

Assessment of Fishing Ban's Efficacy Based on Analytic Hierarchy Process: A Case Study of the Lower Qiantang River

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Abstract

Scientific evaluation of the fishing ban's efficacy could provide critical support for sustainable management and protection of natural waters. However, commonly used spatiotemporal evaluation methods were difficult to scientifically and comprehensively reflect the actual fishing ban's efficacy. This paper focused on the Lower Qiantang River, a critical ecological corridor in Zhejiang Province of China, as the research object. Two representative time points, 2018 (pre-ban) and 2023 (5 years after the fishing ban), were selected to construct a three-level monitoring and evaluation index system containing eleven specific indicators from three aspects—ecological environment, economic output, and social consciousness. Then, a model based on the analytic hierarchy process (AHP) was developed to systematically evaluate the fishing ban's efficacy. Comparative analysis of nine key ecological, economic, and social indicators revealed significant improvements post-ban, reflecting continuously improved water quality, a certain degree of restoration of the aquatic ecosystem, and the continuous enhancement of the public's awareness of ecological protection. Notably, the comprehensive assessment index rose from 0.88 to 1.16 (a 31.67% increase), underscoring the ban's role in optimizing resource allocation and fostering sustainable fisheries management. The method and model adopted in this paper further improved the theoretical and methodological system for evaluating the fishing ban's efficacy in various natural freshwaters.

Keywords

Seasonal Fishing Ban, Indicator System, AHP, Assessment, The Lower

1. Introduction

The Qiantang River watershed (55,000 km²), recognized as Hangzhou's "Mother River", constitutes a vital ecological corridor in Zhejiang Province. While its hydrological dynamics sustain diverse aquatic ecosystems, anthropogenic stressors—including sand mining, overfishing, and flow regulation—drive habitat fragmentation and biodiversity decline [1]. Accordingly, an annual fishing ban (March 1-June 30) has been implemented since 2019. Subsequent studies indicated measurable recovery in fish stocks and community resilience following the ban [1] [2]. However, these investigations primarily focused on ecological indicators or relied on survey-based methodologies, and employed singular indicators—tracking biotic assemblages, physicochemical parameters, or socioeconomic outputs—limiting systematic and intuitive digital presentation of the effectiveness. Though demonstrating initial positive outcomes, this research area remains in a preliminary stage of development due to the absence of systematic frameworks capable of comprehensively evaluating fishing ban effectiveness. Specifically, there is a critical need for integrated assessment methods that quantify interactions among ecological, socioeconomic, and regulatory factors using multidimensional indicators.

The Analytic Hierarchy Process (AHP) offers a robust multi-criteria decision framework for complex socio-hydrological systems [3]. This methodology quantifies qualitative expert judgments through structured pairwise comparison of hierarchical criteria [4] [5]. Multi-criteria evaluations of fishing ban efficacy remain limited. Chen's [6] structural-functional AHP application in Shenzhen Bay demonstrated a 113.00% increase in ecological resilience indices post-ban (2013: 0.518; 2017: 1.104), underscoring its feasibility for application in the evaluation of fishing ban effects.

This research addressed the identified gap by developing a tailored AHP-based assessment framework for the Lower Qiantang River. We integrated time-series monitoring and survey of water ecological environment, economic output, and social consciousness indicators to quantitatively evaluate the fishing ban's efficacy in the Lower Qiantang River. Our systematic approach improved the theoretical and methodological system for evaluating the fishing ban's efficacy in various natural freshwaters.

2. Materials and Methods

2.1. Study Area

The research area encompasses the main channel of the Qiantang River between Duji Bridge and Fuxing Bridge (29°45'-30°13'N, 119°39'-120°11'E), a critical freshwater fishery zone under the jurisdiction of Hangzhou's Xihu, Fuyang, and Ton-

glu districts. A total of nine representative monitoring sites have been identified, as shown in **Figure 1** and **Table 1**.

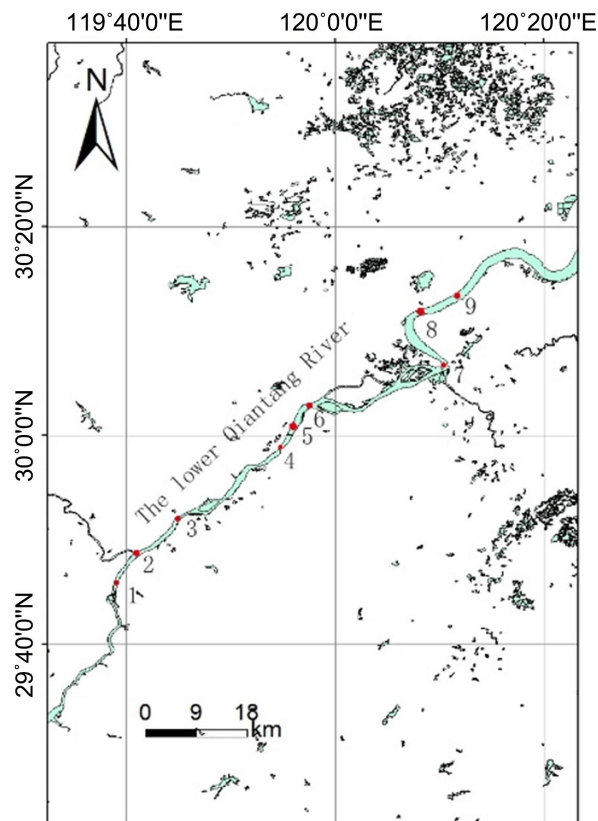


Figure 1. Study area and monitoring site locations in the Lower Qiantang River

Table 1. List of monitoring sites in the Lower Qiantang River.

