



Title	Role of flood-control basins as summer habitat for wetland species : A multiple-taxon approach
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1 Title:
2 Role of flood-control basins as summer habitat for wetland species - A multiple-taxon
3 approach

4
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23

24 **Abstract** (219 words)

25 In the era of global climate change, the risk of large-scale flood disasters has been
26 increasing. Green infrastructure has gained increasing attention as one of the strategies
27 for adaptation to mega-floods because it can concurrently enhance regional biodiversity
28 and ecosystem services. Previous studies have assessed the efficacy of flood-control
29 infrastructure in protecting biodiversity in urban areas. However, whether such
30 infrastructure enhances biodiversity in other environments remains largely unknown. In
31 this study, we assessed the function of flood-control basins constructed for flood risk
32 management as summer habitat for wetland species in agricultural landscapes. We
33 compared the species assemblages of four different taxa (fishes, aquatic insects, birds
34 and plants) among four water body types (flood-control basins, channelized
35 watercourses, drainage pumping stations, and remnant ponds). We found that the
36 flood-control basins had comparable or higher species richness and abundance of most
37 taxa than the other water body types. We also found that the species compositions in the
38 flood-control basins were characterized by pioneer species, which prefer shallow water
39 or can adapt to fluctuations in water levels (e.g., herbivorous insects, shorebirds, and
40 hygrophytes). These findings suggest that flood-control basins can provide summer
41 habitat for wetland species, especially for species that inhabit environments with
42 hydrological variation, and utilizing flood-control basins as green infrastructure is a
43 reasonable option for conserving regional biodiversity in agricultural landscapes.

44

45 **Keywords**

46 Anthropogenic infrastructure; Biodiversity; Green infrastructure; Flood risk reduction

47 **1. Introduction**

48 The disaster risk of large-scale floods has been increasing with the changing
49 climate. Mean air temperature has globally increased by 0.72 °C since the 19th century,
50 and in the East Asian region, the increase in heavy precipitation associated with frequent
51 floods could cause serious damage to infrastructure, livelihoods, and settlements (IPCC,
52 2014). Conventional infrastructure (i.e., gray infrastructure) has been widely used to
53 reduce flood disaster risk but may not be enough to prevent future disasters due to the
54 elevated magnitude and intensity of the disasters, increased maintenance cost, and
55 limited tax income (Ministry of Land, Infrastructure, Transport and Tourism of Japan,
56 2011; Palmer *et al.*, 2015; Auerswald *et al.*, 2019). Under these natural and
57 socioeconomical conditions, green infrastructure (GI) has gained attention as one of the
58 adaptation strategies to mega-floods. GI is defined as “a strategically planned network
59 of natural and seminatural areas with other environmental features designed and
60 managed to deliver a wide range of ecosystem services such as water purification, air
61 quality, space for recreation and climate mitigation and adaptation” in the European
62 Union (EU) (European Commission, 2016). GI is superior to gray infrastructure in
63 terms of the introduction and maintenance costs and ecosystem service provisions; thus,
64 the utilization of GI and/or a combination of gray infrastructure and GI are possible
65 solutions for future disaster risk reduction (Ministry of Environment of Japan, 2016;
66 Monty *et al.*, 2016).

67 In riverine ecosystems, introducing GI constructed for flood risk management
68 could also contribute to the restoration of degraded wetland biodiversity (Opperman *et*
69 *al.*, 2009; Greco and Larsen, 2014). Previous studies showed that flood-control
70 infrastructure in urban areas, such as rainwater retention ponds, can provide an
71 alternative habitat for wetland species (Scher and Thiéry, 2005; Simaika *et al.*, 2016;
72 Oertli, 2018). However, studies on the efficiency of the infrastructure in biodiversity
73 conservation have mainly been conducted in urban areas and are limited in other
74 landscapes (but see Diefenderfer *et al.*, 2012). To protect urban areas, which are
75 generally situated at downstream, lower elevations, from flooding, we should explore
76 the preservation and restoration of wetland GI in upstream rural areas from a catchment
77 perspective. In addition, considering the uncertainty of GI function for defense against
78 natural hazards and that of the natural hazard’s magnitude, the economic benefits of
79 introducing GI could be higher than those of gray infrastructure in areas where the
80 human population size is lower than a certain threshold (Onuma and Tsuge, 2018).
81 Therefore, assessing the ecological function of flood-control infrastructure in

82 less-populated areas, such as agricultural landscapes, is the essential first step toward
83 sustainable freshwater management using GI.

84 In the agricultural landscape of northern Japan, large flood-control basins (total
85 of 1,150 ha) have been constructed since 2008 (Hokkaido Regional Development
86 Bureau, 2018). A flood-control basin is infrastructure that temporally stores floodwater
87 in a large storage area surrounded by levees during a high-flow event. In the present
88 study, we aimed to evaluate the abilities of the basins to provide summer habitat for
89 wetland species. A multiple-taxon approach is effective in comprehensively
90 understanding the effect of anthropogenic activities on ecosystems because biological
91 responses to environmental changes generally differ among taxa (e.g., Lawton *et al.*,
92 1998; Mueller and Geist, 2016). Thus, we selected four freshwater taxa (fishes, aquatic
93 insects, wetland birds, and wetland plants) as target species, which include primary
94 producers, herbivores, and predators in wetland ecosystems. In addition, there are
95 various water body types in agricultural landscapes, such as ditches, rivers, and ponds,
96 and each water body shows type-specific species compositions (Davies *et al.*, 2008;
97 Ishiyama *et al.*, 2016). Moreover, each water body type has a distinct function in
98 regional biodiversity (Pander *et al.*, 2018; Pander *et al.*, 2019). We investigated these
99 taxa in summer in four different water body types, namely, flood-control basins,
100 channelized watercourses, drainage pumping stations, and remnant ponds. We then
101 compared the species assemblages of the flood-control basins with those of the three
102 other water body types and clarified the ecological function of flood-control basins as
103 newly created wetland habitats.

104

105 **2. Methods**

106 **2.1. Study area**

107 We conducted a field survey in the central part of the Ishikari Plain, Hokkaido,
108 northern Japan. In this region, river channelization and farmland expansion started
109 approximately one hundred years ago, and most floodplain wetlands had already been
110 converted to farmland (GSI, 2000). River flooding often occurs in this region because of
111 the gentle bed slope of the Chitose River. In particular, the flood caused by heavy
112 rainfall in August 1981 caused severe damage to urban and agricultural lands in this
113 region (inundated area; 614 km²) (Segawa *et al.*, 2008; Hokkaido Regional
114 Development Bureau, 2010). For flood risk management in this region, the Japanese
115 Ministry of Land, Infrastructure, Transport and Tourism decided to construct six
116 flood-control basins, which temporally reserve floodwater in compartments surrounded
117 by levees (Fig. 1a). These basins are located near the main river or tributary of the

118 Chitose River, and the area of the reservoirs ranges from 150 to 280 ha (total 1,150 ha).
119 One basin, the Maizuru flood-control basin, was finished in 2016, and five are under
120 construction.

121 We selected 5 flood-control basins, including the Maizuru basin, as survey sites.
122 The four basins other than the Maizuru basin were under construction; thus, we selected
123 part of the reservoirs as survey sites (Table 1; Fig. 1a). We also selected other water
124 body types: 4 channelized watercourses, 5 remnant ponds, and 5 drainage pumping
125 stations for comparison with flood-control basins (Table 1). Channelized watercourses
126 are semilentic, linear, small water bodies and are mainly used as irrigation canals (Fig.
127 1b). Watercourses in the study region are severely channelized, and sludge cleanings are
128 regularly conducted in some of them. The mean water velocity in watercourses is 0.102
129 m/s. Drainage pumping stations consist of waterways flowing from farmlands and a
130 reservoir that is connected to a main channel via a sluice gate (Fig. 1c). During a heavy
131 rainfall event, the sluice gate is closed to prevent back-flow from a main channel. The
132 reservoirs in drainage pumping stations with aquatic vegetation were selected as survey
133 sites. Here, we regard the watercourses and drainage pump stations as typical gray
134 infrastructures because these infrastructures were widely constructed for only human
135 land-use development. Remnant ponds are permanent water bodies that include cut-off
136 channels and remnants of the back marsh. These ponds are not used for agricultural
137 activities (Fig. 1d), and can be regarded as semi-natural wetlands.

138

139 **2.2. Fish**

140 Fish surveys were conducted once from July 4th to 19th, 2016. We caught fish
141 using one fyke net (0.4 m diameter, 2.0 m bag length, and 3 m wing length) and two
142 minnow traps (0.25 m width, 0.48 m length, and 0.25 m depth) at each site. We set these
143 traps for 24 hours near shores covered by aquatic vegetation. We recorded the numbers
144 and types of species of collected fish and quickly released them to the survey sites. We
145 also categorized the collected fishes into native or nonnative species according to the
146 Hokkaido Blue List 2010 (Hokkaido Prefecture, 2010) and assessed the status of native
147 fish species according to the national and regional red lists (Ministry of Environment of
148 Japan, 2017; Hokkaido Prefecture, 2018).

149

150 **2.3. Aquatic insects**

151 An aquatic insect survey was conducted once from July 4th to 19th, 2016. We
152 established 10 nearshore survey lines covered by aquatic vegetation at each study site.
153 We collected insects using a D-frame net (0.3 m width, 1.8 m length, and 1 mm mesh

154 size) for 30 seconds at each point. We preserved samples in 70 % ethanol and brought
155 them to the laboratory. Then, we categorized them into species or family levels
156 according to Kawai and Tanida (2005) and Ito *et al.* (1977) and recorded the number of
157 species and abundance at each site. In this study, we considered several genera, such as
158 the *Cercion* and *Sympetrum*, as morphospecies groups in the analysis because their
159 larvae cannot be categorized at the species level (Table A1). We also recorded the
160 number of species and abundance of aquatic insects collected by one fyke net and two
161 fishing baskets in the fish surveys and included samples in the analysis. We assessed the
162 status of these species according to national and regional red list (Hokkaido Prefecture,
163 2001; Ministry of Environment of Japan, 2017).

