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Current Status and Future Prospects of Endangered Species Restoration Projects for Freshwater Fishes, Amphibians, and Reptiles in South Korea

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ABSTRACT

To understand restoration and conservation projects conducted in Korea for endangered freshwater fishes and amphibians/reptiles, information about Request for Protocols-related studies on restoration, breeding, and release were collected. Trends of studies were visualized via word clouds and VOSviewer program using a text mining technique. Analysis of restoration projects for endangered freshwater fishes elucidated that most research studies conducted to date were focused on genetics and release through captive breeding that could be classified into captive breeding and habitat environments. As for research projects related to amphibians/reptiles, monitoring projects had the highest number, followed by genetic, translocation, and monitoring studies. In addition, restoration projects for amphibians/reptiles included a large number of post-capture translocation projects. Thus, many projects were confirmed by public institutions rather than by the Ministry of Environment. Network analysis revealed that it was largely classified into capture, translocation, and *Kaloula borealis*. Based on these results, limitations, achievements, and challenges associated with projects conducted thus far are highlighted. Research directions for future restoration and conservation of endangered freshwater fishes and amphibians/reptiles in South Korea are also suggested.

Keywords: Conservation, Network analysis, Recovery, Restoration, VOSviewer, Word cloud

Introduction

Global biodiversity has been decreasing consistently due to various human-induced disturbances such as climate change and indiscriminate development of infrastructure (Barbarossa *et al*., 2021; Becker *et al*., 2007; Gibbons *et al*., 2000; Halliday, 2021; He *et al*., 2019). Up to one million plant and animal species face extinction, with many approaching it within the next few decades (Tollefson, 2019). To prevent species extinction, the International Union for Conservation of Nature (IUCN) has created a red list of threatened species, based on which many countries have enacted laws on endangered species (e.g., United States, Endangered Species Act; United Kingdom, Wildlife Countryside Act; Canada, Species at Risk Act ; Australia, Environment Protection and Biodiversity Conservation Act). The Ministry of Environment (MOE) in South Korea has also legislated the "Wildlife Protection and Management Act" to prevent the extinction of wildlife by systematically protecting and managing wildlife and their habitats, to maintain the ecosystem by promoting biodiversity, and to ensure a healthy natural environment in which wildlife coexists with human beings.

Amphibians are among the most endangered animals in the world. Approximately 41% species face extinction (IUCN, 2021). Freshwater fish are listed as the second most endangered animals after amphibians. Global management strategies are urgently needed to protect them (Bruton, 1995). The median extinction rate of freshwater fish due to climate change conditions is projected to be approximately 7% higher than the median background extinction rate (Tedesco *et al*., 2013). More than 7% of all amphibians will become extinct within the next century (Alroy, 2015). The Fish and Wildlife Service (FWS) in the

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United States has been conducting restoration for endangered species based on a species restoration plan that incorporates both habitats and populations (US Fish and Wildlife Service (USFWS), 2019; 2020; 2021). The MOE in Korea has desi gnated 27 species of freshwater fish and eight species of amphibians and reptiles as endangered species for protection (MOE, 2017). Restoration projects have been conducted to conserve their habitats and populations. The MOE in Korea has recently established a master plan for endangered species restoration and emphasized the importance of habitat restoration.

Text mining is a tool for extracting significant information from atypical words. Extension of text mining and knowledge discovery are possible (Fayyad & Smyth, 1996; Simoudis, 1996). This tool was first suggested by Feldman (Feldman & Dagan, 1995). It has been mainly applied to analyze trends of certain study subjects or fields, such as publishing, information technology, pharmaceuticals, and healthcare. It is currently used in various study areas (Bolasco *et al*., 2005; Gupta & Lehal, 2009; Zhang *et al*., 2015). Because most text mining tools provide visualized results, they are effective in identifying changes and trends of targeted studies. Text mining has also been used to investigate current status of restoration studies for endangered species (Guerrero *et al*., 2021; Wang *et al*., 2021).

To achieve effective restoration of endangered freshwater fishes, amphibians, and reptiles, appropriate species-specific restoration plans are necessary. Such restoration plans should be prepared based on analysis of pre-conducted restoration projects. Therefore, the aim of this study was to analyze contents of Request for Protocols (RFP) of endangered species restoration projects for freshwater fishes, amphibians, and reptiles announced by national institutes or engineering companies using text mining tools to identify changes in restoration trends in Korea. Based on results obtained, outcomes, limitations, and problems of restoration plans in Korea were determined and future directions for restoration strategies to effectively conserve endangered species were suggested.

Materials and Methods

Data collection

We collected RFPs from 2002 to 2020 for endangered freshwater fishes and from 2007 to 2020 for amphibians/reptiles to understand restoration and conservation of studies endangered freshwater fishes and amphibians/reptiles conducted in Korea. Data were retrieved from PRISM, the Korea ON-Line E-Procurement system (http://www.g2b.go.kr/), Policy Research Information & Management (https://www.prism.go.kr/), ScienceOn, Science & Technology Infrastructure (https://scienceon.kisti.re.kr/), and Google search engine (https://www.google.com) were searched using "endangered freshwater fishes", "endangered amphibians", and "endangered reptiles", as well as national and scientific names of concerned endangered freshwater fishes and amphibians/reptiles. Data related to restoration, breeding, and release were chosen as secondary filters of primary secured data to analyze restoration research and conservation status by species for endangered freshwater fishes and amphibians/reptiles. In this study, species-specific journal papers were excluded from the analysis to determine aspects of restoration and conservation projects.

