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Evaluating the ecological influence of hydraulic projects: A review of aquatic habitat suitability models

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ABSTRACT

In order to evaluate the ecological influence of hydraulic projects, aquatic habitat suitability modeling was proposed. Compared with other environmental flow methods, this method, for the first time, integrated considering hydrology parameters and ecology attributes, quantitatively describing the relationships between species and habitat. Aquatic habitat suitability models began with one-dimensional physical habitat simulation model (PHABSIM) at micro-scale physical habitat. Afterwards, habitat suitability models for meso- and macro-scale were developed; eco-factors indicating physical habitat and water quality situation were included; two- and three-dimensional model were employed to provide the situation of eco-factors. Based on field survey or mathematical models, the state of habitat eco-factors can be obtained. By establishing habitat suitability evaluation criteria, the impact of aquatic habitats on the particular life stage of indicate species can be assessed, the effect of reservoir regulation mode and habitat restoration projections can be predicted. Here, we summarized aquatic habitat suitability models in different spatial scale, and the advantages and disadvantages of each model were analyzed and concluded.

1. Introduction

With the increasing demand of water resources and energy, numerous hydraulic projects have been built. The projects bring great benefits for human beings but also intensify the water use conflict between river channel and watershed; the water quantity, water quality, and hydrodynamic processes of rivers are affected, and the ability of rivers to maintain regular aquatic ecosystem structure and function has degraded [1,2]. Providing habitat for aquatic species is one of the most important function of a river.

A habitat is the combination of the organism-inhabited space and all eco-factors (eco-factors refer to environmental factors that have impacts on organism) in that space, including abiotic environments and other organisms that are necessary for the existence of individuals or groups. Habitat quality has a significant impact on the species "presence-absence" and species richness. It is the determining factor for the abundance and distribution of aquatic organisms (including fish, invertebrates, hydrophytes and algae). The change of habitat conditions influences the aquatic organisms' habitat selection [3–7]. In river ecosystems, the habitat of aquatic organisms closely relates to hydrodynamic processes, parts of or entire life stages of fish depend on specific hydraulic conditions. For example, Chinese sturgeon spawns demersal fish eggs with great specific gravity and viscosity, and high flow velocity is conducive to pick up and scatter eggs, which is benefit for the mixture and fertilization of sperm and eggs, reduces the possibility of fertilized eggs bonding into a group, and improves hatchability [8]; rheotaxis fish depend on the flow direction and strength to adjust their swimming direction and speed, and even choose migration routes; hydrodynamic processes also influence the water temperature, suspended sediment concentration, river bed topography, etc.

An aquatic habitat suitability model (HSM) is based on the preferences of species to their habitat. It integrates flow-related changes in the habitat with the preferred hydraulic habitat conditions for target species or assemblages. This method can quantitatively relate flow regime with the quality of life of species, and it considers the impacts of channel morphology, geomorphic features, discharge variation processes, and water quality.

The target species that can be used for an aquatic habitat suitability simulation include endangered fish, important economic fish, benthos and dominant species and so on [9–12]. Considerable collection of field habitat, hydraulic and biological data is involved in developing a

