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FULL PAPER

Priority maps for protecting the habitats of threatened freshwater fishes in urban areas: a case study of five rivers in the Fukuoka Plain, northern Kyushu Island, Japan

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Abstract Selecting candidate areas to protect the habitats of threatened freshwater fish species is a major challenge in urban areas. Therefore, we conducted a case study using a Marxan analysis based on fish fauna and land use data of five rivers flowing in the Fukuoka Plain, northern Kyushu Island, Japan, to construct priority maps to protect threatened freshwater fishes in the urbanized plain. We organized threatened fish fauna and land use data in the fourth-mesh scale, drawn as a 500-m square, resulting in 147 meshes with fauna and land use data. We assessed two cases—meshes were either analyzed as having the same cost (case 1) or having cost sizes classified into four classes based on cluster analysis of land use data (case 2). We divided the threatened species into those from either stream fish or floodplain fish and analyzed them separately. When meshes with high priority in both case 1 and case 2 were defined as primacy meshes for habitat protection, 10 and 28 meshes were identified in the stream and floodplain fish, respectively. Of the primacy meshes, 40 % for the stream fish and 54 % for the floodplain fish were distributed in urbanized areas, indicating that habitat protection was necessary in several urbanized areas on the plain. Meshes with low priority in case 1 and with high priority in case 2 were defined as the second most important meshes for habitat protection. The number of second most important meshes for the floodplain fish was smaller than that for the stream fish; therefore, the floodplain fish required habitat protection in urbanized areas to a greater extent than the stream fish.

Keywords Endangered fish · Complementary analysis · Million city · GIS

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Introduction

The loss of biodiversity in freshwater habitats is mostly associated with human activities (Abell 2002) such as irrigation, industrialization (Szöllosi-Nagy et al. 1998), rapid urbanization (Urban et al. 2006), and pollution (Lima-Junior et al. 2006). Activities such as rapid urbanization often make it difficult to successfully restore habitats for freshwater organisms, because attempts to stop or mitigate the negative effects of urbanization are impeded by the high human population density and by economic constraints (Yoshimura et al. 2005). Habitat management in urbanized areas is necessary to balance biodiversity conservation with high human population density or economic constraints. Therefore, one of the goals is to achieve the necessary minimum biodiversity conservation for the smallest possible cost (McDonnell et al. 2002).

Marxan is a tool for the complementary analysis of species richness and selects the minimum candidate units for habitat conservation with maximum species richness (Game and Grantham 2008; Ball et al. 2009). Simulations are initialized with a set of planning units drawn at random and then planning units are added to and removed from the set in a series of interactions with the value of each new set compared with that of the previous set until an equilibrium solution is achieved using the smallest number of planning units (Cook and Auster 2005; Zielinski et al. 2006). Because the tool can optimize conservation planning units from a large number of potential sites, the tool has been successfully used for conservation studies of various taxonomic groups such as amphibians (Campos et al. 2014), birds (Lin et al. 2014), dragonflies (Bush et al. 2014), freshwater fishes (Heiner et al. 2011), and marine vertebrates (Mazor et al. 2014).

Marxan can minimize the sum of variable costs such as species penalty and boundary length (Zielinski et al. 2006; Game and Grantham 2008; Ball et al. 2009) and a few studies have analyzed spatial conservation prioritization alongside other types of cost including human impact (Heiner et al. 2011) and activities of economic importance (Mazor et al. 2014). Quantifying the difficulties of habitat protections in urban areas to a cost amount could facilitate the creation of a more effective priority list to successfully protect habitats in urban areas.

Because Japan is a mountainous island nation, large urban areas are predominantly built on deltas, plains, and alluvial fans (Yoshimura et al. 2005). Therefore, biodiversity loss in freshwater habitats of these lowland areas in Japan is worse than in other countries with larger lowland areas. Therefore, habitat management for freshwater organisms is a major challenge in Japanese urban areas. The objective of this study was to describe effective maps for protecting threatened freshwater fishes in Japanese urban areas.

The Fukuoka Plain, northern Kyushu Island, Japan, was selected as the target region for our case study because the plain is the most densely populated area on the island and an extensive dataset on freshwater fish fauna. We performed Marxan analyses based on fish fauna and land use data of five rivers in the plain to map the priority areas for protecting threatened fish species.

