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環境生態指標之應用–以北港溪爲例

Application of Environmental Indicators to Improve Bei-Gang River Environment in Taiwan

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摘 要

環境指標在河川環境相關管理上扮演重要的角色，其可幫助描述生態系統的變化與趨勢，並在某種空間與時間尺度下，診斷環境劣化問題的原因。爲了客觀評估環境狀況，本研究綜合應用不同層級的生物指標與環境狀況指標，提出適用於台灣的河川環境狀況分析方法，並以烏溪上游北港溪爲例，以瞭解河川環境劣化原因並進一步提出改善河川環境的建議。根據生態調查與指標呈現成果，北港溪研究河段中造成縱向連續性阻絕的結構物大旗堰應以建立魚道的方式做爲復育手段。本研究說明此環境指標爲一可用工具，可作爲台灣河川環境改善復育工作的有效輔助。

關鍵詞：環境指標，河川復育，棲地。

ABSTRACT

Ecological indicators play an important management role by helping characterize status and trends in ecological systems and diagnose causes of declining condition across a range of spatial and temporal scales. To better assess rivers and streams in Taiwan and encourage the nationwide applicability of a suite of environmental indicators, Bei-Gang River was chosen as a case study to determine how the environment of Bei-Gang River was degrading and how to possibly improve the river condition. The results of ecological survey and application of indicators indicated that the longitudinal connectivity could be improved by fishway passage construction. This study demonstrates a useful tool to give direction to mitigation efforts for improving river environment of future applications in Taiwan.

Keywords: Environmental Indicators, River Restoration, Aquatic habitat.

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I. Introduction

Over the last few decades there has been increasing concern about human impacts on river ecosystems. The increasing necessity to restore rivers and streams has made a priority in putting environmental policy into practice (Gore and Shields, 1995; Wohl *et al*., 2005; Peter, 2006). River restoration work requires an understanding of the structure and functions of stream ecosystems and the physical, chemical, and biological processes that shape them (USDA, 2001). It should include proposing indicators for characterizing an ecological system and devising diagnostic and surveillance procedures and techniques; predicting the possible effects of alternative human activities on ecological systems in different scenarios; specifying action plans to steer an ecosystem toward its desired state; and initiating the development of specific scientific research in response to both observed and resulting problems (Gosselin, 2008).

Improved linkage between physical characteristics of rivers and biological performance or potential is a recurrent theme in contemporary river management (Clifford *et al*., 2006). Ecological indicators are one of the linkages primarily used either to assess the condition of the environment (e.g., as an early-warning system) or to diagnose the cause of environmental change (Dale & Beyeler 2001). The information gathered by ecological indicators can also be used to forecast future changes in the environment, to identify actions for remediation, or, if monitored over time, to identify changes or trends in indicators (Niemi *et al*., 2004). There is a large array of ecological indicators available for application to environmental problems. However, selecting appropriate ones that will provide convincing scientific underpinnings for management and policy decisions on real world problems is a challenge (Dale & Beyeler 2001).

In Taiwan, river restoration is gaining force among scientific discourse. Using indicators to understand the environmental conditions and disturbances in the rivers and streams has received increased attention (Lai *et al*., 1994; Hsu and Yang, 1997; Liang *et al*., 1997; Chu 2005; Hu *et al*., 2007). However, lack of integration and widespread application has hindered further progress of river management (Chen *et al*., 2006).

In a previous study (Hu *et al*., 2007), a suite of environmental indicators and an evaluation procedure were developed in a three-year project, to establish a tool for examining river conditions nationwide. This assessment tool was one of the first in Taiwan to measure river integrity as a whole and provides an easily understood, common language for ecologists and engineers. However, to better assess rivers and streams in Taiwan and establish the applicability of these indicators on a national level, tests of the indicators' ability to accurately characterize stream condition in more rivers are needed. More practical case studies would enhance its interdisciplinary validation and show the relevance of this procedure for river assessment and management.

The objectives of this study were to test the indicators' applicability by using Bei-Gang River as a case study to determine the environmental condition and the possible cause of river degradation; and suggest restoration solutions in order to improve river environment, as an aid to decision making.

