with one-way ANOVA. Densities were log(x + 1) transformed.

Table 1. Water bird species recorded in the experiment and guild assignments.

Shorebirds	Shallow Waders	Deep Waders	Ducks	Other Water Birds
Ixobrychus cinnamomeus (Cinnamon Bittern)	*Mesophoyx intermedia* (Intermediate Egret)	*Ardea cinereal* (Grey Heron)	*Anas acuta* (Northern Pintail)	*Alcedo atthis* (Common Kingfisher)
Ixobrychus sinensis (Yellow Bittern)	*Egretta garzetta* (Little Egret)	*Ardea purpurea* (Purple Heron)	*Anas clypeata* (Northern Shoveler)	*Chlidonias hybrida* (Whiskered Tern)
Nycticorax nycticora (Black-crowned Night-Heron)	*Recurvirostra avosetta* (Pied Avocet)	*Ardea alba* (Great Egret)	*Anas crecca* (Green-winged Teal)	*Sternula albifrons* (Little Tern)
Charadrius alexandrines (Kentish Plover)	*Tringa tetanus* (Common Redshank)	*Himantopus himantopus* (Black-winged Stilt)	*Anas penelope* (Eurasian Wigeon)	*Chlidonias leucopterus* (White-winged Tern)
Charadrius dubius (Little Ringed Plover)	*Tringa nebularia* (Common Greenshank)		*Anas platyrhynchos* (Mallard)	*Tachybaptus ruficollis* (Little Grebe)
Pluvialis fulva (Pacific Golden-Plover)	*Tringa stagnatilis* (Marsh Sandpiper)			*Gallinula chloropus* (Eurasian Moorhen)
Actitis hypoleucos (Common Sandpiper)	*Threskiornis aethiopicus*(Sacred Ibis)			*Fulica atra* (Eurasian Coot)
Calidris alpine (Dunlin)	*Platalea minor* (Black-faced Spoonbill)			
Calidris ruficollis (Red-necked Stint)				
Tringa glareola (Wood Sandpiper)				

To assess responses of guilds to water-level and aquaculture types, we also used 3-way ANOVA to test the effects of guild, aquaculture type and water levels on density and the number of species in the data for each year. We also used Duncan tests for post-hoc analyses. For results with interaction effects, we first analyzed the effects of guilds and water levels on densities and numbers of species for each aquaculture types in each year with two-way ANOVA. Then, we compared densities and numbers of species of different guilds in the control and drawdown separately for each aquaculture type with one-way ANOVA. Additionally, we analyzed the effects of water level treatment in each bird guild for each aquaculture type with one-way ANOVA.

To understand factors related to bird density and number of species, we examined correlations among density, the number of species, bird guild, trawl biomass (including fish, shrimp and crab as well as snail separately) and pond area with Spearman rank analysis. Data of bird density and number of species were also from the same 10 consecutive surveys, because this period of concentrated usage may have a higher potential to respond to associated factors.

In addition, we compared densities of selected species among water depth ranges with one-way ANOVA. The selected species were Black-faced Spoonbills, Great Egrets, Little Egrets, Black-winged Stilts, Dunlins and Kentish Plovers, which represented the deep wader, shallow wader and shorebird guilds and had higher abundance than others in their respective guilds.

3. Results

3.1. Water Bird Guilds among Water Depths

Over the 4 years, densities and numbers of species of shorebirds, shallow, deep waders and ducks differed among water depth ranges in different aquaculture types, whereas other water birds were higher in water depth ranges >5 cm, but only in milkfish ponds (Table 2). Shorebirds, shallows and deep waders generally were higher in depth ranges of ≤40 cm, whereas ducks were higher in depth ranges of >5 cm.

3.2. Effects of Water-Level, Aquaculture Type, Year, and Guild on Water Bird Densities and Numbers of Species

Over 4 years, drawdown treatment had higher densities of water birds, and the 4th year (2015) had the highest densities (Table 3). All interactions, however, were significant except for the year and aquaculture type. Further examinations showed that aquaculture types differed in bird densities in the control except in year 2 and year 4 and differed in bird densities in the drawdown treatment in 4 years, with milk fish as the consistent higher type except in year 2 (Appendix A). Compared to the control, bird densities of aquaculture types in the drawdown treatment were higher over the 4 years except no-feed tilapia in the 1st year and milk fish in the 4th year. Statistical results for the number of species were very similar to densities, and thus are not described again.

The 1st year results showed that shallow and deep waders, milkfish ponds and drawdown ponds had higher densities than other treatments in their respective variables (Table 4). All interactions, however, were significant. Further examinations showed that guild and drawdown had significant interactions in all aquaculture types except for wild fish (Appendix B). Densities of bird guilds differed in all aquaculture types in the control except for tilapia with feed and differed across all types in the drawdown treatment. Deep waders were often the most abundant among guilds in the control, whereas shallow and deep waders were often more abundant among guilds in the drawdown treatment. Bird guilds varied in their responses to the water-level variable in aquaculture types. Shallow and deep waders often significantly increased, whereas ducks did not differ in any aquaculture type.

The 2nd year results showed that shorebirds, shallow and deep waders, wild fish and tilapia with feed types as well as drawdown treatment had higher densities than other treatments in their respective variables (Table 4). All interactions, however, were significant. Further examinations showed that the guild and water-level had significant interactions with all aquaculture types except for wild fish. Bird guilds did not differ in aquaculture types in the control but differed across all types in the drawdown treatment. Shorebirds, as well as shallow and deep waders were often higher in the drawdown treatment. Responses of bird guilds varied in the water-level variable in aquaculture types. Responses of bird guilds differed in the water-level variable. Shorebirds had significant responses to the water-level variable involving no-feed tilapia and milkfish, whereas shallow and deep waders responded more to no-feed tilapia and tilapia with feed.