Point No.	Longitude	Latitude	Description
1	119°39'16.36"	29°45'27.03"	Duji Bridge
2	119°41'08.47"	29°48'27.61"	The confluence of the two rivers
3	119°46'03.29"	29°52'19.06"	Zhai Xi Bridge
4	119°54'53.91"	29°58'18.22"	Zhongbu Bridge
5	119°56'26.03"	30°00'39.34"	Fuyang Bridge
6	119°58'06.91"	30°02'39.79"	The first bridge over the Fuchun River
7	120°10'39.17"	30°06'11.47"	The confluence of the three rivers
8	120°08'17.46"	30°11'34.62"	Qiantang River Bridge
9	120°10'44.28"	30°12'24.98"	Fuxing Bridge

This area is an important component of the Qiantang River. It has important and special ecological functions in maintaining ecological balance and biodiversity, protecting rare species resources, conserving water sources, and storing floods and droughts [7]. Prior to the 2019 fishing ban, anthropogenic activities such as water conservancy projects, sand mining, and excessive development had led to serious damage to the area, including continuous pollution of water quality, gradual depletion of water sources, significant ecological degradation, and fishery resource depletion [7]. Therefore, in order to curb the continuous deterioration of water ecosystems, starting from 2014, ecological restoration projects, including water pollution control, stock enhancement, and seasonal fishing bans, have been successively conducted in the section.

2.2. The Temporal Scale of Monitoring and Evaluation

Determining appropriate temporal scales for monitoring is critical to ensure the accurate assessment of aquatic ecosystem restoration. Restoration trajectories depend inherently on degradation severity, regional climatic conditions, and socio-economic contexts, with recovery periods spanning 3 - 5 years for moderately impacted systems to decades (>20 - 50 years) for severely impaired ecosystems [8]. Nevertheless, interim evaluations remain essential for adaptive management, enabling corrective interventions during restoration rather than exclusively assessing endpoint outcomes. Consequently, this study employs a comparative temporal framework analyzing ecological conditions at two strategic intervals: baseline (2018; pre-ban implementation) and post-restoration (2023; 5 years post-ban), providing a critical mid-term assessment of the fishing ban's efficacy in the Lower Qiantang River.

2.3. The Indicator System for Monitoring and Evaluation and the Methods for Obtaining Indicators

Theoretical frameworks suggest that monitoring and evaluation accuracy increase with indicator specificity [5]. Based on multi-year fishery resource survey data from the lower Qiantang River basin, we developed an initial evaluation index system and designed a questionnaire for expert consultation. Experts were recruited based on the following criteria: 1) professional engagement in water ecological restoration, 2) ≥ 5 years of field experience, 3) possession of a bachelor's degree or higher with an associate professor-level (or equivalent) professional title, and 4) demonstrated commitment to completing iterative consultation rounds. Eight eligible experts participated. Indicator selection proceeded through iterative questionnaire rounds, retaining items only if the expert consensus met both of the following thresholds: a mean importance score > 4.0 and a coefficient of variation < 0.25 .

After two rounds of expert inquiries, this study finally established a three-tiered monitoring and evaluation framework. This framework comprises eleven specific indicators derived from the ecological, economic, and social domains to quantify key elements within the Lower Qiantang River system. The complete indicator

system and corresponding data acquisition methodologies are detailed in **Table 2**. Within the ecological domain, Chlorophyll-a concentration serves as a fundamental proxy for algal biomass and a key water quality indicator in freshwater ecosystems [9]. However, discrete water quality monitoring points offer spatially and temporally limited snapshots. To comprehensively assess ecosystem health, integrating indicators reflecting structural changes in biological communities is essential. Economically, fishery output provides a direct measure of economic dynamics pre- and post-fishing ban implementation. Socially, public acceptance and policy compliance are critical determinants for the long-term efficacy of conservation measures, as enhanced societal awareness underpins ecosystem resilience and sustainable resource management.

Table 2. Comprehensive monitoring and evaluation index system for assessing the fishing ban's efficacy in the Lower Qiantang River.

Level 1	Level 2	Level 3	Description and obtaining methods	Type
Comprehensive assessment of the fishing ban's efficacy in the Lower Qiantang River (A)	Ecological environment (B1)	Chlorophyll-a content (C1)	Chlorophyll-a (Chl-a), the primary photosynthetic pigment in phytoplankton, serves as a key indicator of algal biomass for water quality assessment [9]. Quarterly on-site sampling and subsequent laboratory quantification followed standardized protocols from Freshwater Plankton Research Methods [10], with spectrophotometric analysis conducted following ethanol extraction.	–
		Fish species richness (C2)	Fish species richness serves as a fundamental indicator of aquatic ecosystem resilience and a staple indicator in biodiversity assessments [11]. This parameter was quantified through field surveys, systematic fish market inventories, and structured stakeholder interviews with fishers during peak (May-November) and off-peak (December-April) operational seasons.	+
		Fish stock density (C3)	Fish stock density quantifies aquatic resource abundance and provides a direct measure of fishing ban restoration outcomes [1]. This indicator was determined through standardized field surveys conducted during post-spawning recruitment periods (November) to capture representative population estimates.	+
		Pielou evenness index (C4)	Pielou evenness index ($J = H'/\log S$, where H' represents the Shannon-Wiener diversity index and S denotes species richness) quantifies the uniformity of species spatial distributions within ecological communities. Values range between 0 and 1, with higher values signifying greater equitability among species. This indicator, widely applied in structural community ecology [12], was derived from systematic field surveys conducted during previously defined peak (May-November) and off-peak (December-April) seasonal periods.	+

