Continental Northeast Asian Amphibians

Origins, Behavioural Ecology, and Conservation

Amaël Borzée

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CHAPTER

1

Introduction to continental northeast Asian Amphibians

Amphibians in continental northeast Asia have multiple origins, with clades originating from southern Asia, before and after the orogenesis of the Qinghai-Tibet Plateau, others having crossed over central Asia before the aridification of the region, and others still, coming from the American continent across the Bering bridge during climatic oscillations (e.g., Li et al., 2015; Zhou et al., 2017; Fong et al., 2020; Othman et al., 2021; Othman et al., 2022). Despite the multiple origins, the number of species is still rather limited, making it possible to cover the totality of the knowledge accumulated on each of the species for each of the nations, and for the whole region as a whole (e.g., Kim and Han, 2009; Fei et al., 2012; Maslova, 2016; Kuzmin et al., 2017; Kim et al., 2019; Borzée et al., 2021).

The habitat where the species occurs is variable, including dense evergreen forests in the south, broad-leaf deciduous vegetation, conifer forests, and Taiga forests in the north. However, not all lands are planted with trees, and steppes are widespread in central regions, with low vegetation typical of the region north of the Arctic circle in the north, and low elevation alluvial wetlands surrounding the Yellow Sea. This latter region is of key importance for amphibians of the region as it has been heavily modified for rice agriculture for thousands of years (Fuller et al., 2008), and amphibian populations in the area have shifted accordingly, negatively as well as positively (e.g., Borzée et al., 2021). The importance of the Yellow Sea in the region is such that this book could also be called “Amphibians of the Greater Yellow Sea Basin”. In this regard, continental northeast Asia is here defined as the area north of the Yangtze River, ranging west until about 110 degrees of longitude, roughly in Xi’an area, and thus restricting the focal area to the zone bathed by the same monsoon regime, and ranging north along this longitude as far north as amphibians are present, until the bank of the East Siberian Sea in the Russian Federation (hereafter Russia). In addition, it is interesting to notice the almost perfect dichotomy in the presence of clades along the Yilan—Yinong fault (e.g., Yu et al., 2021), north of the Yellow Sea.

As a result of the large diversity in species, and landscape, a wide variety of behaviour is expressed by amphibians of the region, ranging from wetland-restricted species, to direct developers, and other species spending months amplexed under the ice of fast-flowing streams to wait for an opportunity to breed (Fig. 1.1). The variety has also resulted in species perfectly able to cope with human activities, and increase in population size, while others cannot survive even when remotely impacted by human activities (e.g., Park et al., 2014).

Continental Northeast Asian Amphibians. https://doi.org/10.1016/B978-0-323-91857-2.00007-5

FIG. 1.1

Example of the amphibian diversity in continental northeast Asia, here introducing (A) *Bombina orientalis*, a species for which both males and females can emit release calls; (B) *Dryophytes suweonensis*, a species surprisingly threatened compared to the status of Hylids in the world, but unsurprisingly on the brink of extinction in Korean landscapes and (C) *Karsenia koreana*, the only direct developing species in northeast Asia. The larval development skips the aquatic phase, with juveniles hatching from eggs while already presenting the external adult morphology, in miniature.

From Amaël Borzée.

The variation in threats and the ability of species to cope with their changing environment has resulted in different conservation needs, with some species seeing their survival becoming conservation action-dependent, and others having no difficulties, and even benefiting, from some human activities. For instance, surveys at more than 3200 independent rice paddies in spring in the Republic of Korea (hereafter R Korea) have resulted in the detection of *Dryophytes japonicus* at every site. Conservation of amphibians in continental northeast Asia has long been neglected, but looking at it from a biome-weighted perspective has shown that conservation actions need to be stepped up (Button and Borzée, 2021). Indeed, amphibian-focused conservation research is picking up (e.g., Do et al., 2022; Jeon et al., 2023), education and efforts are presently increasing (Fig. 1.2), with visible impacts, for instance with the restriction of the trade of certain species.