Materials and methods

Target areas. The target areas were located within the Fukuoka Plain, including Fukuoka City, which is the most populated area in Kyushu. The population of this city exceeded one million people in 1975 and is now approximately 1.5 million (Fukuoka City 2015). Several rivers flow on the plain, and six of these reach a main river length (MRL) of over 10 km. We targeted five of these six rivers, excluding the Hii River due to the lack of fish faunal data (Fig. 1). The longest river in our sample was the Naka River (MRL: 35.1 km). Population density varies throughout these river systems. The Naka River has a high population density in the middle and lower basins; the Mikasa River (MRL: 20.7 km) has a high density in all basins; the Tatara River (17.4 km) has a high density in the middle and lower basin; the Muromi River (15.1 km) has a high density in the lower basin; and the Zuibaiji River (12.8 km) is not highly urbanized and has a particularly high density of paddy areas in the middle and lower basins (Fig. 1).

Targeted species and numerical targets. Fish faunal data were derived from the freshwater fish faunal database (Fishery Research Laboratory, Kyushu University 2014). Faunal data from 157 sites in the target river systems after 2005 were extracted from the database. Data were organized into a unit of the fourth mesh (approximately 500 × 500 m, National Land Information Division, Japan 2014), which is a quarter size of third mesh in the Geographic Information System (GIS), resulting in 147 meshes (Fig. 1). Subsequently, 19 species or subspecies included in the Red Data Book from the Fukuoka Prefecture (2014) were selected from the faunal dataset and were classified based on their habitat use into stream or floodplain dwelling species (Nakajima et al. 2010, Table 1). Nakajima et al. (2010) classified the habitat uses of freshwater fishes on Kyushu Island into three types: (1) permanent water, (2) temporary water (floodplain), and (3) both permanent and temporary waters. Therefore, we used a similar classification, where type 1 was classified as the stream fish, and types 2 and 3 were classified as the floodplain fish.

Before Marxan analysis, we must determine how many meshes were protected for each species (numerical targets). The numerical targets were set based on the actual occurrence of each species within all meshes. When a species was present in fewer than 10 % of all meshes, the target was set to include every occurrence of the species, while it was set to include half of the actual occurrences for two species (*Cottus pollux* and *Oryzias latipes*) with much more actual occurrences than other species (Table 1).

Land use and cost setting. We focused on the difference of urban land use among meshes to quantify the difficulties of habitat protection in urban areas as a cost amount. Land use data from 2009, including urbanized (UA), paddy (PA), forested (FA) uses and water surface of rivers, dams and sea (WS), were downloaded from the GIS homepage of the National Land Information Division, Japan (2014). These data were recounted in the unit of the fourth mesh because data were originally supplied at the 1/25 size of the fourth mesh. The free software Quantum-GIS v. 1.8.0 (Quantum GIS Development Team 2013) was used for the analysis. Using the land use dataset excluding WS, a cluster analysis based on the Euclidean distance was conducted, whereby the meshes were classified into six types (u1: extra-high urban area; u2: high urban area; p1: middle urban and high paddy area; p2: low urban and extra-high paddy area; f1:

