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At home in Jiangsu: Environmental niche modeling and new records for five species of amphibian and reptile in Jiangsu, China

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Abstract

Environmental niche models are useful tools for generating hypotheses for the distribution of species and informing conservation planning, especially at the edge of species' ranges and for those with limited data. Here we report on the recent documentation of four species of amphibian (*Hylarana latouchii*, *Odorrana tianmuii*, *Polypedates braueri*, and *Zhangixalus dennysi*) and one reptile (*Protobothrops mucrosquamatus*) with few or no previous geolocated records from Jiangsu, China. We combined our opportunistic field sampling data from Jiangsu, which is at the edge of each of these species' ranges, with publicly available occurrence records and climatic data to generate environmental niche models for these five species using Maxent. All models showed good model performance with AUC values ranging from 0.899 to 0.983. Additional potentially suitable areas within southern Jiangsu were predicted for the four amphibian species, although the significant anthropogenic habitat modifications in the province may limit their contemporary distributions. For all five species, the climatic variable that contributed most to the model was the precipitation of the driest month (Bio 14), indicating they are limited by moisture availability. Our study adds new information about the climatic preferences of these five species and highlights the value of complementing environmental niche modeling with field surveys for robust inferences and conservation planning, particularly at the edge of species' ranges.

Key Words

distribution, Maxent, Ranidae, Rhacophoridae, Viperidae

Introduction

Reptiles and amphibians are often difficult to detect, as many are small, nocturnal, and cryptic (Tanadini and Schmidt 2011; Durso and Seigel 2015; Hammond et al. 2021), which can make determining their distributions difficult. Yet, this baseline information is crucial for conservation, especially in light of contemporary anthropogenic pressures (Luedtke et al. 2023). One tool available to better understand the range of species is species distribution modeling, also known as environmental (or ecological) niche modeling, which combine species occurrence data with environmental data to generate predictions (Elith and Leathwick 2009). While models are imperfect approximations of reality (Merow et al. 2013), they can still be very useful for guiding field surveys for target species (Rhoden et al. 2017; Sarker et al. 2019), predicting responses to climate change (Duan et al. 2016), increasing ecological knowledge of species (Ananjeva et al. 2015; Hou et al. 2023), and informing conservation planning (Kidov and Litvinchuk 2021; Shin et al. 2021). Models that incorporate both presence and absence data are ideal (Lawson et al. 2014; Fiedler et al. 2018), but absence data is rarely available for reptiles, amphibians, and many other taxa. Other approaches only need presence data, though many of these rely on pseudo-absences (Barbet-Massin et al. 2012). One commonly used open-source software that utilizes presence-only data is Maxent (Phillips et al. 2017), which has been used to investigate a wide variety of amphibians and reptiles at past, present, and future scales (Kim et al. 2020; Shin et al. 2021; Andersen et al. 2022). Model accuracy improves with additional data if spatial bias in sampling is addressed, and as such the value of gathering new species occurrence records should not be overlooked (Kramer-Schadt et al. 2013; Zhu and Qiao 2016).

During field surveys in southern Jiangsu, People's Republic of China, we encountered two Ranid frogs (*Hylarana latouchii* and *Odorrana tianmuii*; Fig. 1), two Rhacophorid frogs (*Polypedates braueri* and *Zhangixalus dennysi*), and one viper (*Protobothrops mucrosquamatus*) that had few or no previously reported geolocated records from the province. Jiangsu is located in eastern China and has 20 native species of amphibian and 56 native reptiles (Zou and Chen 2002; Fei et al. 2012). The province straddles the Palearctic and Indomalayan biogeographic realms (Munguía et al. 2012), and each of these five species with limited records from Jiangsu are Indomalayan species found at the northeastern edges of their respective ranges. We used Maxent to model the current climatic niche of these species to better understand their ecological requirements and potential for further occurrence in Jiangsu.

