News Release（研究成果情報）

H29.8.18
氷見市

学芸員の研究論文が農学で権威のある国際誌に掲載！
～水田のプランクトンがイタセンパラを救う～

概要

国の天然記念物で絶滅の危機に瀕している淡水魚イタセンパラは、水田から排水されるプランクトンによって保護されていることが、氷見市教育委員会学芸員らの研究により解明されました。

氷見市教育委員会の西尾正輝主任学芸員の研究グループは、2010年から2012年にかけて伝統的な用排兼用（※1）河川である万尾川のイタセンパラの生息状況を調べたところ、イタセンパラの個体数は河川周辺の水田面積や草刈りによって決まることを見出しました。その理由として、豊富な動物プランクトンを含む水が、水田から万尾川へ排水されること。地域住民による米害虫対策の河岸の草刈りが、日当たりを作り出すこと。これらの2点によりイタセンパラの餌や生息地が提供されていることが明らかになりました。

これらの成果をまとめた論文は、世界的に評価の高い国際誌「Agriculture, Ecosystems & Environment」（※2）の電子版に8月7日（現地時間）に掲載されました。

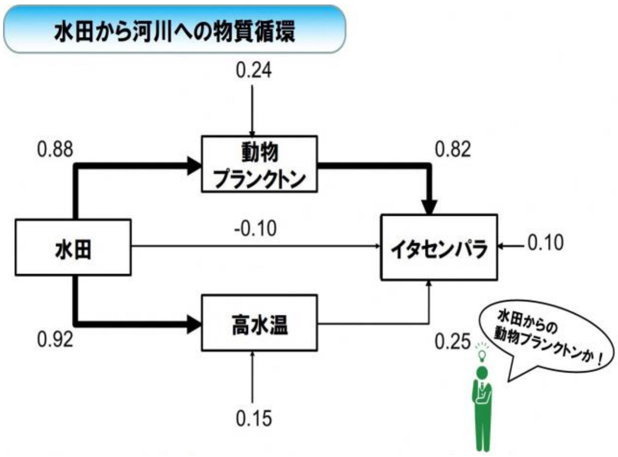


図１．水田からの河川への動物プランクトンの供給がイタセンパラの生息に有効

図２．イタセンパラの生息に必要な環境条件

今後への期待

今回の成果は、生物多様性が一体となった伝統的な農業システムの好事例として、氷見市が目指す「世界農業遺産」への登録に大きく寄与するものと思われます。これからの稲作は、生産者の高齢化や高収益作物への転作に伴い、厳しさを増していくと思われます。人と自然に優しい伝統的な循環型農業を維持するために、スマートフォンで水田水管理コストを削減する最新の管理手法を用いるなど、伝統的農業システムと革新的管理手法を融合させることで、今後もイタセンパラ生息河川周辺（万尾川）の「米作り」の継続を期待したい。

お問合せ先：ひみラボ水族館（電話）９１－２２４９　（メール）himilabo@p1.cnh.ne.jp
担当：氷見市教育委員会　教育総務課　西尾　正輝

補足説明

論文執筆者（筆頭著者）：氷見市教育委員会　西尾正輝　主任学芸員（37歳）

論文名：Paddy management for potential conservation of endangered Itasenpara bitterling via zooplankton abundance
（動物プランクトンを介した絶滅危惧種イタセンパラの潜在的な保全のための水田管理）

著　者：西尾正輝（氷見市教育委員会）・江戸謙顕（文化庁）・山崎裕治（富山大学）

雑誌名：Agriculture, Ecosystems & Environment（アグリカルチャー　エコシステムズ　エンバイロンメント）

本研究は、文化庁、富山県および河川財団の助成を受けて実施されました。

※1　用排兼用・・・用水路と排水路の機能をもつ。ほ場整備の影響により、伝統的な「用排兼用」は減少し、大部分が用水路と排水路を分離させた「用排分離」となっている。

※2　Agriculture, Ecosystems　＆　Environment・・・科学雑誌の重要度を示す指標インパクトファクターにおいて、農業学際分野を扱う英雑誌56誌の中で1位（IF値 4.099）のトップジャーナルです。

Agriculture, Ecosystems & Environment

Volume 247, 1 September 2017, Pages 166–171

Paddy management for potential conservation of endangered Itasenpara bitterling via zooplankton abundance

Masaki Nishio[a, c], Kaneaki Edo[b], Yuji Yamazaki[c]

[a] Board of Education in Himi City, Himi, Toyama 935-8686, Japan
[b] Agency for Cultural Affairs, Chiyoda Ward, Tokyo 100-8959, Japan
[c] Graduate School of Science and Engineering for Research, University of Toyama, Toyama 930-8555, Japan

Received 4 October 2016, Revised 4 July 2017, Accepted 5 July 2017, Available online 7 August 2017

