

Chapter 7

Effectiveness of Wildlife-Friendly Farming on Aquatic Macroinvertebrate Diversity on Sado Island in Japan

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Abstract Paddy fields are important as alternative wetland habitats for a range of aquatic and semi-aquatic wildlife that once inhabited floodplain habitats. However, depopulation and aging in rural communities have led to the loss of biodiversity across rural areas of Japan. In Japan, wildlife-friendly farming is typically implemented using charismatic wildlife as an icon, and much attention has been given as a means for restoring paddy field biodiversity. Sado Island in central Japan is among the leading areas for such wildlife-friendly farming in terms of the implemented area. Nevertheless, scientific evaluation is largely lacking for the effectiveness of wildlife-friendly farming on paddy field biodiversity. Using four aquatic macroinvertebrate taxa as indicator groups, we surveyed over 300 paddy fields in winter and summer across Sado Island. In winter, although most indicator groups were significantly associated with the percentage of water coverage in paddy fields, winter flooding had limited effects on aquatic macroinvertebrate abundance or richness, because of large variations in water coverage among paddy fields. In contrast, implementing diversion ditches provided additional habitats for aquatic macroinvertebrates that prefer deep-water habitats, resulting in the separation of macroinvertebrate composition between paddy fields and their adjacent ditches in both winter and summer. Furthermore, agrochemical reduction and fallow flooding were effective in enhancing aquatic macroinvertebrate abundance and richness in summer. Overall, diverse practices of wildlife-friendly farming contributed to the enhancement of aquatic macroinvertebrate diversity on Sado Island.

Keywords Environmentally friendly farming • Paddy field • Rice agriculture • Biodiversity • GIAHS • Ecological restoration • Benthic macroinvertebrate

Introduction

In many lowland areas of Monsoon Asia, natural wetlands have been completely transformed into paddy fields (Donald 2004; Elphick 2000). In such areas, paddy fields are known to serve as alternative wetland habitats, providing refuge and foraging areas for a range of aquatic wildlife that once inhabited natural wetland habitats (Fujioka et al. 2010; Mukai et al. 2005). Owing to high fluctuations in water permanence, paddy fields are generally inhabited or visited by species with a high dispersal rate (e.g., opportunistic species) or those with high resistance to disturbance. Nevertheless, over 5,000 wildlife species, such as birds, amphibians, fish, invertebrates, plants, fungi and viruses have been recorded in or around paddy fields, including red list species (Kiritani 2010). However, biodiversity in human-dominated wetland habitats is threatened in many Asian countries, because of the overuse of agrochemicals (i.e., herbicides, insecticides, fungicides and chemical fertilizers), land consolidation, invasion by nonnative species and changes in management styles over time (Natuhara 2013). Thus, paddy fields that were initially created for rice production are now widely recognized as high-value conservation areas for aquatic and semi-aquatic wildlife (Elphick 2000; Natuhara 2013).

In Japan, the role of paddy fields as alternative wetland habitats has led to considerable attention being given to their restoration, with the implementation of wildlife-friendly farming (Natuhara 2013). Typical wildlife-friendly farming practices include the reduction or omission of agrochemicals, creation of non-crop habitats within or adjacent to paddy fields, or implementation of winter flooding. In addition, wildlife-friendly farming is typically implemented using charismatic wildlife as an icon, such as the crested ibis (*Nipponia nippon*), Oriental white stork (*Ciconia boyciana*), or Japanese medaka (*Oryzias*) (Ministry of Agriculture, Forestry and Fisheries of Japan 2010). Biomonitoring has been introduced in many parts of Japan as an incentive to farmers for paddy field restoration. It has been suggested through a nationwide program that the effectiveness of wildlife-friendly farming be monitored using Odonata, Coleoptera/Hemiptera, Anura, Tetragnathidae, and Lycosidae as indicator groups, as these animals are expected to serve as major predators for agricultural pest insects (Ministry of Agriculture, Forestry and Fisheries of Japan 2012). Although these indicator groups were selected on the basis of increases in abundance under a range of wildlife-friendly farming practices across Japanese paddy fields, their responses to specific management practices are largely unknown.

Sado Island in central Japan is among the leading areas for wildlife-friendly farming in terms of the implemented area. The island-wide practice of sustainable, wildlife-friendly farming throughout the human-dominated landscape (i.e., Satoyama) and indigenous culture led to the designation of Sado Island as a Globally-Important Agricultural Heritage System (GIAHS) site in 2011.

In this chapter, we first introduce Sado's rice certification initiative. We subsequently discuss the results of biological surveys conducted in paddy fields across Sado Island. Finally, we propose recommendations and future challenges for wildlife-friendly farming on Sado Island.

***Toki-to kurasu sato dukuri*—Sado's Rice Certification Initiative**

Starting from the fiscal year of 2008, the Sado Municipal Government introduced a rice certification initiative called Toki Brand Rice Certification Initiative, which is known by the local name *Toki-to kurasu sato dukuri*. To be approved by the rice certification initiative, farmers must comply with all of the following: (1) grow Koshihikari rice plants on Sado Island, (2) be approved as an eco-friendly farmer, (3) perform biological surveys twice in the cultivation period (once in June and once in August), (4) apply 50 % or less of the agrochemicals of conventional farming, and (5) implement one of four *Ikimono-wo hagukumu nouhou* or Biodiversity-enhancing practices (hereafter termed BEPs). In Sado's conventional farming, a total of 18 active pesticide (i.e., herbicides, insecticides, and fungicides) compounds and 6 kg/10 a (1,000 m²) of nitrogen fertilizer are applied in the cultivation period from April to September. Under Sado's rice certification initiative, a total of nine active



Fig. 7.1 Biodiversity-enhancing practices (BEPs) of the *Toki-to kurasu sato dukuri* rice certification initiative of the Sado Municipal Government, Japan. Financial incentives are given to farmers in return for implementing one or more BEPs. The subsidies are based on produce for the fiscal year of 2013 (1 yen \approx 0.01 US dollars: (a) Winter flooding (2,000 yen/10 a), (b) Fishway (4,000 yen/1 set), (c) Diversion ditch (3,000 yen/10 a), and (d) Fallow flooding (0 yen/10 a)

pesticide compounds and 3 kg/10 a of nitrogen fertilizers can be used in the cultivation period.