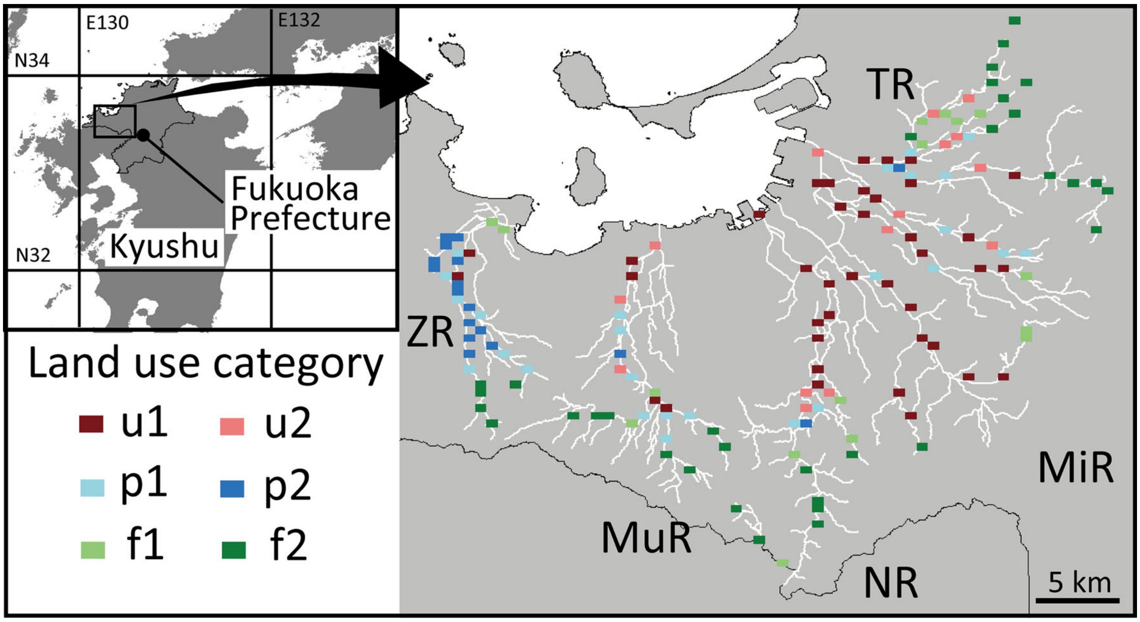

Fig. 1 Map of the analyzed meshes for five rivers (*TR* Tatara River; *MiR* Mikasa R.; *NR* Naka R.; *MuR* Muromi R.; *ZR* Zuibaiji R.) flowing in the Fukuoka plain, northern Kyushu, Japan. Meshes are drawn in the scale of the fourth mesh (500 × 500 m) and are color-coded according to each land use type (*u1* extra-high urban area; *u2* high urban area; *p1* middle urban and high paddy area, *p2* low urban and extra-high paddy area; *f1* middle urban and forested area; and *f2* low urban and extra-high forested area) based on cluster analysis shown in Fig. 2

Table 1 The number of sites with actual presence (No. of AP), numerical targets set for the Marxan analysis, and category in local Red Data Book (RBD) in each freshwater fish species inhabiting the Fukuoka urban area

Species name (abbreviation)	Actual presence		Numerical targets	RDB Category
	No.	%		
1. Stream type				
Lethenteron sp. N (LN)	5	3.4	5	EN
Oncorhynchus masou masou (Omm)	7	4.8	7	EN
Sarcocheilichthys variegatus variegatus (Svv)	4	2.7	4	VU
Tachysurus aurantiacus (Tau)	1	0.7	1	EN
Liobagrus reini (Lre)	3	2.0	3	VU
Cobitis matsubarae (Cma)	12	8.2	12	NT
Coreoperca kawamebari (Cka)	12	8.2	12	NT
Cottus pollux (Cpo)	26	17.7	13	NT
2. Floodplain type				
Tanakia lanceolata (Tla)	4	2.7	4	VU
Tanakia limbata (Tli)	9	6.1	9	NT
Acheilognathus rhombeus (Arh)	8	5.4	8	NT
Acheilognathus tabira nakamurae (Atn)	4	2.7	4	CR
Rhodeus ocellatus kurumeus (Rok)	6	4.1	6	EN
Rhodeus smithii atremius (Rsa)	7	4.8	7	EN
Abbottina rivularis (Ari)	7	4.8	7	NT
Biwia zezera (Bz)	8	5.4	8	NT
Misgurnus anguillicaudatus (Ma)	2	1.4	2	VU
Cobitis striata hakataensis (Csh)	4	2.7	4	CR
Oryzias latipes (Ola)	43	29.3	22	NT

RDB Fukuoka Pref. 2014: *CR* critically endangered, *EN* endangered, *VU* vulnerable, *NT* near threatened