https://doi.org/10.1016/j.agee.2017.07.007

図３．Agriculture, Ecosystems ＆ Environment の電子版（８月７日に電子版に公開されました）

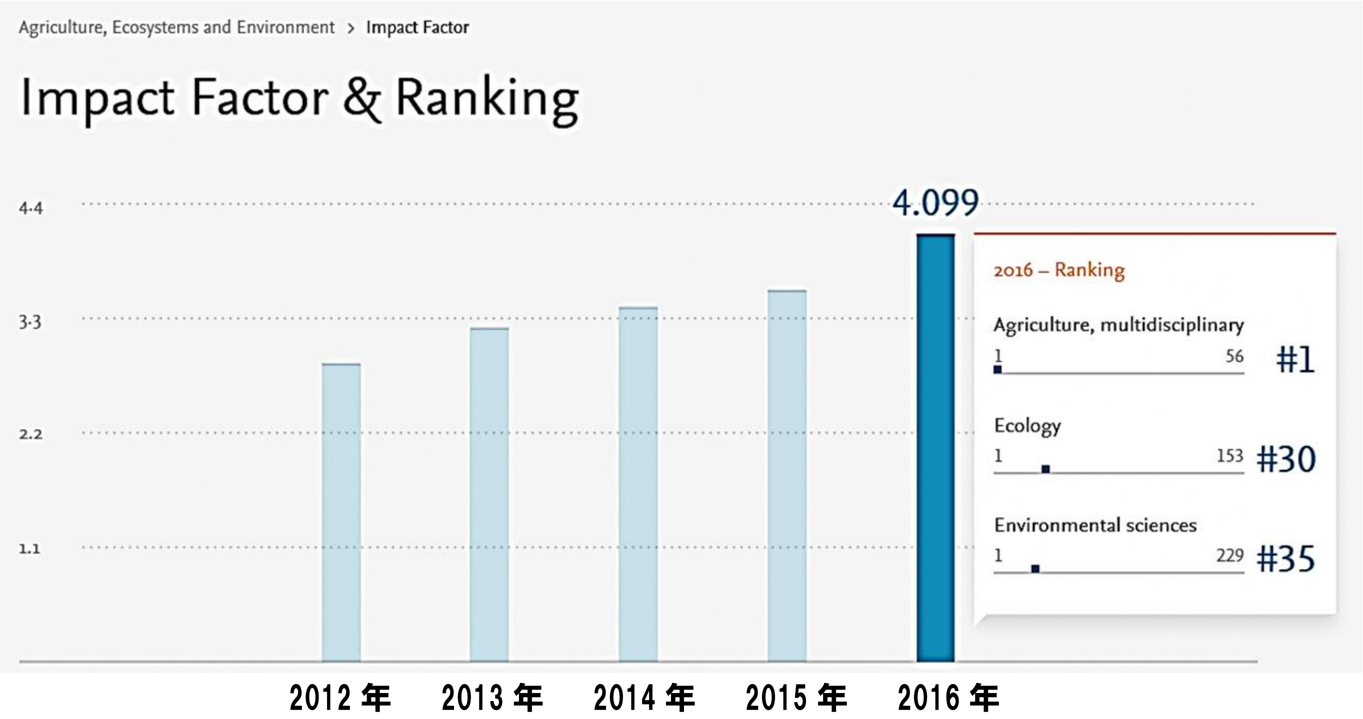
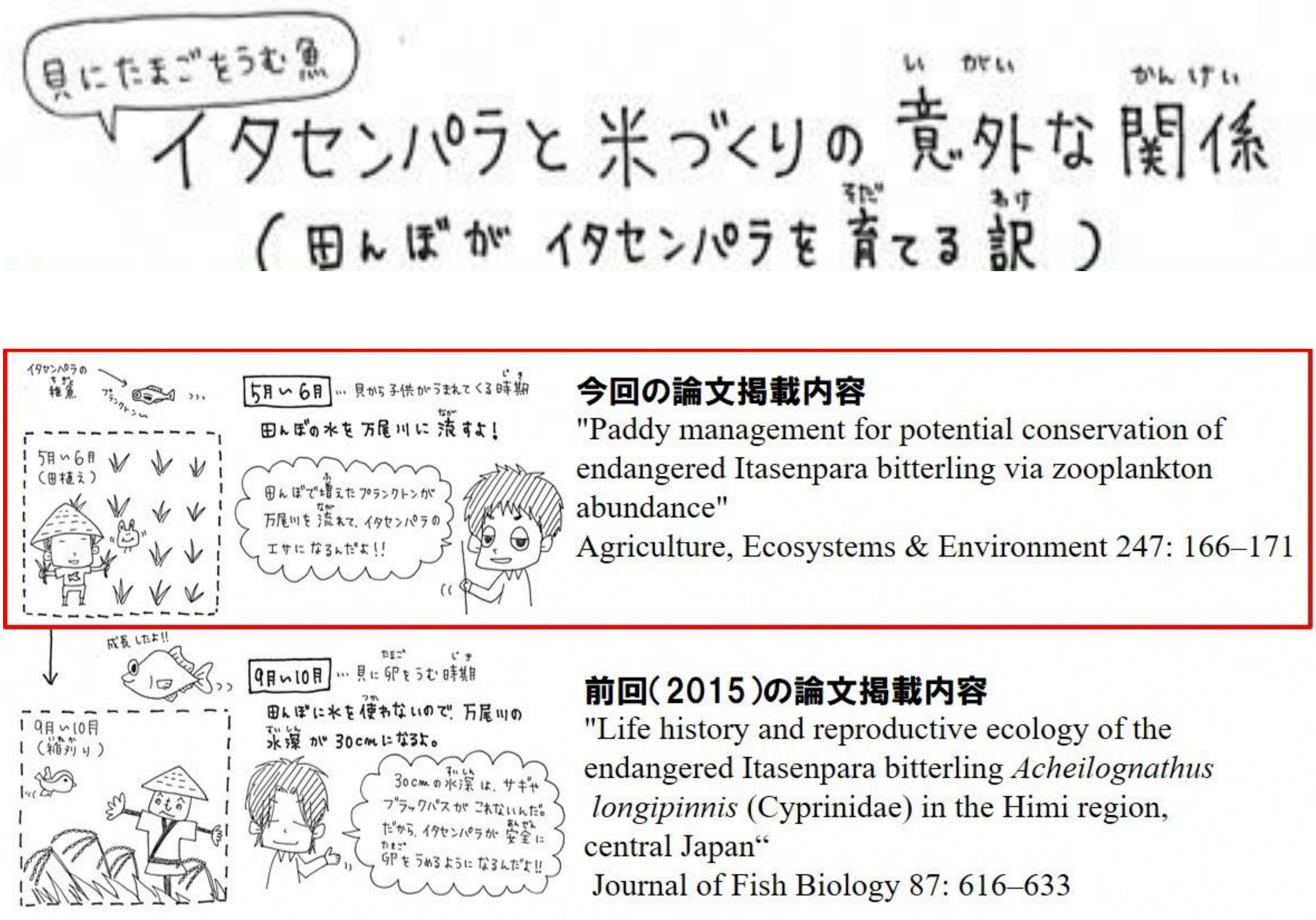


図４．Agriculture, Ecosystems and Environment は、農業学際分野５６誌の中で１位のインパクトファクター（４．０９９）を有するトップジャーナルです。



今回の論文掲載内容

"Paddy management for potential conservation of endangered Itasenpara bitterling via zooplankton abundance"
Agriculture, Ecosystems & Environment 247: 166–171

前回(2015)の論文掲載内容

"Life history and reproductive ecology of the endangered Itasenpara bitterling *Acheilognathus longipinnis* (Cyprinidae) in the Himi region, central Japan"
Journal of Fish Biology 87: 616–633

