Potential impact of land-use change on habitat quality in the distribution range of crocodile lizards in China

Xiaoli Zhang1,2 | Xudong Qin3 | Facundo Alvarez4 | Zening Chen1,2 | Zhengjun Wu1,2

1Key Laboratory of Ecology of Rare and Endangered Species and Environmental Protection (Guangxi Normal University), Ministry of Education, Guilin, China
2Guangxi Key Laboratory of Rare and Endangered Animal Ecology, Guangxi Normal University, Guilin, China
3Guangxi Daguishan Crocodile Lizard National Nature Reserve, Hezhou, China
4Programa de Pós-graduação em Ecologia e Conservação, Campus Nova Xavantina, Universidade do Estado de Mato Grosso, Brazil

Correspondence
Zhengjun Wu and Zening Chen
Key Laboratory of Ecology of Rare and Endangered Species and Environmental Protection (Guangxi Normal University), Ministry of Education, Guangxi, Guilin 541004, China.
Email: wu_zhengjun@aliyun.com and chenzn@gxnu.edu.cn

Funding information
Biodiversity Survey, Monitoring and Assessment Project of Ministry of Ecology and Environment, China, Grant/Award Number: 2019HB2096001006; Natural Science Foundation of Guangxi Province, Grant/ Award Number: AD2122005B; Guangxi Natural Science Foundation; National Natural Science Foundation of China, Grant/Award Number: 31760623 and 32160131

Abstract
The over-exploitation of land resources poses a serious threat to biodiversity on a global scale. Changes in land-use and human exploitation have had a major impact on wild populations and their habitat in China. We assessed how habitat quality has changed over time (1995–2020). Specifically, we analyzed how the habitat quality of crocodile lizard has changed over time based on multi-temporal land-use data (1995, 2000, 2010, 2015 and 2020) using a land-use transfer matrix and habitat quality model. The results showed that the main landscape types in the study area were arable land (21.21% of the area) and woodland (69.59% of the area) during the period. Construction land (land used for development) had decreased by 991 km², a decrease rate of 59.84% from 1995 to 2000, and increased to 2349 km², an increase rate of 71.69% from 2000 to 2020. The proportion of grasslands and areas with water were negligible and overall, did not vary significantly in size over the study period. The main feature of land use change in the study area was the loss of grasslands and woodlands through development. The habitat quality model indicated that habitat quality was highest and degradation was lowest in Dayao mountain, Guxiu town, Qichong village and Beituo town. Habitat quality improved in Daguishan and Luokeng areas. Habitat quality was good in Daping mountain and Linzhouding, but they were highly fragmented with patches of low-quality habitat of varying sizes. Habitats were severely degraded in the Dateng Gorge area. The rate of habitat degradation has slowed over time in the study area, but gradually increased in degradation intensity, and low-quality habitats were widely distributed and overlapped with the crocodile lizards distribution area. We recommend that protected areas for the crocodile lizard be more closely monitored and managed to halt further decline in habitat quality.

KEYWORDS
environment landscape, habitat quality, InVEST, Shinisaurus crocodilurus, space–time evolution

TAXONOMY CLASSIFICATION
Conservation ecology, Landscape ecology, Population ecology, Zoology
1 | INTRODUCTION

Habitat quality refers to the ability of an ecosystem in a specific time and space to provide suitable and sustainable environments for organisms (Regolin et al., 2021). Habitat quality and availability can be used as proxies for biodiversity (Sharp et al., 2018). Understanding the spatiotemporal variability of habitat quality is important for expanding ecological conservation of wildlife (e.g., protect genetic diversity, predict population dynamics) (Crawford & Nusha, 2018; Thornton et al., 2013). In general, habitat quality varies with the intensity of nearby land use (Liu et al., 2022). Land use types, intensities and patterns alter the condition of natural resources and thus affect the survival and reproduction of wildlife (Dai et al., 2019; Whittington et al., 2019). Biogeochemical cycles and habitat quality for animals and plants are changed because of increased human disturbance (Abbott et al., 2019; Kiskaddon et al., 2019; Lin et al., 2020; Powers & Jetz, 2019). And changes in these cycling processes may have adverse effects on the structure and function of ecosystems. With urban expansion and development of land in developing countries, habitat quality is increasingly influenced at the landscape level, which has made habitat conservation to be an urgent issue (Liu et al., 2022).

Urbanization and industrialization have accelerated since the 20th century, and the over-exploitation of land resources poses a severe threat to biodiversity (Deng et al., 2021). Because over-exploitation of land can result in habitat degradation, fragmentation and loss (Brudvig et al., 2015). Several studies have concluded that land-use and land-cover changes (LULCC) activities are intensifying, and that wildlife habitat is increasingly being developed for agriculture and infrastructure (Jha & Bawa, 2006; Karki et al., 2018; Khan et al., 2021; Newbold et al., 2015). Evidence from different taxa and geographical regions suggested that land-use was not equally affected all organisms in terrestrial ecological communities and that different functional groups of species may respond differently (Felipe-Lucia et al., 2020; Newbold et al., 2020). The Researchers expected large carnivore populations to decline more in disturbed land than other animal groups (Newbold et al., 2020). However, amphibians and reptiles are the two most vulnerable groups of terrestrial vertebrates, being at a significantly higher risk than mammals and birds for threats such as habitat loss and fragmentation (Mayani-Parás et al., 2019). Amphibians and reptiles generally have low dispersal abilities and are more habitat specialists than other vertebrates, making them particularly sensitive to landscape changes (Audrey et al., 2016; Joly et al., 2003; Wang et al., 2020). Therefore, habitat degradation and destruction are the focus of amphibian conservation. Despite many related studies have been conducted in mammals, birds, amphibians, it is amazing that little attention has been paid on reptiles (Gibbons et al., 2000) and are likely to be at a high risk of extinction (IUCN, 2006). The destruction and fragmentation of habitats reduce the structural complexity and functional integrity of habitats occupied by reptiles (Liu et al., 2016). Several factors, such as habitat loss, water pollution, climate change and mining, have been identified as negatively affecting breeding activities, reproduction and survival for reptiles (Becker et al., 2007; Gardner et al., 2007). These processes cause significant interference to the survival, reproduction and spread of reptiles, affecting species composition and community structure (Hung et al., 2017). Lately, these processes have also caused population declines due to the obstruction of population genetic exchange, reducing the range size of the species and resulting in local population extirpation (Mayani-Parás et al., 2019).