The 3rd year results showed that shallow and deep waders and drawdown ponds had higher densities than other treatments in their respective variables (Table 4). All interactions were significant except for guild and aquaculture types. Further examinations showed that guild and drawdown had significant interactions with all of the aquaculture types except for tilapia with feed. Bird guilds in the control did not differ for any aquaculture types except for tilapia with feed, but did differ for all types in the drawdown treatment. Shorebirds as well as shallow and deep waders were generally higher in the drawdown treatment in aquaculture types. Responses of bird guilds varied with the water-level variable in aquaculture types. Densities of shorebirds were significant in aquaculture types in the water-level variable, whereas shallow and deep waders also responded to different aquaculture types except for tilapia with feed.

Table 2. Densities and numbers of species of water bird guilds in different ranges of water depths in different aquaculture types.

Types	Guilds	df	Welch F	p	Water Depth (cm)			
					≤5	>5–≤20	>20–≤40	>40
Wild fish ponds								
	Density (No./ha)							
	Shorebird	3132.1	6.61	<0.001	0.00 ± 0.00 ^{b}	0.30 ± 0.08 ^{a}	0.70 ± 0.40 ^{ab}	0.04 ± 0.04 ^{b}
	Shallow	3112.3	5.0	0.003	21.95 ± 14.52 ^{ab}	7.90 ± 2.00 ^{a}	1.51 ± 0.25 ^{b}	0.90 ± 0.33 ^{b}
	Deep	3120.3	8.81	<0.001	6.18 ± 1.89 ^{ab}	7.17 ± 1.14 ^{a}	2.24 ± 0.53 ^{b}	1.17 ± 0.55 ^{b}
	Duck	3146.8	6.12	0.001	0.11 ± 0.11 ^{b}	3.22 ± 0.84 ^{a}	0.91 ± 0.32 ^{ab}	0.41 ± 0.41 ^{b}
	Other	3132.7	1	0.394	0.16 ± 0.16	0.32 ± 0.21	0.24 ± 017	0.72 ± 0.28
	No. of species							
	Shorebird	3143.9	4.15	0.007	0.03 ± 0.03 ^{ab}	0.12 ± 0.03 ^{a}	0.15 ± 0.04 ^{a}	0.02 ± 0.02 ^{b}
	Shallow	3110.7	16.62	<0.001	1.17 ± 0.24 ^{a}	1.15 ± 0.09 ^{a}	0.54 ± 0.07 ^{b}	0.32 ± 0.09 ^{b}
	Deep	3109.9	17.86	<0.001	0.89 ± 0.16 ^{a}	1.03 ± 0.07 ^{a}	0.49 ± 0.07 ^{b}	0.30 ± 0.09 ^{b}
	Duck	3140.2	5.03	0.002	0.03 ± 0.03 ^{b}	0.15 ± 0.03 ^{a}	0.10 ± 0.03 ^{ab}	0.02 ± 0.02 ^{b}
	Other	3108.9	1.87	0.138	0.03 ± 0.03	0.05 ± 0.02	0.05 ± 0.02	0.18 ± 0.06
No feed Tilapia								
	Density (No./ha)							
	Shorebird	3189.9	5.92	0.001	1.36 ± 0.43 ^{a}	0.58 ± 0.19 ^{a}	0.04 ± 0.03 ^{b}	Shorebird
	Shallow	3183.2	4.83	0.003	8.73 ± 3.14 ^{ab}	15.85 ± 4.86 ^{a}	1.29 ± 0.22 ^{b}	Shallow
	Deep	3179.0	9.89	<0.001	3.20 ± 0.91 ^{a}	3.86 ± 0.96 ^{a}	1.44 ± 0.24 ^{a}	0.41 ± 0.10 ^{b}
	Duck	3153.1	3.61	0.015	0.10 ± 0.07 ^{b}	2.98 ± 1.05 ^{a}	1.24 ± 0.68 ^{a}	0.00 ± 0.00 ^{b}
	Other	3158.5	2.3	0.079	0.10 ± 0.07	0.31 ± 0.12	0.49 ± 0.16	0.33 ± 0.14
	No. of species							
	Shorebird	3188.3	9.25	<0.001	0.28 ± 0.06 ^{a}	0.17 ± 0.04 ^{a}	0.03 ± 0.02 ^{b}	0.02 ± 0.02 ^{b}
	Shallow	3168.0	12.5	<0.001	1.37 ± 0.14 ^{a}	1.28 ± 0.11 ^{a}	0.60 ± 0.09 ^{b}	0.67 ± 0.14 ^{b}
	Deep	3168.7	8.74	<0.001	0.62 ± 0.10 ^{ab}	0.90 ± 0.08 ^{a}	0.69 ± 0.11 ^{a}	0.31 ± 0.09 ^{b}
	Duck	3172.5	3.42	0.019	0.02 ± 0.02 ^{b}	0.11 ± 0.03 ^{a}	0.09 ± 0.04 ^{ab}	0.00 ± 0.00 ^{b}
	Other	3143.8	6.12	0.001	0.02 ± 0.02 ^{b}	0.10 ± 0.03 ^{ab}	0.21 ± 0.05 ^{a}	0.15 ± 0.06 ^{ab}
Milkfish								
	Density (No./ha)							
	Shorebird	3104.2	24.3	<0.001	3.61 ± 2.27 ^{ab}	10.77 ± 1.39 ^{a}	5.57 ± 1.44 ^{a}	0.16 ± 0.07 ^{b}
	Shallow	3105.8	11.5	<0.001	3.03 ± 1.39 ^{b}	12.43 ± 2.56 ^{a}	14.95 ± 4.16 ^{a}	0.74 ± 0.16 ^{b}
	Deep	3114.4	8.1	<0.001	1.55 ± 0.53 ^{b}	8.31 ± 1.57 ^{a}	4.15 ± 1.93 ^{ab}	1.00 ± 0.16 ^{b}
	Duck	3173.8	3.58	0.015	0.00 ± 0.00 ^{b}	0.20 ± 0.10 ^{ab}	0.34 ± 0.26 ^{ab}	2.61 ± 1.18 ^{a}
	Other	3173.8	7.42	<0.001	0.00 ± 0.00 ^{b}	0.74 ± 0.28 ^{a}	1.24 ± 0.43 ^{a}	0.50 ± 0.19 ^{a}