Methods

Field sampling took place at night (~19:00–24:00 h) on 10, 14, and 25 September 2023 in the southern portion of Jiangsu, China, near the county-level cities of Yixing and Liyang (Fig. 2). These sites were selected due to presence of mountains contiguous with southern latitudes, thus exhibiting a higher probability of detecting Indomalayan

Figure 1. Study amphibian species: *Zhangixalus dennysi* (**a**), *Polypedates braueri* (**b**), *Hylarana latouchii* (**c**), and *Odorrana tianmuii* (**d**). Photos **a, c, d**: Kenneth Chin; **b**: Zhenqi Wang.

species. Surveys consisted of opportunistic sampling to maximize the number of reptile and amphibian species encountered and involved driving along roads slowly as well as walking on foot in and along streams and rivers (Niemiller 2005; Dodd Jr. 2016). Rocks, logs, and other possible cover objects were overturned and replaced. All reptile and amphibian species encountered were photo vouchered for iNaturalist and released at the point of capture within minutes and GPS coordinates were obtained using cell phones.

We modeled the climatic niches of four amphibians and one reptile we encountered during our surveys that were at the edge of their respective known ranges (Fei et al. 2012): *Hylarana latouchii* Boulenger, 1899 (taxonomy following Sun et al. 2021); *Odorrana tianmuii* Chen, Zhou & Zheng, 2010 (taxonomy following Li et al. 2017); *Polypedates braueri* Vogt, 1911 (taxonomy following Kuraishi et al. 2013); *Zhangixalus dennysi* Blanford, 1881 (taxonomy following Jiang et al. 2019); and *Protobothrops mucrosquamatus* Cantor, 1839 (taxonomy following Guo et al. 2019b). All field identifications were based on visual observations, made easier by the absence of sister or cryptic species for any of the species in the area (Fei et al. 2012). The exception to this was *H. latouchii*, which is visually similar to *Odorrana tormota* Wu, 1997; for this species, individuals were identified by lateral patterning, shape of dorsolateral fold, and tympanum shape (Chen et al. 2018). For the other four species (*P. mucrosquamatus*, *O. tianmuii*, *P. braueri*, and *Z. dennysi*) dorsal patterning was sufficient to distinguish them from similar locally occurring species (Fei et al. 2012; Guo et al. 2021). Our records for these five species are available as a Suppl. material 1 (DOI: 10.17632/gz87mn8nnw.2).

