

ECOLOGICAL HEALTH ASSESSMENT OF LIAO RIVER MAINSTREAM BASED ON FISH BIOTIC INTEGRITY INDEX

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Abstract. In this study, the fish biotic integrity index (IBI) was applied to evaluate the health status of Liao River mainstream in China. A total of 3565 fish individuals were collected from seven sampling sites in May (spring) and September (autumn) of 2020 and 2021. 24 candidate indicators selected for building the Fish Integrity Index (F-IBI) of the mainstream Liao River. The F-IBI values of each index were calculated using the 1, 3 and 5 assignment method, and the river health criteria were divided into four quartiles based on the 75% quantile of the F-IBI values below the sampling points to determine the evaluation criteria of the F-IBI system of the main stream of the Liao River, which were divided into five grades, namely healthy, subhealthy, fair, poor and very poor. The results show that the health of the main stream of the Liao River is mostly at average or below average level, and the evaluation results of station1, station5 and station7 were all at poor or below health level for two consecutive years; among them, station2 and station3 have higher overall scores in each season, and most of the points are above sub-healthy level, which is similar to the results of previous periods. The results indicate that F-IBI is feasible for evaluating the health of the Liao River and can be used as a basis for assessing the ecological health of the main stream of the Liao River.

Keywords: *Liao River, Fish Index of Biological Integrity, 1, 3, 5 assignment method, river health, aquatic ecology*

Introduction

As a natural ecosystem on which humans and other organisms depend, rivers not only play an important role in maintaining the material cycle, energy flow and ecological balance and healthy development of terrestrial and aquatic ecosystems, but also in regulating climate, maintaining human life and ensuring biodiversity (Bao et al., 2021). They not only play an important role in maintaining the material cycle, energy and ecological balance and healthy development of terrestrial and aquatic ecosystems, but also play an important ecological function in regulating climate, maintaining human life and ensuring biodiversity (Sun et al., 2020). With the development of society, today's river ecosystems are constantly degraded, and the problems of river water environment and water ecology are constantly highlighted, so the accurate evaluation of the health of river ecosystems has attracted extensive research and attention, and has become a hot issue of river health management in the United States, Canada, Australia, China and other countries (Luo et al., 2018; Wang et al., 2019; Li and Kang., 2014). River health assessment can not only assess the ecological status of rivers, but also consider the effectiveness of river management initiatives, which is of great importance for river ecological management, water conservation and management (Hu et al., 2021).

The application of the index of biotic integrity (IBI) to evaluate the ecological health of rivers has effectively addressed the limited use of physical and chemical indicators to evaluate the health of rivers (Hou and Wang., 2018). The IBI has become an important approach to river ecosystem conservation and management, emphasizing the importance of in analyzing the causes of environmental problems in rivers and objectively assessing the health of rivers from an ecosystem perspective (Zhang et al., 2007). In 1981, Karr was the first to propose the use of fish to establish the IBI to evaluate river health, and the Biotic Integrity Assessment was approved by the US Environmental Protection Agency (EPA) and has been widely used in various states in the US (Aparicio et al., 2011) benthic fauna (Jun et al., 2012) and plankton (Shen et al., 2012). In 1999, the EPA proposed the use of the Biotic Integrity Index to evaluate the health of riverine ecosystems. The method is widely applicable because it is integrated with the main biogeographic theory (Zhang et al., 2020).

Fish as a major indicator of river health (Yuan et al., 2021), many scholars at home and abroad have conducted extensive research using the fish-index of biotic integrity (F-IBI) to assess the ecological health of rivers, and the United States has applied the F-IBI to evaluate the health of rivers in at least 29 states, making it the most mature country in the world to apply the IBI to evaluate the health of rivers (Gao et al., 2015). In China, scholars have used F-IBI to evaluate the health of the Yangtze River (Zhu and Chang., 2004), Yellow River (Li et al., 2018), Prince River (Song et al., 2010) and the Hun River (Zhang et al., 2015). The assessment of river health status has been carried out. The Liao River system is one of the seven major rivers in China and one of the important water sources in the northeast of the country. In recent years, especially along with the economic growth within Liaoning Province, the demand for water resources far exceeds the ecological renewal of the river, and the water quality of the main stream of the Liao River suffers from serious pollution (Wang and Zhang., 2007; Pei et al., 2010). The water quality of the main stream of the Liao River has been seriously polluted. In 2010, the Liaoning River Protection Area Administration was established and the scope of the protected area was defined with the aim of restoring the health of the water ecosystem in the Liaoning River Nature Reserve (Liu et al., 2013). The purpose of the reserve is to restore the health of the water ecosystem in the Liao River Nature Reserve. Therefore, the present study takes fish in the main stream of the Liao River as the research object, constructs the F-IBI system applicable to the main stream of the Liao River, evaluates the river health of the main stream of the Liao River, provides suggestions for the development of the ecological health of the main stream of the Liao River, and provides data support for the establishment of a water ecosystem health evaluation method applicable to China.

Materials and methods

Overview of the study area

The main stream of the Liao River originates in Fudian in Liaoning, and flows through 14 counties in four cities of Liaoning Province in China, namely Tieling, Shenyang, Anshan and Panjin, before entering the Bohai Sea at the Liaohekou Nature Reserve in Zhaohuanhe Township, Dawu District, Panjin City. It has a total area of 40,988 km² and a length of 554 km. Both sides of the river are important agricultural areas in Liaoning Province and form a major part of the Liao Plain (Liu et al., 2013). The banks of the river are an important agricultural area in Liaoning Province and

form a major part of the Liao Plain. The main stream of Liao River is located in the temperate continental monsoon climate zone, with a large temperature difference during the year.

Sample collection and determination

According to the topography and terrain conditions of the main stream of the Liao River, the representativeness of each sampling point was fully considered, and the influence of different elements such as urban factors, the role of reservoirs, the confluence of the main stream, the confluence of tributaries and the river's mouth to the sea was taken into account (Liu et al., 2013). Seven survey stations were set up (Fig. 1), namely Fudian (East-West Liao River confluence), Liao River Special Bridge (Kangping section), Tongjiangkou Special Bridge (Tieling section), Juliu River (Xinmin section), Liao River Bridge (Liaocheng section), Zhanghuangdi Liao River Bridge (Tai'an section) and Freezing Bridge (Panjin section), the distribution of which is shown in Table 1.

