Evaluation of environmental factors to predict breeding success of Black-tailed Gulls

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ABSTRACT

This study demonstrated prediction of breeding success of Black-tailed Gulls in relation to the selected environmental factors through evaluation of relative importance in determining breeding success. The data were obtained from the 258 selected and 120 non-selected sites for breeding of the gulls during the breeding periods in 2002–2003. Breeding success at the selected sites, and environmental factors such as vegetation cover, vegetation height, rock cover, nest-wall, nearest distance between neighbors and slope, were measured at each sampling site. For predicting breeding success of Black-tailed Gulls, we used two different artificial neural networks in this study: self-organizing map (SOM) and multilayer perceptron (MLP). SOM was used to classify the sampling sites based on the environmental factors, whereas MLP was implemented to prediction of breeding success of the gulls at the non-selected sites based on environmental conditions. In our results, SOM discriminated clearly the sampling sites and presented differences in environmental factors between the selected and non-selected sites. Subsequently, the breeding success was accordingly predicted by MLP. Nest-wall was considered the most important environmental factor in determining survival status of the gulls. An increase in nest-wall and vegetation cover was required to support breeding of the specimens for managing the habitats for Black-tailed Gulls.

1. Introduction

Environmental conditions were critical in determining breeding habitats and consequently influenced the breeding success of the birds and preservation of breeding populations (Lack, 1968; Buckley and Buckley, 1980). The selection of breeding habitats in gulls, which were generally bred colonially in isolated islands, was reported to be sensitive to predators and extreme weather regarding protection of eggs and chicks (Partridge, 1978; Cody, 1985; Good, 2002). For instance, the physical conditions surrounding nests (e.g., vegetation cover, nest-wall, slope, etc.) provided concealment against predators of nesting gulls (Burger and Gochfeld, 1987; Lee et al., 2006a). Some other conditions that would indirectly influence survival of eggs and chicks would be exhaustion from heat stress or strong wind (i.e., the physical aspect) and the risk of predation (i.e., the biological aspect) (Yorio et al., 1995; Lee et al., 2006b).

With regards to the breeding of gulls, important ecologically limiting factors were the availability of foods and the condition of breeding habitats (Pierotti, 1982; Minguez et al., 2003). The two factors needed to be considered for the conservation of breeding habitats and evaluated for their effects on offspring survival (Cody, 1985; Jones, 2001). Successful habitat conservation lay in management of these factors on a regular basis. Studies on conservation of gulls, however, were practically
difficult in field conditions. First the conditions in breeding habitats were generally unstable and unpredictable (Pierotti, 1981; Cody, 1985). As is well known, environmental conditions showed year-to-year variations: the breeding habitats could be favorable one year, but would turn out to be hostile for the specimens in the next year. It was difficult to observe survival of the gulls in stable conditions for a long time. Second, conservation and management of bird habitats at isolated islands would add up another degree of complexity in characterizing breeding habitats (Schreiber and Burger, 2001; Minguez et al., 2003). Generally, the isolated islands were more vulnerable to extreme weather such as typhoons or high temperatures (Burger and Gochfeld, 1988). Finally, the previous studies (Burger and Gochfeld, 1987; Borboroglu and Yorio, 2004) on habitat suitability relied more on the physical environment, focusing only on the reason why the habitats were selected. Both the causes of habitat selection and strategies of conservation should be based on the bird-environment relationships, as evaluated by such things as breeding success.

The studies (Yorio et al., 1995; Good, 2002; Borboroglu and Yorio, 2004) with regards to environmental factors influencing habitat suitability were also concerned with on revealing the reason why the habitat was “not” selected. In unstable environmental conditions with year-to-year weather changes, variation of good conditions at the selected sites observed in different years was higher than variation of poor conditions at the non-selected sites (Mönkkönen et al., 1997; Lee et al., 2006a). These differences in variation between the favorable and poor environmental factors played an important role in characterizing the suitability of habitats. However, it was difficult to quantitatively address the importance of environmental factors in determining the level of breeding success at the non-selected sites. In respect of habitat suitability for gulls, the studies on breeding gulls were mainly carried out at favorable sites concentrating on breeding population status (Yorio et al., 1998; Lee et al., 2005), nest-site characteristics (Burger and Gochfeld, 1988; Lee et al., 2006a), control of food resource (Schreiber and Burger, 2001) and effects of artificial nests (Mayer and Ryan, 1991).

