

Environmental Factors Influencing Fish Species Distribution in Irrigation Channels around Ariake Sea, Kyushu, Japan

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Abstract

Freshwater ecosystems have suffered a long history of anthropogenic disturbances that are responsible for declining fish populations. Fish populations in irrigation channels, in particular, still remain unprotected and relatively unstudied. This study looked to investigate what environmental variables and anthropogenic disturbances had the greatest influence on fish species distribution in irrigation channels. Fish sampling and environmental data collection was conducted throughout six municipalities, spanning 43 sites, in southern Fukuoka, Kyushu, Japan. A total of 37 fish species and 17 environmental variables were statistically analyzed using detrended correspondence analysis (DCA) and receiver operating characteristic (ROC) curve analysis. DCA results showed that channel width, channel substrate and submerged plants had a statistical correlation with fish species distribution. We believe proper management of irrigation channel substrate conditions and macrophyte cover will go a long way in supporting fish species biodiversity and reducing pressure from invasive species. ROC curve analysis revealed a disparity in the environmental preferences of endangered and invasive species. This result suggests that the distribution of endangered species in irrigation channels may be heavily influenced by invasive species. Further research must be done before drafting an effective management solution.

Keywords: Paddy field; Threatened fish species; Water quality; Freshwater fish; Irrigation ditch

Introduction

The start of Japanese wet-rice cultivation corresponds to the beginning of the Yayoi period 2300-2800 years ago [1]. Archaeological evidence suggests that some of the oldest rice paddies in the Japanese archipelago are those that have been found in northern Kyushu [2]. During this period land was plentiful and cultivation took place along natural flood plains. There was little need for large scale human induced irrigation of paddy fields. Naturally, as the population increased the demand for more land and cultivation increased along with it. Wet-rice cultivation would need to take place away from the natural flood plains in order to meet the demands of the rising population. It was not until the Heian period (794-1159) that natural flood plains were dug out as permanent channels and the rerouting of streams and rivers for the irrigation of paddy fields took place [3]. It was of little concern at that time how the rerouting and construction of irrigation channels would impact the local freshwater fauna.

Japanese rivers differ from most continental rivers because they are short (max. length: 367 km), steep (average slope: 0.44%), and exhibit very flashy flow regimes [4]. Japanese rivers and streams are host to a rich freshwater fish fauna. There are a total of 321 sub-species, 18 orders, 53 families, and 145 genera [5]. Of these species 88 are endemic to Japan and only 11% of the fish are introduced species [6]. In Kyushu the average number of species per major catchment is 43 [7]. However, the number of those species found in irrigation channels is much lower due to the harsher environmental conditions and lentic nature of the water.

Freshwater ecosystems have suffered a long history of anthropogenic disturbances that are responsible for declining fish populations [8]. Some of the prevailing anthropogenic pressures that threaten biodiversity include habitat destruction and fragmentation, eutrophication and chemical pollution, invasive alien species, over-exploitation and climate change [9]. Up until the 1970's environmental issues were mostly ignored in Japan. Most people used their rivers for waste disposal due to their steep nature. Fortunately, during the past decade water quality has significantly improved, fostered by

the enforcement of the Environmental Pollution Prevention Act in 1970 [7]. However, irrigation channels have not encountered the same pressure for rehabilitation. Irrigation channels are fed into by industrial wastewater, agricultural runoff, surface runoff and human sewage that often undergo limited to no treatment. These compounded anthropogenic pressures have drastic effects on the water quality of the irrigation channels.

Due to previous studies largely focusing on fish populations in riverine environments, irrigation channel fish populations have remained relatively unstudied. To increase our understanding of how natural and anthropogenic disturbances shape aquatic communities and individual performance, it is crucial to identify the most vulnerable species and the cause of decline [10]. Scientific identification of the factors threatening biodiversity and understanding of the relative importance of such factors are prerequisite to drafting effective plans [11]. In this study we looked to identify what environmental variables and anthropogenic disturbances had the greatest influence on fish species distribution in irrigation channels and assessed what species may be at risk.