Fish sampling was carried out at seven sites in the main stream of the Liao River in May and September 2020 and May and September 2021, with multiple sites evenly selected along 400 m above and below the sampling sites. Samples of fish from wadeable nearshore areas were collected by electrofishing for 0.5 h at water depths less than 1.5 m. Fish samples from water depths greater than 1.5 were taken using drift gillnets with a net diameter of 1.0-2.0 cm and ground cages with a net diameter of 1.5 cm. Species identification was based on the Liaoning Aquatic Economic Flora and Fauna Atlas (Liaoning Provincial Department of Ocean and Fisheries, 2011) (Fig. 2).

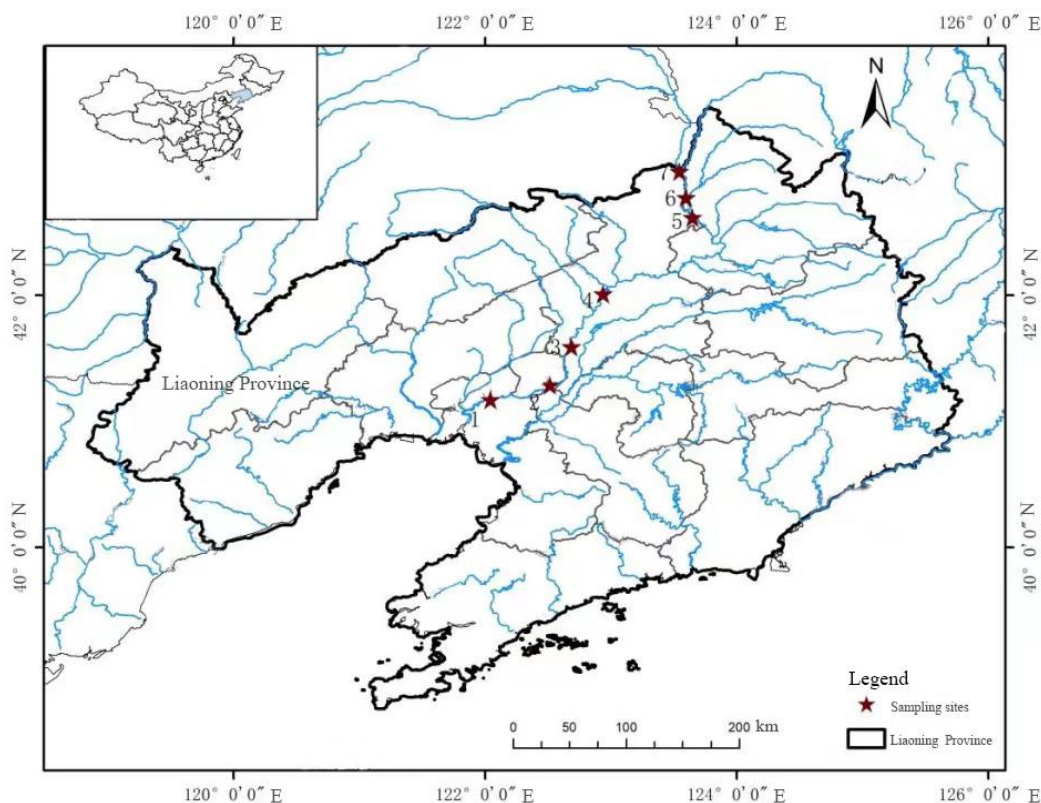


Figure 1. Distribution table of survey stations in Liao River



Figure 2. Sampling site in Liao River

Table 1. Distribution of sampling points in Liao River

Sampling sites	Longitude	Latitude	Altitude (m)
Station 1	122°12'57"	41°12'35"	10
Station 2	122°30'59"	41°17'14"	10
Station 3	122°41'05"	41°35'18"	20
Station 4	122°56'23"	42°0'28"	30
Station 5	123°38'52"	42°36'52"	80
Station 6	123°35'51"	42°46'19"	80
Station 7	123°32'35"	42°58'43"	90

Data analysis

Screening reference points

The ideal reference points should be selected from areas that are completely free from human disturbance. Impaired points are areas that are heavily disturbed by human activities, and due to rapid social development and the fact that there are still no uniform standards for reference points, resulting in fewer undisturbed river sections, points that are less disturbed by human activities should be selected as reference points as much as possible, and these points are considered to have relatively good data on indicators such as biological, physical and chemical environment (Yuan et al., 2021). The biological and physico-chemical environmental indicators at these sites are considered to be relatively good. Therefore, in this study, reference was made to previous studies on the Liao River (Zhang et al., 2014). Therefore, in this study, reference was made to the reports of previous studies on the Liao River, and combined with the field survey and sampling situation, point 3, which was least disturbed by human activities, was selected as the reference point.

Building the F-IBI system

Determination of candidate indicators Based on the composition and ecological characteristics of fish species in the main stream of Liao River, and taking into account the contents of this survey and the actual situation, this study referred to the more

mature indicators of IBI in Karr's method (Karr, 1981). Based on the composition and ecological characteristics of fish species in the main stem of the Liao River and the actual situation of the survey, 24 preliminary indicators were selected from the five categories of species composition and abundance, trophic structure, tolerance, reproductive co-locations, fish abundance and health status (Table 2), with reference to the more mature indicators used in the IBI in Karr's method (Song et al., 2010). The IBI is designed to reflect, as far as possible, the effects of changes in the basin environment on the abundance, structure and function of fish (individuals, populations and communities), and thus to enable effective monitoring and evaluation of the quality of the water environment (Huo et al., 2013). This will enable effective monitoring and evaluation of the quality of the water environment.