図５．イタセンパラと米づくりの関係（今回の発表内容は赤枠）

Agriculture, Ecosystems and Environment 247 (2017) 166–171

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Paddy management for potential conservation of endangered Itasenpara bitterling via zooplankton abundance

Masaki Nishio[a,c,*], Kaneaki Edo[b], Yuji Yamazaki[c]

[a] Board of Education in Himi City, Himi, Toyama 935-8686, Japan
[b] Agency for Cultural Affairs, Chiyoda Ward, Tokyo 100-8959, Japan
[c] Graduate School of Science and Engineering for Research, University of Toyama, Toyama 930-8555, Japan

ARTICLE INFO

Keywords:
Land use
Agricultural management
Rice field
Hydrological connectivity
Floodplain species
Zooplankton

ABSTRACT

In recent decades, the decline of biodiversity due to land-use changes in agricultural landscapes has become a central issue in ecology. Paddy management practices support animal diversity in agricultural landscapes. Using an endangered fish (the Itasenpara bitterling) inhabiting rivers connected to paddy fields as its subject, this study investigated two hypotheses: first, paddy field management affects the spatial distribution of Itasenpara bitterling in the adjacent river, and second, zooplankton and warm water supplied by paddy fields to the adjacent river are the primary factors influencing bitterling abundance. To model habitat suitability for the juvenile Itasenpara bitterling, rivers around paddy fields were examined using geographical information system tools and field survey methods in conjunction with a generalized linear model. The supply of zooplankton from paddy fields to the adjoining river positively contributed to juvenile Itasenpara bitterling abundance. This finding suggests that paddy management practices contribute to zooplankton abundance, and thus increase habitat suitability for juvenile Itasenpara bitterling.

1. Introduction

The conservation of semi-natural ecosystems such as agro-ecosystems is crucial to the ongoing maintenance of biodiversity (Tilman et al., 2001; Foley et al., 2005), especially because agricultural lands occupy approximately 40% of all terrestrial areas worldwide (Ramankutty and Foley, 1999). Agro-ecosystems harbor unique biodiversity compared with natural ecosystems. However, semi-natural landscapes have experienced major land-use changes in recent decades, contributing to the loss of biodiversity, a central issue to biological conservation in recent years (Krebs et al., 1999; Tilman et al., 2001; Benton et al., 2003; Billeter et al., 2008). Thus, in recent decades research has increasingly recognized the value of traditional agricultural habitats (Tscharntke et al., 2005; Knop et al., 2006; Kleijn et al., 2011). As many endangered species inhabit traditionally managed agricultural landscapes, integrative conservation efforts that balance biodiversity with productive agricultural systems are especially important (Pimentel et al., 1992; Bengtsson et al., 2003; Tscharntke et al., 2005; Bennett et al., 2006).

Paddies in particular provide habitats for numerous aquatic organisms (Kobori and Primack, 2003; Washitani, 2008; Kadoya et al., 2009; Kato et al., 2010). The Ramsar Convention has defined paddy fields as wetlands, a term also recognized by at least 114 countries worldwide at the Convention of Parties in 2008 (http://www.ramsar.org/document/resolution-x31-enhancing-biodiversity-in-rice-paddies-as-wetland-systems). According to the Food and Agricultural Organization of the United Nations, paddy fields in Asia account for 90% of the world's rice production. Floodplains are threatened ecosystems, as more than 90% of floodplains in North America and Europe have been modified for cultivation (Tockner and Stanford, 2002). Thus, global efforts have been made, especially in Asia, to restore the integrity of river floodplains (Zerbe and Thevs, 2011). Rice cultivation has a substantial impact on the biodiversity of floodplains (Elphick and Oring, 1998; Armitage et al., 2003; Washitani, 2008) and Japan has a long history of rice cultivation (more than 2500 years; Fujiwara, 1998). Paddy fields managed through traditional agricultural systems (i.e., a dual-purpose channel, with paddy fields connected to the channel and ponds) have functioned as secondary floodplain habitats for endangered Cyprinidae (Suzuki et al., 2008; Onikura et al., 2009). However, there has been no report that such paddy fields affect the spatial distribution of fish in the adjoining rivers.

The Itasenpara bitterling *Acheilognathus longipinnis* is a freshwater fish that engages in an unusual spawning symbiosis with freshwater mussels in autumn. The hatched larvae live in the mussels for about

---

[*] Corresponding author at: Board of Education in Himi City, Himi, Toyama 935-8686, Japan.
E-mail address: masaki.nishio@city.himi.lg.jp (M. Nishio).

http://dx.doi.org/10.1016/j.agee.2017.07.007
Received 4 October 2016; Received in revised form 4 July 2017; Accepted 5 July 2017
0167-8809/ © 2017 Elsevier B.V. All rights reserved.

seven months, after which the juveniles swim up from the mussels in June and mature in the following autumn (Kitamura et al., 2009; Nishio et al., 2012, 2015). The Itasenpara bitterling is a typical plankton-feeding cyprinid that is endemic to Japan. This species was designated as a natural monument of Japan in 1974 and nationally recognized as being scientifically important. Also, the species was listed as critically endangered in the Red List of the Ministry of the Environment of Japan in 2014 and as vulnerable in the International Union for Conservation of Nature (IUCN) Red List of Threatened Species in 2017. The natural habitat of the Itasenpara bitterling is floodplain water (Kitanishi et al., 2012, 2013; Nishio et al., 2015, 2017). However, these fish are currently distributed in only three regions of Japan (the Toyama, Osaka, and Nobi plains) owing to the disappearance of floodplains (Nishio et al., 2012, 2015; Yamazaki et al., 2014). In the Toyama plain, these fish are currently only found in two small river systems (the Moo and Busshouji Rivers). Traditional agricultural systems (i.e., water control via dual-purpose channels) have alternatively functioned as floodplain habitats via water level fluctuation for Itasenpara bitterling and freshwater mussels as a spawning substratum in the Moo River (Nishio et al., 2015, 2016, 2017), where ~1000 Itasenpara juveniles were observed in a 300 m section from May to June 2007 (Himi City, 2008). On the other hand, in the Busshouji River with newer agricultural systems (i.e., water control via separate irrigation and drainage channels), fewer than 40 juvenile Itasenpara bitterling were found in a 1.6 km section from May to June 2007 (Himi City, 2008).

