Reconciling biodiversity conservation and flood risk reduction: The new strategy for freshwater protected areas

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RESEARCH ARTICLE

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Reconciling biodiversity conservation and flood risk reduction: The new strategy for freshwater protected areas

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Abstract

Aim: Natural disaster risk reduction (DRR) is becoming a more important function of protected area (PAs) for current and future global warming. However, biodiversity conservation and DRR have been handled separately and their interrelationship has not been explicitly addressed. This is mainly because, due of prevailing strategies and criteria for PA placement, a large proportion of PAs are currently located far from human-occupied areas, and habitats in human-occupied areas have been largely ignored as potential sites for conservation despite their high biodiversity. If intensely developed lowland areas with high flooding risk overlap with important sites for biodiversity conservation, it would be reasonable to try to harmonize biodiversity conservation and human development in human-inhabited lowland areas. Here, we examined whether extant PAs can conserve macroinvertebrate and freshwater fish biodiversity and whether human-inhabited lowland flood risk management sites might be suitable to designate as freshwater protected areas (FPAs).

Location: Across Japan.

Methods: We examined whether extant PAs can conserve macroinvertebrate and freshwater fish biodiversity and analysed the relationship between candidate sites for new FPAs and flood disaster risk and land use intensity at a national scale across Japan based on distribution data for 131 freshwater fish species and 1395 macroinvertebrate species.

Results: We found that extant PAs overlapped with approximately 30% of conservation-priority grid cells (1 km^2) for both taxa. Particularly for red-listed species, only one species of freshwater fish and three species of macroinvertebrate achieved the representation target within extant PAs. Moreover, more than 40% of candidate conservation-priority grid cells were located in flood risk and human-occupied areas for both taxa.

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Main conclusions: Floodplain conservation provides suitable habitat for many freshwater organisms and helps control floodwaters, so establishing new FPAs in areas with high flood risk could be a win-win strategy for conserving freshwater biodiversity and enhancing ecosystem-based DRR (eco-DRR).

KEYWORDS
aquatic animals, climate change, complementarity, eco-DRR, river, win-win strategy

1 | INTRODUCTION

Societal expectations for protected areas (PAs) have changed intermittently over the past 150 years (Watson et al., 2014). Recently, these expectations have focused on a diverse set of functions, including supporting human life, improving human health and well-being, boosting climate change resilience, and conserving biodiversity (e.g. The Promise of Sydney, IUCN World Parks Congress, 2014). In addition, in the aftermath of recent large-scale natural disasters such as the Great East Japan Earthquake in 2011 and apocalyptic northern Queensland flood in 2019 in Australia (EM-DAT, 2021), disaster risk reduction (DRR) is becoming an essential function of proposed PAs (Murti & Buyck, 2014). Traditionally, the strategy for establishing stringent PAs was to separate a portion of the natural environment from human activities. Therefore, PAs were preferentially established in areas unsuitable for commercial activity, rather than in those with high biodiversity conservation value (Margules & Pressey, 2000). Thus, most extant PAs were established at higher elevation or in isolated locations – these are often described as "rock and ice" habitats (Joppa & Pfaff, 2009). Protected areas, however, may play a role in ecosystem-based DRR (eco-DRR: the sustainable management, conservation and restoration of ecosystems to reduce disaster risk) and can be established in human-dominated areas, such as urban and agricultural landscapes. Under the encouragement of the Aichi Biodiversity Targets, both the number and area of PAs are rapidly increasing worldwide (Watson et al., 2014); with the PAs estate increasing by 2.3% on land (i.e. covering 15% of land) and 5.4% in the oceans (i.e. 7% of the oceans) from 2010 to 2020 (IUCN, 2020). Given global efforts to achieve the Post-Aichi Biodiversity Targets, a new strategy for identifying candidate sites for PAs is required to enhance the effectiveness of PAs in meeting societal needs (Convention on Biological Diversity, 2020).

Freshwater ecosystems are degrading at a faster rate than any other biome in the world (Dudgeon et al., 2006; Reid et al., 2019). However, extant PAs do not sufficiently cover the distribution of endangered freshwater species, because freshwater ecosystem conservation was largely not a priority when they were established (Nel et al., 2007). In Japan, the main PA system is composed of national parks. The principle purpose of this national park system is to conserve biodiversity and maintain the scenic and recreational value of the designated areas. As is the case internationally, the existing national parks (34 in total, with an average area ±SD of 632.8 km^2 ± 669) tend to be located mainly in mountainous areas. Although all national parks in Japan enclose some freshwater habitats, none were established purely to conserve freshwater ecosystems. Therefore, there is an urgent need to establish additional freshwater protected areas (FPAs). In order to conserve as many species as possible, new FPAs should be placed in lowland areas where the majority of riverine animals are distributed (Tockner & Stanford, 2002). In general, because lowland areas are highly productive but sparsely distributed in mountainous regions, they tend to be heavily populated. Studies have shown that areas of high productivity overlap with areas of high biodiversity in many regions of the world (Chase & Leibold, 2002).