II. Method

2.1 Study Area

The Bei-Gang River originates from the west side of He-Huan mountain and is a tributary of the Wu River in central Taiwan (Figure 1). It is 63.9 km long, flows towards the west, and converges with Nan-Gang River at Guo-Hsin Township. It drains a basin of 535.1 km^2 mainly in Nan-Tou

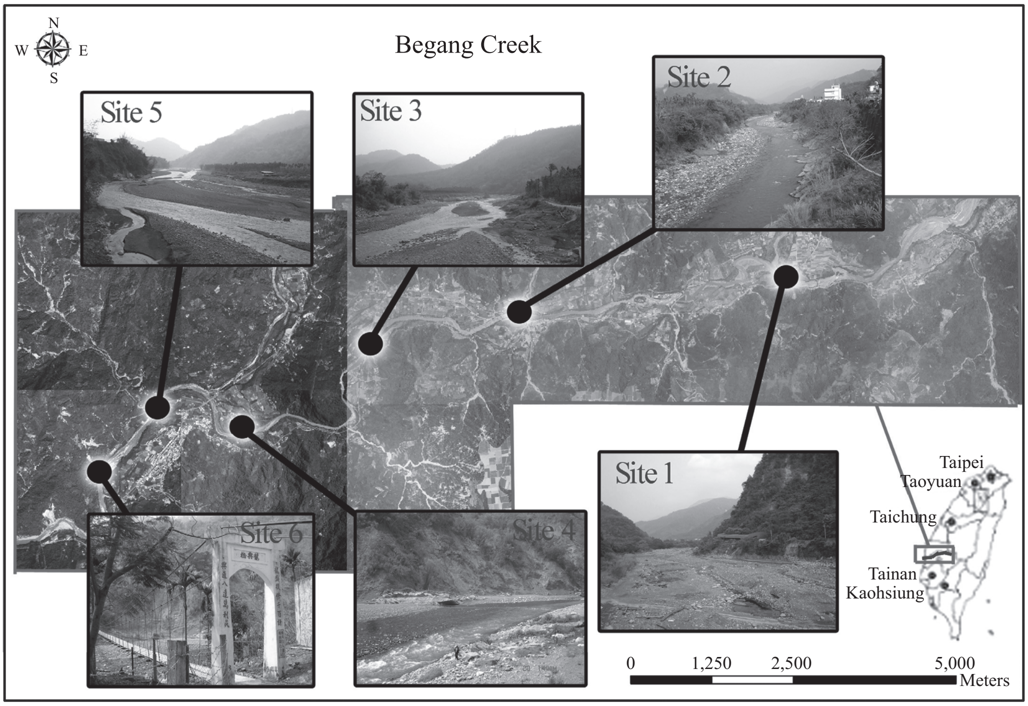


Figure 1 Study area and sampling sites

County with major land use of agriculture. The annual average temperature is about 20.7ºC, and the average yearly rainfall is around 2210 mm. The average slope is steep (1/60), and the average substrate diameter is 150-250 mm. Along the Bei-Gang River, a 4.5 m high and 90 m long concrete structure, Da-Chi Dam, is located in Da-Chi village. It was completed in 1997 to meet expanded water demand in the Bei-Gang basin. It was designed to provide a water supply of 0.6 tons per day and is expected to expand to 43.2 tons in 2011 (Hsu, 2002). In the summer 2004, a major tropical typhoon hit central and south Taiwan with heavy rainfall of up to 1600 mm within four days, and damaged the Da-Chi Dam causing a severe breach about 2 m long, 2.5 m wide, and 1.5 m deep on the crest.

2.2 Field Survey

We conducted a field survey at six sites along the Bei-Gang River. Da-Chi Dam is located at site 4 (Figure 1). We did sampling, including physico-chemical, physical, and biological measurements, four times (April, June, August, and October) in 2006.

We analyzed water samples for turbidity, dissolved oxygen, pH, total phosphorus, and conductivity. Physical characterization included docu mentation of general land use, qualitative description of stream condition, summary of the riparian vegetation features, and measurements of instream habitat, including width, depth, flow, and substrate.

For biological measurements, we collected the fish, benthic macroinvertebrates, and algae assemblages. These assemblages with different life spans may respond differently to certain stressors and help understand the ecosystem.

