Modelling the effect of tourism disturbance on hatching rate of the Chinese giant salamander (*Andrias davidianus*) by using artificial neural network

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**ABSTRACT**

The endangered Chinese giant salamander (*Andrias davidianus*) is an endangered species among the conserved Chinese amphibians. Tourism-related pressures have increased for this species recently. The effect of tourism on the hatching rate of the target species was determined by experimentally observing the influences of different intensities of tourism disturbance on salamander in the Zhangjiajie Chinese Giant Salamander National Nature Reserve. Water quality factors (e.g. total nitrogen, total phosphorus, dissolved oxygen and *Escherichia coli* abundance) were analysed, and hatching rate was estimated. Results showed that high levels of tourism disturbance (500,000–1,200,000 visitors per year) had active effects on the hatching time and negative effects on the hatching rate. The prediction performance of artificial neural network models was validated by the low root mean square error values of 2.2539 and 3.2612 for the training and testing data and high determination coefficient values of 0.9732 and 0.9508 for the training and testing data, respectively. The potential for positive or negative feedback mechanisms in such relationships between tourists and wildlife highlights the importance of considering both sides of the complex interaction to find a balance between the development of tourism and wild animal protection.

**HIGHLIGHTS**

- High tourism disturbance deteriorated the water quality.
- Artificial neural network model was successfully used in predicting the hatching rate.
- A mutual relationship was observed between salamander and tourists.
1. Introduction

Tourism provides a strong foundation for the local economy. The increase in economic activity provides a wide range of economic benefits, such as enhanced output (sales) for local businesses, new jobs and subsequent augmentation in sales and personal income tax revenue to the local government (Boruah et al. 2021; Ren et al. 2021). However, the increased interest in nature-based human activities threatens biodiversity values and can cause disturbance to wildlife (Larm et al. 2021). High levels of tourism and recreation have several deteriorating effects on wildlife species and related natural ecosystems (Castillo-Vizuete et al. 2021; Smith et al. 2021). For example, based on vehicle-based observations conducted in Southern Sri Lanka, vehicle noise, distance, tourist behaviour and time of the day disturb the feeding activity of free-ranging elephants (Ranaweerage et al. 2015). The physiological stress response of tigers to human disturbance has been studied by assessing the faecal glucocorticoid metabolite concentrations of the animals. Results showed that human disturbance could act as potential stressors for wildlife, resulting in physiological stress and fitness responses (Abhinav et al. 2019). The immediate response of wildlife to disturbance is the change in their behaviour, and the long-term effects include altered breeding rate of individuals and changes in abundance (Almalki 2021; Xu et al. 2021). Therefore, researchers have focused on this concern to effectively understand the relationship between anthropogenic disturbances and biological response (Sharma et al. 2021; Rohr et al. 2021). The results may contribute to the sustainable development in tourism.

The Chinese giant salamander (*Andrias davidianus*) is the world’s largest amphibian and has ever been used in some Chinese regions as food, medicinal material and ornamental animal. This animal was once widely distributed throughout the drainages of the Yangtze, Yellow and Pearl Rivers (Zhang et al. 2016; Zhang et al. 2003). *A. davidianus* is severely threatened by the unsustainable overexploitation of wild individuals since the 1950s (Pan et al. 2016). In response to its decline in the wild, *A. davidianus* is listed as critically endangered by the 2004 International Union for Conservation of Nature (Segev et al. 2010). At least 30 preserves have been established in China for *A. davidianus* protection (Luo et al. 2018b). With the development of tourism in the nature reserves, increasing numbers of tourists will inevitably cause deterioration of water in the habitats of salamanders (Luo et al. 2021).

Factors that might affect the threatened species have attracted great attention, and high levels of tourism disturbance exert negative effects on the quality of habitat (Leclerc et al. 2021; Neves 2020). The effects of habitat on salamanders have been studied. A small-scale experiment has been conducted by Wu et al. (2007). The findings showed that clean water at temperature of 9–25°C, weak alkaline or neutral pH value, high hardness, chemical oxygen demand (COD) ≤ 15 mg/L and total phosphorus (TP) ≤ 0.02 mg/L would be beneficial to the breeding of salamander. Meng et al. (2018) found that the most suitable water environment for wild salamanders is slow-flowering water with pH 7 and high dissolved oxygen (DO ≥ 5 mg/L). Furthermore, water environmental factors such as TP, total nitrogen (TN), DO and abundance of *Escherichia coli* can influence the salamander reproduction (Ma et al. 2021). The chemical properties of water under different intensities of tourism disturbance have been determined, and the results show that tourism indirectly disturbs the population size by reducing DO in water and increasing TN, TP and abundance of *E. coli* (Luo et al. 2021). A reliable modelling approach is needed to describe the complex relationship between the water quality factors and hatching rate of salamander. In the conventional linear regression model, process outputs in the prediction horizon are
expressed as a linear function of inputs and outputs. The region of acceptable approximation may become too small to be practically controllable (Saha et al. 2021).