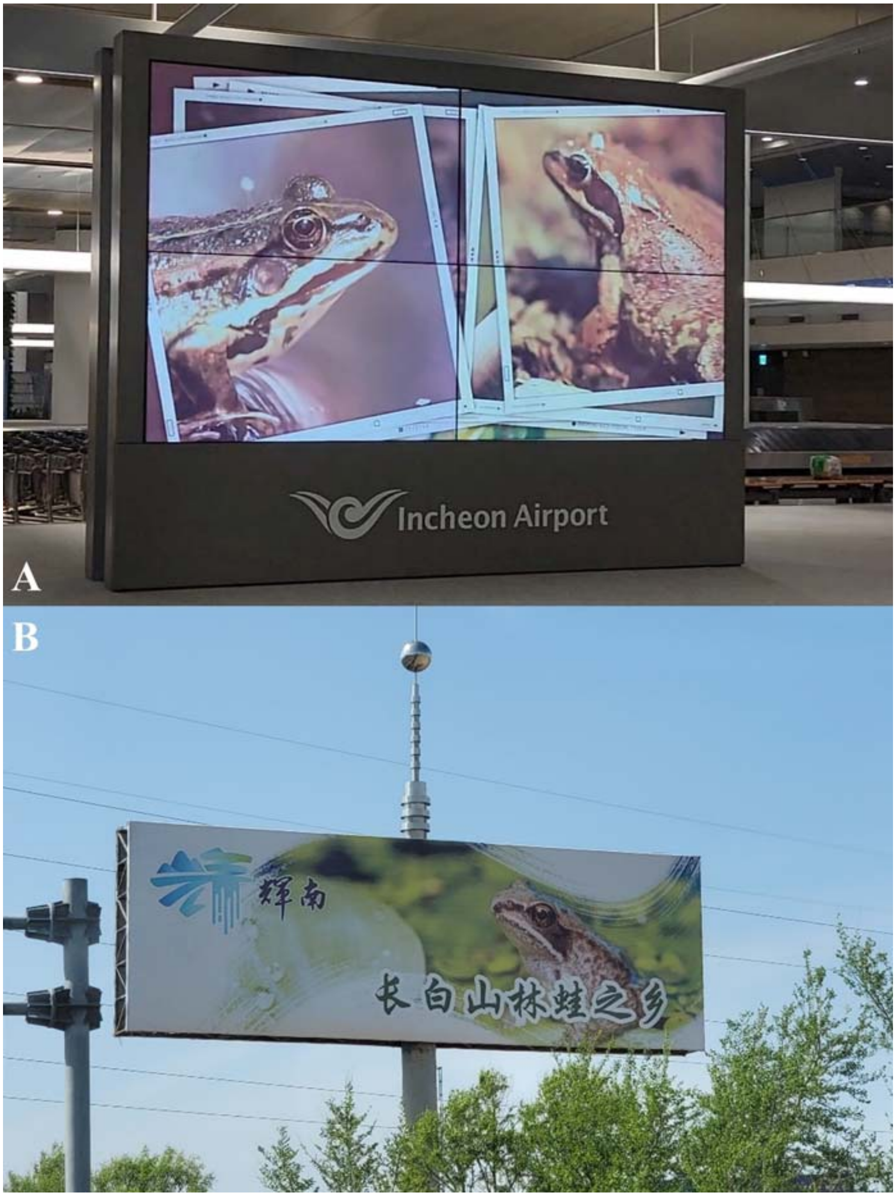

FIG. 1.2

Awareness about amphibians, and their value in the environment, has slowly increased in continental northeast Asia, although sometimes as a food source that needs to be protected. (A) Warning message from the customs services of the Republic of Korea when landing at Incheon Airport on the 15th of November 2022. (B) Advertisement from Huinan about Changbai Mountain being the hometown of *Rana dybowskii*. Taken on the side of a highway in the vicinity of Changbai Mountain, Jilin, China in May 2023.

From Amaël Borzée.

As a broad introduction to threats in the region, one of the most common global threats, the chytrid fungus (*Batrachochytrium dendrobatidis*), is luckily not (yet) a threat as species co-evolved with the batrachochytrid (Scheele et al., 2019). However, habitat loss is prevalent as the capitals of four nations (the People's Republic of China, hereafter China, the Democratic People's Republic of Korea, hereafter DPR Korea, Mongolia and R Korea) are present within the focal range studied, and some of the landscapes are the most populated in the world, impacting amphibians directly, and indirectly through human activities and resilience to habitat changes (e.g., Groffen et al., 2022; Shin et al., 2022). Climate change is also having a major impact on most species in terms of shift in suitable habitat (e.g., Duan et al., 2016; Kuzmin et al., 2017; Kim et al., 2021), but also breeding phenology (Jang et al., 2023), and in relation with other emerging pathogens (Roh et al., 2023).