Data analysis

To understand research trends, we used the text mining technique. The title, content, and scope of the RFP secured by animal taxa groups were translated into English and extracted to build a corpus for analysis. For the analysis of the corpus, we used word cloud visualization, a method mainly used in text mining. Network analysis was performed between keywords in the corpus using the VOSviewer program. Network analysis was performed between the keywords in the corpus, and the weighted and density of the keywords were represented using network visualization and a word density map to view the analysis results.

A word cloud is a program that uses text mining techniques and visualization based on weights and frequencies of keywords, with higher frequencies presented with larger font sizes. An online generator WordClouds.com (Zygomatic, Netherlands) was used to create a cloud of the corpus (WordClouds.com). VOSviewer 1.6.16 (Leiden University, Netherlands) was used to visualize co-occurrence of keywords and to identify their connectivities. This program builds a map using the VOS mapping technique based on the co-occurrence of keywords and visualizes it (Van Eck & Waltman, 2007). VOSviewer can construct a two dimensional distance-based map of co-occurrence keywords (Van Eck & Waltman, 2010). It is mainly used when analyzing references due to its advantages of being simple and convenient when expressing bibliometric maps (Van Eck & Waltman, 2010).

Results

Trends of Endangered species recovery projects

Freshwater fishes

A total of 34 research projects related to the recovery of endangered freshwater fishes were carried out from 2002 to 2020, showing an upward trend since 2010 (Fig. 1a). It was confirmed that most projects conducted to date were mainly focused on genetic and release through captive breeding. Projects related to the recovery of endangered species were found to be increased after the Four Major Rivers Project. The release of breeding individuals

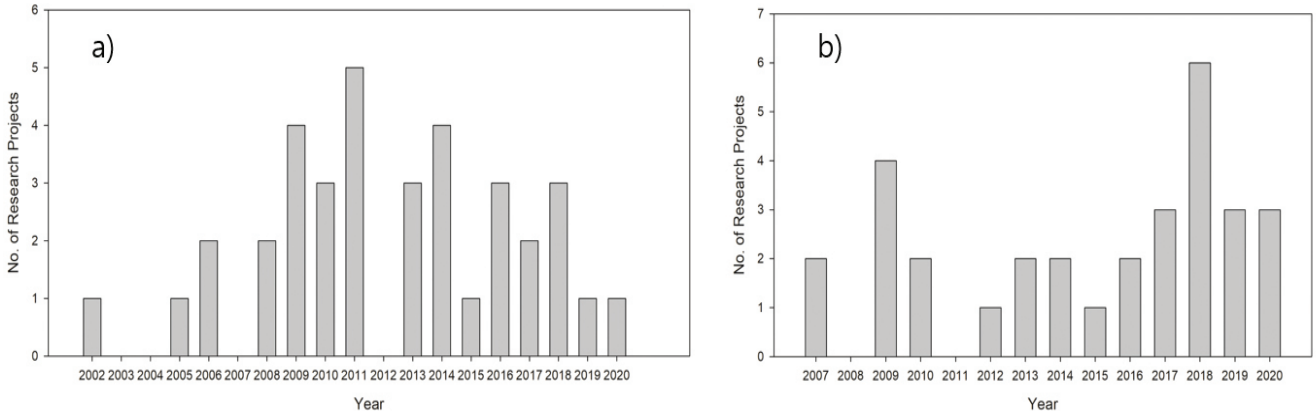

Fig. 1. Number of research projects presented year-wise. a) Freshwater fish; b) amphibians and reptiles.

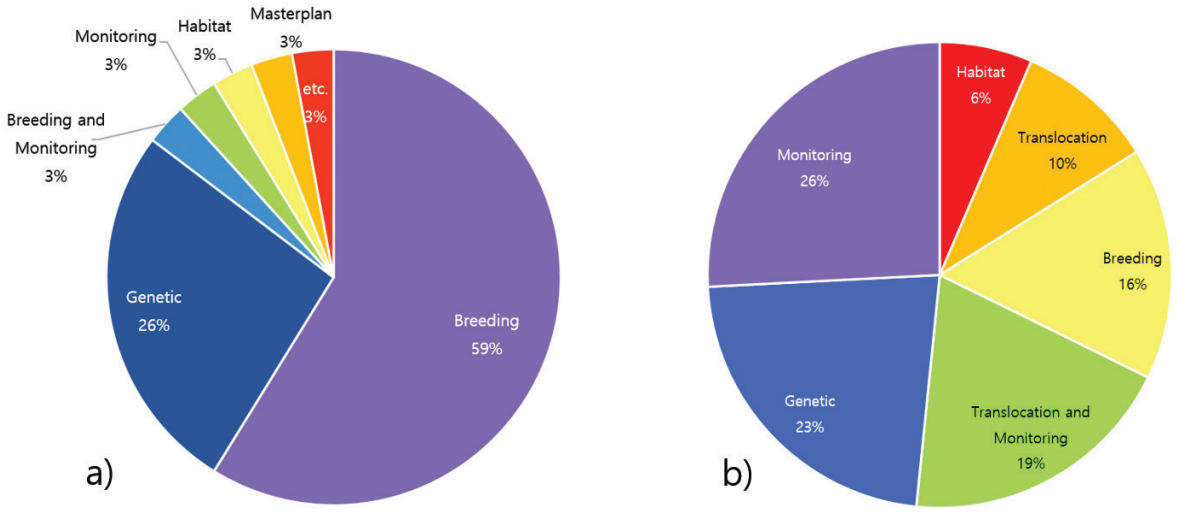

Fig. 2. Proportions of study fields under the restoration projects conducted. a) Freshwater fish; b) amphibians and reptiles.