Among the several tools of multivariate modelling, the artificial neural network (ANN) is preferred. The vast application of ANN on non-linear multivariate modelling in environmental engineering for complex problems is promising. Some inherent advantages, such as universal approximation, mapping capacity, self-studying, tracking and anti-interference capabilities of the algorithm, are associated with the adequate performance of ANN model (Ghosal et al. 2019; Jiang et al. 2020). The ANN method is broadly used for prediction in different fields because of its capacity to obtain non-linear relation between input and output variables in the training process of model development (Lee et al. 2021; De Andrade et al. 2021; Pathak et al. 2022). Limited studies have focused on defining the model of tourism intensity on the target species.

In the present study, the relationship between the hatching rate of A. davidianus and the anthropogenic disturbance was examined by assessing the quality of water in the National Nature Reserve for the Chinese Giant Salamander in Zhangjiajie, Hunan Province, China. The influence of the quality of habitat was predicted by adopting an ANN model. The results can be used as a baseline to understand the effects of tourism on the salamander’s behaviour and its hatching rate. Ultimately, strategies can be developed to reduce tourism-induced disturbance on wildlife in protected areas.

2. Materials and methods

2.1. Study site

The investigated sites were located in the National Nature Reserve for the Chinese Giant Salamander in Zhangjiajie, Hunan Province, China (Luo et al. 2019). It is situated at 28° 52′–29° 48′ N and 109° 400′–110° 200′ E with a land area of 142.85 km², including the Lishui, Loushui, Suoshui and Yuanshui rivers, some of which flow through the karst caves. This area has a subtropical monsoonal climate with a mean annual temperature of 14–22°C (Luo et al. 2009) and a mean annual rainfall of 1,595.8 mm (data obtained from the local meteorological bureau). The farmed site (ecological breeding base of the Zhangjiajie Zhuyuan Giant Salamander Biotechnology Co., Ltd.) is located in Kongkeshu village, Sangzhi county, Zhangjiajie City, Hunan province (29° 28′21″N and 110° 22′31″E) and is situated 471 m above sea level.

The effect of tourism disturbance on the properties of water in the lakes was determined by classifying the streams in the reserve into two parts, namely, water quality testing at field sites and observing salamander hatching behaviour at simulated experiments. In the field sites, the streams were recognised as three levels of anthropogenic disturbances, namely, low, moderate and high) mainly according to the numbers of tourists. Tourist data were acquired from the administration department for each survey point and were determined by recording the number of tourist at each survey point each day. Group 1 was located on the sites with fewer than 10,000 visitors per year, which was defined as low interference. Group 2 was located on the sites with 10,000–500,000 visitors per year, which was defined as moderate-anthropogenic-disturbance area. Group 3 was located in the scenic spots and considered as high-anthropogenic-disturbance area, where the number of visitors could exceed 500,000 people per year. Each site consists of six sample sites (The investigated sites can be seen in Table S1). The water properties (mean values of DO, TN, TP and E. coli abundance) are listed in Table 1. The differences in the
water quality might be caused by tourism-associated activities, such as splashing and the generation of litter, organic waste and sewage.

Nine artificial streams were selected at a simulated ecology farm in the reserve to observe the hatching behaviours of the salamanders. The stream pattern of ecological breeding pool of *A. davidianus* is shown in Figure 1. By controlling the water flow and increasing the nutrient (e.g. sodium dihydrogen phosphate and ammonium chloride) concentrations, the qualities (TN, TP and DO) of water in the nine streams, representing high-, moderate- and low-disturbance streams, were simulated (Figure S1). Each level of disturbance experiment was conducted in three simulated streams. Each stream had dimensions of 13.2 m × 1.1 m × 0.2 m (length × width × height) with 20 dens. In each stream, sand, pebbles and some soil were found at the bottom, and plants grew on top. Each den was cuboid-shaped and had dimensions of 1.2 m × 1.2 m (length × width), with an entrance of 0.25 m × 0.2 m × 0.3 m (length × width × height). Each stream had 30 salamanders (age, 9–10 years; weight, 9.8–12.2 kg), with a 1:1 sex ratio.

### 2.2. Data collection

Water samples were collected from the river surface at a depth of 0.2 m from 14th August to 13th October in 2020. Before sampling, all sample bottles were washed, rinsed with distilled water and sterilised. All samples were immediately transported to the laboratory within 48 h. The DO of water at each site was measured using a portable water quality analyser (HACH, Colorado, USA). TN was measured via potassium persulfate UV spectrophotometry, and ammonium was measured using the salicylate method. TP was measured using the stannous chloride method. The abundance of *E. coli* was measured using the multiple tube fermentation technique (Adebisi et al. 2020).