We collected fish for 100 m on one side of each sampling site using an electrofisher (8 A/12 V). Plastic baskets were used to collect the sucker fish. Collected fish were held in aerated buckets for

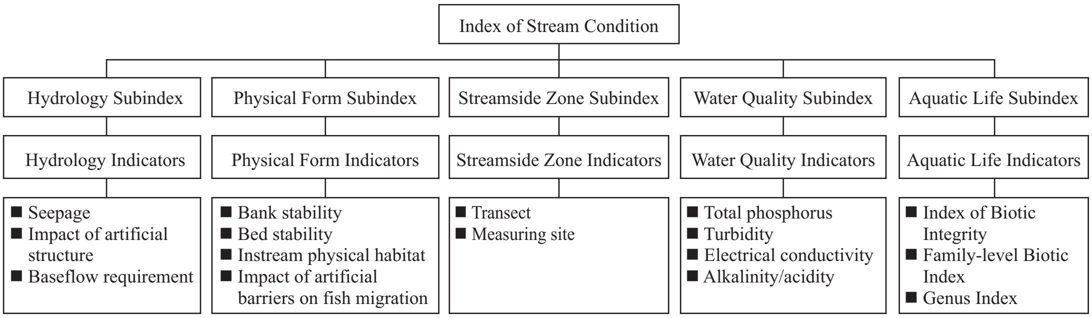


Figure 2 Modified indicators in five sub-indices (i.e. hydrology, physical form, streamside zone, water quality, and aquatic life) used to assess the environmental condition. The maximum of each sub-index is 10

identification, enumeration, and fish length measurements, and returned to the stream after all collections were completed. We sampled benthic macroinvertebrate assemblages beginning at the downstream boundary of each site and proceeded upstream using a Suber net sampler within the 100 m reaches by collecting three jabs. Samples were preserved in 10% formalin for identification. Each organism was identified to family level. Algae were collected from cobbles or boulders randomly sorted from each site. A tooth brush was used to remove diatom films from an area of ca. 100 cm^2 on cobbles or boulders. After dissolving and filtering, specimens are preserved in a 3-5% formalin solution for subsequent laboratory identification.

2.3 Indicators Application

Hu *et al*. (2007) had developed a suite of ecological indicators to fit the unique environment of Taiwan and suggested that more case studies could establish its applicability. In this paper, these indicators were further used to address the integrity of the system as an ecological whole, as well as each component part. Three biotic indices, the modified Index of Biotic Integrity (IBI index) for fish (Karr, 1991), Hilsenhoff's Family-level Biotic Index (FBI) for aquatic insects (Hilsenhoff 1998, and the Genus Index (GI) of algae (Wu, 1999; Wu and Kow, 2002) were combined with modified Index of Stream Condition, i.e. ISC (Ladson *et al*., 1999, Hu *et al*., 2007) to describe the overall river condition. IBI, FBI, and GI were obtained based on the field surveys. The framework of the modified ISC is shown in Figure 2. It was developed based on review of previous assessment methods, interview with experts with knowledge of different fields, and discussion with WRA to make it reliable. Seventeen indicators in the modified-ISC were used to quantify aspects of stream condition. Related indicators made up each sub-index, i.e. hydrology, physical form, streamside zone, water quality, and aquatic life. The indicators in physical form and water quality were kept the same as the original ISC, while those in hydrology, streamside zone, and aquatic life were modified. The overall ISC score is the sum of sub-index scores and is between 0 and 50, the higher scores indicating better condition (Hu *et al*., 2007).

III. Results

Results of water quality measurements are given in Table 1. Turbidity measured at the six sites was mostly higher than 300 NTU. Measurements of the average composition of the substrates are presented in Figure 3. The average substrate diameter at site 1 was the coarsest.