Flood disasters are some of the worst natural disasters in terms of damage incurred and loss of life (Perry,). In the period 2006–2015, floods accounted for more than 45% (1719 floods) of the total natural disasters around the world (Chau, 2017; Sanderson & Sharma, 2016). At the global scale, more than US$56 billion were lost (i.e. infrastructure damage and lost commercial activity) due to floods in 2016, representing the largest economic losses among all natural disasters. Most of the 10 largest floods in history, such as the flood disaster in Thailand in 2013, have occurred in Asian monsoon countries (Guha-Sapir et al., 2016). The magnitude of damage caused by hydrological disasters has increased in recent years in densely populated lowland floodplains (James & Cutter, 2008). Furthermore, many climate models predict an increase in heavy precipitation as temperatures rise, which may increase flooding risk (Kollat et al., 2012; Wuebbles et al., 2008). Thus, effective DRR strategies for floods are crucial for maintaining human well-being.

Lowland FPAs are increasingly important due to the need for both DRR and biodiversity conservation. If intensely developed lowland areas with high flooding risk overlap with important sites for biodiversity conservation, this would indicate an urgent need to start a discussion on how to achieve biodiversity conservation alongside human development in human-inhabited lowland areas. Doing so would potentially achieve a win-win solution by reducing flooding risk while simultaneously conserving biodiversity. However, the relationship between biodiversity and disaster risk has not yet been explicitly defined. Therefore, in this study, we (1) examined whether extant PAs, which serve as FPAs, can conserve macroinvertebrate and freshwater fish biodiversity, and (2) analysed the relationship between candidate sites for new FPAs and flood disaster risk and land use intensity at a national scale across Japan.

2 | METHODS

2.1 | Distribution records of freshwater fishes and macroinvertebrates

We compiled national-scale distribution data for freshwater fishes and macroinvertebrates from several surveys contained in the Japanese government's River Environmental Database (Ministry of Land, Infrastructure, Transport and Tourism, http://www.nilim.go.jp/lab/fbg/ksnkankyo/index.html, accessed 12 October 2021), which includes data from 2000 to 2010, and the Natural Environmental Survey Database (Ministry of the Environment, http://www.biodic.go.jp/, accessed 12 October 2021), which includes data from the same period. We identified both intra- and international exotic species based on the expert opinions of several freshwater scientists in Japan and removed them from further analysis. Those records not identified to the species level were also removed. We aggregated the species distribution records into 1 km × 1 km grid cells, because point locations for several records were not available.

2.2 | Status of Japanese river and environmental data

The total length of all rivers in Japan is 350 158 km, and the national river density (total river length/total land surface area; 0.93 km/km^2) is higher than for other countries such as the United States (0.13 km/km^2) and some European countries such as Spain (0.19 km/km^2) and Germany (0.21 km/km^2) (Andreadis et al., 2013). The freshwater fauna of Japan has declined due to human activities such as river channelization, damming and land-use change (Nakamura et al., 2017). We focused on national parks as a focal PA system because they constitute the core of Japanese PA systems (The Nature Conservation Society Japan, 2013). The mean annual cost of flood damage in Japan was approximately 1.2 billion USD from 1990 to 2017, but has rapidly increased to 15.5 billion USD during the most recent 3-year period (2018–2020) (EM-DAT, 2021).

PA planning is always influenced by local human activities in the form of land cost. In this study, we adopted the human influence (HI) index calculated using global human footprint data (NASA Socioeconomic Data and Applications Center, Palisades, NY; http://dx.doi.org/10.7927/H4BP00QC, accessed 12 June 2015) to represent the land cost of each planning unit (1 km × 1 km grid cell). We defined special protection zones and special zones (classes I, II and III) of national park as national PAs in this study. The distribution of the focal PAs was obtained from polygon data (GIS data) downloaded from the National Land Information Division (https://nlftp.mlit.go.jp/ksj/index.html, accessed 10 May 2010) and was refined using a 1/25000 geographical map to improve accuracy before use.

The flood hazard map was built by collecting flood inundation maps (a total of 191 maps created in 2012) officially published by the Ministry of Land, Infrastructure, Transport and Tourism and prefectural government (http://nlftp.mlit.go.jp/ksj/gml/datalist/KsjTmplt-A31.html, accessed 12 June 2015). Because flood control plans vary with the river segment and authority, the magnitude of the flooding and the resolution as well as the flood risk categories (e.g. water depths) of hazard maps differ among river segments. The recurrence interval of the flood hazard maps of each river segment ranged from once per 100 years to once per 300 years. We standardized the resolution to 1 km × 1 km and assigned the expected maximum depth within a grid cell as the flood depth, and then flood risk was classified into six categories based on expected flood depth: Risk 0: 0 m; Risk 1: 0–0.5 m; Risk 2: 0.5–1.0 m; Risk 3: 1.0–2.0 m; Risk 4: 2.0–5.0 m; Risk 5: ≥5.0 m.