Table 2. *Cont.*

Types	Guilds	df	Welch F	*p*	Water Depth (cm)			
					≤5	>5–≤20	>20–≤40	>40
	No. of species							
	Shorebird	3116.6	55.46	<0.001	0.50 ± 0.15 [bc]	1.52 ± 0.11 [a]	0.69 ± 0.09 [b]	0.12 ± 0.03 [c]
	Shallow	3126.2	24.24	<0.001	1.37 ± 0.24 [ab]	2.09 ± 0.17 [a]	1.31 ± 0.16 [b]	0.57 ± 0.08 [c]
	Deep	3138.4	8.85	<0.001	0.71 ± 0.15 [b]	1.32 ± 0.11 [a]	0.93 ± 0.11 [ab]	0.64 ± 0.08 [b]
	Duck	3177.5	1.76	0.156	0.00 ± 0.00	0.07 ± 0.03	0.06 ± 0.03	0.13 ± 0.04
	Other	3180.5	5	0.002	0.00 ± 0.00 [b]	0.14 ± 0.04 [ab]	0.19 ± 0.05 [a]	0.15 ± 0.04 [a]
Tilapia with feed								
	Density (No./ha)							
	Shorebird	3141.6	8.72	<0.001	0.59 ± 0.31 [b]	2.28 ± 0.52 [a]	0.301 ± 0.11 [b]	0.04 ± 0.04 [b]
	Shallow	3132.7	7.75	<0.001	9.32 ± 4.40 [a]	4.70 ± 0.83 [ab]	5.71 ± 3.85 [ab]	1.00 ± 0.19 [b]
	Deep	3141.8	14.9	<0.001	4.52 ± 1.16 [a]	3.90 ± 0.50 [a]	2.83 ± 0.90 [ab]	0.76 ± 0.19 [b]
	Duck	3129.9	3.26	0.024	0.10 ± 0.10 [b]	0.48 ± 0.20 [b]	1.83 ± 1.05 [a]	0.00 ± 0.00 [b]
	Other	3172.4	0.83	0.478	0.15 ± 0.10	0.31 ± 0.10	0.57 ± 0.33	0.32 ± 0.16
	No. of species							
	Shorebird	3139.9	13.41	<0.001	0.18 ± 0.06 [ab]	0.35 ± 0.06 [a]	0.11 ± 0.04 [b]	0.01 ± 0.01 [b]
	Shallow	3163.0	19.84	<0.001	1.40 ± 0.16 [a]	1.22 ± 0.10 [ab]	0.86 ± 0.13 [b]	0.43 ± 0.07 [c]
	Deep	3172.1	21.11	<0.001	0.94 ± 0.10 [a]	0.95 ± 0.09 [a]	0.62 ± 0.09 [b]	0.26 ± 0.06 [c]
	Duck	3163.9	3.25	0.023	0.02 ± 0.02 [b]	0.08 ± 0.03 [ab]	0.11 ± 0.04 [a]	0.00 ± 0.00 [b]
	Other	3176.9	0.44	0.723	0.06 ± 0.04	0.12 ± 0.03	0.11 ± 0.04	0.08 ± 0.03

[a], [b], and [c] indicate grouping results of post-hoc comparisons. [ab] indicates that it belongs to both a and b groups.

Table 3. Results of three-way ANOVA on drawdown, aquaculture type and year on water bird density and number of species. Error d.f. s= 288.

Variables	Degree of Freedom	Density		No. of Species	
		F	*p*	F	*p*
Year	3	11.4	<0.001	19.7	<0.001
Type	3	2.3	0.078	13.0	<0.001
Drawdown	1	293.1	<0.001	214.5	<0.001
Year × Type	9	1.8	0.076	2.4	0.13
Year × Drawdown	3	6.4	<0.001	5.9	0.001
Type × Drawdown	3	7.0	<0.001	8.0	<0.001
Year x Type × Drawdown	9	6.4	<0.001	4.4	<0.001

Table 4. Results of 3-way ANOVA on guild, aquaculture type and drawdown on water bird density and the number of species in different years.

Variables	Year 1		Year 2		Year 3		Year 4	
	F	*p*	F	*p*	F	*p*	F	*p*
Density								
Guild	20.4	<0.001	14.4	<0.001	52.2	<0.001	20.0	<0.001
Type	5.9	0.001	4.6	0.004	2.0	0.107	3.4	0.017
Drawdown	77.9	<0.001	29.3	<0.001	129.2	<0.001	70.7	<0.001
Guild × Type	2.2	0.013	2.5	0.003	1.4	0.174	1.2	0.303
Guild × Drawdown	5.0	0.001	7.5	<0.001	15.0	<0.001	10.5	<0.001
Type × Drawdown	7.2	<0.001	8.0	<0.001	9.8	<0.001	1.9	0.13
Guild × Type × Drawdown	2.2	0.011	3.1	<0.001	2.5	0.004	4.8	<0.001
No. of species								
Guild	32.5	<0.001	23.9	<0.001	65.5	<0.001	41.6	<0.001
Type	7.6	<0.001	0.8	0.522	7.8	<0.001	8.3	<0.001
Drawdown	71.0	<0.001	38.0	<0.001	102.7	<0.001	85.5	<0.001
Guild × Type	1.6	0.083	1.9	0.032	1.9	0.035	1.3	0.2
Guild × Drawdown	10.0	<0.001	10.3	<0.001	19.1	<0.001	18.6	<0.001
Type × Drawdown	4.2	0.006	9.5	<0.001	14.4	<0.001	2.7	0.047
Guild × Type × Drawdown	1.5	0.120	3.7	<0.001	4.1	<0.001	3.3	<0.001

Guild d.f. = 4, type d.f. = 3, drawdown d.f. = 1, Error d.f. = 360.