164 165 **2.4. Wetland birds**

166 We conducted a point-count survey to investigate bird assemblages in July
167 2016. We established a vantage observation point adjacent to the focal water body and
168 recorded the numbers of species and individuals occurring within a 200 m radius. All
169 sites were surveyed three times. We categorized each recorded species into wetland or
170 nonwetland species based on Takagawa *et al.* (2011) and assessed their status according
171 to national and regional red lists (Hokkaido Prefecture, 2017; Ministry of Environment
172 of Japan, 2017). We included only wetland species in the analyses. For abundance, we
173 used the greatest value among the three visits.

174 175 **2.5. Wetland plants**

176 We surveyed vascular plant species in both habitats (i.e., open water and shore)
177 once from July to August 2016. First, we set 2 to 9 quadrats (2 m x 2 m) in each site to
178 include all types of plant communities. The survey quadrats were set within an area that
179 was 5 m from the land direction and 5 m from the water direction across the water
180 border. Second, we recorded the number of species and coverage of wetland species in
181 each quadrat. In this study, we regarded hygrophytes and hydrophytes (emergent,
182 submerged, floating-leaved, and free-floating aquatic macrophytes) as wetland plants.
183 We also categorized wetland species into native or nonnative species according to the
184 Hokkaido Blue List 2010 (Hokkaido Prefecture, 2010) and assessed the status of these
185 species according to national and regional red lists (Hokkaido Prefecture, 2001;
186 Ministry of Environment of Japan, 2017) (Table A1). We used the number of species
187 and coverage of native wetland species in the analysis.

188 189 **2.6. Environmental factors**

190 To investigate the habitat qualities of each water body type, we surveyed water
191 quality and surrounding environmental factors. In July and September 2016, we
192 measured dissolved oxygen (DO), electrical conductivity (EC), water temperature, and
193 pH at one point in each site using an HQd portable meter (HQ40d, Hack, Colorado, US)
194 and EC meter (WM-32EP, DKK-TOA, Tokyo, Japan). We measured DO within 5 hours
195 after sunrise. We collected 100 ml of water at each site and calculated NH₄-N, NO₂-N,
196 PO₄-P, total N (TN), and total P (TP) with a portable spectrophotometer (TNP-10,
197 DKK-TOA, Tokyo, Japan). These measured values of each site were averaged for the
198 two periods. In July and September 2016, we measured water levels by a grade rod with
199 a 5 cm level at 20 points in each site, at 10 points on the shore and at 10 points in the
200 center of the water body. Water levels were averaged for each position (center or shore)
201 and period, and the fluctuation of water levels at each site was calculated as the absolute
202 value of the difference in water levels between July and September. We also visually
203 estimated the vegetation cover on the water bodies in 5 % increments at each site in July
204 2016. For the surrounding environmental factors of each site, we measured the area of
205 the studied water body, the area of the surrounding water body, and the ratio of forest
206 shoreline by using the most recent digital vegetation map (scale of 1: 25,000) (Ministry
207 of Environment of Japan, 2004). We calculated the area of the surrounding water body
208 within two buffer sizes (500 and 1,000 m) at each site; the surrounding water body did
209 not include the surveyed water body. We conducted these procedures using Quantum
210 GIS (QGIS Development Team, 2017).

211

212 **2.7. Statistical analyses**

213 To investigate whether species richness and abundance/coverage differed
214 among water body types, first, we constructed generalized linear models (GLMs) for
215 each taxon and estimated species richness and abundance/coverage of each taxon in
216 each water body type. In the GLMs, we used the number of species or
217 abundance/coverage of each taxon and water body type as response and explanation
218 variables, respectively. We applied a Poisson distribution and a negative binominal
219 distribution to GLMs for species richness and abundance/coverage, respectively. For
220 wetland plants, we used the number of quadrats as an offset variable. Second, we
221 conducted a multiple comparison analysis using the above constructed models to
222 examine whether species richness and abundance/coverage differed among the water
223 body types. In addition, we constructed GLMs with a normal distribution to examine
224 whether each environmental factor differed among the water body types. Environmental
225 factors and water body types were used as response and explanation variables,

226 respectively.

227 To investigate the difference in species composition of each taxon among the
228 water body types, we ordinated species compositions by nonmetric multidimensional
229 scaling (NMDS). In the NMDS, we used the log-transformed
230 species-abundance/coverage data of each taxon and Bray-Curtis scale as the length
231 index. For wetland plants, we averaged the coverage of each species at each site. We
232 plotted the distribution of the study sites, the primary species, and red list species. We
233 also conducted a permutational multivariate analysis of variance (PERMANOVA) to
234 test the difference in species composition of each taxon among the water body types.
235 We excluded the one and two watercourse sites for the analyses of native fishes and
236 wetland birds because we did not observe any target species of each taxon at these sites.

237 We used R (R development core team, 2018) for all analyses except
238 PERMANOVA. We used the MASS R package (Ripley *et al.*, 2018), the multcomp R
239 package (Hothorn *et al.*, 2017), and the vegan R package (Oksanen *et al.*, 2018) for the
240 GLMs with a negative binominal distribution, multiple comparison analysis, and
241 NMDS, respectively. We used Past (Hammer *et al.*, 2001) for PERMANOVA.

242

243 **3. Results**

244 **3.1 Fish**

245 We caught 3,268 and 3,027 individuals consisting of 10 native and 6 nonnative
246 species, respectively (Table A1). *Gymnogobius castaneus* and *Pungitius* sp. (freshwater
247 type) were dominant native fish species, while *Rhodeus ocellatus ocellatus* and
248 *Pseudorasbora parva* were dominant nonnative species. Both the number of species and
249 abundance of native fish and the number of nonnative fish did not differ among the
250 water body types (Fig. 2ab). However, the abundance of nonnative fish in remnant
251 ponds and flood-control basins was significantly greater than that in channelized
252 watercourses (Fig. 2b). Although red list species, such as *Phoxinus phoxinus*
253 *sachalinensis* (Php) and *Lefua nikkonis* (Ln), tended to occur in the remnant ponds and
254 drainage pumping stations (Fig. 3a), the difference in the species compositions of native
255 fishes among the water body types was not significant (PERMANOVA: Table 2a).

256

257 **3.2 Aquatic insects**

258 We caught 2,951 individuals consisting of 31 species, including morphospecies
259 (Table A1), and did not catch any nonnative species. Species of the Corixidae family
260 and *Sympetrum* spp. were dominant among the study sites. In comparison to the
261 channelized watercourses, in the remnant ponds and flood-control basins, the number of

262 aquatic insect species was higher (Fig. 2c). The abundance of aquatic insects was higher
263 in the flood-control basins than in the channelized watercourses and drainage pumping
264 stations and did not differ from the abundance in the remnant ponds (Fig. 2c). NMDS
265 showed that the channelized watercourses, remnant ponds, and flood-control basins
266 were separately plotted, and the drainage pumping stations were plotted in the middle of
267 the other water body types. Most endangered species occurred to the right of the x-axis,
268 indicating that these species tended to occur in the remnant ponds and flood-control
269 basins (Fig. 3b). The species composition of aquatic insects differed between the
270 flood-control basin and other water body types (PERMANOVA, Table 2b).

271

272 **3.3 Wetland birds**

273 We observed 16 wetland bird species (Table A1). *Anas zonorhyncha* was the
274 dominant species among the sites. The number of wetland bird species was significantly
275 higher in the flood-control basins than in the channelized watercourses, while
276 abundance did not differ among the water body types (Fig. 2d). NMDS showed that the
277 species composition of the flood-control basins overlapped with that of the other water
278 body types except the channelized watercourses (Fig. 3c), although the difference
279 between flood-control basins and watercourses was not statistically significant
280 (PERMANOVA, Table 3c).

281

282 **3.4 Wetland plants**

283 We observed 39 native and 1 nonnative species of wetland plants (Table A1).
284 The main native species were *Phragmites australis* (Cav.) Trin. ex Steud., *Oenanthe*
285 *javanica* (Blume) DC. and *Trapa japonica* Flerow, while there was only one nonnative
286 species (*Phalaris arundinacea* L.). The number of wetland plants did not differ among
287 the water body types, while coverage was lower in the channelized watercourses than in
288 the other water body types (Fig. 2e). NMDS showed that all water body types except the
289 channelized watercourses slightly overlapped with each other (Fig. 3d). NMDS also
290 showed that endangered species were broadly distributed across the various water body
291 types, except the channelized watercourses (Fig. 3d). Most species were hygrophytes
292 and emergent macrophytes, but submerged (Po, Table A1) and floating-leaved (Trj,
293 Table A1) macrophytes were also found in the flood-control basins. In addition, three
294 endangered species; *Carex capricornis* Meinsh. ex Maxim., *Monochoria korsakowii*
295 Regel et Maack, and *Monochoria vaginalis* (Burm.f.) C. Presl ex Kunth occurred only
296 in the flood-control basins. The species composition of wetland plants in the

297 flood-control basins differed from that in the channelized watercourses and ponds
298 (PERMANOVA; Table 2d).

299

300 **3.5 Local and landscape environments**

301 In terms of water quality, EC was higher in the channelized watercourses than
302 in the other water body types, and the water temperature was higher in the ponds and
303 flood-control basins than in the other types. Other water quality indices (DO, pH,
304 NH₄-N, NO₂-N, PO₄-P, TN, and TP) did not differ among the water body types (Table
305 A2). Water levels in the center area did not differ among the water body types in either
306 season. On the shoreline, however, the summer water levels were deeper in the ponds
307 than in the flood-control basins, the autumn water levels were deeper in the ponds than
308 in the channelized watercourses and drainage pumping stations, and the fluctuation in
309 water levels did not differ among the sites (Table A2, Fig. A1). For surrounding
310 environmental factors, the highest ratio of forest shoreline was found in the ponds
311 (Table A2). The mean values of vegetation cover on the water bodies tended to be lower
312 in the channelized water courses and flood-control basins than in the drainage pumping
313 stations and remnant ponds, although the mean values did not significantly differ among
314 the water body types (Table A2).