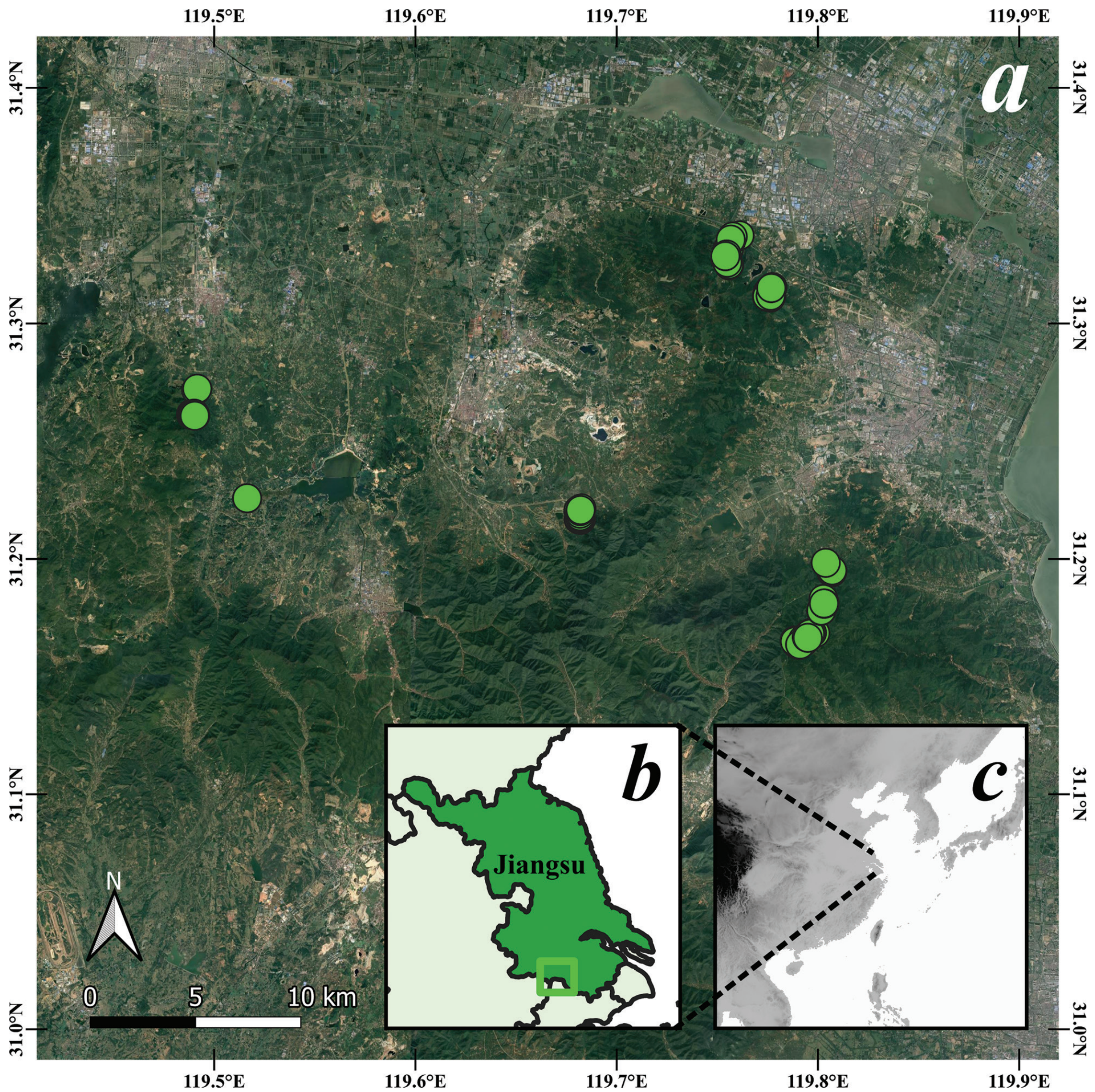

Figure 2. Sampling localities in Jiangsu, China. Map *a* shows the locations, represented by green dots, of all amphibians and reptiles observed during our field sampling (Satellite map: Google 2023 TerraMetrics). Inset *b* shows the focal area of the field surveys in southern Jiangsu outlined with a green rectangle. Inset *c* shows the broader location of Jiangsu (Elevation layer: Ryan et al. 2009).

In addition to our sampling data, we downloaded species occurrence data from GBIF.org, filtering for records with coordinates and no geospatial issues, for the five focal species (DOI: *P. mucrosquamatus* 10.15468/DL.AGK3WJ; *H. latouchii* 10.15468/DL.BXFK83; *P. braueri* 10.15468/DL.QBJWRW; *Z. dennysi* 10.15468/DL.TQTAP9; *O. tianmuii* 10.15468/DL.BRTRR3). For *P. braueri*, we searched GBIF for all *Polypedates* records within the range of the species as roughly outlined by Kuraishi et al. (2013), as *P. braueri* should be the only *Polypedates* species within this area but due to confusion regarding the species complex many records are incorrectly listed as *P. megacephalus* or *P. leucomystax*.

We also searched the scientific literature and other authoritative sources for records of these species from Jiangsu specifically. We found and incorporated nine geolocated locality records for *O. tianmuii* throughout its range from Li et al. (2017) and one record of *P. mucrosquamatus* from Jiangsu (Ye et al. 2024). For *H. latouchii*, the only existing geolocated record in Jiangsu we found was reported on iNaturalist (https://www.inaturalist.org/observations/153953701). For *Z. dennysi* there was only an undated museum record at Harvard's Museum of Comparative Zoology (MCZ:Herp:A-5624) from "Nanking" (no coordinates and not a precise locality; Museum of Comparative Zoology 2023). For *P. braueri* we found no geolocated records for Jiangsu.