Thus, effectively assessing and monitoring biodiversity and habitat quality changes and identifying the mechanisms causing these changes are essential for ecological management in fast-changing and human-dominated regions (Sun et al., 2019). There are three primary methods commonly used to evaluate changes in biodiversity and habitat quality: traditional field and habitat surveys (Do Nascimento et al., 2020), assessments of ecological indicators (Coates et al., 2016; Riedler & Lang, 2018) and simulations using ecological models (Akbari et al., 2021; Sallusto et al., 2017). Traditional terrestrial habitat monitoring methods are often time consuming, and their accuracy is difficult to assess due to differences between subjects (Lengyel et al., 2008). The Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) when used to evaluate biodiversity indicators or proxies of biodiversity, is a powerful tool to monitor biodiversity dynamics and habitat quality, especially in areas with limited available data on biodiversity (Sharp et al., 2016). Among the InVEST models, the habitat quality assessment model relies on the proximity of habitats to human land-use and the intensity of land-use (Sharp et al., 2018). Habitat quality is affected by habitat suitability, threats due to habitat quality reduction factors, habitat sensitivity to reduction factors and access to the habitat (Lee & Jeon, 2020). InVEST models introduced habitat quality as a proxy for biodiversity assessment (Gong et al., 2019). This approach allows for a rapid assessment of the status and changes in biodiversity status as a proxy for a more detailed biodiversity status (Sun et al., 2019).

The crocodile lizard (Shinisaurus crocodilurus Ahl, 1930) is a monotypic species in the monotypic family Shinisauridae. It is an ancient lineage from the Pleistocene, with ~100 million years of evolutionary history (Xie et al., 2021). Individuals of this species are diurnal, semiaquatic, viviparous and occur in rocky streams in cool mountain forests in southern China and northern Vietnam (Huang et al., 2008; van Schingen, Schepp, et al., 2015). The species is threatened with extinction due to continued deforestation, habitat destruction and poaching. As such, it is listed as endangered by the International Union for Conservation of Nature (IUCN) (Nguyen et al., 2014). Here, in order to fully analyze changes in habitat quality across the crocodile lizards distribution range, in conjunction with a habitat quality model, we set two main objectives: (1) analyzing land-use change in the study area from 1995 to 2020 and (2) assessing habitat quality in the crocodile lizards distribution areas of Guangdong and Guangxi.
2 | MATERIALS AND METHODS

2.1 | Study area

The distribution range of crocodile lizards is restricted to southern China and northern Vietnam, where suitable habitat consists of small, isolated, fragmented and steadily shrinking habitat patches (Huang et al., 2008; Le & Ziegler, 2003; van Schingen, Ihlow, et al., 2014). Within Guangdong and Guangxi, populations are relatively scattered and far apart (Figure 1). Therefore, we selected part of the Pearl River Basin as the primary research area, including all crocodile lizards distribution areas (102°14′ to 115°53′ E, 21°31′ to 26°49′ N). This river spans the Yunnan-Guizhou Plateau, the hills of Guangdong and Guangxi and the Pearl River Delta Plain from west to east (He et al., 2018; Wang et al., 2021). The climate in the study region has subtropical monsoon features, where the annual average temperature is approximately 14–21°C. And annual precipitation ranges between 1200 and 2200 mm (Wu et al., 2019), decreasing from southeast to northwest and primarily falling during April–September. The dominant vegetation is composed of evergreen forests (~65.3%), followed by cropland (~18.1%) (Wang et al., 2021). They are mainly distributed in the middle of the basin, which happens to be in the transitional areas of high-to-low elevations in Guangxi province (Wang et al., 2021).

2.2 | Data collection

Land-use and land-cover maps from 1995, 2000, 2010, 2015 and 2020 (1×1 km) were used in this research. Data from the crocodile lizards' distribution area mainly include the Dayao mountain, the Guxiu area, the Mengshan area, the Qichong area, the Beituo area, the Daguishan area, the Luokeng area and the Maoming. Crocodile lizards have been reported from all of these areas (Huang et al., 2008; Zhang, 1991). County-level administrative zoning map and protected area boundary data were analyzed. The county-level administrative zoning map was obtained from the Ministry of Natural Resources of China (http://bzdt.ch.mnr.gov.cn). Land-use and land-cover maps came from the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (http://www.resdc.cn).

2.3 | Land use transfer matrix

Land use data were classified in three levels, according to the "China Land Use/Land Cover Remote Sensing Monitoring Data Classification System" (https://www.resdc.cn/). We reclassified landscape types into 14 different types (Table 1). Then, we overlaid land use data from 1995, 2000, 2005, 2010, 2015 and 2020 to construct the land-use transfer matrix, input/output direction and the area of each type of land-use within the study area using the spatial analysis tools in ArcGIS10.6 (ESRI, America).

2.4 | InVEST-Habitat quality model

The InVEST model allows for the calculation of habitat quality by combining the sensitivity of landscape type and the intensity of external threats by assessing the service function of biodiversity based on habitat quality (Peng et al., 2018). In ecology, the InVEST model has been successfully used to assess land-use change and regional habitat quality. Plant ecology, animal ecology or bird ecology studies tend to target specific species and populations in target regions, assessing the habitat quality of biodiversity service functions.

FIGURE 1 Geographic location of the study area, regional hydro-topographic configuration and occurrence data for the target species.
(Bhagabati et al., 2014). Habitat quality was determined by a function using four factors: (1) the relative impact of each threat, (2) the relative sensitivity of each habitat type to each threat, (3) the distance between habitats and (4) sources of threats (Chen et al., 2016). At the pixel scale, the threat level of each pixel cell was translated into habitat quality using the total threat level and a half-saturation function. The formula we used follows (Sharp et al., 2014):

\[
Q_{xj} = H_j \times \left[ 1 - \left( \frac{D_{xj}}{D_{xj}^* + k^*} \right) \right] \quad (1)
\]

where \(Q_{xj}\) is ecological habitat quality value of land use type \(j\), \(H_j\) is a habitat quality score ranging from 0 to 1, where non-habitat land-use types are given by a score of 0, and perfect habitat classes score 1. In our study, \(H_j\) is the habitat suitability in Table 3. \(k\) is the half-saturation constant (Liang & Liu, 2017; Sun et al., 2015) and \(z\) is a constant.

\[
D_{xj} = \sum_{r=1}^{R} \sum_{y=1}^{Y} \left( \alpha_r / \sum_{r=1}^{R} \alpha_r \right) r_{xy} \beta_j \text{S}_p \quad (2)
\]

where \(D_{xj}\) represents the total threat level of the grid \(x\) in LULC or habitat type \(j\), \(y\) indexes all grid cells on \(r\)'s raster map and \(Y\) indicates the set of grid cells on the raster map of \(r\). Note that each threat map can have a unique number of grid cells due to variation in raster resolution. \(\alpha_r\) is the weight; \(r_{xy}\) is the number of stress factors on the grid unit; \(\beta_j\) is the accessibility level of grid \(x\); \(S_x\) is the sensitivity of landscape \(j\) to stress factors, ranging from 0 to 1; \(i_{xy}\) is the stress factor influence distance. If \(S_p = 0\) then \(D_{xj}\) is not a function of threat \(r\). In our study, \(S_p\) is the sensitivity of different land use types to different ecological threat factors in Table 3. Also, note that threat weights are normalized so that the sum across all threat weights equals 1. The impact of threat \(r\) that originates in a grid cell \(y\), \(r_{xy}\) on habitat in a grid cell \(x\) is given by \(i_{xy}\). It is represented by the following equations, mainly including the linear or exponential distance-decay function:

\[
i_{xy} = 1 - \left( \frac{d_{xy}}{d_{max}} \right) \text{if linear} \quad (3)
\]

\[
i_{xy} = \exp \left( - \left( \frac{2.99}{d_{max}} \right) d_{xy} \right) \text{if exponential} \quad (4)
\]

where \(d_{xy}\) is the linear distance between grid cells \(x, y\) and \(d_{max}\) is the maximum effective distance of the reach across the threat space. Generally, the impact of a threat on a habitat decreases as the distance from the degradation source increases, so that grid cells that are more proximate to threats will experience higher impacts (Sharp et al., 2014).