BEPs include the implementation of winter flooding (flooded for a 2-month period between November and February), diversion ditch (locally known by the name *e*) construction within paddy fields along levees, fishways, and fallow flooding (Fig. 7.1). Under Sado's rice certification initiative, fallow flooding qualifies if it is implemented adjacent to a cultivated paddy field, although very few farmers implement such a practice. Nevertheless, some farmers implement fallow flooding instead of cultivating rice, because it is an easy way to suppress weeds during the fallowing period. For fallow flooding, we evaluated its effectiveness on aquatic macroinvertebrate communities in the fallow per se.

Although most farmers implement one of the four BEPs, some farmers implement two or more BEPs at a time in a single paddy field. Upon successful approval, subsidies are given on the basis of the type or combinations (if any) of BEPs. Among the four BEPs, the most common practice is winter flooding, followed by the implementation of a diversion ditch (Fig. 7.2). In contrast to the *Nouchi mizu hozen kanri shiharai koufukin* or Payment for Conserving Farmland and Water by

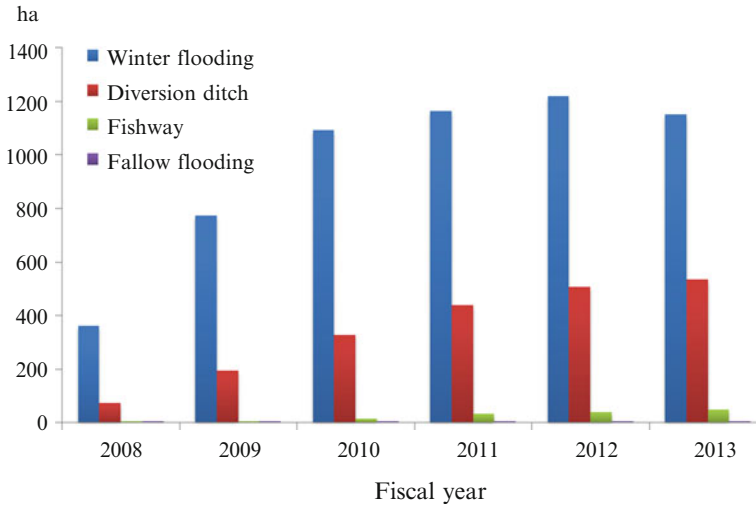


Fig. 7.2 The cultivation areas (ha) for four Biodiversity-enhancing practices (BEPs) on Sado Island. Winter flooding and diversion-ditch implementation are two common BEPs

the Ministry of Agriculture, Forestry and Fisheries of Japan, in which winter flooding typically qualifies only when farmers flood their rice paddy fields to about 15 cm depth to facilitate straw decomposition and to enhance aquatic wildlife, winter flooding under Sado's certification initiative is typically performed with rainwater only. Under Sado's certification initiative, farmers should only intentionally fill ruts from tractors with rainwater (Fig. 7.1a). The reason for keeping the water depth of paddy fields low in winter is that the crested ibis is believed to avoid foraging in deep-water paddy fields in winter, as indicated from empirical evidence of ibis use of wetlands in winter (Colwell and Taft 2000). Thus, the winter flooding practice performed under Sado's rice certification initiative can be considered to be a special type of winter flooding.

The certified *Toki-to kurasu sato* rice or Toki Brand rice is distributed as high value-added rice. At Itoyokado, one of the major supermarkets in Japan, *Toki-to kurasu sato* rice is sold at 2,880 yen (including 5 % tax) (approximately 28.8 US dollars) per 5 kg (as of March 2014), which is 668 yen higher than that of the average Niiigata Koshihikari retailed from February 2013 through January 2014 (2,212 yen (22.1 US dollars) per 5 kg; Ministry of Agriculture, Forestry and Fisheries of Japan 2014).

Indicator Groups

We used four aquatic macroinvertebrate groups (Gastropoda, Heteroptera, Odonata and Coleoptera) to assess the effectiveness of wildlife-friendly farming on biodiversity. These aquatic macroinvertebrate groups have been suggested as indicator groups for biodiversity in lentic habitats (Le Viol et al. 2009; Oertli et al. 2005),

because they (1) represent animal communities in lentic habitats; (2) have different ecological requirements, life cycles, feeding modes and dispersal abilities; (3) respond differently to physicochemical gradients (Bilton et al. 2006; Oertli et al. 2005); and (4) are highly complementary in aquatic macroinvertebrate food webs (Downing 2005). We used the abundance of each taxonomic group and the total family richness of the four taxonomic groups (GHOC richness) as indicators of aquatic macroinvertebrate diversity in paddy fields.