For the environmental data for our modeling, we downloaded 19 bioclimatic layers, covering 1970–2000, from the WorldClim 2.1 database (Fick and Hijmans 2017) at a 30" resolution (~1 km^2). Layers were clipped to cover the full range of the study species using QGIS v. 3.32.2, and the built-in GRASS plug-in was used to calculate Pearson's correlation coefficients for all pairs of variables (Zhu and Qiao 2016, QGIS.org 2023). For highly correlated pairs ($|r| > 0.8$), we selected bioclimatic layers based on knowledge of the species and those shown to be relevant in modeling of related species (Table 1; Najibzadeh et al. 2017; Kidov and Litvinchuk 2021; Rai et al. 2021; Rupasinghe et al. 2021; Jiang et al. 2022).

To account for spatial bias in sampling, all occurrence records were spatially thinned at a distance of 10 km using *Wallace* v2.0.6 (Kramer-Schadt et al. 2013; Zhu and Qiao 2016; Kass et al. 2023). Additionally, for *P. mucrosquamatus*, *H. latouchii*, and *P. braueri*, the GBIF datasets contained significantly more records from the Island of Taiwan compared to the remainder of these species' ranges. To account for this disparity, which was caused by differing numbers of iNaturalist users and is not reflective of relative abundance, we standardized the dataset from the Island of Taiwan. We divided the land area of the Island of Taiwan (~36,200 km^2) by the total land area of each species' range, estimated using the measuring tool in QGIS, and thinned the records from the Island of Taiwan further until the proportion of records in the Island of Taiwan compared to the rest of the range was equal to the respective ratios of land area, rounding up to the nearest whole number (Kramer-Schadt et al. 2013). As a result, the following numbers of records for each species were used: *P. mucrosquamatus* (n = 104); *H. latouchii* (n = 66); *O. tianmuii* (n = 34); *P. braueri* (n = 125); *Z. dennysi* (n = 74).

Table 1. Bioclimatic variables from the WorldClim 2.1 database (Fick and Hijmans 2017) used in Maxent modeling for four amphibians (*H. latouchii*, *O. tianmuii*, *P. braueri*, *Z. dennysi*) and one reptile (*P. mucrosquamatus*).

Class	Bioclimatic Variable	
Amphibian models	Bio 1	Annual mean temperature
	Bio 2	Mean diurnal temperature range
	Bio 4	Temperature seasonality
	Bio 12	Annual precipitation
	Bio 14	Precipitation of driest month
	Bio 15	Precipitation seasonality
	Bio 18	Precipitation of warmest quarter
Reptile model	Bio 1	Annual mean temperature
	Bio 2	Mean diurnal temperature range
	Bio 3	Isothermality
	Bio 7	Temperature annual range
	Bio 12	Annual precipitation
	Bio 14	Precipitation of driest month
	Bio 15	Precipitation seasonality
	Bio 18	Precipitation of warmest quarter

Environmental niche modeling was done using Maxent 3.4.4 (Phillips et al. 2017). We used a random seed with the random test percentage set to 25, a regularization multiplier of 1, and a sampling of 10,000 replicates to run 20 bootstrap replicates using the default feature classes. We also applied a jackknife analysis to estimate the relative contributions of each variable. We used the maximum training sensitivity plus specificity threshold (MTSS) generated by Maxent for each species as the threshold for suitability (Liu et al. 2013).

Results

Our environmental niche models (Fig. 3) all had moderately or very high area under the receiver-operator curve (AUC) values (Swets 1988), which is a common measure of model fit (Merow et al. 2013). The AUC values were as follows: *P. mucrosquamatus*: 0.901; *H. latouchii*: 0.961; *O. tianmuii*: 0.983; *P. braueri*: 0.899; *Z. dennysi*: 0.924. The model for *P. mucrosquamatus* predicted no suitable area above the MTSS threshold in Jiangsu, though the models for all four amphibians showed some suitable habitat in the southern half of the province.