Continued

	Shannon-Wiener diversity index (C5)	Shannon-Wiener index ($H' = -\sum_{i=1}^S P_i \log P_i$, where P_i is the proportion of the number of individuals in the i -th species), synthesizes species richness and evenness to provide a comprehensive biodiversity measure. Higher values indicate increased community structural complexity and enhanced ecosystem stability—particularly through strengthened trophic interactions and functional redundancy—establishing it as a validated tool for evaluating biodiversity conservation outcomes [13] [14]. H' values were derived from systematic field surveys during previously defined peak (May-November) and off-peak (December-April) seasons to capture community dynamics across critical periods.	+
Economic output (B2)	Economic output per vessel (C6)	This indicator quantifies the per-vessel economic value of fishery landings, reflecting enterprise-level productivity and household income capacity in small-scale fisheries [15]. It was precisely determined through FAO-compliant operational data collection, integrating systematic field observations with statistical processing of logbook records and fish ticket transactions following the FAO Statistical Reporting Framework for Capture Fisheries [16].	+
	Catch per Unit Effort (C7)	Catch per Unit Effort (CPUE) serves as a fundamental abundance index and socioeconomic indicator in fisheries management, reflecting harvesting efficiency while quantifying the relative impacts of fishing bans on fishery productivity [17] [18]. This indicator was derived through harmonized data collection protocols following the FAO Technical Guidelines for Fisheries Monitoring [19], integrating standardized field observations with statistical processing of vessel logbooks, gear deployment records, and catch verification data.	+
	Input-Output ratio (C8)	This economic efficiency ratio benchmarks resource productivity in fisheries by quantifying the value added per unit of input cost. Elevations in this indicator signal enhanced economic sustainability through improved resource stewardship [20]. Calculated as gross revenue divided by total variable costs (fuel, gear, labor), the ratio was derived from integrating standardized field observations with statistical verification of vessel-level accounting records, logbooks, and input purchase invoices following FAO Guidelines for Socioeconomic Monitoring [21].	+

Continued

Social consciousness (B3)	Fishermen's satisfaction index (C9)	These dual indices quantify stakeholder acceptance of fishing ban policies and public engagement in biodiversity conservation. The Fishermen's Satisfaction Index ($S_f(\%) = S_f / T_f \times 100$) measures sector-specific adaptation capacity, where S_f represents satisfied fishers and T_f the total surveyed fishers. Complementarily, the Community Satisfaction Index ($S_c(\%) = S_c / T_c \times 100$) assesses non-fisher stakeholder engagement, with S_c denoting satisfied community members and T_c total non-fisher respondents. Data were derived from surveys.	+
	Community satisfaction index (C10)		+
	Ecological conservation awareness index (C11)	This indicator quantifies ecological conservation awareness as the proportion of surveyed individuals supporting fishing bans. Elevated awareness correlates strongly with pro-environmental behaviors, including reduced resource exploitation, minimized ecological footprint, and enhanced pollution mitigation—collectively contributing to aquatic biodiversity conservation, ecosystem resilience, and sustainable fisheries governance.	+

“+” represents a positive indicator, “−” represents a negative indicator.

2.4. Field Survey and Measurements

Water samples were collected quarterly at 9 monitoring sites in both 2018 and 2023, followed by spectrophotometric determination of chlorophyll-a content. Fish resource surveys were conducted during peak (May–November) and off-peak (December–April) operational seasons in 2018 and 2023, with annual sampling campaigns temporally aligned across years to control for phenological variation. Each 10-day campaign documented species composition, abundance, and key biological parameters (e.g., length–weight relationships, fecundity). Sampling spanned nine spatially distributed points with 1 km river segments upstream and downstream. We employed standardized gear at all sites: drift gillnets (50 - 100 m length $\times$ 1.5 - 2 m height; 2.0 - 12 cm mesh) and shrimp traps (4.5 - 8 m length; 0.8 - 2.0 cm mesh). To account for rare species, field data with socio-ecological validation—structured interviews with fishers and verification of commercial landings at riverside piers—were supplemented.

2.5. Methods for Evaluating the Fishing Ban's Efficacy

The evaluation of the fishing ban in the Lower Qiantang River comprised two principal stages: determination of indicator weights and comprehensive evaluation. First, a hierarchical multi-factor evaluation index system was established, structured across three tiers: Level 1 (A: Comprehensive Objective), Level 2 (B1–B3: Ecological, Economic, Social Dimensions), and Level 3 (C1–C11: Specific Indicators) as detailed in **Table 2**. Subsequently, indicator weights were determined, a critical step as these weights directly influence multi-indicator comprehensive

evaluation outcomes. To integrate expert judgment with objective monitoring data, this study employed the AHP. Expert opinions were systematically gathered using pairwise comparisons, with indicator importance quantified via a standardized 1 - 9 scale [22]. AHP calculations generated the final weights, and the consistency of expert judgments was rigorously validated using the Consistency Ratio (CR), with $CR < 0.1$ confirming acceptable consistency.