2.3 | Data analysis

2.3.1 | Status of freshwater organism in Japan

To clarify the relationship between grid cell species richness and environmental status (i.e. HI index and flood risk categories), we built a Poisson linear regression model for each target group (i.e. all species and only red-list species) in each species group (i.e. fishes and macroinvertebrates). Finally, we built four full models. The response variable was the species richness of each grid cell, and the explanatory additive variables were flood risk categories (a categorical variable), HI index (a continuous variable) of the grid cells and the quadratic term of the HI index. Model selection was performed through a best-subset selection procedure (Breiman, 1996) based on Akaike's information criterion (AIC) by using the R ver. 4.1.0 (R Development Core Team 2021) *dredge* function in the MuMIn R package (Barton & Barton, 2015).

2.3.2 | Target set, Marxan complementarity and irreplaceability analysis

Using the distribution records of freshwater fishes and macroinvertebrates, we performed a complementarity analysis using Marxan (Ball et al., 2009). Marxan is a practical tool that allows users to delineate conservation candidate sites by referencing "conservation area goodness" to maximize protection coverage at minimal cost. Here, we used an index of human activity as a cost layer in the Marxan analysis (see below). The conservation features we input into Marxan were the distribution grids of each freshwater fish (6303 grid cells for all species and 3183 grid cells for red-listed species) and macroinvertebrate species (1484 grid cells for all species and 737 grid cells for red-listed species). We assumed two protection scenarios by considering feasibility: in scenario 1, conservation feasibility is determined by human activities, and in scenario 2, conservation feasibility is equal throughout the planning units, meaning that no land is considered to be more or less desirable for human use (i.e. even cost). Scenario 1 reflects the current status of human activities. Because changes in future human activity are uncertain, we built scenario 2 to set potentially important sites for conservation independent from the current status. Hence, for scenario 1, the HI index (Human Influence Index) was adopted as the cost layer in Marxan. This index incorporates proxies of human population pressure (population density), land use and infrastructure (built-up areas, nighttime lights, land use/cover) and accessibility (coastlines, roads, railroads, navigable rivers) (Wildlife Conservation Society – WCS, and Center for International Earth Science Information Network – CIESIN – Columbia University 2005). In scenario 2, we set all the planning units with an even cost (value of 1 for convenience). We used two kinds of conservation targets, reflecting two common objectives of conservation planning. First, a representation target was considered achieved if any portion of the species' distribution was included in conservation-priority grid cells. Second, a sliding target was considered achieved for a species where 100% of its occupied grid cells were included in conservation-priority grid cells when the species' area of occupancy is <50 grid cells (for fishes) or <5 grid cells (for macroinvertebrates), and if 10% of its occupied grid cells were included in conservation-priority grid cells when its area of occupancy is >1000 grid cells (for fishes) and >200 grid cells (for macroinvertebrates). For species with ranges that fall between these two thresholds, the representation target was interpolated using a linear regression on the log-transformed area of occupancy at the national scale (Maiorano et al., 2006; Rodrigues et al., 2004). The thresholds were intended to ensure species persistence nationally, and were determined based on the expert opinions of several freshwater scientists in Japan. The main reason for the use of separate thresholds for fishes and macroinvertebrates was the over 10-fold difference in average area of occupancy between the two taxa.

We used actual distribution records for the analysis because species distribution models of riverine animals that were built in previous studies, especially in Japan, did not show sufficient explanatory power at finer grain sizes such as 1 km × 1 km (Fukushima et al., 2007), and because errors of commission (false positives) in predicted occurrence can introduce strong biases in the results of complementarity analysis.

To identify conservation-priority areas, we ran Marxan 100 times under each scenario to obtain each solution and the Marxan selection frequency, which is used as a measure of irreplaceability for each planning unit. The notion of irreplaceability reflects a site's potential contribution to conservation goals or, conversely, the extent to which options for meeting those goals are lost if the site is lost (Le Saout et al., 2013). We set two target groups: (1) all species of fish and macroinvertebrate, and (2) only red-listed species. Species categorized as threatened according to the Red List of Japan (Biodiversity Center of Japan; http://www.biodic.go.jp/rdb/rdbf.html) were defined as red-listed species. Of the grid cells that overlapped with extant PAs, those cells that were occupied by the target taxa (both all species and red-listed species) were automatically designated as conservation-priority areas.

2.3.3 | Relationship between biodiversity and environmental status of each grid

To compare the number of conservation-priority grid cells across a gradient of flood risk categories and of HI index, we used Pearson's chi-squared test with post-hoc tests for each variable. We treated HI index as a categorical variable to understand the detailed relationship between HI index and the selected grid cells, because we expected that there would be nonlinear relationships between the number of conservation-priority grid cells and values of the HI index. We classified the range of HI index values into five categories by aggregating the data into intervals of 20%.

3 | RESULTS

3.1 | Status of freshwater organisms in Japan

We collected data for 131 freshwater fish species (in 6306 grid cells) and 1395 macroinvertebrate species (in 1484 grid cells). Of these, 57 freshwater fish species (in 3183 grid cells) and 65 macroinvertebrate species (in 737 grid cells) were red-listed.