We referred to InVEST model manual and related research, combined with the actual situation of the study area and crocodile lizards distribution areas (Huang et al., 2008), to determine the relevant parameter values (Sharp et al., 2014). We considered arable land, reservoirs, urban land, rural settlements and construction land as the main ecological threats to crocodile lizard habitat quality (Table 2). The ecological threats are weighted, reflecting the intensity of interference with the habitat types. We set the maximum range of action of each stressor, which means that the interference intensity of the stressor to the habitat types decreases with increasing distance. At the same time, we chose the attenuation function to describe the mode of threat mitigation in space. We assigned a value to the sensitivity of these threat factors (Table 3)—the higher the value, the more sensitive it is to ecological threats.

**Table 1** Classification system of land-use in study area.

| Code number | Land-use types | Code number | Land-use types |
|-------------|---------------|-------------|---------------|
| 1           | Arable land   | 41          | Canals        |
| 3           | Grasslands    | 43          | Reservoir ponds |
| 6           | Unused lands  | 45          | Tidal flats   |
| 21          | Woodlands     | 46          | Beaches       |
| 22          | Bush forests  | 51          | Urban lands   |
| 23          | Sparse woodlands | 52         | Rural settlements |
| 24          | Other woodlands | 53         | Construction land |

**Table 2** Stress factors of the study area with their corresponding weight values, impact distances and types of response.

| Stress factors | Maximum impact distance/km | Weight | Decay type |
|----------------|-----------------------------|--------|------------|
| Arable land    | 8                           | 0.8    | Exponential |
| Reservoir      | 3                           | 0.5    | Exponential |
| Urban land     | 6                           | 0.75   | Exponential |
| Rural settlements | 10                     | 1      | Exponential |
| Other construction land | 1         | 0.4    | Linear     |

**2.5 Data processing**

According to the guidance of the user manual (Sharp et al., 2014), rasterise land use data. All threats should be measured in the same scale and units (i.e. all measured in density terms or all measured in presence/absence terms) and not some combination of metrics (Sharp et al., 2014). Areas classified as “No Data” in the threat maps were reclassified. When the pixel did not contain a threat, we set the threat level for that pixel to zero (Sharp et al., 2014). According to the natural breakpoint method in ArcGIS software, the grid habitat quality of each study period was divided into four categories: poor (0–0.2), medium (0.2–0.5), good (0.5–0.7) and high (0.7–1.0) (Deng et al., 2021).
3 | RESULTS

3.1 | Land use change from 1995 to 2020

Our results showed that the leading landscape types in the study area were arable lands and woodlands in the past 25 years. The largest proportion of the area was woodland, which accounts for approximately 69.59% of the total study area, while arable land accounted for approximately 21.21%. Regarding the area change of each land-use type, the arable lands acreage showed a downward trend decreasing from 18,405 km² to 17,864 km² between 1995 and 2020. Although the arable areas steadily decreased, the woodlands areas in the region remained relatively stable over time, covering near 60,233.60 km². Construction land (land used for development) areas had decreased by 991 km², a decrease rate of 59.84% from 1995 to 2000 and increased to 2349 km², an increase rate of 71.69% from 2000 to 2020. The proportion of grasslands area and water areas was negligible and overall they did not vary a lot in size over the study period (Figure 2).

The land-use transfer matrix showed that arable land and grassland gained land converted from woodland, as well as conversely woodland gained land converted from arable land and grassland. At the same time, construction land was growing in a faster way, with construction land gaining land converted from grassland and woodland during the study period (Table 4). From 1995 to 2020, 671,000 km² of arable land was converted to woodland, accounting for 68.41% of the area transferred from woodland. 655,000 km² of

---

**TABLE 3** Sensitivity of different land use types to different ecological threat factors.

| Code | Land use type              | Habitat suitability | Ecological threat factors | Arable land | Reservoir | Urban land | Rural settlements | Other construction land |
|------|---------------------------|---------------------|---------------------------|-------------|-----------|------------|-------------------|--------------------------|
| 0    | No data                   | 0                   |                           | 0           | 0         | 0          | 0                 | 0                        |
| 1    | Agricultural lands         | 0                   |                           | 0           | 0         | 0          | 0                 | 0                        |
| 3    | Grassland                 | 0                   |                           | 0           | 0         | 0          | 0                 | 0                        |
| 6    | Unused land               | 0                   |                           | 0           | 0         | 0          | 0                 | 0                        |
| 21   | Woodland                  | 0.8                 |                           | 0.8         | 0.5       | 0.7        | 0.7               | 0.5                      |
| 22   | Bush forest               | 1                   |                           | 1           | 0.9       | 0.6        | 0.7               | 0.6                      |
| 23   | Sparse woodland           | 0.6                 |                           | 0.6         | 0.6       | 0.6        | 0.8               | 0.4                      |
| 24   | Other woodland            | 0.1                 |                           | 0.3         | 0.4       | 0.2        | 0.2               | 0.3                      |
| 41   | Canal                     | 1                   |                           | 1           | 0.9       | 0.9        | 0.7               | 0.7                      |
| 43   | Reservoir pond            | 0                   |                           | 0           | 0         | 0          | 0                 | 0                        |
| 45   | Tidal flat                | 0                   |                           | 0           | 0         | 0          | 0                 | 0                        |
| 46   | Beach                     | 0                   |                           | 0           | 0         | 0          | 0                 | 0                        |
| 51   | Urban land                | 0                   |                           | 0           | 0         | 0          | 0                 | 0                        |
| 52   | Rural settlement          | 0                   |                           | 0           | 0         | 0          | 0                 | 0                        |
| 53   | Other construction land    | 0                   |                           | 0           | 0         | 0          | 0                 | 0                        |

**FIGURE 2** Annual surface variation, from 1995 to 2020, of the different land uses within the study area.
With the areas converted to construction land in the past 10 years, 22.95% of the area transferred from grasslands was converted into woodlands, accounting for 22.95% of the total area converted to construction land, respectively. Calculated in stages, the largest land-use type was woodland in the study area between 1995 and 2000. Woodland significantly increased by gaining land converted from other land use types, mainly from grassland (4100hm$^2$) and arable land (500hm$^2$), accounting for 93.35% of the area converted from grassland and 16.13% of the area converted out of cropland, respectively. From 2000 to 2010, construction land, woodland and areas with water sources became the main land-use types. Woodland has gained access to land converted from other land use types, mainly from arable lands (4900hm$^2$) and grasslands (11,800hm$^2$). Construction land (11,000hm$^2$) and water areas (4000hm$^2$) all gained land converted from other land use types, mainly from arable land and woodlands. From 2010 to 2020, 124,700hm$^2$ of arable land and 71,400hm$^2$ of woodland was converted to construction land, increasing nearly 18-fold compared with the areas converted to construction land in the past 10 years.

