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Suitable habitat mapping in the Yangtze River Estuary influenced by land reclamations

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ABSTRACT

We proposed an approach to calculate estuarine habitat suitability and habitat fragmentation by integrating various environmental factors. Based on fuzzy logic method, water depth, salinity, and fluctuation rate of salinity were integrated into a Habitat Suitability Index (*HSI*) to map suitable habitat pattern of target species in estuaries. Then the *HSI* is used to calculate Habitat Aggregation Index (*HAI*) that represents the degree of habitat fragmentation. The proposed method was applied to the Yangtze River Estuary which has experienced long term land reclamation activities during the past two decades including the transformations of coastal wetlands to urban infrastructures and the deep-water channel construction. We selected Chinese mitten crab (*Eriocheir sinensis*) as a target species in this study, the results indicated that under the impact of land reclamation in the Yangtze River Estuary the isoclines of low salinity moved seaward and the optimum salinity range for Chinese mitten crab has been compressed. The suitable habitat for Chinese mitten crab decreased 325.4 km^2 and the HAI has also decreased 2% during the first stage of land reclamation (scenario 1–scenario 2) with a transformation of 237.2 km^2 coastal wetlands to concretes. During the second stage of land reclamation (scenario 2–scenario 3), the combined effects of coastal wetlands disappearance (282.7 km^2) and deep-water channel construction (92.2 km) have led to a degeneration of suitable habitat for Chinese mitten crab about 427.4 km^2 and HAI decreased 6%. Land reclamations in the Yangtze River Estuary not only directly occupied suitable habitat for the Chinese mitten crab, but also altered the habitat patterns and destroyed habitat connectivity, which showed high potential to affect the migration of this species. This proposed approach is flexible for habitat evaluation in estuaries.

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1. Introduction

Worldwide efforts have been launched to promote sustainable urban development and growth with minimal effects to natural ecosystems, however excessive and disordered reclamation projects often severely damage estuaries (Bulleri and Chapman, 2010). These reclamation activities can weaken estuarine tidal power and change hydrological characteristics (Liu and Diamond, 2005), block ecological and hydrological connectivity in coastal wetlands (Wu et al., 2002), reduce phytoplankton, zooplankton, aquatic shellfish and fish biodiversity, and cause change in dominant species and community structure (Healym and Ckeykr, 2002). Land reclamations might directly occupy estuarine habitats (Ma, 2009; Cai, 2012), by transforming coastal wetlands for benthic organisms into ports and farmland, among other available but often less suitable sites (Sun et al., 2015). Moreover, land reclamations change habitat distribution patterns under the effects of hydrological processes (Sun et al., 2015; Zhang et al., 2016).

Former studies selected different environmental variables to quantify suitable habitat for target species driven by anthropogenic activities (Yi et al., 2010a,b; Vincenzi et al., 2006; Fukuda, 2009). For example, Van Dolah et al. (1999) analyzed dissolved oxygen, sediment chemistry and toxicity averages to assess benthic habitat quality. Amara et al. (2007) measured temperature indices of salinity and sediment chemical contaminants to evaluate fish habitat quality. Yi et al. (2010a,b) examined water level, velocity, and temperature to understand water inflow effects on carp habitat suitability.

In general, environmental variables chosen for aquatic habitat assessments are taken as an instantaneous measure or an average value representing some specific period of time, which have neglected the spatial variability and fluctuations of critical environmental factors. Montague and Ley (1993) reported fluctuations in salinity decreased benthos abundance due to physiological stress

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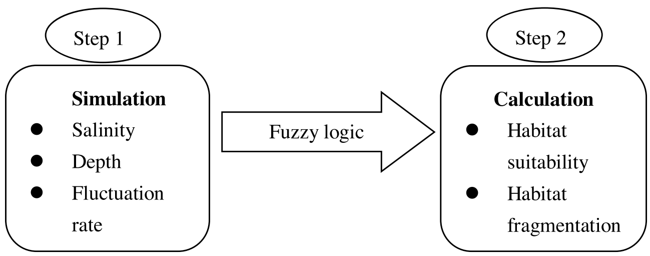

Fig. 1. Approach to assess habitat suitability and fragmentation. Step 1: Temporal and spatial variability of environmental factors; Step 2: Suitable habitat assessment.

reducing growth and survival. Feng et al. (2008) indicated fluctuations in salinity frequency and amplitude exhibited substantial effects on *Litopenaeus vannamei* (Whiteleg shrimp) juvenile growth rates. Khairnar et al. (2015) reported water salinity fluctuation frequency and amplitude and the interaction between the variables affected the growth rate and energy budget of juvenile tongue sole. However, simulations of the effects of fluctuations in environmental factors on organisms under suitable habitat conditions remain scarce in the literature (Zhang et al., 2016; Li et al., 2015a,b).