Black-tailed Gulls (Larus crassirostris) are mainly observed along the coast of Korea, Japan, China and eastern Siberia (Won, 1981; Wild Bird Society of Japan, 1986). Black-tailed Gulls are especially common in Korea, which breed seven colonial habitats in the islands around the Korean peninsula; Baengnyeongdo, Chilbado, Chilsando, Dokdo, Hongdo and Nando (Lee et al., 2005). The Korean government designated and preserved these colonial habitats as a natural monument. The government limited access by humans to these habitats for conservation. One of the seven colonial habitats, Hongdo Island, was the largest breeding habitat. Numerous accounts of research on Black-tailed Gulls had been carried out: breeding status [Lee et al., 2005], breeding strategy [Kwon, 2004] and nest-site selection [Lee et al., 2006a]. Although many studies had been conducted on the gulls in the islands, a concrete management plan for the conservation had not been established yet. The previous study related with nest-site characteristics [Lee et al., 2006a,b] only proposed the future importance of information on habitat breeding relationships regarding conservation management of the gulls.

As a continuation of the studies on the Black-tailed Gulls, we focused on patterning of the environmental factors characterizing nest-site selection and subsequently on determining the degree of contribution of the environmental factors on the breeding success of the gulls. In this study, we utilized artificial neural networks, which are known to be an efficient tool in dealing with complex ecological data (Lek and Guégan, 1999; Lek et al., 2005), and proposed a general method for characterizing environmental factors and revealing relational importance of environmental factors in determining biological states of the specimens (i.e., breeding success) with combinational use of unsupervised and supervised neural networks.

2. Methods

2.1. Study site

Hongdo Island (34°31’87”N, 128°43’88”E) has the largest breeding colony of Black-tailed Gulls in Korea, numbering approximately 10,000 pairs in 1995 (Paek and Yoo, 1996), and its size is 98,380 m². Cliffs with a slope of over 45° surround the coastline. The mean ambient temperature from April to July (the breeding period) varied between 13.1 °C and 30.5 °C. Annual mean rainfall varied from 170 to 340 mm (Korea Meteorological Administration, 2004). The vegetation which was used as the major nesting material (Lee et al., 2006a,b) consisted mainly of a sedge (Carex boottiana), which covers the whole island except on the rocky cliffs. The island was additionally covered with a mixture of plant species, of which Camellia japonica, Opuntia ficus indica, Aster spathulifolius and Taraxacum mongolicum are the main species (Cultural Properties Administration, 2003).

2.2. Ecological data

During the breeding season (early April–late July) of 2002 and 2003, we carried out field surveys for the breeding of the gulls. Breeding success was calculated as the number of fledged chicks per total number of eggs. Six environmental factors (vegetation cover, vegetation height, rock cover, nest-wall, nearest distance between neighbors and slope at site) were measured to describe characteristics of breeding habitats of Black-tailed Gulls in a total of 378 sampling sites: 258 sites selected by Black-tailed Gulls for breeding (i.e., nests) and 120 non-selected sites for the breeding (Table 1). The detailed

<table>
<thead>
<tr>
<th>Environmental factors</th>
<th>Selected site</th>
<th>Non-selected site</th>
<th>Kruskal-Wallis ( \chi^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vegetation cover (%)</td>
<td>51.2 (1.9)*</td>
<td>39.7 (2.3)</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Vegetation height (cm)</td>
<td>47.4 (0.9)</td>
<td>41.2 (1.5)</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Rock cover (%)</td>
<td>44.2 (1.6)</td>
<td>29.4 (2.2)</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Nest-wall (%)</td>
<td>55.7 (1.6)</td>
<td>27.5 (2.0)</td>
<td>P &lt; 0.001</td>
</tr>
<tr>
<td>Nearest distance between neighbors (cm)</td>
<td>86.5 (1.2)</td>
<td>90.5 (1.7)</td>
<td>0.01 &lt; P &lt; 0.05</td>
</tr>
<tr>
<td>Slope at site (°)</td>
<td>3.6 (0.3)</td>
<td>-1.7 (0.3)</td>
<td>P &lt; 0.001</td>
</tr>
</tbody>
</table>

* The numbers in parentheses are standard errors.
descriptions on the field data were reported in Lee et al. (2006a).