was resumed in 2018. There was no release in 2013 to 2017. For each species, breeding and restoration studies were conducted on 15 of 27 endangered freshwater fish species and 14 species were released into the wild (Table S1). For research projects on freshwater fish recovery, 58.8% were projects on breeding only, 26.5% on genetic diversity, 2.9% on monitoring, and 2.9% of projects on both breeding and monitoring (Fig. 2a). Studies on habitat restoration and identification of the cause of habitat destruction have not been conducted until recently. The first study focusing on ecological characteristics and conservation of endangered species (*Kichulchoia brevifasciata, Gobiobotia macrocephala, Microphysogobio rapidus,* and *Pseudobagrus brevicorpus*) was conducted in 2019. Project-related breeding was mainly carried out by the MOE. The Ministry of Land, Infrastructure and Transport (MOLIT) also placed an order for some projects during the Four Major Rivers project. However, recovery projects were no longer supported after completion.

Amphibians/Reptiles

A total of 31 research projects related to the recovery of endangered amphibians and reptiles were carried out from 2007 to 2020, with most projects being performed in 2018 (Fig. 1b). Research projects on breeding were conducted on all eight endangered amphibian species (Table S2). Regarding amphibian-related projects, monitoring projects showed the highest frequency (25.8%), followed by genetic projects (22.6%) and translocation and monitoring projects (19.4%) (Fig. 2b). Regarding habitat restoration projects, only one project was carried out for freshwater fishes in 2019. However, two projects ("Restoration Work of *Pelophylax chosenicus's* habitat in Ansan Suin line" and

"Restoration project of Ilwol Reservoir, the habitat of *Dryophytes suweonensis*") related to habitat for endangered amphibians (*P. chosenicus* and *D. suweonensis*) were carried out. Additionally, recovery projects for amphibian/reptiles included a large number of capture and translocation projects. Thus, a number of projects ordered by public corporations other than the MOE were confirmed.

Analysis of endangered species business contents through text mining analysis

Freshwater fishes

Upon identifying the RFP related to restoration of endangered freshwater fishes by word cloud, "release" was found to have the highest frequency of 67, followed by "breeding" and "captive" (identified 63 and 53 times, respectively), while "habitat" and "genetic" were identified 43 and 39 times, respectively. In addition, words such as "monitoring" and "restoration" exhibited a high frequency (Fig. 3a). Results of network analysis were similar to those using word cloud. It is broadly classified into two groups: captive breeding and habitat environments. Captive breeding showed strong relationships with release monitoring, release, and restoration, while habitat environments were strongly related to environmental factors (Table 1, Fig. 4).

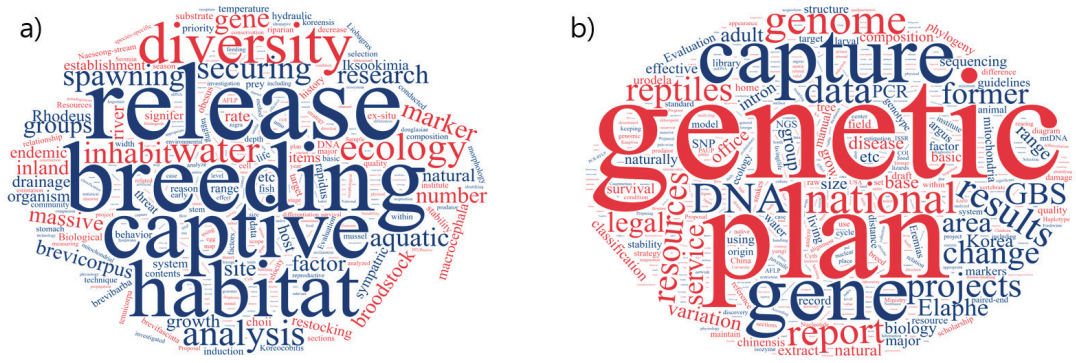

Fig. 3. Word clouds of the most frequently used terms in a) freshwater fish restoration projects and b) amphibians and reptiles restoration projects. Free online word cloud generator and tag cloud creator WordClouds.com. Retrieved December 30, 2020 from https://www.wordclouds.com/.