Table 2. Candidate indicators of F-IBI (Song et al., 2010)

Attribute categorization	Parameter abbreviations	Candidate parameter indicators	Response to disturbances
Species composition and abundance	F1	Total number of fish species	Decrease
	F2	Shannon-Wiener Diversity Index	Decrease
	F3	Percentage of <i>Leuciscinae</i>	Decrease
	F4	Percentage of <i>Parabramis pekinensis</i>	-
	F5	Percentage of <i>Acheilognathi-nae</i>	Decrease
	F6	Percentage of <i>Gobioninae</i>	Increase
	F7	Percentage of <i>Cyprininae</i>	Increase
	F8	Percentage of <i>Cobitis</i>	Decrease
	F9	Percentage of <i>Gobiidae</i>	Decrease
	F10	Percentage of locally held fish species	-
	F11	Percentage of economic fish	Decrease
	F12	Percentage of pelagic fish	Decrease
	F13	Percentage of demersal fish	Increase
	F14	Percentage of cold water fish	-
Nutritional structure	F15	Percentage of carnivorous fish	Decrease
	F16	Percentage of phytophagous fish	Decrease
	F17	Percentage of omnivorous fish	Increase
Tolerance	F18	Percentage of sensitive fish	Decrease
	F19	Percentage of tolerant fish	Increase
Breeding co-locations	F20	Proportion of spawning fish	Decrease
	F21	Number of fish with spawning behavior	Increase
Fish population and health status	F22	Total fish catch	Decrease
	F23	Percentage of individuals with abnormalities	Increase
	F24	Number of widespread species	Decrease

If a candidate indicator scores zero in more than 95% of the sample points or has a narrow distribution, the fish stock represented by the indicator has a relatively constant distribution in the basin and the indicator should be dropped (Barbour et al., 1996). The indicator should be dropped.

Discriminability analysis of candidate indicators The box-line plot discriminant method was used to compare the overlap between reference and observation points in the 25%-75% box range. Significant differences in candidate indicators must satisfy one of the following conditions: (Bao et al., 2021) the median of the reference points exceeds the 25%-75% box range of the observation points; (Sun et al., 2020) the median of the observation points exceeds the 25%-75% box range of the reference points; finally, the parameters with significant levels of parameter variability are selected as evaluation indicators in combination with one-way ANOVA (Barbour et al., 1996).

Correlation analysis of candidate indicators Pearson correlation analysis was performed on the remaining indicators to test the redundancy of the candidate indicators (Barbour et al., 1996). If $|R| < 0.9$, the test is passed but non-high correlation. If $|R| > 0.9$, it means that there is a high overlap of information between the two indicators, then one of them can be taken and the one with more information is retained.

After the above steps of screening, the core biological indicators of F-IBI suitable for the main stream of Liao River were finally determined. In addition, statistical analyses of the data were carried out using Excel 2021 and SPSS 19.0 software.

Indicator assignment and evaluation criteria

The assignment criteria of the indicators were determined based on the survey data of the main stream of Liao River for four times in spring and autumn from 2020 to 2021. The F-IBI values of each indicator in the main stream of the Liao River were calculated using the 1, 3 and 5 assignment method. The actual values measured for each indicator were divided into three grades from low to high, with the best grade assigned to the 5 region, the middle grade assigned to the 3 region and the worst grade assigned to the 1 region. The scores for each indicator are summed to give the IBI score for the sampling site. The evaluation criteria of the F-IBI system for the main stream of the Liao River were determined by quadratically scoring the river health criteria according to the 75% quantile of the final IBI scores of all sampling points, and classifying the different degrees of health in order: very poor, poor, fair, subhealthy and healthy.

Results

Fish composition

In this survey, the total number of specimens collected was 3,565, belonging to 41 species in 35 genera of 4 orders (*Table 3*). Among them, *Rhodeus sinensis* Günther accounted for 12.5% of the total number of specimens collected and was the dominant species in the Liaoning River basin, while *Carassius auratus* and *Rhodeus sinensis* were widespread species in the Liaoning River basin. The number of fish species sampled is shown in *Figure 3*. The results show that the dominant group in the Liao River basin is the carp family; the loach family accounts for the second largest share, accounting for 31.87% of the total, while others include *Gobiidae*, *Channidae*, *Eleotridae*, *Sphyraenidae*, *Osphronemidae*, *Siluridae*, *Bagridae* and *Adrianichthyidae*, accounting for 2.50% of the total. The *idella*, *molitrix*, *nobilis*, *asotus* are belonging to widespread species.