Infrared video cameras (effective pixels of 2,048 × 1,536, 4-mm lens, HIKVISION DS-2CD3T35D-15, Hangzhou Hikivision Digital Technology Co. Ltd., Hangzhou, China)

### Table 1. The water quality of the streams.

| Anthropogenic-disturbance area | DO (mg/L) | TN (mg/L) | TP (mg/L) | *E. coli* (×10CFU/100 mL) |
|--------------------------------|-----------|-----------|-----------|--------------------------|
| High                           | 5.3 ± 0.20| 0.47 ± 0.02| 0.098 ± 0.005| 22 ± 0.50                |
| Medium                         | 7.5 ± 0.10| 0.36 ± 0.02| 0.057 ± 0.002| 9.5 ± 0.50               |
| Low                            | 10.2 ± 0.27| 0.22 ± 0.01| 0.035 ± 0.001| 4.1 ± 0.20               |

**Figure 1.** Imitation ecological breeding pond of Chinese giant salamander.
were installed at the top of the dens and above each stream to observe the behaviour inside and outside the dens (Figure 2). The 24-h recordings from the cameras and manual observation were used as basis to determine the number of fertilised eggs (two cell embryo stage as the symbol of fertilization) and hatching seedling (accurate to 10 eggs/1 matrix). The average hatching rate was calculated as follows (Luo et al. 2021):

\[
\text{Hatching rate (\%)} = \frac{\text{number of hatching seedling}}{\text{fertilized eggs}} \times 100\% 
\]

(1)

2.3. Data analysis

A combination of ANN and genetic algorithms (ANN-GA, Matlab 8.1/R2013a, Math Works, Inc., Natick, MA, USA) was presented to predict the breeding rate of the salamander. According to the initial study (Luo et al. 2018a), tourism disturbance did not affect the physical properties (i.e. pH, water temperature, total hardness and turbidity) of water in the salamander habitats. However, tourism significantly influenced all the chemical properties of water, except for the COD. Therefore, the input variables for the ANN model were DO, TN, TP and \( E. \) coli abundance. The hatching rate was considered as the output variable. The ANN model was employed with a three-layer feedforward backpropagation algorithm, which is a gradient descent method. All values of the input variables for the ANN model were normalised between \(-1\) and \(+1\) by using the following equation:

\[
N_i = 2 \times \frac{(N_N_{\text{min}}) / (N_{\text{max}} - N_{\text{min}}) - 1}{N_{\text{max}} - N_{\text{min}}} 
\]

(2)

where \( N_i \) stands for the normalised values, and \( N, N_{\text{min}} \) and \( N_{\text{max}} \) are the original, minimum and maximum values of the variables, respectively.

The accuracy of the model can be evaluated based on the mean absolute error (MAE), mean square error (MSE), root of mean squared error (RMSE) and coefficient of determination (\( R^2 \)). MAE, MSE and RMSE can be estimated as follows:

\[
\text{MAE} = \frac{1}{n} \sum_{i=1}^{n} |N_i - N_p| 
\]

(3)
\[
MSE = \frac{1}{n} \sum_{i=1}^{n} (N_i - N_p)^2 \tag{4}
\]

\[
RMSE = \left[ \frac{1}{n} \sum_{i=1}^{n} (N_i - N_p)^2 \right]^{0.5} \tag{5}
\]

\[R^2\] represents the linear association between the actual and predicted values.

\[
R^2 = 1 - \frac{\sum_{i=1}^{n} (N_p - N_i)^2}{\sum_{i=1}^{n} (N_i - \bar{N})^2} \tag{6}
\]

where \(n\) is the number of input values, \(N_i\) and \(N_p\) are the actual and predicted values obtained from the ANN model corresponding to the \(i\)th input, respectively, and \(\bar{N}\) is the average of the actual values.

For comparison, regression analysis (RA) was carried out, and the data were also obtained from Matlab 8.1/R2013a between hatching rate and the determining factors. In the RA model, hatching rate (%) was considered as a dependent variable, whereas parameters such as TN, TP, \textit{E. coli} abundance and DO were considered as independent variables. \(R^2\) was used to indicate the accuracy of the RA model.