For all five species, the precipitation of the driest month was the variable with the greatest percent contribution to the model (Table 2), contributing between 42.1% (*P. mucrosquamatus*) and 83.3% (*Z. dennysi*). Other variables that contributed more than 10% to models included annual precipitation (*P. mucrosquamatus*), mean diurnal temperature range (*H. latouchii*), annual mean temperature (*O. tianmuii* and *P. braueri*), and temperature seasonality (*P. braueri*; see Table 2).

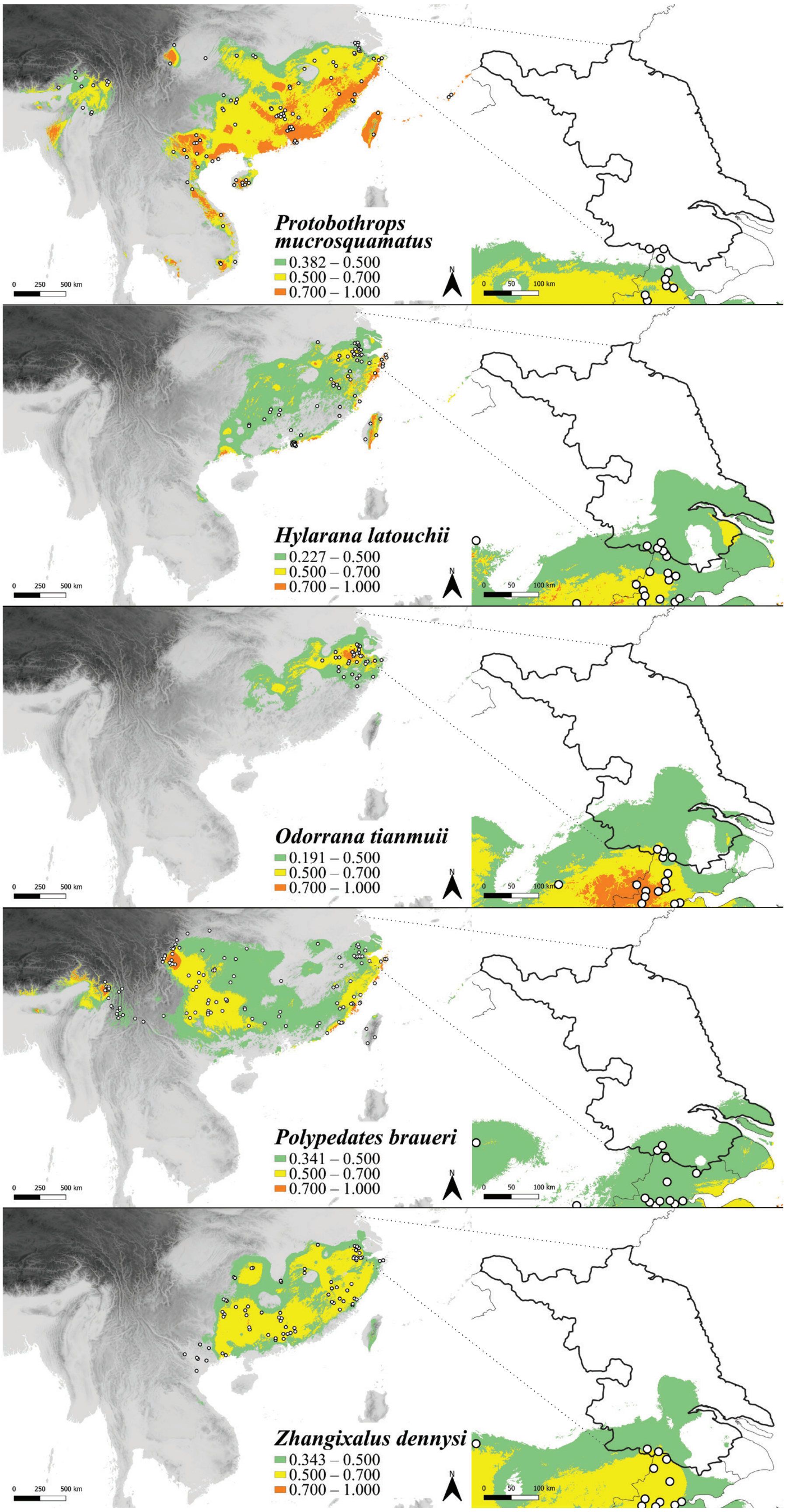

Figure 3. Full Maxent environmental niche models of the five focal species are shown on the left (elevation layer: Ryan et al. 2009) with a view of Jiangsu on the right. We used each models' maximum training sensitivity plus specificity threshold (MTSS) as the minimum threshold for suitability (green; MTSS–0.5), with higher values corresponding to medium (yellow; 0.5–0.7) and high (orange; 0.7–1) predicted climatic suitability. Locality records used in modeling are represented with white dots.

Table 2. Percent contribution of bioclimatic variables to environmental niche models for the five study species, with the maximum and minimum contributions across all 20 runs given in parentheses. Variables contributing more than 10% bolded and those not included indicated by a dash.

Variable	*P. mucrosquamatus*	*H. latouchii*	*O. tianmuii*	*P. braueri*	*Z. dennysi*
Annual mean temp. (Bio 1)	7.1 (1.4–12.4)	1.3 (0.0–4.1)	**10.6** (4.5–18.6)	**12.2** (7.7–21.8)	0.8 (0.0–2.2)
Mean diurnal temp. range (Bio 2)	9.1 (1.6–19.9)	**13.7** (1.8–24.8)	0.3 (0.0–2.3)	4.3 (0.2–16.1)	2.8 (0.5–6.1)
Isothermality (Bio 3)	2.2 (0.1–10.5)	–	–	–	–
Temp. seasonality (Bio 4)	–	0.9 (0.0–2.7)	9.9 (2.8–17.7)	**21.8** (12.5–31.7)	3.8 (1.1–11.8)
Temp. annual range (Bio 7)	2.6 (0.3–7.9)	–	–	–	–
Annual precip. (Bio 12)	**31.7** (16.8–43.8)	0.8 (0.0–3.1)	0.5 (0.0–1.6)	8.7 (2.1–16.9)	3.0 (0.0–11.3)