### 3.2 Temporal and spatial dynamics of habitat quality

#### 3.2.1 Habitat quality in the Pearl River Basin

Based on the habitat quality calculations (Table 5), the habitat quality in the study area showed a "decrease–increase" trend from 1995 to 2020, consistent with the results of the land-use transfer matrix. The standard deviation of the habitat quality index increased from 0.7218 to 0.7250 between 1995 and 2015 (Table 5). The maximum habitat degradation degree decreased from 0.1301 to 0.1285 from 1995 to 2015. Nevertheless, the maximum of the habitat degradation degree increased to 0.1332 after 2015 (Table 5). The habitat quality model showed that habitat quality within the study area did not vary significantly over time scales. Low habitat quality areas were widely distributed, mainly concentrated in counties and districts around the crocodile lizards' range (Figure 3).

#### 3.2.2 Habitat quality of *Shinisaurus crocodilurus* distribution area

We calculated the habitat quality index of the crocodile lizards' distribution area separately (Table 6). The habitat quality index of the crocodile lizards' distribution area was consistent with the results of the whole study area, which first decreased and then increased. The degree of habitat degradation was different from that of the entire study area. The mean value of the habitat degradation degree declined from 1.9353 to 1.9060 between 1995 and 2015. After that, the mean value of the habitat degradation degree increased to 1.9356 and the maximum value decreased from 5.8231 to 5.5984.

Spatial distribution of habitat quality indicated that the Dayao Mountain (DYS), Guxiu, Qichong (GX) and Beituo areas (BT) had the highest habitat quality and the lowest degree of habitat degradation during the period (Figures 4 and 5). Subsequently, habitat quality in the Dagui Mountain (DGS) and Luokeng areas (LK) remains positive, with some areas of poor habitat quality. Habitat quality was better in Daping Mountain (DPS) and Linzhouding (LZD), but these patches were highly fragmented patches and low-quality patches of varying sizes. The worst habitat quality was found in the Dateng Gorge area (DTX) and accompanied by large-scale anthropogenic disturbance (Figure 5).

### 4 DISCUSSION

#### 4.1 The impact of land-use change on the crocodile lizards' habitat

In our study, the land-use transition matrix was used to explore the temporal and spatial changes in land-use types in the lizards' distribution range. We found that the main landscape types in the study area were arable land and woodland during the period 1995 to 2020. Over time, the construction land shows a “decrease–increase”, especially from 2000 to 2020, during which construction land area peaked at 71.69%. From 2010 to 2020, a large amount of arable land and woodland was used for economic development or rural residences. Therefore, it was probable that the study area has experienced rapid economic development and urbanization in the past 25 years (Zhang et al., 2018). It is worth noting that the change in the range of the crocodile lizards fitted with the pattern of land-use change in the study area. In other words, as the area of construction land increased, the crocodile lizards’ distributions range gradually decreased. These results suggested that land-use change had a negative impact on the habitat of the crocodile lizards. A survey showed that none of the previously reported crocodile lizards were found in Xiali and Beituo of Mengshan County and Xianhui of Zhaoping County in Guangxi, and the crocodile lizards in these areas may have become extinct (Huang et al., 2008). At the same time, suitable habitat is steadily shrinking due to illegal logging and coal mining (van Schingen et al., 2016). Species distribution models showed that potentially suitable habitat for crocodile lizards is fragmented, small and disconnected with extremely poor coverage within protected areas (van Schingen, Ihlow, et al., 2014). The negative impact was also evident in the Yangtze River basin, where wildlife habitat degradation has increased in the middle and lower reaches of the Yangtze (Li et al., 2021). The negative impacts of urbanization on habitat quality have surpassed the positive effects of environmental protection programs (Li et al., 2021). Established areas extended further into natural habitats (Haase et al., 2014; Hennig et al. 2015), and such encroachment may ultimately affect conservation hotspots, even
if they are located far from urban centers (McDonald et al., 2014). Therefore, in order to prevent the ecological disaster caused by the loss of biodiversity, the implementation of environmental protection policies, along with environmental conservation and restoration programs, must be rigid (Li et al., 2021).

### 4.2 Habitat quality change of crocodile lizards

The InVEST model showed that the low-quality habitats were widely distributed, mainly in the periphery of the crocodile lizard’s distribution areas. High-quality habitats were concentrated...
in the mountainous forest areas in the central and eastern part of the study area, mainly DYS, GX, QC, BT, DGS and LK. Our study was consistent with previous fieldwork investigations. The long evolutionary history of crocodile lizards as well as their life history traits make them highly sensitive to environmental conditions (Wu et al., 2012; Ziegler et al., 2019). Crocodile lizards are “living fossils”, and the only surviving member of their family (Xie et al., 2021). The ecological niche of crocodile lizards are in valleys below 800 m.a.s.l. and appears to be restricted to tiny sections of clean and remote streams (van Schingen, Pham, et al., 2015; Wu et al., 2007; Zhao et al., 2006; Ziegler et al., 2019). High habitat quality areas, such as DYS, GX, QC and BT are mainly located in sparsely populated mountainous areas (e.g. within Jinxiu county, Mengshan county and Zhaoping county). During the Cenozoic era, Dayao Mountain (DYS) was located in the central region of the Guangxi Arcuate Mountains, an essential pathway for animal migration in the Guangxi province (Huang et al., 2014), where the terrain was high in the middle, before dropping off, and the climate was warm and rainy. Based on genetic analyses and population demography of crocodile lizards, Dayao Mountain (DYS) may be an ancient refuge for this species in the history (Huang et al., 2014). Guangxi and Luokeng might have been the source of an initial population expansion (Huang et al., 2014). Initial field surveys showed that between 1977 and 1991, the main distribution sites of crocodile lizards in Guangxi were within DYS, BT, DGS, QC, GX and MS (Zhang, 1991; Zhang et al., 2005). From 2001 to 2004, the main distribution sites of crocodile lizards in Guangxi decreased, with crocodile lizards present in the wild mainly in DYS, BT and DGS (Zhang et al., 2005). Field surveys in 2008 showed that none of the previously reported crocodile lizards were found in BT of Mengshan County in Guangxi, and the crocodile lizards in these areas may have become extinct (Huang et al., 2008). Poaching and habitat fragmentation may be responsible for the result (Huang et al., 2008; Ziegler et al., 2019). At the same time, crocodile lizards have high requirements for water quality in their habitat. In Vietnam, streams inhabited by crocodile lizards are characterized as soft waters (GH < 1–2) (where GH = general hardness) with a high-water quality, indicated by a high oxygen content, and low nutrient concentrations of nitrogen and phosphate (van Schingen, Pham, et al., 2014; Ziegler et al., 2019). Furthermore, the water ranges from neutral to relatively acidic conditions with pH values ranging from 4.5 to 7.37, while pH values of 6.5 were measured in Dayaoshan Nature Reserve, Guangxi, China (DYS; Long et al., 2007; van Schingen, Pham, et al., 2014). And crocodile lizards prefer habitats with sandy water substrates because the abundance of sand in the water body provides a buffering effect and also enables crocodile lizards to climb from out of the water to land (Wu et al., 2012).

