The Journal of GIS Association of Korea, Vol.6, No.1, pp.91-102, April 1998

GIS기법을 이용한 중소하천의 어류종다양성 예측기법 연구*

박종화*·홍성학***

Estimation of Fish Species Diversity of Small and Medium Rivers of Korea with Fish Species-Habitat Relationship Models of GAP*

Chong-Hwa Park**·Sung-Hak Hong***

요 약

본 연구의 목적은 우리나라 중소하천의 어류 종다양성 예측을 위한 모형의 개발 및 정확성 검증을 하는 것이다. 본 예측 모형은 미국의 GAP의 일환으로서 뉴욕주 어류-야생동물연구팀이 개발한 어류종다양성 예측모형을 기초로 하였으며, 하천의 크기, 물리적서식지, 및 수질의 세가지 서식지 요인을 활용한다. 본 연구에서는 미국 EPA 수질환경기준과 우리나라 수질기준을 적용하여 2개의 예측모형을 개발하였으며, 본 연구 대상지는 한강 수계의 탄천, 사기막천, 수동천, 및 조종천을 대상으로 한다.

본 연구의 발견사항은 다음과 같이 요약할 수 있다. 첫째, 본 연구대상지 총 118개 하천구간은 예측모형I과 예측모형II에 의하여 각각 9개와 14개의 서식지 유형으로 분류되었다. 둘째, 멸종위기종인 퉁가리, 회귀종인 배가사리 및 쉬리의 분포예측도를 작성하고, 정확도를 검증한 결과 예측모형 I과 II는 각각 80.6% 및 81.2%로 판명되었다. 셋째, 예측모형 I 과 II를 이용한 종풍부도 예측결과는 각각 94% 및 95%를 보였으며, 수질이 어류 종풍부도에 지대한 영향을 미치는 것으로 판명되었다. 넷째, 예측모형 I 및 II의 각 하천구간 출현종의 정확도는 각각 50.5% 및 68.7%로서 낮은 편이었으며, 수질오염이 심한 하천을 제외한 정확도는 각각 67.1% 및 86.5%로 향상되었다. 마지막으로, 우리나라 수질기준을 적용한 예측모형 II의 정확도가 높으며, 이들 예측모형의 정확도는 수질향상 및 자연형 하천복원에 의하여 향상될 수 있는 것으로 판명되었다.

ABSTRACT : The objectives of this research were to develop fish-habitat relationship models which can be used to estimate fish species richness of small and medium rivers in Korea, and test the accuracy of the models. The models are based on the Aquatic GAP Analysis model in the New York Cooperative Fish & Wildlife Research Unit (1996), and they employ three habitat factors; river size, physical habitat, and water quality of each river segment. Model I and model II are

---

* 본 논문은 환경부 G7 과제 "국내 여건에 맞는 하천공법의 개발" 과제(1996-1998)의 일부로서 수행되었으며, "Estimation of Bioligical Diversity of Small and Medium River Ecosystem of Korea", Proc. of Intern'l Conf. on Modeling Geographical and Environ. Systems with Geographic Information System(GIS), 22-25 June 1998, Hong Kong, 및 "Aquatic Gap Analysis of Small and Medium Streams of Korea", Proc. of the 8th Annual Gap Analysis Meeting, 20-24 July 1998, Santa Barbara, CA의 발표내용을 기초로 작성하였음

** 서울대학교 환경대학원 교수 (Graduate School of Environment Studies, Seoul National Univ. Shinlim-dong, Kwanak-gu, Seoul, 151-742 Korea, 02-880-5664)

*** SK컴퓨터 통신(10th Floor, West Wing, Posco Center, Daechi 4-dong, Kangnam-gu, Seoul, Korea, 011-717-5113)

based on the water quality standard for life support of EPA and the water quality class of Korea, respectively. Test sites for this study include one urban stream and three less spoiled tributaries of the Han River.

The results of this research can be summarized as follows. First, the number of habitat types identified by model I and model II are nine and 14, respectively. Second, the average accuracy of the three distribution maps of rare or endangered fish species are 80.6% (model I) and 81.2% (model II). Third, the accuracy of fish species richness are 94% (model I) and 95% (model II), and the water quality is the most important factor affecting fish species richness. Fourth, the accuracy of fish species list are 50.5% (model I) and 68.7% (model II), but the accuracy of less spoiled stream segments and that of polluted stream segments are 67.1% and 86.5%, respectively. Finally, it can be concluded that the overall performance of model II is better than that of model I at our test sites.