Table 1 Water quality results at six sampling sites along Bei-Gang River in April, June, August and October 2006

Site	Month	Water temperature (°C)	Air temperature (°C)	DO (mg/l)	Electrical conductivity (µs/cm)	pH	Turbidity (NTU)	TP (mg/l)
st 1	April	24.6	31.6	8.9	405	7.8	759	0.3447
	June	25.5	31.9	8.6	119	7.1	395	0.0967
	August	23.9	30.9	7.4	303	8.2	508	0.2210
	October	23.2	29.0	8.3	291	7.4	474	0.2281
st 2	April	23	32.6	8.7	394	7.9	726	0.3398
	June	25.6	35.3	8.4	424	7.2	424	0.1075
	August	25.9	32.7	8.5	241	8.2	409	0.2022
	October	25.5	31.5	8.1	212	7.1	172	0.2123
st 3	April	23	32.1	8.7	401	8.8	664	0.2921
	June	25.7	30.7	8.5	292	7.4	80	0.0675
	August	26	34.3	8.4	213	7.2	376	0.2320
	October	24.7	33.7	7.0	301	8.1	429	0.2149
st 4	April	22.6	27.6	9.0	404	8.3	541	0.3661
	June	26.1	35.8	8.8	202	7.2	344	0.0782
	August	26.7	31.8	8.6	386	8.1	474	0.2560
	October	26.1	32.0	7.8	293	7.2	106	0.2054
st 5	April	24.5	32.7	8.1	578	8.6	589	0.3135
	June	27.2	32.0	8.1	201	7.2	374	0.2074
	August	26.9	29.1	8.0	401	7.8	545	0.2413
	October	28.1	31.3	8.1	308	7.3	43	0.2016
st 6	April	21.4	36.2	8.5	393	8.3	880	0.3546
	June	26.5	31.2	8.5	203	7.0	300	0.1275
	August	28	29.6	7.1	422	8.1	444	0.2312
	October	26.8	29.8	7.9	303	7.2	48	0.2192

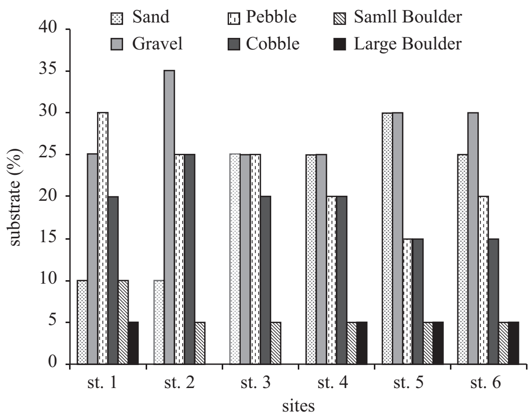


Figure 3 Substrate composition at each site along Bei-Gang River

In the ecological survey (Table 2), ten fish species were identified. Eight of these are endemic to Taiwan. From the survey results, the distribution of fish did not seem to be influenced by the dam structure which is located at site 4. For instance, an endangered species, Sinogastromyzon puliensis (Cypriniformes, Homalopteridae; Liang, 1974; TESRC, 1996) was found at both upstream (site 3) and downstream (site 6) of Da-Chi Dam. Six orders, eleven benthic macroinvertebrates families, and 22,174 individuals of algae identified to 14 genus and 28 species were found. Because of high sediment concentration, algal samples collected very few organisms on boulders or cobbles at some sites. Table 3 shows the numbers of species found at each site and indicated a slight difference among sites.

Table 2 Results of biotic survey (numbers of different species) collected at each site along Bei-Gang River during the study period