The results of the Poisson linear regression models showed that relationships between species richness and environmental status (i.e. HI index and flood risk categories) varied with taxa and species group (Figure 1, Appendix S1–S3). For all freshwater fish and macroinvertebrate species, full models were selected as the best model, and the HI index showed a hump-shaped relationship with species richness. Additionally, higher species richness was associated with high flood risk categories. For red-listed freshwater fishes, species richness positively correlated with HI index and tends to be high for high flood risk categories. In contrast, flood risk was the only variable that correlated with species richness for red-listed macroinvertebrates. Macroinvertebrate species richness showed a unimodal relationship with flood risk and was highest at medium flood risk categories.

3.2 | Extant PAs and protection of fishes and aquatic macroinvertebrates

The number of conservation-priority grid cells obtained by the Marxan did not show clear differences between the two scenarios for either species group (Table 1). In both scenarios, approximately 28% of the grid cells with fish observations and 62% of the grid cells with macroinvertebrate observations were selected as conservation-priority grid cells. When red-listed species were used to identify priority grid cells, approximately 17% and 11% of the grid cells with fish and macroinvertebrate observations were selected in both scenarios. Moreover, grid cell irreplaceability was highly correlated among scenarios in each species and target group ($r > 0.93$, Figure 2, Appendix S4 and S5).

Extant PAs occupied only 12–30% of conservation-priority grid cells in all cases (i.e. species groups, target groups and scenarios; Figure 3). Particularly for red-listed species, a maximum of only 18% or 10 species (in scenario 2 for freshwater fish) of conservation-priority grid cells were included in extant PAs. Moreover, only one species (2% of red-listed species) of freshwater fish and three species (5% of red-listed species) of macroinvertebrate achieved the representation target within extant PAs.

3.3 | The features of conservation candidate sites

For all species of both groups, conservation-priority grid cells were unevenly distributed across the gradient of flood risk and were more heavily distributed at low or high flood risk (Figure 4; chi-squared test, $p < .01$; Appendix S6, S7). In particular, >40% of candidate conservation-priority grid cells were located in flood risk areas, and most of them were at high flood risk (i.e. Risk 3–5; Figure 4). The proportion of conservation-priority grid cells located in high flood risk areas was higher for red-listed species of both groups, and 80% of the candidate conservation-priority grid cells for macroinvertebrate species were located in flood risk areas. The number of conservation-priority grid cells was higher in areas of high HI index as well in those of low HI index (including extant PAs) in all cases (chi-squared test, $p < .01$; Appendix S6, S7).

4 | DISCUSSION

This study suggests there is a great discrepancy with regard to biodiversity conservation in extant PAs in freshwater ecosystems. In particular, only a few red-listed species in each group were represented within extant PAs. This is not surprising because many PAs had globally been established in locations that are disproportionately unimportant for biodiversity (Venter et al., 2018), but our results were some of the lowest rates among previous studies focusing on gaps between extant PAs and biodiversity (Lawrence et al., 2011).

According to our analysis, approximately 30% of identified conservation-priority grid cells were located in grid cells with low HI index values, and half were located in low flood risk areas (Figure 4). These grid cells would be the most significant for FPA establishment, because additional FPAs could be relatively easy to establish in these locations. However, the number of grid cells in low HI index areas in which establishing FPAs is feasible was not large, because 10–30% of conservation-priority grid cells overlapped with extant PAs, which have been strategically established in undeveloped areas and have reduced utility for freshwater biodiversity conservation. We also found that >40% of the identified conservation-priority grid cells were located in high flood risk areas (Figure 4). In addition, the species richness of both taxa and species groups was high in areas of medium to high HI index and/or flood risk. These results can be attributed to the natural longitudinal distribution of riverine animals and the effects of artificial flood control systems. Many riverine animals, particularly fishes, spend all or part of their life cycle in floodplains, and thus the species richness of freshwater