3. Results

3.1. Tourism disturbance and water quality

In the high-level tourism disturbance sites, approximately \(6.20 \times 10^5\) to \(2.61 \times 10^6\) tourists were recorded in 2014–2019, and they utilised a large number of tourism facilities and intensive tourist activities. All sites are located near paved tourist walkways (distance from the habitats to the sample sites is less than 2 m). In the moderate level tourism disturbance sites, \(1.20 \times 10^4\) to \(8.73 \times 10^4\) tourists were recorded in 2014–2019, with fewer tourism facilities and activities. The distance from the habitats to the paved tourist walkways is \(3 - 50\) m. In the category of low-level tourism disturbance, \(0.80 \times 10^3\) to \(0.42 \times 10^4\) tourists were recorded in 2014–2019, with fewer tourism activities. The distance between the habitats and the paved tourist walkways is \(200 - 500\) m. The mean values of water qualities were calculated from six sampling sites in different interference areas (Table 1). The analysis of variance showed that tourism disturbance remarkably influenced the DO, TN, TP and \textit{E. coli} abundance in the water of the salamander habitats (Table S2). Thus, the mean values of water qualities were used to guide the simulated experiments. In the present study, the effects of the water quality on the hatching rate of salamander were investigated by varying one parameter whilst keeping the other parameters constant. Understanding the effect of human disturbance on the hatching rate of the salamander could provide valuable information for optimising conservation and management strategies.

3.2. Effects of TN and TP on the hatching rate of salamander

The effect of TN on the hatching behaviour of salamander at TP of \(0.098\) mg/L, DO of \(10.2\) mg/L and \textit{E. coli} abundance of \(41\) CFU/100 mL was determined. The hatching time and rate of the salamander under different TN concentrations (A, high-disturbance; B, moderate-disturbance; C, low-disturbance) are shown in Figure 3(a). The hatching times of the salamander at TN concentrations of \(0.47\), \(0.36\) and \(0.22\) mg/L were 54, 53 and
47 days, respectively. Figure 3(b) shows the hatching behaviour as a function of TP concentration at TN of 0.36 mg/L, DO of 7.5 mg/L and *E. coli* abundance of 95 CFU/100 mL. The hatching times of the salamander at TP concentrations of 0.098, 0.057 and 0.035 mg/L were 44, 42 and 44 days, while the hatching rates were 55.2%, 60.7% and 62.7%, respectively. The hatching time was remarkably shorter in the areas with low disturbance than in the moderate- or high-disturbance regions. Hatching rate was higher in the low-disturbance area than the two other areas.

### 3.3. Effect of DO on the hatching rate of salamander

Experiments on hatching process were conducted at TN of 0.36 mg/L, TP of 0.057 mg/L and *E. coli* abundance of 220 CFU/100 mL. As shown in Figure 4, the hatching times were 51, 46 and 42 days, while the hatching rates were 55.2%, 60.2% and 67.5% at DO values of 5.3, 7.5 and 10.2 mg/L, respectively.

Figure 3. The hatching times and hatching rates of the salamander’s egg under different TN(a) and TP(b) from different human intensity disturbances (A: High-disturbance; B: Moderate-disturbance; C: Low-disturbance).
3.4. Effect of E. coli abundance on the hatching rate of salamander

Tourism disturbance greatly affected the E. coli abundance in water. In the high-disturbance area, the abundance of E. coli was markedly higher than that in the two other disturbance areas (Table 1). Figure 5 describes the effects of E. coli abundance on the hatching time and rate of salamander with TN of 0.47 mg/L, TP of 0.098 mg/L and DO of 5.3 mg/L.

3.5. ANN and RA model analysis

The problem of predicting the hatching rate in this study is a fitting problem. Therefore, a three-layer feedforward network was adopted, and it is considered a promising model of the hatching process because of its simplicity in simulation and prediction (Schönfeld et al. 2021; Dong and Nastac 2021). The input and output layers were determined using
an experimental setup composed of four input neurons (TN, TP, DO and *E. coli* abundance) and one output neuron (hatching rate). The training and testing data of the ANN model are shown in Table 2. In each run, the training state usually varied with the first 100 epochs, and then approached a stable state, where the ANN performance did not improve any further.

As shown in Figure 6, after three epochs, the MSE reached its lowest value, implying that the observed values were very close to the prediction. Thus, the network training was good. The suitability of the ANN model was also confirmed based on the plots, such as the predicted versus actual value plots of the training, validation and test sets. As shown in Figure 7, the $R^2$ values were close to 1, indicating that the network training was good. Moreover, the performance of the ANN and RA models were investigated. Table 3 shows that the ANN model had a higher $R^2$ value ($R^2 = 0.9732$ for the training data; $R^2 = 0.9508$ for testing data) and lower RMSE (2.2539 for the training data; 3.2612 for the testing data).