Island-Wide Surveys

We performed aquatic macroinvertebrate surveys at 392 paddy fields in winter (December 2009 to March 2010) and 396 paddy fields in summer (June to July 2010) across Sado Island in central Japan (Fig. 7.3). Owing to overlap with

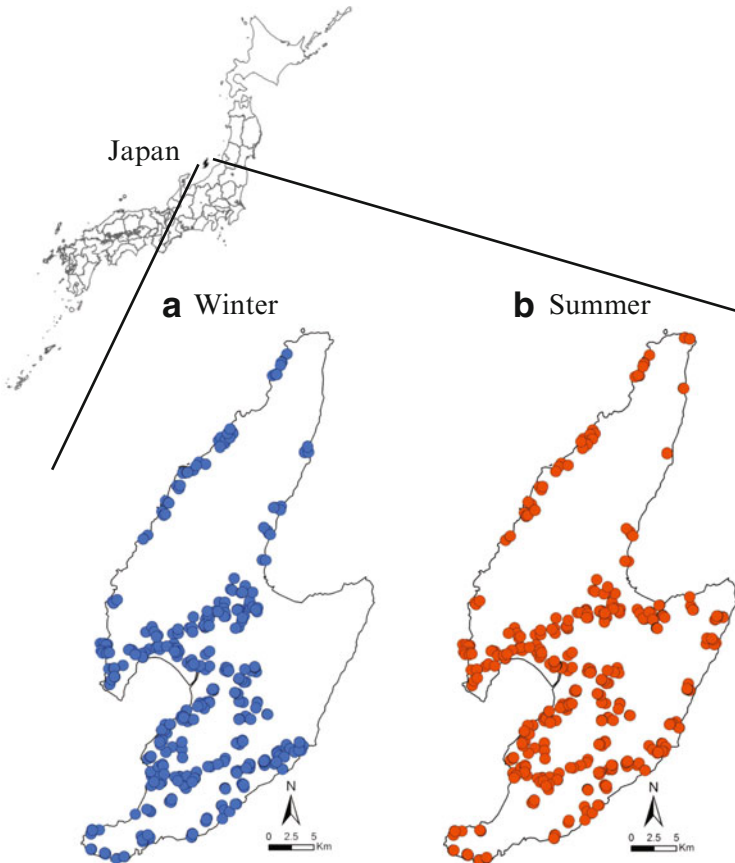


Fig. 7.3 Map of winter (a; N = 392) and summer (b; N = 396) paddy survey sites for aquatic macroinvertebrates on Sado Island

another ongoing survey in paddy fields, the winter survey was not performed in southeastern Sado. In each season, the field surveys were conducted by three or four groups, with each group consisting of staff of an environmental consulting company (Sanwaccon) and two farmer volunteers. The research groups concurrently surveyed different regions of the island. At the time of the study, rice grown under conventional farming could no longer be legally distributed through the Japan Agricultural Cooperatives, and most farmers had reduced agrochemicals by at least 30 % relative to conventional farming. The type of wildlife-friendly farming practice of each paddy field was recorded on the basis of Sado's unpublicized farmland management data and, when available, through direct communications with farmers. The study sites were either dominated by deciduous forests (e.g., *Quercus*) in the mountains, or by paddy fields in the plains.

At each paddy field, we haphazardly sampled two sites each from the long sides and one site each from the short sides of the levee for a total of six sites. Because many farmers are concerned about damage to rice plants from wading inside the paddy fields, we did not perform sampling in the central part of paddy fields.

At each levee side, we placed a water-resistant cardboard quadrat (areas 1 m² in winter and 0.81 m² in summer) below the levee to collect aquatic macroinvertebrates. Two field crews swept the water column and sediments inside the quadrat using D-framed nets (width 20 cm × depth 15 cm, mesh 1 mm) for 5 min. Although some paddy fields had little water in winter, we nevertheless sampled a total of six sites at each paddy field. When a paddy field was associated with a diversion ditch, we sampled three additional quadrat samples from the ditch. In the field, we sorted the net contents from sediments by eye and, when possible, identified Gastropoda, Heteroptera, Odonata, and Coleoptera to the family level with the aid of available keys (Kawai 1985). Owing to financial and time constraints, we did not attempt to identify these aquatic macroinvertebrates to lower taxonomic levels. For Odonata larvae in winter, we grouped the data into the order level, because of logistical problems associated with identification in the field and volunteer training. In the summer survey, we transported all samples to the laboratory for taxonomic identification or confirmation.

The paddy fields examined had a range of farmland management and rice plantation. For the purpose of the present chapter, we used subsets of the datasets that implemented one of the following practices with the Koshihikari strain: reduced inputs of agrochemicals by 30 % (reference sites), reduced inputs of agrochemicals by 50 %, or fallow flooding. Consequently, we used 361 paddy sites from the winter survey and 328 paddy sites from the summer survey for further analyses.

Data Analysis and Statistical Models

Aquatic macroinvertebrate communities are expected to be influenced by both local and landscape variables such as farming practices, the physicochemical environment of paddy fields, and landscape components around paddy fields.

We, therefore, evaluated the importance of each wildlife-friendly farming practice relative to other local and landscape variables.

We used ArcGIS version 10.1 (ESRI, Redlands) to calculate the percent coverage of paddy fields, forests and non-crop vegetation (i.e., fallows and grassland) as well as the density of farm ponds within 10 multi-scale buffers ranging from 50 to 2,000 m in radius (i.e., 50, 100, 200, 300, 500, 700, 1,000, 1,200, 1,500, and 2,000 m). We created buffers from the center of each paddy field that had a shape identical to that of the paddy field. Within these buffers, we calculated the percent coverage of each land use according to the latest vegetation and land-use map (scale 1:25,000) of the Japan Integrated Biodiversity Information System (Ministry of the Environment, Japan 2000). On the basis of aerial photos taken between July and October 2010, we added polygon data for abandoned paddy fields or fallows to the existing map.

To explore the influence of the geographic location of paddy fields on indicator groups, for each study site we calculated the horizontal distance to the nearest forest edge (area $\geq 1,000 \text{ m}^2$) and to the sea. In addition, we computed the altitudinal difference between the study site and the nearest forest edge as measures of accessibility to the nearest forest.