Table 3. Composition of fish collected at sampling sites in Liao River Basin

Orders	Genus	Species	Sampling sites							Season		
			1	2	3	4	5	6	7	Spring	Autumn	
Cypriniformes	<i>Cobitis</i>	<i>granoei</i>					+			+	+	
	<i>Barbatula</i>	<i>nuda</i>					+	+	+	+	+	
	<i>Mudskipper</i> <i>Misgurnus</i>	<i>anguillicaudatus</i>	+	+	+				+		+	
	<i>Paramisgurnus</i>	<i>dabryanus</i>			+					+	+	
	<i>Opsariichthys</i>	<i>bidens</i>				+	+		+	+	+	
	<i>Abbottina</i>	<i>Abbottina rivularis</i>	+		+					+	+	
	<i>Rhynchocypris</i>	<i>lagowskii</i>					+	+		+	+	
	<i>Ctenopharyngodon</i>	<i>idellus</i>	+							+	+	
	<i>Hypophthalmichthys</i>	<i>molitrix</i>	+	+							+	+
		<i>nobilis</i>	+	+							+	+
	<i>Rhodeus</i>	<i>sinensis</i> Günther	+	+	+	+	+	+	+	+	+	
	<i>Acheilognathus</i>	<i>macropterus</i>						+	+	+	+	
		<i>chankaensis</i>	-					+	+	+	+	
	<i>Hemiculter</i>	<i>leucisclus</i>	+	+	+	+	+	+	+	+	+	
	<i>Pseudorasbora</i>	<i>parva</i>	+		+	+	+		+	+	+	
	<i>Paraleucogobio</i>	<i>strigatus</i>		+	+	+	+			+	+	
	<i>Pseudogobio</i>	<i>vallanti</i>				+	+		+	+	+	
	<i>Huigobio</i>	<i>Huigobio Hchinssuensis</i>		+		+				+	+	
	<i>Gobio</i>	<i>Gobio tenuicorpus</i>					+			+	+	
		<i>Gobio cynocephalus</i> Dybowsky				+				+	+	
		<i>Gobio soldatovi</i>				+				+	+	
	<i>Cyprinus carpio</i>	<i>Cyprinus carpio</i>	+		+			+	+	+	+	
		<i>carp</i> <i>Cyprinus carpio</i> var <i>Specularis</i>							+	+	+	
<i>Carassius</i>	<i>Carassius auratus</i>	+	+	+	+	+	+	+	+	+		
<i>Zacco</i>	<i>platypus</i>											
<i>Erythroculter</i>	<i>oxycephaloides</i>	+	+						+	+		
<i>Culter</i>	<i>Culter alburnus</i>	+				+			+	+		
<i>Megalobrama</i>	<i>Megalobrama amblycephala</i>	+							+	+		
Perciformes	<i>Hypseleotris</i>	<i>swinhonis</i> Günther						+	+	+		
	<i>Synechogobius</i>	<i>hasta</i>			+				+	+		
	<i>Aboma</i>	<i>lactipes</i>		+					+	+		
	<i>Channa</i>	<i>Channa argus</i>	+						+	+		
	<i>Liza</i>	<i>haematocheila</i>	+						+	+		
	<i>Macropodus</i>	<i>belontiidae</i>						+		+		
	<i>Chloea</i>	<i>laevis</i>		+					+	+		
	<i>Rhinogobius</i>	<i>Rhinogobiu giurinus</i>						+		+		
<i>Rhinogobiu brumeus</i>												
Siluriformes	<i>Silurus</i>	<i>asotus</i>	+			+		+	+	+		
	<i>Perccottus</i>	<i>glenii</i>						+	+	+		
	<i>Pelteobagrus</i>	<i>Pelteobagrus fulvidraco</i>	+	+					+	+		
Cyprinodontiformes	<i>Oryzias</i>		+	+	+		+		+	+		

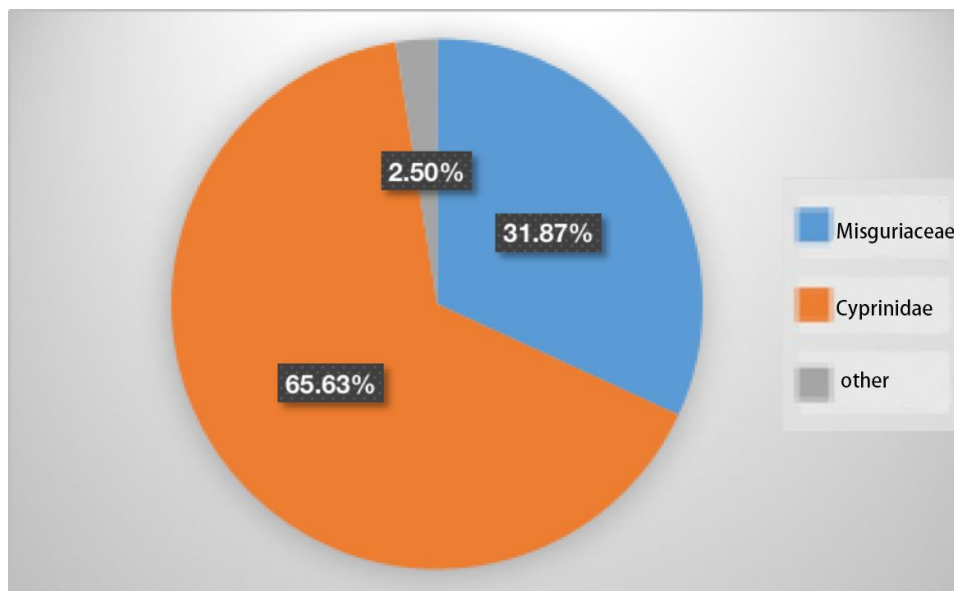


Figure 3. Distribution of fish species in Liao River Basin

F-IBI index evaluation system

This study screens the indicator system for spring and autumn indicators in 2020 and 2021 respectively, and establishes the F-IBI indicator system for evaluating the environment of the Liao River basin.

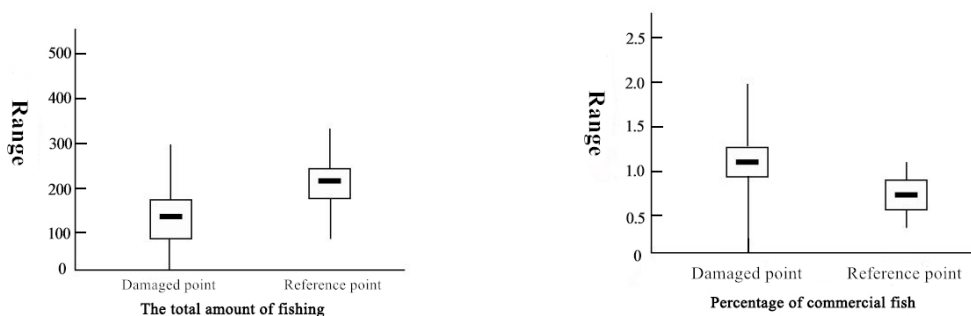
Analysis of the distribution range of biological parameters

The indicators were screened out because insufficient data were collected on the percentage of abnormal individuals, the percentage of *Adrianichthyidae*, the percentage of *Siluridae*, the percentage of *Channidae* and the percentage of spawning fish in the total.

Discriminatory capacity analysis

Total catch, percentage of economic fish species, percentage of number of sensitive fish species, percentage of groundfish, and percentage of pelagic fish met the criteria as analyzed by the spring 2020 candidate indicator box line chart (Fig. 4).

The analysis of the autumn 2020 candidate indicator box line graphs showed that the criteria for total catch, percentage of economic fish species, percentage of number of sensitive fish species, percentage of groundfish, percentage of *Gobioninae* and percentage of *Cyprininae* were met (Fig. 5).