Materials and Methods

Study area

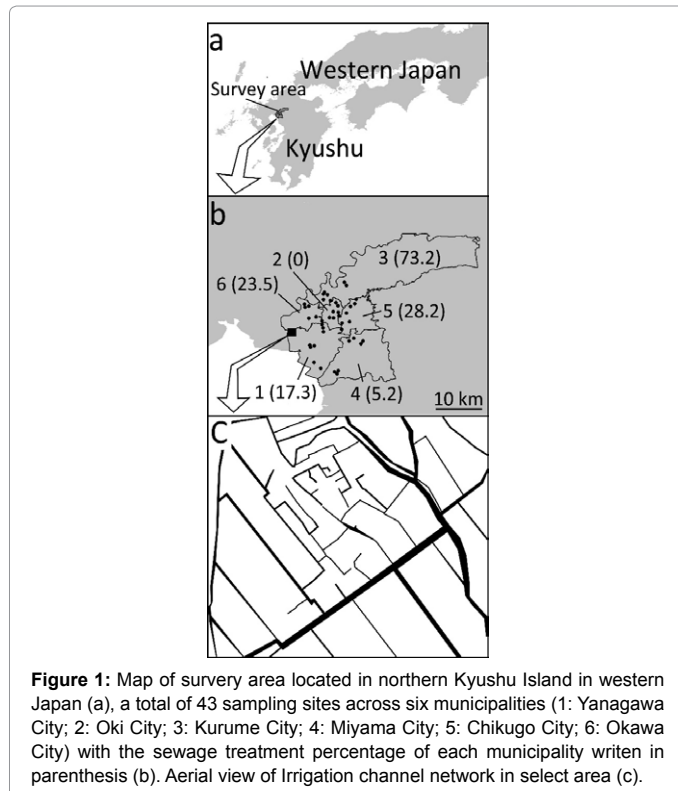
The study was conducted in the irrigation channels of southwestern Fukuoka Prefecture, Kyushu, Japan (Figure 1). The water in these channels originates from the mountains in the east. As water flows downstream it is artificially split into multiple channels and is

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dispersed throughout the city. These channels serve to transport water and to irrigate paddy fields. Water is pumped up from the channel and is used to irrigate the nearby fields. The unused water is then returned to the channel, subsequently altering the chemical composition of the water. As this process is repeated several times traveling downstream, the chemical composition of the water downstream becomes drastically different from that of upstream. The irrigation channels are also fed into by industrial wastewater, agricultural runoff, surface runoff and human sewage that undergo varying stages of treatment depending on the municipality. A total of 43 sites spanning six cities were selected. The Study areas were chosen due to the varying levels of sewage treatment that takes place across the six municipalities (Figure 1). The cities do not have access to large sewage treatment plants and must rely on on-site treatment units. Roughly seven survey sites per city were chosen. Potential survey sites were selected based on size, connectivity, location and estimated species abundance (high and low). Survey site and sewage treatment maps (Figure 1) were created using QGIS ver.2.4.0 [12].

Environmental data collection

On site measurement of pH, electric current (EC), current velocity and dissolved oxygen (DO) was conducted throughout multiple days in the months of June and November, 2014. The measurement of pH was done using a pHTestr 30 (Eutech/Oakton instruments, Vernon Hills, IL USA). EC was measured using an ECTest (Eutech/Oakton instruments, Vernon Hills, IL USA). Current velocity was measured using a VR-301 propeller-type current meter (KENEK Corporation, Tokyo, Japan). DO was measured using a DO-5509 dissolved oxygen meter (Lutron Electronic Enterprise, Taipei, Taiwan).

Channel depth and width were measured on-site using a 2 m measuring rod. Each site was divided into ten evenly spaced segments where the depth and width of each segment was measured and recorded.