### 4. Discussion

#### 4.1. Effects of water quality factors on the hatching rate of the salamander

Hatching time is an important index that reflects the developmental rate of the embryo. The entire embryonic development, which involves a series of steps of cell differentiation and morphogenesis, is affected internally by gene expression and externally by the nutrients in the water habitat (Peng et al. 2019). By increasing the content of TN and TP

| Run number | TN   | TP   | DO   | *E. coli* abundance | Hatching rate (%) |
|------------|------|------|------|---------------------|-------------------|
| 1          | −1   | 1    | 0    | 0                   | 58.5              |
| 2          | −1   | 0    | 1    | 0                   | 37.2              |
| 3          | −1   | 0    | −1   | 0                   | 67.5              |
| 4          | 0    | 0    | 0    | 0                   | 52.7              |
| 5          | −1   | 0    | 0    | 1                   | 43.5              |
| 6          | 1    | 0    | 0    | −1                  | 65.2              |
| 7          | 0    | −1   | −1   | 0                   | 72.8              |
| 8          | 0    | 0    | 0    | 0                   | 55.2              |
| 9          | 0    | 0    | 0    | 0                   | 54.1              |
| 10         | 0    | 0    | 1    | −1                  | 63.2              |
| 11         | 0    | 0    | 1    | 1                   | 41.7              |
| 12         | 0    | 1    | −1   | 0                   | 60.5              |
| 13         | 0    | 1    | 1    | 0                   | 55.2              |
| 14         | −1   | 0    | 0    | −1                  | 68.4              |
| 15         | 0    | 1    | 0    | −1                  | 62.7              |
| 16         | 1    | 0    | −1   | 0                   | 60.2              |
| 17         | 0    | −1   | 0    | 1                   | 47.8              |
| 18         | 0    | 1    | 0    | 1                   | 42.5              |
| 19         | 1    | 0    | 1    | 0                   | 55.2              |
| 20         | 0    | 0    | 0    | 0                   | 57.5              |
| 21         | −1   | −1   | 0    | 0                   | 62.7              |
| 22         | 0    | −1   | 1    | 0                   | 57.5              |
| 23         | 0    | 0    | 0    | 0                   | 51.2              |
| 24         | 1    | 1    | 0    | 0                   | 42.8              |
| 25         | 0    | 0    | −1   | 1                   | 52.2              |
| 26         | 0    | 0    | −1   | −1                  | 67.9              |
| 27         | 1    | 0    | 0    | 1                   | 58.5              |
| 28         | 0    | −1   | 0    | −1                  | 70.3              |
| 29         | 1    | −1   | 0    | 0                   | 62.1              |
in water, tourist activities will increase the primary biomass of the water body, thereby indirectly increasing the abundance of food resources for giant salamanders. Wang et al. (2017) sampled and analysed the river reach under different disturbance intensities in the nature reserve and found that the average biomass of macroinvertebrates in the low-disturbed area was only 2.8 g/m², and the dominant species was *Stenopsyche* sp. (biomass: 0.77 g/m²). The average biomass of the moderate-disturbed area reached 22.6 g/m², and the dominant species were *Baetis* sp. (biomass: 6.85 g/m²), *Hydropsyche* sp. (biomass: 4.94 g/m²) and *Stenopsyche* sp. (biomass: 2.42 g/m²). A certain intensity of tourism interference has no obvious negative effect on the growth and reproduction of giant salamander (Luo et al. 2020). The concentration of nutrients exceeding the tolerance of embryos will lead to the retardation or cessation of embryonic development. Moreover, the increased TN and TP in the high-disturbance stream may greatly simulate algae reproduction, which will consume a large amount of DO in water habitats. Low DO may cause metabolic dysfunction among salamanders, leading to the different hatching rates in the three disturbance regions. Similar to our results, de Solla et al. (2002) reported that high nutrient concentration in the agricultural runoff caused abnormal embryonic development of native salamander, with hatching success of only 0–11.3% in the agricultural sites and 97.5%–99.9% in the reference sites.

DO concentration in water is a crucial parameter for the assessment of the condition or evolution of the health of an aquatic ecosystem (Urbain and Miller 1930). *A. davidianus* is an amphibian that mainly lives in water, and it needs to obtain oxygen from water through skin to assist in respiration. Therefore, enough DO is needed in the water. If the DO content in the water is very low, these amphibians may leave the habitat, become weak, or even die (Luo et al. 2018a). In the present study, DO was positively related to hatching rate but negatively related to hatching time. This finding was obtained, because the oxygen consumption rate of embryo increases with the increase in DO content, thus shortening the incubation time of seedlings (Liu et al. 1995). Similar conclusions have been reported in other species, in which DO was an important ecological factor that directly affected the embryonic development (Waters and Hightower 2007; Sacerdote and King 2009). In the present study, tail fanning was the dominant behaviour involved in the fetching process, and it increased the water flow and DO concentration to satisfy the

Figure 6. Number of epochs and performance parameters in training state.
Figure 7. Regression plots of a: total set (including the training and validation set); b: training set; c: validation set; d: test set.
requirement of high DO for embryonic growth. This is an active behavioural regulation of giant salamander egg protection behaviour on low-DO water environment (Luo et al. 2018a).