Precip. of driest month (Bio 14)	**42.1** (32.6–54.5)	**76.6** (68.6–87.1)	**71.8** (64.2–78.8)	**45.9** (30.4–60.0)	**83.3** (67.8–92.4)
Precip. seasonality (Bio 15)	1.5 (0.0–5.1)	0.6 (0.0–4.4)	2.5 (0.0–5.0)	5.4 (1.1–11.5)	0.2 (0–1.6)
Precip. of warmest quarter (Bio 18)	3.7 (0.1–21.2)	6.2 (3.0–12.3)	4.4 (2.6–6.7)	1.7 (0.5–6.7)	6.1 (1.2–13.3)

Discussion

All five environmental niche models had moderately high AUC values and fit our understanding of each species' contemporary range (Fig. 3). The model for *P. mucrosquamatus* predicted no suitable habitat in Jiangsu, indicating that the individual we found was likely on the very edge of the species' range. Conversely, the models for each of the four anurans predicted some suitable habitat in the southern half of the province, although for these species no specific records in Jiangsu exist north of the records we obtained. Anthropogenic impacts are a possible limiting factor in the distribution of the study species in Jiangsu, which is highly developed, and our models only included climatic conditions and did not account for human impacts (Du et al. 2014; Chuai et al. 2016). The extirpation of species such as the Chinese alligator (*Alligator sinensis*) from Jiangsu due to habitat loss and fragmentation has been documented (Zou and Chen 2002; Pan et al. 2019), and it is possible that these four anurans previously had more extensive ranges in the province. Conversely, the presence of the species could be linked to recent expansions in distribution caused by contemporary climate change (Duan et al. 2016; Biber et al. 2023). This scenario may be more likely for *P. mucrosquamatus* than the amphibians, as the field surveys were conducted during the period of the highest movement for Indomalayan snakes (Rahman et al. 2013) and our observation of this species was very close to both the edge of the province boundary and its predicted range.