1.1 Taxonomic scope

While it was easy to define the geographic scope based on climate and ecozone, selecting the species to be included was not as straightforward, as species do not always conform to human expectations, and boundaries. Therefore, species with about 30% of their range, or less, in the focal region were excluded, as well as invasive species such as *Xenopus laevis* as while they can be found in the area, even breeding, they have not yet established viable populations.

Other species worth mentioning due to their close relationship with the focal species in terms of distribution or behavioural ecology include the following genera and species: (1) *Bufo minshanicus*, due to its close phylogenetic and geographic relationship with other *Bufo* species of the region, and similar breeding behaviour; and *Duttaphrynus melanostictus* due to the geographic proximity. (2) The following *Rana* species as parts of their ranges are within the focal area, although generally not properly defined, and most species are cryptic *R. luanchuanensis*, *R. culaiensis*, *R. zhenhaiensis*, *R. kukunoris* and *R. pirica*. (3) *Hoplobatrachus rugulosus/chinensis* due to its distribution north of the Yangtze River, and the commonalities in threats resulting from rice agriculture. (4) *Microhyla heymonsi* and *Microhyla fissipes* due to their range, although without properly defined northern boundaries, and the strong connection of *M. fissipes* with rice agriculture. (5) *Hyla chinensis* due to the relation with the other Hylid species, and the very narrow range north of the Yangtze River (Fig. 1.3).

1.2 Knowledge disclaimer

The information in this book is correct and up to date to the best of the literature currently available, but taxonomy is bound to change, distributions will be clarified, ecological requirements redefined, and threats will shift (Luedtke et al., 2023). Therefore, the information provided here can be seen as temporary knowledge, to