	Fish					
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Cobitis sinensis	0	0	0	0	0	1
Acrossocheilus paradoxus	4	4	1	0	5	3
Condidia barbatus	0	0	0	0	0	2
Hemimyzon formosanum	9	9	15	2	4	10
Crossostoma lacustre	0	5	2	3	4	2
Rhinogobius candidianus	0	5	0	2	2	11
Sinogastromyzon puliensis	0	0	4	0	0	11
Zacco pachycephalus	1	9	2	2	4	6
Pseudobagrus brevianalis brevianalis	21	7	9	4	11	3
Varicorhinus barbatulus	1	1	1	0	0	0
	Macroinvertebrate					
Baetidae	0	8	7	8	5	6
Ephemeridae	0	0	0	0	1	0
Heptageniidae	0	0	0	0	1	0
Hydropsychidae	13	15	43	55	46	18
Philopotamidae	1	0	0	0	0	0
Perlidae	1	2	0	1	0	0
Ptilodactylidae	0	0	0	0	0	3
Hydrophilidae	0	0	0	0	0	2
Corydalidae	2	0	1	0	1	0
Chironomidae	0	0	0	2	0	2
Tipulidae	0	0	0	0	1	0
	Algae					
Anabaena sp.1	0	2	0	0	0	0
Lyngbya sp.1	122	178	64	120	0	492
Oscillatoria sp.1	0	10	0	0	0	0
Achnanthes sp.1	0	48	4	0	0	0
Cymbella sp.1	68	146	18	34	588	120
Cocconeis sp.1	56	90	36	34	44	74
Fragilaria sp.1	96	140	74	114	102	936
Gomphonema sp.1	12	842	24	106	846	502
Gomphonema sp.2	216	406	62	268	548	408
Gyrosigma sp.1	0	42	14	0	0	0
Melosira sp.1	90	50	44	38	0	56
Navicula sp.1	0	578	40	36	92	172
Navicula sp.2	274	728	156	136	582	424
Navicula sp.3	58	406	62	56	46	286
Navicula sp.4	152	84	8	64	106	84
Nitzschia sp.1	448	1266	506	830	478	658
Nitzschia sp.2	0	112	0	0	0	0
Nitzschia sp.3	28	930	212	504	1380	194
Rhopalodia sp.1	0	18	0	0	0	0
Synedra sp.1	14	14	0	46	950	114
Characium sp.1	0	4	0	0	0	4
Chlamydomonas sp.1	0	0	0	0	0	50
Closterium sp.1	0	0	0	0	18	0
Cosmarium sp.1	6	14	0	0	6	0
Oedogonium sp.1	20	20	10	0	48	0
Scenedesmus sp.1	0	4	0	0	0	0
Spirogyra sp.1	6	0	48	26	0	114
Stigeoclonium sp.1	24	64	4	28	36	124

Table 3 Number of species collected at each site along Bei-Gang River during the study period

	No. of species					
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
fish	5	7	7	5	6	9
Macroinvertebrate	4	3	3	4	6	5
Algae	17	25	18	16	16	18

For each site and each time, we calculated the modified-IBI, FBI, and GI from the survey data (Table 4). An asterisk (*) indicates sites and times were samples collected few organisms, no values could be calculated. The modified-IBIs were lowest in June at all sites except site 2. This difference for site 2 resulted from the higher score for insectivorous, like Pseudobagrus brevianalis, which was collected in the June sample. The average score of site 2 was 'moderately impaired', while those of the others were 'slightly impaired'. Generally, the modified-IBI for site 3 was greatest among the six sites. FBI values did not vary much over time and space. However, no macroinvertebrates were collected in the June samples. The average scores for GI rated the sites as severely polluted on the basis of algae, except site 6, which was rated as moderately polluted. We tried to understand if there was any relationship between turbidity and the observed assemblages or the calculated indices to explain the condition. However, no significant connection could be found as shown in Figure 4. The integrated performance of aquatic life equally weights the fish, macroinvertebrate, and algae indices. As a result, site 3 and site 6 exhibited relatively good conditions during our surveys in 2006.

In the modified ISC (Figure 5), site 1 performed the best among all the six sites. In overall condition, both the hydrology and physical form sub-indices scored 7.5. The streamside zone sub-index scored 8.67, indicating both width of streamside zone and longitudinal continuity rated high. Water quality and aquatic life sub-indices, with score of 5.89 and 4.02 respectively, were the lowest two, suggesting that Bei-Gang River's overall physiochemical status is worse than physical condition. As a whole, ISC value is 33.57, evaluated as marginal B level.

IV. Discussion and Conclusion

Environmental indicators play an important management role by helping characterize status and trends in ecological systems and causes of declining condition across a range of spatial and temporal scales (Dale & Beyeler 2001; Niemi *et al.*, 2004). An established suite of environmental indicators (Hu *et al.*, 2007) for examining river conditions and suggesting restoration solutions in Taiwan was used in this study to test its applicability and help improving the Bei-Gang River in central Taiwan. The combined use of fish, benthic macroinvertebrates, and algae with their corresponding indices, IBI, FBI, and GI, as a monitoring tool was applied for quantitative assessments of community structure. The modified ISC further guides river managers in their selection of restoration strategies.