This study clarified the relationship between endangered Itasenpara bitterling abundance in rivers (its natural habitat) and the connected paddy fields in order to develop a model that explained the relationship between bitterling distribution and other factors. Understanding the potential roles of local habitat conditions in the current distribution of the Itasenpara bitterling may help in identifying feasible approaches to the restoration of degraded bitterling habitat in floodplains. This study was hypothesized that hydrological connectivity directly impacts juvenile Itasenpara distribution, as paddy fields can mediate the habitat quality of adjoining rivers. The objectives were to examine (i) whether the water management strategies employed in rice cultivation affect the spatial distribution of the Itasenpara bitterling in the adjacent rivers and (ii) whether the primary factors affecting the spatial distribution of the Itasenpara bitterling are zooplankton and warm temperatures supplied by the paddy fields to adjoining rivers. To investigate these two research questions, Itasenpara bitterling distribution was predicted using geographic information system (GIS) tools and field survey methods in conjunction with a generalized linear model (GLM) to assess the importance of landscape-scale factors.

2. Methods

2.1. Study area

This study was conducted in the Moo River system, which comprises a low-gradient river that flows into Toyama Bay, Japan (Fig. 1; Supporting information Appendix S1), along with a small-scale catchment area of about 9 km^2. The Moo River system is approximately 10 km long, 5–10 m wide, 10 m above sea level, and has an average riverbed gradient of 0.2%. The Moo River system has three tributaries: the Moo (in this study, segments S1, S2, S3, and S4); Hounoki (S5, S6, and S7); and Nakayachi (S8 and S9) rivers. About 36% of the catchment area around this river is used in rice cultivation, and usage of the river system in particular as a dual-purpose-channel for rice cultivation has been substantially maintained even in recent years. Water levels are controlled artificially based on the irrigation needs of paddy fields. During the irrigation season (April to June), the water gates are closed, maintaining a water depth of approximately 1 m for rice cultivation and creating a lentic environment in the channel. Water circulates between the paddy fields and the Moo River system, with warm water, abundant in zooplankton from the fields, draining into the river system. The riverbed is comprised of sand with some mud and clay deposits, while most of the riverbanks remain in their natural condition. Emergent plants, including the common reed *Phragmites australis* and Manchurian wild rice, are abundant. Several bitterling species, including *A. longipinnis*, the southern red tabira bitterling *A. tabira jordani*, the slender bitterling *Tanakia lanceolata*, and the Chinese rose bitterling *Rhodeus ocellatus ocellatus*, inhabit the study site (Nishio et al., 2015).

2.2. Survey site and field sampling

This study divided the river system into segments based on the following criteria: i) water gates prevent the migration of water and aquatic organisms (S3, S4, S6, S7, and S9); ii) the environment is sectioned by a water gate and the confluence of tributaries (S2, S5, and S8); and iii) the confluence of the Moo and Hounoki rivers greatly alters the environment (S1). In this study, these nine segments were considered independent of one another (Fig. 1).

To characterize the Itasenpara bitterling's habitat within these segments of the Moo River system, this study divided a 50 m stretch of each segment into eight reaches at equal intervals. At every 5 m, sampling spots were identified with suitable sites for two 0.5-by-0.5-m quadrats on the right and left bank of each reach. This sampling design generated 176 quadrats along each segment. In June 2010, in each quadrat, it was noted whether Itasenpara bitterling were present or absent, and the water depth (WD), riverbank material (RM), sediment material (SM), current velocity (CV), and vegetation cover area (CA) were measured to determine habitat suitability. The juvenile Itasenpara bitterling in each quadrat were captured using a dip net, as they swim close to the water surface in June. Two types of SM were identified and coded: sand (1) and clay (0). CA was estimated visually in each quadrat. The RM was coded as natural (1) or artificial (0).

2.3. Water temperature and zooplankton

Data on water temperature and zooplankton samples were collected from May to July 2012. A temperature data logger (Tidbit v2 UTBI-001; Onset Computer Corporation, Burne, MA, USA) was used to monitor water temperature at the lowest reach of each segment. Water temperature was measured every hour during the irrigation and non-irrigation seasons between May and July 2012. Water was collected at the surface and mid-water levels of eight reaches of each segment during the same period, and 100 mL were filtered through a 190-μm mesh net to estimate zooplankton abundance. Zooplankton was preserved in 5% formalin and then counted under a microscope (BX40; Olympus, Tokyo, Japan).

2.4. Environmental measurements using GIS

Environmental variables for each segment were measured directly or calculated using a GIS dataset, and the water catchment area associated with each segment was delineated. The ratio of paddy fields within the water catchment area (RPW), longitudinal gradient of the riverbed (LGR), and distance to the nearest artificial structure (DNR) were calculated using the GIS dataset. Polyline data for each segment were delineated from river centerline data provided by the National Land Numerical Information. Watershed delineation was conducted manually using Digital Map 25000 (Map Image). A 1:25,000 vegetation map from the 6th National Survey on the Natural Environment was used to estimate paddy field area. To calculate LGR, the elevation at both ends of each segment was extracted from the Digital Elevation Model (DEM) at a 10 m resolution, and the difference between the two values was divided by the segment length [LGR = (elevation at upstream end − elevation at downstream end)/segment length]. DEM data were compiled from the Fundamental Geospatial Data of Japan with an accuracy of 1:25,000. The DNR was defined as the minimum distance along the riverbank of each segment and calculated from point