2.5.1. Construction of the Judgment Matrix

Expert judgment was elicited via structured scoring to assess the relative importance of each indicator within the hierarchy. Specifically, a pairwise comparison approach was employed: experts evaluated all combinations of criteria at each hierarchical level, determining their relative influence on the corresponding upper-level objective [23]. These qualitative judgments were quantitatively scaled using the established 1 - 9 scale method (Table 3), forming the judgment matrices necessary for the AHP.

Table 3. The meaning of “1 - 9 scale” values used in AHP.

Scale value	Definition	Description
9	Extremely important	One is more important than the other extreme.
7	Much more important	One is much more important than the other.
5	More important	One is more important than the other.
3	Slightly important	One is slightly more important than the other.
1	Equally important	Two factors are equally important.
$2n, n = 1, 2, 3, 4$		The importance of element i relative to element j is between $a_{ij} = 2n - 1$ and $a_{ij} = 2n + 1$.
Inverse	Inverse comparison	If comparing factors i with j yields a_{ij} , then comparing factors j with i yields $a_{ji} = 1/a_{ij}$.

By using the defined 1 - 9 scale (Table 3) above, the elements $a_1, a_2, \dots, a_n$ could be compared pairwise to obtain the judgment matrix A for subsequent AHP calculations [24]:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

From this, the judgment matrix of each level indicator in the evaluation index system for the fishing ban's efficacy in the Lower Qiantang River was derived as shown in Table 4.

Table 4. The judgment matrix of the evaluation index system for the fishing ban's efficacy in the Lower Qiantang River.

The judgment matrix of level 1 (A)-level 2 (B1-B3)						
A-B	B1	B2	B3	$A = \begin{bmatrix} 1 & 3 & 4 \\ \frac{1}{3} & 1 & 2 \\ \frac{1}{4} & \frac{1}{2} & 1 \end{bmatrix}$		
B1	1	3	4			
B2	1/3	1	2			
B3	1/4	1/2	1			
The judgment matrix of level 2 (B1)-level 3 (C1-C5)						
B1-C	C1	C2	C3	C4	C5	$B1 = \begin{bmatrix} 1 & \frac{1}{2} & \frac{1}{3} & 2 & \frac{1}{4} \\ 2 & 1 & \frac{1}{2} & 2 & \frac{1}{3} \\ 3 & 2 & 1 & 3 & \frac{1}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{3} & 1 & \frac{1}{3} \\ 4 & 3 & 2 & 3 & 1 \end{bmatrix}$
C1	1	1/2	1/3	2	1/4	
C2	2	1	1/2	2	1/3	
C3	3	2	1	3	1/2	
C4	1/2	1/2	1/3	1	1/3	
C5	4	3	2	3	1	
The judgment matrix of level 2 (B2)-level 3 (C6-C8)						
B2-C	C6	C7	C8	$B2 = \begin{bmatrix} 1 & \frac{1}{3} & \frac{1}{2} \\ 3 & 1 & 2 \\ 2 & \frac{1}{2} & 1 \end{bmatrix}$		
C6	1	1/3	1/2			
C7	3	1	2			
C8	2	1/2	1			
The judgment matrix of level 2 (B3)-level 3 (C9-C11)						
B3-C	C9	C10	C11	$B3 = \begin{bmatrix} 1 & \frac{1}{2} & \frac{1}{4} \\ 2 & 1 & \frac{1}{3} \\ 4 & 3 & 1 \end{bmatrix}$		
C9	1	1/2	1/4			
C10	2	1	1/3			
C11	4	3	1			

2.5.2. Calculation of Indicator Weights at all Levels

Let the complementary judgment matrix $A = (a_{ij})_{n \times n}$, making $r_i = \sum_{j=1}^n a_{ij}$, $i, j = 1, 2, \dots, n$ and obtain the sets $\{r_i\}$ and $\{r_j\}$, $i, j = 1, 2, \dots, n$. Then, sum the matrix A by columns, calculate the geoindicator mean $\{\bar{R}_j\}$ of $\{r_j\}$ to perform a numerical transformation, making $R_i = \sum_{j=1}^n \bar{R}_{ij}$, $i, j = 1, 2, \dots, n$, and obtain the sets $\{R_i\}$ and $\{R_j\}$, $i, j = 1, 2, \dots, n$, which means that the complementary judgment matrix $A = (a_{ij})_{n \times n}$ was transformed into a consistent matrix $R = (r_{ij})_{n \times n}$. Finally, calculate the weight vector $W = [w_1, w_2, \dots, w_n]^T$ of the consistent matrix R , where $w_i = R_i / \sum_{j=1}^n R_j$ ($i, j = 1, 2, \dots, n$).

From this, the weight sets of A, B (B1-B3), and C (C1-C11) were obtained, with $W_A = [0.6232, 0.2395, 0.1373]^T$, $W_{B1} = [0.1063, 0.1545, 0.2584, 0.0852, 0.3956]^T$,

$W_{B_2} = [0.1638, 0.5390, 0.2973]^T$, and $W_{B_3} = [0.1374, 0.2389, 0.6237]^T$, respectively, as shown in **Table 5**. It could be observed that for the indicators at level 2, the ecological environment had the highest weight, followed by economic output and social consciousness. Among the three-level indicators, the Shannon-Wiener diversity index (C5), fish resource density (C3) (ecological indicators), and catch per unit of fishing effort (C7) (economic indicator) were identified as the top three contributors. Conversely, fishermen's satisfaction (C9) and community satisfaction (C10) were ranked lower, reflecting their relatively diminished influence on the overall evaluation.