The 4th year results showed that shallow and deep waders, wild fish and milkfish types and drawdown ponds had higher densities than other treatments in their respective variables (Table 4). Guild and water level and all 3 factors had significant interactions. Further examinations showed that the guild and water-level had significant interactions with all of the aquaculture types except for tilapia with feed. Bird guilds in the control differed for milkfish and no-feed tilapia, and also differed in the drawdown treatment of all types. Deep waders were more abundant in the control, whereas shallow and deep waders were generally more abundant in the drawdown treatment in aquaculture types. Responses of the bird guilds varied with the water-level variable in aquaculture types. Densities of shorebirds were only significant in milkfish ponds in the water-level variable. Shallow waders increased in response to the drawdown treatment involving all aquaculture types, whereas deep waders and ducks responded to all types except for tilapia with feed.

3.3. Food Abundance and Water Birds

Bird densities were significantly correlated with snail biomass, trawled biomass and estimated pond biomass based on trawl (Table 5), but were not correlated with estimated tilapia biomass or pond areas. Bird densities were also correlated with shallow waders, deep waders, ducks and other guild densities. Numbers of bird species were significantly correlated with snail biomass, trawled biomass, estimated pond biomass based on trawl, water Chl *a* and pond area, and were negatively correlated with estimated tilapia biomass. Numbers of species were correlated with densities of deep wader and shorebird and bird densities. Deep wader densities were correlated with snail biomass, trawled fish biomass, trawled biomass and estimated pond biomass based on trawl, while shallow wader and shorebird densities had similar correlations. Polychaete densities were not correlated with any variables. In addition, pond Chl *a* was correlated with trawled shrimp and crab biomass, trawled snail biomass, trawled biomass and estimated pond biomass based on trawl, but were negatively correlated with estimated tilapia biomass.

3.4. Densities of Selected Species among Water Depths

Bird species generally responded to water levels (Figure 2). The densities of Great Egrets, Black-winged Stilts, Black-faced Spoonbills, Dunlins and Kentish Plovers were higher at lower water levels (Welch $F_{3,681} = 5.5$, $p = 0.001$; Welch $F_{3,580} = 24.4$, $p < 0.001$; Welch $F_{3,521} = 8.9$, $p < 0.001$; Welch $F_{3,524} = 22.6$, $p < 0.001$; Welch $F_{3,530} = 27.8$, $p < 0.001$; respectively). However, the densities of Little Egret did not differ among depth ranges (Welch $F_{3,641} = 1.1$, $p = 0.341$).

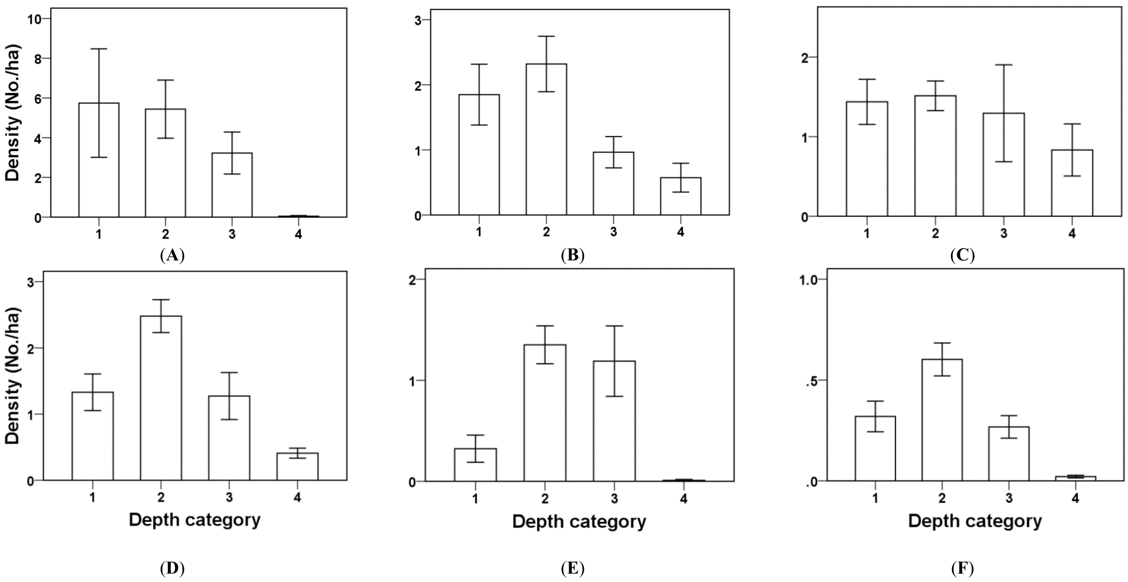

Figure 2. Densities of (**A**) Black-faced spoonbills, (**B**) Great egrets, (**C**) Little egrets, (**D**) Black-winged stilts, (**E**) Dunlins and (**F**) Kentish plovers in different water depth categories in four years of the experiment. Bars represent mean, and upper and lower lines indicate 1 SE. Depth category 1 is ≤5 cm, category 2 is >5 to ≤20 cm, category 3 is >20 to ≤40 cm, and category 4 is >40 cm.

Table 5. Spearman rank correlations among food abundance and water bird variables.

Variables	Density	No. Species	Shorebird	Shallow Wader	Deep Wader	Duck	Other Guild	Area	Trawled Shrimp and Crab	Trawled Snail	Trawled Biomass	Trawl Estimated Total	Estimated *Tilapia* Biomass	Polychaete Density
No. species	0.56 **													
Shorebird		0.59 **												
Shallow wader	0.87 ***													
Deep wader	0.62 **	0.53 **												
Duck	0.49 *													
Other guild	0.54 **			0.60 **										
Area		0.42 *												
Trawled shrimp and crab						−0.44 *		0.58 **						
Trawled snail	0.60 **	0.49 *					0.47 *							
Trawled biomass	0.59 **	0.49 *		0.54 **	0.68 **		0.48 *			0.99 ***				
Trawled estimated total	0.58 **	0.58 **		0.52 *	0.63 **		0.43 *			0.93 ***	0.95 ***			
Estimated *Tilapia* biomass		−0.41 *							−0.491 *					
Chl *a*		0.48 *						0.50 *	0.66 **	0.50 *	0.56 **	0.67 **	−0.48 *	−0.48 *

* denotes $p < 0.05$; ** denotes $p < 0.001$; *** denotes $p < 0.001$.