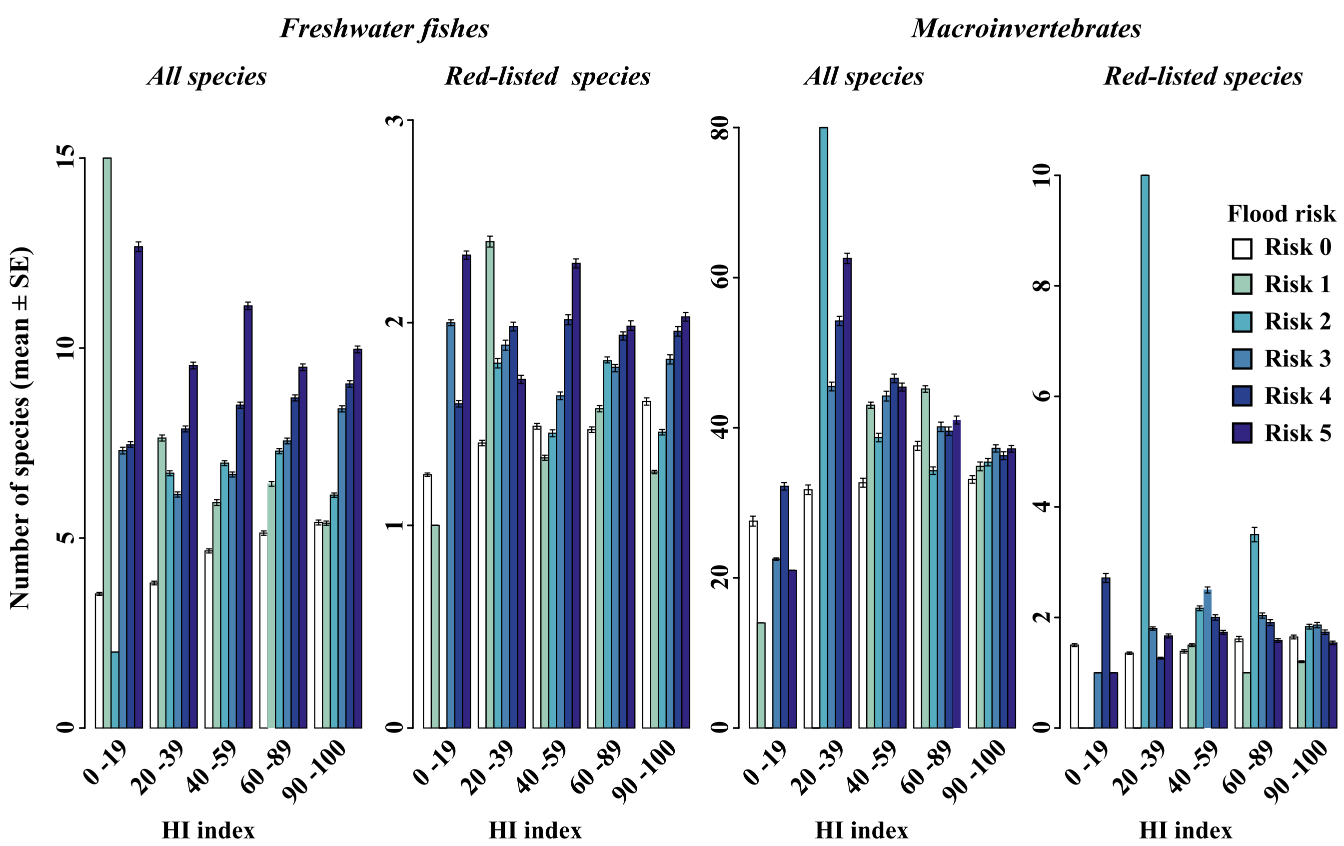

FIGURE 1 Mean number of species in each HI index and flood risk grid. Error bars denote two standard errors of the mean

Conservation purpose	Scenario	Freshwater fish		Macroinvertebrate	
		Mean	SD	Mean	SD
All species	Scenario 1	1674.95 (28%)	3.04	924.18 (62%)	0.41
	Scenario 2	1734.06 (27%)	5.49	924.74 (62%)	1.54
Red list species	Scenario 1	1092.15 (17%)	2.94	164.19 (11%)	0.42
	Scenario 2	1128.82 (18%)	3.7	164.99 (11%)	1.34

TABLE 1 Number of conservation candidate priority grids culcurated by Marxan argorithms in each taxa, scenario, and target group. Mean and SD were caulurated by results of each 100 run of Marxan selections. The percentage of ocupcupancy grids were noted in brackets

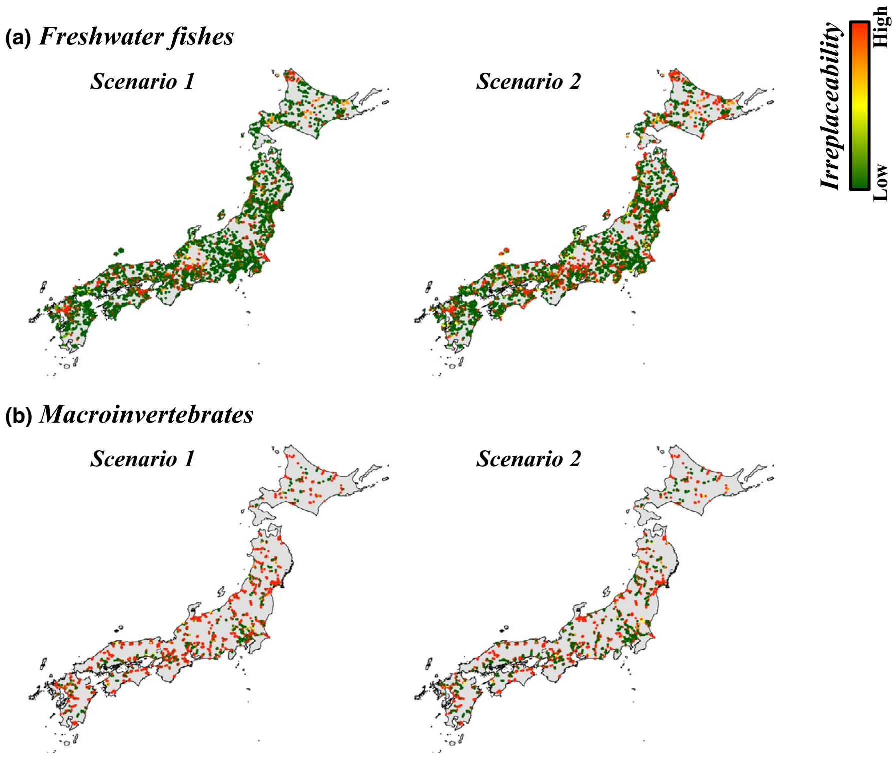

FIGURE 2 Irreplaceability value maps of all (a) fish and (b) macroinvertebrate species under scenarios 1 and 2