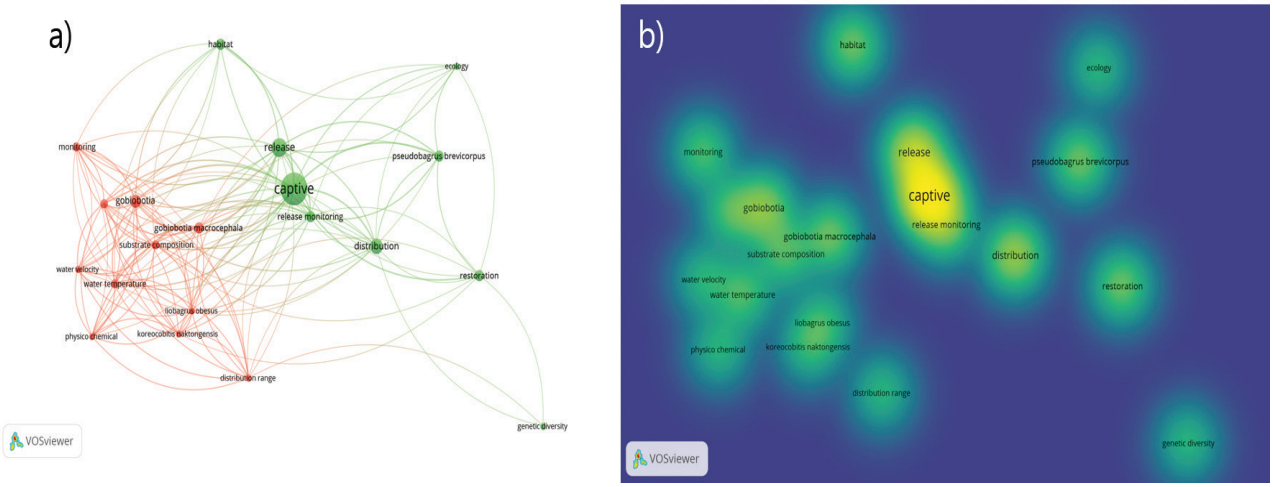

Fig. 4. Visualization map of restoration projects for endangered freshwater fishes. a) Network visualization map based on document-weights; b) density visualization map based on total link-weights.

Amphibians/Reptiles

As a result of identifying the RFP related to restoration of endangered amphibians/reptiles via word cloud, "habitat" appeared 117 times, "*Kaloula borealis*" appeared 110 times, while "plan" and "monitoring" appeared 98 and 79 times, respectively. Additionally, "survey" and "breeding" were performed 63 and 59 times, respectively (Fig. 3b). As a result of network analysis, it was confirmed that it was largely classified into three categories: capture, translocation, and *K. borealis*. With regards to capture, plan and habitat showed strong relationships with each other. In addition, relationships between translocation and release were high. There was a link between *K. borealis* and the management plan (Table 1, Fig. 5).

Discussion

To successfully restore endangered species, various factors such as ecology, genetics, habitat, distribution, impairment diagnosis, and monitoring should be considered in tandem (Barnas *et al*., 2015; Campbell *et al*., 2002; Jachowski & Singh, 2015; Lawler *et al*., 2002; Moyle *et al*., 2003; Norris & Mcculloch, 2003). In addition, they should be systematically applied to each restoration step (Cochran-Biederman *et al*., 2015). Projects conducted for endangered species restoration in Korea were focused on the development of captive breeding techniques for various species (Fig. 2 and 3). As most projects ordered by national institutes in Korea should be finished within the fiscal year (normally end of December of a certain year), tasks that can be achieved in short-term periods such as captive breeding and release were mainly conducted. Such biased restoration studies could result in decreased restoration efficiency. Restoration in the U.S. has shown the same problem (U. S. Government Accountability Office, 2006). Until now, no restoration or recovery plans for species

Table 1. Top 5 keywords identified by network analysis using VOSviewer. Total link strength (TLS) attributes represent the number of links of an item with other items (Links) and the total strength of the links between an item and other items (Occurrences)

Freshwater Fishes				Amphibians/Reptiles			
Keyword	**TLS**	**Links**	**Occurrences**	**Keyword**	**TLS**	**Links**	**Occurrences**
captive	59	17	17	monitoring	68	13	13
release	39	17	9	capture	66	13	14
Gobiobotia	41	14	6	plan	66	13	16
water depth	36	14	4	habitat	64	13	15
substrate composition	33	15	4	wildlife	53	13	10

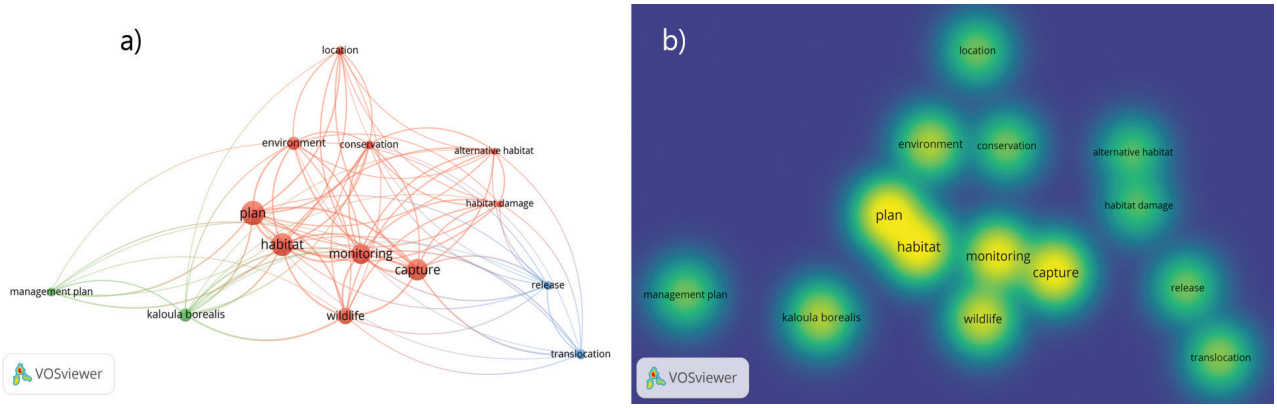

Fig. 5. Visualization map of restoration projects for endangered amphibians and reptiles. a) Network visualization map based on document-weights; b) density visualization map based on total link-weights.

have made reckless restoration. However, ineffectiveness and duplicated expenses for restorations have frequently occurred. Therefore, master plans and species recovery plans with consistent release are urgently required to improve the effectiveness and stability of species restoration.