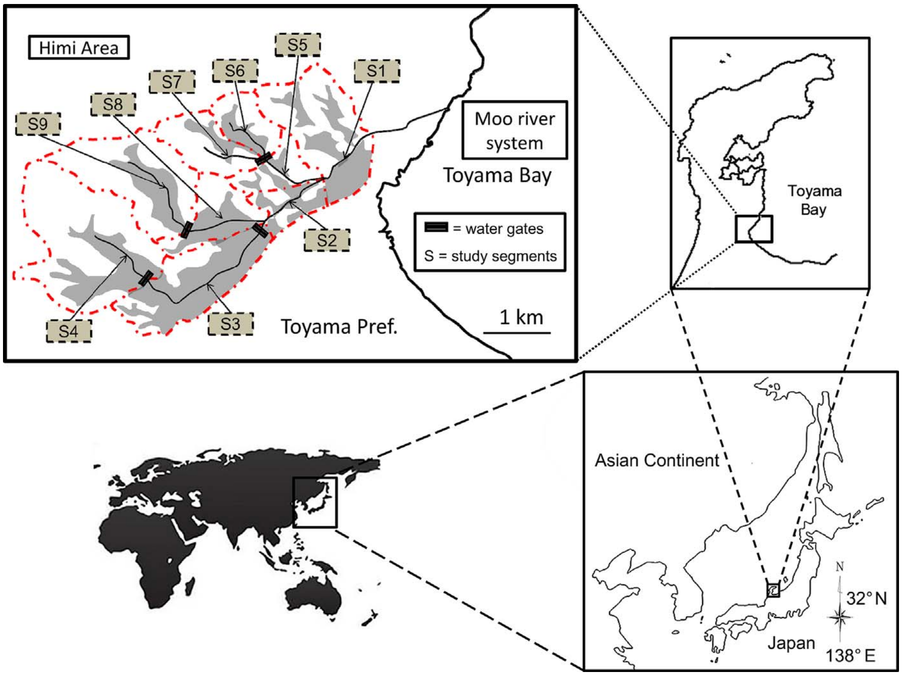


Fig. 1. Map of study segments (S1–S9) of the Moo River system, Western Toyama Prefecture, Japan. Paddy fields are highlighted in grey. Note: water gates are closed during the irrigation season, preventing the migration of bitterlings and freshwater mussels.

data generated along the riverbank of each segment at 10 m intervals. Data outlining buildings and roads, provided by the Fundamental Geospatial Data of Japan, were used to identify artificial structures.

2.5. Statistical analyses

Statistical analysis was performed using R 2.12.2 (http://www.r-project.org/). Correlograms of Moran's *I* (Fortin and Dale, 2005) were constructed to assess the degree of spatial autocorrelation of juvenile Itasenpara bitterling. Distance classes were defined as contiguous segments or subsequent contiguous segments. To test the significance ($P < 0.05$) of Moran's coefficients for each lag distance, 1000 Monte Carlo permutations of the original data were tested. Pearson's correlation coefficient was used to identify any associations between habitat variables in each segment, as well as between habitat variables and the abundance of juvenile Itasenpara bitterling. The GLM was used to determine the factors that influence the occurrence of the juvenile Itasenpara bitterling. A correlation matrix was used to identify any collinearity between covariates, and Pearson's correlation coefficients ($|r|$) > 0.70 were excluded to prevent multi-collinearity between explanatory variables (Table 1). The covariates WD, RM, SM, LGR, and DNR were subsequently excluded from the analysis. A Poisson regression analysis was conducted on all possible sets of explanatory variables from a null model including no predictors to a full model including all predictors. The Akaike Information Criterion (AIC; Akaike, 1974) was used for model selection. In addition, the differences in AIC (ΔAIC) between each model and the best model were calculated and environmental variables with $\Delta\text{AIC} < 2$ were examined (Burnham and Anderson, 2002). All explanatory variables were standardized to maximize model resolution.

Spearman's rank correlation was used to identify associations among zooplankton abundance, water temperature, RPW, and the abundance of juvenile Itasenpara bitterling during the irrigation and non-irrigation seasons. Variables that correlated significantly to juvenile Itasenpara bitterling abundance were used in path analysis to test their correlation within a given path, and the "beta" (standardized regression) coefficient was calculated. To determine statistical significance, path analysis was coupled with regression analysis (Petraitis et al., 1996). Path analysis was performed using Stata 8 (College Station, TX, USA) with a significance level of 5%.

3. Results

3.1. Juvenile Itasenpara bitterling abundance and spatial autocorrelation

The occurrence of the juvenile Itasenpara bitterling differed between the study segments and was confirmed in six out of nine segments (Supporting information Appendix S1) at an average of 16 ± SE 8 quadrats. No significant coefficient was detected for quadrats with juvenile Itasenpara bitterling between contiguous river segments

Table 1
Pearson's correlation coefficients among different environmental variables and the abundance of juvenile Itasenpara bitterling.

Variables	Abundance of juvenile Itasenpara bitterling	1	2	3	4	5	6	7	8
(1) Ratio of paddy fields within the water catchment area (RPW)	0.851**	–							
(2) Water depth (WD)	−0.219	0.018	–						
(3) Riverbank material (RM)	0.361	0.097	−0.945***	–					
(4) Sediment material (SM)	0.769*	0.507	−0.411	0.414	–				
(5) Current velocity (CV)	−0.225	−0.238	−0.325	0.249	−0.062	–			
(6) Vagetation cover area (CA)	0.502	0.513	−0.408	0.354	0.516	−0.126	–		
(7) Longitudinal gradient of riverbed (LGR)	−0.655	−0.528	0.718*	−0.648	−0.765*	0.092	−0.682	–	
(8) Distance to the nearest artificial structure (DNR)	−0.556	−0.529	0.473	−0.480	−0.405	0.430	−0.327	0.781*	–

[a] Significance of correlations: *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

Table 2
Coefficients of selected variables and coefficients and standard errors (SE) of best-fit models for explaining the abundance of juvenile Itasenpara bitterling.

Model	AIC	ΔAIC	Intercept	Coefficients (SE)		
				Variable[a]		
				Ratio of paddy fields within the water catchment area (RPW)	Current velocity	Cover area
1	50.3	0.00	1.68 (0.52)	1.30 (0.13)		
2	52.1	1.80	1.67 (0.18)	1.37 (0.20)		−0.09 (0.21)
3	52.3	1.95	1.68 (0.18)	1.30 (0.13)	0.03 (0.16)	

[a] Abbreviations: AIC, Akaike information criterion; ΔAIC, differences in AIC.

(Moran's $I = -0.02$; z-score = 0.55; $P > 0.05$) or subsequent contiguous segments (Moran's $I = -0.14$, z-score = –0.14, $P > 0.05$). Consequently, there was no evidence of spatial autocorrelation in the abundance of juvenile Itasenpara bitterling.