1. INTRODUCTION

Most river ecosystems of Korea have been severely damaged during the fast urbanization and industrialization process since the 1960s. The following three factors can be pointed out as the major causes of such ecological destruction (Park, 1997). First, the development of floodplains and river engineering projects have caused a large-scale habitat destruction across the country. Most riparian vegetation on mid and lower parts of rivers have been destroyed, and floodplains have been converted to agricultural lands, built-up areas, and traffic corridors. Dams and weirs are blocking the migratory routes of many fish species. Second, aquatic species sensitive to water pollution have been obliterated in many polluted urban streams. Thus the biodiversity of freshwater ecosystem has been severely diminished. Third, the decrease in base flow and dry-up of river beds during dry seasons adversely affect the freshwater aquatic ecosystems of Korea. The growing demand for water resources and the construction of large-scale sewerage treatment plants also contribute to the drying up of river channels in urbanized areas.

A multidisciplinary research team for the development of river restoration technologies was selected in 1996 by the Ministry of Environment of Korea through a competitive bidding based on research proposals, and a sizable research fund from our government has been awarded since then. The research consortium consists of hydrologists, river engineers, landscape architects, and ecologists. Two engineering companies and one landscaping company are also participating in the consortium and are contributing matching funds.

Ecologists specializing in riparian vegetation, algae, aquatic insects, birds, amphibia, and fish have been studying collectively for three years on selected urban streams as well as less spoiled small tributaries of the Han River (MOE, 1996). It was soon realized that the application of GIS, remote sensing, and aquatic Gap analysis is essential to the successful river restoration (Chun, 1997).

Positive signs of river restoration can be found from many urban streams. At least the deteriorating trend of our urban rivers has stopped these days due to the massive construction of sewerage treatment plants. Signs of the improvement in water quality can be found at many previously polluted river segments. The scarce normal flow volume of some urban rivers are supplemented by the pumping up of ground waters from subway stations or of discharge water from sewerage treatment plants. River restoration projects of small scale also have been implemented at several urban rivers. The scope of our research team includes demonstration river restoration projects and monitoring of the sites (MOE, 1996).

This paper has the following four objectives. First, develop fish-habitat relationship models for the small and medium rivers of Korea. Second, evaluate the accuracy of developed fish-habitat relationship models. Third, locate suitable habitats for each fish species and produce distribution maps for the fish species. Fourth, estimate fish species richness of each stream segment.

2. METHODS

2.1 Study Sites

Four first tributaries of the Han River are included in the study sites (Table 1). The Tan Stream is an urban stream that flows through the southeastern part of Seoul and adjacent suburbs. Except for the headwaters in mountainous areas, the major part of the stream is channelized and its water quality is deplorable. Two segments of this stream have been selected for the river restoration demonstration project by our research team, and two more stream restoration projects have been implemented by local governments.

Three other first tributaries of the Han River, Chojong Stream, Sudong Stream, and Sagimak Streams are included in this research for control streams. Most of the watershed of these streams are sparsely developed, and decent second growth forest covers much of the watershed. Most of the free flowing stream segments are flanked by decent riparian vegetation. Consequently, the

Table 1 Outlines of study sites

	Length(Km)	Watershed Size(Km^2)	Remarks
Chojong stream	38.8	256.1	Semi-natural
Sudong stream	18.6	88.9	Semi-natural
Sagimak stream	28.3	78.6	Semi-natural
Tan stream	34.4	306.4	Urban stream

biodiversity of these streams is much higher than that of other urban streams in Korea. The data collected at these streams can also be used to set goals for restoring small and medium-sized urban rivers of Korea.

According to the land cover classification of the sites with Landsat TM (Sep. 1, 1996), the percentage of forest cover, agricultural land, built-up and barren, and water surface is 73.7%, 8.7%, 15.6%, and 2.0%, respectively.

2.2 Outlines of Gap Analysis Program

1) Gap Analysis Program

The Gap Analysis Program of Biological Resources Division of USGS is a national program for the identification of gaps in the Protection of biodiversity at state, regional, and national scales (Scott, 1987). Thus the three stages of GAP are to produce regional or state level vegetation maps with Landsat TM data, to identify areas with high biodiversity by utilizing wildlife-habitat relationship models (WHRM), and to locate places where additional protection measures would efficiently increase the representation of native biodiversity (Davis, 1996). Examples of developing terrestrial vertebrate distribution maps by utilizing WHRM can be found in the Gap handbook (Csuti, 1998). Outcomes of GAP are used for regional conservation risk assessment and the development of conservation strategies for reducing that risk.