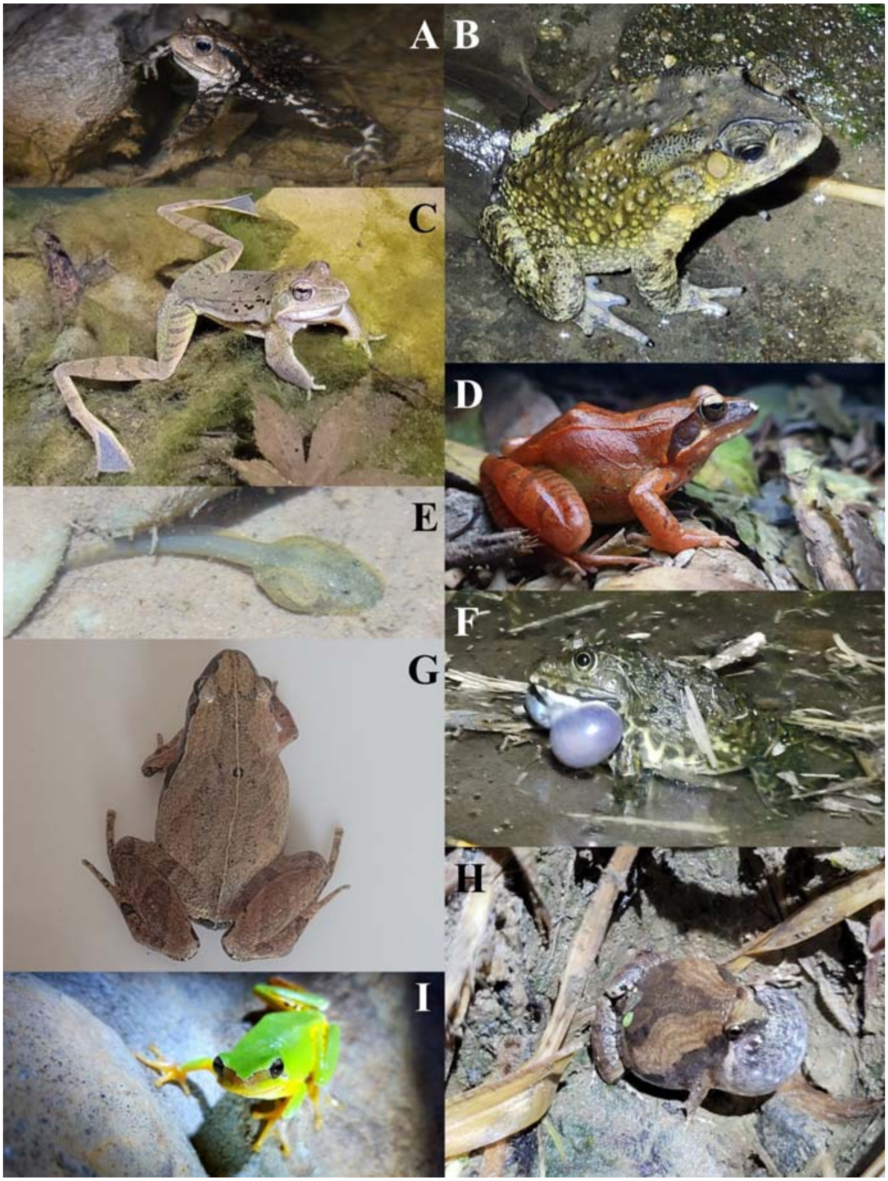

FIG. 1.3

Species with about 30% or less of their range in the focal region were excluded, including the following: (A) *Bufo minshanicus*, (B) *Duttaphrynus melanostictus*, (C) *Rana culaiensis*, (D) *Rana zhenhaiensis*, (E) *Rana kukunoris*, (F) *Hoplobatrachus chinensis/rugulosus*, (G) *Microhyla heymonsi*, (H) *Microhyla fissipes*, and (I) *Hyla chinensis. Invasive species that do not have clearly established populations were also excluded.*

From Amaël Borzée.

be built upon, as knowledge does not come in a block, but in bricks that can be used to build a library. As a specific example, *Rana taihangensis* and *Pelophylax mongolius* were described while this book was being written, with clear ecological, behaviour and threats available from the literature for *R. taihangensis*, but not for *P. mongolius*. Similarly, the knowledge provided for *Onychodactylus koreanus* will need to be refined if the clade present in DPR Korea is elevated to the species level.

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CHAPTER

Bufonidae (*Bufo* & *Strauchbufo*)

2

The Bufonidae family has a global distribution, with two species complexes distributed in northeast Asia. Their regional distribution was shaped by several geological events, including glacial oscillations and the resulting sea level variations, several orogeneses, and the development of monsoon systems (Borzée et al., 2017; Fong et al., 2020; Othman et al., 2022a, 2022b). In addition, these natural phenomena were followed by a blurring of geographic boundaries due to anthropogenic activities. Following the definition of northeast Asia used here, this family includes four species, within two genera, with similar but diverging patterns of colonisation of northeast Asia.

2.1 *Bufo*

The *Bufo* genus became established in eastern Asia around 10 million years ago, matching with the desertification of central Asia. This clade further split into a mainland clade, the *Bufo gargarizans* species complex, aged 6 to 9 million years, and the *Bufo japonicus* species complex, restricted to the Japanese Archipelago, aged 7 to 8 million years (Othman et al., 2022b). The two species related to the continental clade, *Bufo tibetanus* and *Bufo andrewsi*, are restricted to high elevations and diverged from the *B. gargarizans* species complex around 11.32 million years ago. The other non-focal species related to *B. gargarizans*, *Bufo bankorensis* restricted to Taiwan Island, diverged around 1.3 million years ago (Othman et al., 2022b).