3.2. *Environmental conditions and juvenile Itasenpara bitterling abundance*

The occurrence of the juvenile Itasenpara bitterling positively correlated to the ratio of paddy fields within the water catchment area (RPW) ($r = 0.851$) and sediment material ($r = 0.769$; Table 1). The environmental conditions associated with the presence of juvenile Itasenpara bitterling are described in Table 2. All models considered RPW—and the best model only RPW—to be a positive factor in bitterling occurrence. In addition, RPW had the greatest positive tendency (1.37), while vegetation cover area had the greatest negative tendency (−0.09; Table 2). During the irrigation season, zooplankton abundance was positively correlated with the abundance of juvenile Itasenpara bitterling ($r_s = 0.93$; $P < 0.01$) and RPW ($r_s = 0.78$; $P < 0.05$). Water temperature during the irrigation season also positively correlated to the abundance of juvenile Itasenpara bitterling ($r_s = 0.83$; $P < 0.01$) and RPW ($r_s = 0.70$; $P < 0.05$). A significant path coefficient was identified for the pairing of zooplankton abundance and warm water from paddy fields. However, a significant path coefficient for juvenile Itasenpara bitterling occurrence was identified only in its pairing with zooplankton abundance (Fig. 2). During the non-irrigation season, zooplankton abundance and water temperature were not significantly correlated with RPW (zooplankton abundance $r_s = 0.05$; $P > 0.05$, water temperature $r_s = 0.60$; $P > 0.05$) or with the abundance of juvenile Itasenpara bitterling (zooplankton abundance $r_s = 0.19$; $P > 0.05$, water temperature $r_s = 0.49$; $P > 0.05$).

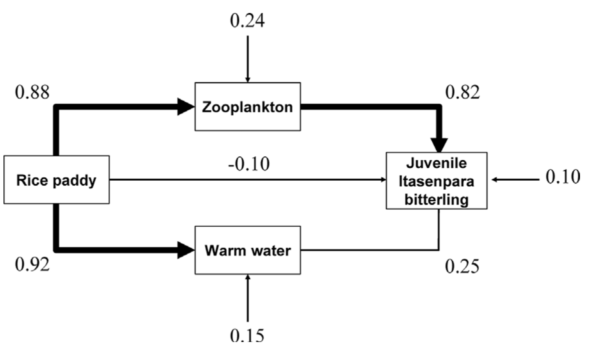


Fig. 2. Path diagram of paddy field and presence of bitterlings during the irrigation season. Beta coefficients are shown along their respective path segments. Thick arrows indicate significant effects ($P < 0.05$).

4. Discussion

4.1. *Bitterling responses to paddy field management*

The ratio of paddy fields within the water catchment area (RPW) had a significant positive effect on the spatial distribution of the juvenile Itasenpara bitterling in the Moo River. All previous studies investigated the suitability of paddy fields as habitat or spawning sites for fish (Naruse and Oishi, 1996; Katano et al., 2003; Abe et al., 2007a, 2007b), but a direct correlation between RPW and the abundance of fish in a contiguous river has not been reported yet. Therefore, this study is significant in this respect by being the first to report on the association between RPW and the abundance of fish in a contiguous river.

Paddy fields are connected to adjacent rivers by ditches in the Moo River. During the irrigation season, river water is pumped into the paddy fields, and paddy field water is discharged back into the rivers through the ditches. The strong correlation between RPW and bitterling abundance suggests that the discharged water was the primary factor affecting the spatial distribution of juvenile Itasenpara bitterling in the study river.

Zooplankton has been previously reported to be abundant in paddy fields (Ichimura, 1954). Because zooplankton feeds phytoplankton, the abundance of zooplankton depends on that of phytoplankton (Kurasawa, 1957). Phytoplankton has been reported to be abundant in paddy fields due to fertilization (Taira and Hogetsu, 1987; Simpson et al., 1994). In addition, light intensity in paddy fields has been reported to be suitable for photosynthesis of phytoplankton (Kurasawa, 1957). During the irrigation season, the amount of zooplankton in the river positively correlated to RPW in this study, and a significant path coefficient was calculated for the pairing of RPW and zooplankton abundance (Fig. 2). These findings also indicate that zooplankton generated in the paddy fields were discharged into the contiguous river. Furthermore, zooplankton abundance positively correlated to juvenile Itasenpara bitterling abundance during the irrigation season, and a significant path coefficient was estimated for this pairing (Fig. 2).

Paddy fields are typically shallow with relatively high water temperatures, compared with contiguous rivers (Kanao et al., 2009). Water temperatures in the paddy field in this study were significantly higher than those of the contiguous river. Thus, paddy fields provided warm water to the contiguous river. Water temperature positively correlated to juvenile Itasenpara bitterling abundance; however, the path coefficient for the pairing was not significant (Fig. 2). The findings of this study indicate that the impact of RPW on the spatial distribution of the juvenile Itasenpara bitterling might have been stronger than that of elevated water temperatures.

The GLM revealed that vegetation cover negatively affected the distribution of juvenile Itasenpara bitterling. Any spot without vegetation cover is exposed to the sun, and water temperatures are typically higher at these points than in shaded areas. Consequently, sunny spots may provide more suitable habitats for juvenile fish (Billman et al., 2006; Kanao et al., 2009). In the Moo River, where vegetation cover is high, the presence of the rice leaf bug *Trigonotylus caelestialium* hampers the growth of rice plants. Farmers routinely remove vegetation in proximity to paddy fields to reduce the rice leaf bug's habitat and thus its impact. As a result, the vegetation cover along the contiguous river is reduced, potentially providing a more suitable habitat for juvenile Itasenpara bitterling. Therefore, mowing is one of the important practices of paddy management that influences Itasenpara bitterling, similar to water management in relation to plankton supply.

The findings of this study suggest that an extensive paddy field area could contribute to an abundance of zooplankton, which subsequently may be transported to the contiguous river and consumed by juvenile Itasenpara bitterling. Therefore, the abundance of paddy fields may determine the spatial distribution of the bitterling in the rivers, contributing to the survival of this endangered species. During the irrigation season, paddy fields with zooplankton provide an important feeding ground for the Itasenpara bitterling. Because floodplain wetlands that are rich in plankton also function as habitats for juvenile fish (Tockner et al., 2000; Górski et al., 2013), paddy fields adjoining to the river function as floodplains supplying abundant plankton.