2) Aquatic Gap Analysis

The need for applying GAP to freshwater and estuary ecosystems (Jennings, 1997) is urgent due to the vulnerability of aquatic ecosystems. It is estimated that 68% of all freshwater mussel species, 51% of crayfish species, 40% of amphibian species, and 39% of freshwater fish species are either vulnerable, imperiled, critically imperiled, or presumed extinct in the U.S. (TNC, 1966). The vulnerability of freshwater ecosystems of Korea is surely much greater than above mentioned estimation.

The application of Gap Analysis to aquatic ecosystems is relatively new compared to terrestrial ecosystems. The development and application of Gap Analysis to aquatic systems began in mid-1995 with the first portion of a pilot study in the Allegheny River basin in western New York by the New York Cooperative Fish & Wildlife Research Unit (1996). The first statewide pilot project for the aquatic component of Gap Analysis was started in January of 1997 in Missouri (Sowa, 1998).

2.3 Fish Species-habitat Relationship Models

1) Process of the Modeling

The method for estimating fish species richness used in this study is greatly indebted to the model developed by the New York Cooperative Fish & Wildlife Research Unit (1996). The modeling process has the following five steps. First, a geographic data base was constructed by utilizing site survey, existing topographic and thematic maps, and land cover classification with Landsat TM data. A river segment map was also produced from the river channel map. Second, habitat types of the study area were identified by clustering of habitat factors. Third, habitat requirements for each fish species of the region were identified by compavison between observed fish inventory data and the GIS data base. Fourth, a range map for each species was produced and species richness for all river segments was estimated. Finally, the accuracy of the estimation model was evaluated by comparing field data and estimated results.

2) Types of Models

Two fish species-habitat relationship models based on three factors, stream size, physical habitat, and water quality, were developed. First, the stream size reflects stream morphological conditions related to depth, velocity, water temperature, dissolved oxygen, substrate materials, and riparian vegetation types. The stream size is based on the size of the watershed of each stream segment for this modeling.

Second, the physical habitat factor reflects the modification of river channel and adjacent riparian land by human activities. Such modification causes the destruction of riparian vegetation, decreasing volume of base flow, and habitat deterioration due to channelization and blocking of fish migratory routes. The physical habitat is based on the percentage of modification of the stream segment due to river engineering works, farming, and construction of various types of artifacts.

Finally, the water quality affects the composition of fish species within a stream segment. Fish species requiring high dissolved oxygen, low biological oxygen demand, cool temperature can only survive in stream segments with good water quality. Very limited number of fish species can survive in polluted urban streams.

Both fish species-habitat relationship models are based on three types of stream size and physical habitat, but different water quality standards have bean employed. Model I is identical to that developed by New York Cooperative Fish & Wildlife Research Unit (1996) and employs the water quality standard for life support of the U.S. EPA. The standard classifies water into two classes, biologically suitable and stressful. The classific ation is based on water temperature, dissolved oxygen, pH, nitrogen and phosphate compounds, microorganisms, etc. Model II is based on the Korean water quality standard which has five classes. This standard is used to evaluate water resources of streams and lakes in Korea.

2.4 Data Base

1) Fish Species List

The fish list for modeling was prepared by site survey and literature survey. For three years our research team has been conducting ecological survey of our test sites, the Tan Stream and Sagimak Stream. The fish survey at the Sagimak Stream, for example, is conducted every two months at six sampling points. The species and number of fish caught at each site are recorded. A total of 19 and 23 fish species have been identified from the Sagimak Stream and Tan Stream.

Three reliable limnological survey reports (Choi, 1985 ; OOE, 1987 ; Kwon 1992) on two more streams of the Han River are also include in order to increase the accuracy of fish species-habitat relationship models. Fish species of 26 and 38 have been identified from the Sudong Stream and Chojong Stream. Out of 150 species of fresh water fish of Korea, 45 fish species are included in our fish species list.