315

316 **4. Discussion**

317 **4.1 Fish**

318 We found that the number of species and abundance of native fishes did not
319 differ among the water body types. In addition, fish assemblages in the flood-control
320 basins did not differ from those in the other types of water bodies. These results indicate
321 that flood-control basins can function as a habitat for common species. In agricultural
322 landscapes, dispersal and recolonization of wetland fishes heavily depend on the
323 structure of the habitat network (i.e., hydrologic connectivity) (Ishiyama *et al.*, 2014;
324 Ishiyama *et al.*, 2015). All studied flood-control basins were connected with main
325 channels or branches, and the water body surrounding the basins was relatively large
326 (Table A2). Such high immigration potential of the basins may facilitate the rapid
327 colonization of common species after construction. However, we also found that the
328 basins were unlikely to provide habitat for red list species. Two red list species,
329 *Pungitius tymensis* and *Phoxinus phoxinus sachalinensis*, occurred only in the remnant
330 ponds or drainage pumping stations (Table A1). One red list species, *Lefua nikkonis*,
331 occurred in the flood-control basins but at a lower abundance than that in the other
332 water body types (Table A1). These red list species prefer standing water (Kawanabe

333 and Mizuno, 1998); Ishiyama *et al.* (2014) suggested that it was difficult for such lentic
334 species to widely colonize water bodies in agricultural landscapes because altered
335 hydrologic connections, such as channelized streams, can impede the dispersal of
336 species with poor swimming ability. Management of the surrounding watercourses with
337 GI construction would increase the habitat availability of the flood-control basins for
338 more diverse species in the future.

339 Notably, flood-control basins could also provide a habitat for nonnative fish
340 species. In fact, we found that nonnative fish species such as *Pseudorasbora parva* and
341 *Rhodeus ocellatus ocellatus* colonized most of the water body types we surveyed, and
342 the abundance of nonnatives in the remnant ponds and flood-control basins was high
343 (Fig. 2b, Table A1). In the basins, *Pseudorasbora parva* was also one of the dominant
344 species (Table A1), although the impact of this species on native ecosystems is unknown
345 (National Institute for Environmental Studies, 2018). Invasions of nonnative species
346 have globally altered freshwater ecosystems (Gallardo *et al.*, 2016). Monitoring
347 invasion success and its ecological consequences in flood-control basins is required to
348 understand the benefits and risks to biodiversity provided by flood-control basins.

349 However, the fish survey was conducted only at one shoreline point per site.
350 Under the limited sampling, we could not consider the habitat heterogeneity of each
351 water body, suggesting that the ecological functions of some waterbodies for fish
352 assemblages might be underestimated. Additional investigations or surveys using
353 different sampling methods may help to further confirm our results (Mueller *et al.*,
354 2017).

355 356 4.2 Aquatic insects

357 We found that the species richness and abundance of aquatic insects in the remnant
358 ponds and flood-control basins were higher than in the other water body types (Fig. 2c)
359 and that most of the red list species occurred in the remnant ponds (7 of 8 species, Table
360 A1). The abundance and heterogeneity of aquatic plants largely contribute to the
361 sustained diversity of aquatic insects (Thomaz and Cunha, 2010; Florencio *et al.*, 2014),
362 and tree canopy cover can also support the organic inputs that these insects use for
363 habitat or foraging (Valente-Neto *et al.*, 2016). In our study region, vegetation cover on
364 the water and amount of forest edge were relatively high in the remnant pond sites
365 (Table A2), resulting in an increased species richness and abundance of aquatic insects,
366 including red list species.

367 Our results also showed that species compositions in the flood-control basins
368 differed from those in the remnant ponds, although species richness and abundance of

369 aquatic insects did not differ between these water body types (Figs. 2c, 3b). This result
370 could be because the abundance of pioneer species in the basins was larger than in other
371 the water body types. For instance, the dominant species in the basins was from the
372 family Corixidae (Table A1). Most of these species could colonize the basins after or
373 even during construction of the basins because these species feed on algae or detritus
374 and thus are a common group in new standing water (Bloechl *et al.*, 2010). At the same
375 time, some odonate species, such as *Lestes sponsa* and *Aeshna mixta soneharai*,
376 occurred more frequently in the remnant ponds than in the other water body types (Fig.
377 3c, Table A1). Vegetation around aquatic habitats significantly affects lentic odonate
378 assemblages (Kadoya *et al.*, 2004; Simaika *et al.*, 2016). For example, *Lestes sponsa*
379 inhabits ponds where emergent plants grow, and immature adults migrate from the
380 water and inhabit the forest edge (Ozono *et al.*, 2012). *Aeshna mixta soneharai* also
381 inhabits ponds where tall emergent plants grow and lays egg on dead shoots of emergent
382 plants (Ozono *et al.*, 2012). The rich forest and aquatic vegetation cover of the remnant
383 ponds likely provide a higher-quality habitat for these odonates at both adult and larval
384 stages.

385 For the red-listed species, the insect community of the flood-control basins was
386 characterized by predaceous diving beetles, such as *Cybister japonicus*, *Hyphydrus*
387 *japonicus*, and *Graphoderus adamsii* (Fig. 3b). Several studies have reported that
388 aquatic insects, including these coleopteran species, rapidly colonized new standing
389 water, and insect diversity increased for several years (e.g., Fairchild *et al.*, 2000;
390 Stewart and Downing, 2008; Gallardo *et al.*, 2012). This result may indicate that
391 flood-control basins provide a habitat for some rare aquatic insects.

392

393 4.3 Wetland birds

394 We found comparable or higher species richness and abundance and similar
395 species compositions in the flood-control basins than in the other waterbody types,
396 suggesting that this artificial type of infrastructure can be an alternative habitat for the
397 regional wetland bird community. These results can be explained by the suitable
398 vegetation conditions in the flood-control basins for various wetland birds with
399 contrasting habitat requirements. First, despite the young age of the flood-control basins
400 (< 10 years after the construction), their vegetation coverages did not significantly differ
401 from those of the other water body types (Table A2). This result indicates that the
402 flood-control basins have been experiencing rapid colonization of aquatic plants. Rich
403 vegetation can provide both nesting and foraging habitats for several local breeding
404 waterbirds such as *Tachybaptus ruficollis* and two *Anas* duck species (Mori *et al.*, 2000;

405 Hattori and Mae, 2001), all of which were observed in the flood-control basins. Second,
406 although species compositions did not differ among the water body types, the
407 flood-control basins may be the only habitat still inhabitable for species preferring
408 shallow-water wetlands, such as migrating shorebirds. In fact, 6 of the 7 shorebird
409 species, including national and local endangered *Tringa glareola*, were unique in the
410 flood-control basins. Migrating shorebirds have been in decline globally due mainly to
411 the prevalent loss of natural wetlands in their migration flyways (Amano *et al.*, 2010;
412 Sutherland *et al.*, 2012). Thus, the flood-control basins, at least currently, may be
413 important stopover sites for their long-distance migration.

414

415 4.4 Wetland plants

416 Species richness and coverage of wetland plants were higher in the
417 flood-control basins, drainage pumping station, and remnant pond than in the
418 channelized watercourse (Fig. 2e), suggesting that the linear structure of the shoreline
419 (Fig. 1b) and flat bottom maintained by regular sludge cleaning in the watercourse
420 resulted in decreased wetland plant diversity and abundance. Such an anthropogenic
421 flow modification might decrease the diversity in riparian vegetation communities by
422 altering the hydrology (Lacoul and Freedman, 2006; Harvolk *et al.*, 2014). Species
423 compositions in the flood-control basins were similar to the species composition in the
424 drainage pumping stations (Table 2) and were characterized by plants that can change
425 their life forms between hygrophyte and emergent depending on the water levels
426 (species that have “e, h” in Table A1). Fluctuations in the water levels were slightly
427 higher along the shorelines of the flood-control basins and drainage pumping stations
428 than along the shorelines of the other types of water bodies, although the values were
429 not significant (Table A2, Fig. A1), which should permit plants with higher
430 morphological plasticities to survive in the flood-control basins and drainage pumping
431 stations. In addition, the flood-control basins included plants of all types of life forms,
432 such as hygrophytes that are adaptive to temporal drying and flooding (Casanova and
433 Brock, 2000), emergent and floating-leaved macrophytes that prefer shallow water
434 depths (Lacoul and Freedman, 2006), and submerged macrophytes that are highly
435 adaptive to deep water (Jeppesen *et al.*, 2000), demonstrating the variable water depth
436 inside each flood-control basin. Rare plant species that uniquely occurred in the
437 flood-control basins were the common weeds in the paddy fields that are tolerant to
438 water level fluctuations and soil drying in autumn and winter (Tominaga, 2003).
439 Fluctuations in the water levels were slightly higher in the centers and shorelines of the
440 flood-control basins than in the other types of water bodies (Table A2), a likely reason

441 the rare plant species survived. Conventional water management, such as the
442 construction of dams and levees, has led to hydrologic stability in wetlands and
443 decreased habitat for species that adapt to temporal fluctuations in water levels (e.g.,
444 Nielsen *et al.*, 2012). Thus, the existing flood-control basins are responsible for
445 providing habitat to various life forms of plants, including rare plant species.

446

447 4.5 Conclusion and conservation implications

448 By comparing flood-control basins with the other water body types, we found
449 that the basins provided an alternative habitat for several wetland taxa in summer,
450 including red list species. We also found that the species compositions in the basins
451 were characterized by pioneer species, which prefer shallow water depths or adapt to
452 fluctuations in water levels (e.g., herbivorous insects, shore birds, and hygrophytes).
453 However, we investigated four taxa in only one season. The ecological importance of
454 each water body can change seasonally because wetland organisms can use different
455 environments depending on the season. Additional studies examining the seasonal
456 variations in environments and species compositions among multiple taxa and water
457 bodies are needed to obtain a more comprehensive understanding of flood-control
458 basins.