Due to its special geographical, geological, and hydrological characteristics, Taiwan frequently encounters typhoons and earthquakes. Its natural setting creates highly vulnerable watersheds whose rivers discharge disproportionately large quantities of sediment. When concerning restoring river ecosystems, sediment problems should always be taken into consideration. In our survey results, water quality, more specifically turbidity, would be the main reason that causes the degradation of

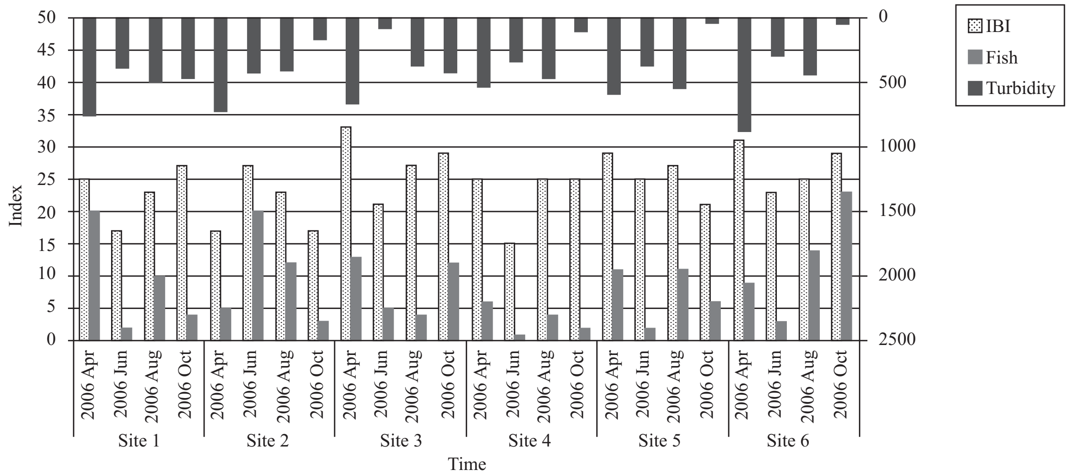
Table 4 Values of modified Index of Biotic Integrity (IBI), Family-level Biotic Index (FBI), and Generic Index (GI) at six different sites during the time of this study

		IBI	FBI	GI	Overall
Site 1	April	25	4.00	*	0.39
	June	17	*	0.00	0.13
	August	23	4.00	0.08	0.37
	October	27	3.53	0.24	0.42
	Average	23	2.88	0.08	0.41
Site 2	April	17	2.50	0.50	0.38
	June	27	4.00	0.00	0.40
	August	23	4.00	0.09	0.37
	October	17	4.00	0.12	0.33
	Average	21	3.63	0.18	0.37
Site 3	April	33	4.00	0.25	0.45
	June	21	*	0.00	0.16
	August	27	4.00	0.00	0.40
	October	29	4.00	0.07	0.42
	Average	27.5	3.00	0.08	0.44
Site 4	April	25	4.00	0.19	0.39
	June	15	4.00	0.00	0.31
	August	25	3.25	0.00	0.41
	October	25	4.07	0.05	0.38
	Average	22.5	3.83	0.06	0.37
Site 5	April	29	4.00	0.00	0.41
	June	25	4.00	*	0.39
	August	27	4.00	0.33	0.40
	October	21	4.00	0.41	0.36
	Average	25.5	4.00	0.18	0.39
Site 6	April	31	4.00	1.20	0.44
	June	23	*	*	0.17
	August	25	4.50	0.18	0.37
	October	29	4.00	0.13	0.42
	Average	27	3.13	0.38	0.43