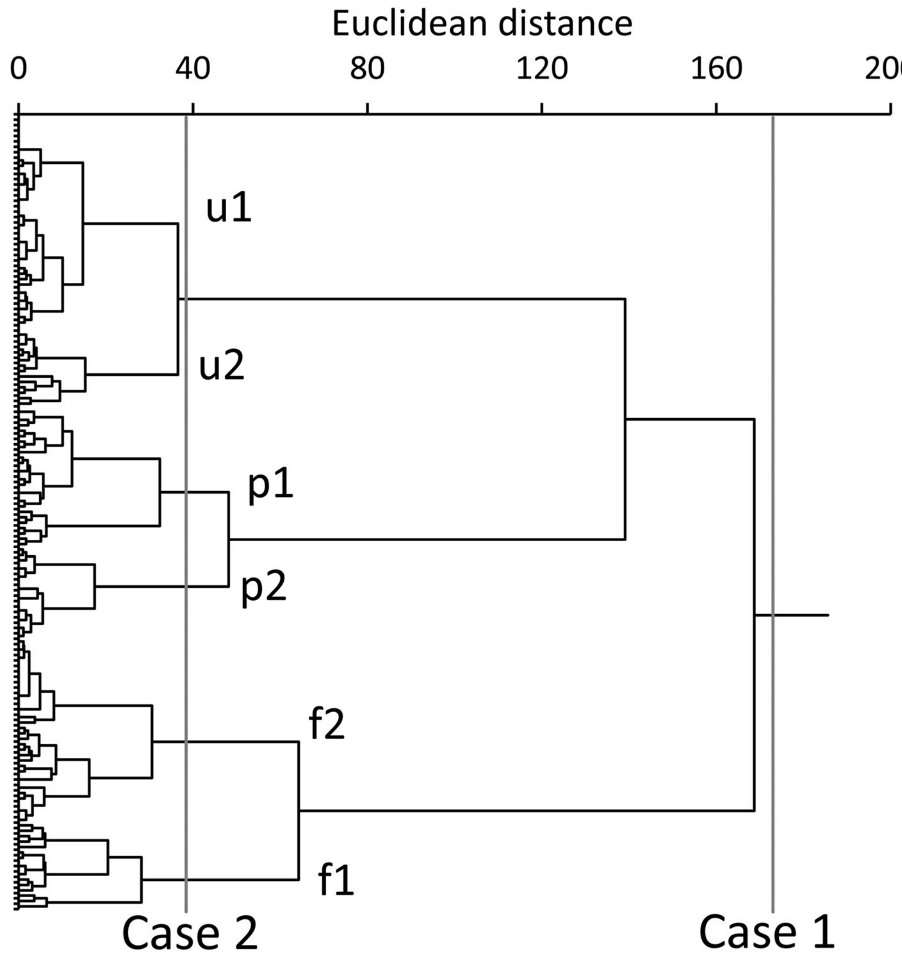

Fig. 2 Similarity of land use for the fourth mesh level determined by the cluster analysis based on the land use data. Land uses types are explained in Fig. 1

middle urban and forested area; and f2: low urban and extra-high forested area; Fig. 2, Table 2). The average area in urban use was calculated for each type, and costs were set depending on the urban use (C-urban). We could find large WS in a few meshes with dams and these meshes were classified into f1 by the cluster analysis.

We prepared two cases to compare different cost settings. The same cost size, without C-urban, was set for all meshes in the first case. In the second case, the appropriate costs were set based on C-urban, where costs ranged from 1 to 4 (cost 4: average urban area >0.02 km^2 [u1]; cost 3: >0.01 [u2]; cost 2: >0.005 [p1 and f1]; and cost 1: ≤0.005 [p2 and f2]). This analysis was conducted using the add-in software for statistical analysis in Microsoft Excel (Ekuseru-Toukei 2012, Social Survey Research Information Co., Ltd., Tokyo).

Table 2 Sizes of cost depending on the urban areas (*SCu*), given to each land use type in case 2, and average area (range) of land use for each type

Type	SCu	UA	PA	FA	WS
u1	4	22.3 (19-25)	0.8 (0-5)	0.3 (0-3)	1.6 (0-6)
u2	3	16.1 (12-19)	5.4 (0-9)	1.4 (0-5)	2.1 (0-11)
p1	2	8.0 (1-14)	12.3 (9-15)	3.0 (0-11)	1.7 (0-7)
p2	1	3.1 (0-5)	21.3 (17-25)	0.0 (0)	0.6 (0-5)
f1	2	8.1 (0-4)	2.2 (0-10)	21.5 (15-25)	0.7 (0-8)
f2	1	0.9 (4-12)	2.4 (0-8)	9.8 (0-16)	3.5 (0-19)

Land uses types are explained in Fig. 1

UA Urbanized area, *PA* paddy area, *FA* forested area, *WS* water surface of rivers, dams and sea

Prioritization. Complementary analyses for the effective protection of threatened freshwater fishes were performed using Marxan version 1.8 (Game and Grantham 2008; Ball et al. 2009). The analyses were run 100 times for each habitat use and each case type, and the priority of each mesh was determined based on the number of times it was selected over the 100 iterations. Three priority level categories were created (high priority: over 90; low priority:

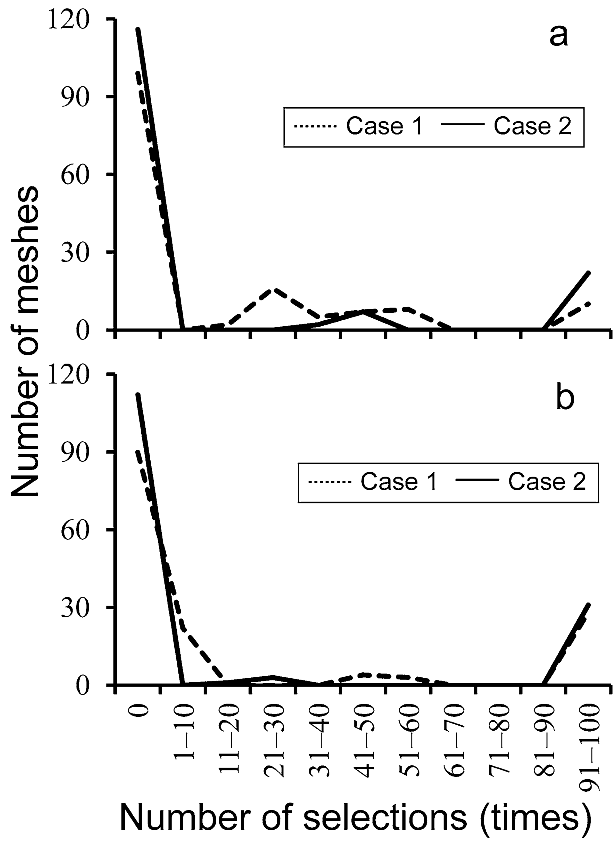

Fig. 3 Number of meshes selected by Marxan analyses in each range of selections for each case in stream (**a**) and floodplain (**b**) types

1-90; no priority: 0), on the basis of the number of meshes in each range of selected times (Fig. 3).

Targeted meshes were divided into three classes based on their priority levels in case 1 and the differences in their priority levels in cases 1 and 2. Meshes selected as high priority in both cases were defined as primacy meshes, and those with low priority in case 1 and high priority in case 2 were defined as second most important meshes. All other meshes were defined as unimportant meshes.

The principal component analysis (PCA) was based on the correlation coefficient matrix as one of the methods for the analysis. The PCA was conducted using same land use dataset as the cluster analysis to check the characteristics of land use for the meshes selected as the primacy and second important meshes. Scatter plots based on the top two principal components were created for each habitat use and priority level. This analysis was also conducted using the add-in software in Microsoft Excel.

These three classifications were color-coded on maps of stream and floodplain fish using the free software DIVA-GIS v. 7.5.0 (Hijmans et al. 2012). In addition, we checked the efficiency of protection measures for protecting primacy and second most important meshes in each species by calculating the coverage (%) of number of selected meshes for number of numerical targets set for Marxan analyses. The coverage was determined using the equation: $[(PM + SIM)/TN \times 100]$, where PM is the number of primacy meshes, SIM is the number of second most important meshes, and TN is the number of numerical targets.

Results

There were 10 and 28 meshes classed as high priority in case 1 in the stream and floodplain fish, respectively (Table 3). The meshes with high priority in case 1 were also selected as high priority in case 2 when the costs were weighted by urban use. These are the primacy meshes for habitat protection of threatened fishes on the targeted plain. After creating the PCA plots based on the top two principal components (Table 4), the plots of the stream fish showed that 40 % of the primacy meshes were distributed in u1 and u2, while the other plots were variously distributed throughout the land use types (Fig. 4a). The PCA plots of the floodplain fish showed that 54 % of the primacy meshes were distributed in u1 and u2, and the other plots were mostly found in p1 and p2 (Fig. 4b).

Within the stream type, there were 12 second most important meshes with low priority in case 1 and high priority in case 2 (Table 3), resulting from selecting meshes with low urban use from the meshes determined as low priority in case 1. The second most important meshes were distributed in p1, p2, and f2 on the PCA plot (Fig. 4a). The number of second most important meshes in the floodplain fish was very small when compared with the stream fish (Table 3), and they were distributed in only p2 on the PCA plot (Fig. 4b).

Table 3 Number of sites for each priority level (high: >90 times, low: 1–90, none = 0) determined from the Marxan analyses for each type and case, and number of final prioritization for each habitat protection

	Stream type		Floodplain type	
	Case 1	Case 2	Case 1	Case 2
1. Priority in each case				
High	10	22	28	31
Low	38	9	29	4
None	99	116	90	112
2. Final prioritization				
Primacy	10		28	
Second most important	12		3	
Unimportant	125		116	

Table 4 Summary of the results of the principal component analysis using land use data in survey meshes

Principal component	Eigenvalue	Proportion	PA	FA	UA
Component 1	1.65	0.550	0.041	0.896	-0.919
Component 2	1.29	0.430	-0.992	0.417	0.363
Component 3	0.06	0.020	0.119	0.150	0.152