For the modelling process, the status of breeding success was valued at 0 for breeding failure (i.e., all chicks are dead) and 1 for successful breeding (i.e., one or more young chicks fledged). The status of breeding success was used as a dependent variable for the model described below. Six environmental factors at each nest were used as independent variables. They were rescaled within the minimum and maximum range (0–1) before being provided to the model as input.

2.3. Modelling procedure

Two different artificial neural networks were used in combination in this study: a self-organizing map (SOM) (Kohonen, 1982, 2001) for unsupervised learning and a multilayer perceptron (MLP) with a backpropagation algorithm (Rumelhart et al., 1986) for supervised learning. The modelling procedure was carried out in two steps: first SOM was carried out to discriminate sampling sites between the selected and non-selected sites in accordance with different environmental factors, and second MLP was used to predict breeding success based on the selected environmental factors.

2.3.1. Self-organizing map (SOM)

SOM consists of two input and output layers which were composed of neurons serving as the computational units in the network. Input and output layers connected with weight vectors (i.e., connection intensity) (Fig. 1a). When the input vector (six environmental factors in this study), \( x \), was given to the network, the distance between the weight vector, \( w \), and the input vector, \( x \), was calculated by Euclidean distance \( \| x - w \| \). Data from the 378 sample sites (258 selected sites and 120 non-selected sites) were given to the SOM model. The output layer consisted of \( D \) output neurons (map size) in a two-dimensional hexagonal lattice (Kohonen, 2001). To choose a suitable map size, the SOM with different map sizes was carried out in preliminary tests, and 15 (=5×3) neurons were chosen as the number of output neurons based on experience and the results from different map sizes. Of \( D \) neurons, the best matching neuron, which had the minimum distance, was chosen as the winner. For the best matching and its neighborhood neurons, the new weight vectors were updated by following the SOM learning algorithm.

The cluster boundaries in the units on SOM were further detected by a hierarchical cluster analysis with the complete linkage method after the learning process (Park et al., 2003b). A detailed description of SOM algorithm was given in Kohonen (2001), Chon et al. (1996) and Park et al. (2003a,b). We used the functions implemented in the SOM toolbox (Alhoniemi et al., 2000) for Matlab (The Mathworks, 2001) developed by Laboratory of Information and Computer Science in the Helsinki University of Technology by adopting the initialization and training methods suggested by Alhoniemi et al. (2000) for optimization. The functions could be implemented easily by any ecologists. The software library was free and available from the website http://www.cis.hut.fi/projects/somtoolbox.

2.3.2. Multilayer perceptron (MLP)

To predict the breeding success of Black-tailed Gulls at the non-selected sites, MLP was used as a nonlinear predictor (Haykin, 1994). MLP consisted of three layers: input, hidden and output layers (Fig. 1b), and was used to extract relationships between independent and dependent variables (Kung, 1993). Each layer was composed of neurons being characterized as computational units in the network. This process required independent variables (i.e., six environmental factors) in the input layer and dependent variables (1 for breeding success sites and 0 for failed sites in this study) in the output layer. Detailed learning rules could be found in Rumelhart et al. (1986) and Kung (1993) for theoretical considerations, and Lek et al. (1996) and Lek and Guégan (1999) for ecological applications.

With preliminary tests, the structures of the models was determined at 6–3–1 (input node–hidden node–output node). The dataset of 378 sampling sites (258 selected sites and 120 non-selected sites) was divided into 3 subdatasets. 129 out of 258 sites selected by Black-tailed Gulls for breeding were used for training the MLP model, and other 129 breeding sites were used for the validation of the trained MLP model. Finally, 120 non-selected sites for breeding, which were not used for the training or validation of the MLP model, were used as the test dataset. Overtraining was avoided by the comparison of the final results and by an early stop of the learning process.

After learning, the proportion of correct answers out of the total number of samples was calculated to evaluate the predictability of the MLP model. Cohen’s \( \kappa \) statistics (Cohen,
1960) were computed to indicate agreement levels between measured values and calculated values of the MLP model. The learning process of the MLP was repeated 10 times to evaluate variation of the contribution by randomly initializing weights of the MLP, and the contribution of each input variable was evaluated for each repetition.