4. Discussion

4.1. Water Bird Usage of Drawdown Aquaculture Ponds

Wintering migratory water birds responded to water drawdown of aquaculture ponds. Overall, drawdown aquaculture ponds attracted higher densities and numbers of species during 4 years of the experiments. The study ponds had once harbored 18% (454 (the max. no. of 2015)/2511 (the population number from a 2015 global survey [34])) of the Black-faced Spoonbill global population during this experiment. Shorebirds, shallow waders and deep waders commonly responded to the lowered water levels, but ducks and other water birds had a much smaller response. In wetlands, Taft, Colwell, Isola and Safran [17] also showed increases of water bird densities and species richness after drawdown. Among the few examples in aquaculture, Navedo et al. [25] showed that shorebirds took advantage of water-level manipulation after harvests to feed in shrimp ponds in Mexico. On the other hand, flooding can increase species richness and densities of water birds in rice fields [35,36] that would otherwise be completely dry under regular operation during winter. These water level manipulation experiments show that water depth is the main factor that can provide habitats for water birds in aquaculture ponds and agriculture fields [18].

Drawdown of aquaculture ponds can easily attract large numbers of feeding water birds because of the following reasons. Firstly, lower water levels in aquaculture ponds can concentrate fish and shrimps into smaller volumes of water, making them visible and accessible to predation by waders. This resource pulse can be vital for survival and breeding of water birds because their breeding season starts after returning north [21,37]. Secondly, high food abundance and no vegetation cover in aquaculture ponds may lead to a high rate of foraging success, which can attract water birds. These circumstances can also lengthen the stays of water birds, thus making them easily observable by surveyors [38]. In addition, exposed mudflats with ample food can also attract feeding shorebirds.

Drawdown ponds benefited shallow and deep-water waders and shorebirds more than ducks and other water birds. These waders were sensitive to water levels and often appeared in aquaculture ponds where suitable water-levels were reached or abundant foods were observed. Little egrets can play the role of being food scouts for other waders (personal observations). Ponds with aggregations of little egrets would attract other waders, such as the Black-faced Spoonbills. Deep waders sometimes were more commonly found at the control water-level because of their long legs. Shorebirds also responded to our water-level manipulations. When water was drawn down in ponds, patches of mud flat gradually emerged around the periphery because of its higher ground. Shorebirds used these mud flats for feeding in this experiment. In aquaculture ponds, the topography of periphery may affect the environmental usage of water birds, as shown by different aquaculture types. Milkfish ponds often attracted shorebirds because they had mild slopes around their periphery. When water was further lowered to make the dry area, more mud flats were exposed for use by shorebirds. Feaga, Vilella, Kaminski and Davis [39] reported that shorebirds are sensitive to water levels in the Americas. Navedo et al. [25] also found that shorebirds grasped the opportunity of mud flat exposure for feeding in shrimp ponds.

Ducks were adapting to aquaculture operations in this aquaculture area. They are quite sensitive to human activities, and thus preferred wild fish ponds or ponds with less human disturbance [40]. These ponds were not in operation for the short term or are no longer in operation and usually had more vegetation [41]. In this study, duck densities were higher in the drawdown treatment in the 4th year. Ducks, however, got used to utilizing aquaculture ponds after cultivation periods.

Bird densities and numbers of species were related to benthic biomass of aquaculture ponds. Similarly, Gawlik [21] and Herring, Gawlik, Cook and Beerens [37] showed that water birds are sensitive to food densities. Water birds, however, were more sensitive to trawled estimated biomass than Tilapia biomass in this study. There are three possible reasons for this. Firstly, trawled biomass may be a good indicator of overall productivity in these semi-intensive ponds because organic matter eventually deposits in benthic environments and provides food for benthic organisms. Secondly, trawled organisms including snails, shrimps, crabs and gobies are food for both waders and shorebirds, which were higher in densities and compositions among guilds. Thirdly, tilapia was lower in numbers compared to trawled organisms, and their high biomass was contributed to by their relative higher body sizes. Water birds might respond more to high numbers of benthic organisms rather than to those of tilapia. Despite these relationships, drawdown still have strong effects on water birds because lower water depths can constrain food organisms and make them more accessible for water birds.

4.2. Waterbird Conservation

Black-faced Spoonbills may serve as an umbrella species to protect overwintering water birds. Iconic species, such as Black-faced Spoonbills, may attract attention from the public and funding from government agencies [42]. Once a water depth is suitable for Black-faced Spoonbills, it is also suitable for shallow- and deep-water waders. If mud flats are exposed, then shorebirds can benefit too. In this experiment, we could not restrict food access by other birds; Black-faced Spoonbills still needed to compete with other birds for food. As the population of Black-faced Spoonbills recovers [43], it expands its range searching for food and new habitats. Preserving food sources of Black-faced Spoonbills may be necessary, which may also provide food and habitats for many co-occurring water bird species.

The seasonality of traditional shallow-pond milkfish aquaculture can serve as a general guideline for migratory water bird friendly aquaculture, as revealed by results for different types of aquaculture. Conservation policies can have 2 directions to follow this seasonality. The 1st is to sustain a shallow-pond milkfish aquaculture, which can naturally share food with water birds. This approach needs to provide economic incentives to invite farmers to preserve the operation of a shallow-pond milkfish aquaculture. Currently, shallow-pond milkfish aquaculture cultivates fry or smaller fish for angling rather than larger fish because the former provides more economic benefits [44]. Shallow milkfish ponds have been gradually converted into deep-water aquaculture, involving fish types such as grouper and tilapia; these ponds cultivate fish throughout the winter [11,12]. Most milkfish in the market are produced in smaller deep ponds, which also cultivate milkfish all-year round [44]. Economical profitability is essential for these aquaculture farmers [44]. The associated economic incentives may include the secured purchase price and contract or operation subsidy to sustain farmers that are joining this shallow-pond milkfish aquaculture policy approach. An easement approach may also be feasible, with successful examples of the Wetland Reserve Program in the US [45]. When the incomes of these farmers are secured, shallow-pond milkfish aquaculture may be more strongly sustained.