The main goal of restoration projects for freshwater fishes was to augment captive breeding populations. Therefore, studies on breeding techniques and genetic diversity have been mainly conducted. However, important factors such as cause of degradation and habitat improvement were not considered at all, making it difficult to find successful restoration, although the restoration was conducted for more than 10 years (e.g., *P. brevicorpus*). Habitat-related plans for rehabilitation, conservation, and improvement should be urgently prepared for species recovery. Additional captive breeding techniques for massive breeding and supporting the entire life cycle (F1 → F2) are still insufficient. Therefore, appropriate recovery plans for freshwater fish species that account for all aforementioned information should be prepared in the near future for systematic and successful restoration.

In most restoration projects conducted for amphibians and reptiles, animals, especially *K. borealis*, were captured and translocated due to land developments. However, complete restoration studies with captive breeding are insufficient, despite genetic diversity being highly mentioned. Although the development of captive breeding techniques is important for species recovery and conservation, relatively fewer studies have been conducted for amphibians as compared to those for freshwater fishes. As ment ioned above, various factors related to restoration should be considered simultaneously for successful restoration of a species. For the restoration of amphibians and reptiles in Korea, factors such as the entire area of restoration fields, ecology, captive breeding, and cause of degradation among others should be considered as such information will be helpful for preparing highly scientific and professional recovery plans.

Endangered species restorations are normally conducted by national governments or institutes because most restorations take a long time to reach their goal (Arha & Thompson, 2012; Fischman *et al*., 2018; Nagle, 2017). Species restoration is a long-term project, which means it requires a considerable budget. As a result, restoration often becomes stagnant. In some cases, private companies were supporting (e.g., Samsung Electronics, *Eremias argus* in 2012; Hankook Tire, *Pseudopungtungia nigra* in 2018). However, most of them were temporary. Most restoration projects for endangered freshwater fish were supported by MOE, except for some cases where projects were conducted by the MOLIT during the Four Major Rivers project. The MOE also supported restoration of amphibians and reptiles for the development of breeding techniques. However, capture and transportation projects were mainly conducted by engineering companies. For the success of restoration, securing the budget is an important aspect. Therefore, discovery of budget support methods (procuring funds) supported by national institutes or engineering companies is required. In the case of national natural monuments (*Cobitis choii*, *P. brevicorpus*, and *Mauremys reevesii*), working with the Cultural Heritage Administration is highly recommended as it could improve the progress and effectiveness of the restoration process. It is also recommended to secure compensation expenses when land development is conducted in habitats for endangered species under MOLIT & Housing Corporation.

Various factors can impact the successful recovery of endangered freshwater fishes and amphibians/reptiles. Systematization of projects is the most important factor to consider. If the recovery is performed according to the division of work for each institution and a restoration plan is established through system composition such that endangered species recovery can be carried out continuously, then complete recovery can be accomplished. In addition, upon sufficient advancement of mass breeding technology, achievement of efficient release through natural adaptation training, and establishment of habitat improvement guidelines via identification of causes of endangered species degradation, future recovery projects can be expected to improve drastically. Furthermore, social value of endangered species conservation and recovery projects can be increased by establishing a public relation plan and promoting citizen participation and awareness.

Conflict of Interest

The authors declare that they have no competing interests.

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References

Alroy, J. (2015). Current extinction rates of reptiles and amphibians. *Proceedings of the National Academy of Sciences of the United States of America*, 112(42), 13003–13008. doi:10.1073/pnas.1508681112

Arha, K., Thompson, and Jr. B.H. (Eds.). (2012). *The Endangered Species Act and Federalism: Effective Conservation*

Through Greater State Commitment. Oxfordshire, UK: Routledge.

Barbarossa, V., Bosmans, J., Wanders, N., King, H., Bierkens, M.F.P., Huijbregts, M.A.J., *et al*. (2021). Threats of global warming to the world's freshwater fishes. *Nature Communications*, 12(1), 1701. doi:10.1038/s41467-021-21655-w

Barnas, K.A., Katz, S.L., Hamm, D.E., Diaz, M.C., and Jordan, C.E. (2015). Is habitat restoration targeting relevant ecological needs for endangered species? Using Pacific salmon as a case study. *Ecosphere*, 6(7), 142. doi:10.1890/ES14-00466.1

Becker, C.G., Fonseca, C.R., Haddad, C.F.B., Batista, R.F., and Prado, P.I. (2007). Habitat split and the global decline of amphibians. *Science*, 318(5857), 1775–1777. doi:10.1126/science.1149374

Bolasco, S., Canzonetti, A., della Ratta-Rinald, F., and Singh, B.K. (2005). Understanding Text Mining: A Pragmatic Approach. In S. Sirmakessis. (Ed.). *Knowledge Mining. Studies in Fuzziness and Soft Computing* (185), Berlin: Springer.