Table 5. Overall ranking of indicator weights.

Level 3	Level 2			Overall sorting results	Arrange in order
	Ecological environment (B ₁)	Economic output (B ₂)	Social consciousness (B ₃)		
	0.6232	0.2395	0.1373		
Chlorophyll-a content (C1)	0.1063			0.0663	7
Fish species richness (C2)	0.1545			0.0963	4
Fish stock density (C3)	0.2584			0.1610	2
Pielou evenness index (C4)	0.0852			0.0531	8
Shannon-Wiener diversity index (C5)	0.3956			0.2465	1
Economic output per vessel (C6)		0.1638		0.0392	9
Catch per Unit Effort (C7)		0.5390		0.1291	3
Input-Output ratio (C8)		0.2973		0.0712	6
Fishermen's satisfaction index (C9)			0.1374	0.0189	11
Community satisfaction index (C10)			0.2389	0.0328	10
Ecological conservation awareness index (C11)			0.6237	0.0856	5

2.5.3. Consistency Testing

To validate matrix consistency, a two-step approach was employed. First, calculate CI of matrix $R = (r_{ij})_{n \times n}$, making $CI = (\lambda_{\max} - n) / (n - 1)$, where $\lambda_{\max}$ denotes the largest eigenvalue of matrix R , calculated as $\lambda_{\max} = \left(\sum_{i=1}^n AW_i / w_i \right) / n$, and AW represents the matrix product of the original judgment matrix A and weight vector $W = [w_1, w_2, \dots, w_n]^T$. Then, calculate CR of matrix R , making $CR = CI / RI$, where RI is the Random Index value from published standards for matrix order n [22]. A $CR < 0.10$ indicates satisfactory consistency, confirming logical coherence in expert judgments. As shown in **Table 6**, all hierarchical comparison matrices demonstrated satisfactory consistency ($CR < 0.10$), validating their use in subsequent analyses.

Table 6. Hierarchical order list.

	A-B	B1-C	B2-C	B3-C
$\lambda_{\max}$	3.0183	5.1634	3.0092	3.0092
CI	0.0092	0.0409	0.0056	0.0112
RI	0.58	1.12	0.58	0.58
CR	0.0158	0.0365	0.0096	0.0193
Consistency test results	satisfaction with consistency	satisfaction with consistency	satisfaction with consistency	satisfaction with consistency

2.5.4. Comprehensive Evaluation of Indicators at all Levels

In order to make the evaluation results more scientific and objective, this study set the indicator values as positive and negative. Positive indicators are directly proportional to the effect of the fishing ban, whereas negative indicators show an inverse relationship. To eliminate the influence of different data scales, a benchmark value was selected to normalize the raw data before calculating the comprehensive evaluation index. This transformation converts the data into standardized values without scale differences. Based on the attributes and characteristics of the indicators used in this study, the specific gravity method was chosen for data normalization as follows:

$$I_{ijt} = \begin{cases} C_{ijt}/C_{ij0}, & \text{when } C_{ij} \text{ is a positive indicator;} \\ C_{ij0}/C_{ijt}, & \text{when } C_{ij} \text{ is a negative indicator} \end{cases}$$

where I_{ijt} is the dimensionless rating coefficient of indicator C_{ij} in year t , C_{ijt} is the value of indicator C_{ij} in year t , C_{ij0} is the reference benchmark value of indicator C_{ij} . In the absence of nationally standardized thresholds, C_{ij0} was derived by using the dataset geometric mean (specifically: annual monitoring averages across 2018 and 2023 sampling sites). This approach minimizes skewness from extreme values common in ecological datasets.

Based on $\{I_{ijt}\}$ and the weight vector W , the comprehensive assessment index I was calculated by using the formula $I = \sum_{i=1}^n I_i \times W_i$.

3. Results

3.1. Monitoring and Investigation Results of Fishing Ban's Efficacy

Comparative monitoring outcomes across equivalent seasonal periods reveal distinct pre- (2018) and post-implementation (2023) effects of fishing restrictions in the Lower Qiantang River, as quantified through the eleven ecological-economic-social indicators detailed in **Table 7**.

3.2. Comprehensive Assessment Index

Standardization of indicator values was achieved using the specific gravity method, eliminating scale differences (**Table 8**). Subsequent application of our integrated assessment framework revealed significant improvement in the Lower Qiantang

River’s ecological and socioeconomic conditions following fishing bans. The comprehensive assessment index increased from 0.88 (2018 pre-ban baseline) to 1.16 (2023 implementation phase), representing a 31.67% enhancement. This quantifiable progression demonstrates successful policy implementation.

Table 7. The monitoring and investigation results and changes in indicators.