Our results showed that the habitat quality in the Dateng Gorge has been poor in the past 25 years, with high levels of habitat degradation. This might be connected with the construction of water conservancy and hydropower projects. The Dateng Gorge is a canyon in the lower reaches of the Qianjiang River in the West River system of the Pearl River Basin, formed by the Qianjiang waterway between the Dayao Mountains and the Lotus Mountains (Yang et al., 2017). The connection of the mountains may provide a migration channel for the crocodile lizards, which may be a fundamental reason for its presence (Yang et al., 2017). Upon completion of the Dateng Gorge Water Conservancy Project, the downstream area of the ditch in the Dawandu sub-field where crocodile lizards had been recorded, especially the creeks where crocodile lizards are widely distributed, will be submerged to the middle reaches (Yang et al., 2017). Hydropower facilities fragment streams into several channel segments and can alter the flow and sediment regimes (Csiki & Rhoads, 2014; Fantin-Cruz et al., 2015; Takahashi & Nakamura, 2011) and inhibit the dispersal of riparian plants and the migration of aquatic organisms (Andrea et al., 2012; Chen et al., 2015; Fencl et al., 2015; Perkin et al., 2015; Zhang et al., 2021). The situation has resulted in the loss of better quality habitat for crocodile lizards or even a break in flow, which had a significant negative impact on the growth and development of crocodile lizards (Yang et al., 2017). Moreover, during the construction of mining roads, large amounts of blasting and excavation debris were dumped into the stream, causing the pollution of inhabited streams (van Schingen, Pham, et al., 2014; van Schingen, Schepp, et al., 2015; Yu et al., 2005). And local villagers often use electro-fishing and poisonous chemicals to fish in the stream and this can kill all of the crocodile lizards in the water (Huang et al., 2008), further exacerbating the decline of wild populations and loss of habitat. Thus, future economic development in the Dateng Gorge area should be minimized in order to protect the current limited habitat of the crocodile lizards.

### TABLE 5 Spatial statistics of habitat quality and degradation in the study area.

| Year | Statistical parameters of habitat quality | Statistical parameters of habitat degradation degree |
|------|------------------------------------------|--------------------------------------------------|
|      | Minimum | Maximum | Average | Standard deviation | Minimum | Maximum | Average | Standard deviation |
| 1995 | 0       | 0.999   | 0.4505  | 0.3218           | 0       | 0.1301  | 0.0218  | 0.0205           |
| 2000 | 0       | 0.999   | 0.4487  | 0.3221           | 0       | 0.1301  | 0.0217  | 0.0205           |
| 2010 | 0       | 0.999   | 0.4431  | 0.3235           | 0       | 0.1299  | 0.0214  | 0.0203           |
| 2015 | 0       | 0.999   | 0.4408  | 0.3250           | 0       | 0.1285  | 0.0211  | 0.0202           |
| 2020 | 0       | 0.998   | 0.4458  | 0.3248           | 0       | 0.1332  | 0.0211  | 0.0199           |
FIGURE 3  Spatial–temporal distribution characteristics of habitat quality and habitat degradation from 1995 to 2020. For habitat quality, red indicates high habitat quality and blue indicates low habitat quality; for habitat degradation, red indicates severe habitat degradation and blue indicates weak habitat degradation.

TABLE 6  Spatial statistics of habitat quality and degradation in the crocodile lizards’ distribution area.

| Year | Statistical parameters of habitat quality | Statistical parameters of habitat degradation degree |
|------|------------------------------------------|---------------------------------------------------|
|      | Minimum | Maximum | Average | Standard deviation | Minimum | Maximum | Average | Standard deviation |
| 1995 | 0        | 0.9665  | 0.6838  | 0.1971            | 0        | 5.8231  | 1.9353  | 0.8633            |
| 2000 | 0        | 0.9665  | 0.6816  | 0.2004            | 0        | 5.8223  | 1.9292  | 0.8627            |
| 2010 | 0        | 0.9659  | 0.6795  | 0.2030            | 0        | 5.8058  | 1.9267  | 0.8638            |
| 2015 | 0        | 0.9737  | 0.6798  | 0.2077            | 0        | 5.7627  | 1.9060  | 0.8702            |
| 2020 | 0        | 0.9658  | 0.6814  | 0.2029            | 0        | 5.5984  | 1.9356  | 0.8832            |
4.3 | Conservation suggestions

In the face of a massive crisis of deteriorating habitat quality for the lizards, while coping with local habitat destruction due to agricultural purposes, agreements with respective local farms helped to keep at least core zones of important habitats intact in the crocodile lizards’ nature reserve in China (van Schingen, Schepp, et al., 2015). Second, the Chinese government should encourage the development of the local economy and educate local people about the laws relating to wildlife conservation and prohibit the capture or trade of crocodile lizards. Third, the nature reserves should be expanded to restore forest conditions within the reserves to create more suitable habitats for the crocodile lizard. Further, Chinese crocodile lizards could be bred in captivity in nature reserves and released back into nature to restore the wild populations (Huang et al., 2008). Therefore, a breeding station was constructed in 2003, and the first round of crocodile lizards released back into the wild (Long et al., 2007; Zollweg, 2011, 2012). In 2009, 30 crocodile lizards were released into the Guangdong Luokeng Crocodile Lizard Provincial Nature Reserve (Zhong, 2009). Fifteen crocodile lizards were released into the wild for the first time in the Daguishan crocodile lizards National Nature Reserve in 2019 (Tang et al., 2019). The Department of Forestry of Guangxi Zhuang Autonomous Region released 20 crocodile lizards into the Daguishan crocodile lizards National Nature Reserve in September 2020 (Hu, 2020). The efforts have already led to a stable and even slightly increasing subpopulation within the Daguishan Nature Reserve in 2011 (Zollweg, 2012).

5 | CONCLUSIONS

Based on the land-use transfer matrix and the InVEST model, we analyzed the temporal and spatial dynamics of land-use change...
trends and habitat quality in the crocodile lizard’s distribution area in the Pearl River Basin from 1995 to 2020. The land use transfer matrix showed that the dominant landscape types were arable land and woodland in the study area. From 1995 to 2020, the arable land area decreased from 18,405 km² to 17,864 km², and the construction land area showed a “decrease – increase” trend. A large amount of arable land (118,200 km²) and woodland (63,900 km²) was used for economic development (58.08% compared with 31.40%), indicating that the study area had experienced rapid economic development and increasing urbanization in the past 25 years. The InVEST model showed that the low-quality habitats were widely distributed, mainly in the periphery of the crocodile lizards distribution areas. High-quality habitats were concentrated in the mountainous forest areas in the central and eastern part of the study area. Among the various crocodile lizard populations, habitat quality was highest and degradation was lowest in DYS, GX, QC and BT. Habitat quality was better in DGS and LK. Habitat quality was good in DPS and LZD, but they were highly fragmented with patches of low-quality habitat of varying sizes. Habitat quality was poor and habitats were severely degraded in the Dateng Gorge. However, with rapid economic development, human footprint has gradually expanded into the remaining suitable habitat for crocodile lizards, with serious impacts on their habitats. Effective conservation of current crocodile lizard habitat and restoration of wild populations is urgently required. Changes in land-use and landscape patterns are a visual indication of the effectiveness of conservation in nature reserves. There is conflict between conservation and development in nature reserves, and it is important to get the right relationship between them.