459 Our results showed that the channelized watercourses generally presented low
460 abundance and biodiversity for most taxa. Channelization often leads to simplified
461 habitat heterogeneity and decreased biodiversity of wetland species (Nakano and
462 Nakamura, 2008; Nagayama and Nakamura, 2018). These previous studies also support
463 that channelized watercourses in this region did not contribute to the creation of wetland
464 habitat (i.e., gray infrastructure). However, recent studies demonstrate that watercourses,
465 among other lentic water bodies, can function as dispersal corridors of wetland
466 organisms and provide an important habitat in agricultural landscapes (Ishiyama *et al.*,
467 2014; Ishiyama *et al.*, 2015). Therefore, rehabilitation of gray infrastructure, such as
468 increasing habitat complexity and connectivity, would contribute to increasing the
469 biodiversity in the gray infrastructure and in the surrounding lentic water bodies,
470 including flood-control basins. On the other hand, surprisingly, drainage pump stations
471 that we regarded as gray infrastructures provided important habitat for some wetland
472 plants, such as hygrophyte and emergent species. This result suggests that drainage
473 pump stations can also work as green infrastructure as well as flood-control basins.

474 Flood-control basins in this region serve important ecological functions to
475 compensate for wetland loss. However, the habitat uniqueness of the basins will likely
476 change with future vegetation succession. The direction of vegetation succession in

477 wetlands generally depends on trends in the hydrologic regime (Lacoul and Freedman,
478 2006), which suggests that succession would be promoted due to the sediment
479 accumulation carried by slow water inflows. Sedimentation can cause a decline in
480 hydrophytic plants and the development of hygrophytes and terrestrial plants in the
481 basins, resulting in quantitative and qualitative changes in the habitats of higher
482 trophic-level taxa, such as aquatic insects, fishes, and birds. Fortunately, flood-control
483 basins are designed to retain river water, and the release timing and/or frequency can be
484 operated via a sluice gate. Thus, controlling the sediment amounts and/or water levels in
485 the basins could be one possible solution. Land managers should monitor the condition
486 and direction of vegetation succession in the basins and understand effective measures
487 for keeping the present habitat condition through adaptive management.

488

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494

495

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685

686 **TABLE**

687 Table 1 Area and water depth of the four studied water body types

688

689 Table 2 PERMANOVA pairwise tests between the water body types

690 F values (F) and Bonferroni-correlated *p* values (*p*) are shown.

691

692 **FIGURE**

693

694 Fig. 1 Pictures of surveyed water body types

695 The picture of the Maizuru basin was provided by the Sapporo Development and
696 Construction Department, Hokkaido Regional Development Bureau.

697

698 Fig. 2 Estimated species richness and abundance of four taxa.

699 CW: channelized watercourse, DPS: drainage pumping station, POND: remnant pond,
700 and FCB: flood-control basin. Black circles denote values estimated by GLMs. The
701 whiskers indicate 95 % CI. Gray circles denote each observed value. Different letters
702 indicate significant differences in the multiple comparison analysis ($p < 0.05$).

703

704 Fig. 2 (continued)

705

706 Fig. 2 (continued)

707 The values for species richness and coverage of vegetation indicate values per quadrat
708 (2×2 m).

709

710

711 Fig. 3 Nonmetric multidimensional scaling (NMDS) ordination of four taxa.

712 The stress values for native fish and aquatic insects are 0.157 and 0.177, respectively.

713 Symbols indicate the study sites in the channelized watercourses (cross marks),

714 drainage pumping stations (gray squares), ponds (white triangles), and flood-control

715 basins (black circles). The text in each plot indicates the position of each species. For

716 native fish and wetland birds, we plotted all species, while for aquatic insects and

717 wetland vegetation, we plotted species that occurred at more than three survey sites or

718 were listed in the national or regional red list. Underlined bold text indicates the species
719 listed on red lists.

720 **Native fish;** Ga sp. (*Gasterosteus* sp.), Puf (*Pungitius* sp. (freshwater type)), Put

721 (*Pungitius tymensis*), Gyc (*Gymnogobius castaneus*), Ln (*Lefua nikkonis*), Nb

722 (*Noemacheilus barbatulus toni*), Th (*Tribolodon hakonensis*), Caa (*Carassius auratus*

723 *langsdorfii*), Php (*Phoxinus phoxinus sachalinensis*), and Hn (*Hypomesus*

724 *nipponensis*).

725 **Aquatic Insects;** Ls (*Lestes sponsa*), Sp (*Sympetma paedisca*), Ia (*Ischnura asiatica*),

726 Col (*Coenagrion lanceolatum*), Ce spp. (*Cercion* spp.), Epb (*Epithea bimaculata*

727 *sibirica*), Sy spp. (*Sympetrum* spp.), Anp (*Anax parthenope*), Aem (*Aeshna mixta*

728 *soneharai*), Ae_j (*Aeshna juncea juncea*), Hya (*Hydrophilus acuminatus*), Bp (*Berosus*
729 *punctipennis*), En_j (*Enochrus japonicus*), Hy_j (*Hyphydrus japonicus*), Cy_j (*Cybister*
730 *japonicus*), Gra (*Graphoderus adamsii*), Col spp. (*Colymbetinae* spp.), Ha spp.
731 (*Haliplidae* spp.), No_j (*Noterus japonicus*), Noa (*Noterus angustulus*), Gy spp.
732 (*Gyrinidae* spp.), Ge spp. (*Gerridae* spp.), Apm (*Appasus major*), Ap_j (*Appasus*
733 *japonicus*), R spp. (*Ranatra* spp.), Not (*Notonecta triguttata*), and Cor spp. (*Corixidae*
734 spp.).

735

736 Fig. 3 (continued)

737 The stress values for wetland birds and wetland plants are 0.111 and 0.156, respectively.

738 **Wetland birds;** Pn (*Podiceps nigricollis*), Tar (*Tachybaptus ruficollis*), Aig (*Aix*
739 *galericulata*), Anp (*Anas platyrhynchos*), Anz (*Anas zonorhyncha*), Ayf (*Aythya*
740 *fuligula*), Ach (*Actitis hypoleucos*), Car (*Calidris ruficollis*), Cat (*Calidris temminckii*),
741 Trb (*Tringa brevipes*), Trg (*Tringa glareola*), Trn (*Tringa nebularia*), Chd (*Charadrius*
742 *dubius*), Gc (*Gallinula chloropus*), Ara (*Ardea alba*), and Arc (*Ardea cinerea*).

743 **Wetland plants;** Lea (*Lemna aoukikusa* Beppu et Murata), Pes (*Persicaria sagittata*
744 (L.) H. Gross var. *sibirica* (Meisn.) Miyabe), Scw (*Scirpus wichurae* Boeck. f. *concolor*
745 (Maxim.) Ohwi), Jud (*Juncus decipiens* (Buchenau) Nakai), Tyl (*Typha latifolia* L.),
746 Mov (*Monochoria vaginalis* (Burm.f.) C. Presl ex Kunth), Alp (*Alisma*
747 *plantago-aquatica* L. var. *orientale* Sam.), Acc (*Acorus calamus* L.), Caca (*Carex*
748 *capricornis* Meinsh. ex Maxim.), Lyl (*Lycopus lucidus* Turcz. ex Benth.), Oj (*Oenanthe*
749 *javanica* (Blume) DC.), My (*Myriophyllum ussuriense* (Regel) Maxim.), Lue (*Ludwigia*
750 *epilobioides* Maxim. subsp. *epilobioides*), Scr (*Scirpus radicans* Schk.), Civ (*Cicuta*
751 *virosa* L.), Sis (*Sium suave* Walter var. *nipponicum* (Maxim.) H. Hara), Trj (*Trapa*
752 *japonica* Flerow), Scta (*Schoenoplectus tabernaemontani* (C.C.Gmel.) Palla), Po
753 (*Potamogeton octandrus* Poir. var. *octandrus*), Zl (*Zizania latifolia* (Griseb.) Turcz. ex
754 Stapf), Spe (*Sparganium erectum* L.), Mok (*Monochoria korsakowii* Regel et Maack),
755 Lyt (*Lysimachia thyrsoflora* L.), and Pha (*Phragmites australis* (Cav.) Trin. ex Steud.)

756

757 **Highlights**

758 3 to 5 bullet points (maximum 85 characters, including spaces, per bullet point).

759

760 ● We investigated fish, aquatic insects, birds, and plants in flood-control basins.

761 ● We compared species assemblages in flood-control basins with other water bodies.

762 ● Flood-control basins had comparable or higher diversity for most taxa.

763 ● Use of flood-control basins is useful for conserving regional biodiversity.

764

765 **TABLE**

766 Table 1 Area and water depth of the four studied water body types

Water body type	n	Area (ha)		Water depth (cm)			
		Mean	Min–Max	Summer		Autumn	
				Mean	Min–Max	Mean	Min–Max
Channelized watercourse	4	0.34	0.2–0.4	61.75	27.0–113.5	44.19	24.5–66.0
Drainage pumping station	5	1.07	0.2–3.1	61.05	17.0–109.0	34.4	13.0–59.0
Remnant pond	5	1.09	0.3–2.1	116.95	46.5–379.5	100.65	46.5–237.5
Flood-control basins	5	28.68	4.1–100.9	59.35	11.5–181.5	77.05	13.0–221.5

767

768 Table 2 PERMANOVA pairwise tests between the water body types

(a) Native fish

	Statistic	Drainage pumping station	Remnant pond	Flood-control basin
Channelized watercourse	F	0.85	1.30	1.10
	<i>P</i>	1.00	1.00	1.00
Drainage pumping station	F		0.29	2.21
	<i>P</i>		1.00	0.30
Remnant pond	F			2.87
	<i>P</i>			0.18

(b) Aquatic insects

	Statistic	Drainage pumping station	Remnant pond	Flood-control basin
Channelized watercourse	F	1.96	2.96	4.90
	<i>P</i>	0.33	0.10	0.04
Drainage pumping station	F		1.18	2.10
	<i>P</i>		1.00	0.05
Remnant pond	F			2.51
	<i>P</i>			0.04

769 F values (F) and Bonferroni-correlated *p* values (*p*) are shown.

770

771 Table 2 (continued)

(c) Wetland birds

	Statistic	Drainage pumping station	Remna nt pond	Flood-control basin
Channelized watercourse	F	3.13	6.23	1.31
	<i>P</i>	0.90	0.28	1.00
Drainage pumping station	F		4.37	0.71
	<i>P</i>		0.11	1.00
Remnant pond	F			2.06
	<i>P</i>			0.15