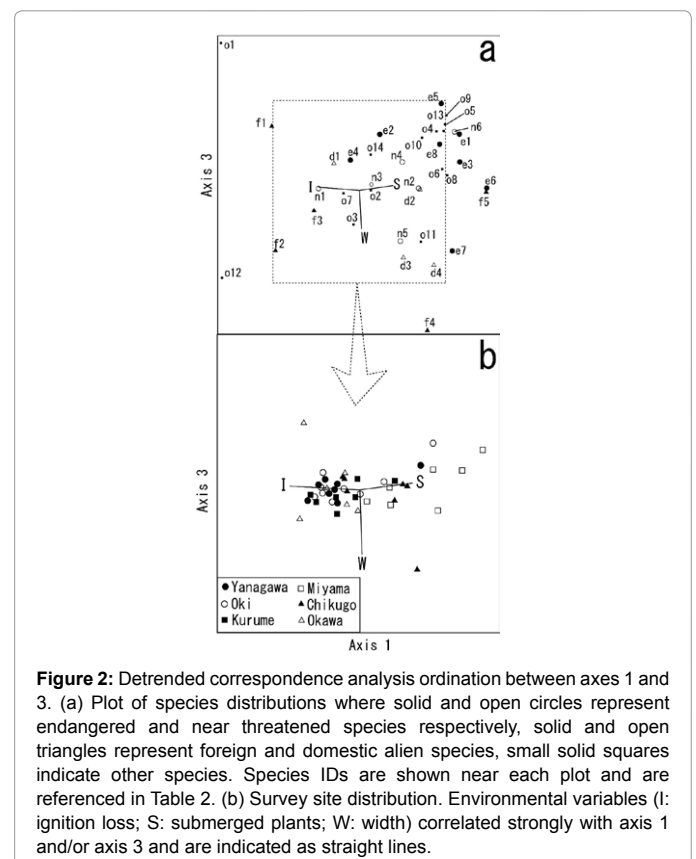
The average depth and width across the ten segments was then used to represent the site as a whole. Concrete revetment and aquatic plant coverage was calculated in a similar fashion. Each site was once again divided into ten evenly spaced segments. In each segment the presence of concrete in the bed and bank was noted. Through the summation of all segments, we were able to calculate the total concrete revetment for that specific site. For aquatic plant coverage, the presence of emergent, floating and submerged plants was recorded for each segment. Again, by totalling each category we were able to calculate the percentage of aquatic plant coverage for each site (Figure 2).

Water and soil samples were collected at each site and stored for future analysis. The water samples were tested for suspended solids (SS), chemical oxygen demand (COD), total nitrogen (TN) and total phosphate (TP) in accordance to the manuals of the Japan Society for Analytical Chemistry [13]. The soil samples were analyzed through loss on ignition testing in accordance to the standards of the Japanese Geotechnical Society [14].

Fish sampling and data analysis

Fish sampling was done concurrently with environmental data collection. Sampling was carried out by a team of four researchers equipped with casting nets and hand nets. A minimum of 30-60 minutes was allotted for sample collection and species identification at each site. As irrigation channels differed greatly in size, the allotted time for each site was properly adjusted. Fish fauna identification was accomplished in accordance to Nakabo [15]. After identification, a picture of the fauna was taken and presence/absence data was recorded. All fish captured were released back into the channel.

We used detrended correspondence analysis (DCA) to analyze the



relationship between 17 environmental variables and species presence/absence distribution of 37 species across 43 sites. The Box-Cox power transformation [16] was applied to improve distribution normality prior to DCA. Statistical analysis software PC-ORD ver. 5.31 (MjM software, Gleneden Beach, Oregon, U.S.A.) was used to perform DCA. A receiver operating characteristic (ROC) curve was used to further analyze the relationship between prominent environmental variables and the presence/absence of each species by using EXCEL add-in software (EXCEL-TOUKEI 2012, SSRI, Shinjuku, Tokyo, Japan). The presence/absence was set to 1/0 in ROC analysis for confirming positive correlation with each environmental variable and 0/1 for confirming negative correlation. When an area under the ROC curve (AUC) was >0.7 it was evaluated as a high or moderate correlation [17]. In addition, ROC curves were also used to determine the optimal cutoff point (COP) for each environmental variable [17].

Results

Environmental variables

The average, standard deviation, minimum and maximum values of all measured environmental variables across 43 sites were calculated and recorded in Table 1. Nearly all environmental variables, aside from pH, had high variability. This is evident from the large standard deviation values which were often greater or equal to the average. Although pH only had a standard deviation of 0.78, the logarithmic nature of the measurement exacerbates this result. However, the min-max range of pH only varied by a factor of 3 and never exceeded the critical level for fish survival. The wide range between min and max of the variables shows that environmental conditions varied drastically among channels.

