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Evaluation of the changed properties of aquatic animals after dam construction using ecological network analysis

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Abstract: Dam construction results in variations of hydrology, river morphology and habitat and the biota associated with the reservoir change significantly compared to the assemblage before dam construction in order to match these changed environmental conditions. Some attempts so far have been made to ascertain the changed properties of aquatilia due to dam construction. Most of them, however, were focused on perturbances to single factors, such as rearing habitats, reproduction and migration routes, etc. Few have been done on the performance of aquatilia from the whole-ecosystem perspective. Herein, we evaluate the structural properties of aquatic animals and their complex ecological relationships within the ecosystem before and after dam construction based on ecological network analysis. In light of the results, we provide useful suggestions for the conservation of the aquatic animals and their habitats, and propose feasible methods for the application of ecological network analysis to river ecosystem subjected to human disturbance.

Keywords: Aquatic Animals, Dam Construction, Ecological Network Analysis.

1. INTRODUCTION

All countries in the world have been constructed dams for all kinds of purposes, such as water storage, irrigation, hydropower, flood mitigation, etc. It is reported that approximately 70% of the world's rivers is intercepted by large reservoirs (Kummu and Varis, 2007). It has been well documented that dam project results in changes of hydrology, river morphology and habitat, thus disturbing the biota associated with the changed environment (Williams and Wolman, 1984; Vörömarty et al., 2003; Hu et al., 2008). Especially, dams can change the living properties of the by altering the structure and function of the river ecosystem, thus worsening the plight of terrestrial biodiversity and aquatic fauna as well (Wu, 2003; Shen et al., 2004; Stone, 2008). Consequently, the ecological damage or risk to the aquatic animals due to dam construction has become a hot issue of increasing concern recently. However, most studies so far were focused on the assessment of impact to single factors, such as fish reproduction or vegetation. Few works have been done on the dam-induced ecological impact on aquatilia in the whole ecosystem perspective.

Ecological network analysis (ENA) is an environmental application of input-output analysis, focused on examining the structure and the function of ecosystems by the flows of material or energy within them. In fact, ENA has been applied to aquatic ecosystems to elicit the developmental information, e.g., the Chesapeake Bay, Northern Benguela and Neuse River Estuary. In this study, we elucidate the rationale and procedure of assessing the changed structural and functional properties of aquatic animals within the ecosystem due to dam project based on ENA. Modeling the integrated environmental impact to address sustainability issues of the river ecosystem, this study may serve as a complement of the holistic management of the combined human-natural system affected by large projects.

2. THE ECO-ENVIRONMENTAL IMPACT OF DAM PROJECT

Dams fragment river systems, causing significant effects throughout the river ecosystem (especially the aquatic ecosystem) in several on multiple factors and via different levels (Figure 1). These effecting levels are individual, population, community and ecosystem in biological terminology. The associated factors of these levels are hydrology, river morphology, habitat and related biota within the river ecosystem. The proceeding process of the impact triggered by the hydrologic construction, when considering all the levels and ways as mentioned above, seem too complex to speculate accurately due to the interactions between all the factors. Nonetheless, the inter-relationships of these elements, which contribute a great part to the responding performance of the affected environment on the ecosystem scale, should not be ignored. As a consequence of the impact, different status will be reached for the river ecosystem when exposed to the hazard over time, resulting in a series of continual stages. As we can see, the affected river basin will eventually reach an ecological equilibrium, which behaves as a balanced or a degrading ecosystem, depending on the intensity of the possible damages.