(d) Wetland plants

	Statistic	Drainage pumping station	Pond	Flood-control pond
Channelized watercourse	F	1.72	4.02	3.85
	<i>p</i>	0.96	0.05	0.05
Drainage pumping station	F		1.10	1.03
	<i>p</i>		1.00	1.00
Pond	F			3.18
	<i>p</i>			0.04

772

773

774

a) Flood-control basins



b) Channelized watercourses



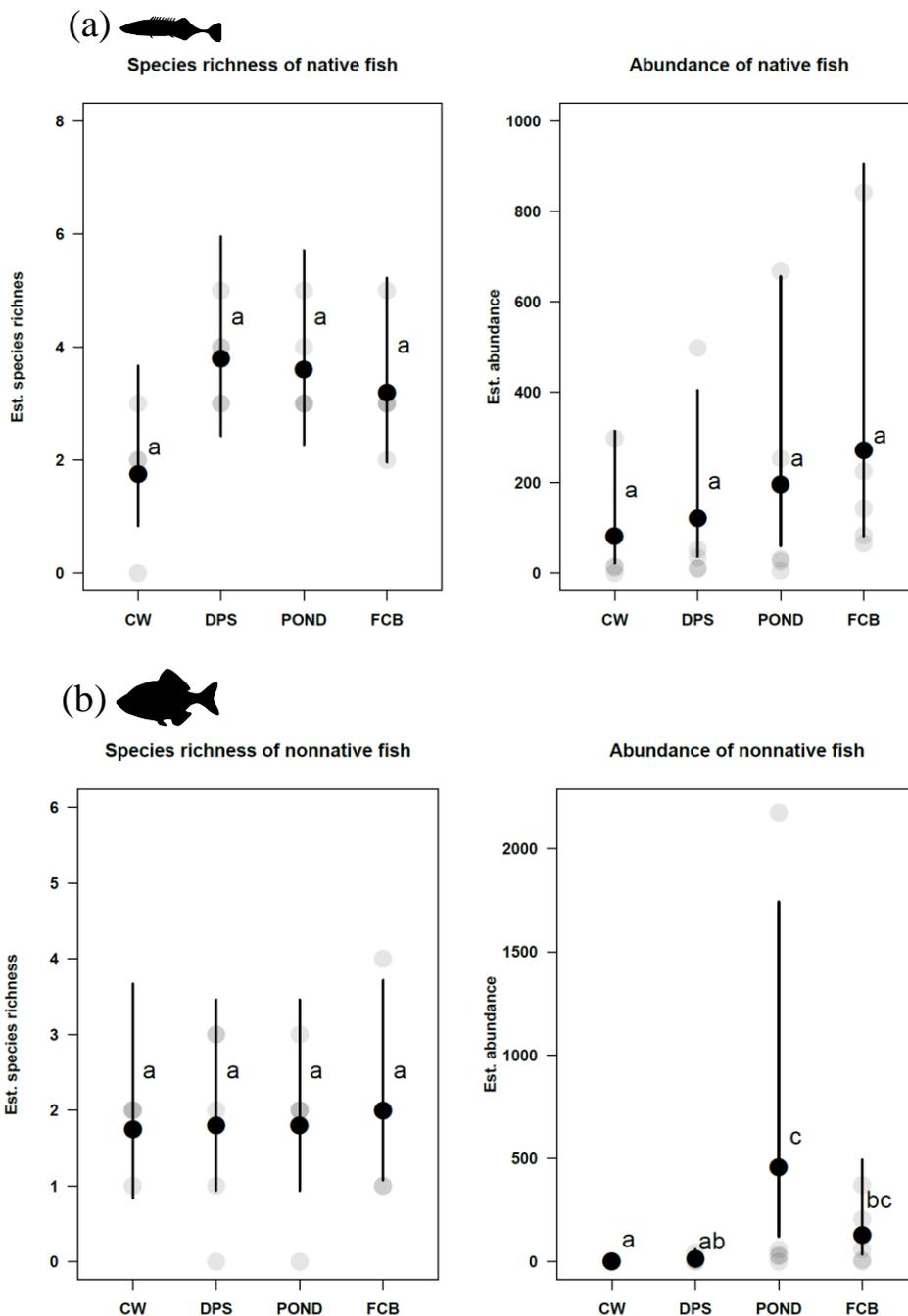
c) Drainage pumping stations



d) Remnant ponds



778 The picture of the Maizuru basin was provided by the Sapporo Development and
779 Construction Department, Hokkaido Regional Development Bureau.



780

781 Fig. 2 Estimated species richness and abundance of four taxa.

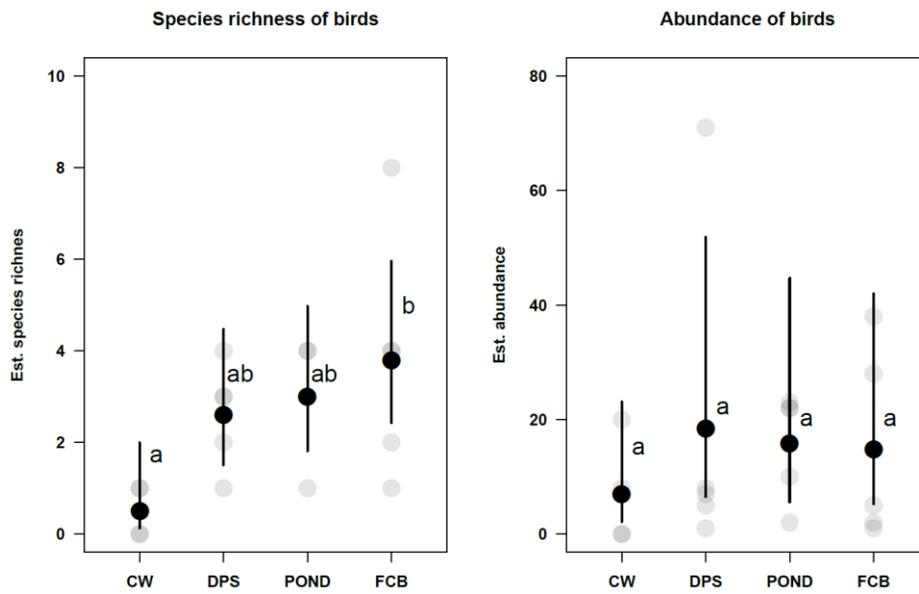
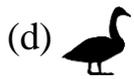
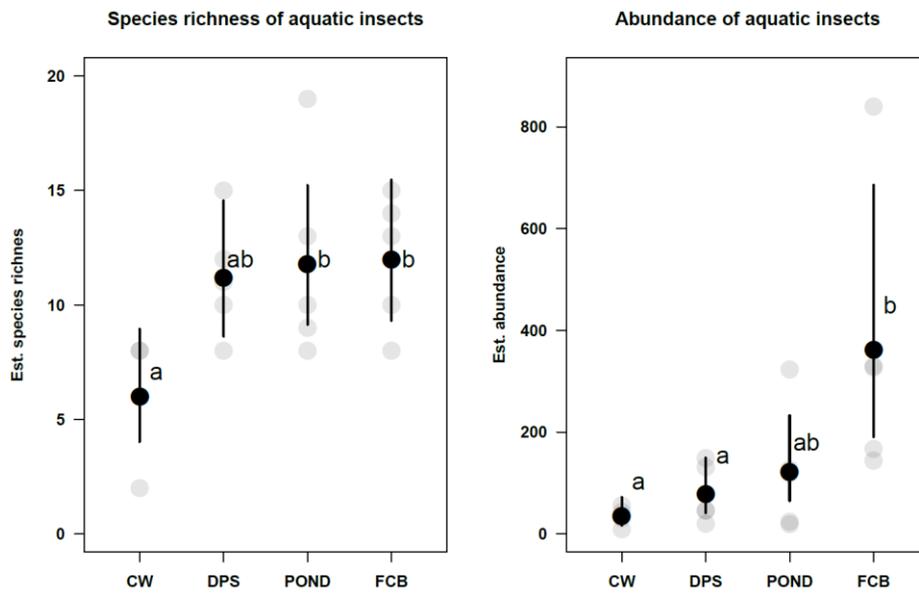
782 CW: channelized watercourse, DPS: drainage pumping station, POND: remnant pond,

783 and FCB: flood-control basin. Black circles denote values estimated by GLMs. The

784 whiskers indicate 95 % CI. Gray circles denote each observed value. Different letters

785 indicate significant differences in the multiple comparison analysis ($p < 0.05$).

786

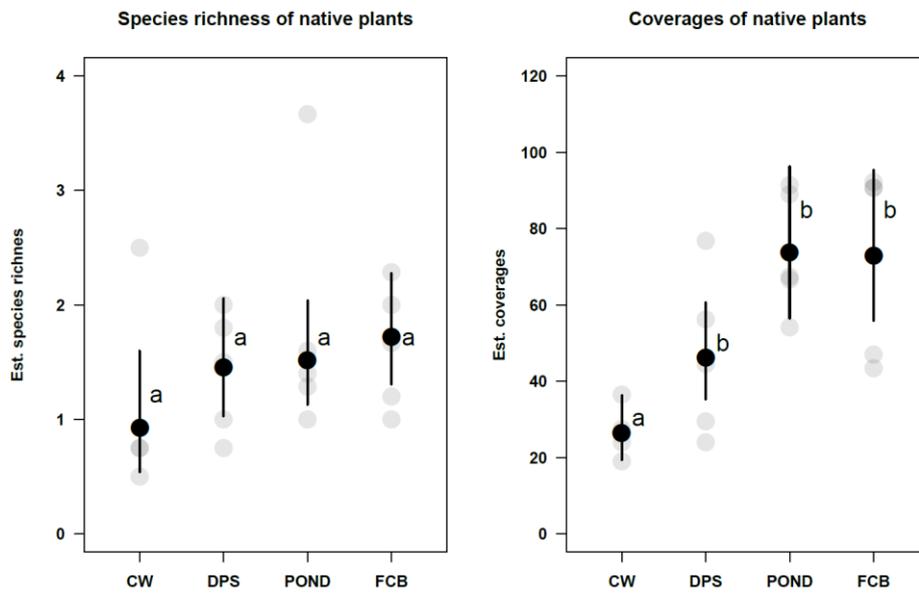


787

788 Fig. 2 (continued)

789

(e) 



