Statistical model for the occurrence of common carp at a lakeshore

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Abstract

To evaluate factors influencing the occurrence of common carp at a lakeshore, nine tagged common carp were monitored and environmental data were obtained simultaneously from July 2005 to November 2007. To analyse the relationship between fishing ground conditions and the occurrence of common carp at the lakeshore, a generalised additive model optimised using a distributed genetic algorithm was applied. According to the model, the occurrence of tagged carp at the lakeshore was related to current velocity, water temperature, water level, water level change, wind speed, date and occurrence the previous day. This method may be useful for selecting a good model, and a sensitivity analysis of each response variable should help to estimate the difference in the response to each factor.

1 Introduction

Various kinds of fishing gear have been employed in Lake Biwa and with the exceptions of trawl nets and special dip-nets, almost all of the gear have a passive catching function and are used on the lakeshore. The largest passive gear utilised in the lake fisheries is employed by the set-net fishery, which achieves the second largest catch. The set-net fishery has existed in this region from a long time ago, although the amount of the catch has recently decreased. For this fishery, the most important catch species are cyprinids such as the common carp (*Cyprinus carpio*), crucian carps (*Carassius auratus langsdorfii*, *Carassius autratus grandoculis*, *Carassius cuvieri*) and so on. The catching ability of this fishery, however, has not changed to enable it to capture cyprinids more effectively. Many factors influence the amount of catch by this fishery, and given the passive capture function of the net, the behaviour of the target fish greatly affects the capture process. Generally, fishermen have obtained information on catching fish empirically based on their experiences with fishing operations because one cannot directly observe the behaviour of fish underwater. Moreover, amongst the fishermen engaged in this fishery, the location of the fishing ground and season are held to be very important factors influencing the catch [1]. In addition, many environmental factors influence the catch, such as the current profile [2], water temperature [3], [4] and water level [5]. A scientific understanding of the occurrence of fish on the fishing ground would be useful for evaluating why one can catch target fish at the lakeshore and the role of season. Such data may support common claims by the fishermen. Since many factors can influence fish occurrence, statistical models such as generalised linear models (GLMs) and generalised additive models (GAMs) play important roles in clarifying biological phenomena by analysing the multiple factors that influence fisheries data [6].

Yamane *et al*. [2] attempted to evaluate the environmental factors that influence the catch in a set-net using a GLM, although their model was inadequate for prediction and they obtained little information on the factors that influence fish occurrence. Explaining complex biological phenomena is difficult using a simple statistical procedure such as linear models due to the impossibility of analysing the nonlinear data of periodic biological phenomena, such as diel and seasonal activity [7], [8] and the response to an environmental stimulus [4], [9] having the optimal range for target fish.

Therefore, this study obtained data on the occurrence of tagged common carp and environmental factors at the lakeshore, which is the fishing ground for common carp, and a nonlinear GAM was constructed inductively from the data. The main purpose of this study was to identify factors involved in the occurrence of common carp at the lakeshore.

2 Materials and Methods

Study site

Lake Biwa is the largest lake in Japan. It consists of north (616 km^2, mean depth 43 m) and south (58 km^2, mean depth 4 m) basins and is one of the oldest lakes in the world [10]. The study site was a shore on the west coast of the south basin, one of the deepest areas, to a maximum depth of about 5 m.

Fish occurrence monitored using a bio-logging

Nine common carp were captured with set-nets installed in the study area. The mean mass of the fish was 4.3 kg (range 2.3–9.8 kg) and the mean total length was 62 cm (range 52–77 cm). An acoustic transmitter (V16P-4L; Vemco, Canada) was implanted in the body cavity of each fish. The surgical procedure was similar to that described by Komeyama et al. [3]. The acoustic tag (16 mm in diameter, 80 mm long, and 10 g in weight) had a life span of about 700 days and emitted signals at random intervals of 5–30 s at 69 kHz. After the tagged fish were kept in a tank to recover, they were released at the lakeshore near where they were caught. Five fixed acoustic receivers (VR2; Vemco) were installed in this area. The receivers identified the tagged fish in the detection zone automatically, and the date and time of day were recorded in flash memory. The results of a preliminary test showed that the detection distance of the transmitter was about 500 m. The amount of time that the tagged fish spent at the lakeshore was estimated from the VR2 data in terms of hours per day. When a tagged fish was recorded at least once within an hour, it was assumed to be present at that hour.

