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Characterization of firefly habitat using a geographical information system with hydrological simulation

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ABSTRACT

Firefly habitat was estimated using a geographical information system (GIS) and hydrological simulation in the Natori River basin in Tohoku, Japan. To investigate suitable conditions for firefly habitat, the relationships between observed firefly habitat and physical environment, such as geological conditions, hydrological conditions and land use types obtained from digital maps were determined. Suitability criteria for firefly habitat were then defined based on habitat suitability index (HSI) estimation. We found that watershed areas smaller than 5000 m^2 with flat plains (slopes less than 0.15) are ideal geological conditions for firefly habitat. Further, we found that non-urbanized areas with urban ratios less than 0.1, deciduous forests, agricultural lands, and paddy fields are the best land use types for firefly habitat. This evaluation also indicates that fireflies prefer to live in shallow and calm water environments (water depths less than 500 mm and velocity less than 1.0 m/s). The habitat locations determined by these criteria were validated by comparing them to field observations of firefly habitat. The results indicate that this model was successful in estimating the existence of firefly habitat in hydroenvironments.

1. Introduction

Numerous attempts have been made to evaluate watershed environments for freshwater biology. Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) are popular indexes not only for water quality, but also for watershed environment evaluations. Over the past few years, a considerable number of environmental assessment studies have been made using underwater dwelling animals and plants (Poff and Allan, 1995; Biggs, 1995; Biggs and Stokseth, 1996; Townsend et al., 1997; Sa et al., 2006; Devineau and Fournier, 2007). Those studies are conceptually based on the assessments of water species habitats according to the surrounding environment conditions.

Studies of habitat distribution are facilitated by geographical information systems (GIS). In general, GIS has been used to create maps of habitat distribution, and to extract habitat information (Haines-Young et al., 1993; Naveh, 1991; Clark et al., 2000; Hong et al., 1998; Lewis, 1995; Munkhtuya and Enkhtsetseg, 2000; Hirzel et al., 2002). Although a large number of studies are available on the application of GIS techniques to produce habitat distribution maps and extract habitat information, there are very few studies on hydrologic environments, such as rivers, streams, and waterways. Various

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studies and simulation models have been developed and used to provide information of hydraulic and hydrological conditions in the form of maps. These models can provide hydrologic environment data, and have been connected to ecological databases (Abbott et al., 1986; Kite and Kouwen, 1992; Silburn and Connolly, 1995; Olivera and Maidment, 1999; Voinov et al., 1999; Echhardt and Arnold, 2001; Christiaens and Feyen, 2002; Karssenberg, 2002; Vachaud and Chen, 2002). The literature states that underwater plants, animals, and fish depend on hydraulic and hydrological conditions, especially, stream velocity and water depth (Karr, 1981; Moss et al., 1987; Bayley and Osborne, 1993; Richter et al., 1997; Taniguchi and Nakano, 2000; Ogbeibu and Oribhabor, 2002; Zalewski, 2002). Also the hydraulic features in a river, drive riverbed conditions, which in turn influence underwater dwelling species (Borchardt and Statzner, 1990; Borchardt and Davis, 1998; Palmer et al., 1992; Richardson, 1992; Matthaei et al., 1997; Kobayashi and Kagaya, 2002). To the degree that the distribution of a species can be precisely expressed, factors of environmental condition and habitat can be applied in broader contexts, such as habitat conservation, identification of new species, and planning and management of future land uses. Once the relationship between the distribution of a species and its environmental conditions is known, environmental and ecological evaluation is possible using GIS and hydrological simulation.

Recently, instream flow incremental methodology (IFIM) and the physical habitat simulation model (PHABSIM), which is one of the fish habitat assessment methods, have been used by many researchers to evaluate habitat by standardizing physical conditions, such as velocity, depth, and bed load (Rand and Newman, 1998; Winkle et al., 1998; Luis et al., 2004). Also the habitat evaluation procedure (HEP) has been used in environment assessment and has wider applications than PHAMSIM. PHABSIM is mainly used for river management, while HEP deals with the broader field environment. Even though HEP and PHABSIM have different targets, they have the same essential approach of using a habitat suitability index (HSI). An HSI model physically evaluates habitat suitability by analyzing inhabitation data, such as population by environmental indices (Hirzel and Guisan, 2002; Hirzel et al., 2001).

In this study, the firefly was selected as a species to evaluate hydrologic environments. Japanese people believe that fireflies, such as *Luciola cruciata* and *Luciola lateralis* are indicator species for abundant vegetations with lush greenery environment and biodiversity of the watercourses. Therefore, Japanese firefly has been a research subject for a long time (Minami, 1963; Burch and Davis, 1967; Ohba, 1978; Uemura et al., 2003). Minami (1963) has reported on Japanese firefly life cycles and its local environmental needs. Japanese fireflies generally exist in different environments during each stage of their life span, namely in the hydrosphere during the larval stage, in the soil during the pupal stage, and in the atmosphere during the adult stage. We used GIS coupled with hydrological simulations to evaluate each of these air, soil, and water firefly habitats using PHABSIM with dynamic data. We also discussed the applicability of coupling a hydrological model with PHABSIM model, which uses medium resolution data.

2. Methods

This study process consisted of GIS dataset preparation, runoff simulation, field observation, and data analysis. GIS data operation included layers, such as geology, hydrology, and land use, and was then used to identify the firefly habitat in the study area. The analysis requests numerical map data. Elevation map was used to obtain the land slope and catchment area. Land use maps were used to identify vegetation types and to determine the urbanization ratio. Widely used distributed hydrological model was used to evaluate the water level and velocity (Fig. 1). Field observation data, which was used to determine the firefly habitat, was obtained by viewing fireflies at night and interviewing local residents. Using the available information, data analysis was carried out to examine the firefly habitat conditions.

2.1. *Study area*

The study area was the Natori River basin, located approximately between 38°N and 38°30′N latitude, in the Tohoku district, in northeast Japan as shown in Fig. 2. The basin area is 939 km^2 with a 55 km river length. Its headwaters are in the Zao mountain range. They pass through the Sendai plain and finally drain into Sendai Bay. The elevation difference between the river mouth and the summit is about 1800 m. Natori basin can be divided into three subbasins: (1) the western mountainous area mainly covered with forest; (2) the central area with complex land use; (3) the eastern plain area. The eastern plain is mainly comprised of paddy fields and urban areas. The capital city of Tohoku district is Sendai, with a population of one million, is located in the eastern plain. The mean annual precipitation is 1600 mm including winter snows. The mean monthly temperature ranges from 2 °C in the winter to 24 °C in the summer.

2.2. *Dataset*

To evaluate firefly habitat conditions, quantitative environmental information is necessary. We used open sources from the Internet, including geomorphologic maps and meteorological data provided by Japanese Geographical Survey Institute (GSI). We used elevation data with 1 and 50 m spatial resolution, land use data with 100 m resolution, and vector basin data. Terrain slope was derived from the elevation data by taking the steepest gradient from the surrounding eight grid cells. Land use was classified into 16 categories and was used to calculate the urban ratio by calculating the ratio of urban to other land use types in an 81 cell neighborhood. From the open sources Integrated Biodiversity Information System provided by the Japanese Ministry of Environment, we used vegetation data classified into 10 categories with a 1 km resolution. Meteorological data, such as temperature and rainfall used for the hydrological model was obtained from the Japan Meteorological Agency (JMA). The hourly data was observed from three gauging stations in the Natori River basin.