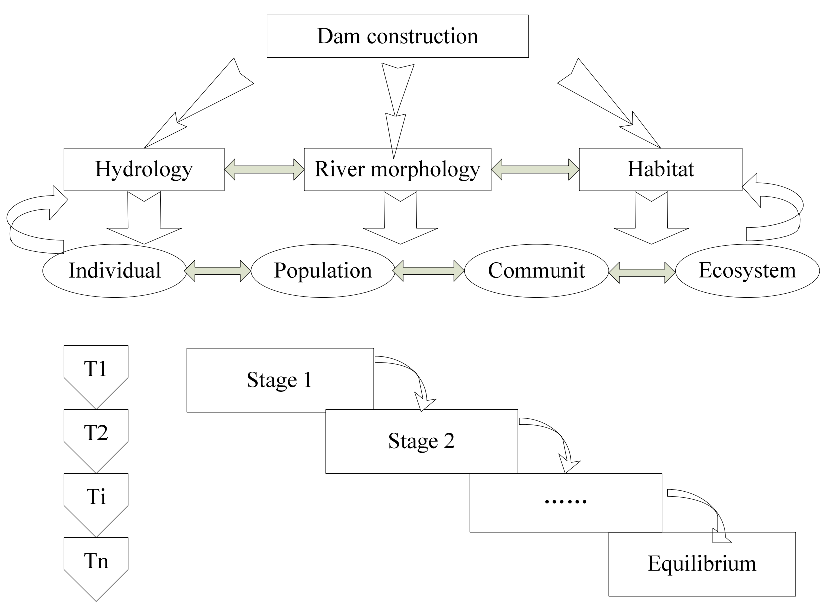

Figure 1-2 The post-dam eco-environmental impact process on different scales.

Lots of studies so far have been reported concerning both direct and indirect impact of single factors by dam project through various mechanisms quantitatively or qualitatively. Herein, we characterize and outline the main eco-environmental impact after an overall review of literatures (Table 1). What is quite revealing is that dams and reservoirs impact the environment through their presence in the landscape, altering basin connectivity and modifying hydrologic regimes sediment movement and water quality, and thus inducing other ensuing intervention to habitat and aquatic organism.

In particular, dams may disrupt the natural seasonal flow patterns to which aquatic animals are adapted, block and destroy spawning grounds and migratory paths fragment their habitats, erode inhabited island and sap the rivers' ability to detoxify and flush out pollutants, thus worsening the plight of terrestrial biodiversity and aquatic fauna as well (Wu, 2003; Shen et al., 2004; Stone, 2008). This may lead to an alteration of the food chain of aquatic animals and in turn impair the adaptable abilities to the changed habitat. It appears that environmental perturbations usually act to shorten the length of the chain and diminish disproportionately the flows at higher levels. In this sense, the analysis of the reticulated food chain of aquatic animals before and after dam construction may serve as the indicator of damage or risk of the holistic ecosystem, thus reflecting the structural and functional properties of river system associated with the sustainability issues.

Table 1 Main manifested post-dam eco-environmental impact.

Scenario	Possible changes	Main indicators	Reference
Hydrology	Alter the river's natural flow patterns and increase flow fluctuation; delay the arrival of floods; increase water renewal time.	Impoundment volume; decreased velocity; retention time.	He et al., 2006; He et al., 2007; Kummu and Varis, 2007.
Water quality	Degenerate the water quality by heavy metal pollution, eutrophication, decomposition of underwater organic matter, etc.	Temperatures; DO; MnO_4, NH_4, Pb; methylmercury; decomposition rate.	Liu et al., 2004; Gong, 2004; He et al., 2006; Burke et al., 2009.
Sediment	Cause discontinuities in the transportation of sediments and elevate the river bed of upstream and lower that of downstream.	Sediment trapping efficiency; volume reduction of sedimentation.	Tullos, 2009; Grant et al.,2003; Rădoane and Rădoane, 2005
Habitat	Alter the physical and chemical characteristics, causing habitat fragmentation and decreased the biocomplexity.	Continuity; thermal regime; flow distribution; OM, N, P.	Tiffan et al., 2002; Tiemann et al., 2004; Tomsica et al., 2007.
Channel morpholog y	Cause channel erosion and land clearing, terrace floodplains.	Sedimentation; landslide; bank erosion rate.	Williams and Wolman, 1984; Church, 1995.
Aquatic fauna	Be in poorer health, and the species and numbers of fish altered. peak early in the life of a reservoir, then decline, because of lower overall productivity.	Biodiversity; fish production; food chains; extinction risk.	King et al., 1998; Franssen et al., 2007; An et al., 2002.
Aquatic flora	Lower species diversity by flood, trigger community degradation and unstabilize the ecosystem, increase the invasive species.	Biodiversity index; primary productivity; dominance species.	Morley, 2007; Chen et al., 1994; Huang, 2001; Liu et al., 2007.

3.MODELING PROCEDURE OF THE AQUATIC ECOSYSTEM BASED ON ENA

Modeling procedure of the aquatic ecosystem based on ENA was proposed (Figure 2). First, figure out the related effects of dam construction on aquatic ecosystem empirically based on environmental impact analysis; Second, evaluate the changed intensity of habitat and climate of the aquatic ecosystem; Third, analyze the food chain aquatic animals within the ecosystem and their relationships based on structural analysis and functional analysis (including throughflow analysis, utility analysis and ascendancy analysis) of ENA; Last, quantify the potential eco-environmental impact with a conversion of the existing changes to the impact intensity, which entails a holistic comparison of the changed properties associated with aquatic animals.