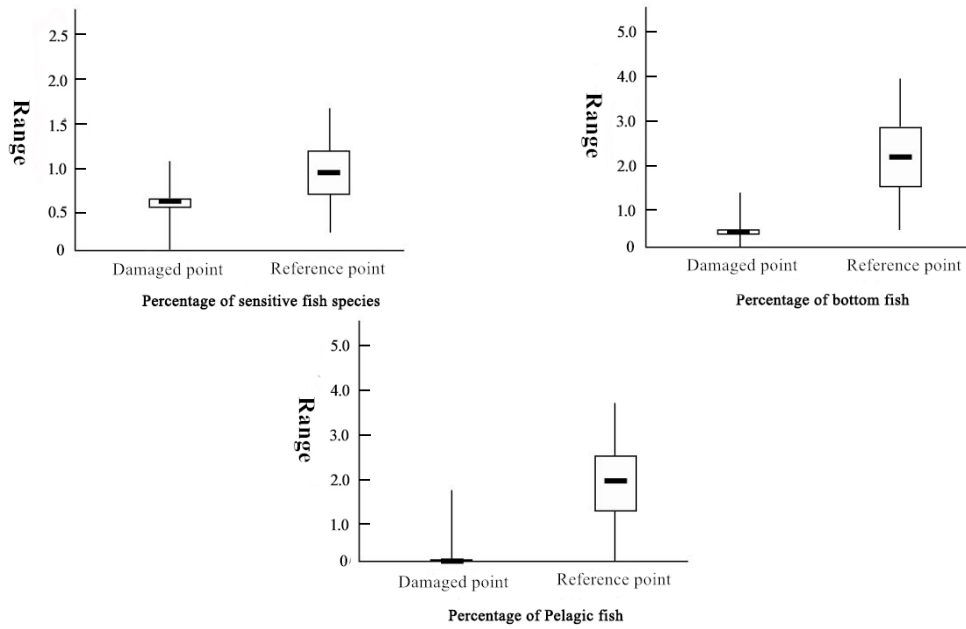


Figure 4. Box chart of candidate indicators for spring 2020

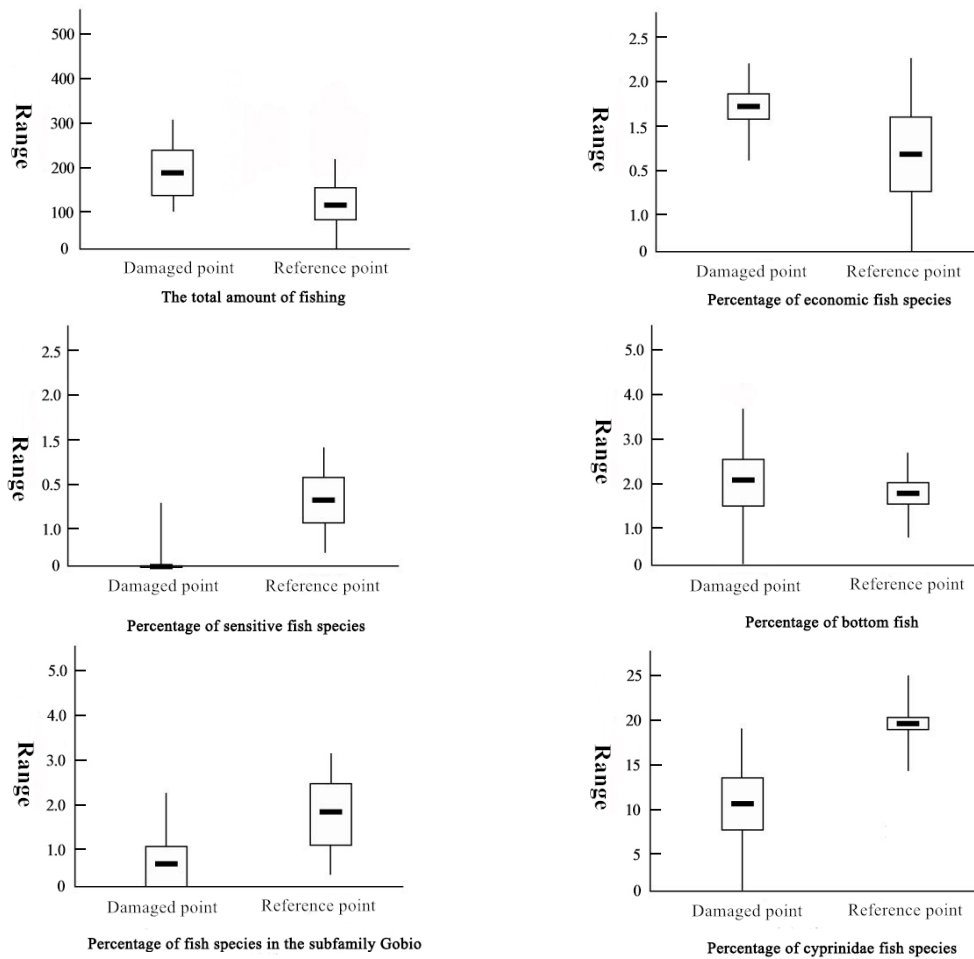


Figure 5. Box chart of candidate indicators for autumn 2020

The results of the spring 2021 survey indicator screening (*Fig. 6*) showed that the total number of fish species, the Shannon-Wiener Diversity Index, the percentage of *Cobitidae*, the percentage of phytophagous fish, percentage of groundfish, percentage of *Gobioninae* and percentage of *Cyprininae* in the minnow subfamily all met the criteria.