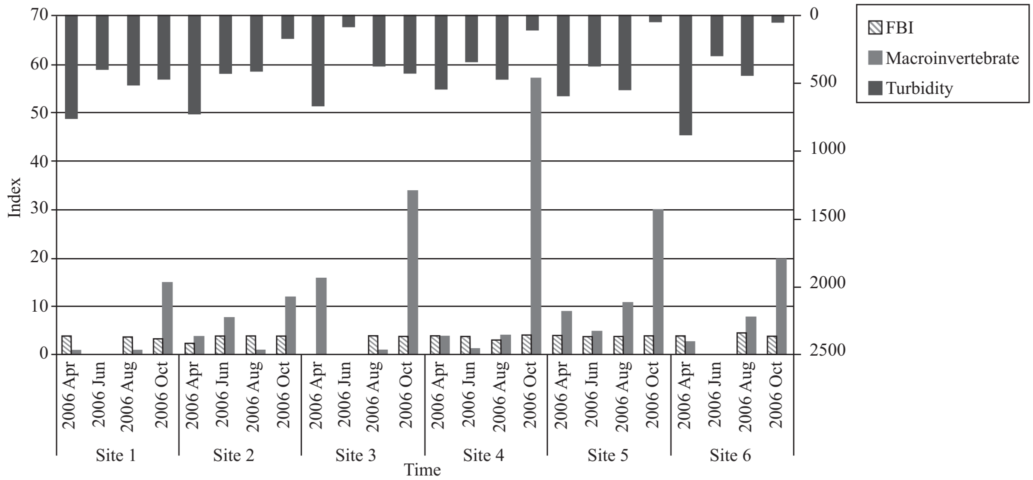
PS 1. * represent the situations that samplings were hardly collected because of the effect of high turbidity making it difficult for algae and macroinvertebrate to stick, and thus no values could be calculated; PS 2. The categories of Modified-IBI are: A: 35-45, Non-impaired; B: 23-34, Slightly impaired; C: 15-22, Moderately impaired; D: 0-14, Severely impaired. The categories of FBI are: A: 0-3.75, Excellent; B: 3.76-4.25, Very good; C: 4.26-5.00, Good; D: 5.01-5.75, Fair; E: 5.76-6.50, Fairly poor; F: 6.51-7.25, Poor; G: 7.26-10.00, Very Poor. The categories of GI are: A: > 30, Mildly polluted; B: 11-30, Slightly polluted; C: 1.5-11, Gently polluted; D: 0.3-1.5, Moderately polluted; E: < 0.3, Severely polluted. (Excerpted from Hu *et al*., 2007); Overall performance equally weights the IBI, FBI, and GI. (i.e. IBI/45 + (1-FBI/10) + GI/30)/3.

aquatic life, which performed the worst in the overall evaluation. According to our personal communications with the local residents in the Bei-Gang River vicinity, dramatic change of water turbidity before and after the Chi-Chi earthquake in 1999, which shifted rock formation in central Taiwan seriously, setting the conditions for occurrence of more landslides and other related disasters (Cheng *et al*., 2005; Teng *et al*., 2000).

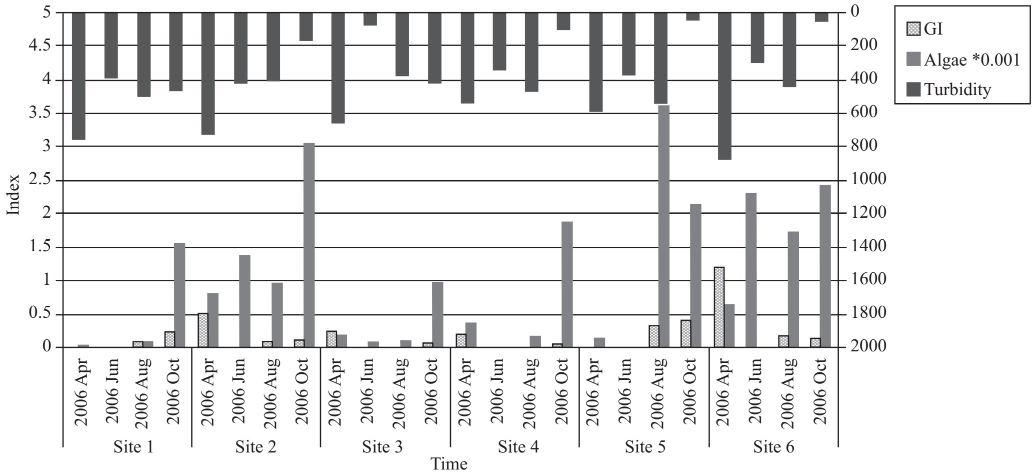
A river's character is strongly influenced by



(a) Relationship between the turbidity measured and fish collected



(b) Relationship between the turbidity measured and macroinvertebrate collected



(c) Relationship between the turbidity measured and algae collected

Figure 4 Relationship between the turbidity measured and the assemblages collected and indices calculated