Fig. 2 – Classification of selected and non-selected sites on the SOM map (a) according to environmental factors. (b) SOM units were classified with a hierarchical cluster analysis. Dark hexagons represent the numbers of selected sites, whereas grey ones display non-selected sites. The size of hexagon is linearly proportion to the number of selected and non-selected sites assigned in a SOM unit. Latin numbers stand for the cluster numbers identified on the SOM map through a hierarchical cluster analysis. The numbers in the cluster dendrogram correspond to the same numbers of the SOM units.

Fig. 3 – Visualization of environmental factors calculated in the trained SOM in grey scale. Darker shading represents high value for each factor, whereas lighter shading is low value.
2.3.3. Sensitivity analysis

To evaluate the influence of each independent variable (i.e., environmental factors) on the values of the dependent variable (i.e., breeding success) in MLP, a sensitivity analysis was carried out. Many authors performed a sensitivity analysis in various ways (Helton, 1993; Zurada et al., 1994; Hamby, 1994; Yao et al., 1998; Dimopoulos et al., 1999; Gevrey et al., 2003). According to Gevrey et al. (2003), we used the partial derivatives method to evaluate the influence of each environmental factor on breeding success of Black-tailed Gulls. The profile of variation in the output variable was produced based on the partial derivatives of the MLP in accordance with small changes in the input variable (Dimopoulos et al., 1995, 1999).

2.4. Statistical analysis

Kruskal–Wallis \( \chi^2 \)-tests were used to determine differences in environmental factors measured at the selected sites and non-selected sites (Burger and Gochfeld, 1987). All means were represented with a standard error. Each factor was compared between clusters defined by SOM through the Tukey’s HSD test. The numbers in parentheses are standard errors. The same superscript characters are not significantly different at the 5% confidence level by the Tukey’s HSD test.

\[
\text{VC} = \text{vegetation cover}, \text{VH} = \text{vegetation height}, \text{RC} = \text{rock cover}, \text{NW} = \text{nest-wall}, \text{ND} = \text{nearest distance between neighbors}, \text{SL} = \text{slope at site}.
\]

The numbers in parentheses are standard errors. The same superscript characters are not significantly different at the 5% confidence level by the Tukey’s HSD test.

### Table 2 – Differences (mean and standard error) of environmental factors at different clusters defined in the SOM

<table>
<thead>
<tr>
<th>Cluster</th>
<th>N</th>
<th>VC (%)</th>
<th>VH (cm)</th>
<th>RC (%)</th>
<th>NW (%)</th>
<th>ND (cm)</th>
<th>SL (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>90</td>
<td>21.8 (0.4)^a</td>
<td>45.0 (0.4)^b</td>
<td>29.3 (0.4)^b</td>
<td>23.9 (0.5)^b</td>
<td>91.3 (0.4)^a</td>
<td>0.7 (0.2)^a</td>
</tr>
<tr>
<td>II</td>
<td>86</td>
<td>22.5 (0.5)^a</td>
<td>34.9 (0.5)^b</td>
<td>64.8 (0.5)^b</td>
<td>55.5 (0.5)^b</td>
<td>88.8 (0.5)^a</td>
<td>2.8 (0.2)^b</td>
</tr>
<tr>
<td>III</td>
<td>105</td>
<td>67.4 (0.4)^b</td>
<td>50.2 (0.4)^b</td>
<td>34.3 (0.5)^b</td>
<td>90.5 (0.4)^b</td>
<td>0.6 (0.2)^a</td>
<td>3.5 (0.2)^b</td>
</tr>
<tr>
<td>IV</td>
<td>97</td>
<td>72.4 (0.4)^b</td>
<td>49.9 (0.5)^b</td>
<td>47.3 (0.5)^b</td>
<td>73.7 (0.4)^a</td>
<td>80.6 (0.4)^a</td>
<td>3.5 (0.2)^b</td>
</tr>
</tbody>
</table>

VC = vegetation cover, VH = vegetation height, RC = rock cover, NW = nest-wall, ND = nearest distance between neighbors, SL = slope at site.