Bruton. M.N. (1995). Have fishes had their chips? The di lemma of threatened fishes. *Environmental Biology of Fishes*, 43(1), 1–27. doi:10.1007/BF00001812

Campbell, S.P., Clark, J.A., Crampton, L.H., Guerry, A.D., Hatch, L.T., and Hosseini, P.R., *et al*. (2002). An assessment of monitoring efforts in endangered species recovery plans. *Ecological Applications*, 12, 674–681. doi:10.2307/3060977

Cochran-Biederman, J.L., Wyman, K.E., French, W.E., and Loppnow, G.L. (2015). Identifying correlates of success and failure of native freshwater fish reintroductions. *Conservation Biology*, 29(1), 175–186. doi:10.1111/cobi.12374

Fayyad, U., Piatetsky-Shapiro, G., and Smyth, P. (1996). From data mining to knowledge discovery: An Overview. In *Data Mining to Knowledge Discovery in Databases*. AI Magazine, 17(3), 37. doi:10.1609/aimag.v17i3.1230.

Feldman, R., and Dagan, I. (1995). Knowledge discovery in textual databases (KDT). *Proceedings of KDD' 95:the First International Conference on Knowledge Discovery and Data Mining*, 112-117.

Fischman, R.L., Meretsky, V.J., Drews, W., Stephani, K., and Teson, J. (2018). State imperiled species legislation. *Environmental Law*, 48, 81–124.

Gibbons, J.W., Scott, D.E., Ryan, T.J., Buhlmann, K.A., Tuberville, T.D., Metts, B. S., *et al*. (2000). The global decline of reptiles, déjà vu amphibians: Reptile species are declining on a global scale. Six significant threats to reptile populations are habitat loss and degradation, introduced invasive species, environmental pollution, disease, unsustainable use, and global climate change. *BioScience*, 50(8), 653–666. doi:10.1641/00063568(2000)(050[0653:TGDORD]2.0.CO;2

Guerrero, A.M., Sporne, I., McKenna, R., and Wilson, K.A. (2021). Evaluating institutional fit for the conservation of threatened species. *Conservation Biology*, 35, 1437-1450. doi:10.1111/cobi.13713

Gupta, V., and Lehal, G.S. (2009). A survey of text mining techniques and applications. *Journal of Emerging Technologies in Web Intelligence*, 1(1), 60–76.

Halliday, T. (2021). Population declines. *In The Book of Frogs*. Chicago: University of Chicago Press, pp. 26 –29. doi.org/10.7208/9780226184791

He, F., Zarfl, C., Bremerich, V., David, J.N.W., Hogan, Z., Kalinkat, G., *et al*. (2019). The global decline of freshwater megafauna. *Global Change Biology*, 25(11), 3883–3892. doi:10.1111/gcb.14753

IUCN. (2021) *The IUCN Red List of Threatened Species* (version 2021. 1). Gland, Switzerland: International Union for Conservation of Nature. Retrieved April 15, 2021 from https://www.iucnredlist.org

Jachowski, D.S., and Singh, N.J. (2015). Toward a mechanistic understanding of animal migration: incorporating physiological measurements in the study of animal movement. *Conservation Physiology* 3, doi:10.1093/conphys/cov035

Lawler, J.J., Campbell, S.P., Guerry, A.D., Kolozsvary, M.B., O'Connor, R.J., and Seward, L.C.N. (2002). The scope and treatment of threats in endangered species recovery plans. *Ecological Applications*, 12(3), 663667. doi:10.2307/3060975

MOE. (2017). *List of Endangered Species*. Seoul: Ministry of the Environment.

Moyle, L.C., Stinchcombe, J.R., Hudgens, B.R., and Morris, W.F. (2003). Conservation genetics in the recovery of endangered animal species: A review of US endangered species recovery plans (1977 –1998). *Animal Biodiversity and Conservation*, 26(2), 85–95.

Nagle, J.C. (2017). The original role of the states in the Endangered Species Act. 53 Idaho Law Review, 385. Retrieved April 15, 2021 from https ://ssrn.com/abstract=3122618

Norris, K., and Mcculloch, N. (2003). Demographic models and the management of endangered species: A case study of the critically endangered Seychelles magpie robin . *Journal of Applied Ecology*, 40(5), 890–899.

Simoudis, E. (1996). Reality check for data mining. *IEEEExpert*, 11(5), 26–33. doi:10.1109/64.539014

Tedesco, P.A., Oberdorff, T., Cornu, J.F., Beauchard, O., Brosse, S., Dürr, H.H., *et al*. (2013). A scenario for impacts of water availability loss due to climate change on riverine fish extinction rates. *Journal of Applied Ecology*, 50(5),

1105–1115. doi:10.1111/1365-2664.12125
Tollefson, J. (2019). Humans are driving one million species to extinction. *Nature*, 569(7755), 171.doi:10.1038/d41586-019-01448-4
USFWS. (2019). *Recovery Plan for the Topeka Shiner (Notropis topeka)*. MountainPrairie Region: US Fish and Wildlife Service.
USFWS. (2020). *Draft Recovery Plan for the Sharpnose (Notropis oxyrhynchus) and Smalleye (N. Buccula) Shiner*. Arlington, TX : US Fish and Wildlife Service.
USFWS. (2021). *Recovery Plan for the Reticulated Flatwoods Salamander (Ambystoma bishopi)*. Atlanta, GA : US Fish and Wildlife Service.
U.S. Government Accountability Office. (2006). *Endangered species: time and costs required to recover speciesare largely unknown*. Report No. GAO-06-463R. Washington : U.S. GAO.
Van Eck, N.J., and Waltman, L. (2007). VOS: A new method for visualizing similarities between objects. In H-J. Lenz and R. Decker (Eds.). *Advances in Data Analysis. Proceedings of the 30th Annual Conference of the German Classification Society*, pp. 299–306. Heidelberg: Springer.
Van Eck, N.J., and Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, 84(2), 523–538. doi:10.1007/s11192-009-0146-3
Wang, Z., Zeng, J., Meng, W., Lohman, D.J., and Pierce, N.E. (2021). Out of sight, out of mind: Public and research interest in insects is negatively correlated with their conservation status. *Insect Conservation and Diversity*, 14(6) doi:10.1111/icad.12499
Zhang, Y., Chen, M., and Liu, L. (2015). A review on text mining. *Proceedings of 6th IEEE International Conference on Software Engineering and Service Science (ICSESS)*. doi:10.1109/icsess.2015.7339149