Fish species

The average, min and max species richness across the 43 sites was recorded in Table 1. The highest species richness was 17, observed in Miyama City. The lowest species richness was 3, observed in Chikugo City. The average number of species observed per site was 9.67. A total of 37 different species were observed throughout the 43 sites (Table 2). Of the 37 species observed eight species were listed on the local red data book as endangered species [18], four species were domestic

Variable	Avg ± SD	Min–Max
pH	7.77 ± 0.78	6.58-9.60
EC (µS/cm)	561.21 ± 236.68	3.07-1254
Velocity	5.38 ± 13.55	0-61
Oxygen	6.92 ± 3.02	2.7-22.9
SS (mg/L)	31.52 ± 32.85	1.29-157.00
COD-Mn (mg/l)	6.90 ± 2.46	2.08-10.93
TN (mg/l)	2.66 ± 0.95	1.03-6.45
TP (mg-P/l)	0.31 ± 0.30-	0.03-1.58
Ignition Loss	9.41 ± 4.31	2.23-20.18
Depth (cm)	90.40 ± 42.98	18.5-250
Width (cm)	443.50 ± 298.96	26.70-1325
Emergent (%)	23.00 ± 29.01	0-100
Floating (%)	11.52 ± 19.93	0-80
Submerged (%)	7.91 ± 17.12	0-70
Conc. Bank (%)	80.42 ± 26.92	0-100
Conc. Bed (%)	21.63 ± 30	0-100
Sp. Richness	9.67 ± 2.95	3-17

Table 1: The average (Avg), standard deviation (SD), minimum (Min) and maximum (Max) of all measured environmental variables.

Species ID	Scientific Name	Num. of Sightings	Total sighting rank
Critically Endangered			
e1	<i>Acheilognathus tabira ssp.</i>	4	22
e2	<i>Hemigrammocypripis rasborella</i>	2	29
Endangered			
e3	<i>Cobitis kaibarai</i>	2	24
e4	<i>Rhodeus ocellatus kurumeus</i>	37	4
e5	<i>Rhodeus atremius atremius</i>	1	34
Vulnerable			
e6	<i>Misgurnus anguillicaudatus</i>	1	30
e7	<i>Sarcocheilichthys variegatus variegatus</i>	2	25
e8	<i>Tanakia lanceolata</i>	7	16
Near Threatened			
n1	<i>Abbottina rivularis</i>	25	5
n2	<i>Acheilognathus rhombeus</i>	1	35
n3	<i>Biwia zezera</i>	14	13
n4	<i>Nipponocypris sieboldii</i>	10	14
n5	<i>Oryzias latipes</i>	20	9
n6	<i>Tanakia limbata</i>	6	17
Domestic Alien			
d1	<i>Carassius cuvieri</i>	38	3
d2	<i>Gnathopogon elongatus</i>	1	36
d3	<i>Opsariichthys uncirostris</i>	17	11
d4	<i>Squalidus chankaensis tsuchigae</i>	6	20
Foreign Invader			
f1	<i>Channa argus</i>	3	23
f2	<i>Gambusia affinis</i>	21	8
f3	<i>Lepomis macrochirus</i>	24	6
f4	<i>Micropterus salmoides</i>	1	37
f5	<i>Paramisgurnus dabryanus</i>	1	31
Other (Native Species)			
o1	<i>Carassius auratus beurgeri</i>	1	33
o2	<i>Carassius auratus langsdorfi</i>	41	1
o3	<i>Cyprinus carpio</i>	18	10
o4	<i>Hemibarbus barbus</i>	2	27
o5	<i>Odontobutis obscura</i>	6	18
o6	<i>Pseudogobio esocinus</i>	6	19
o7	<i>Pseudorasbora parva</i>	41	2
o8	<i>Pungtungia herzi</i>	2	26
o9	<i>Silurus asotus</i>	5	21
o10	<i>Squalidus gracilis gracilis</i>	9	15
o11	<i>Zacco platypus</i>	15	12
o12	<i>Mugil cephalus cephalus</i>	2	28
o13	<i>Tridentiger brevispinis</i>	1	32
o14	<i>Rhinogobius sp.</i>	22	7

Table 2: Total number of sightings and sighting rankings for all observed species across 43 sites.