An attribute data base encompassing environmental requirements of the selected fish species has been compiled by using available literature (Kim, 1993; Choi, 1994) and expert opinion. Types of data elements and their classes are as follow : stream size (small, medium, large), habitat quality (intolerant, moderately tolerant, tolerant), water quality (tolerant, intolerant), substrate (sand, gravel, submerged weed), stream velocity (stagnant, low, fast), stream morphology (headwater, upstream, midstream, downstream, estuary), and water quality (class 1 to 4). The Korean torrent catfish, *Liobagrus andersoni*, for example, Prefers small streams, and are intolerant to the modification of physical habitat and to poor water quality.

2) GIS DB

The GIS data base for this research has been constructed with Arc/Info 7.0 and Sun Ultra 1 workstation. The process of stream size mapping is as follows. First, hydrology maps of four test streams are produced by digitiging 1/25,000 topographic maps. Second, based on confluence of the hydrology maps 118 stream segments are identified. The lengths of stream segments ranges from 238m to 6,815m. Third, watershed size for each stream segment is calculated. The size of watershed range from 0.44km^2 to 272.60km^2. Finally, the size of each watershed is classified into three classes ; small (less than 100km^2), medium (100-3,000km^2), and large (larger than 3,000km^2). Only six stream segments of the test sites are medium-sized streams and the rest are small streams.

The map of physical habitat reflects the percentage of the length with in a stream segment modified by river engineering works, farming, and the construction of various types of artifacts on either side of the riparian lands. The factor is classified into three classes ; intact (less than 25%), modified (25-75%), and highly modified (more than 75%). Headwaters of three test streams usually belong to the intact class. The middle and lower parts of test streams passing through urban or rural settlements usually belong to the highly-modified class.

The two maps of water quality are based on our own measurements and water quality reports of the Ministry of Environment (1996, 1997). As shown in the previous section, model I is based on the U.S. EPA standard which classifies water quality into two classes : biologically suitable and stressful. Stream segments with biologically suitable water quality can be found in most upper and mid segments of the three control streams, but the main part of the Tan Stream has a biologically stressful water quality. Model II is based on the Korean water quality standard and has four classes, class 1 being the best quality. As expected, most headwaters have a water quality of class 1 or 2. Lower segments of control streams and most stretches of the Tan Stream have the worst water quality.

3. RESULTS AND DISCUSSION

3.1 Fish Species-habitat Models

Habitat types identified at the research site are nine for model I and fourteen for model II. The most common habitat types of model I is a small stream, unmodified physical habitat with suitable water quality. The next common type is the same stream size and water quality, but with a slightly modified physical habitat. These two types occupy 64% of the stream segments. On the other hand, 31% of the stream segments have very poor habitat types due to poor physical habitat and water quality.

The most common habitat types of model II is a small-stream, unmodified physical habitat, with a class 1 water quality. The next common habitat type is a small-stream, slightly-modified physical habitat with a class 2 water quality. These two common types occupy 51% of the stream segments. Stream segments of poor habitat types such as highly modified or class 3 or lower water quality occupy 30% of the stream segments.

3.2 Fish Distribution Maps

By utilizing the GIS DB of the test site and attribute data base on the environmental requirements of 45 fish species. the possibility of the presence of three endangered or rare fish species, *Liobagrus andersoni*, *Microphysogobio longidorsalis*, and *Coreoleuciscus splendidus*, was predicted. It is expected that *Microphysogobio longidorsalis* can be found at 82 stream segments out of 118 stream segments, and two other fish species at 48 stream segments.

The result can be used to make distribution maps of these endangered or rare fish species. From the distribution maps, it can be seen that these sensitive species are usually confined to headwaters and upstreams of the test streams. Since such isolated distribution has a high possibility of local extinction of these species, it is essential to connect fragmented habitats by improving the poor habitat quality of those lower parts of streams.

3.3 Species Richness

Species richness of all stream segments was estimated by the fish species-habitat relationship model I and II. The results of model I (Figure 1) can be concluded as follows. First, expected fish species of stream segments with poor water quality decreases around a fourth level of those with good water quality. This explains that water pollution is the most significant limiting factor of the diversity of fish species within urban streams. Second, stream segments with slightly-modified or moderately-modified physical habitat and suitable water quality have the the most diverse fish species. For example, 39 fish species are expected at medium-size stream segments with moderate modification and suitable water quality. Third, there is little difference in the diversity of fish species between small streams and medium streams of the test sites.