Supplementary Table S1. List of restoration projects for endangered freshwater fishes

Projects title	Species	Organization	Year
Restoration project of *Brachymystax lenok*	*BL*	local cooperation	2020-2022(3yrs)
Research on the ecological characteristic and conservation of endangered species	*KB, GM, MR, PB*	MOE	2019-2020(1yr)
Research on Current status and restoration of *Acheilognathus somjinensis*	*AS*	MOE	2018-2020(3yrs)
Research on the conservation plan for endangered freshwater fishes, *Microphysogobio rapidus* and *Pseudobagrus brevicorpus*	*MR, PB*	MOE	2018-2019(1yr)
Genetic diversity of animal resources	*RP, AS, I. Pumila, PP*	MOE	2018(1yr)
Research on the breeding and restoration of *Rhodeus pseudosericeus*	*RP*	MOE	2017-2019(3yrs)
Research on the conservation plan of endangered freshwater fishes, *Pseudobagrus brevicorpus*	*PB*	MOE	2017(1yr)
The study of ecological health of Naesong river for conservation and restoration of endangered freshwater fishes	*GN*	MOE	2016-2017(10mths)
Research on the restoration and recovery of aquatic animal in inland waters	*PB*	MMAF	2016(1yr)
Research on the application of stem cell for breeding of endangered fishes	*CC*	MOE	2016(1yr)
Development of master plan for conservation of endangered freshwater fishes	endangered freshwater fishes	MOE	2015(1yr)
Mass release of fry *Gobiobotia naktongensis* for Restoration	*GN*	KWRC	2014-2016(2yrs)
Captive breeding project for conservation of *Pseudobagrus brevicorpus* in upper flow of Baekgok Reservoir	*CC*	KRC	2014-2016(2yrs)
Monitoring of endangered freshwater fishes and Research of management plan (2014)	*KN, GM, GB, PT, TS*	MOE	2014(1yr)
The Genetic and Genomic Evaluation of Indigenous Biological Resources	*BL*	MOE	2014(1yr)
2013 Breeding, Re-introduction and Monitoring of Endangered freshwater fishes	*KN, GM, GB, PT, TS*	MOE	2013 (1yr)
The Genetic Evaluation of Important Biological Resources	*I. pacifica*	MOE	2013 (1yr)
The Genetic Evaluation of Important Biological Resources - Genetic Diversity Research of Important Animal Resources-	*AK, SM*	MOE	2013 (1yr)
Research on the ex situ conservation of freshwater species	*AS, MK*	MAFF	2011-2012(2yrs)
Research on the breeding and restoration of endangered freshwater fishes	*LO, PN, CC, KN, TS*	MOE	2011-2012(1yr)
Research on the breeding and restoration of endangered fresh water fishes (2011)	*PB*	MOE	2011(1yr)
The Genetic Evaluation of Important Biological Resources - '11 Genome Research of Endangered species	*LO, TS*	MOE	2011(1yr)

Projects title	Species	Organization	Year
Genetic analysis and research of major biological resource: Analysis of genetic diversity in Endangered species	*PS*	MEST	2011(1yr)
Research on the breeding and restoration of endangered freshwater fishes in 4 major river basins in Korea	*GN, LR, GB, PT*	MLTMA	2010-2012(3yrs)
Research on the breeding and restoration of endangered freshwater fishes from 4 major river in Korea	*LO, TS*	MOE	2010(1yr)
Breeding and restoration of endangered freshwater fishes from 4 major river basins in Korea	*GN, GB, PT*	MLTMA	2010(1yr)
Research on the breeding and restoration of *Pseudopungtungia nigra*	*PN, CC*	MOE	2009-2010(1yr)
Breeding and Restoration of endangered freshwater fishes	*PB, PN*	MOE	2009-2010(1yr)
The Genetic Evaluation of Important Biological Resources -Genome and Genetic diversity Research of Endanger and Endemic species -	*OO, MR, CB, RS, I. Pumila, KB, RP, AM*	MOE	2009(1yr)
Genetic analysis and research of major biological resources : For 16 Endangered species	*GN, LC, LR*	MOE	2009(1yr)
Development project of *Tanakia* as aqua-pet	*TS*	MAF	2008(1yr)
Genetic analysis and research of major biological resources : 2008 : For 30 endangered species and endemic species	*GB, MK, GM, PT, AS*	MOE	2008(1yr)
Study of the genetic diversity, captive breeding and development of ecological restoration technique for Endangered freshwater fishes, Pseudobagrus brevicorpus	*CC*	MOE	2006-2009(3yrs)
Development of conservation, restoration and breeding technique for endangered Korean endemic fishes	*PB, PN, LO*	MOE	2002-2005(3yrs)