### Table 3 – Correctly discriminated nests for breeding success of Black-tailed Gulls by MLP model after the ten repetitions

<table>
<thead>
<tr>
<th></th>
<th>Breeding discrimination</th>
<th>Total</th>
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<tbody>
<tr>
<td></td>
<td>Success</td>
<td>Failure</td>
</tr>
<tr>
<td>Training</td>
<td>N</td>
<td>159.2 (0.4)^a</td>
</tr>
<tr>
<td></td>
<td>Percentage</td>
<td>84.2 (2.6)</td>
</tr>
<tr>
<td>Validation</td>
<td>N</td>
<td>75.9 (0.4)</td>
</tr>
<tr>
<td></td>
<td>Percentage</td>
<td>79.9 (3.8)</td>
</tr>
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</table>

Cohen \( \kappa \) for training and validation were 0.642 (0.041 standard error) and 0.584 (0.054), respectively.

* The numbers in parentheses are standard errors.

Fig. 3 showed distribution of the connection intensity (weights) for each environmental factor on the trained SOM map with a grey scale, displaying the relative effect of each factor on patterning of input datasets. Dark represented high values, whereas light indicated low values. Each factor was characteristically presented in various ways in different clusters. Nest-wall and slope of the site were higher in the lower right areas of the SOM map (cluster IV), whereas the nearest distance between neighbors was higher in the upper left areas (cluster I). Vegetation cover appeared to be higher in the lower areas (clusters III and IV). Whereas vegetation height was higher in the lower left areas (cluster III), rock cover was higher in the upper right areas (cluster II). Overall, three factors (nest-wall, slope at site and vegetation cover) appeared to be higher in the bottom right areas of the SOM map, while being lower in the upper left areas. This was in accordance with the values collected from field data (Table 2).

3.2. Prediction of breeding success

MLP was applied to predict breeding success at the non-selected sites as stated before. Table 3 showed the prediction results of breeding success from MLP. In the training, more than 84.2% of sampling sites was correctly identified, and Cohen’s \( \kappa \) statistic was 0.642, indicating good agreement in the results of breeding success obtained from field and the MLP model. In the validation, 75.9 out of 95 sample sites (predictability 79.9%) were correctly distinguished, and Cohen’s \( \kappa \) statistic was 0.584, indicating corrected agreement between the expected and predicted values.

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Cohen \( \kappa \) for training and validation were 0.642 (0.041 standard error) and 0.584 (0.054), respectively.

* The numbers in parentheses are standard errors.
A sensitivity analysis was carried out to evaluate contribution of environmental factors for determining breeding success. The sum of mean square error of partial derivatives was computed to estimate relative importance of each factor (Fig. 4). The highest contributing factor was nest-wall which contributed more than 73.8% in variation of output, indicating the most important factor for selection of habitats for breeding success. Vegetation cover followed nest-wall with 11.6% contributing to output. Other factors showed distinctively low contributions compared with the factors stated above. These results were in general in accordance with those of the SOM (Figs. 2 and 3).

Fig. 5 displayed the relationships between the possibility of breeding success predicted by MLP and their environmental factors at the non-selected sites. Overall the breeding success at the non-selected sites was distinctively low with average 38.8%. Based on breeding success, the non-selected sites were arranged in the descending order of prediction. The environmental factors were arranged in the same order. The pattern of nest-wall was very similar to breeding success. Similar breeding success was also observed in accordance with vegetation cover, while other factors showed different patterns. These results were similar to the contribution of environmental factors to breeding success as shown by sensitive analysis (Fig. 4).

4. Discussion

This study confirmed the previous reports that the environmental factors or ecological situations surrounding the breeding sites for birds were critically influential in breeding success in direct or indirect manners (Burger and Shisler, 1980; Cody,
adults vegetation cover were associated with breeding success in density in breeding pairs of Black-tailed Gulls on Hongdo at the non-selected sites were substantially low (Fig. 5). Sensitivity analysis efficiently revealed the relative importance of environmental factors in determining breeding success. As expected, the predicted values of breeding success per se, since the previous studies mainly relied on differences in environmental factors without further consideration of their consequent effects on breeding success. We utilized two different artificial neural network models in combination in this study for the purpose of elucidating environment-breeding relationships more objectively: SOM for classifying breeding sites corresponding to important environmental factors and MLP for predicting the influence of environmental factors specifically on the breeding success of the gulls. As demonstrated in this study, artificial neural networks were versatile in extracting information out of complex ecological data (Chon et al., 1996; Lek and Guégan, 1999; Park et al., 2003a,b; Lee et al., 2006a;b; Park and Chung, 2006). Especially the combinational use of unsupervised and supervised networks was efficient in characterizing the environmental conditions (Table 2, Figs. 2 and 3) and subsequently in tracing down the responsible factors for determining breeding success (Figs. 4 and 5).