2.1.1 *Bufo gargarizans*

2.1.1.1 *Origin and distribution*

This species goes under several common names, although names such as "Asiatic toad" are not meaningful following the multiple species splits, instead, names such as Zhoushan Toad, based on the type locality, or Chinese Toad as its ranges is limited to the country, should be retained. The taxonomy of *B. gargarizans* in mainland China still needs to be clarified as the clade is about 5.2 million years old, and includes a diverging high-elevation species (named *B. minshanicus*) in Sichuan, Shaanxi and Gansu that diverged about 2.7 million years ago and needs taxonomic attention. Similarly, there is a clade about 2.8 million years old in the

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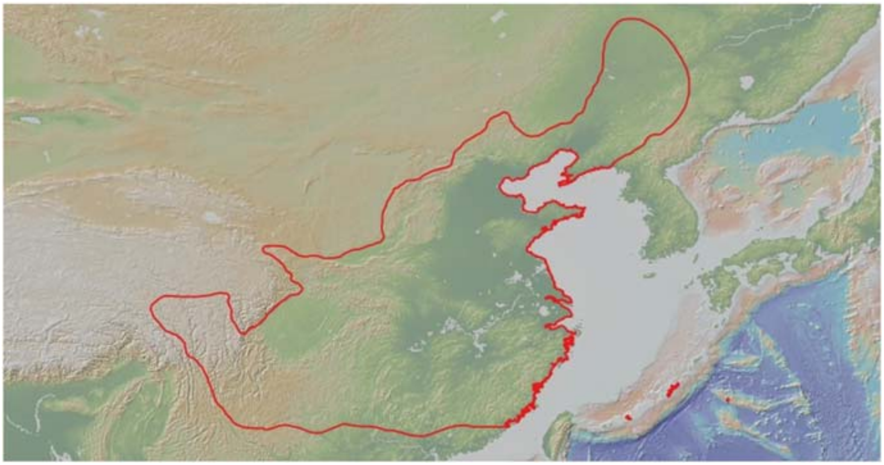

FIG. 2.1

Distribution of *Bufo gargarizans*, the Zhoushan Toad, or Chinese Toad.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

southeast of the range, while the *B. g. gargarizans* clade distributed to the west and north is about 1.8 million years old (Othman et al., 2022b).

Here noting the restricted distribution of *B. minshanicus* to the highlands in Sichuan, Qinghai Gansu and Shaanxi, *B. gargarizans* ranges in the south from central Guangdong and northern Guangxi — as the population in northern Viet Nam belongs to another not yet described species. The western edge of the range goes along the boundaries of the high plateau, through central Yunnan, the lower elevations of the Sichuan basin and southern Shaanxi, generally restricted to lower elevations south of Xi'an. The species further distributes north in Shanxi and Hebei, limited north by the arid areas (Fei et al., 2012). To the west, the species is known to reach in central Liaoning, likely all the way to Changchun, Jilin, further north, but the boundary and overlap with *B. sachalinensis* are yet to be determined, and *B. gargarizans* could be entering the extreme northeast of DPR Korea (Othman et al., 2022b). In addition, as the species has been heavily traded for human consumption over the centuries, pockets of populations out of range are to be expected. Similarly, there are two populations of *B. sachalinensis* in central China. Consequently, the boundaries of the range before human activities are not known (Fig. 2.1).

2.1.1.2 Habitat

The species lives in a broad range of habitats, from sea level up to high elevation, determined to be 4300 m when it was synonymous with *B. tibetanus* (Zhan and Fu, 2011; Fei et al., 2012), but likely limited to about 3800 m of elevation for the clade *B. minshanicus,* and 2800 m for *B. g. gargarizans* following Othman et al. (2022b).

The species breeds in generally lentic habitats, or slow-flowing waterbodies such as man-made reservoirs, but it can exceptionally be found in large streams, marshlands and rice paddies. After the breeding season, adults rely on a very broad range of habitats, including grasslands, wetlands, coniferous, mixed, and deciduous forests.

2.1.1.3 Behavioural ecology

The breeding phenology of the species is latitude, and weather, dependent, and spawning is observed right after emergence from hibernation as early as mid-January in southern China, and as late as May at Beijing's latitude (Fei et al., 2012). Males are present at the breeding sites earlier than females, generally waiting in well vegetated areas at the edge of the water bodies (Fig. 2.2). Females spawn about 4000 eggs in two strings that can be up to 2 m long, entangled in the vegetation and around 60 cm below the water surface. The eggs take a five to ten days to hatch, and tadpoles will stay in the vegetation at the beginning of their development, before swimming in large schools in open water once they reach the free-swimming stage (Fig. 2.3). Development takes about two months, with metamorphs leaving the water body between mid-March and late June, with most toadlet emerging in synchrony to decrease predation risks. Juveniles will stay in the vicinity of the breeding area until dispersion, and hibernation, starting from mid-October to early December. The species hibernates underground or under other substrates in humid habitats, in multiple types of habitats, including forests, plains and human-built structures, although generally close to the breeding sites. Hibernation underwater is likely to have been mistakenly reported from morphologically similar species. It takes three to four years for the species to reach sexual maturity.