MR, Microphysogobio rapidus; PB, Pseudobagrus brevicorpus; CC, Cobitis Choii; PN, Pseudopungtungia nigra; RP, Rhodeus pseudos ericeus; LO, Liobagrus obesus; KB, Kichulchoia brevifasciata; GM, Gobiobotia macrocephala; KN, Koreocobitis naktongensis; GB, Gobiobotia brevibarba; PT, Pseudopungtungia t enuicorpa; TS, Tanakia signifer; GN, Gobiobotia nakdongensis; LR, Lethenteron reissneri; MK, Microphysogobio koreensis; AS, Acheil ognathus somjinensis; BL, Brachymystax lenok; I. Pumila, Iksookimia pumila; PP, Phoxinus phoxinus; OO, Odontobutis obscura; CB, Culter brevicauda; RS, Rhynchocypris semotilus; AM, Acheilognathus majusculus; I. pacifica, Iksookimia pacifica; SM, Squalidus multimaculatus; LC, Lethenteron camtschaticum; AK, Acheilognathus koreensis; PS, Pungitius sinensis

MOE, Ministry of Environment; MAF, Ministry of Agriculture and Forestry; MMAF, Ministry of Maritime Affairs and fisheries; Ministry of Agriculture, fisheries and Food; KWRC, Korea Water Resources Corporation; KRCC, Korea Rural Community Corporation

Supplementary Table S2. List of restoration projects for endangered amphibians and reptiles

Projects Name	Organization	Year
Establishment of conservation plan for *Kaloula borealis* in Anyang and execution service	GH	2020(1yr)
Capture, translocation and monitoring service of *Kaloula borealis* in Suwon Arboretum	Suwon-si	2020(1yr)
Capture, translocation and monitoring service of *Kaloula borealis* in Uiwang Gocheon	KLHC	2020(1yr)
Monitoring service report of the alternative habitat for *Pelophylax chosenicus* in Guseong District	KRCC	2019(1yr)
Molecular phylogeography, genetic diversity, and population genetic structure of Salamanders of the genus *Hynobius* in the Northeast Asia	MSIT	2019(1yr)
Project report of breeding and conservation of *Elaphe schrenckii*	KNPS	2019(1yr)
Monitoring service of the amphibian in Multifunctional administrative city	KLHC	2018-2021(4yrs)
Bioinformatic analysis in large scale genomic data of *Mauremys reevesii* (and another 1 species) using GBS technology	MOE	2018(1yr)
Capture, translocation and monitoring service of *Kaloula borealis* in Dangjin Daedeoksucheong District	KLHC	2018(1yr)
Genetic diversity of animal resources	MOE	2018(1yr)
Capture, translocation and monitoring service of *Kaloula borealis* in Former Real Estate Gosaek 2 District	KRCC	2018(1yr)
Capture and translocation service of *Kaloula borealis* in Gwangju Station Area Urban Development Project Pwanji District	Gwangju-si	2018(1yr)
Capture, translocation and monitoring service of *Kaloula borealis* in Hwaseong Byeongjeom Complex Town	KLHC	2017-2020(3yrs)
Monitoring service report of *Kaloula borealis* in Boueong Park	K-eco	2017(1yr)
Capture, translocation and monitoring of *Kaloula borealis* in Nodeul Island	Seoul-si	2017(1yr)
Monitoring service of the alternative habitat of *Kaloula borealis* in Chungbuk Headquarters	KEPCO	2016(1yr)
Management and academic service of *Kaloula borealis* in Dalseong Wetland	Daegu-si	2016(1yr)
Research on the genetic diversity of endemic biological resource	MOE	2015(1yr)
Restoration Work of *Pelophylax chosenicus* habitat in Ansan Suin line	KWRC	2014(1yr)
Restoration project of Ilwol reservoir the habitat of *Pelophylax chosenicus*	KRCC	2014(1yr)
Breeding and restoration of *Dryophytes suweonensis*	MOE	2013-2014(2yrs)
Monitoring service for habitat of *Kaloula borealis*	MOD	2013(1yr)
Detail inspection of Endangered amphibian *Kaloula borealis* and Research on the improvement of analysis after breeding and restoration project	MOE	2012(1yr)

Projects Name	Organization	Year
The genetic evaluation of important Biological resource - Genomic research of endangered species	MOE	2010(1yr)
Capture, translocation and monitoring service of *Kaloula borealis* in Dangjeong Neighborhood Park	Gunpo-si	2010(1yr)
Research on the breeding and restoration of *Mauremys reevesii*	MOE	2009-2011(3yrs)
Developing Standard Rearing Protocols of Endangered Endemic Reptiles and the Study of their Basic Ecology	MOE	2009-2011(3yrs)
Capture and translocation of *Pelophylax chosenicus* in National Institute of Ecology center	MOE	2009(1yr)
The genetic evaluation of important Biological resource -For 16 endangered species	MOE	2009(1yr)
The genetic evaluation of important Biological resource -For 20 endangered species	MOE	2007(1yr)
Monitoring of flora and fauna in Yeongjong City to protect bird and *Kaloula borealis*	KLC	2007(1yr)

MOE, Ministry of Environment; MEST, Ministry of Education, Science and Technology; MLTMA, Ministry of Land, Transport and Maritime Affairs; KLHC, Korea Land & Housing Corporation; KLC, Korea Land Corporation; KNPS, Korea National Park Service; MSIT, Ministry of Science and ICT; K-eco, Korea Environment Corporation; KEPCO, Korean electric power corporation; MOD, Ministry of National Defense