UA Urbanized, *PA* paddy, *FA* forested areas

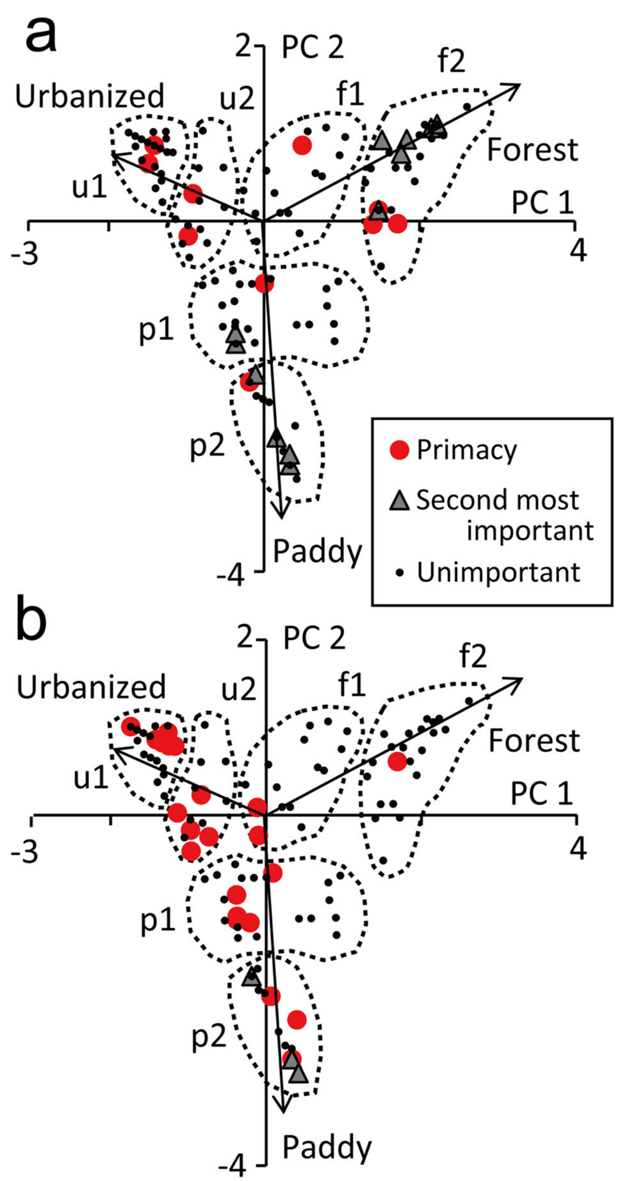

Fig. 4 PCA plots of prioritized meshes in stream (**a**) and floodplain (**b**) types for principal components 1 and 2 by the principal component analysis based on land use data. The plots distinguish different priority levels by the use of different symbols; those of the same land use type based on the cluster analysis are surrounded by dotted lines, and the types, such as u1, u2, and p1 are explained in Fig. 1. Each *arrow* indicates the orientation of each land use generated from the eigenvectors of each land use for components 1 and 2

The priority maps of each fish type are shown in Fig. 5. The primacy meshes with high priority for the stream fish occur frequently in the middle and upper basins of the Naka and Muromi rivers. No meshes were found in the other river basins. The meshes for the floodplain fish were found frequently in the middle and lower basins of the Tatara River, and in the middle of the Naka River, in moderation within the lower basin of the Muromi and Zuibaiji rivers, and infrequently in the Mikasa river basin. Most of the second most important meshes in both fish types were distributed in the Zuibaiji River, where the least land is under urban use (Fig. 1). As the efficiencies for protecting primacy and second most important meshes, the coverage (%) of number of selected meshes for number of numerical targets in each species is summarized in Table 5. The efficiency based on the coverage for most species was more than 70 % of each numerical target.

Discussion

Importance of consideration of "C-urban". A few freshwater fishes, including *Aphyocypris chinensis* and *Hemigrammocypris rasborella*, have already disappeared from the Fukuoka Plain (Nakajima et al. 2006; Takaku et al. 2007; Nakajima and Onikura 2009), and several species are in danger of extinction (Fukuoka Prefecture 2014). A few studies have found that the urbanization of the plain is responsible for the extinction of these fishes and continues to endanger the habitats of persisting species (Nakajima et al. 2006; Onikura et al. 2006; Takaku et al. 2007). Current challenges have increased the need to designate suitable areas of protected habitats for the threatened fishes in the Fukuoka plain with high population density. Therefore, we propose that the primacy and second most important meshes selected by the analyses with consideration of the urban use (C-urban) in the present study are protected immediately as an emergency measure for the surviving fishes on the plain.