aliens and four were foreign invaders. The eight endangered and six near threatened freshwater fish species were classified as follows: Critically Endangered: *Acheilognathus tabira ssp.* 2 (Species ID: e1), *Hemigrammocypripis rasborella* (e2); Endangered: *Cobitis kaibarai* (e3), *Rhodeus ocellatus kurumeus* (e4), *Rhodeus atremius atremius* (e5); Vulnerable: *Misgurnus anguillicaudatus* (e6), *Sarcocheilichthys variegatus variegatus* (e7), *Tanakia lanceolata* (e8); and Near Threatened: *Abbottina rivularis* (n1), *Acheilognathus rhombeus* (n2), *Biwia zezera* (n3), *Nipponocypris sieboldii* (n4), *Oryzias latipes* (n5), *Tanakia limbata* (n6). The domestic alien species were *Carassius*

cuvieri (d1), *Gnathopogon elongatus* (d2), *Opsariichthys uncirostris* (d3) and *Squalidus chankaensis tsuchigae* (d4). The foreign invader species were *Channa argus* (f1), *Gambusiaaffinis* (f2), *Lepomis macrochirus* (f3), *Micropterus salmoides* (f4) and *Paramisgurnus dabryanus* (f5). The remaining species were designated as other and were not listed on the red list. These species include freshwater fish (o1: *Carassius auratus beurgeri*, o2: *C. a. langsdorfi*, o3: *Cyprinus carpio*, o4: *Hemibarbus barbus*, o5: *Odontobutis obscura*, o6: *Pseudogobio esocinus*, o7: *Pseudorasboraparva*, o8: *Pungtungia herzi*, o9: *Silurus asotus*, o10: *Squalidus gracilis gracilis*, o11: *Zacco platypus*), brackish water fish o12: *Mugil cephalus cephalus*, o13: *Tridentiger brevispinis* and diadromous fish o14: *Rhinogobius* sp.

The total number of sightings for each individual species is recorded in Table 2. The two most frequently observed species were *C. a. langsdorfi* and *P. parva*. Both were found in 41 out of 43 sites. There were eight species that were observed only once throughout the 43 sites. These species were *A. rhombeus*, *C. a. beurgeri*, *G. elongates*, *M. anguillicaudatus*, *M. salmoides*, *P. dabryanus*, *R. a. attremius* and *T. brevispinis*.

Relationship between fish fauna and environmental variables

The DCA created 3 axes that explained approximately 60% of the ordination of fish fauna in our survey area. The first axis correlated positively with submerged plants and negatively with ignition loss while the third axis correlated negatively with width of channel. Most threatened and near threatened species were plotted on right side, suggesting that these species prefer sites with high submerged plants and low ignition loss. Whilst three foreign invaders were plotted on the left side, suggesting that they are able to adapt to poor sediment quality. Although most sites were plotted around the center of this ordination, all sites of Miyama City were plotted on the right side.

Relationship between fish distribution and correlated environmental variables

Of the 37 species analyzed, ten had a positive and four had a negative correlation with submerged plants. Six species had positive while another six had negative correlations with width of channel. Fourteen species had a positive while twelve had a negative correlation with ignition loss (Table 3). Whilst six endangered species had a positive correlation with submerged plants, three domestic and foreign invader species had a negative correlation with submerged plants. Three endangered species had a negative correlation with channel width where as two invader species had a positive correlation. Five endangered species had a negative correlation with ignition loss while four invader species were positively correlated with ignition loss.

Discussion

Water and soil quality in Japanese irrigation channels

Japanese rivers and lakes are subject to strict water quality guidelines that outline the acceptable levels for both fish and human use [19]. However, Japanese irrigation channels have not faced the same regulation pressures and to date have not received any strict guidelines regarding acceptable water quality levels for fish populations [19]. There are, however, lesser unenforced guidelines for water quality that outline potential goals. The only form of regulation in regards to water quality in irrigation channels deals with the maintenance of non-toxic levels to human health. Results of our environmental variable analysis (Table 1) show that there is a very large range of variability in nearly all measured variables. This means that the water and soil quality of an