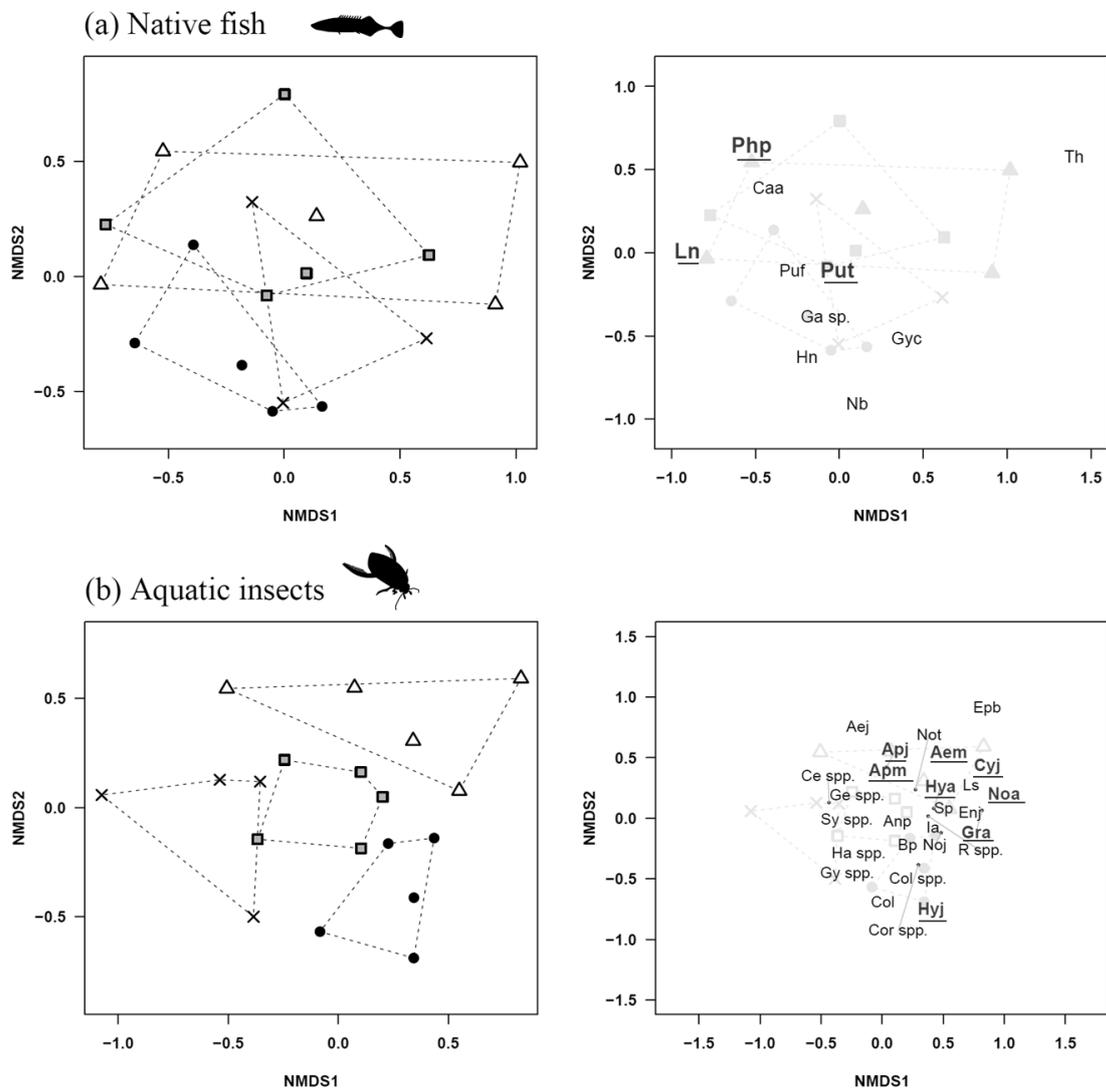
790

791 Fig. 2 (continued)

792 The values for species richness and coverage of vegetation indicate values per quadrat
793 (2×2 m).

794

795



797

798 Fig. 3 Nonmetric multidimensional scaling (NMDS) ordination of four taxa.

799 The stress values for native fish and aquatic insects are 0.157 and 0.177, respectively.

800 Symbols indicate the study sites in the channelized watercourses (cross marks),

801 drainage pumping stations (gray squares), ponds (white triangles), and flood-control

802 basins (black circles). The text in each plot indicates the position of each species. For

803 native fish and wetland birds, we plotted all species, while for aquatic insects and

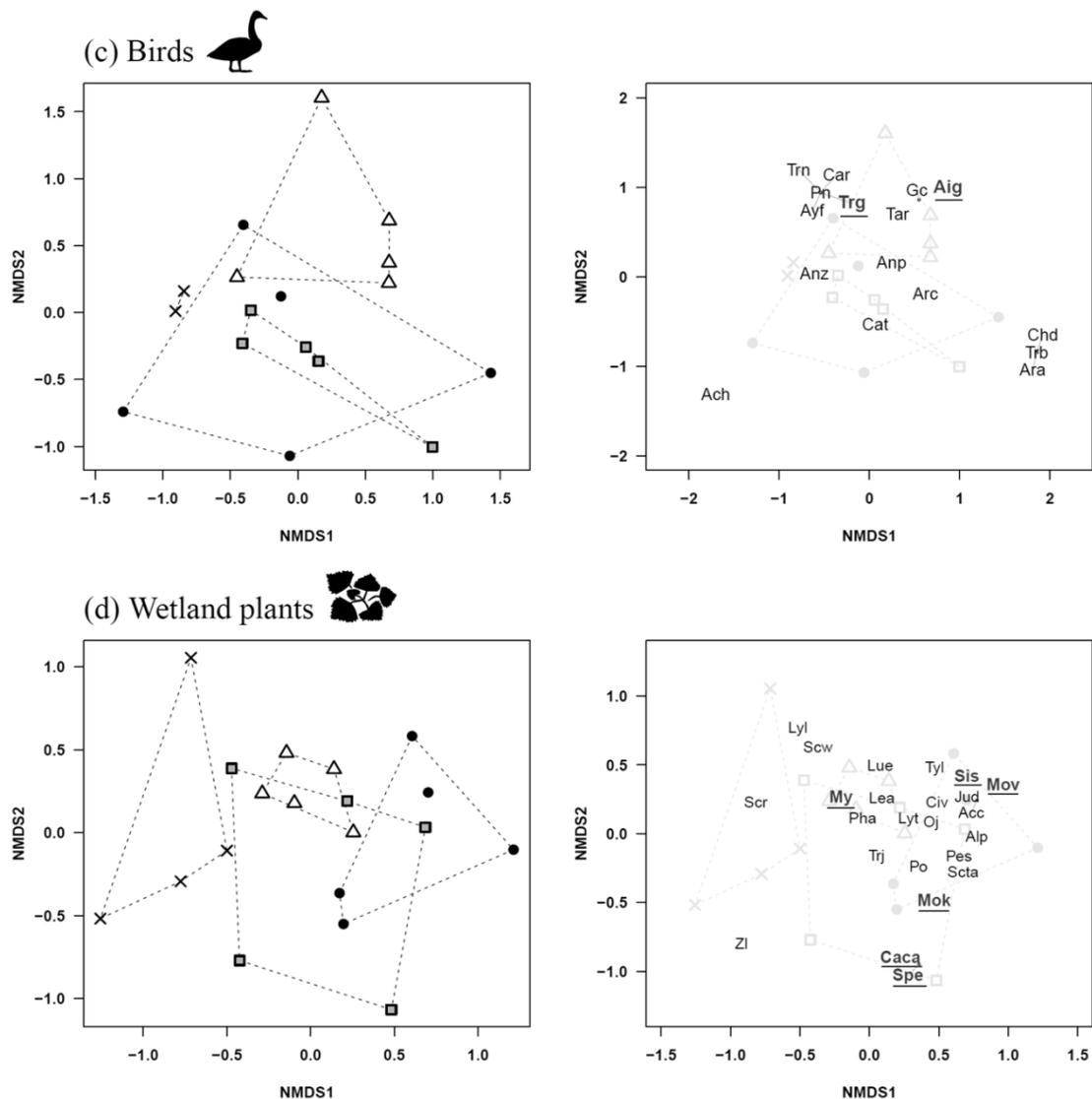
804 wetland vegetation, we plotted species that occurred at more than three survey sites or

805 were listed in the national or regional red list. Underlined bold text indicates the species

806 listed on red lists.

807 **Native fish;** Ga sp. (*Gasterosteus sp.*), Puf (*Pungitius sp.* (freshwater type)), Put808 (*Pungitius tymensis*), Gyc (*Gymnogobius castaneus*), Ln (*Lefua nikkonis*), Nb

809 (*Noemacheilus barbatulus toni*), Th (*Tribolodon hakonensis*), Caa (*Carassius auratus*
810 *langsdorfii*), Php (*Phoxinus phoxinurus sachalinensis*), and Hn (*Hypomesus*
811 *nipponensis*).
812 **Aquatic Insects;** Ls (*Lestes sponsa*), Sp (*Sympecma paedisca*), Ia (*Ischnura asiatica*),
813 Col (*Coenagrion lanceolatum*), Ce spp. (*Cercion* spp.), Epb (*Epithea bimaculata*
814 *sibirica*), Sy spp. (*Sympetrum* spp.), Anp (*Anax parthenope*), Aem (*Aeshna mixta*
815 *sonoharai*), Aej (*Aeshna juncea juncea*), Hya (*Hydrophilus acuminatus*), Bp (*Berosus*
816 *punctipennis*), Enj (*Enochrus japonicus*), Hyj (*Hyphydrus japonicus*), Cyj (*Cybister*
817 *japonicus*), Gra (*Graphoderus adamsii*), Col spp. (*Colymbetinae* spp.), Ha spp.
818 (*Haliplidae* spp.), Noj (*Noterus japonicus*), Noa (*Noterus angustulus*), Gy spp.
819 (*Gyrinidae* spp.), Ge spp. (*Gerridae* spp.), Apm (*Appasus major*), Apj (*Appasus*
820 *japonicus*), R spp. (*Ranatra* spp.), Not (*Notonecta triguttata*), and Cor spp. (*Corixidae*
821 spp.).
822



823

824 Fig. 3 (continued)

825 The stress values for wetland birds and wetland plants are 0.111 and 0.156, respectively.

826 **Wetland birds;** Pn (*Podiceps nigricollis*), Tar (*Tachybaptus ruficollis*), Aig (*Aix*
 827 *galericulata*), Anp (*Anas platyrhynchos*), Anz (*Anas zonorhyncha*), Ayf (*Aythya*
 828 *fuligula*), Ach (*Actitis hypoleucos*), Car (*Calidris ruficollis*), Cat (*Calidris temminckii*),
 829 Trb (*Tringa brevipes*), Trg (*Tringa glareola*), Trn (*Tringa nebularia*), Chd (*Charadrius*
 830 *dubius*), Gc (*Gallinula chloropus*), Ara (*Ardea alba*), and Arc (*Ardea cinerea*).