Habitat management is required to achieve the necessary minimum of biodiversity conservation at the smallest possible cost (McDonnell et al. 2002). The present study tried to construct effective maps for protecting threatened freshwater fishes by complementary analyses of species

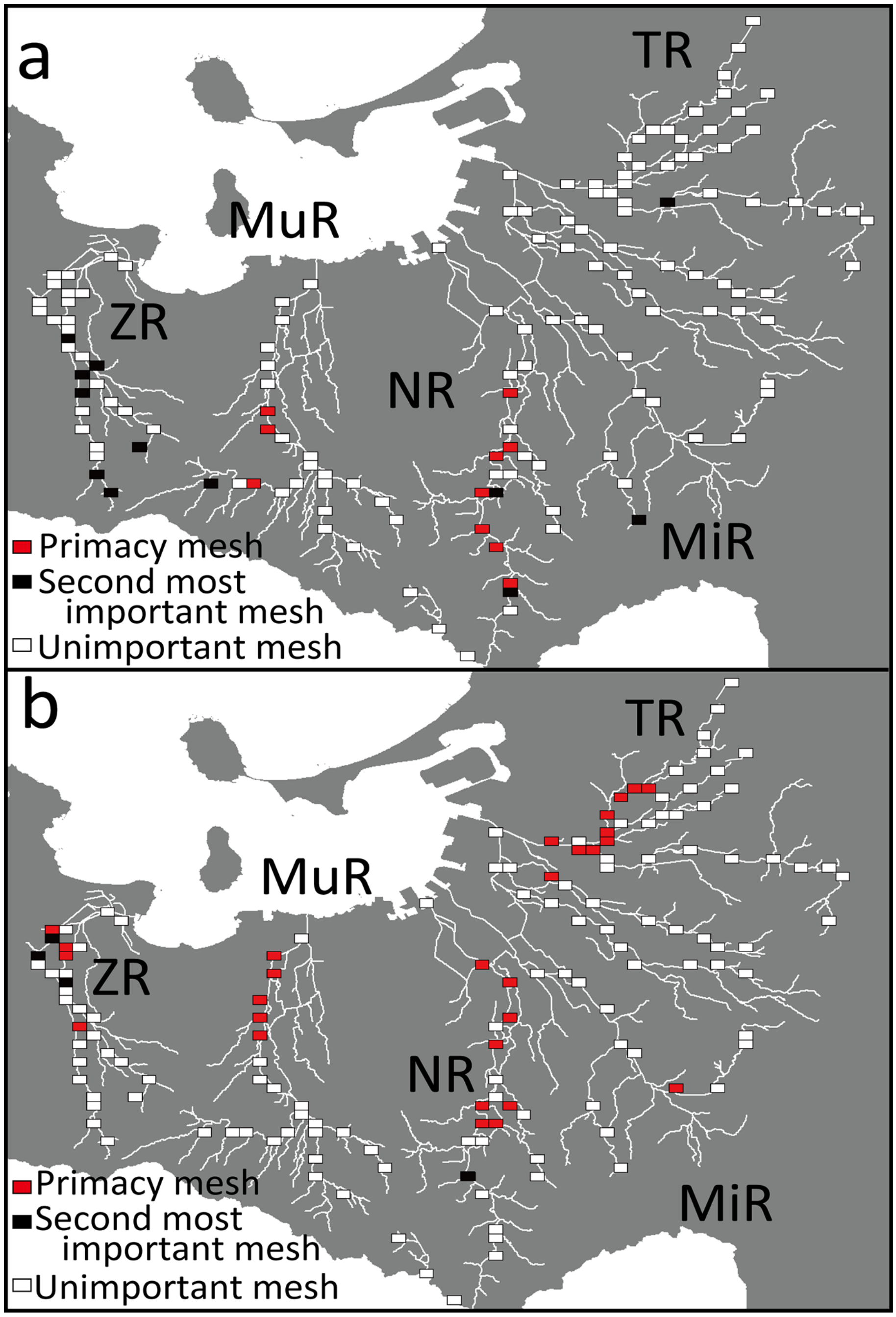

Fig. 5 Priority maps for habitat protection of the threatened fish species in stream (**a**) and floodplain (**b**) types. The meshes are color-coded according to the priority level of the final prioritization. Abbreviations of river names are shown in Fig. 1

richness with and without weighting costs associated with C-urban. Meshes selected as low priority in case 1 without C-urban and high priority in case 2 with C-urban were treated as second most important meshes in present study (Table 3). The second most important meshes were selected from those with low urban uses such as p1, p2, and f2 (Fig. 4), indicating that these selections can make habitat protection easier on the Fukuoka Plain, where human population density is high. Our study also emphasizes that adequate site selection with consideration to management costs is an important aspect of systematic management planning as with several previous studies (e.g., Langhans et al. 2014; Mazor et al. 2014).