Environmental factors

To monitor the environmental conditions in the study area, a current meter with a temperature sensor (ACM-8M or Compact-EM; Alec Electronics, Japan) was fixed to the bottom of the net at a depth of 4.5 m. The magnitude of the current and water temperature were recorded daily. Daily wind speed, rainfall data and hours of sunlight in the study area were obtained from the Japan Meteorological Agency, and water level data were provided by the Water Information System of the Ministry of Land, Infrastructure and Transport of Japan.

Statistical models for fish occurrence

The occurrence of fish was analysed using a GAM with a binomial error distribution and logistic link function to determine which factors were related to occurrence. The occurrence y is expressed as the statistical model

$$y = g(\eta) + \varepsilon\,, \tag{1}$$

where $g(\cdot)$ is the link function, ε is the error term and η is the linear predictor. The occurrence was binomially distributed as count data from 0 to 24 hours, such that

$$g(\eta) = 24\left(\frac{\exp(\eta)}{1+\exp(\eta)}\right), \tag{2}$$

where 24 are the hours in a day, and the predicted value $\hat{y}$ is given by

$$\hat{y} = g(\eta) = 24\left(\frac{\exp(\eta)}{1+\exp(\eta)}\right). \tag{3}$$

η is the linear combination of each response value for environmental factors and can be express as a function with the form

$$\eta = \sum_{i=0}^{11} f_i x_i + \beta \,, \tag{4}$$

where β is constant; x_0 to x_{11} are explanatory variables for the current velocity, water temperature, water temperature change, water level, water level change, rainfall, wind speed, hours of sunlight, lunar cycle, date, individual number and occurrence the previous day, respectively and f_i is the natural cubic spline (N-spline) as a smoothing function. This model includes a nonlinear function in the linear combination. To estimate unknown parameters of the model, distributed genetic algorithms (DGAs) [11] were used after the method of Hiroyasu *et al*. [12]. A DGA is an efficient method for optimising certain objective functions. In this study, the DGA evaluated the model fitness and selected important factors in the model based on the Akaike Information Criterion (*AIC*),

$$fitness = AIC = -2\log L + 2k \,, \tag{5}$$

where L is the likelihood of the model for the observed values and k is number of unknown parameters (knots of the N-spline and constant) in the models estimated with the DGA. The likelihood as the fitness of this model is given by

$$L(\eta \mid y, 24) = \prod_{t=0}^{n} \binom{24}{y_t} \eta_t^{\,y_t} (1-\eta_t)^{24-y_t} \,, \tag{6}$$

where n is dataset length, indexed by subscript t. Consequently, the log-likelihood is

$$\log L(\eta \mid y, 24) = \sum_{t=0}^{n} \left(\log\binom{24}{y_t} + y_t \log(\eta_t) + (24 - y_t)\log(1-\eta_t) \right). \tag{7}$$

The DGA plays the important role of a reducer to restrict the number of knots in the N-spline and helps to simplify and optimise the model.

3 Results

Occurrence of common carp and environmental factors

The tagged fish were monitored and environmental data were obtained simultaneously from July 2005 to November 2007. Days lacking data were not included in the analysis. All of the tagged fish were monitored successfully and recorded at least once between 9 May 2005 and 26 November 2007. The total monitoring time was about 20,400 hours from 15 July 2005 to 26 November 2007, and this study analysed five individuals that contributed over 5% of the total time. The amount of time that the tagged fish spent at the study site was estimated from the VR2 record in terms of hours per day. These data sets were calculated using a GAM to elucidate the factors that affect fish occurrence.

Result of the generalised additive model

The fitness increased gradually and converged on 10,400 after 400 generations (Figure 1). The greatest fitness, the AIC, was 10,393. The predicted values of the model were expressed as observed values (Figure 2) and the log-likelihood was -5158.