Species ID	Submerged			Width			Ignition Loss		
	P/N	AUC	COP	P/N	AUC	COP	P/N	AUC	COP
e1	P	0.79	10		0.36	N/A	N	0.92	6.08
e2	P	0.93	20		0.48	N/A		0.43	N/A
e3	P	0.97	40	N	0.79	204.5	N	0.85	6.08
e4		0.34	N/A	N	0.71	569		0.68	N/A
e5	P	0.80	10		0.33	N/A		0.31	N/A
e6	P	0.92	40	N	0.81	148	N	0.76	6.08
e7	P	0.95	40		0.55	N/A	N	0.91	4.67
e8		0.69	N/A		0.34	N/A	N	0.74	8.62
n1		0.46	N/A		0.33	N/A		0.56	N/A
n2		0.38	N/A	P	0.90	753	N	0.90	3.25
n3		0.42	N/A	N	0.70	468		0.35	N/A
n4		0.62	N/A		0.51	N/A		0.32	N/A
n5		0.61	N/A		0.53	N/A		0.46	N/A
n6	P	0.84	10		0.33	N/A	N	0.90	8.62
d1	N	0.73	20		0.39	N/A	P	0.79	7.52
d2		0.38	N/A	P	0.90	753	N	0.90	3.25
d3		0.60	N/A		0.51	N/A	N	0.76	9.77
d4		0.62	N/A		0.63	N/A	N	0.84	8.62
f1		0.58	N/A		0.58	N/A	P	0.87	11.61
f2	N	0.73	0		0.45	N/A	P	0.65	N/A
f3	N	0.72	0		0.45	N/A	P	0.57	N/A
f4		0.38	N/A	P	1	1325		0	N/A
f5	P	0.92	40	N	0.81	148	N	0.76	6.08
o1		0.38	N/A		0.62	N/A	P	0.90	13.81
o2		0.62	N/A	P	0.87	244		0.49	N/A
o3		0.58	N/A		0.50	N/A		0.65	N/A
o4		0.59	N/A	P	0.71	434.5	N	0.94	3.25
o5		0.64	N/A		0.33	N/A	N	0.73	8.62
o6		0.66	N/A		0.51	N/A	N	0.96	4.67
o7	N	0.95	30		0.51	N/A		0.88	7.52
o8	P	0.87	10		0.40	N/A	N	0.90	4.67
o9		0.58	N/A	N	0.82	365		0.36	N/A
o10		0.64	N/A		0.39	N/A	N	0.72	8.62
o11		0.63	N/A		0.54	N/A	N	0.91	8.62
o12		0.38	N/A	P	0.93	715		0.61	N/A
o13	P	0.80	10		0.50	N/A	N	0.95	2.46
o14		0.49	N/A		0.58	N/A		0.48	N/A

Table 3: Receiver operating characteristic (ROC) curve analysis results comparing the three prominent environmental variables with species presence/absence and absence/presence. Positive and negative correlations are noted as P and N respectively. Area under the curve (AUC) values below 0.7 were determined as having a weak correlation and consequently have had their cut-off point (COP) values omitted. Species ID and scientific names are shown in Table 2.

irrigation channel differs drastically depending on the location of the channel itself and where along the channel the measurement was taken.

Loss on ignition is a method used to estimate the organic matter composition of soil as well as the substrate of marine and freshwater ecosystems [20]. In this study loss on ignition was used to assess

channel substrate and indirectly the quality of water. The lowest recorded pH out of all the sites was 6.58 recorded in Chikugo City. Uncoincidentally, this site was also recorded as having the highest loss on ignition recorded at 20.18%. However, despite the poor water quality and substrate conditions, this site was recorded as having average species richness [9]. This observation hints that there are more factors at play that govern the distribution of fish species in irrigation channels than simply the overall quality of water and substrate. It appears that sewage treatment coverage had little to do with the overall species richness of a municipality. In fact, the top three cities with the greatest sewage treatment coverage had lower species richness than the bottom three treated cities. Some factors that were more important in determining the overall species richness include survey site location and complexity of the irrigation network. Unfortunately, it is difficult to truly gauge the impacts of anthropogenic pressures on fish species as they might be masked or modified by natural factors that govern the performance of individuals and the structure of aquatic communities [21,22].

The quality of channel substrate was directly correlated to current velocity. Sites with a higher current velocity yielded a much lower loss on ignition. It is also important to note that sites with the highest species richness were all lotic environments. This observation can be explained by the proximity of the irrigation channel to the nearest river or stream. Areas of the irrigation channel that are directly fed into by a river or stream possess a current. These areas act as transitional zones between a river and the agricultural channel. Transitional zones have a higher species richness because fish encompassing all lifestyle preferences (both lentic and lotic) must pass through in order to traverse the channel [23]. Another explanation for this observation is that when water in an irrigation channel branches and travels further downstream, the effects of sedimentation become stronger. Areas upstream that possess a current have a mechanism for cycling nutrients and waste disposal while lotic areas further downstream act as deposition sites and subsequently experience lower water and soil quality.