Similar results can also be found from model II. By using the four class Korean water quality standard, it could be seen that fish species diversity of stream segments with a class 2 water quality is significantly higher than that of stream segments with a class 1 water quality. Figure 2 shows the expected diversity of fish species with in all stream

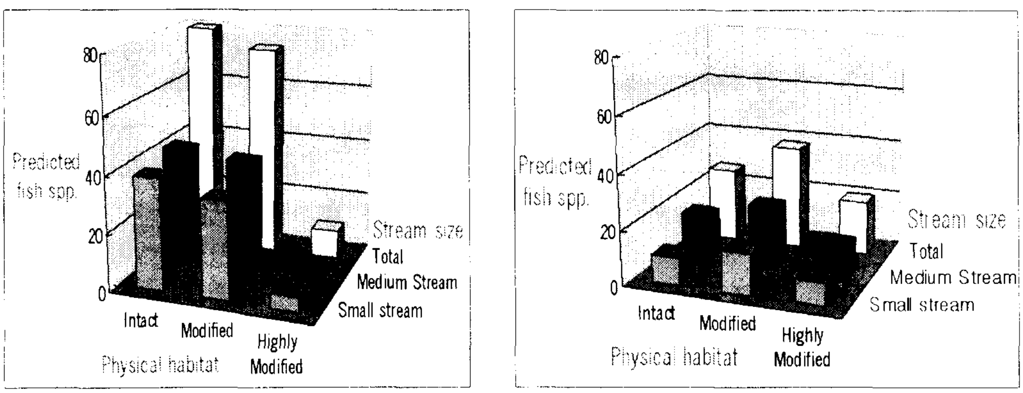

Figure 1 Estimated species richness of test sites shows that species richness of suitable water quality (left) is much higher than that of stressful water quality (right).

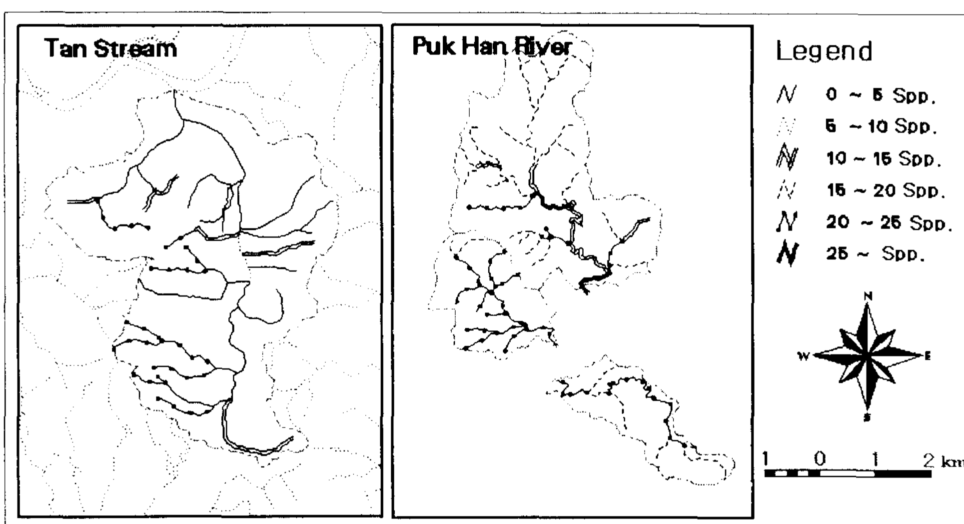

Figure 2 Expected fish species richness obtained through the fish species-habitat relationship model II.

segments obtained with model II.

3.4 Accuracy of Fish Species-habitat Relationship Models

1) Accuracy of Fish Species List

The outcomes of the accuracy of the fish species-habitat relationship model Ⅰ and Ⅱ are shown on Table 2 and Table 3, respectively. The result can be summarized as follows. First, the mean accuracy of species list estimated by the model Ⅰ and the model Ⅱ is 50.5% and 68.7%, respectively. It is certain that the accuracy of the models is much lower than our expectation.