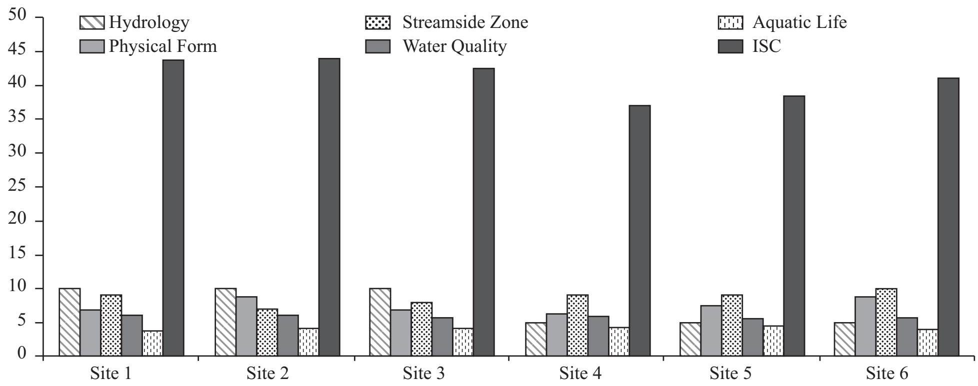


Figure 5 Index of Stream Condition (ISC) scores for the study area. Aquatic life, scored 3.61, was the lowest. As a whole, ISC value is 33.16 evaluated as marginal B level. (ISC scores and its corresponding grade are: A: 45-50, Excellent; B: 35- 44, Good; C: 25-34, Marginal; D: 15-24, Poor; E: <14, Very poor. Excerpted from Hu *et al.*, 2007)

the amount and timing of the water and sediment provided to it. This concern is much associated with the effects of increased sediment loads to rivers and issues of habitat loss. The management of terrestrial sediment delivery to streams is an important factor in maintaining habitat quality in rivers, as primary producers such as invertebrates and fish can be negatively affected by increases in fine sediment loads (Waters, 1995). Although the relationship was not significant in our findings, most of the fish we found are benthic species, which can live more easily in areas where high turbidity is measured. However, it is still a remaining question whether sediment loads or water discharge control this biological performance.

Based on the results of indicators evaluation and the main problem addressed, the study was also undertaken to make recommendations for river restoration from an integrated point of view.

Da-Chi dam was damaged in 2004 and since then its water supply function has no longer been met, and has been replaced by other alternative. There has then been a much debated proposal to the government to remove the dam for restoring the Bei-Gang River ecosystem to its formerly highly valued fishery status. While the cost of repairing or maintaining a small dam can be as much as three times greater than the cost of removing it (Born *et al*., 1998), increasing concerns about adverse effects, such as physical and biological alterations, together with related social and economic forces, have led to a growing call for the restoration of rivers by removing dams. Fish do rely on the unimpeded rivers and corridors to migrate up and down for food, spawning etc. However, before making a decision that is both socially and economically acceptable, assessment of the real impacts of the dam structure and the result of dam removal need to be fully understood (Tomsica *et al*., 2007). In our field survey, the Da-Chi Dam did not significantly influence fish distribution. All the species were collected both upstream and downstream of the dam. The endangered species, S. puliensis, was found at upstream (site 3) and downstream (site 6) of Da-Chi Dam, although with the quantity a little more in downstream than in upstream reach. Considering the damaged condition of Da-Chi Dam and the high turbidity of the river, fishway construction could be a feasible restoration action. Using the breach of the dam structure and linking up the fishway entrance with consolidation works (e.g. modified-boat passage) by reducing the discontinuity effect of dams could provide an easier-found route for fish migrating.

In summary, our study proved the applicability of the suite of indicators which consists of physical, phsiochemical, and biological as the first lens, following by the overall condition evaluation to set priorities when addressing the problems of river environments. Because of its quick and easy results in this process by providing information about the current river conditions, the results of the present study suggest future use of these indicators on the river systems in Taiwan is feasible. However, monitoring for longer period is highly needed. River restoration in Taiwan is still in a beginning stage with continuous efforts. We need to contribute to build our knowledge on experimentation and monitoring to evaluate the actions in continuous efforts.

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