**AUTHOR CONTRIBUTIONS**

Xiaoli Zhang: Conceptualization (equal); data curation (equal); formal analysis (equal); funding acquisition (equal); investigation (equal); methodology (equal); project administration (equal); resources (equal); software (equal); supervision (equal); validation (equal); visualization (equal); writing - original draft (equal); writing - review and
Dongxu Qin: Conceptualization (equal); data curation (equal); formal analysis (equal); funding acquisition (equal); investigation (equal); methodology (equal); project administration (equal); resources (equal); software (equal); supervision (equal); validation (equal); visualization (equal); writing – original draft (equal); writing – review and editing (equal). Facundo Alvarez: Conceptualization (equal); data curation (equal); formal analysis (equal); funding acquisition (equal); investigation (equal); methodology (equal); project administration (equal); resources (equal); software (equal); supervision (equal); validation (equal); visualization (equal); writing – original draft (equal); writing – review and editing (equal). Zening Chen: Conceptualization (equal); data curation (equal); formal analysis (equal); funding acquisition (equal); investigation (equal); methodology (equal); project administration (equal); resources (equal); software (equal); supervision (equal); validation (equal); visualization (equal); writing – original draft (equal); writing – review and editing (equal). Zhengjun Wu: Conceptualization (equal); data curation (equal); formal analysis (equal); funding acquisition (equal); investigation (equal); methodology (equal); project administration (equal); resources (equal); software (equal); supervision (equal); validation (equal); visualization (equal); writing – original draft (equal); writing – review and editing (equal).

ACKNOWLEDGMENTS
We thank the National Natural Science Foundation of China (NSFC grant: 31760623) and Guangxi Natural Science Foundation (AD21220058) for funding. FA thanks the postgraduate program in Ecology and Conservation of UNEMAT - Nova Xavantina.

FUNDING INFORMATION
This study was funded entirely by the National Natural Science Foundation of China (NSFC grant: 31760623, 32160131), Biodiversity Survey, Monitoring and Assessment Project of Ministry of Ecology and Environment, China (2019HB2096001006) and Guangxi Natural Science Foundation, China (AD21220058), Project of Guangxi Daguishan National Nature Reserve and Project of Guangdong Luokeng National Nature Reserve.

CONFLICT OF INTEREST
The authors declare that this research was conducted out with commercial and/or financial concerns and is free of potential conflicts of interest.

OPEN RESEARCH BADGES
This article has earned Open Data and Open Materials badges. Data and materials are available at https://doi.org/10.5061/dryad.s1r8pk9n.

DATA AVAILABILITY STATEMENT
https://doi.org/10.5061/dryad.s1r8pk9n

ETHICS STATEMENT
The animal study was reviewed and approved by Institutional Animal Care and Use Committee (IACUC) of Guangxi Normal University (Reference Number: 202205-001).

ORCID
Xiaoli Zhang https://orcid.org/0000-0002-6531-8568
Zening Chen https://orcid.org/0000-0002-2266-7776
Zhengjun Wu https://orcid.org/0000-0002-2478-7034

REFERENCES
Abbott, B. W., Bishop, K., Zarnetske, J. P., Minaudo, C., Chapin, F. S., Krause, S., Hannah, D. M., Conner, L., Ellison, D., Godsey, S. E., & Plont, S. (2019). Human domination of the global water cycle absent from depictions and perceptions. Nature Geoscience, 12, 533–540. https://doi.org/10.1038/s41561-019-0374-y
Akbari, A., Pittman, J., & Feick, R. (2021). Mapping the relative habitat quality values for the burrowing owls (Athene cunicularia) of the Canadian prairies using an innovative parameterization approach in the InVEST HQ module. Environmental Management, 68, 310–328. https://doi.org/10.1007/s00267-021-01502-w
Andrea, K. F., Mark, W. F., Douglas, L. P., Fox, D. A., & Bringolf, B. B. (2012). Critical linkage of imperiled species: Gulf sturgeon as host for purple Bankcilmber mussels. Journal of the North American Benthological Society, 31, 1223–1232. https://doi.org/10.1899/12-081.1
Audrey, T., Jéremy, D., Le, C. H., Boris, B., Olivier, C., Simon, B., & Alexandre, R. (2016). Effects of habitat and fragmented-landscape parameters on amphibian distribution at a large spatial scale. Herpetological Journal, 26, 73.
Becker, C. G., Fonseca, C. R., Haddad, C. F. B., Batista, R. F., & Prado, P. I. (2007). Habitat split and the global decline of amphibians. Science, 318, 1775–1777. https://doi.org/10.1126/science.1149374
Bhagabati, N. K., Ricketts, T., Sulistyawati, T. B. S., Conte, M., Ennaanay, D., Hadian, O., McKenzie, E., Olweno, N., Rosenthal, A., Tallis, H., & Wolny, S. (2014). Ecosystem services reinforce Sumatran tiger conservation in land use plans. Biological Conservation, 169, 147–156. https://doi.org/10.1016/j.biocon.2013.11.010
Brudvig, L. A., Damschen, E., Haddad, N. M., Levey, D. J., & Tewksbury, J. J. (2015). The influence of habitat fragmentation on multiple plant-animal interactions and plant reproduction. Ecology, 96, 2669–2678. https://doi.org/10.1890/14-2275.1
Chen, S. Q., Chen, B., & Fath, B. D. (2015). Assessing the cumulative environmental impact of hydropower construction on river systems based on energy network model. Renewable & Sustainable Energy Reviews, 42, 78–92. https://doi.org/10.1016/j.rser.2014.10.017
Chen, Y., Qiao, F., & Jiang, L. (2016). Effects of land use pattern change on regional scale habitat quality based on InVEST model: A case study in Beijing. Acta Scientiarum Naturalium Universitatis Pekinensis, 52, 553–562. (in Chinese). https://doi.org/10.13209/j.0479-8023.2016.057
Coates, P. S., Casazza, M. L., Ricca, M. A., Brussee, B. E., Blomberg, E. J., Gustafson, K. B., Overton, C. T., Davis, D. M., Niell, L. E., Espinosa, S. P., Gardner, S. C., & Delehanty, D. J. (2016). Integrating spatially explicit indices of abundance and habitat quality: an applied example for greater sage-grouse management. Journal of Applied Ecology, 53, 83–95. https://doi.org/10.1111/1365-2664.12558
Crawford, L. A., & Nusha, K. (2018). Analysis of genetic diversity in a peatland specialist butterfly suggests an important role for habitat quality and small habitat patches. Conservation Genetics, 19, 1109–1121. https://doi.org/10.1007/s10592-018-1082-7

This article has earned Open Data and Open Materials badges. Data and materials are available at https://doi.org/10.5061/dryad.s1r8pk9n.