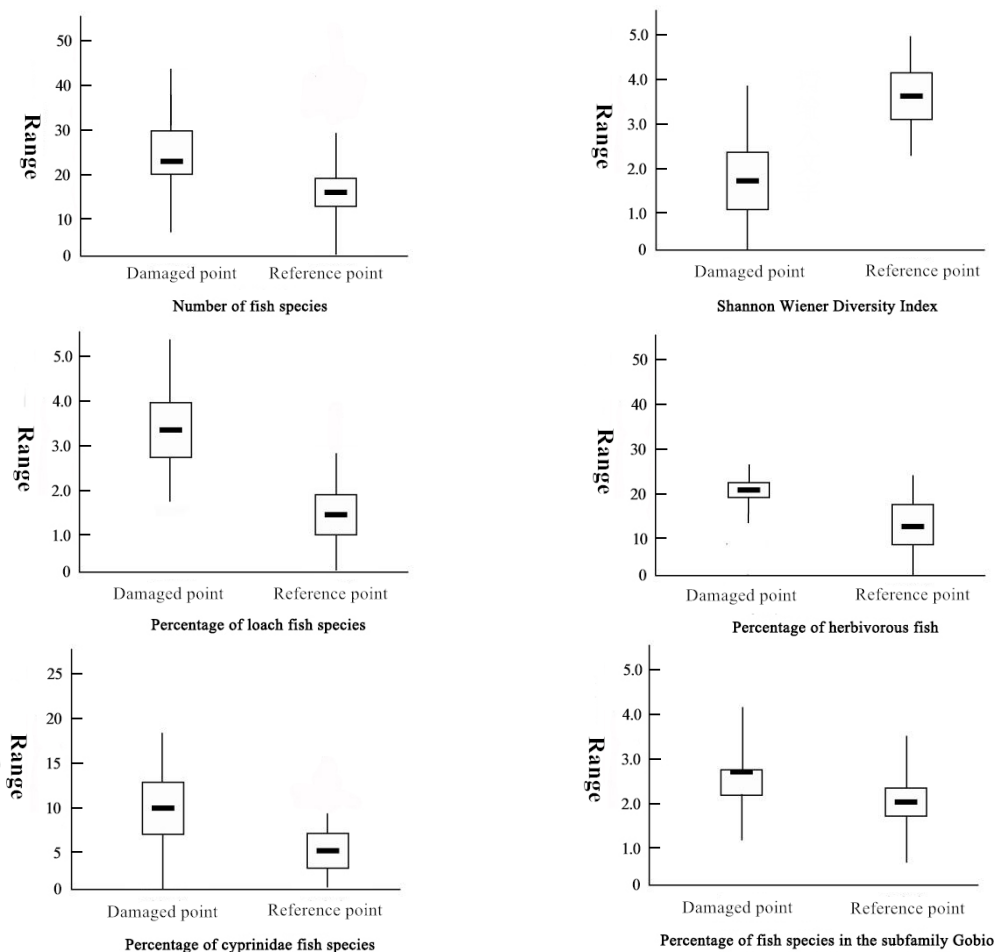
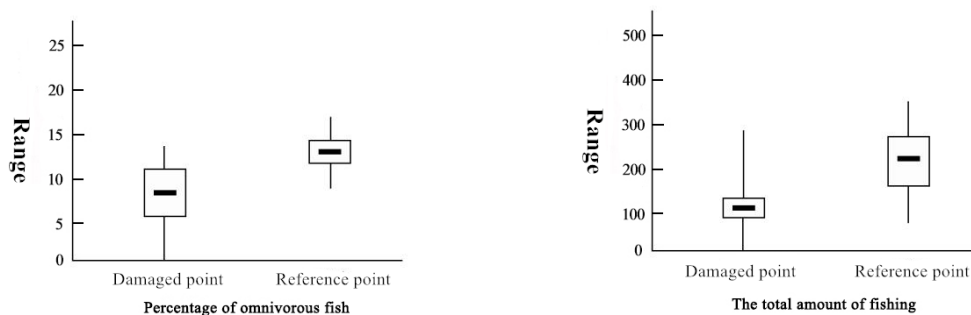


Figure 6. Box chart of candidate indicators for spring 2021

The results of the autumn 2021 survey indicator screening (*Fig. 7*) show that the percentage of omnivorous fish, total catch, percentage of demersal fish and number of widespread species all meet the criteria.



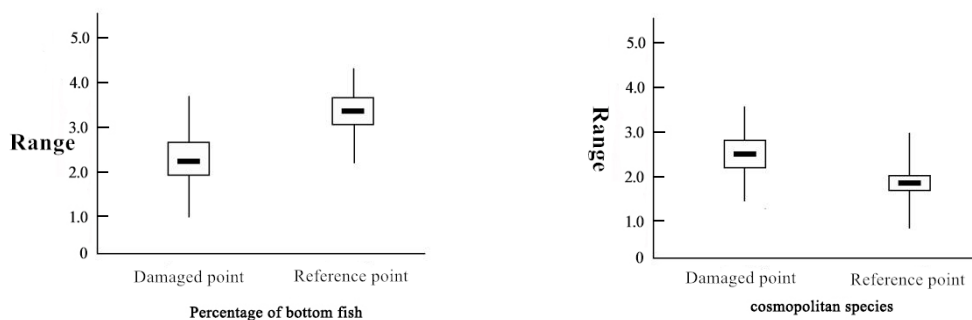


Figure 7. Box chart of candidate indicators for autumn 2021

Correlation analysis

Pearson correlation coefficients were calculated for the candidate indicators screened in 2.2 and those with high correlations ($|R| < 0.9$) were excluded.

Observation of *Table 4* showed that the indicators showed non-high correlation ($|R| < 0.9$), so the five indicators were selected to evaluate the spring health of the Liao River basin.

Table 4. Pearson correlation coefficient of candidate indicators in spring 2020 in Liao River Basin

	Total catch	Percentage of economic fish species	Percentage of number of sensitive fish species	Percentage of demersal fish	Percentage of pelagic fish
Total catch	1				
Percentage of economic fish species	-0.064	1			
Percentage of number of sensitive fish species	-0.539	0.242	1		
Percentage of demersal fish	-0.183	0.261	0.436	1	
Percentage of pelagic fish	0.409	-0.235	-0.0261	0.158	1

Considering that the percentage of ground fish is more widely used in F-IBI studies, the indicator of percentage of sensitive fish species was deleted and the remaining five indicators could be used to evaluate the spring health status of the Liaoning River basin (*Table 5*).