Coliform is an aerobic and facultative anaerobic gram-negative non-spore bacillus, which is most sensitive to the number of tourists (Liu et al. 1995; Meng et al. 2018). In the present study, \textit{E. coli} abundance was positively related to hatching time but negatively related to hatching rate. A similar phenomenon was observed in the previous research (Luo et al. 2018a), in which high tourism disturbance greatly stimulated aquatic microbial growth. This condition may affect both the larvae and adults of the salamander, thus reducing the hatching rate. Ascites disease is usually caused by the proliferation of \textit{E. coli} (Liu et al. 2021). At the initial stage of the disease, the giant salamander shows decreased food intake, weight loss and slow reaction, and they are seen wandering alone or crawling around the pool wall. With the development of the disease, water accumulation in the abdomen and head of the giant salamander remarkably increased. When the condition is serious, the abdomen turns upward, the eyeball bulges, the liver swells and bleeding points are observed. According to the observation, severe human interference may increase the infection rate of diseases and deteriorate the maintenance of the salamander population. Consequently, the number of tourists and the scale of tourism facility development in the nature reserves need to be continuously controlled, especially in ecologically sensitive phases and areas.

### 4.2. Validation of model

ANN was previously developed from the basic concept of AI that tried to simulate the human brain and nervous system processes (Stamenković 2021). The model consists of interconnected artificial neuron groups that stimulate the brain structure to store and use knowledge and process information using a connectionist approach (Ghosal et al. 2019). It learns through examples, in which an actual measured set of input variables and corresponding output are presented to determine the rules that control the relationships between the variables (Yabalak 2018). The most frequently used ANN architecture consists of the input layer, output layer and one or more hidden layer, forming a multilayer feed forward-back propagation training network. In this set of networks, information moves forward in one direction from the input layer towards the hidden layer and finally to the output. An ANN model was developed by training the network by using a set of experimental values. After successful training, the network was used to predict the cutting force for validation and testing. Figure 7 shows the regression values of training, validation and testing of the normalised data set by using the ANN models and their plot against the experimental data for salamander hatching rate. The predicted points are coming to the close proximity of the actual value, indicating the good predictability of the ANN model.

The calculation capabilities were determined using different data obtained using the RA and ANN models, and their performances were compared by performing statistical
analysis based on indicators, such as MAE, MSE and RMSE. The correlation coefficients of the proposed regression models are provided in Table 3. Higher performances were observed in ANN approach than the RA model, because ANN behaves like an interpolation polynomial by forcing curves to pass from all modelled points, and the extended number of inputs compared to the regression model (Gülüm et al. 2018). Previous studies corroborate that ANN model is better than the RA model in terms of illustrating the influence of variables on investigated outputs (Boukelia et al. 2020; Hanief et al. 2017).

5. Conclusion

Understanding the effect of anthropogenic stressors on the salamander populations can provide valuable information for optimising conservation and management strategies. The results showed that high tourism disturbance adversely affected the hatching rate of the salamander in the Zhangjiajie Chinese Giant Salamander National Nature Reserve. Tourism might disturb the hatching process by increasing the TN, TP and E. coli abundance and reducing the DO in the water. The ANN model successfully predicted the hatching process with high $R^2$ values (0.9732 and 0.9508 for the training and testing data, respectively) and lower values of statistical error (1.8938 and 2.2539 for MAE and RMSE of the training data, respectively; 2.4967 and 3.2612 for the MAE and RMSE of the testing data, respectively). Based on the results of this study and from previous studies on the salamander hatching process, a mutual relationship exists between salamander and tourists with both direct and indirect effects in both directions. The intensity of tourism disturbance needs to be reduced by controlling the number of tourists to protect the wildlife in nature reserves.

Disclosure statement

The authors declare no conflict of interest.

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**Data availability statement**

Most of the datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

**References**

Abhinav T, Vinod K, Sagar K, Mahender R, Sergey N, Andre G, Govindhaszamy U. 2019. Physiological stress responses of tigers due to anthropogenic disturbance especially tourism in two central Indian tiger reserves. Conserv Physiol. 7(1):z45.

Adebisi OO, Adetomiwa AA, Gbala ID. 2020. Comparative assessment of bacteriological quality of drinking water using membrane filtration and multiple tube fermentation methods. JASEM. 24(5):853–856.

Almalki M. 2021. Breeding biology of saunders’s tern (Sterna sandvicensis) in the Farasan Islands, Kingdom of Saudi Arabia. Saudi J Biol Sci. 28(3):1931–1937.

Borah I, Hasin S, Popradit A, Sawasdee V, Cheentam S. 2021. Biodiversity of birds in urban green space for support ecotourism activities in Valaya Alongkorn Rajabhat University Thailand. J Environ Manag Tour. 12(4):1131–1138.