SOM revealed the major factors for discriminating the sampling sites as nest-wall and vegetation cover (Table 2, Fig. 3). The results confirmed the previous reports. Borboroglu and Yorio (2004) found that vegetation cover provided Kelp Gulls (Larus dominicanus) with protection from ground and avian predators and extreme weather. In the previous study using PCA and SOM, Lee et al. (2006a) showed that the factors regarding the “wall” effect such as nest-wall and vegetation cover were associated with breeding success in Black-tailed Gulls. The major cause of breeding failure observed on Hongdo Island was ‘killed by neighboring adults’ according to the pecking behavior (Lee, 2004). The density in breeding pairs of Black-tailed Gulls on Hongdo Island was higher than in the other breeding colonies (Lee et al., 2005) and this high density caused the high risk of attack from neighbors in colonial breeding (Yorio et al., 1995; Schreiber and Burger, 2001), attacking from the adults in the neighborhood sites would be critical in the breeding success in this case. Based on this reasoning, the sites for Black-tailed Gulls should be managed for nest-wall and vegetation cover in the islands.

MLP was further used for elucidating the relationship between environmental factors and breeding success (Figs. 4 and 5). Sensitivity analysis efficiently revealed the relative importance of environmental factors in determining breeding success. As expected, the predicted values of breeding success at the non-selected sites were substantially low (Fig. 5). Sensitivity analysis accordingly evaluated nest-wall and vegetation cover as important in determining breeding success of the Black-tailed Gulls. At the non-selected sites, values of nest-wall and vegetation cover observed were correspondingly low as expected. Sensitivity analyses were suitable for selecting important factors in breeding site selection in this study. Nest-wall and vegetation cover influenced strongly the determination of breeding sites and breeding success of Black-tailed Gulls.

Higher areas except for rocky cliff in the Hongdo Island were covered with sedge vegetation. Black-tailed Gulls on Hongdo Island received high predation stress by neighboring adults and were exposed to strong winds and typhoon during the breeding periods (Kwon, 2004; Lee et al., 2006a). To defend the breeding sites from these disturbances and to obtain higher breeding success, the gulls needed high values of nest-walls and vegetation cover consequently (Lee et al., 2006a). These observations in previous reports were in accordance with the results from the models proposed in this study as stated above.

The results in this study confirmed the general belief that environmental factors were selectively important in determining breeding success, i.e., survival status (life or death) of birds. Laughing Gulls (Larus atricilla) in the Culebra National Wildlife Refuge, Puerto Rico bred three different islands. The difference of cover rates and densities of vegetations influenced breeding success in the gulls in different manners through determining attacks by the predators or heat stress from the environment (Yorio et al., 1995; Borboroglu and Yorio, 2004). In order to improve breeding success, parents should have defense mechanisms against external pressure (i.e., predators or extreme weather). One of the key defense mechanisms was the choice of favorable sites with the beneficial environmental factors as shown in this study. This type of selectively characterizing environmental factors would be specifically helpful for establishing sustainable management policies for conservation of natural populations in isolated area, such as the gull population bred in the islands, and could be efficiently realized by the use of the biologically-inspired machine learning techniques including artificial neural networks.

5. Conclusions

Two different artificial neural networks, SOM and MLP, were utilized in combination to analyze the role of environmental factors in determining breeding success. SOM provided visualization of patterning input vectors and accordingly revealed patterns of the samples and important factors for breeding success. Two factors (nest-wall and vegetation cover) were influential in determining breeding success through analysis of the data collected from both selected and non-selected sites. Through training with the relationships between environmental factors and breeding success at the selected sites, MLP was feasible in predicting the breeding success at the non-selected sites. Sensitivity analysis showed that nest-wall and vegetation cover were the two most important factors in determining survival of Black-tailed Gulls. The biologically inspired machine learning techniques in ecological informatics could be an alternative tool for informing sustainable ecosystem management.
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