Indicators	Units	2018	2023	Changes
Chlorophyll-a content (C1)	$\mu\text{g}\cdot\text{L}^{-1}$	3.24 ± 0.42	2.21 ± 0.33	↓ 31.72
Fish species richness (C2)		51.00 ± 2.00	72.00 ± 3.00	↑ 41.18
Fish stock density (C3)	$\text{ind}\cdot\text{m}^{-3}$	0.008 ± 0.002	0.012 ± 0.003	↑50.00
Pielou evenness index (C4)		0.88	0.66	↓24.49
Shannon-Wiener diversity index (C5)		2.69	2.77	↑2.97
Economic output per vessel (C6)	$\text{\$}\cdot\text{vessel}^{-1}$	363.00 ± 56.23	995.59 ± 103.49	↑174.27
Catch per Unit Effort (C7)	$\text{kg}\cdot(\text{vessel}\cdot\text{d}^{-1})^{-1}$	10.02 ± 1.24	15.78 ± 1.78	↑57.48
Input-Output ratio (C8)		5.78 ± 1.00	8.75 ± 1.09	↑51.38
Fishermen’s satisfaction index (C9)	%	95.20	90.80	↓4.62
Community satisfaction index (C10)	%	89.10	93.40	↑4.83
Ecological conservation awareness index (C11)	%	70.00	100.00	↑42.86

Table 8. Evaluation of the fishing ban’s efficacy in the Lower Qiantang River.

Indicators	weights (W_i)	Benchmark value	Normalized indicator value (I_i)		$I_i \times W_i$	
			2018	2023	2018	2023
Chlorophyll-a content (C1)	0.0663	2.68	0.83	1.21	0.05	0.08
Fish species richness (C2)	0.0963	60.60	0.84	1.19	0.08	0.11
Fish stock density (C3)	0.1610	0.01	0.82	1.22	0.13	0.20
Pielou evenness index (C4)	0.0531	0.76	1.15	0.87	0.06	0.05
Shannon-Wiener diversity index (C5)	0.2465	2.73	0.99	1.01	0.24	0.25
Economic output per vessel (C6)	0.0392	601.17	0.60	1.66	0.02	0.06
Catch per Unit Effort (C7)	0.1291	12.57	0.80	1.25	0.10	0.16
Input-Output ratio (C8)	0.0712	7.11	0.81	1.23	0.06	0.09
Fishermen’s satisfaction index (C9)	0.0189	92.97	1.02	0.98	0.02	0.02
Community satisfaction index (C10)	0.0328	91.22	0.98	1.02	0.03	0.03
Ecological conservation awareness index (C11)	0.0856	83.67	0.84	1.20	0.07	0.10
Comprehensive assessment index (I)					0.88	1.16

4. Discussion

4.1. Assessment Results of the Five-Year Fishing Ban's Efficacy

The Qiantang River fishing ban has demonstrated significant efficacy in augmenting fishers' revenues while advancing ecological resource sustainability [1] [2] [25]. For example, Zhang *et al.* [1] utilized hydroacoustic surveys to demonstrate that the 2019 four-month ban significantly enhanced core fish resource indicators—including density, biomass, and size structure—while shifting pelagic species distributions towards greater ecological equilibrium. Ge [2] integrated field sampling with questionnaire data to document increased post-ban catches, juvenile fish abundance, and fish community complexity. Here, monitoring and survey data indicate significant improvements across nine key ecological, economic, and social indicators. For instance, Chlorophyll-a content decreased by 31.72% (from $3.24 \pm 0.42 \mu\text{g}\cdot\text{L}^{-1}$ to $2.21 \pm 0.33 \mu\text{g}\cdot\text{L}^{-1}$), fish species richness increased by 41.18% (from 51 ± 2.00 to 72 ± 3.00 species), and fish stock density rose by 50.00% (from $0.008 \pm 0.002 \text{ ind}\cdot\text{m}^{-3}$ to $0.012 \pm 0.003 \text{ ind}\cdot\text{m}^{-3}$). These findings align strongly with previous research.

However, in contrast to other indicators, the Pielou evenness index exhibited a declining trend. This divergence is likely attributable to two factors: 1) heightened heterogeneity in species abundance driven by colonization pressures from invasive and rare species, and 2) selective fishing practices following the ban, which may have intensified interspecific resource competition. Fisher satisfaction represents another negatively impacted indicator, showing a small but notable decline of 4.62%. The four-month annual seasonal fishing ban directly disrupts livelihoods, as fishers previously generated income year-round but now face complete income loss during the closure period. Compounding this, older fishers with limited formal education constitute a vulnerable demographic—their diminished capacity to secure alternative short-term employment often eliminates household income streams during the ban. This socioeconomic vulnerability manifests as significantly reduced quality of life, resulting in diminished fisher satisfaction. Implementing the fishing quota system and establishing subsidies for fisherman retraining as well as ecological compensation funds might be important measures to improve the values of these two indicators.

By using the method of system analysis, a comprehensive assessment of the fishing ban's efficacy for the Lower Qiantang River based on multiple indicators was also conducted. The comparison of the comprehensive evaluation index is shown in Table 8, showing that over the five-year ban (2018-2023), the index increased from 0.88 to 1.16 (+31.67%). This improvement reflects continuously improved water quality, a certain degree of restoration of the aquatic ecosystem, and the continuous enhancement of the public's awareness of ecological protection, aligning with the broader goal of sustainable fisheries development and providing a robust theoretical foundation for future policy iterations.

Due to the implementation of the ongoing annual fishing ban (March 1-June 30), this evaluation was mainly a phased evaluation, and further strengthening is

needed for continuous tracking, monitoring, and evaluation in the future.