Table 5. Pearson correlation coefficient of candidate indicators in autumn 2020 in Liao River Basin

	Total catch	Percentage of economic fish	Percentage of number of sensitive fish species	Percentage of demersal fish	Percentage of <i>Gobioninae</i>	Percentage of <i>Cyprinidae</i>
Total catch	1					
Percentage of economic fish	-0.234	1				
Percentage of number of sensitive fish species	-0.436	-0.168	1			
Percentage of demersal fish	-0.153	0.362	0.919	1		
Percentage of <i>Gobioninae</i>	-0.423	0.261	0.042	0.243	1	
Percentage of <i>Cyprinidae</i>	0.001	-0.623	0.253	-0.068	0.286	1

Looking at *Table 6*, two indicators, the percentage of fish species of the subfamily Carp and the percentage of fish species of the subfamily Minnow, were significantly correlated, while the rest of the indicators were not highly correlated. Considering that the subfamily Carp contains more information than the percentage of fish species of the subfamily Minnow, the percentage of fish species of the subfamily Minnow was deleted, so all six indicators could be used to evaluate the spring health of the Liaoning River basin.

Table 6. Pearson correlation coefficient of candidate indicators in spring 2021 in Liao River Basin

	Total number of fish species	Spiced Vina Diversity Index	Percentage of <i>Cobitidae</i>	Percentage of phytophagous fish	Percentage of <i>Cyprinidae</i>	Percentage of <i>Gobioninae</i>
Total number of fish species	1					
Spiced Vina Diversity Index	0.685	1				
Percentage of <i>Cobitidae</i>	-0.536	-0.428	1			
Percentage of phytophagous fish	-0.302	-0.632	-0.243	1		
Percentage of <i>Cyprinidae</i>	-0.003	0.327	-0.193	-0.581	1	
Percentage of <i>Gobioninae</i>	-0.538	0.413	-0.286	0.218	0.946	1

Observation of *Table 7* showed that the indicators were not highly correlated, so the four indicators were selected to evaluate the spring health of the Liao River basin.

Table 7. Pearson correlation coefficient of candidate indicators in autumn 2021 in Liao River Basin

	Total catch	Percentage of omnivorous fish	Percentage of demersal fish	Number of widespread species
Total catch	1			
Percentage of omnivorous fish	-0.431	1		
Percentage of demersal fish	-0.376	0.203	1	
Number of widespread species	0.523	-0.302	-0.116	1

Based on the above screening, the indicators selected to construct the F-IBI indicator system are shown in *Table 8*.

Table 8. Index system of F-IBI in Liao River Basin

Time	F-IBI Indicator
Spring 2020	Total catch, percentage of economic fish species, percentage of number of sensitive fish species, percentage of demersal fish species
Autumn 2020	Total catch, percentage of economic fish species, percentage of demersal fish, percentage of number of <i>Gobioninae</i> , percentage of number of <i>Cyprinina</i>
Spring 2021	Total number of fish species, Shannon Viner Diversity Index, percentage of <i>Cobitidae</i> , percentage of phytophagous fish, percentage of number of <i>Cyprinina</i>
Autumn 2021	Percentage of omnivorous fish, total catch, percentage of demersal fish, number of widespread species

Scoring and evaluation

The IBI parameter scores for each site are shown in *Table 9*. The results show that sites 1, 5 and 7 have lower overall scores in each season and sites 2 and 3 have higher overall scores in each season; the Liao River has a poorer health level in autumn. From a year perspective, the health level decreases in 2021 compared to 2020, with an increase in poorer and very poor level conditions.

Table 9. Evaluation results of F-IBI in Liao River Basin

Sampling sites	2020				2021			
	Spring		Autumn		Spring		Autumn	
	Score	Level	Score	Level	Score	Level	Score	Level
1	18	General	16	General	8	Very poor	13	Poor
2	25	Health	18	General	17	General	24	Health
3	26	Health	28	Health	22	Sub-health	25	Health
4	12	Poor	22	Sub-health	16	General	14	Poor
5	13	Very poor	14	Poor	13	Poor	12	Very poor
6	24	Health	27	Health	23	Sub-health	15	Poor
7	11	Very poor	7	Very poor	10	Very poor	9	Very poor

Discussion

Fish composition of the Liao River basin

The literature on the fish resources of the Liao River is scarce, and Pei Xuejiao (Pei et al., 2010) the survey by Pei Xuejiao et al. in the Liaohe River basin found 25 species of fish with a total of 2,090 fish, while 41 species of fish with a total of 3,565 fish were collected in the four surveys in this study. The common species of fish collected in spring and autumn in both years were *auratus*, *anguillicaudatus* and *sinensis gunther*, all of which are fouling-tolerant species with high tolerance and wide range of activities (Liu et al., 2013). This is consistent with the results of Liu Bin's analysis on the fish composition of the main streams of the Liao River. According to this survey, most of the collected fish samples were mainly small fish such as *auratus* and *parva*, and for large fish such as carp and silver carp, they basically showed juvenile fish, and the phenomenon of fish miniaturization was prominent, which is similar to the situation of fishery resources in some other rivers in China (Wu et al., 2007; Jiang and He, 2008). Compared with other rivers in northern China, the Huntai River (Liu et al., 2016) and the Western Liao River basin (Zhang et al., 2015). The fish in the Liao River basin are mainly carps, with more pollution-tolerant species, probably due to the heavy industrial pollution in the north, which has reduced the ecological quality of the rivers and made it difficult for sensitive fish species to survive.

Seasonally, the spring catches in 2020 and 2021 were more consistent, while the autumn catches in 2021 were less diverse than those collected in 2020. The reason for this is that the sampling period coincided with the flooding period of the river and the rapid water in parts of the Liao River basin, which made it difficult to catch. This survey had more catches in autumn than in spring, and Song Zhigang (Song et al., 2010). In the fish collection surveys of the Prince Edward River basin in spring and autumn 2009, there were also more catches in autumn than in spring, which is consistent with the results of this survey.

Selection of reference points

When evaluating river health using IBI, the key step in constructing the F-IBI system is the selection of reference points, which is both an important benchmark for assessing the degree of pollution of river health and directly affects the final evaluation results, but as there is no unified selection standard yet, the specific selection process often uses historical data, or selects the original section of the river without human disturbance as the reference point (Barbour et al., 1996; Maxted et al., 2000). Such situations are also common in national and international studies, Peter uses population density as a reference point (Barbour et al., 1996). In the case of Maxted, water quality physical and chemical indicators are used to classify the reference sites in conjunction with land use practices and river habitat quality (Maxted et al., 2000), while Blocksom uses data on forest area and population density in the area to determine reference sites (Blocksom et al., 2002). Malik uses cluster analysis and other methods to select reference sites for the study of fish integrity in Pakistani rivers (Qadir and Malik, 2009).