The importance of landscape variables on farmland biodiversity depends on spatial scales (Raebel et al. 2012). Using a generalized linear model (GLM) with negative binomial or Poisson distributions, we analyzed each of the ten landscape sectors separately and tested at each radius how family richness or the abundance of each indicator group responded to the percentage of each landscape sector. Prior to performing GLM, we employed arcsine-square-root transformation to achieve normal distribution for percentage data. For each landscape sector, we selected the best spatial scale on the basis of the lowest Akaike Information Criterion (AIC) (Burnham and Anderson 2002). Note that we only considered one spatial scale from each landscape sector for each macroinvertebrate indicator in further analyses. When none of the spatial scales showed sufficient explanatory power relative to the null model ($\Delta\text{AIC} < 2$), we did not include the landscape sector as an explanatory variable in further analyses.

The relationship between species and environment is often non-linear, so we employed a statistical model that accounts for such non-linear relationships. For this purpose, we performed a generalized additive model (GAM) to examine the relationships between environmental variables and the family richness or abundance of indicator groups. Prior to performing GAM analyses, we examined collinearity among explanatory variables using correlation analyses and scatter plots. When highly correlated variables ($r > 0.7$) were identified, we excluded one of the variables from further analyses. A preliminary analysis indicated that the percent coverage of forest and paddy fields were highly correlated at most spatial scales. Therefore, we omitted the data for the percent coverage of forest from further analyses.

In GAM, we treated response variables as either negative binomial or Poisson distributions. We used ten environmental variables (excluding X and Y) as

explanatory variables and the best spatial scale of each landscape sector for explaining the variation for each of the five response variables (i.e., indicator abundance and richness). Exclusion of the environmental variables in GAM was based on backward stepwise selection with reference to decreases in AIC (Burnham and Anderson 2002). The existence of spatial autocorrelation in model residuals can lead to underestimation of the importance of each predictor variable (Dormann et al. 2007). Therefore, we calculated Moran's I statistics to test for the existence of spatial autocorrelation in the residual of each GAM model, following the procedure described in Dormann et al. (2007). We evaluated the model performance by explained deviance (D^2), the equivalent of R^2 in standard least square regression analysis (Guisan and Zimmermann 2000). We assessed the relative importance of four representative farming practices (reduced inputs of agrochemicals, fallow flooding, winter flooding, and diversion-ditch implementation) in two ways: their statistical significance by analysis of variance (ANOVA) and their effects on the explained deviance by comparing the explained deviance in the model excluding each farming practice from predictors to that of the full model.

Because water is generally deeper in a diversion ditch than an adjacent paddy field, the diversion ditch was expected to provide an additional habitat for aquatic macroinvertebrates that prefer deep water. Using nonmetric multidimensional scaling (NMDS) and random permutations of the data (with 999 runs), we tested whether aquatic macroinvertebrate composition differed between diversion ditches and their adjacent paddy fields.

Effectiveness of Wildlife-Friendly Farming on Aquatic Macroinvertebrate Abundance and Richness

In winter, Gastropoda, Heteroptera, and Coleoptera were identified in paddy fields while no Odonata larvae were found in any rice paddy fields (average GHOC richness = 0.7 families \pm 1.1 SD; range 0–5, N = 361). Although some Odonata larvae are expected to over-winter in or around paddy fields, such over-wintering larvae were only found in diversion-ditch habitats (see section “[Effectiveness of diversion-ditch implementation on aquatic macroinvertebrate composition](#)”). The abundance and richness of the indicator groups were significantly associated with the percentage of water cover in paddy fields (Fig. 7.4; Table 7.1). Among the wildlife-friendly farming practices, winter flooding showed moderate to high contributions to the abundance of Gastropoda and Coleoptera, as indicated by both ANOVA ($P < 0.01$) and changes in explained deviance (2.7–5.7 %) when the winter-flooding term was excluded from the GAM models. In contrast, other wildlife-friendly farming practices, such as reduced inputs of agrochemicals, implementation of flooded fallows, and implementation of diversion ditches, had little effect on aquatic macroinvertebrate diversity. Although some wildlife-friendly