In two instances, a model predicted sizable amounts of climatically suitable areas where the species likely does not occur. First, our model for *Z. dennysi* predicted a substantial amount of suitable area in the Island of Taiwan. The ocean is an obvious biogeographic barrier that may explain this absence, but if *Z. dennysi* were to be introduced to Taiwan anthropogenically, our results indicate that, at least in terms of climatic suitability, it could easily become established. Second, our model for *O. tianmuii* showed a substantial amount of suitable habitat west of the species' actual range, although this area is occupied by the closely related *O. schmackeri* (Li et al. 2017), indicating that these two species may have very similar climatic niches. Interestingly, the model for *P. braueri* strongly matched the distribution given by Kuraishi et al. (2013). While the degree of range overlap between *P. braueri* and *P. megacephalus* remains unclear, this result does lend support to recognizing the *Polypedates* in southernmost China as a distinct species (*P. megacephalus*) from those in the remainder of the country (*P. braueri*).

Surprisingly, the precipitation of the driest month (Bio 14) was the variable with the highest percent contribution in each of the five models, despite the evolutionary distance between these species. This indicates that moisture availability in the driest portion of the year is potentially a limiting factor for each of these organisms. Climate change is forecasted to have significant effects on the distribution of amphibians and reptiles (Duan et al. 2016; Biber et al. 2023), and given the importance of this bioclimatic variable for all five models, changes in rainfall patterns will likely be more influential on these species than temperature changes (Qian et al. 2007; Guo et al. 2019a).

While our field sampling efforts were opportunistic and not comprehensive, they still yielded observations of five species with few or no specific formal records from Jiangsu. This indicates a lack of previous sampling, and additional survey effort can more accurately delineate the range of these species within Jiangsu, especially considering that the models for all four anurans predicted some suitable habitat beyond our sampling sites. Furthermore, we anticipate that more sampling may yield records of previously undocumented Indomalayan reptiles and amphibians for the province. For example, our surveys did not detect *Kurixalus inexpectatus* (Rhacophoridae), a species described in 2022 in Zhejiang in mountains contiguous with our sampling sites (Messenger et al. 2022). We did not attempt to model the distribution of *K. inexpectatus* due to insufficient locality records (van Proosdij et al. 2016), but consider it likely to be found in Jiangsu in the future.

While species distribution models can be generated solely from the vast amounts of existing publicly available data, models are most effective when they both inform and are informed by field efforts. Environmental niche modeling can guide field surveys to be conducted in areas where target species, or even new species, are likely to be found (Rhoden et al. 2017; Sarker et al. 2019). Conversely, obtaining additional occurrence data, especially data that extend the known range of a species, improves the accuracy of models at present as well as past and future scales (Qin et al. 2017; Zhang et al. 2019; Yousaf et al. 2022). The positive feedback loop between modeling and field sampling should be utilized to improve conservation efforts and deepen ecological knowledge of species.

Authors contributions

Conceptualization: AB and DBK; Investigation: all authors; Methodology: XZ, KRM, and DBK; Supervision: AB; Writing - original draft: DBK; Writing - review and editing: SNO, DG, AB, DBK, KRM, XZ, HA, VKP; Visualization: DBK and KCYA.

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Supplementary material 1

Records for *Protobothrops mucrosquamatus*, *Hylarana latouchii*, *Odorrana tianmuii*, *Polypedates braueri*, and *Zhangixalus dennysi*

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