animals generally tends to increase in lowland areas (Tockner & Stanford, 2002). Nevertheless, the distributions of floodplain-dependent species are restricted to remnant habitats in lowland areas because most historic floodplains worldwide have been developed for human use and are impacted by flood control measures such as artificial levees (Tockner & Stanford, 2002). Therefore, our model tends to select areas with high flooding risk and human influence as sites for additional FPAs. Floodplain conservation provides suitable habitats for many freshwater organisms and may help to control floodwaters, suggesting that establishing FPAs in high flood risk areas would be a win-win strategy both for conserving freshwater biodiversity and enhancing eco-DRR.

Establishment and management costs are crucial considerations for the designation of additional PAs, including FPAs. However, in our study system, the irreplaceability of each planning unit remained similar across the two scenarios for each species group, and the majority of conservation-priority grid cells for both taxa and species groups had high to medium HI-index value. These findings suggest that important sites for freshwater biodiversity under our conservation targets are already limited, and the selection of priority grid cells within more developed areas cannot be avoided. The species richness of many types of animals (including macroinvertebrates) is positively correlated with human population density at coarser grain size (e.g. 10 km ×10 km), whereas it is negatively correlated at finer grain size (e.g. 1 km ×1 km) (Pautasso, 2007), suggesting that small-scale habitats with high biodiversity are vulnerable in densely populated areas. These studies support our suggestions that additional PAs are essential in human-dominated areas (i.e. those with a high HI index) as well as in "high and far" areas (Joppa & Pfaff, 2009). It is worth noting that the establishment of additional FPAs in human-occupied areas would not necessarily entail human displacement, because biodiversity can be maintained alongside human activities.

Substantial economic and social costs are incurred when FPAs are established in human-dominated areas as compared to "high and far" areas. However, floods, such as the large flood of the Seine River in France that occurred in 2016, may cause damages of more than several billion dollars (Guha-Sapir et al., 2016). Full recovery from such a disaster – meaning that key system characteristics such as population number, labour force and access to food

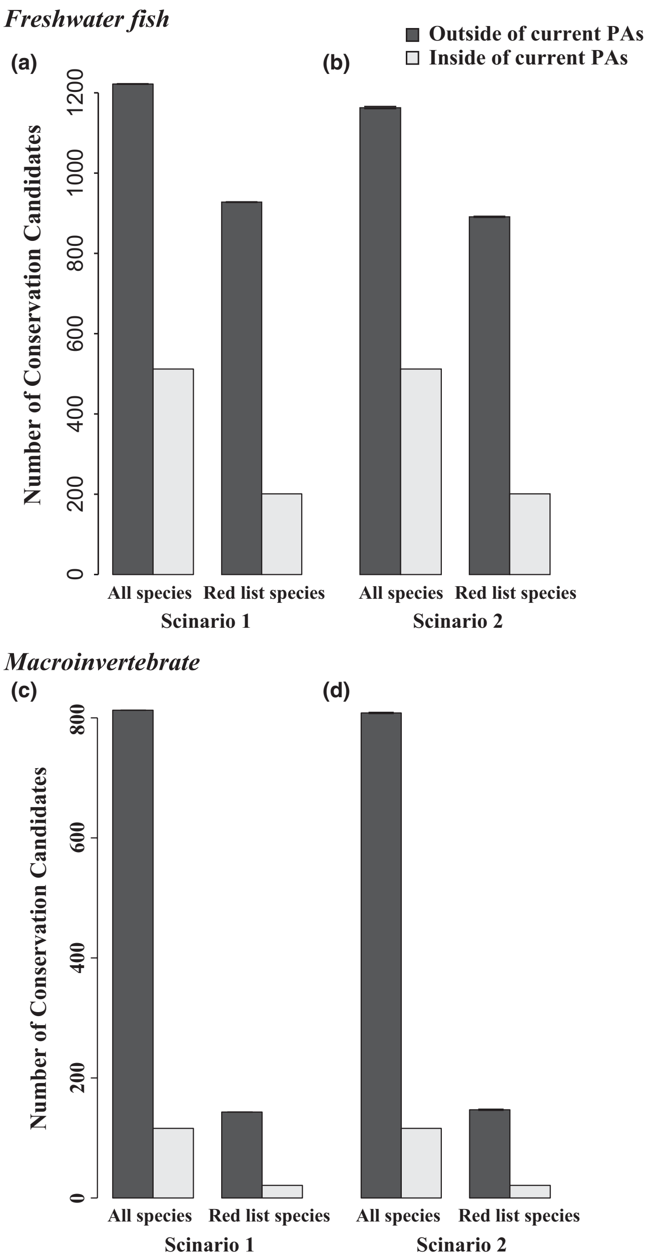

FIGURE 3 The number of conservation candidate grid cells located inside and outside of extant protected areas of freshwater fish species under (a) scenario 1 and (b) scenario 2, and macroinvertebrate species under (c) scenario 1 and (d) scenario 2

and electricity are recovered to 100% of the pre-disaster situation – can be achieved only with abundant resources and a large budget (Mens et al., 2011). Alternative strategies are available, however. De Biesbosch in the Netherlands and Liberty Island in Yolo Bypass in the Sacramento River of central California were once modified as urban and agricultural areas (Sloey et al., 2015; Warner et al., 2018). Flood disasters occurred at these places in 1424 and 1997, respectively, and the inhabitants decided to leave the regions because they could not afford the cost and resources needed to recover. Part of De Biesbosch has become a national park and part of Liberty Island a conservation reserve, representing some of the few FPAs in the world (Sloey et al., 2015; Warner et al., 2018).