2.1.1.4 Threats and conservation

Bufo gargarizans is listed as Least Concern by the IUCN Red List of Threatened Species and the population is stable (Kuzmin et al., 2004) because of its wide distribution across diverse habitats and its large population size. The genetic diversity between subpopulations is however low, likely as a result of inadvertent translocations (Li et al., 2015), and the species is declining in some areas, mostly because of habitat loss. The species can cope with some degrees of habitat degradation, but the total loss of overwintering habitat as a result of deforestation for the development of urban areas and agricultural fields, and the loss of breeding habitat through dam construction and water management has resulted in local extirpations (Kuzmin et al., 2004). It is however important to note that the species can take advantage of smaller reservoirs built for agricultural purposes. Other threats include roadkills as the species is abundant in open landscapes in the periphery of urban areas, water pollution due to the presence of the species close to cities and agricultural fields (e.g., Wang et al., 2016; Sun et al., 2018), climate change resulting in prolonged droughts and a northward shift of suitable habitat (Duan et al., 2016; Yang et al., 2020), and collection for traditional medicine in China. In contrast, the species occurs in many protected areas, providing a stronghold for some subpopulations.

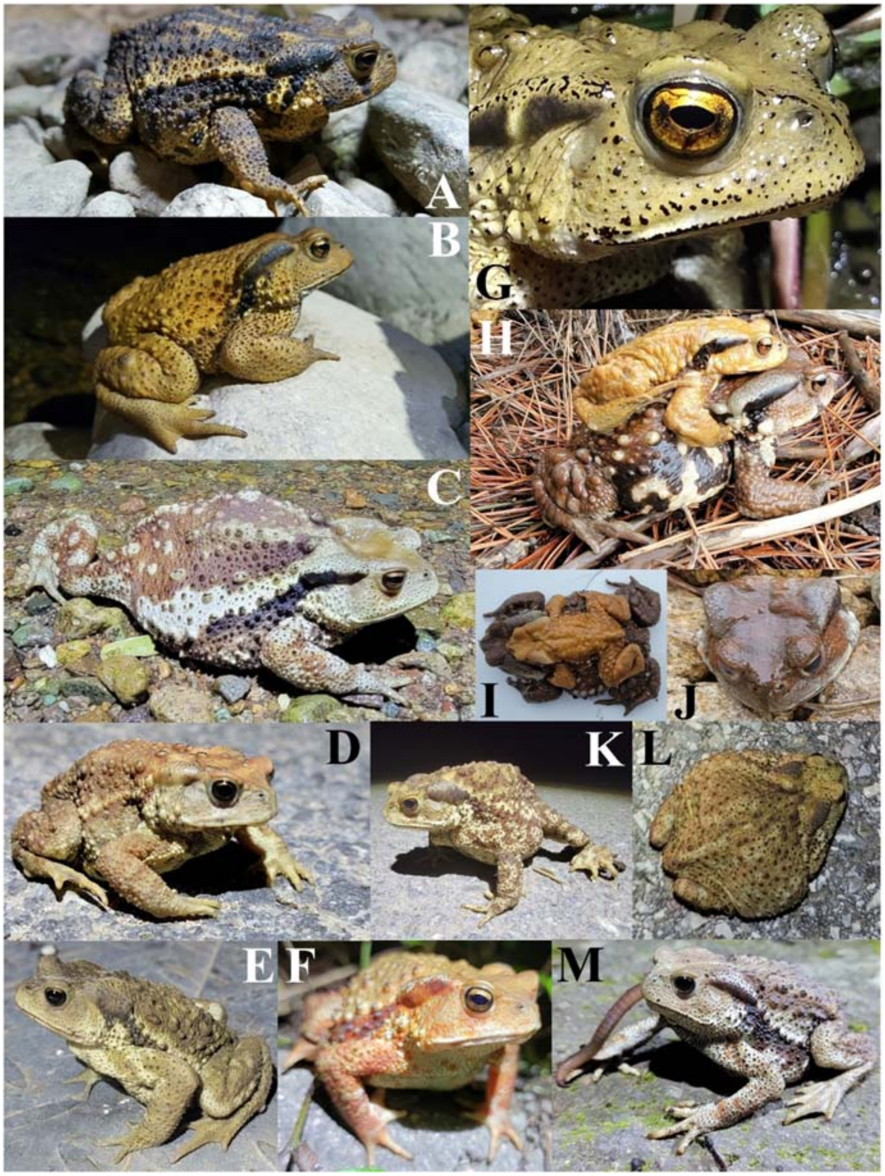

FIG. 2.2

Adult *Bufo gargarizans*. The species is highly variable in colouration (A to G). There is a colour and body size sexual dimorphism in the species, males generally being smaller than females (H and I). The species is still harvested for human consumption (J). When threatened the species can use specific body postures to look bigger (K), although they can naturally get pretty chubby (L), eating a wide variety of smaller animals, here illustrated with an earthworm (M).

From Amaël Borzée.