DATA AVAILABILITY STATEMENT
https://doi.org/10.5061/dryad.s1r8pk9n
Huang, H. Y., Wang, H., Li, L. M., Wu, Z., & Chen, J. (2014). Genetic diversity and population demography of the Chinese crocodile lizard (Shinisaurus crocodus) in China. PLoS One, 9, e91570. https://doi.org/10.1371/journal.pone.0091570

Hung, K. J., Ascher, J. S., & Holway, D. A. (2017). Urbanization-induced habitat fragmentation erodes multiple components of temporal diversity in a Southern California native bee assemblage. PLoS One, 12, e0184136. https://doi.org/10.1371/journal.pone.0184136

IUCN. (2006). IUCN red list of threatened species 2006. Gland, Switzerland: International Union for the Conservation of nature (IUCN).

Jha, S., & Bawa, K. S. (2006). Population growth, human development, and deforestation in biodiversity hotspots. Conservation Biology, 20, 906–912. https://doi.org/10.1111/j.1523-1739.2006.00398.x

Joly, P., Morand, C., & Cohas, A. (2003). Habitat fragmentation and amphibian conservation: Building a tool for assessing landscape matrix connectivity. Comptes Rendus Biologies, 326, 132–139. https://doi.org/10.1016/S1631-0691(03)0050-7

Karki, S., Thandar, A. M., Uddin, K., Tun, S., Aye, W. M., Aryan, K., Kandel, P., & Chettri, N. (2018). Impact of land use land cover change on ecosystem services: A comparative analysis on observed data and people's perception in Inle Lake, Myanmar. Environmental Systems Research, 7, 1–15. https://doi.org/10.1186/s40068-018-0128-7

Khan, T. U., Mannan, A., Hacker, C. E., Ahmad, S., Amir Siddique, M., Khan, B. U., Din, E. U., Chen, M., Zhang, C., Nizami, M., & Luan, X. (2021). Use of gis and remote sensing data to understand the impacts of land use/land cover changes (lulc) on snow leopard (Panthera uncia) habitat in Pakistan. Sustainability, 13, 3590. https://doi.org/10.3390/su13073590

Kiskaddon, E., Chernicky, K., & Bell, S. (2019). Resource use by and trophic variability of Armases cinereum (crustacea, Brachyura) across human-impacted mangrove transition zones. PLoS One, 14, e0212448. https://doi.org/10.1371/journal.pone.0212448

Le, K. Q., & Ziegler, T. (2003). First record of the Chinese crocodile lizards from outside of China: Report on a population of Shinisaurus crocodus Ahl, 1930 from North-Eastern Vietnam. Hamadryad, 27, 193–199.

Lee, D. J., & Jeon, S. W. (2020). Estimating changes in habitat quality through land-use predictions: Case study of roe deer (Capreolus pygargus tianschanicus) in Jeju Island. Sustainability, 12, 10123. https://doi.org/10.3390/su122310123

Lengyl, S., Déri, E., Varga, Z., Horváth, R., Tóthmérész, B., Henry, P. Y., Kobler, A., Kutnar, L., Babjí, V., Selilskár, A., & Christia, C. (2008). Habitat monitoring in Europe: A description of current practices. Biodiversity and Conservation, 17, 3327–3339. https://doi.org/10.1007/s10531-008-9395-3

Li, Q., Zhou, Y., Cunningham, M. A., & Tao, X. (2021). Spatio-temporal changes in wildlife habitat quality in the middle and lower reaches of the yangtze river from 1980 to 2100 based on the invest model. Journal of Resources and Ecology, 12, 43–55. https://doi.org/10.5814/j.issn.1674-764x.2021.01.005

Liang, Y. J., & Liu, L. J. (2017). Simulating land-use change and its effect on biodiversity conservation in a watershed in Northwest China. Ecosystem Health and Sustainability, 3, 1335933. https://doi.org/10.1080/20964129.2017.1335933

Lin, J. J., Chen, N. W., Yuan, X., Tian, Q., Hu, A., & Zheng, Y. (2020). Impacts of human disturbance on the biogeochemical nitrogen cycle in a subtropical river system revealed by nitrifier and denitrifier genes. The Science of the Total Environment, 746, 141139. https://doi.org/10.1016/j.scitotenv.2020.141139

Liu, S. S., Liao, Q. P., Xiao, M. Z., Zhao, D., & Huang, C. (2022). Spatial and temporal variations of habitat quality and its response of landscape dynamic in the three gorges reservoir area, China. International Journal of Environmental Research and Public Health, 19, 3594. https://doi.org/10.3390/ijerph19063594
Regolin, A. L., Oliveira-Santos, L. G., Ribeiro, M. C., & Bailey, L. L. (2021). Powers, R. P., & Jetz, W. (2019). Global habitat loss and extinction risk of terrestrial vertebrates under future land-use-change scenarios. Nature Climate Change, 9(4), 323–329. https://doi.org/10.1038/s41558-019-0406-z

Regolin, A. L., Oliveira-Santos, L. G., Ribeiro, M. C., & Bailey, L. L. (2021). Habitat quality, not habitat amount, drives mammalian habitat use in the brazilian pantanal. Landscape Ecology, 36, 1–15. https://doi.org/10.1007/s10980-021-01280-0

Riedler, B., & Lang, S. (2018). A spatially explicit patch model of habitat quality, integrating spatio-structural indicators. Ecological Indicators, 94, 128–141. https://doi.org/10.1016/j.ecolind.2017.04.027

Sallustio, L. De Toni, A., Strollo, A., Di Febbraro, M., Gissi, E., Casella, L., Geneletti, D., Munafò, M., Vizzari, M., & Marchetti, M. (2017). Assessing habitat quality in relation to the spatial distribution of protected areas in Italy. Journal of Environmental Management, 201, 129–137. https://doi.org/10.1016/j.jenvman.2017.06.031

Sharp, R., Tallis, H. T., Ricketts, T., Guerry, A. D., Wood, S. A., Chaplin-Kramer, R., Nelson, E., Ennaanay, D., Wolny, S., Olvero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., ... Perelman, A. (2018). InVEST 2.4.4 User’s Guide. The Natural Capital Project, Stanford.

Sharp, R., Tallis, H. T., Ricketts, T., Guerry, A. D., Wood, S. A., Chaplin-Kramer, R., Nelson, E., Ennaanay, D., Wolny, S., Olvero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Arkema, K., Lonsdorf, E., ... Perelman, A. (2016). InVEST 2.4.4 User’s Guide. The Natural Capital Project, Stanford.