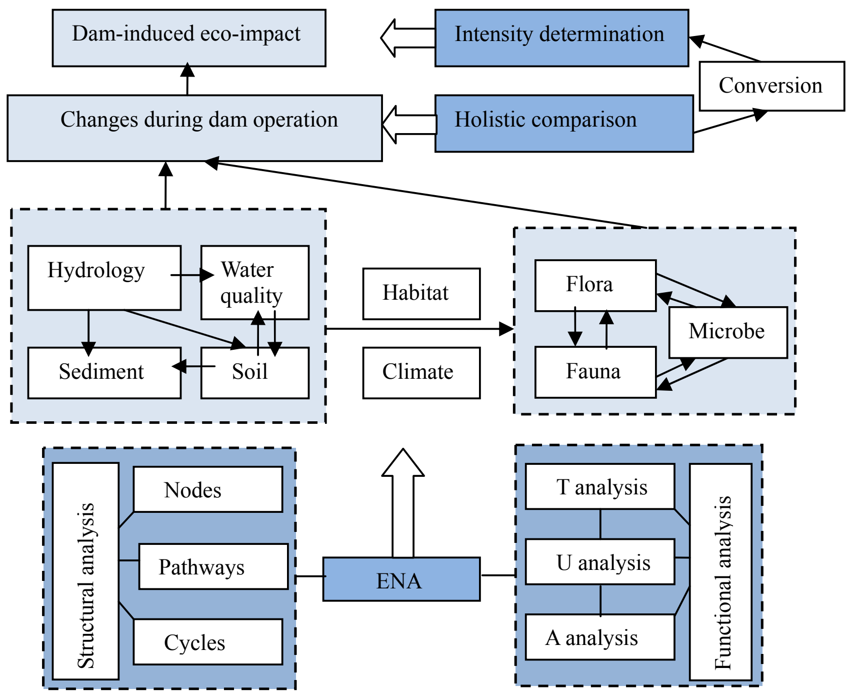

Figure 2 Quantify the potential eco-environmental impact of dam project on the river ecosystem

Notes: T analysis stands for throughflow analysis, U analysis stands for utility analysis, while A analysis in the graph stands for ascendancy analysis.

In order to determine the changed intensity of the properties aquatic animals and assess the ecological impact of dam project on the aquatic ecosystem, three indices (TST, integrated mutualism index and Ascendancy) derived from ENA synthesis were selected as the potential goal function for the sustainability condition of aquatic ecosystem, thus realize the implement of a holistic management of river basin.

- TST

TST stands for the total system throughput. In ENA, it measures the size or growth of the system in terms of the flows through all its compartments, can be considered as the carrier of the development of ecosystem. Each energy or material flow between different components within the system contributes to TST. In the context of dam construction on the river ecosystem, TST defines the holistic intervention intensity of dam project on aquatic animals, which may reveal the impact scenario of the whole aquatic ecosystem.

- Integrated mutualism index

As a tool for describing the interactions among compartments, the utility analysis allows a quantitative analysis of the processes and of the intensity of interactions in an ecological network, thereby revealing the changes of integration and complexity of ecosystem behaviors after dam construction (Fath, 2007). The direct mutualism indicated the direct interaction between different functional components, and indirect mutualism defined the integral relations between components in direct or indirect way. Positive/negative signs of mutualism index are capable for identifying the relationships between different compartments or the synergism of the whole aquatic ecosystem in both direct and indirect ways.

- Ascendancy

Based on AMI and total system throughput (TST), Ulanowicz developed the ascendancy as a measure of the network's potential for competitive advantage over other network configurations, encompassing the natural growth and development of ecological system and asserted that it increases during the developmental process (Ulanowicz, 1980, 2004). Based on the assumption that complex structure is the secret of the sustainability of ecosystem, ascendancy may indicate the impact intensity to the biodiversity and biocomplexity.

4. CONCLUSION

With the introduction of ecological network analysis, we illustrated the rationale and procedure of evaluate the changed properties of aquatic animals and their habitat within the ecosystem caused by dam project. Based on which The related eco-environmental impact on aquatic ecosystem were elucidated, and a ENA-based conceptual model of analyzing the of the river ecosystem was addressed. Finally, three indices were proposed as the potential goal function for sustainability issues of system. This study may address the challenge of a holistic management of aquatic system affected by large projects.

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