Relationships among fish fauna/each species and environmental variables

Results of the detrended correspondence analysis produced three statistically correlated variables. These variables were channel width, channel substrate (Loss on Ignition) and submerged plants. Although most sites were plotted around the center of this ordination, all sites of Miyama City were plotted on the right side. This is an interesting observation because Miyama City was also noted as having the highest species richness. The reason for this has to do with the complexity of the irrigation channel network and the quality of water. Sites of cities plotted around the center of the ordination have heavily branched networks. Although these cities also possess sites with moving water, they are heavily dominated by areas of still water. The abundance of lentic waters reduces the overall water and soil quality and consequently species richness of these cities. Miyama City on the other hand possesses a rather simple irrigation channel network. This simplicity means far less branches on the network which leads to a stronger overall current velocity present throughout the channel. This characteristic has allowed Miyama City to maintain higher water and soil quality levels as well as overall higher species richness.

Previous studies [24,25] have documented that species diversity and stream fish assemblages are affected by wetted width. In this study, channel width had a statistical correlation with species distribution. However, this does not mean that increasing the width of a channel will

directly increase fish species diversity. This result supports the findings of Yan et al. [24] and suggests that channel width has an influence on fish species assemblages at the species level.

The quality of channel substrate plays a crucial role in the selection of spawning sites for many fish species found in the channel. Five species observed within the channel have been previously found to directly rely on the substrate as a life history trait and for spawning purposes. These species are *Z. platypus*, *P. esocinus*, *S. v. variegatus*, *N. sieboldii* and *A. rivularis* [26]. Six species of bitterling found in the channel have been found to indirectly rely on the quality of substrate. These species are *R. o. kurumeus*, *T. limbata*, *A. tabira* ssp. 2, *T. lanceolata*, *R. a. atremius* and *A. rhombeus* [26]. Bitterling are parasitoids that lay their eggs into live bivalves where their embryos develop inside the gills of the bivalve [27]. For this reason, bitterling species are highly dependent on the presence of bivalves in their environment. As substrate quality decreases the presence of bivalves decreases as well. Naturally, as bivalve presence declines, the population size of bitterling species in that environment will decline as well [28].

ROC curve analysis results from this study support the findings of Nakajima et al. and Onikura et al. [26-28]. In this study 7 out of the 11 species previously found to directly and indirectly rely on channel substrate had a very strong negative correlation ($AUC > 0.90$) with Loss on Ignition (Table 3). The remaining four species (*N. sieboldii*, *A. rivularis*, *R. o. kurumeus* and *R. a. atremius*) did not have a significant statistical correlation. However, the lack of correlation from these species can be justified. The lack of correlation in *R. a. atremius* may be explained by its very small sample size. Although *R. o. kurumeus* did have a significant sample size it was only marginally off ($AUC = 0.68$) from having a significant correlation. On the other hand, both *N. sieboldii* and *A. rivularis* had meaningful sample sizes but showed no statistical correlation. The reason for this is that both species rely on the substratum for spawning purposes. However, sample collection was conducted during feeding and spawning season which is outside of spawning season. During this time they do not rely on the substratum. If sample collection were to be done during spawning season there would likely be a stronger measurable correlation.

The presence or absence of macrophytes can drastically alter fish species diversity and community dynamics of freshwater environments. Macrophytes in lakes and rivers provide cover for fish and macro invertebrates, alter substrate composition, produce oxygen and act as food [29]. In this study the presence of submerged macrophytes was one of the three environmental variables that showed a statistical correlation with fish species distribution. Submerged macrophytes improve the structural heterogeneity of microhabitats in aquatic ecosystems, often providing an important habitat for zooplankton [30]. Submerged macrophytes are utilized by fish for the nursing of juveniles, feeding, and predator avoidance [31]. However, excessive development of free-floating macrophytes on the water surface can reduce the biomass of submerged macrophytes and results in a relatively simple habitat structure [30]. Poor water quality arising from floating weed mats is considered to be the main determinant of reduced fish abundance and diversity [32].