It must be clear that reference points selected within the same ecoregion or the same zoogeographic area are often difficult to use to assess the biological integrity of other areas, and that where a valid reference system is not available within the same biogeographic system, although it is possible to draw on reference systems obtained from other studies within the same system, the applicability of the assessment indicator system must be evaluated in order to verify the degree of applicability of the method (Hall et al., 2000) The method should be evaluated for its applicability. Generally, the reference state can be determined in four ways: (Bao et al., 2021) the original state of the river; (Sun et al., 2020) the state of no or minimal human disturbance; (Luo et al., 2018) the state of minimal human disturbance in the basin; and (Wang et al., 2019) the state that can be achieved through restoration. Based on the characteristics of the area through which the main stream of the Liao River flows, and combined with the standardized method for selecting reference points established by Qu et al. (Liu et al., 2016). The third of the above four methods is more applicable, so the third method is adopted to determine the reference state. In this study, the main stream area of the Liao River has been disturbed by humans to varying degrees, and there are no river sections in pristine condition, and there is no quantitative historical data. In future studies, we can collect and analyze more accurate data around the sample sites to determine the disturbance level of the sample sites, while taking into account the influence of various habitats, so as to improve the accuracy of the reference site selection and enhance the feasibility and validity of the IBI study.

Applying F-IBI to evaluate ecosystem health in the Liao River Basin

The results of the study show that stations 1 and 5 showed poor and very poor river health from spring 2020 to autumn 2021, which are located at the border point between urban and rural areas and have a poor environment; station 7 showed very poor river health in all four surveys due to pollution from the nearby chemical plant; stations 2 and 3 had high health scores and basically maintained a healthy level, which is due to the relatively nearby This is due to the fact that the area around the site is relatively open, with only sand control forests and little human interference; the health of the river at stations 4 and 6 is average, which is probably due to the dense villages around station 4 and the high coverage of farmland, and the pollution of the nearby river caused by farmers' farming; station 6 is located near an abandoned sand quarry and has an average

environmental condition. The results of the F-IBI index assessment show that: (1) the percentage of sensitive fish species in the ecosystem of the Liao River basin has a low score, indicating that the basin is more polluted and disturbed by human activities; (2) the percentage of carnivorous fish in the Liao River basin is low, indicating that the diversity of river species is low. In general, most of the seven sites in the Liao River basin surveyed in this study had low IBI scores due to the development of industry and the discharge of domestic sewage, which had a great impact on the fish survival environment. The trends of health levels at different time points in this study are generally consistent, which proves that it is feasible to apply the fish integrity index to evaluate the health level of Liao River rivers.

Liu Bin has studied the fish community structure in the main stream of Liaohe River (Liu et al., 2013). The results showed that the fish diversity and species richness indices of the protected area were higher in the upper reaches than in the lower reaches; the number of fish species was higher in autumn than in spring, while the uniformity of fish individuals was higher in spring than in autumn. The results are similar to the present fish integrity assessment, indicating that the results of the F-IBI assessment of the health of the main stream of the Liao River are feasible and have a certain degree of judgment and differentiation (Pei et al., 2010). The results of the F-IBI are more feasible and have a certain degree of judgment and differentiation. In addition, compared with Pei Xuejiao who used the fish integrity assessment system to evaluate the river health status of 33 stations in the Liaohe River Basin in 2009, the F-IBI score decreased, indicating that the health status of the Liaohe River main stream showed a downward trend (Pei et al., 2010). Liang Guanglin conducted a water quality assessment on the Liaohe main stream from 2012 to 2018. The results showed that the water quality fluctuated between moderate and good critical levels, and the upstream water quality was generally slightly better than the downstream water quality, and the seasonal variation of water quality was very similar to the present study (Liang et al., 2021).

The data obtained from this study cannot reflect the overall health condition of the main stream of the Liao River. In addition, only the spring and autumn seasons were selected, which cannot reflect the changes of fish in the main stream of the Liao River in each season.

Suggestions for the protection and management of the main stream of the Liao River

The priority task for restoring the ecological health of the river is to reduce the discharge of pollutants from the main stream of the Liao River. The discharge of industrial wastewater, urban sewage and other point sources and agricultural surface sources in the vicinity of the river should be supervised, and all sewage should be treated to the standard before being discharged into the Liao River (Ouyang et al., 2018).

It is recommended that more efforts be made to protect the fish in the main stream of the Liao River, with particular attention to the problem of invasive alien fish (Zhu et al., 2004). It is recommended that more efforts be made to protect the fish in the main stream of the Liao River, with particular attention to the invasion of foreign fish. The fish survey data of the river basin should be compiled to grasp the distribution and abundance of local fish, analyze the characteristics of local endangered species, and implement more measures to protect fish habitats and better protect local fish. In addition, carnivorous fish can be introduced into the Liaoning River basin through artificial enhancement to improve the ecological health of the water.

The ecosystem of the main stream of the Liao River is in general health. With the increasing development of the surrounding urbanization, the Liao River is also under increasing environmental pressure. Strengthening the monitoring of the river's hydrology, water quality and the ecological environment of the wetlands in the basin and strictly controlling the discharge of pollutants into the river are the most important means to ensure the health of the Liao River ecosystem.

Conclusions

(1) The fish species composition and abundance, food nutrient structure, pollution tolerance, breeding co-locations, individual quantity and health status of fish were proposed as the objects of the study, and the final indicators were selected from the 24 candidate indicators and used for each sampling to establish the F-IBI evaluation system.

(2) The results of this study show that the ecological health of the dry water streams of the Liao River is mostly at average or below average level, similar to the results of previous periods. Applying the F-IBI evaluation system to reflect the water ecological health of the Liao River basin in the spring and autumn of 2020 and 2021 provides more realistic data on the background of the water ecosystem.

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