Considering different factors to assess the suitable habitat may result in a different pattern of suitable habitat, which may lead to different degrees of habitat fragmentation (Zhang et al., 2016). To date, results of several studies reported habitat fragmentation played an important role in habitat quality (Radinger and Wolter, 2015; Kerezsy et al., 2014; Reino et al., 2013), which might subsequently influence species dispersal patterns (Diebel et al., 2010; Stoll et al., 2013), block biological connectivity, reduce intraspecific gene flow (Dixo et al., 2009), affect biomass, and even lead to species extinction (Fahrig, 2002; Chelgren and Dunham, 2014).

Instead of assessing suitable habitats with static environmental factors, the objectives of this study were to build an estuarine habitat fragmentation model integrating temporal and spatial variability of estuarine environmental factors. Land reclamation and freshwater inflow alteration effects were analyzed based on spatial pattern variability in suitable habitats after compiling target estuarine species requirements for fluctuation rate, water depth, and salinity.

2. Methods

Aquatic habitat quality under different land reclamation activities was assessed by establishing an estuarine habitat model to calculate habitat suitability and fragmentation based on spatial pattern variation of critical environmental factors. The approach comprised two steps: (a) simulating spatial distributions of critical environmental variables for target species habitat; and (b) mapping suitable habitat patterns and defining the habitat fragmentation index (Fig. 1).

We selected water depth, water salinity, and fluctuation rate of water salinity as critical environmental factors in this study. The diversity requirements of critical environmental factors for suitable habitat assessment were integrated using the fuzzy logic method, which was employed to calculate the Habitat Suitability Index (HSI) as follows:

$$HSI = fuzzy\,(H, S, F) \quad (1)$$

where H is water depth, S is salinity, and F is fluctuation rate of salinity. The fuzzy logic method was derived as Fig. 2.

Former studies demonstrated fluctuations in water salinity exhibited important influences on aquatic organism growth and some aquatic organisms suffered extensive mortality rates due to instantaneous variation in salinity (Browne and Wanigasekera, 2000; Calliari et al., 2008). Therefore, based on temporal variation in estuarine salinity, we defined a fluctuation rate (F), which represents water fluctuation and selected a standard deviation formula as its expression:

$$F = \sqrt{\frac{1}{N}\sum\nolimits_{i=1}^{N}\left(x_i - \frac{1}{N}\sum\nolimits_{i=1}^{N} x_i\right)^2} \quad (2)$$

where x_i denotes salinity at moment i, and N represents tide fluctuation time. Standard deviation reflects the data set dispersion measures, therefore within the same time, the larger the fluctuation rate the greater the water salinity fluctuations.

Based on the fuzzy logic method, all variables were translated into different linguistic variables, and the linguistic variables were defined by membership functions shaped by the following four parameters (a_m, b_m, c_m, d_m): (i) membership degree increases linearly from 0 to 1 between a_m and b_m; (ii) membership degree is equal to 1 between b_m and c_m; and (iii) membership degree decreases from 1 to 0 between c_m and d_m (Fig. 2). The parameters used to define membership functions for three environmental factors have been shown in Table 1, all these were defined based on requirement of target species to three critical environmental factors (Table 2) and the variation range of these environmental factors in the study area.

After the linguistic variables and their membership functions are defined, the fuzzy rules connect the input variables to the HSI using the IF–THEN form. For example, "IF salinity (S) IS 'moderate' AND depth (H) IS 'moderate' AND fluctuation rate (F) IS 'High', THEN habitat suitability IS 'Moderate'". All the fuzzy rules used in this study have been listed in Table 3, these rules were defined based on the review of the requirement of target species to three critical environmental factors and their membership functions. Then the minimum–maximum fuzzy inference method was used here to execute the fuzzy rules. From these rules, the habitat suitability output is a fuzzy subset. We calculated the crisp value using the Center of Gravity method. The method is expressed as follows (Klir and Yuan, 1995):

$$V_{COG} = \int_{Z_{\min}}^{Z_{\max}} z\mu_c(z)\,dz \Big/ \int_{Z_{\min}}^{Z_{\max}} \mu_c(z)\,dz \quad (3)$$

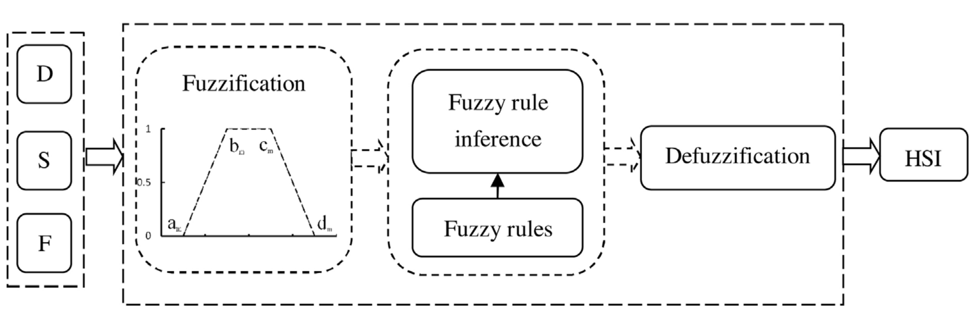

Fig. 2. Fuzzy logic method.

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