Second, the accuracy of the predicted

Table 2 Accuracy of fish species list of the model I

ID	Habitat types Conditions	Fish species Obs.	Pred.	Accuracy (%)	Errors(%) Com.	Omi.
1	S_S, Intact, Suitable	18	28	60.7	39.2	3.5
2	M_S, Intact, Suitable	21	33	57.5	42.4	6.0
4	S_S, M_Mod, Suitable	27	28	78.5	21.4	17.8
5	M_S, M_Mod, Suitable	33	39	71.7	28.2	12.8
7	S_S, H_Mod, Suitable	4	5	20.0	80.0	60.0
13	S_S, M_Mod, Stress	6	11	27.2	72.7	27.2
16	S_S, H_Mod, Stress	6	5	60.0	40.0	60.0
17	M_S, H_Mod, Stress	2	7	28.5	71.4	0

Table 3 Accuracy of fish species list of the model II

ID	Habitat types Conditions	Fish species Obs.	Pred.	Accuracy (%)	Errors(%) Com.	Omi.
1	S_S, Intact, Class 1	16	20	87.5	12.5	37.5
2	M_S, Intact, Class 1	14	21	92.8	3.0	24.2
9	S_S, M_Mod, Class 2	22	27	81.8	18.1	40.9
10	M_S, M_Mod, Class 2	28	33	82.1	17.8	35.7
11	S_S, H_Mod, Class 2	5	4	40.0	60.0	40.0
15	S_S, M_Mod, Class 3	12	6	25.0	75.0	25.0
23	S_S, H_Mod, Class 4	3	6	100	0	100
24	M_S, H_Mod, Class 4	5	2	40.0	60.0	0

species list of stream segments with good water quality is much higher than the total average. For example, the accuracy of the predicted fish list of model Ⅰ is 67.1% for good water quality, and only 33.9% for polluted streams. The accuracy of the predicted fish list of model Ⅱ is 86.5% for good water quality, and only 51.3% for polluted streams. The inaccuracy of our data base on the requirement of water quality for each fish species may be responsible for the low accuracy for poor water quality.

Table 4 Prediction accuracy of three target fish species

		Microphysogobio ongidorsalis	*Coreoleuciscus splendidus*	*Liobagrus andersoni*	Mean
Model Ⅰ	Sampling Pts.	8	13	7	
	Expected Pts.	8	11	4	
	Accuracy(%)	100.0	84.6	57.1	80.6
Model Ⅱ	Sampling Pts.	8	13	7	
	Expected Pts.	7	11	5	
	Accuracy(%)	87.5	84.6	71.4	81.2

Third, the commission error and omission error of predicted fish list for highly modified streams are significantly higher than those of better physical habitat quality. For example, the commission error for highly modified stream segments is 63.7% with model Ⅰ and 40.0% with model Ⅱ, and omission error of 40.0% is also significantly higher than less modified stream segments. This also reflects our insufficient knowledge base on the effects of habitat modification on fish species.

Fourth, the performance of the models can be improved significantly by improving water quality and reducing the degree of physical habitat modification. River restoration projects will certainly increase fish species diversity as well as the accuracy of the fish species-habitat relationship models.

Finally, the performance of the model Ⅱ is better than the model Ⅰ at the test sites. It is also more convenient to use existing water quality monitoring data than collect additional water quality data based on U.S. EPA standard.

2) Accuracy of Fish Distribution Maps

The accuracy of expected distribution maps of three endangered or rare fish species, *Liobagrus andersoni, Microphysogobio longidorsalis*, and *Coreoleuciscus splendidus*, was tested by comparing observed and pedicted data. The number of sampling points, based on our limnological reports, where selected fish species have been collected and the number of river segments where the same species are expected are shown on Table 4. It can be seen that the average accuracy of model I and model II is 80.6% and 81.2%. Both models show the similar accuracy level ; overall accuracy is significantly decreased by the lower accuracy for *Liobagrus andersoni.*

3) Accuracy of Species Richness

The accuracy of fish species richness from each stream segment can be tested by computing regression coefficients of scatter-grams produced by plotting the numbers of observed fish species and predicted fish species of each stream segment. The regression coefficients of model I and model II are 0.94 and 0.95. It can be concluded that the accuracy of expected number of fish species of stream segments of this test site is remarkably high.

4. CONCLUSIONS

By developing fish species-habitat ralation-ship models based on geographic data base and relatively simple attribute data for the environmental requirements of fish species, it is possible to acqaire useful information to restore the degraded freshwater ecosystems of Korea. Three factors, river size, modification of physical habitat, and water quality, were used for the development of two fish species-habitat relationship models. Model I is based on water quality standard for the U.S. EPA and model II is based on the Korean water quality standard.