4.2. Conclusions and implications for conservation

In the catchment area of the Moo River system where the present study was conducted, the area of cultivated paddy had decreased sharply from 260 ha in 2000 to 123 ha in 2010 (Himi City, 2001, 2016). This rapid decline is due to an increase in paddy abandonment by ageing population in this region and the transformation from paddy to dry fields for the cultivation of popular Job's tears *Coix lacryma-jobi ma-yuen*. The present results indicate that floodplain species are susceptible to such land-use changes, and the surrounding paddy fields in which such floodplain species are still present deserve conservation priority. The habitat of floodplain species (including many endangered species) can be easily identified on maps, and it is important to identify the hotspots of as many floodplain species as possible and to conduct paddy management suitably for these species in these areas. Although expanding paddy area is not a very feasible option due to the ongoing process of paddy abandonment, at least continuing the current paddies and their traditional management is important in supporting diverse communities of freshwater fish, including the endangered Itasenpara bitterling. If managed appropriately, a dominant form of agriculture such as rice production can provide an ideal habitat for floodplain species.

The effects of land-use changes on semi-natural biodiversity have rarely been investigated in monsoon Asia. Future studies should examine different paddy systems in other regions within this part of Asia, as well as different types of agricultural land worldwide.

Acknowledgments

This study was supported in part by the River Fund of the River Foundation, Japan, and the Natural Monuments Investigation Subsidy (Agency for Cultural Affairs). It was conducted in collaboration with the Faculty of Science of the University of Toyama and the Himi Collaborative Research Laboratory, Himi City. All experiments were carried out with the permission of the Agency for Cultural Affairs and the Ministry of the Environment.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.agee.2017.07.007.

References

Abe, T., Kobayashi, I., Kon, M., Sakamoto, T., 2007a. Spawning behavior of kissing loach (*Leptobotia curta*) in temporary waters. Zool. Sci. 24, 850–853.

Abe, T., Kobayashi, I., Kon, M., Sakamoto, T., 2007b. Spawning of the kissing loach (*Leptobotia curta*) is limited to periods following the formation of temporary waters. Zool. Sci. 24, 922–926.

Akaike, H., 1974. A new look at the statistical model identification. IEEE Trans. Autom. Control 19, 716–723.

Armitage, P.D., Szoszkiewicz, K., Blackburn, J.H., Nesbitt, I., 2003. Ditch communities: a major contributor to floodplain biodiversity. Aquat. Conserv. 13, 165–185.

Bengtsson, J., Angelstam, P., Elmqvist, T., Emanuelsson, U., Folke, C., Ihse, M., Moberg, F., Nyström, M., 2003. Reserves, resilience and dynamic landscapes. AMBIO 32, 389–396.

Bennett, A.F., Radford, J.Q., Haslem, A., 2006. Properties of land mosaics: implications for nature conservation in agricultural environments. Biol. Conserv. 133, 250–264.

Benton, T.G., Vickery, J.A., Wilson, J.D., 2003. Farmland biodiversity: is habitat heterogeneity the key? Trends Ecol. Evol. 18, 182–188.

Billeter, R., Liira, J., Bailey, D., Bugter, R., Arens, P., Augenstein, I., Aviron, S., Baudry, J., Bukacek, R., Burel, F., Cerny, M., De Blust, G., De Cock, R., Diekötter, T., Dietz, H., Dirksen, J., Dormann, C., Durka, W., Frenzel, M., Hamersky, R., Hendrickx, F., Herzog, F., Klotz, S., Koolstra, B., Lausch, A., Le Coeur, D., Maelfait, P.J., Opdam, P., Roubalova, M., Schermann, A., Schermann, N., Schmidt, T., Schweiger, O., Smulders, J.M.M., Speelmans, M., Simova, P., Verboom, J., Van Wingerden, K.R.E.W., Zobel, M., Edwards, J.P., 2008. Indicators for biodiversity in agricultural landscapes: a pan-European study. J. Appl. Ecol. 45, 141–150.

Billman, E.J., Wagner, E.J., Arndt, R.E., 2006. Effects of temperature on the survival and growth of age-0 least chub (*Iotichthys phlegethontis*). West. N. Am. Nat. 66, 434–440.

Burnham, K.P., Anderson, D.R., 2002. Model Selection and Multimodel Inference: a Practical Information-theoretic Approach, 2nd edition. Springer-Verlag, New York.

Elphick, C.S., Oring, L.W., 1998. Winter management of Californian rice fields for waterbirds. J. Appl. Ecol. 35, 95–108.

Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentice, I.C., Ramankutty, N., Snyder, P.K., 2005. Global consequences of land use. Science 309, 570–574.

Fortin, M.J., Dale, M.R.T., 2005. Spatial Analysis: A Guide for Ecologist. Cambridge University Press Cambridge.

Fujiwara, H., 1998. Inquiring into the Origin of Rice Cultivation. Iwanami Shoten, Tokyo (in Japanese).

Górski, K., Collier, K.J., Duggan, I.C., Taylor, C.M., Hamilton, D.P., 2013. Connectivity and complexity of floodplain habitats govern zooplankton dynamics in a large temperate river system. Freshw. Biol. 58, 1458–1470.

Himi City, 2001. Area of Cultivated Land by District. Statistics of Himi City, Himi (in Japanese).

Himi City, 2008. Restoration Project Report of Natural Monument, Itasenpara Bitterling, Part 3. Board of Education in Himi City, Himi (in Japanese).

Himi City, 2016. Area of Cultivated Land by District. Statistics of Himi City, Himi (in Japanese).

Ichimura, S., 1954. Ecological studies on the plankton in paddy field. I. Seasonal fluctuations in the standing crop and productivity of plankton. J. Jpn. Bot. 14, 269–279.

Kadoya, T., Suda, S., Washitani, I., 2009. Dragonfly crisis in Japan: a likely consequence of recent agricultural habitat degradation. Biol. Conserv. 142, 1899–1905.

Kanao, S., Ohtsuka, T., Maehata, M., Suzuki, N., Sawada, H., 2009. Effectiveness of paddy fields as an initial growth environment for larval and juvenile nigorobuna *Carassius auratus grandoculis*. Nippon Suisan Gakkai Shi 75, 191–197 (in Japanese with English abstract).

Katano, O., Hosoya, K., Iguchi, K., Yamaguchi, M., Aonuma, Y., Kitano, S., 2003. Species diversity and abundance of freshwater fishes in irrigation ditches around rice fields. Environ. Biol. Fishes 66, 107–121.

Kato, N., Yoshio, M., Kobayashi, R., Miyashita, T., 2010. Differential responses of two anuran species breeding in rice fields to landscape composition and spatial scale. Wetlands 30, 1171–1179.