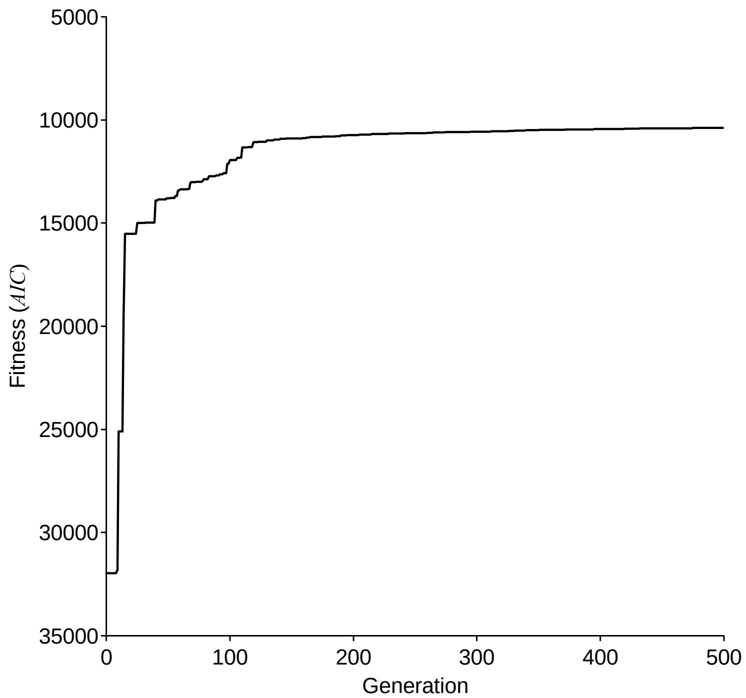

Figure 1. Fitness values according to generation.

The DGA selected current velocity, water temperature, water level, water level change, wind speed, date and occurrence the previous day as suitable models based on the AIC. The number of knots for the factors current velocity, water temperature, water level, water level change, wind speed, date and occurrence the previous day was 4, 4, 5, 7, 7, 7 and 4, respectively. This suggests that the occurrence of tagged carp at the lakeshore was related to the current velocity, water temperature, water level, water level change, wind speed, date, and occurrence the previous day. Therefore, statistical model analysis using the DGA seemed to select some of the important factors. When many factors might influence fish occurrence, calculating the fitness of the model for all factors such as with a stepwise method is inefficient. This method may be useful for selecting a good model, although the model fitness for all of the factors combined is not calculated.

In future work, a sensitivity analysis of each response variable could be used to estimate the difference in the influence of the response to each factor. Moreover, to check for stability, replicate calculations will be necessary to show a robust result, as the calculation result presented here is a one-time result.

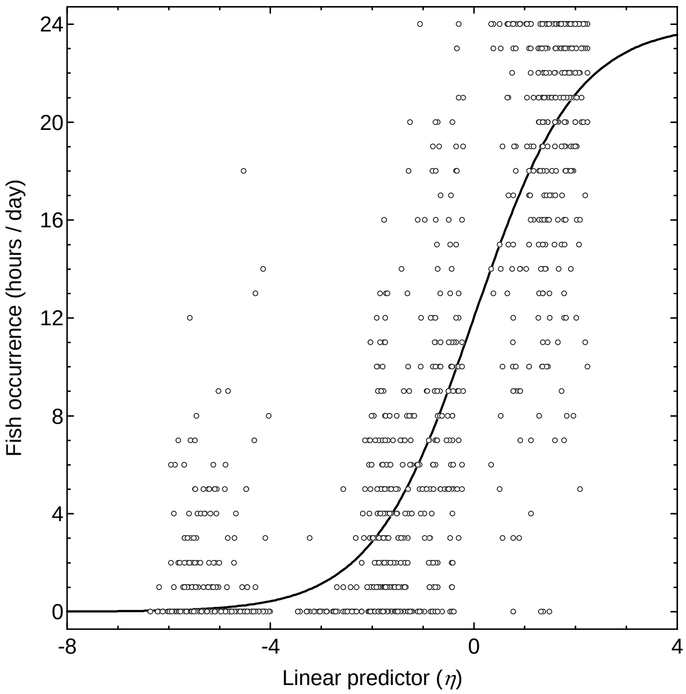

Figure 2. Relationship between fish occurrence and the linear predictor of the generalised additive model (open circles). The dashed line indicates the link function.

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