4.2. Selection of Evaluation Indicators in the Assessment System

The structural-functional indicator method offers a comprehensive selection of indicators, incorporating ecological, economic, and social factors. This approach enhances the evaluation's accuracy and intuitiveness by reflecting the actual impacts of fishing bans more precisely. Currently, limited research has been conducted on applying this method to assess fishing ban effectiveness in natural waters. The indicator system proposed in this study integrates indicators from previous studies [6] [25] while incorporating freshwater ecosystem characteristics and long-term data from our research group. Ultimately, 11 representative indicators were selected through comprehensive analysis, categorized into ecological, economic, and social benefits.

Notably, this system diverges from Lu's [25] Qiantang River fishing ban evaluation framework. Here, Catch per Unit Effort serves as an economic indicator, chlorophyll *a* represents ecological health, and novel indicators such as the Pielou evenness index, input-output ratio, and ecological protection awareness were introduced. Conversely, the indicator number of dominant fish species was removed due to its limited comparability across studies.

This article is an attempt to study the fishing ban's efficacy in freshwater areas based on the Analytic Hierarchy Process, and the result may be confounded by covarying restoration measures (e.g., artificial stock enhancement, water quality remediation) and remain vulnerable to climate-driven hydrological alterations. The indicator system adopted in this article still needs further research and improvement.

5. Conclusions

This study evaluated the fishing ban's efficacy in the Lower Qiantang River using a comprehensive monitoring and assessment framework. Research was conducted at two key temporal points: 2018 (baseline; pre-ban implementation) and 2023 (post-restoration; 5 years post-ban). A three-level monitoring and evaluation index system was constructed, which involved the three critical indicator domains: ecological environment, economic output, and social consciousness, and included eleven specific indicators (Chlorophyll-*a* content, fish species richness, fish stock density, Pielou evenness index, Shannon-Wiener diversity index, economic output per vessel, Catch per Unit Effort (CPUE), input-output ratio, fishermen's satisfaction index, community satisfaction index, and ecological conservation awareness index). Then, the fishing ban effect was evaluated by developing a model based on the analytic hierarchy process. The evaluation methods adopted here considered the principles of scientificity, sensitivity, operability, comprehensiveness, and a combination of quantitative and qualitative methods, further improving the theoretical and methodological system for evaluating the fishing ban's efficacy.

Hierarchical evaluation revealed significant improvements in nine key ecological, economic, and social indicators by 2023. For instance, Chlorophyll-a content decreased by 31.72% (from $3.24 \pm 0.42 \mu\text{g}\cdot\text{L}^{-1}$ to $2.21 \pm 0.33 \mu\text{g}\cdot\text{L}^{-1}$), fish species richness increased by 41.18% (from 51 ± 2.00 to 72 ± 3.00 species), and fish stock density rose by 50.00% (from $0.008 \pm 0.002 \text{ ind}\cdot\text{m}^{-3}$ to $0.012 \pm 0.003 \text{ ind}\cdot\text{m}^{-3}$). The comprehensive fishing ban effect index for the Lower Qiantang River (see **Table 4**) demonstrated a significant increase from 0.88 in 2018 to 1.16 in 2023, reflecting an improvement of 31.67%. These results collectively indicate enhanced water quality, partial restoration of the aquatic ecosystem, and increased public awareness of ecological protection following the ban implementation. The findings align with broader sustainable fisheries development goals and provide a valuable empirical foundation for future policy refinement. However, this study represents a phase-specific evaluation; continuous, long-term monitoring and assessment are required to fully gauge the enduring impact of the ban.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Zhang, A., Luo, W., Wang, J. and Zhou, Z. (2021) The Time-Area Fishing Closure Impacts on Fish Stock; Qiantang River before and after a Four-Month Fishing Closure. *Acta Ichthyologica et Piscatoria*, **51**, 349-356. <https://doi.org/10.3897/aiep.51.63815>
- [2] Ge, J.J. (2021) The Current Status of Fishery Resources in Qiantang River (Lan-Xi-Fuyang Section) and Preliminary Evaluation of the Effects of Fishing Bans. Ph.D. Thesis, Ningbo University. (In Chinese)
- [3] Saaty, T.L. (1980) The Analytic Hierarchy Process. McGraw-Hill.
- [4] Yadav, A., Kansal, M.L. and Singh, A. (2024) Land Use and Land Cover Dynamics in the Upper Ganga Riverine Wetland: Unraveling Ecosystem Services over Two Decades. *Environmental Monitoring and Assessment*, **196**, Article No. 590. <https://doi.org/10.1007/s10661-024-12748-2>
- [5] Zhou, R., Zhang, Y., Peng, S., Wang, Y., Dai, M., Hong, N., *et al.* (2025) Assessment of Wetland Ecological Restoration Effect Based on Fuzzy Analytic Hierarchy Process: A Case Study of Tianjin Qilihai Wetland. *Environmental Monitoring and Assessment*, **197**, Article No. 131. <https://doi.org/10.1007/s10661-024-13563-5>
- [6] Chen, S. (2020) Performance Evaluation of Fishing Ban in Shenzhen Bay Based on Analytic Hierarchy Process (AHP). Ph.D. Thesis, Shanghai Ocean University. (In Chinese)
- [7] Hao, Y.B., Liu, J.D., Zhang, A.J., and Guo, A.H. (2017) Current Status of Fishery Resources in Downstream Section of Qiantang River. *Acta Agriculturae Zhejiangensis*, **29**, 1620-1629. (In Chinese)