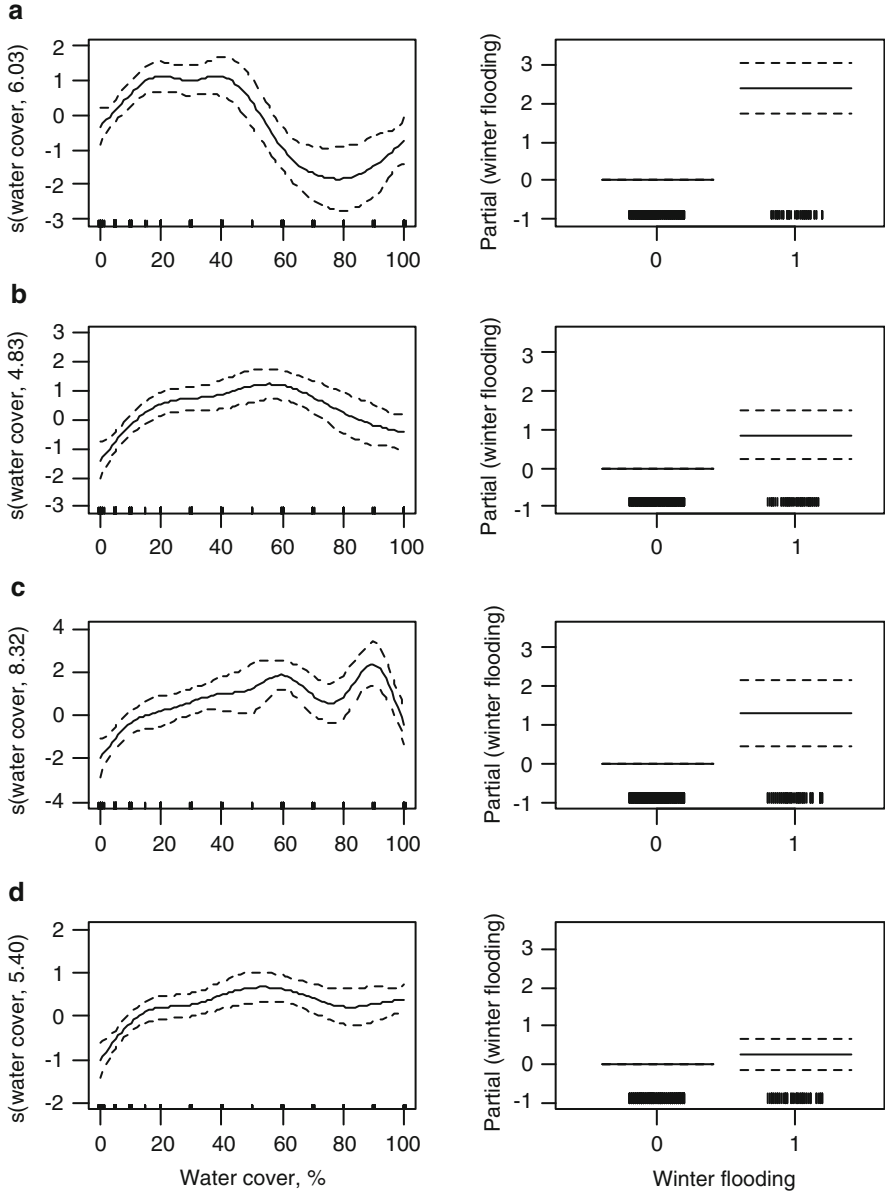


Fig. 7.4 Partial plots for the effects of percentage water cover and winter flooding practice (0 = unimplemented (N = 298), 1 = implemented (N = 63)) on the simplified, generalized additive models of (a) Gastropoda abundance, (b) Heteroptera abundance, (c) Coleoptera abundance, and (d) GHOC (Gastropoda, Heteroptera, Odonata, and Coleoptera) family richness from the winter survey. The dashed lines indicate approximate 95 % confidence limits. The y-axis label indicates the estimated degrees of freedom for the smooth spline term. The rug plot along the x-axis indicates sampling effort

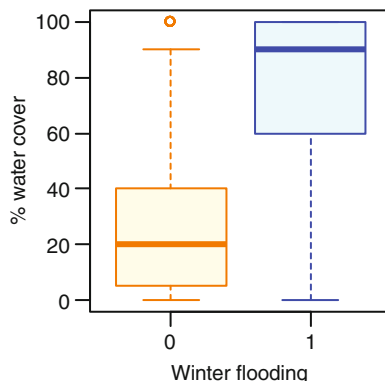
Table 7.1 Contributions of wildlife-friendly farming, morphometric variables, and landscape variables for aquatic macroinvertebrates in simplified, generalized additive models (GAM) from the winter survey on Sado Island, Japan

Source	Gastropoda	Heteroptera	Coleoptera	GHOC family richness
χ^2 values				
Agrochemical reduction (1/0)	removed	removed	removed	4.60*
Fallow flooding (1/0)	15.12***	removed	6.89**	removed
Winter flooding (1/0)	51.91***	7.06**	9.27**	removed
Diversion ditch (1/0)	10.46**	1.22	removed	removed
Autumn plowing (1/0)	4.02*	28.90***	15.52***	8.61**
s(% water cover)	60.48***	43.15***	63.29***	39.64***
s(paddy area)	38.86***	9.6	40.54***	17.19*
s(elevation)	66.66***	19.21*	54.42***	21.84*
s(distance to forest edge)	20.68**	12.61**	3.50	3.04
s(altitudinal difference between forest edge and studied paddy field)	50.18***	0.85	39.12***	removed
s(distance to sea)	89.04***	17.22*	23.70**	5.07
s(PON300)	49.96***	–	–	–
s(PON700)	–	–	–	removed
s(PON2000)	–	–	46.42***	–
s(PAD2000)	–	–	removed	–
s(NCV200)	–	–	72.68***	5.17*
s(NCV700)	–	39.44***	–	–
s(RAC)	–	15.20*	26.73**	32.03***
Deviance explained (%)				
Simplified model	56.9	52.3	71.9	33.5
With agrochemical reduction	57.3	52.5	71.8	33.5
Without agrochemical reduction	56.9	52.3	71.9	32.7
With fallow flooding	56.9	52.3	71.9	33.7
Without fallow flooding	55.9	52.3	71.2	33.5
With winter flooding	56.9	52.3	71.9	33.7
Without winter flooding	51.2	51.6	69.2	33.5
With diversion ditch	56.9	52.3	71.9	33.6
Without diversion ditch	56.5	50.6	71.9	33.5

For each landscape sector (i.e. PON, PAD, and NCV), only the spatial scale that showed the best explanatory power (based on preliminary generalized linear models and model selections) was included as an explanatory variable in the subsequent GAM. When none of the spatial scales showed sufficient explanatory power, the landscape sector was omitted from GAM (see text)

A “–” indicates that the variable was not used in the model, while “removed” indicates that the variable was removed from the simplified model. The numbers followed by three-letter characters indicate the buffer radii used to calculate the area or density of the landscape sector. 1 = implemented, 0 = unimplemented, PON = pond density, PAD = paddy field area, NCV = non-crop vegetation area, RAC = residual autocovariate, and GHOC = Gastropoda, Heteroptera, Odonata, and Coleoptera. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Fig. 7.5 Box plots of percentage water cover in paddy fields with (1; $N = 63$) and without (0; $N = 298$) winter flooding practices. The edges of the each box mark the interquartile range, with the thick horizontal line indicating the median. The whiskers indicate 1.5 times the interquartile range



farming terms showed statistical significance in ANOVA, explained deviance changed little ($\leq 1\%$) when these terms were excluded from the GAM models.