Sun, Q., Zhang, L., Ding, X. L., Hu, J., Li, Z. W., & Zhu, J. J. (2015). Slope deformation prior to Zhouqu, China landslide from InSAR time series analysis. Remote Sensing of Environment, 156, 45–57. https://doi.org/10.1016/j.rse.2014.09.029

Sun, X. Y., Jiang, Z., Liu, F., & Zhang, D. (2019). Monitoring spatio-temporal dynamics of habitat quality in Nanshu Lake basin, eastern China, from 1980 to 2015. Ecological Indicators, 102, 716–723. https://doi.org/10.1016/j.ecolind.2019.03.041

Takahashi, M., & Nakamura, F. (2011). Impacts of dam-regulated flows on channel morphology and riparian vegetation: A longitudinal analysis of Satsunai River, Japan. Landscape and Ecological Engineering, 7, 65–77. https://doi.org/10.1007/s11355-010-0114-3

Tang, X. W., Xiao, W. F., Wei, J., Luo, S. Y., & Lei, C. M. (2019). Daguishan crocodile lizards released into its native habitat. Forestry of Guangxi, 6, 37–39.

Thomson, D. H., Wirsing, A. J., Roth, J. D., & Murray, D. L. (2013). Habitat quality and population density drive occupancy dynamics of snowshoe hare in varied landscapes. Ecography, 36, 610–621. https://doi.org/10.1111/j.1600-0587.2012.07737.x

van Schingen, M., Ihlow, F., Nguyen, T. Q., Ziegler, T., Bonkowski, M., Wu, Z., & Rödder, D. (2014). Potential distribution and effectiveness of the protected area network for the crocodile lizard, Shinisaurus crocodilurus (Reptilia: Squamata: Sauria). Salamandra, 50(2), 71–76.

van Schingen, M., Le, M., Ngo, H. T., Pham, C. T., Ha, Q. Q., Nguyen, T. Q., & Ziegler, T. (2016). Is there more than one crocodile lizard? An integrative taxonomic approach reveals Vietnamese and Chinese Shinisaurus crocodilurus represent separate conservation and taxonomic units. Der Zoologische Garten, 85, 240–260. https://doi.org/10.1016/j.j.zoolgart.2016.06.001

van Schingen, M., Pham, C. T., Thi, H. A., Bernardes, M., Hecht, V., Nguyen, T. Q., Bonkowski, M., & Ziegler, T. (2014). Current status of the crocodile lizard Shinisaurus crocodilurus ahl, 1930 in Vietnam with implications for conservation measures. Revue Suisse de Zoologie, 121(3), 425–439.

van Schingen, M., Pham, C. T., Hang, A. T., Nguyen, T. Q., Bernardes, M., Bonkowski, M., & Ziegler, T. (2015). First ecological assessment on the endangered crocodile lizard shinisaurus crocodilurus ahl, 1930 in Vietnam: Microhabitat characterization and habitat selection. Herpetological Conservation and Biology, 10, 948–958.

van Schingen, M., Schepp, U., Pham, C. T., Nguyen, T. Q., & Ziegler, T. (2015). Last chance to see? A review of the threats to and use of the crocodile lizard. TRAFFIC Bulletin, 27, 19–26.

Wang, C. L., Chen, H., Li, L. Z., Liu, Q. S., & Liu, P. P. (2020). Frontier of amphibian habitat protection and construction and its enlightenment to karst areas. Resources and Environment in the Yangtze Basin, 29, 1224–1235 (in Chinese).
Wu, Z. J., Dai, D. L., Ning, J. J., Huang, C. M., & Yu, H. (2012). Seasonal differences in habitat selection of the crocodile lizards (Shinisaurus crocodilurus) in Luokeng nature Reserve, Guangdong. Acta Ecologica Sinica, 32, 4691–4699. https://doi.org/10.5846/stxb201105030579

Xie, H. X., Liang, X. X., Chen, Z. Q., Li, W. M., Mi, C. R., Li, M., Wu, Z. J., Zhou, X. M., & Du, W. G. (2021). Ancient demographics determine the effectiveness of genetic purging in endangered lizards. Molecular Biology and Evolution, 39, msab359. https://doi.org/10.1093/molbev/msab359

Yang, M. J., Wang, W. R., Han, X., & Cong, R. L. (2017). Measures for the protection of crocodile lizards in Datang gorge reservoir area. Water Resources & Hydropower of Northeast China, 35, 41–43 (in Chinese).

Yu, H., Huang, C. M., Chen, Z., Su, L. N., Cao, H. M., & Gong, M. H. (2005). Study on current population and habitats of Shinisaurus crocodilurus in Guiping City, Guangxi. Sichuan Journal of Zoology, 24, 6 (in Chinese).

Zhang, L. X., Pang, M. Y., Bahaj, A. S., Yang, Y., & Wang, C. (2021). Small hydropower development in China: Growing challenges and transition strategy. Renewable & Sustainable Energy Reviews, 137, 110653. https://doi.org/10.1016/j.rser.2020.110653

Zhang, Q., Gu, X. H., Singh, V. P., Shi, P., & Sun, P. (2018). More frequent flooding? Changes in flood frequency in the Pearl River basin, China, since 1951 and over the past 1000 years. Hydrology & Earth System Sciences, 22, 2637–2653. https://doi.org/10.5194/hess-22-2637-2018

Zhang, Y. X. (1991). The Chinese crocodile lizard. China Forestry Press.

Zhang, Y. X., Zeng, Z. F., & Zhao, J. Y. (2005). Geographical distribution and population size of crocodile lizards in China. Proceedings of the 2005 Symposium and General Meeting of the Amphibian Reptile Branch of the Chinese Zoological Society.

Zhao, J. Y., Zhang, Y. X., & Lang, D. Y. (2006). Ecology of Chinese crocodilian lizard in burrow. Sichuan Journal of Zoology, 25, 261–263 (in Chinese).

Zhong, D. W. 30 crocodile lizards released into the wild yesterday. Guangzhou Daily, 2009.07.31.

Ziegler, T., Van Schingen, M., Rauhaus, A., Dang, P. H., Pham, D. T. K., Pham, C. T., & Nguyen, T. Q. (2019). New insights into the habitat use and husbandry of crocodile lizards (Reptilia: Shinisauridae) including the conception of new facilities for Vietnamese crocodile lizards Shinisaurus crocodilurus vietnamensis in Vietnam and Germany. International Zoo Yearbook, 53, 250–269. https://doi.org/10.1111/izy.12215

Zollweg, M. (2011). Neues aus dem projekt zum schutz der krokodilbschwanz-höckerechse. Zoologische Gesellschaft für Arten- und Populationsschutz e.V. (ZGAP) Mitteilungen, 27, 11–13.

Zollweg, M. (2012). Erfolgreiches projekt zum schutz der krokodilbschwanz-höckerechse in China. Zoologische Gesellschaft für Arten- und Populationsschutz e.V. (ZGAP) Mitteilungen, 28, 15.

How to cite this article: Zhang, X., Qin, X., Alvarez, F., Chen, Z., & Wu, Z. (2022). Potential impact of land-use change on habitat quality in the distribution range of crocodile lizards in China. Ecology and Evolution, 12, e9390. https://doi.org/10.1002/ece3.9390