Boukelia TE, Ghellab A, Laouafi A, Bouraoui A, Kabar Y. 2020. Cooling performances time series of CSP plants: calculation and analysis using regression and ANN models. Renew Energy. 157:809–827.

Castillo-Vizuete D, Gavilanes-Montoya A, Chávez-Velázquez C, Benalcázar-Vergara P, Mestanza-Ramón C. 2021. Design of nature tourism route in Chimborazo wildlife reserve, Ecuador. IJERPH. 18(10): 5293.

De Andrade BCC, Pedrollo OC, Ruhoff A, Moreira AA, Laipelt L, Kayser RB, Biudes MS, De Santos CAC, Roberti DR, Machado NG, et al. 2021. Artificial neural network model of soil heat flux over multiple land covers in South America. Remote Sens. 13(12):2337.

Dong A, Nastac L. 2021. Prediction of secondary dendrite arm spacing in Al alloys using machine learning. Metall Mater Trans B. 52(4):2395–2403.

Ghosal PS, Javaregowda A, Gupta AK, Singh DP. 2019. A novel framework of multivariate modeling of water distribution network through 3 factorial design and artificial neural network. J Environ Sci Health A Tox Hazard Subst Environ Eng. 54(6):541–552.

Giülüm M, Onay FK, Bilgin A. 2018. Comparison of viscosity prediction capabilities of regression models and artificial neural networks. Energy. 161:361–369.

Hanief M, Wani MF, Charoo MS. 2017. Modeling and prediction of cutting forces during the turning of red brass (C23000) using ANN and regression analysis. Eng Sci Technol. 20(3):1220–1226.

Jiang R, Zhang J, Tang Y, Wang C, Feng J. 2020. A collective intelligence based differential evolution algorithm for optimizing the structure and parameters of a neural network. IEEE Access. 8: 69601–69614.

Larm M, Norén K, Angerbjrn A. 2021. Temporal activity shift in arctic foxes (Vulpes lagopus) in response to human disturbance. Global Ecol Conserv. 27:e1602.

Leclerc JC, Brante A, Viard F. 2021. Rapid recovery of native habitat-builders following physical disturbance on pier pilings offsets colonization of cryptogenic and non-indigenous species in a Chilean port. Mar Environ Res. 163:105231.

Lee C, Jung DE, Lee DH, Kim KH, Do SL. 2021. Prediction performance analysis of artificial neural network model by input variable combination for residential heating loads. Energies. 14(3):756.

Liu JY, Xiao HB, Q YY. 1995. Preliminary study on the oxygen consumption rate of Andrias davidianus embryos. Chin J Zool. 30(1):18–21.

Liu L, Ren J, Zheng FX. 2021. Analysis of a case of ascites disease of giant salamander caused by Escherichia coli. Special Econ Animals Plants. 24(8):36–37.

Luo QH, Fu L, Jiang WS, Zhou LQ, Cao W, Tian H, Chen RG. 2021. Effects of water quality on the reproductive behavior and capacity of Andrias davidianus under tourism disturbance. Chin J Appl Ecol. 32(4):1471–1478.

Luo QH, Liu Y, Zhang LY, Chen GJ, Kang LC. 2009. Investigation on resources of Chinese Giant Salamander in Zhangjiajie City. Sichuan J Zool. 28(3):422–436.
Luo QH, Song YJ, Hu X, Zhu SH, Wang H, Ji HB. 2018a. Effects of tourism disturbance on habitat quality and population size of the Chinese giant salamander (Andrias davidianus). Wildl Res. 45(5):411–420.

Luo QH, Tao SX, Jiang WS, Hu X, Liu K, Chen JH, Fu L, Cao W. 2020. Influence of tourism disturbance on prey fish and population size of Chinese giant salamander (Andrias davidianus) in Zhangjiajie city. Life Sci Res. 24(3):199–207.

Luo QH, Tong F, Song YJ, Wang H, Du ML, Ji HB. 2018b. Observation of the breeding behavior of the Chinese Giant Salamander (Andrias davidianus) using a digital monitoring system. Animals. 8(10):161.

Luo QH, Tong F, Tao SX, Cao W, Fu L, Zhu SH. 2019. Effects of tourism disturbance on the habitat and water quality for Andrias davidianus in Zhangjiajie, Hunan, China. Chin J Appl Ecol. 30(6):2101–2108.

Ma HB, Wang YH, Wang FH. 2021. Influence of new breeding equipment on water environmental factors in giant salamander reproduction. Agric Technol Equip. 11:142–143.

Meng Y, Tian HF, Hu QM, Xiao HB. 2018. Factors affecting reproductive performance of female giant salamander. Sci Fish Farming. 7:9–10.