Why was the winter flooding term not always associated with the abundance or richness of indicator groups? When the percentage of water cover was compared between paddy fields that implemented or did not implement winter flooding, large variations in interquartile ranges were apparent in both types of paddy fields (Fig. 7.5). Under Sado's rice certification initiative, farmers can qualify only if they fill the ruts of tractors with rainwater. Because of climatic differences according to the geographic location of paddy fields and different drainage abilities associated with differential types of soil, the extent of winter flooding likely differed greatly from damp soil through swamp to flooded land. Likewise, paddy fields that did not implement winter flooding showed large variations in moisture conditions due to variability in climatic or geographic factors.

The residuals of preliminary GAM models for Heteroptera abundance, Coleoptera abundance, and GHOC family richness in winter showed signs of spatial autocorrelation (Moran's I: all $P < 0.05$), suggesting that the indicator diversity was high where these indicator groups were abundant or taxa rich in surrounding paddy fields (Table 7.1).

In summer, all of the four indicator groups were identified from paddy fields (average GHOC richness = 2.6 families \pm 1.7 SD; range 0–9, $N = 328$). Agrochemical reduction was among the significant terms that explained Gastropoda abundance, Heteroptera abundance, Odonata abundance, and GHOC family richness (all $P < 0.001$), and model performance dropped moderately to greatly (3.6–10.1%) when the agrochemical-reduction term was excluded from the model, as indicated by the explained deviance (Fig. 7.6; Table 7.2). Furthermore, Odonata abundance was greatly influenced by fallow flooding, as indicated by ANOVA ($P < 0.001$) and the marked change in explained deviance (6.7%) following the exclusion of the term. Spatial autocorrelation was not evident in any indicator groups in summer (Moran's I: all $P > 0.05$).

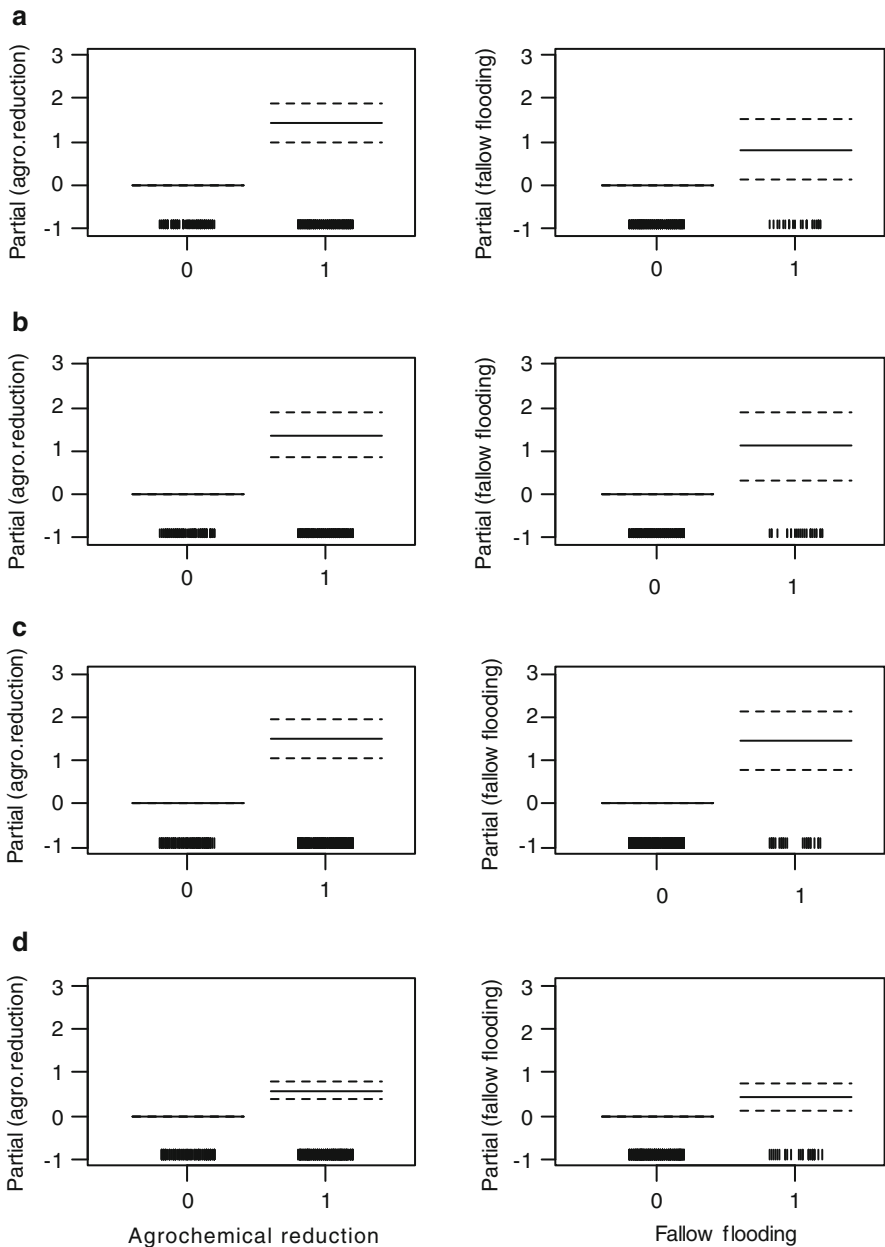


Fig. 7.6 Partial plots for the effects of agrochemical reduction (agro.reduction) (0 = unimplemented (N = 100), 1 = implemented (N = 228)) and fallow flooding practices (0 = unimplemented (N = 302), 1 = implemented (N = 26)) in the simplified, generalized additive models of (a) Gastropoda abundance, (b) Heteroptera abundance, (c) Odonata abundance, and (d) GHOC (Gastropoda, Heteroptera, Odonata, and Coleoptera) family richness from the summer survey. The dashed lines indicate approximate 95 % confidence limits. The rug plot along the x-axis indicates sampling effort

Table 7.2 Contributions of wildlife-friendly farming, morphometric variables, and landscape variables for aquatic macroinvertebrates in simplified, generalized additive models from the summer survey on Sado Island, Japan