While meshes selected as high priorities with and without C-urban were defined as primacy meshes in the present study (Table 3), 40 %–54 % of the primacy meshes were selected from the meshes with high urban use, such as u1 and u2 (Fig. 4). The result suggests that the target plain has several primacy areas with high urban use and it is impossible to substitute other areas with low urban use for these areas.

The Red Data Book published by the local government (Fukuoka Prefecture 2014), which includes data for the

Table 5 Performance for protecting primacy and second most important meshes in each species

Stream type		Floodplain type	
Species	Coverage	Species	Coverage
LN	100.0	Tla	100.0
Omm	85.7	Tli	100.0
Svv	100.0	Arh	100.0
Tau	100.0	Atn	100.0
Lre	100.0	Rok	83.3
Cma	83.3	Rsa	75.0
Cka	91.7	Ari	85.7
Cpo	61.5	Bz	87.5
		Ma	100.0
		Csh	100.0
		Ola	70.0

The efficiency was evaluated using the coverage (%) determined by the equation [(PM + SIM)/TN × 100], where PM is the number of primacy meshes, SIM is the number of second most important meshes, and TN is the number of numerical targets. Species abbreviation and land use types are explained in Table 1 and Fig. 1, respectively

Fukuoka Plain, proposed that conservation management should be adapted to each river to systematically manage habitats for threatened freshwater fishes on the plain. This is particularly true for habitat conservation of stream fishes in the middle and upper basins of the Naka River and for floodplain fishes in the lower basin of the Tatara River (Fukuoka Prefecture 2014). The above-mentioned proposal was based on visual environmental degradation and fish species richness, and without statistical analyses to determine the biodiversity of threatened fishes. However, conservation planning for the protection of species or habitats should be based on cost-effective, representative, and complementary quantification of biodiversity (Margules and Pressey 2000; Lin et al. 2014). The present study identified cost-effective and complementary biodiversity conservation areas for the protection of freshwater fishes on the plain using systematic analysis tools. Therefore, the primacy and second most important meshes mapped in this study (Fig. 5) will aid conservation planning by the local government with a scientific basis.

Stream and floodplain types. The PCA plots in the stream fish were variously distributed throughout the land use classes (Fig. 4a), resulting from the species belonging to this type having various habitat preferences: for example, *Cottus pollux* showed an upstream preference; *Tachysurus aurantiacus*, a midstream preference; and *Sarcocheilichthys variegatus variegatus*, a downstream and midstream preference (Nakabo 2013). While the targets of the floodplain fish were mostly distributed in urban and paddy areas, such as the u1, the p1, and the p2 in the PCA plot (Fig. 4b), these results relate to several species belonging to the habitat type that often appears in paddy channels (Onikura 2015). Paddy fields continue to be converted to urban areas on the plain (Shimatani et al. 2010), and paddy area throughout the five river basins analyzed in this study has decreased by more than 50 % in the last 30 years, while urban areas have increased 1.5 times during the same period.

Such differences of distributions on PCA plots between stream and floodplain fish might reveal variance in the difficulty of habitat protection of threatened fishes in the Fukuoka plain; protection in areas with various land use may be possible for stream type species and impossible for floodplain types. This obvious difference is also demonstrated by the comparison of the number of second most important meshes between stream and floodplain fish.

Further challenges. The present study successfully generated priority maps for protecting threatened freshwater fishes while weighting costs concerning urban use; however, we could not confirm habitat quality in all primacy and second most important meshes selected for protecting threatened fish species. Several studies have evaluated habitat quality by species distribution models in Japan (Kano et al. 2010; Onikura et al. 2012, 2014; Inui et al. 2014; Koyama et al. 2015; Onikura 2015). By using these modeling techniques, habitat quality can be evaluated in each site selected by the Marxan analysis to increase the probability of success in the protection of habitat for threatened fish species.

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