According to several climate change models, the frequency of catastrophic flooding will increase (Hirabayashi et al., 2013), and many countries are likely to need considerable adaptation (Willner et al., 2018). In fact, more than half of the United States by area will need to at least double their protection against flood events within the next two decades (Willner et al., 2018). Under these scenarios, the establishment and management costs for additional FPAs could be less expensive than those for flood recovery. In addition, many countries will face serious population declines over the next century, which will likely lead to land abandonment (Queiroz et al., 2014) and could help to secure lands for additional FPAs.

The spatial resolutions of recent studies that focused on FPAs were mainly at the watershed scale (e.g. Saunders et al., 2002). This grain size is useful because riverine conservation planning often requires spatial configurations such as river networks. However, particularly in mountainous countries including Japan, it is not realistic to consider additional FPAs that are watershed size, because human-occupied areas are concentrated in a limited number of low-elevation areas (Marini et al., 2009). In this situation, a finer grain size, such as 1 km ×1 km, seems practical for considering sites for additional FPAs. Nevertheless, many aquatic animals, especially migratory fishes, do not necessarily complete their life cycle within a 1-km^2 area. Additionally, flood risk often influences by upstream river and riparian conditions (Capon & Pettit, 2018). Therefore, land managers should consider the condition of the entire river network when they select FPA sites, even if the proposed FPA itself is small.

Although the majority of identified conservation-priority areas had high flood risk, some of the stakeholders in these areas, particularly in developed areas, may not support the establishment of FPAs on their land (e.g. Kamal & Grodzinska-Jurczak, 2014), because displacement from an area often entails huge and varied costs (e.g. Maghfiroh & Hanaoka, 2019; Maldonado et al., 2013). Indeed, the resilience of individual livelihoods and other socioeconomic impacts often influence relocation decisions (Cong et al., 2018). Additionally, social capital, including community network and place identities, are also integral to relocation decisions (Chamlee-Wright & Storr, 2009; Cong et al., 2018). Thus, resolving trade-offs among livelihoods, attachments to place and community, and flood exposure should be fundamental for establishing FPAs in developed areas. In recent years, however, many landowners have personally experienced the socioeconomic risks that accompany environmental degradation or have become more aware of the prospect of increased socioeconomic risks and associated declines in human well-being in the future (Rieb et al., 2017). Moreover, experiences of natural disasters have been shown to increase awareness of the need for relocation (Bukvic et al., 2015). Additionally, stakeholders tend to support land-modification projects when the projects provide them with ecosystem services (Howe et al., 2014). Thus, one important way to achieve biodiversity conservation is not