Kitamura, J., Negishi, J.N., Nishio, M., Sagawa, S., Akino, J., Aoki, S., 2009. Host mussel utilization of the Itasenpara bitterling (*Acheilognathus longipinnis*) in the Moo River in Himi. Jpn. Ichthyol. Res. 56, 296–300.

Kitanishi, S., Nishio, M., Uehara, K., Ogawa, R., Yokoyama, T., Edo, K., 2012. Patterns of genetic diversity of mitochondrial DNA within captive population of the endangered Itasenpara bitterling: implications for a reintroduction program. Environ. Biol. Fishes 96, 567–572.

Kitanishi, S., Nishio, M., Uehara, K., Ogawa, R., Yokoyama, T., Ikeya, K., Edo, K., 2013. Strong population genetic structure and its implications for the conservation and management of the endangered Itasenpara bitterling. Conserv. Genet. 14, 901–906.

Kleijn, D., Rundlöf, M., Scheper, J., Smith, H.G., Tscharntke, T., 2011. Does conservation on farmland contribute to halting the biodiversity decline? Trends Ecol. Evol. 26, 474–481.

Knop, E., Kleijn, D., Herzog, F., Schmid, B., 2006. Effectiveness of the Swiss agri-environment scheme in promoting biodiversity. J. Appl. Ecol. 43, 120–127.

Kobori, H., Primack, R.B., 2003. Participatory conservation approaches for *Satoyama*, the traditional forest and agricultural landscape of Japan. AMBIO 32, 307–311.

Krebs, J.R., Wilson, J.D., Bradbury, R.B., Siriwardena, G.M., 1999. The second silent spring? Nature 400, 611–612.

Kurasawa, H., 1957. The phytoplankton zooplankton relationships in two paddy fields in central Japan (with 4 text-figures). J. Faculty Sci. (Hokkaido University Series VI. Zoology) 13, 180–186.

Naruse, M., Oishi, T., 1996. Annual and daily activity rhythms of loathes in an irrigation creek and ditches around paddy fields. Environ. Biol. Fishes 47, 93–99.

Nishio, M., Soliman, T., Yamazaki, Y., 2012. Occurrence and spawning locations of the Itasenpara bitterling (*Acheilognathus longipinnis*) in the Moo River, Toyama, Japan. Jpn. J. Ichthyol. 59, 147–153 (in Japanese with English abstract).

Nishio, M., Kawamoto, T., Kawakami, R., Edo, K., Yamazaki, Y., 2015. Life history and reproductive ecology of the endangered Itasenpara bitterling *Acheilognathus longipinnis* (Cyprinidae) in the Himi region, central Japan. J. Fish Biol. 87, 616–633.

Nishio, M., Tanaka, H., Tanaka, D., Kawakami, R., Edo, K., Yamazaki, Y., 2016. Managing water levels in rice paddies to conserve the Itasenpara Host Mussel, Unio douglasiae nipponensis. J. Shellfish Res. 35, 857–863.

Nishio, M., Kawamoto, T., Kawakami, R., Hata, Y., Edo, K., Yamazaki, Y., 2017. Microhabitat use by the endangered Itasenpara bitterling *Acheilognathus longipinnis* (Cyprinidae) during the spawning season in the Moo River, Toyama, Japan. J. Ichthyol. 64, 25–30 (in Japanese with English abstract).

Onikura, N., Nakajima, J., Kouno, H., Sugimoto, Y., Kaneto, J., 2009. Habitat use in irrigation channels by the golden venus chub (*Hemigrammocypris rasborella*) at different growth stages. Zool. Sci. 26, 375–381.

Petraitis, P.S., Dunham, A.E., Niewiarowski, P.H., 1996. Inferring multiple causality: the limitations of path analysis. Funct. Ecol. 10, 421–431.

Pimentel, D., Stachow, U., Takacs, D.A., Brubaker, H.W., Dumas, A.R., Meaney, J.J., O'Neil, A.S.J., Onsi, E.D., Corzilius, B.D., 1992. Conserving biological diversity in agricultural/forestry systems. BioScience 42, 354–362.

Ramankutty, N., Foley, J.A., 1999. Estimating historical changes in global land cover: croplands from 1700 to 1992. Global Biogeochem. Cycles 13, 997–1027.

Simpson, I.C., Roger, P.A., Oficial, R., Grant, I.F., 1994. Effects of nitrogen fertilizer and pesticide management on floodwater ecology in a wetland ricefield. II. Dynamics of microcrustaceans and dipteran larvae. Biol. Fertil. Soils 17, 138–146.

Suzuki, T., Kobayashi, T., Ueno, K., 2008. Genetic identification of larvae and juveniles reveals the difference in the spawning site among Cyprininae fish species/subspecies in Lake Biwa. Environ. Biol. Fishes 82, 353–364.

Taira, M., Hogetsu, K., 1987. Species composition of phyto-and zoo-plankton communities in fertilized and non-fertilized paddy fields. Jpn. J. Limnol. 48, 77–83 (in Japanese with English abstract).

Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W.H., Simberloff, D., Swackhamer, D., 2001. Forecasting agriculturally driven global environmental change. Science 292, 281–284.

Tockner, K., Stanford, J.A., 2002. Riverine flood plains: present state and future trends. Environ. Conserv. 29, 308–330.

Tockner, K., Malard, F., Ward, J.V., 2000. An extension of the flood pulse concept. Hydrol. Process. 14, 2861–2883.

Tscharntke, T., Klein, A.M., Kruess, A., Steffan-Dewenter, I., Thies, C., 2005. Landscape perspectives on agricultural intensification and biodiversity-ecosystem service management. Ecol. Lett. 8, 857–874.

Washitani, I., 2008. Restoration of biologically-diverse floodplain wetlands including paddy fields. Global Environ. Res. 12, 95–99.

Yamazaki, Y., Nakamura, T., Sasaki, M., Nakano, S., Nishio, M., 2014. Decreasing genetic diversity in wild and captive populations of endangered Itasenpara bittering (*Acheilognathus longipinnis*) in the Himi region central Japan, and recommendations for conservation. Conserv. Genet. 15, 921–932.

Zerbe, S., Thevs, N., 2011. Restoring central Asian floodplain ecosystems as natural capital and cultural heritage in a continental desert environment. Landscape Ecology in Asian Cultures. Springer, Japan, pp. 277–297.