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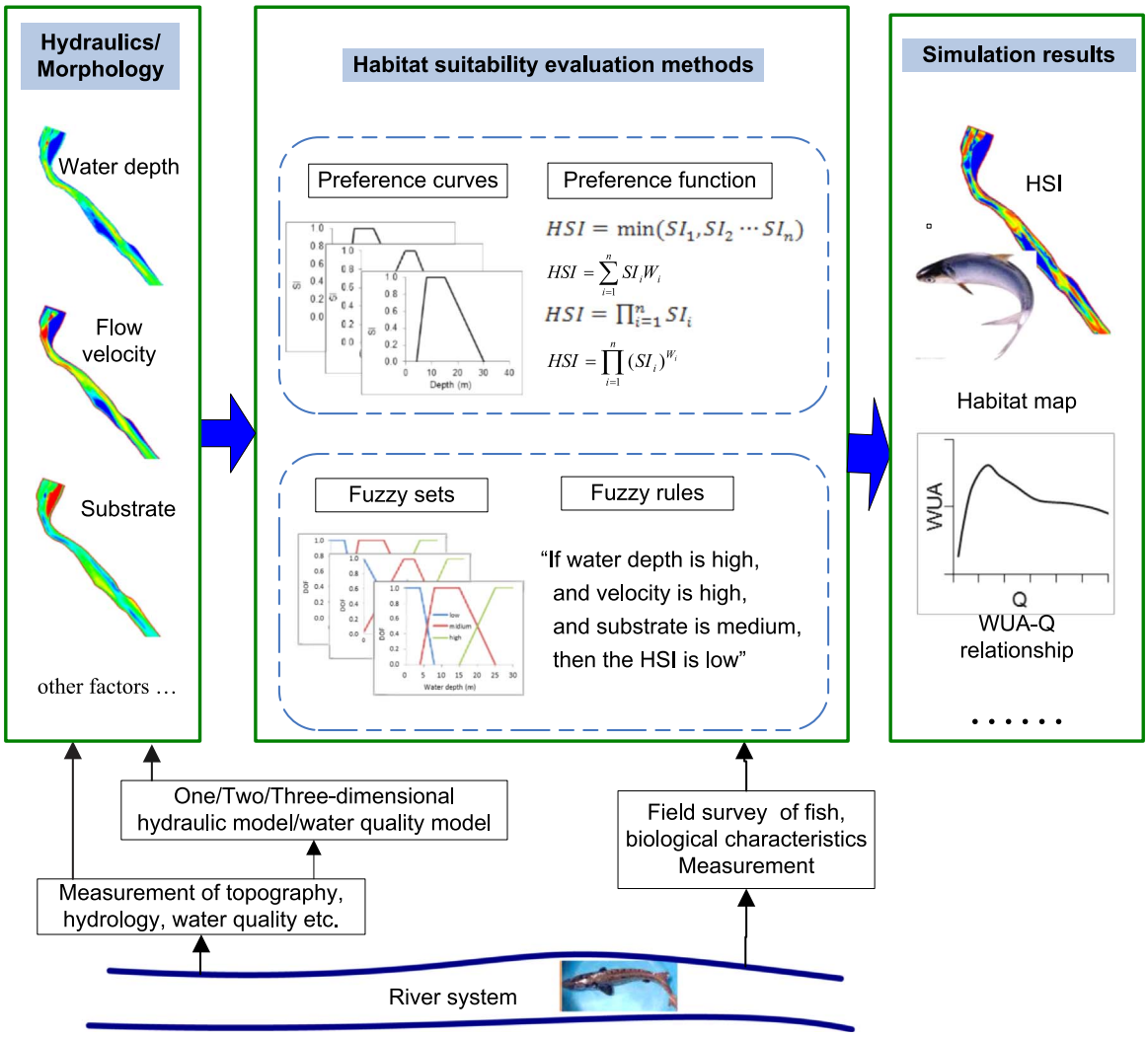

Fig. 1. The main steps to establish a habitat suitability model.

habitat suitability simulation method [13].

The HSM has been regarded as the most scientifically significant and legal reliable method at present and was used to evaluate the influence of hydraulic projects on aquatic organism habitats and the effect of river restoration [14]. It connects biological issues with clear physical meaning, can assess the effect of increasing the minimum instream flow on the river ecosystem [13], and can provide a quantitative technique for river ecosystem conservation and restoration, as well as water resource allocation. Therefore, it has been developed rapidly and widely used since it was proposed [13,14].

The main steps to establish a habitat suitability model are as follows (Fig. 1):

1) Question definition, including the selection of studied river and reach, the model scale, and the selection of target species.
2) Data collection, including the biological data acquisition and ecological habitat survey of the species; river topography, hydrologic and hydraulic data, and water quality data of the selected river reach. This is the basis for establishing a model; it is very critical because it decides the accuracy of the model.
3) Establishing the correlation of the river's habitat eco-factors with the target species. Based on biological and ecological information of the species and the habitat conditions of the river, a habitat suitability evaluation index (HSI) system can be obtained. The HSI can be expressed by preference curves, fuzzy sets, fuzzy rules, and so on.
4) Obtaining spatial distribution of habitat eco-factors, which are related to the HSI. This can be obtained through a hydraulic model, water quality model, or spatial interpolation based on measured data. According to the researched area and requirement of question, one-, two-, or three- dimensional model would be employed.
5) Combining spatial distribution results of habitat eco-factors and the HSI, habitat simulation can be conducted. HSI, habitat map, weight usable area (WUA) and other evaluation factors can be obtained to assess habitat quantity and quality.

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Habitat models serve three main purposes: First, to predict species occurrences on the basis of abiotic and biotic variables; second, to improve the understanding of species-habitat relationships; and third, to quantify habitat requirements [15]. This paper intends to give a summary and conclusion of aquatic habitat suitability models. Typical habitat simulation methods at different spatial scales are analyzed and compared. The scale of the adopted model, habitat simulation method and model, the modeling method are summarized.

2. The scale of the model

The aquatic environments have been seriously affected and degraded by human activities such as damming and irrigation. Assessment based on geomorphologic and ecological data is necessary for evaluating the state of the environment and its management