In this study, Of the 37 fish species surveyed, ten had a positive correlation and four had a negative correlation with the presence of submerged macrophytes (Table 3). An important observation to note is that three of the four negatively correlated species were domestic and foreign aliens. This shows that irrigation channels are still foreign environments for these species and that they generally prefer environmental similar in conditions to that of their native range of

rivers and lakes. The other negatively correlated species was *P. parva*. This species has been noted as having both high life history plasticity and wide-scale habitat use [27]. It was noted by Onikura and Nakajima [33] that structural revetment conditions and macrophyte cover were unimportant for this species. However, the results of this study suggests that when presented with multiple environmental conditions, *P. parva* has a strong aversion (AUC=0.95) to channels with submerged macrophyte cover. The possible reason for this discrepancy may have to do with the scale of the survey area where said research was conducted. The survey sites chosen by Onikura and Nakajima [33] were much smaller in size and all possessed heavy macrophyte cover. In this scenario *P. parva* was found to have no preference as its options were limited and it was forced to adapt to environments with heavy macrophyte cover. However, the survey sites chosen in this study encompassed sites with varying degrees of macrophyte cover. It was in this type of scenario that *P. parva* was found to have a strong aversion to submerged plants due to having the option of preference.

Relationship between native and invasive species

The most commonly observed domestic alien species was *C. cuvieri*. It was the third most observed species overall and was observed at 38 out of 43 sites (Table 2). *C. cuvieri* originates from Lake Biwa and has been widely distributed throughout Japan as a game fish. *C. cuvieri* has been shown to be fairly hardy and adept at avoiding predation at the juvenile stage [34]. DCA results show that *C. cuvieri* is not particularly averted to environments with poor soil and water quality conditions. ROC curve analysis (Table 3) shows that *C. cuvieri* may in fact have a statistical preference (AUC=0.79) to areas with poor soil conditions. This is a unique characteristic shared only by three other invasive species (Table 2). *Carassius auratus beurgeri* was also noted as having a strong positive correlation, however, the small sample size puts the validity of the result into question. We hypothesize that the natural hardiness of these invasive species has allowed them to succeed and even show an affinity to areas with poor substrate conditions. Native species are naturally averted to such conditions and leave the invasive species with little competition.

The most commonly observed foreign invasive species was *L. Macrochirus*. It was the sixth most observed species overall and was present at 24 out of 43 sites (Table 2). *L. Macrochirus*, commonly known as bluegill, is one of the most commonly introduced fish species in the world [35]. It is characterized by an opportunistic behaviour that can lead to aggressive dominance [36]. Studies have shown that the introduction of blue gill into Japanese waters induces a range of changes at multiple trophic levels [37]. In irrigation channels *L. Macrochirus* has been shown to have an allopatric distribution with *O. latipes*. Although no direct correlation between these two species was found in this study. ROC curve analysis suggests that *L. Macrochirus* has a negative correlation (AUC=0.72) with submerged plants. Two other invasive species (*d1*, *f2*) were also found to have a negative correlation with submerged plants. On the other hand, six out of eight endangered species and one threatened species had positive correlations to submerged plants. This observation shows that there is a large disparity between the environmental preferences of endangered and invasive species in terms of submerged plants. We believe a possible explanation for this is that the ability of invasive species to outcompete the endangered species in areas with little macrophyte cover has caused the endangered species to have a strong preference or simply an illusion of preference for environments with heavy macrophyte cover.

Endangered species showed a preference for irrigation channels with a narrow width (Table 3). Whereas invasive species tended to prefer

wider channels. We believe this can be attributed to invasive species a) showing a natural preference to environmental conditions similar to their native range of rivers and lakes b) outcompeting endangered species in wider channels causing a decline in their numbers in those environments.

Conclusions

Fish species distribution was found to be statistically correlated with channel width, channel substrate and submerged plants. Nearly all domestic and endangered species had a positive correlation with submerged plants. Although these macrophytes, in the eyes of a layperson, may seem like unwanted debris clogging up the channel, they are in fact a vital part of a healthy ecosystem. In order to support fish species biodiversity we advise against the total clearing of macrophyte cover in irrigation channels. All domestic and endangered species had a negative correlation with substrate quality while nearly all domestic and foreign invaders had a positive correlation. This result suggests that domestic and endangered species strongly rely on good substrate conditions while invasive species are more adaptive. We believe the management of irrigation channel substrate conditions will go a long way in supporting fish species biodiversity and reducing pressure from invasive species. However, further research must be done before drafting an effective management solution.

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