Neves MB. 2020. The role of fire disturbance on habitat structure and bird communities in South Brazilian Highland Grasslands. Sci Rep. 10:19708.

Pan Y, Wei G, Cunningham AA, Li S, Chen S, Milner-Gulland EJ, Turvey ST. 2016. Using local ecological knowledge to assess the status of the Critically Endangered Chinese giant salamander Andrias davidianus in Guizhou Province, China. Oryx. 50(2):257–264.

Pathak P, Panday SB, Ahi J. 2022. Artificial neural network model effectively estimates muscle and fat mass using simple demographic and anthropometric measures. Clin Nutr. 41(1):144–152.

Peng RB, Jiang MW, Huang C, Jiang XM. 2019. Toxic effects of ammonia on the embryonic development of the cuttlefish Sepia pharaonis. Aquac Res. 50(2):505–512.

Ranaweerage E, Ranjeewa A, Sugimoto K. 2015. Tourism-induced disturbance of wildlife in protected areas: a case study of free ranging elephants in Sri Lanka. Global Ecol Conserv. 4:625–631.

Ren H, Wang F, Ye W, Zhang Q, Han T, Huang Y, Chu G, Hui D, Guo Q. 2021. Bryophyte diversity is related to vascular plant diversity and microhabitat under disturbance in karst caves. Ecol Indic. 120:106947.

Rohr JM, Meiners SJ, Thomas TD, Colombo RE. 2021. Recovery of riverine fish assemblages after anthropogenic disturbances. Ecosphere. 12(4):e3459.

Sacerdote AB, King RB. 2009. Dissolved oxygen requirements for hatching success of two ambystomatid salamanders in restored ephemeral ponds. Wetlands. 4(29):1202–1213.

Saha TK, Pal S, Sarkar R. 2021. Prediction of wetland area and depth using linear regression model and artificial neural network based cellular automata. Ecol Inf. 62(5):101272.

Schöpfel A-B, Mund K, Yan G, Schöpfel AA, Looe HK, Poppe B. 2021. Corrections of photon beam profiles of small fields measured with ionization chambers using a three-layer neural network. J Appl Clin Med Phys. 22(12):64–71.

Segov O, Hill N, Templeton AR, Blaustein L. 2010. Population size, structure and phenology of an endangered salamander at temporary and permanent breeding sites. J Nat Conserv. 18(3):189–195.

Sharma S, Gupta R, Bhatia R, Toor AP, Setia H. 2021. Predicting microbial response to anthropogenic environmental disturbances using artificial neural network and multiple linear regression. Int J Cogn Comput Eng. 2:65–70.

Smith JR, Lindborg RJ, Hernandez V, Abney EA, Witherington BE. 2021. Using behavior indices and vital rates to determine the conservation impact of wildlife tourism: guided sea turtle watch programs in Florida. Global Ecol Conserv. 27:1–87.

Sternfeld A-B, Mund K, Yan G, Sternfeld AA, Looe HK, Poppe B. 2021. Corrections of photon beam profiles of small fields measured with ionization chambers using a three-layer neural network. J Appl Clin Med Phys. 22(12):64–71.

Waters CT, Hightower JE. 2007. Effect of water quality on hatching success of blueback herring eggs in the Chowan River Basin, North Carolina. Proc Annu Conf SEAFWA. 61:23–28.

Wang CR, Liang ZQ, Suo WW, Wu YA, He P, Wu J, Wei QW, Liu XH. 2017. Relationship between macroinvertebrate composition and environmental factors in habitats of Chinese giant salamander in Zhangjiajie, Hunan Province, China. Chin J Appl Ecol. 28(9):3032–3040.

Wu FT, Su QX, Li WJ, Deng RJ. 2007. Water environment factors of Chinese giant salamander habitat in Hupingshan natural reserve. J Changsha Univ Sci Technol. 4:94–98.
Xu W, Gong Y, Wang H. 2021. Alert time reflects the negative impacts of human disturbance on an endangered bird species in Changbai Mountain, China. Global Ecol Conserv. 28(6):e1709.

Yabalak E. 2018. Degradation of ticarcillin by subcritical water oxidation method: application of response surface methodology and artificial neural network modeling. J Environ Sci Health A Tox Hazard Subst Environ Eng. 53(11):975–985.

Zhang H, Jia L, Wang H. 2003. Microstructure and ultrastructure of atretic follicles in the Chinese giant salamander Andrias davidianus. Acta Zool Sinica. 50(4):615–621.

Zhang H, Zhong SW, Ge TT, Peng SS, Yu PC, Zhou ZH, Guo XQ. 2016. Telocytes in ileum of the Chinese giant salamander: ultrastructural evidence. J Cell Mol Med. 20(3):568–574.