The result of this study can be summarized as follows. First, it was possible to classifiy habitat types with the models. Habitat types identified at the research sites are nine for model I and fourteen for model II. The most common habitat types of stream segments are small streams, unmodified physical habitat, and good water quality. Second, the accuracy of distribution maps of three rare or endangered fish species, *Liobagrus andersoni, Microphysogobio longidorsalis,* and *Coreoleuciscus splendidus,* of model I and model II is 80.6% and 81.2%. The habitat fragmentation of these fish species were also identified. Third, species richness within stream segments can be predicted fairly accurately. The accuracy of fish species richness of stream sgements in the research site are 0.94 for model I and 0.95 for model II. Fourth, the accuracy of predicted fish species is strougly affected by the water quality of each stream segment. For example, the accuracy of the predicted fish list of model II is 86.5% for good water quality, and only 51.3% for polluted streams. Finally, it can be concluded that model II is better than model I in terms of accuracy and ease of data collection.

REFERENCES

1. Choi, K. 1985, Nature of Kyonggi Province: Freshwater Fish, Education Committee of Kyonggi Province, Suwon, (in Korean).
2. Choi, Ki-chul, 1994, 100 Freshwater Fish of

Korea, Hyunamsa, Seoul, (in Korean).

3. Chun, S. and C. Park, 1997, A Study on the Application of Remote Sensing Technologies for the Analysis of Natural Environment, Korea Environment Institute, Seoul, KEI/1997/RE-23, .(in Korean)
4. Csuti, B. and P. Crist, 1998, Methods for Developing Terrestrial Vertebrate Distribution Maps for Gap Analysis, A Handbook for Conducting Gap Analysis, http://www.gap.uidaho.edu/gap/handbook/Vertebrates,
5. Csuti, B. and A.R. Kiester, 1996, Hierarchial Gap Analysis for Identifying Priority Areas for Biodiversity, In J. Michael Scott, et al. (eds), Gap Analysis: A Landscape Approach to Biodiversity Planning, 25-37.
6. Davis, F.W. and D.M. Stoms. 1996, A Spatial Analytical Hierarchy for Gap Analysis, in J. M. Scott, et al. (eds), Gap Analysis : A Landscape Approach to Biodiversity Planning, 15-24.
7. Jennings, M.D. 1997, In Pursuit of the Aquatic Component of Gap Analysis, GAP Analysis Bulletin No.6 35.
8. Karr, J.R. 1991, Biological integrity : a long-neglected aspect of water resource management, Ecological Applications, 1:66-84.
9. Kim, I. and Kang E. 1993, Color Dictionary of Korean Fish, Academy Books, Seoul, .
10. Kwon, O. A, 1992, Study on the Freshwater Fish Community of the Jochong Stream for the Development of Biological Education Teaching Materials, Masters Dissertation of Seoul National U. (in Korean).
11. Meixler, M. S. et al. 1996, Aquatic Gap Analysis : Tool for watershed scale assessment of fluvial habitat and biodiversity, .
12. Ministry of Environment, 1996, A Report for the Development of River Restoration Technologies, . (in Korean).
13. New York Cooperative Fish & Wildlife, 1996, Classification of flowing water habitats for predicting fish assemblage diversity, GIS Model for Predicting Biodiversity, http://www.dnr.cornell.edu/hydro2
14. Office of Environment, 1987, Survey Report of the National Ecosystems (I): Freshwater Fish and Water Insects. (in Korean).
15. Park, C. and Y. Cho, 1997, A Critical Review on River Engineering Projects as a Basis for River Restoration of Korea, Proc. of the International Symposium on River Restoration, June 13. pp. 21-55.
16. Scott, J. M. et al. 1987, Species richness: a geographic approach to protecting future biological diversity, BioScience, 37 782-788.
17. Sowa, S.P. The Missouri Aquatic Gap Pilot Project,: 1998, An Overview and Status Report, Proc. of the 8th Annual National GAP Analysis Program Meeting, July 20-24, UC Santa Barbara, no page.
18. Stoms, D. M. 1992, Effects of habitat map generation in biodiversity assessment, PE&RS, 58 1587-1591.
19. TNC, Priorities for Conservation: 1966 Annual Report Card for US Plant and Animal Species. 1996, The Nature Conservancy, Arlington, VA.