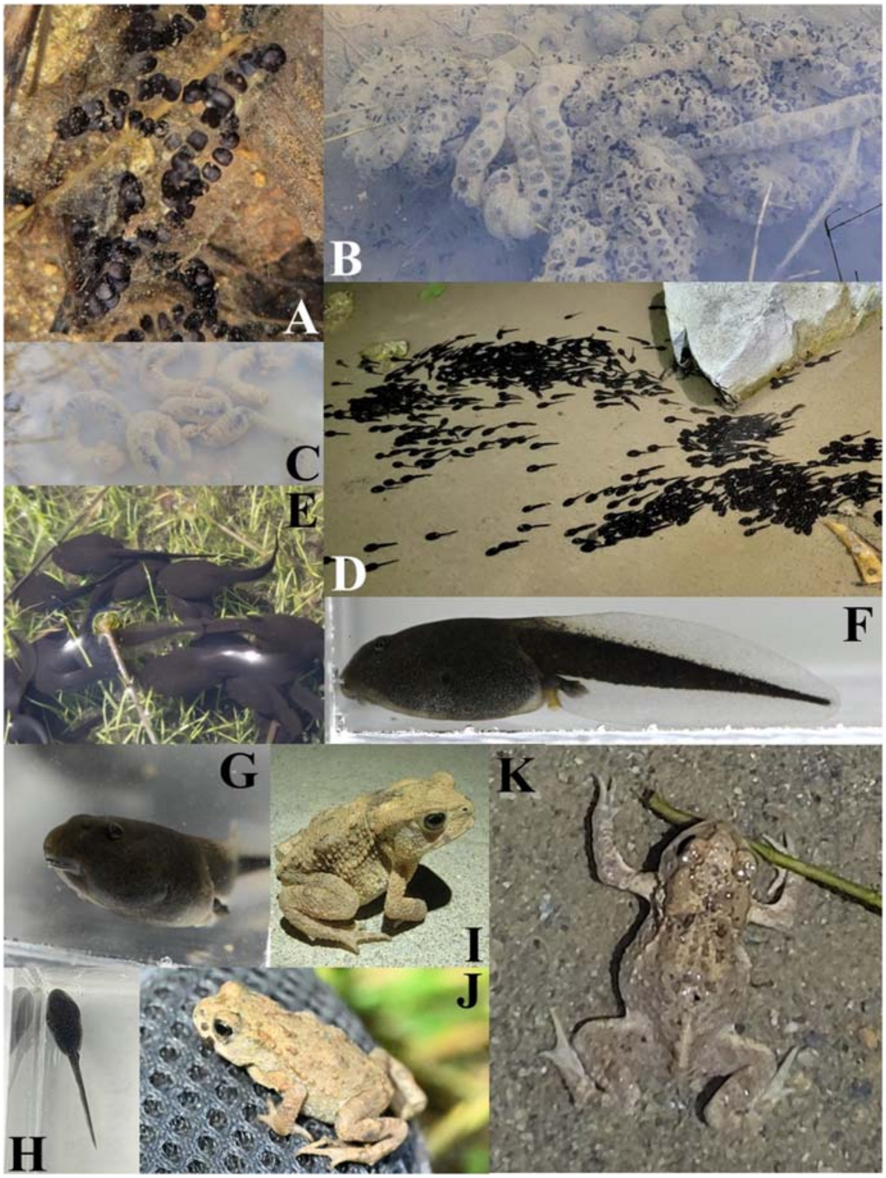

FIG. 2.3

Eggs, tadpoles and juveniles of *Bufo gargarizans*. The eggs are spawned in two long strings (A, B and C), attached to the vegetation. Once free swimming, the tadpoles move in schools (D) and feed in the vegetation (E). The tadpoles are comparatively darker than other species (F and H), with a specific their labial tooth row formula (G). After metamorphosis, the toadlets stay in the vicinity of the breeding site until dispersion (I, J and K).

From Amaël Borzée.

2.1.1.5 Identification

So far, no study specifically focused on the morphological differences between *B. gargarizans* and *B. sachalinensis*, but *B. gargarizans* is much more variable in colouration, ranging from grey to brown and reddish, with or without patterns (Matushkina et al., 2022). In addition, Fei et al. (2009) noted the presence of dark markings on the venter of *B. gargarizans*, which are generally absent in *B. sachalinensis*. When in sympatry with other Bufonidae, the species can be identified through the presence of visible tympanum (not visible in *B. stejnegeri* and *B. andrewsi*), and the absence of black crests (present in *Duttaphrynus melanostictus*). Males of the species do not call, but emit release calls, which are expected to be different between *B. gargarizans* and *B. sachalinensis*. Tadpoles of *B. gargarizans* are expected to be identifiable through their labial tooth row formula, which is 1 + 1/3 (Fei et al., 2012).

2.1.2 *Bufo sachalinensis*

2.1.2.1 Origin and distribution

The Sakhalin toad, *Bufo sachalinensis*, named from its type locality on the Sakhalin island (Nikolskii, 1905), diverged from *B. gargarizans* about 1.8 million years ago, before further diverging into a not-yet-named 1.4 million years old subspecies on the Korean peninsula, and the 0.7 million year old *B. s. sachalinensis* in Russia and China (Othman et al., 2022b, Fig. 2.4).

The species ranges across the lowlands of the Korean Peninsula, and adjacent islands except Jeju Island (Yang et al., 2000; Kim and Han, 2009), but it is absent