831 **Wetland plants;** Lea (*Lemna aoukikusa* Beppu et Murata), Pes (*Persicaria sagittata*
 832 (L.) H. Gross var. *sibirica* (Meisn.) Miyabe), Scw (*Scirpus wichurae* Boeck. f. *concolor*
 833 (Maxim.) Ohwi), Jud (*Juncus decipiens* (Buchenau) Nakai), Tyl (*Typha latifolia* L.),
 834 Mov (*Monochoria vaginalis* (Burm.f.) C. Presl ex Kunth), Alp (*Alisma*
 835 *plantago-aquatica* L. var. *orientale* Sam.), Acc (*Acorus calamus* L.), Caca (*Carex*

836 *capricornis* Meinsh. ex Maxim.), Lyl (*Lycopus lucidus* Turcz. ex Benth.), Oj (*Oenanthe*
837 *javanica* (Blume) DC.), My (*Myriophyllum ussuriense* (Regel) Maxim.), Lue (*Ludwigia*
838 *epilobioides* Maxim. subsp. *epilobioides*), Scr (*Scirpus radicans* Schk.), Civ (*Cicuta*
839 *virosa* L.), Sis (*Sium suave* Walter var. *nipponicum* (Maxim.) H. Hara), Trj (*Trapa*
840 *japonica* Flerow), Scta (*Schoenoplectus tabernaemontani* (C.C.Gmel.) Palla), Po
841 (*Potamogeton octandrus* Poir. var. *octandrus*), Zl (*Zizania latifolia* (Griseb.) Turcz. ex
842 Stapf), Spe (*Sparganium erectum* L.), Mok (*Monochoria korsakowii* Regel et Maack),
843 Lyt (*Lysimachia thyrsoflora* L.), and Pha (*Phragmites australis* (Cav.) Trin. ex Steud.).
844
845

846

APPENDIX

847

848

Table A1 Species list and abundance of each species (mean value \pm standard deviation)

Species	Abbreviation	Red list life form ^{*1}	Study sites											
			CW			DPS			POND			FCB		
Fishes														
Native														
<i>Gasterosteus</i> sp.	Ga sp.											18.00	\pm	23.63
<i>Pungitius</i> sp. (freshwater type)	Puf		21.75	\pm	33.30	61.40	\pm	100.87	33.60	\pm	56.34	57.60	\pm	42.31
<i>Pungitius tymensis</i>	Put	VU / NT				0.20	\pm	0.45						
<i>Gymnogobius castaneus</i>	Gyc		58.75	\pm	111.58	2.40	\pm	2.88	2.20	\pm	2.05	187.20	\pm	338.96
<i>Lefua nikkonis</i>	Ln	EN / EN				33.40	\pm	69.76	7.60	\pm	16.99	1.80	\pm	3.49
<i>Noemacheilus barbatulus toni</i>	Nb		0.25	\pm	0.50									
<i>Tribolodon hakonensis</i>	Th					0.20	\pm	0.45	4.40	\pm	8.73			
<i>Carassius auratus langsdorfii</i>	Caa		0.50	\pm	1.00	2.40	\pm	2.88	109.00	\pm	216.77	1.80	\pm	3.03
<i>Phoxinus phoxinus sachalinensis</i>	Php	NT / NT				20.80	\pm	43.18	39.60	\pm	87.43			
<i>Hypomesus nipponensis</i>	Hn											5.00	\pm	11.18
Nonnative														
<i>Silurus asotus</i>			0.75	\pm	0.96	1.20	\pm	2.17						
<i>Channa argus</i>									0.20	\pm	0.45			
<i>Misgurnus anguillicaudatus</i>						0.60	\pm	1.34				2.80	\pm	3.56
<i>Cyprinus carpio</i>												0.20	\pm	0.45
<i>Rhodeus ocellatus ocellatus</i>			0.50	\pm	0.58	2.80	\pm	4.38	398.60	\pm	885.15	13.60	\pm	22.17
<i>Pseudorasbora parva</i>			1.00	\pm	0.82	10.60	\pm	16.80	59.40	\pm	77.25	112.60	\pm	160.29
Aquatic Insects														
<i>Lestes sponsa</i>	Ls					1.60	\pm	3.05	18.40	\pm	38.93	0.20	\pm	0.45
<i>Sympecma paedisca</i>	Sp					2.60	\pm	3.97	7.40	\pm	9.69	6.20	\pm	6.38
<i>Ischnura asiatica</i>	Ia					0.20	\pm	0.45	0.20	\pm	0.45	0.40	\pm	0.89
<i>Coenagrion lanceolatum</i>	Col		0.75	\pm	0.96	0.60	\pm	0.89	0.20	\pm	0.45	8.40	\pm	8.62
<i>Cercion</i> spp.	Ce spp.		1.50	\pm	2.38	0.20	\pm	0.45	3.40	\pm	4.72	4.80	\pm	9.15
<i>Enallagma circulatum</i>	Enc					0.20	\pm	0.45						

<i>Epitheca bimaculata sibirica</i>	Epb							0.60	±	0.55						
<i>Sympetrum</i> spp.	Sy spp.		21.50	±	14.15		15.40	±	11.67		6.40	±	6.47	6.20	±	6.57
<i>Orthetrum albistylum speciosum</i>	Oa		0.50	±	1.00											
<i>Copera annulata</i>	Coa		0.25	±	0.50											
<i>Aeshna nigroflava</i>	Aen										0.20	±	0.45			
<i>Anax Parthenope</i>	Anp										0.20	±	0.45	0.40	±	0.55
<i>Aeshna mixta soneharai</i>	Aem	NT / R					0.60	±	1.34		18.20	±	21.25	0.60	±	0.89
<i>Aeshna juncea juncea</i>	Aej						0.20	±	0.45		0.40	±	0.55			
<i>Hydrophilus acuminatus</i>	Hya	NT / -					1.00	±	1.22		2.20	±	4.92	0.40	±	0.55
<i>Berosus punctipennis</i>	Bp		0.50	±	1.00		6.60	±	7.99		1.40	±	2.61	7.20	±	12.56
<i>Enochrus japonicas</i>	Enj						0.40	±	0.55		2.60	±	5.81	0.20	±	0.45
<i>Hyphydrus japonicus</i>	Hyj	NT / -					0.80	±	0.84		0.40	±	0.89	6.60	±	13.15
<i>Cybister japonicus</i>	Cyj	VU / R					0.20	±	0.45		1.20	±	1.30	0.60	±	0.89
<i>Graphoderus adamsii</i>	Gra	VU / -									1.20	±	2.68	0.20	±	0.45
<i>Colymbetinae</i> spp.	Col spp.		0.25	±	0.50		0.20	±	0.45		1.20	±	2.68	5.40	±	7.40
<i>Haliplidae</i> spp.	Ha spp.		0.75	±	0.50		4.00	±	5.83		1.60	±	2.07	8.00	±	9.14
<i>Noterus japonicas</i>	Noj		0.25	±	0.50		0.60	±	0.89		0.60	±	1.34	4.40	±	9.84
<i>Noterus angustulus</i>	Noa	- / R									0.40	±	0.89			
<i>Gyrinidae</i> spp.	Gy spp.						0.20	±	0.45					0.40	±	0.55
<i>Gerridae</i> spp.	Ge spp.		3.00	±	3.83		5.60	±	4.22		8.60	±	13.01	11.00	±	10.20
<i>Appasus major</i>	Apm	- / R					0.20	±	0.45							
<i>Appasus japonicus</i>	Apj	NT / -	1.50	±	1.29		5.80	±	6.38		19.40	±	18.32	0.40	±	0.89
<i>Ranatra</i> spp.	R spp.						0.40	±	0.89		2.20	±	3.49	2.80	±	4.09
<i>Notonecta triguttata</i>	Not		0.75	±	1.50		8.80	±	8.50		10.80	±	7.05	4.40	±	5.59
<i>Corixidae</i> spp.	Cor spp.		3.25	±	5.85		22.00	±	29.28		13.00	±	25.22	282.40	±	295.43
Wetland birds																
<i>Podiceps nigricollis</i>	Pn													0.20	±	0.45
<i>Tachybaptus ruficollis</i>	Tar										1.60	±	2.61	1.00	±	1.73
<i>Aix galericulata</i>	Aig	- / NT									0.20	±	0.45			
<i>Anas platyrhynchos</i>	Anp						2.00	±	1.58		6.00	±	5.15	1.60	±	2.07
<i>Anas zonorhyncha</i>	Anz		7.00	±	9.45		15.40	±	30.02		1.40	±	3.13	8.80	±	11.61
<i>Aythya fuligula</i>	Ayf													0.20	±	0.45