The 2nd approach is to apply this seasonality to other types of aquaculture such as common orient clams. This application involves only lowering the water for a certain period of time rather than ceasing cultivation during the winter migratory water bird period, which is not economically acceptable for many farmers. Aquaculture ponds often have high productivity and abundant food. When the water level is lowered below 20 cm, many organisms become accessible to bird feeding. Proper compensation or subsidy is required for this policy. This policy may also be applied to abandoned ponds, which are good roosting sites for water birds. It is also important to preserve abandoned ponds to avoid them changing into other aquaculture or land use types.

In addition, a public awareness campaign is necessary to promote societal understandings of the risks of water birds on the East Asian - Australasian Flyway [5,6]. Successful communication with aquaculture farmers is essential because they are key stakeholders in pond management. Their understanding and join of conservation programs is a basic stepping stone towards developing a Satoumi landscape. Understanding of this conservation issue by consumers and the actions of consumers are also essential to support these conservation programs. When consumers actively buy Black-faced Spoonbill or water bird friendly products [46,47], more farmers may realize the benefits of conservation programs and obtain additional incentives to join them.

4.3. Recommendations for Operations of Aquaculture Ponds

Water level manipulation of these aquaculture ponds provides accessible feeding habitats for water birds. Our experiences may offer basic guidelines for subtropical and tropical aquaculture regions that are intending to promote coexistence between wintering migratory water birds and aquaculture. We suggest the following operations for aquaculture ponds:

1. The mean water level in ponds may be drawn down to 15 to 20 cm in October or November (after harvest). After reaching the designated water-level, the remaining water will dry out naturally through evaporation. This operational period may provide food energy to arrival wintering migratory birds to balance their expenditure during flight [48,49]. This water manipulation may favor primarily shorebirds and waders. This way, the water level gradually lowers, giving water birds ample time to find and feed on live organisms.
2. After ponds dry out in February, adding water into ponds to a water level from 5 to 15 cm may continue facilitating roosting and feeding habitats for water birds. When no cultivation work was present, water birds may roost in and around ponds without much human interference (As noted by Wang's personal observation). Adding water from tidal canals into ponds may supply shrimps, crabs, fish and worms as new food sources. These operations may sustain migratory water bird populations through the spring.
3. Overwintering water birds may need to store energy in the spring before flying back. To provide more food for water birds during spring, ponds may sustain a high water-level during winter, then drawdown around March. Aquatic organisms, however, that are overwintering through March may have the risk of death because of low temperatures. This timing of drawdown can balance the need for water bird feeding and the time requirement for pond preparation before cultivation. This way, farmers can start cultivating fish in April or May, which leaves enough time for fish growth in the warm seasons.

5. Conclusions

This study provides results of benefits of the seasonality of shallow-pond milkfish aquaculture for winter migratory water birds on the East Asian—Australasian Flyway. All types of aquaculture, densities and numbers of species of waders and shorebirds were much higher in these shallow drawdown ponds than in the control ponds. Densities and numbers of species of water birds increased with trawled estimated benthic biomass. The numbers for most selected waterbird species, such as Black-faced Spoonbills, also increased with lower water depths. Other areas may deserve further investigations. These include the effects of drawdown speeds on usage of water birds, waterbird usage of drawdown ponds in different seasons and whether maintaining constant low water levels can maximize Black-faced Spoonbill usage of ponds.

The results of our study provide a potential direction for managing a coastal landscape with harmony between aquaculture and water birds [7]. We suggest the seasonality of shallow-pond milkfish aquaculture as a guideline for achieving this goal. Conservation policies and programs may use economic incentives to sustain water bird-friendly aquaculture. The involvement of stakeholder farmers is essential for creating a Satoumi landscape. Lastly, a public awareness campaign to encourage consumer involvement is also important.

Author Contributions: Y.-K.W. contributed to the conceptualization, methodology, project administration, data analysis and writing of this manuscript. C.-C.L. contributed to the methodology and investigation. K.-Y.H. and C.-C.T. contributed to the conceptualization, supervision, resources and project administration. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Taijiang National Park Headquarter.

Acknowledgments: We thank funding support by the Taijiang National Park Headquarters. We thank Chilin Chen, Kuoshin Wang, Yungfong Huang for bird surveys and Reylin Guo, Ronkai Su, Tinhow Guo, Chiatse Li, Zusheng Huang, Yuneping Yang, Yishiang Lin, Tzeyun Lin, Shanen Peng, Mingyi Han and Hsianghow Chiu for field and lab assistance. We also thank Hans U. Dahms and Cara Lin Bridgman for the comments they provided.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Results of statistical analyses for understanding three-way interactions of year, aquaculture type, and water-level on water bird densities.

Variables	Year 1		Year 2		Year 3		Year 4	
	F	*p*	F	*p*	F	*p*	F	*p*
Aquaculture type	1.98	0.125	1.26	0.293	0.63	0.6	2.97	0.038
Water-level	15.58	<0.001	107.47	<0.001	110.57	<0.001	65.11	<0.001
Aquaculture type * Water-level	13.20	<0.001	1.68	0.179	6.93	<0.001	3.54	0.019
Water-level								
Water-level = control								
Aquaculture type	6.41	0.001	0.86	0.472	2.31	0.093	3.40	0.028
Water-level = drawdown								
Aquaculture type	8.53	<0.001	1.60	0.207	6.87	0.001	3.06	0.04
Aquaculture type								
Type = Wild fish								
Water-level	10.56	0.004	19.68	<0.001	14.69	0.001	35.53	<0.001
Type = No feed tilapia								
Water-level	0.70	0.415	85.92	<0.001	34.99	<0.001	27.81	<0.001
Type = Milkfish								
Water-level	32.63	<0.001	11.93	0.003	87.03	<0.001	2.44	0.136
Type = Tilapia with feed								
Water-level	10.16	0.005	27.19	<0.001	5.80	0.027	18.70	<0.001

Two-way ANOVA d.f. = 3 (type), 1 (water-level), 3 (type X water-level), 72 (error); water-level d.f. = 3 (type), 36; aquaculture type d.f. = 1 (water-level), 18. * indicates an interaction effect; for example, Guild * Water-level represents the interaction between guild and water-level.