Source	Gastropoda	Heteroptera	Odonata	Coleoptera	GHOC family richness
χ^2 values					
Agrochemical reduction (1/0)	43.91 ^{***}	28.46 ^{***}	44.41 ^{***}	removed	33.02 ^{***}
Fallow flooding (1/0)	5.53 [*]	8.12 ^{**}	18.43 ^{***}	removed	7.57 ^{**}
Winter flooding (1/0)	removed	removed	6.52 [*]	removed	removed
Diversion ditch (1/0)	removed	removed	removed	removed	4.63 [*]
Autumn plowing (1/0)	removed	removed	4.55 [*]	5.26 [*]	removed
s(% water cover)	21.49 ^{**}	11.53 [*]	21.49 ^{**}	10.94	removed
s(paddy area)	5.13	3.28	26.45 ^{**}	11.14	removed
s(elevation)	37.58 ^{***}	13.48 ^{**}	37.63 ^{***}	removed	14.71 ^{**}
s(distance to forest edge)	23.52 ^{**}	removed	18.08 [*]	5.78 [*]	14.69 ^{***}
s(altitudinal difference between forest edge and studied paddy field)	22.62 ^{**}	removed	removed	removed	removed
s(distance to sea)	65.57 ^{***}	14.54 ^{**}	47.27 ^{***}	10.23 ^{**}	16.18 ^{**}
s(PON100)	removed	–	–	–	–
s(PON700)	–	9.08	–	removed	–
s(PON1500)	–	–	–	–	removed
s(PAD300)	–	–	20.66 [*]	–	–
s(PAD500)	–	14.87 ^{**}	–	–	–
s(PAD700)	–	–	–	5.29 [*]	–
s(PAD2000)	–	–	–	–	removed
s(NCV100)	25.21 ^{**}	–	–	–	–
s(NCV700)	–	25.11 ^{***}	–	–	–
s(NCV1500)	–	–	removed	–	9.83 ^{**}
s(NCV2000)	–	–	–	6.02 [*]	–
s(RAC)	–	–	–	–	–
Deviance explained (%)					
Simplified model	39.0	31.8	32.5	16.4	20.1
With agrochemical reduction	39.0	31.8	32.5	17.1	20.1
Without agrochemical reduction	35.4	27.5	22.4	16.4	12.1
With fallow flooding	39.0	31.8	32.5	16.3	20.1
Without fallow flooding	38.0	30.4	25.8	16.4	18.5
With winter flooding	39.0	32.1	32.5	16.5	20.1
Without winter flooding	39.0	31.8	31.5	16.4	20.1
With diversion ditch	39.1	32.4	32.6	16.6	20.1
Without diversion ditch	39.0	31.8	32.5	16.4	19.1

A “–” indicates that the variable was not used in the model, while “removed” indicates that the variable was removed from the simplified model. The numbers followed by three-letter characters indicate the buffer radii used to calculate the area or density of the landscape sector. 1 = implemented, 0 = unimplemented, PON = pond density, PAD = paddy field area, NCV = non-crop vegetation area, RAC = residual autocovariate, and GHOC = Gastropoda, Heteroptera, Odonata, and Coleoptera. ^{*} $P < 0.05$, ^{**} $P < 0.01$, ^{***} $P < 0.001$

Effectiveness of Diversion-Ditch Implementation on Aquatic Macroinvertebrate Composition

The NMDS 3-dimensional plots based on the abundance data of the four indicator groups showed different aquatic macroinvertebrate composition between diversion-ditch and paddy habitats in both winter and summer (Fig. 7.7). In winter, paddy