- [8] Munir, R., Muneer, A., Sadia, B., Younas, F., Zahid, M., Yaseen, M., *et al.* (2024) Biochar Imparted Constructed Wetlands (CWS) for Enhanced Biodegradation of Organic and Inorganic Pollutants along with Its Limitation. *Environmental Monitoring and Assessment*, **196**, Article No. 425. <https://doi.org/10.1007/s10661-024-12595-1>
- [9] Zhang, X., Gao, S., Ji, X.L., Yang, H.Q., Zhu, X.M. and Zhen, J.J. (2024) Sea Surface Phytoplankton Distribution in the Pearl River Estuary in 2021 Based on SCHISM-CoSiNE Model. *Marine Forecasts*, **41**, 89-102.
- [10] Zhang, Z.S. and Huang, X.F. (1991) Methods for Studying Freshwater Plankton. Science Press. (In Chinese)
- [11] Leroy, B., Bellard, C., Dias, M.S., Hugueny, B., Jézéquel, C., Leprieux, F., *et al.* (2023) Major Shifts in Biogeographic Regions of Freshwater Fishes as Evidence of the Anthropocene Epoch. *Science Advances*, **9**, eadi5502. <https://doi.org/10.1126/sciadv.adi5502>
- [12] Ling, Q.F. and Li, S.F. (1998) Species Diversity of Fish Communities in the Former Swan Island Channel of the Yangtze River. *Chinese Journal of Aquatic Sciences*, **5**, 1-5. (In Chinese)
- [13] Oyeku, O.G., Anyale, O.O., Akindele, E.O., Atobatele, O.E. and Adeniyi, A.V. (2023) Biological Water Quality of an Impaired Tropical River: The Macrozoobenthos Approach. *Biologia*, **78**, 2131-2145. <https://doi.org/10.1007/s11756-023-01346-1>
- [14] Witwisitpong Maneechan, and Taeng On Prommi, (2022) Diversity of Edible Aquatic Insects Inhabiting Rice Fields in Central Thailand. *Inland Water Biology*, **16**, 1-9. <https://doi.org/10.1134/s199508292301008x>
- [15] Yao, W.Z., Shu, S.Q., Xiong, B., Pu, J., Jia, S., Shun, F.L. and Wang, H.B. (2013) The Production and Life of Fishermen in the Jiangjin Section of the Upper Yangtze River and Its Inspirations to the Management of Nature Reserve of Fishes. *Fishery Information and Strategy*, **28**, 192-198. (In Chinese)
- [16] Food and Agriculture Organization of the United Nations (FAO) (2022) Standard Specifications for the Marking and Identification of Fishing Vessels: FAO Statistical Reporting Framework for Capture Fisheries. Fisheries and Aquaculture Circular No. 1174, Rev. 2. FAO.
- [17] Duan, X.B., Liu, S.P., Xiong, F., Chen, D.Q., Yang, R.H., Chi, C.G. and Mu, T.L. (2008) Analysis of Fishing Structure and Biodiversity in the Upper Mainstream of the Yangtze River before and after Three Years Spring Fishing Off. *Resources and Environment in the Yangtze Basin*, **6**, 878-885. (In Chinese)
- [18] Zhou, J.W., Huang, J.X. and Wang, Q.Z. (2016) Assessment on Achievements of Summer Fishing Ban in Coastal Fishing Grounds in Northern Beibu Gulf, 2015. *Fishery Information and Strategy*, **31**, 132-138. (In Chinese)
- [19] Food and Agriculture Organization of the United Nations (FAO) (2023) Technical Guidelines for Fisheries Monitoring: Principles and Methodologies. FAO Fisheries and Aquaculture Technical Paper No. 688.
- [20] Asche, F., Garlock, T.M., Anderson, J.L., Bush, S.R., Smith, M.D., Anderson, C.M., *et al.* (2018) Three Pillars of Sustainability in Fisheries. *Proceedings of the National Academy of Sciences of the United States of America*, **115**, 11221-11225. <https://doi.org/10.1073/pnas.1807677115>
- [21] Food and Agriculture Organization of the United Nations (FAO) (2021) Guidelines for Socioeconomic Monitoring in Coastal Fisheries and Aquaculture. Fisheries and Aquaculture Circular No. 1185. FAO.
- [22] Saaty, T.L. (2000) Fundamentals of Decision Making and Priority Theory with the

Analytic Hierarchy Process. RWS Publications.

- [23] Zhang, Z., Wang, Z., Li, G., Zhao, M. and Li, W. (2024) The Suitability Assessment on Site Selection for Bottom-Seeding Scallop Culture Based on Analytic Hierarchy Process. *Journal of Oceanology and Limnology*, **42**, 647-663.
<https://doi.org/10.1007/s00343-023-2389-x>
- [24] Saaty, T.L. (1972) An Eigenvalue Allocation Model for Prioritization and Planning. Energy Management and Policy Center, University of Pennsylvania, 28-31.
- [25] Lu, Y.P. (2024) Construction and Application of Evaluation System of Fishing Ban in Inland Waters of Zhejiang Province. Ph.D. Thesis, Yangtze University. (In Chinese)