Table A2. Results of statistical analyses for understanding three-way interactions of year, aquaculture type, and water-level on numbers of species.

Variables	Year 1		Year 2		Year 3		Year 4	
	F	*p*	F	*p*	F	*p*	F	*p*
Aquaculture type	5.27	0.002	0.51	0.678	6.01	0.001	6.09	0.001
Water-level	49.35	<0.001	25.68	<0.001	79.17	<0.001	63.10	<0.001
Aquaculture type * Water-level	2.92	0.04	6.42	0.001	11.09	<0.001	1.97	0.125
Water-level								
Water-level = control								
Aquaculture type	0.86	0.47	6.39	0.001	8.23	<0.001	1.45	0.245
Water-level = drawdown								
Aquaculture type	4.85	0.006	1.70	0.184	8.66	<0.001	5.44	0.003
Aquaculture type								
Type = Wild fish								
Water-level	13.31	0.002	0.76	0.395	55.81	<0.001	18.29	<0.001
Type = No feed tilapia								
Water-level	2.22	0.154	51.27	<0.001	22.18	<0.001	18.47	<0.001
Type = Milkfish								
Water-level	21.39	<0.001	7.52	0.013	35.66	<0.001	23.48	<0.001
Type = Tilapia with feed								
Water-level	17.09	0.001	14.64	0.001	0.16	0.694	5.44	0.032

Two-way ANOVA d.f. = 3 (type), 1 (water-level), 3 (type X water-level), 72 (error); water-level d.f. = 3 (type), 36; aquaculture type d.f. = 1 (water-level), 18. * indicates an interaction effect.

Appendix B

Table A3. Results of statistical analyses for understanding three-way interactions of year, guild, and water-level on water bird densities.

Variables	Wild Fish		No-feed Tilapia		Milk Fish		Tilapia with Feed	
	F	*p*	F	*p*	F	*p*	F	*p*
Year 1								
Guild	4.25	0.003	10.82	<0.001	6.64	<0.001	8.18	<0.001
Water-level	13.79	<0.001	2.92	0.091	43.76	<0.001	24.61	<0.001
Guild * Water-level	2.25	0.07	2.89	0.027	3.19	0.017	3.6	0.009
Water-level								
Water-level = Control								
Guild	3.14	0.023	6.74	<0.001	4.79	0.003	2.28	0.075
Water-level = Water-level								
Guild	3.28	0.019	6.92	<0.001	4.93	0.002	7.05	<0.001
Guild								
Guild = Shorebirds								
Water-level	2.16	0.159	NA		21.07	<0.001	2.33	0.144
Guild = Shallow waders								
Water-level	7.54	0.013	0.11	0.919	14.13	0.001	10.33	0.005
Guild = Deep waders								
Water-level	4.23	0.054	9.89	0.006	8.52	0.009	11.27	0.004
Guild = Ducks								
Water-level	3.83	0.066	NA		4.2	0.055	1	0.331
Guild = Other								
Water-level	3.6	0.074	0.02	0.889	1.74	0.204	5.98	0.025
Year 2								
Guild	3.91	0.006	7.88	<0.001	5.71	<0.001	7.77	<0.001
Water-level	0.59	0.446	40.29	<0.001	9.95	0.002	25.6	<0.001
Guild * Water-level	1.33	0.267	7.61	<0.001	5.46	0.001	8.23	<0.001
Water-level								
Water-level = Control								
Guild	2.16	0.088	1	0.418	0.55	0.702	1	0.418
Water-level = Water-level								
Guild	3.08	0.025	7.96	<0.001	6.4	<0.001	8.18	<0.001
Guild								
Guild = Shorebirds								
Water-level	1.65	0.215	8.05	0.011	12.6	0.002	0.4	0.535
Guild = Shallow waders								
Water-level	0.54	0.473	71.26	<0.001	0.97	0.337	18.56	<0.001
Guild = Deep waders								
Water-level	0.37	0.55	10.11	0.005	0.75	0.397	11.7	0.003
Guild = Ducks								
Water-level	3.57	0.075	NA		1	0.331	NA	
Guild = Other			NA		NA			
Water-level	1	0.331					NA	
Year 3								
Guild	18.69	<0.001	8.38	<0.001	10.8	<0.001	23.25	<0.001
Water-level	34.33	<0.001	32.13	<0.001	69.41	<0.001	4.49	0.037
Guild * Water-level	6.69	<0.001	5.07	0.001	7.68	<0.001	1.41	0.237
Water-level split								
Water-level = Control								
Guild	2.43	0.061	1.61	0.189	1.81	0.144	39.54	<0.001
Water-level = Water-level								
Guild	19.62	<0.001	8.22	<0.001	10.16	<0.001	7.04	<0.001

Table A3. *Cont.*

Variables	Wild Fish		No-feed Tilapia		Milk Fish		Tilapia with Feed	
	F	p	F	p	F	p	F	p
Guild split								
Guild = Shorebirds								
Water-level	5.16	0.036	15.83	0.001	18.69	<0.001	7.47	0.014
Guild = Shallow waders								
Water-level	12.17	0.003	13.34	0.002	33.33	<0.001	0.89	0.359
Guild = Deep waders								
Water-level	15.15	0.001	4.88	0.04	18.81	<0.001	0	0.987
Guild = Ducks								
Water-level	NA		NA		1	0.331	1	0.331
Guild = Other								
Water-level	2.25	0.151	0.61	0.445	2.87	0.107	0.09	0.763
Year 4								
Guild	9.85	<0.001	11.03	<0.001	1.84	0.128	3.48	0.011
Water-level	31.03	<0.001	31.99	<0.001	12.29	0.001	7.05	0.009
Guild * Water-level	7.27	<0.001	5.45	0.001	9.37	<0.001	1.67	0.164
Water-level split								
Water-level = Control								
Guild	2.4	0.064	2.6	0.048	3.96	0.008	0.66	0.623
Water-level = Water-level								
Guild	10.31	<0.001	10.74	<0.001	6.88	<0.001	3.44	0.016
Guild split								
Guild = Shorebirds								
Water-level	1	0.331	2.15	0.16	37.15	<0.001	0	0.987
Guild = Shallow waders								
Water-level	13.31	0.002	9.73	0.006	13.29	0.002	8.86	0.008
Guild = Deep waders								
Water-level	15.15	0.001	11.05	0.004	6.43	0.021	2.9	0.106
Guild = Ducks								
Water-level	11.39	0.003	16.66	0.001	7.52	0.013	0.8	0.384
Guild = Other								
Water-level	2.29	0.148	1	0.331	1.01	0.328	0.05	0.83

Year d.f. = 4, 1, 4, 90; Water-level d.f. = 4, 45; Guild d.f. = 1, 18. * indicates an interaction effect.