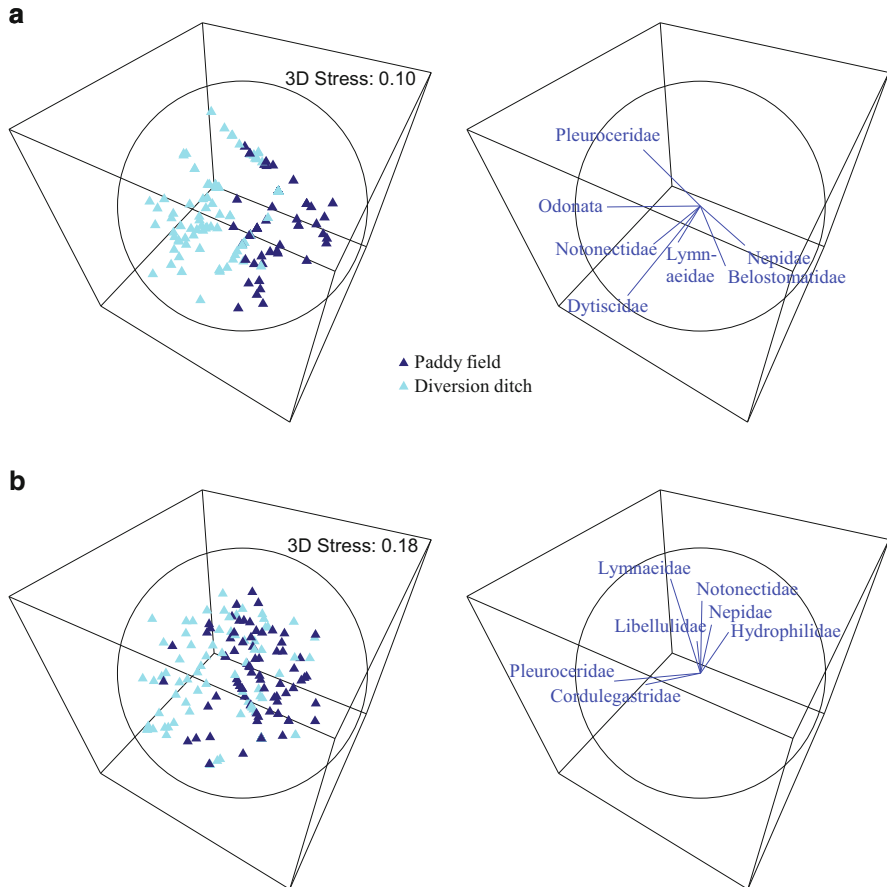


Fig. 7.7 Three-dimensional nonmetric multidimensional (NMDS) scaling ordinations of aquatic macroinvertebrate compositions in paddy fields and their adjacent diversion ditches in: **(a)** winter (Global $\rho = 0.139$, $P = 0.001$, Number of permutations = 999; $N = 116$) and **(b)** summer (Global $\rho = 0.084$, $P = 0.001$, Number of permutations = 999; $N = 86$). Only the data for paddy fields equipped with diversion ditches were used in the NMDS analyses. For clarity, only macroinvertebrate taxa that showed Pearson correlation coefficients equal to or greater than 0.4 are shown on the graphs. Note that the order-level data were used for Odonata larvae in winter, because of logistical problems associated with identification in the field and volunteer training. 3D-stress refers to the fitness to the NMDS model

habitats were associated with two aquatic Heteroptera families (Nepidae and Belostomatidae), while the adjacent diversion-ditch habitats were associated with Pleuroceridae (Gastropoda), Lymnaeidae (Gastropoda), Notonectidae (Heteroptera), Odonata, and Dytiscidae (Coleoptera). In summer, separation in aquatic macroinvertebrate composition between diversion-ditch and paddy habitats was less clear; representative families of the four indicator groups were always associated with the diversion-ditch habitat but no aquatic macroinvertebrate family appeared to represent the paddy habitat.

Conclusions and Recommendations

Scientific evaluation of the effectiveness of wildlife-friendly farming on farmland biodiversity is largely lacking from paddy-dominated landscapes (but see: Amano et al. 2011; Bang et al. 2012). Our chapter is the first attempt to report the effectiveness of wildlife-friendly farming on paddy field biodiversity on the entirety of Sado Island, which is among the leading areas for wildlife-friendly farming practices.

Overall, our results show that diverse practices of wildlife-friendly farming contribute to the enhancement of aquatic macroinvertebrate diversity on Sado Island. Specifically, reduced input of agrochemicals and fallow flooding lead to enhanced aquatic macroinvertebrate abundance and richness in summer. Although the effectiveness of diversion-ditch implementation for enhancing aquatic macroinvertebrate diversity in paddy habitats was less clear, ditches provide additional habitats for aquatic macroinvertebrates that prefer deep water in both summer and winter, as shown by different aquatic macroinvertebrate composition in the respective seasons. In winter, separation in taxonomic composition between paddy and ditch habitats was more pronounced relative to summer, with some taxonomic groups (e.g., Odonata larvae) only found in the ditch habitats. In winter, however, the effectiveness of wildlife-friendly farming practices on paddy field macroinvertebrate diversity under Sado's certification initiative was less clear. Although the percentage of water cover was shown to be among the significant factors that explain aquatic macroinvertebrate diversity in winter, the winter flooding practice under Sado's rice certification initiative had less obvious effects on aquatic macroinvertebrate diversity, because of the fact that the percentage of water cover was variable.

For winter flooding we recommend that the entire paddy field be covered with enough water, because such a protocol has been demonstrated to be effective in enhancing aquatic macroinvertebrate diversity in paddy fields as well as promoting straw decomposition (Elphick and Oring 1998; Lawler and Dritz 2005). Although the precise mechanisms for the significant spatial autocorrelation in winter are unclear, the percentage of water on paddy surfaces might explain such aggregated distributions of aquatic macroinvertebrates.

In general, irrigation water does not run in the non-cultivation season on Sado Island unless farmers implement the irrigation system on their own. When water is limited in winter, we recommend filling a diversion ditch with water rather than attempting to fill in the entire paddy field. As shown by our study, implementing diversion ditches is effective in enhancing aquatic macroinvertebrate diversity in both winter and summer. Thus, winter flooding in diversion ditches may provide an alternative certification prerequisite when flooding the entire paddy field could not be performed because of irrigation reasons. Given that biological communities show spatial and temporal variations and that agricultural policies on Sado Island may change over time, scientific evaluation is best performed periodically to monitor the up-to-date effectiveness of wildlife-friendly farming on paddy field biodiversity.

Future Challenges

Evaluation of the effectiveness of wildlife-friendly farming is best performed using multiple sets of indicator groups (Billetter et al. 2008). However, using multiple sets of indicator groups may involve so much effort that scientific evaluation cannot be performed without sacrificing sample size (i.e., study sites) unless many researchers are involved in the study. In this chapter we used a subset of aquatic macroinvertebrates as indicators for biodiversity to maximize the sample size for island-wide bioassessment (cf. Vellend et al. 2008). Because paddy fields are alternative wetland habitats that are inhabited or utilized by both aquatic and terrestrial fauna, future studies should incorporate both aquatic and terrestrial indicator groups. Wandering spiders, web-building spiders, amphibians, and adult Odonata (also exuviae) are candidates for indicator groups, as these taxonomic groups are not only important as predators for agricultural pest insects but also known to be susceptible to farmland management such as inputs of agrochemicals or moisture conditions (Amano et al. 2011; Tanaka and Ihara 2012). In addition, aquatic plants may serve as indicators for fallow flooding, as macrophytes and algae are commonly used as indicators of the biodiversity of farm ponds (Usio et al. 2013), another representative wetland habitat in Satoyama. Because implementing wildlife-friendly farming involves much labor, burdens for implementing each practice are ideally taken into account when evaluating the effectiveness of wildlife-friendly farming. Using a range of indicators from taxonomically distant groups and taking into account burdens for implementing each wildlife-friendly farming practice may allow for the evaluation of the cost-effectiveness of wildlife-friendly farming on paddy field biodiversity.

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