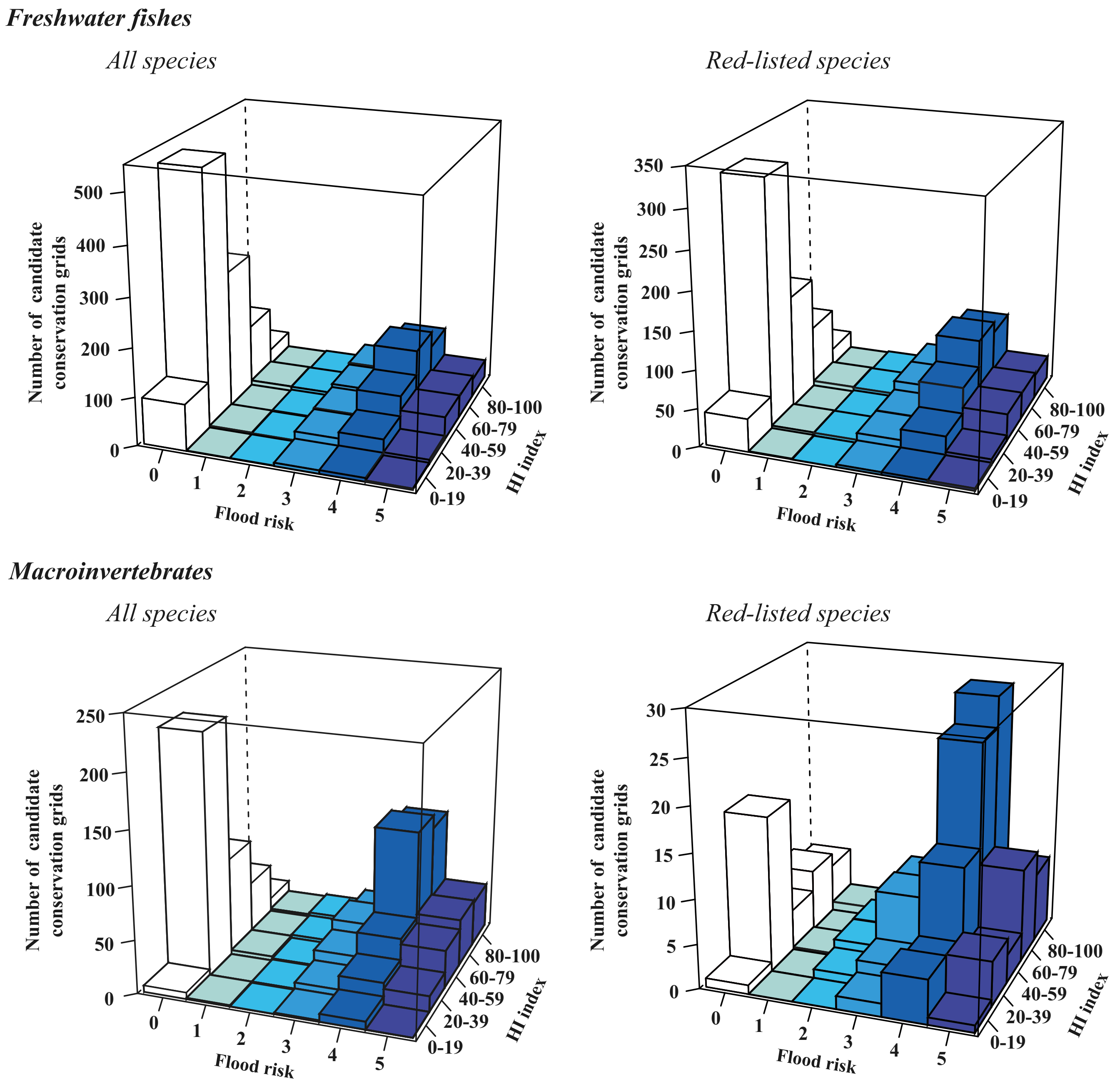

FIGURE 4 Number of candidate conservation grid cells that belong to each flood risk and HI index class

to pursue biodiversity conservation by itself, but to achieve it through floodplain management. For example, although the Kissimmee River restoration projects in Florida, USA, provide suitable habitats for many aquatic and terrestrial organisms, the main purpose of the projects is water management (Koebel, 1995). Similarly, flood control basins constructed in the Chitose River, Japan are used as farmland, but also serve as semi-natural wetlands that provide summer habitat for wetland species (e.g. fishes, aquatic insects, birds and plants), especially those that inhabit environments with hydrological variation (Nakamura et al., 2020; Yamanaka et al., 2020). Also, floodplain ponds along the Ishikari River, Japan are slated for future use as floodwater retention ponds (unpublished information); the fragmented shapes of these ponds will serve as refugia from biological invasions for an endangered minnow (Ishiyama et al., 2020). The designers of Bishan-Ang Mo Kio Park in Singapore, a well-known urban park, used the blue-green infrastructure approach to prevent flooding (by increasing retention capacity and reducing flow velocity) while also improving recreational function (Lim & Xenarios, 2021); as a result, the diversity of various taxa such as freshwater fishes, aquatic insects and birds have also increased within the park (Lim & Xenarios, 2021; Wilkinson et al., 2021). Thus, it is possible that a variety of river management plans could incidentally help biodiversity conservation. Proposed FPAs with ecosystem service functions such as flood DRR through water retention (Schober et al., 2015) may foster agreement among stakeholders and increase the likelihood of establishing additional FPAs.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

PEER REVIEW

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DATA AVAILABILITY STATEMENT

The species distributions of freshwater fishes and macroinvertebrates are available from http://www.nilim.go.jp/lab/fbg/ksnkankyo and http://www.biodic.go.jp. The distribution data of red-listed species are available upon request for research or application purposes (requests should be submitted through the above websites). Requests will be considered by the data owners (the Ministry of Land, Infrastructure, Transport and Tourism or the Ministry of the Environment, Japan), and data will be released after receiving approval from the respective custodians. Any requests, especially on behalf of non-Japanese speakers, may be supported by the corresponding author. All other data used in this study are freely available. Data references are provided in the main text. The dataset for the conservation planning algorithms used in this study is available from the Dryad Digital Repository: https://doi.org/10.5061/dryad.f1vhhmgzp.

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BIOSKETCH

Takumi Akasaka is interested in landscape-ecology and biodiversity conservation in order to find the solution for reconciling human well-being and biodiversity conservation. One of his current researches focuses on the relationship between biodiversity distribution and distribution of natural disaster hazard.

Author contributions: T.A. and F.N. designed the study. T.A. and M.A. conducted the statistical analyses. T.A., M.I., Y.M., M.A. and F.N. drafted the first version of the manuscript. M.T., I.N., T.Y., K.T., I.M., H.M., K.Y., I.H., O.N., M.Y. and K.I. contributed data. All authors contributed to the writing.

SUPPORTING INFORMATION

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