Choi														
<i>Schoenoplectiella triangulata</i> (Roxb.) J.D. Jung et H.K. Choi	Sctr	<i>e, h</i>				0.05	±	0.11			0.17	±	0.38	
<i>Schoenoplectus</i> <i>tabernaemontani</i> (C.C. Gmel.) Palla	Scta	<i>e</i>							1.43	±	3.19	6.56	±	3.94
<i>Scirpus radicans</i> Schk.	Scr	<i>e, h</i>	1.88	±	1.61				1.67	±	2.36			
<i>Scirpus wichurae</i> Boeck. f. concolor (Maxim.) Ohwi	Scw	<i>h</i>	3.75	±	7.50	1.75	±	3.26	8.71	±	7.77			
<i>Myriophyllum ussuriense</i> (Regel) Maxim.	My	NT / R <i>s, e, h</i>							2.11	±	4.72			
<i>Juncus decipiens</i> (Buchenau) Nakai	Jud	<i>e, h</i>										12.91	±	19.08
<i>Juncus ensifolius</i> Wikstr.	Jue	<i>h</i>										1.11	±	2.48
<i>Lycopus lucidus</i> Turcz. ex Benth.	Lyl	<i>h</i>	0.81	±	1.31	0.08	±	0.18	0.40	±	0.89			
<i>Lycopus maackianus</i> (Maxim. ex Herder) Makino	Lym	<i>h</i>										0.14	±	0.32
<i>Lycopus uniflorus</i> Michx.	Lyu	<i>h</i>				0.04	±	0.09						
<i>Scutellaria dependens</i> Maxim.	Scd	<i>h</i>				0.04	±	0.09						
<i>Lythrum salicaria</i> L.	Lys	<i>h</i>				0.20	±	0.45						
<i>Trapa japonica</i> Flerow	Trj	<i>fl</i>				11.50	±	16.11	7.86	±	7.18	3.80	±	3.94
<i>Nuphar japonica</i> DC.	Nj	<i>s, fl</i>				0.20	±	0.45	2.00	±	4.47			
<i>Ludwigia epilobioides</i> Maxim. subsp. epilobioides	Lue	<i>h</i>	0.13	±	0.25	0.85	±	1.90				1.84	±	3.58
<i>Phragmites australis</i> (Cav.) Trin. ex Steud.	Pha	<i>e, h</i>	10.00	±	15.41	8.00	±	9.97	25.18	±	4.51	8.96	±	5.93
<i>Zizania latifolia</i> (Griseb.) Turcz. ex Stapf	Zl	<i>e</i>	10.06	±	10.29	2.80	±	6.26				2.46	±	5.49
<i>Persicaria muricata</i> (Meisn.) Nemoto	Pem	<i>h</i>				0.24	±	0.54						
<i>Persicaria sagittata</i> (L.) H. Gross var. sibirica (Meisn.)	Pes	<i>h</i>				0.16	±	0.26	0.07	±	0.15	0.10	±	0.15

Miyabe

<i>Monochoria korsakowii</i> Regel et Maack	Mok	NT / VU <i>e, h</i>						0.94	±	1.55				
<i>Monochoria vaginalis</i> (Burm.f.) C. Presl ex Kunth	Mov	- / VU <i>e, h</i>						2.22	±	4.97				
<i>Potamogeton octandrus</i> Poir. var. <i>octandrus</i>	Po	<i>s, fl</i>				0.33	±	0.75		1.37 ± 2.48				
<i>Lysimachia thyrsoflora</i> L.	Lyt	<i>h</i>				4.30	±	8.95		0.22 ± 0.50				
<i>Ranunculus repens</i> L.	Rr	<i>h</i>				0.04	±	0.09						
<i>Ranunculus sceleratus</i> L.	Rs	<i>e, h</i>								0.03 ± 0.06				
<i>Sparganium erectum</i> L.	Spe	NT / R <i>e</i>	4.25	±	9.50	0.57	±	1.28		5.91 ± 8.14				
<i>Typha latifolia</i> L.	Tyl	<i>e</i>	0.25	±	0.56	2.77	±	5.32		5.02 ± 7.62				
Nonnative														
<i>Phalaris arundinacea</i> L. *2		<i>h</i>	71.75	±	48.49	98.40	±	38.47	17.20	±	30.32	41.20	±	44.89

849 We denoted the species categories of the national (Japan) and regional (Hokkaido prefecture) red lists according to the Japanese red list (Ministry of
850 Environment of Japan, 2017) and Hokkaido red list (Hokkaido Prefecture, 2001, 2017, 2018), respectively. The categories of the Japanese red list (2017) and
851 Hokkaido red list (2017, 2018) (for wetland birds and fishes) are EN (Endangered), VU (Vulnerable), and NT (Near Threatened). The categories of the
852 Hokkaido red list (2001) (for aquatic insects and wetland plants) are EN (Endangered), VU (Vulnerable), and R (Rare). We also determined species as
853 nonnative according to the Hokkaido blue list (Hokkaido Prefecture, 2010). *1 Life form is identified only for wetland plants. *h*: hygrophyte, *e*: emergent
854 macrophyte, *fl*: floating-leaved macrophyte, *fr*: free-floating aquatic macrophyte, and *s*: submerged macrophyte. *2 According to the Hokkaido blue list
855 (Hokkaido Prefecture 2010), *Phalaris arundinacea* is naturally distributed in this region, but it has also been broadly introduced as pasture species. Since it is
856 difficult to distinguish between native and non-native individuals during a field survey, we regarded *Phalaris arundinacea* as a non-native species in this study
857 and excluded it from the analysis.

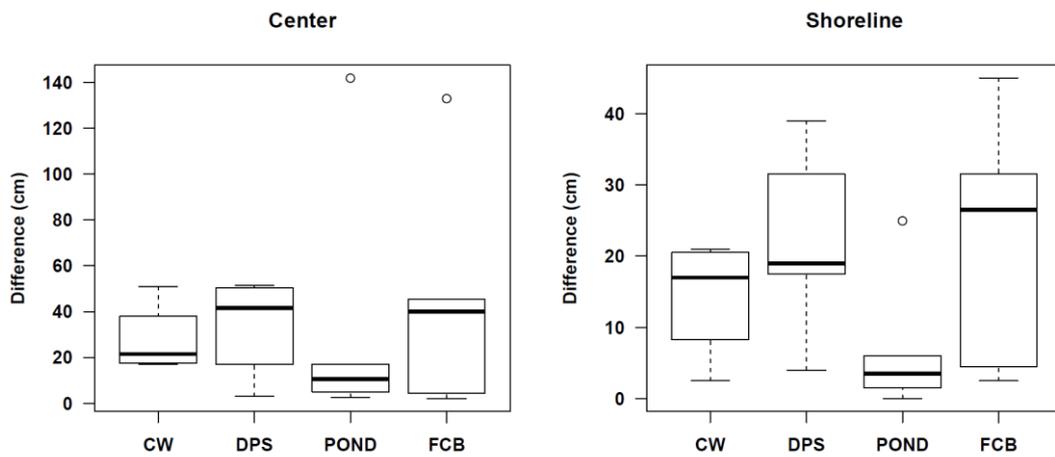
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859

Table A2. Mean values and standard deviations for environmental factors and the results of multiple comparisons among the water body types.

Environment factors	Study sites															
	CW			DPS			POND			FCB						
Water level																
Center in summer	79.50	±	26.34	a	73.30	±	28.95	a	169.00	±	119.72	a	85.60	±	61.76	a
Center in autumn	51.75	±	18.34	a	40.60	±	16.25	a	133.60	±	61.89	a	110.60	±	96.22	a
Shoreline in summer	44.00	±	16.29	ab	48.80	±	24.66	ab	64.90	±	13.84	b	33.10	±	20.60	a
Shoreline in autumn	36.63	±	10.70	a	28.20	±	17.81	a	67.70	±	16.57	b	43.50	±	19.77	ab
Fluctuation in center	27.8	±	15.9	a	32.7	±	21.7	a	35.4	±	59.9	a	45.0	±	53.1	a
Fluctuation along shoreline	14.4	±	8.5	a	22.2	±	13.5	a	7.2	±	10.2	a	22.0	±	18.2	a
Water qualities																
DO	7.22	±	0.64	a	5.38	±	2.68	a	4.20	±	3.12	a	7.65	±	1.58	a
EC	509.30	±	386.60	b	193.61	±	22.80	a	163.84	±	54.51	a	179.98	±	91.70	a
Water temperature	16.63	±	0.42	a	17.04	±	1.30	a	18.92	±	0.81	b	18.58	±	0.85	b
pH	7.20	±	0.09	a	7.02	±	0.21	a	7.14	±	0.47	a	7.33	±	0.24	a
NH ₄ -N	0.04	±	0.01	a	0.23	±	0.16	a	0.21	±	0.16	a	0.11	±	0.04	a
NO ₂ -N	0.01	±	0.01	a	0.04	±	0.05	a	0.03	±	0.04	a	0.01	±	0.02	a
PO ₄ -P	0.07	±	0.05	a	0.09	±	0.06	a	0.06	±	0.04	a	0.04	±	0.02	a
TN	4.15	±	1.00	a	3.36	±	2.59	a	2.23	±	1.03	a	2.98	±	1.12	a
TP	0.07	±	0.06	a	0.11	±	0.08	a	0.09	±	0.04	a	0.06	±	0.04	a
Landscape factors																
Area of survey site	0.34	±	0.09	a	1.07	±	1.26	a	1.09	±	0.71	a	28.68	±	41.46	a
Forest shoreline	0.05	±	0.11	a	0.07	±	0.15	a	0.60	±	0.38	b	0.14	±	0.19	a
Surrounding water body within a 500 m buffer	0.38	±	0.37	a	5.83	±	5.08	a	4.01	±	2.92	a	10.98	±	13.49	a
Surrounding water body within a 1 km buffer	1.28	±	1.35	a	17.66	±	20.43	a	16.06	±	7.27	a	26.82	±	23.57	a
Vegetation on the water	20.00	±	20.00	a	54.00	±	32.09	a	58.00	±	30.33	a	26.00	±	35.78	a

Different letters indicate significant differences in the multiple comparison analysis ($p < 0.05$).



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865 Fig. A1 Fluctuation in water levels in each water body.

866 The fluctuation in water levels at each site was calculated as the absolute value of the
 867 difference in water levels between July and September. CW: channelized watercourse,
 868 DPS: drainage pumping station, PO: remnant pond, and FCB: flood-control basin.

869 The horizontal lines in the boxes indicate the median, the ends of the boxes indicate
 870 the 25th and 75th percentiles, and the whiskers indicate the 5th and 95th percentiles.

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