Table A4. Results of statistical analyses for understanding three-way interactions of year, guild, and water-level on numbers of species.

Variables	Wild Fish		No-feed Tilapia		Milk Fish		Tilapia with Feed	
	F	p	F	p	F	p	F	p
Year 1								
Guild	7.98	<0.001	7.74	<0.001	10.1	<0.001	10.77	<0.001
Water-level	17.21	<0.001	3.48	0.065	31.43	<0.001	23.92	<0.001
Guild * Water-level	4.09	0.004	2.76	0.032	3.55	0.010	4.13	0.004
Water-level								
Water-level = Control								
Guild	3.32	0.018	4.87	0.002	6.47	<0.001	3.22	0.021
Water-level = Water-level								
Guild	6.48	<0.001	5.38	0.001	6.93	<0.001	8.99	<0.001
Guild								
Guild = Shorebirds								
Water-level	2.25	0.151		NA	21.6	<0.001	3.27	0.087
Guild = Shallow waders								
Water-level	8.02	0.011	0.57	0.459	12.59	0.002	11.56	0.003
Guild = Deep waders								
Water-level	6.69	0.019	8.71	0.009	3.27	0.087	5.89	0.026
Guild = Ducks								
Water-level	3.27	0.087		NA	2.42	0.137	1	0.331
Guild = Other								
Water-level	3.86	0.065	0.60	0.449	1.98	0.177	6.23	0.022

Table A4. *Cont.*

Variables	Wild Fish		No-feed Tilapia		Milk Fish		Tilapia with Feed	
	F	***p***	**F**	***p***	**F**	***p***	**F**	***p***
Year 2								
Guild	5.68	<0.001	9.81	<0.001	5.36	0.001	10.58	<0.001
Water-level	1.26	0.265	45.51	<0.001	11.57	0.001	23.56	<0.001
Guild * Water-level	0.55	0.699	9.10	<0.001	4.07	0.004	11.39	<0.001
Water-level								
Water-level = Control								
Guild	2.09	0.098	1.00	0.418	0.79	0.535	1.00	0.418
Water-level = Water-level								
Guild	4.88	0.002	9.91	<0.001	6.16	<0.001	11.41	<0.001
Guild								
Guild = Shorebirds								
Water-level	1.71	0.207	7.58	0.013	12.81	0.002	0.40	1.000
Guild = Shallow waders								
Water-level	0.00	1.000	40.09	<0.001	1.25	0.279	16.16	0.001
Guild = Deep waders								
Water-level	0.106	0.749	9.93	0.006	2.42	0.137	10.76	0.004
Guild = Ducks								
Water-level	3.86	0.065		NA	1.00	0.331		NA
Guild = Other								
Water-level	1.00	0.331		NA		NA		NA
Year 3								
Guild	20.39	<0.001	8.51	<0.001	16.61	<0.001	30.99	<0.001
Water-level	43.11	<0.001	27.53	<0.001	51.99	<0.001	0.23	0.632
Guild * Water-level	7.21	<0.001	5.46	0.001	11.02	<0.001	3.24	0.016
Water-level								
Water-level = Control								
Guild	3.09	0.025	1.46	0.231	2.54	0.053	31.07	<0.001
Water-level = Water-level								
Guild	18.71	<0.001	7.97	<0.001	17.01	<0.001	10.41	<0.001
Guild								
Guild = Shorebirds								
Water-level	4.37	0.051	11.17	0.004	14.88	0.001	7.23	0.015
Guild = Shallow waders								
Water-level	23.04	<0.001	15.35	0.001	30.76	<0.001	0.24	0.630
Guild = Deep waders								
Water-level	17.31	0.001	3.13	0.094	5.74	0.028	3.90	0.064
Guild = Ducks								
Water-level		NA		NA	1.00	0.331	1.00	0.331
Guild = Other								
Water-level	2.25	0.151	0.36	0.556	2.46	0.135	0.00	1.000
Year 4								
Guild	13.49	<0.001	14.04	<0.001	10.76	0.001	7.46	<0.001
Water-level	24.65	<0.001	28.49	<0.001	28.94	<0.001	7.73	0.007
Guild * Water-level	6.42	<0.001	5.29	0.001	10.89	<0.001	3.28	0.015
Water-level								
Water-level = Control								
Guild	3.11	0.024	2.71	0.042	2.83	0.035	1.52	0.214
Water-level = Water-level								
Guild	11.62	<0.001	13.52	<0.001	15.32	<0.001	7.59	<0.001
Guild								
Guild = Shorebirds								
Water-level	1.00	0.331	2.25	0.151	32.11	<0.001	0.00	1.000
Guild = Shallow waders								
Water-level	9.52	0.006	7.57	0.013	21.69	<0.001	12.60	0.002
Guild = Deep waders								
Water-level	17.31	0.001	17.89	0.001	4.13	0.057	0.76	0.395
Guild = Ducks								
Water-level	10.76	0.004	14.88	0.001	7.58	0.013	1.20	0.288
Guild = Other								
Water-level	0.60	0.449	1.00	0.331	0.95	0.342	0.00	1.000

Year d.f. = 4, 1, 4, 90; Water-level d.f. = 4, 45; Guild d.f. = 1, 18. * indicates an interaction effect.

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