FIG. 2.4

Distribution of *Bufo sachalinensis*, the Sakhalin Toad.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

at the higher elevations of the Baekdudaegan Mountain range (Andersen et al., 2022b), resulting in a gap in the distribution of the two sub-species. In DPR Korea, the species is present at some isolated sites along the east coast, with a larger population in the area north of Kumya in southern Hamgyong Province (Borzée et al., 2021b). In China, the species is present in the southernmost areas of Liaoning, it has not been confirmed in Jilin, and it is present in the east of Heilongjiang. The species also occurs in the Russian Far East, including East Siberia and Sakhalin Island, and northwards to the Amur River Basin in Russia (Andersen et al., 2022b). In addition, as the species has been heavily traded for human consumption over the centuries, out-of-range pockets of populations are found in central China (Othman et al., 2022b, Fig. 2.5).

2.1.2.2 Habitat

In R Korea, *B. sachalinensis* ranges from 0 to 1200 m of elevation, although it is present in larger densities at lower elevations (Andersen et al., 2022a), and it is not expected to be found at higher elevations further north due to the latitudinal shift in ecological requirements (Andersen et al., 2022b). The species hibernates buried under the frost line, underground or under other substrates, including the basement of human structures. It breeds in lentic habitats, or low-flowing waterbodies such as man-made reservoirs, but it can exceptionally be found in rice paddies flooded by rainwater. The non-breeding habitat is mostly restricted to mixed and deciduous forests, or in their vicinity, although it is also rarely present in dense conifer forests. The species can tolerate some degree of habitat modification, and it is found in fields when foraging, and in parks in large cities.

2.1.2.3 Behavioural ecology

Bufo sachalinensis is an explosive breeder, with males entering water bodies the last week of February, females arriving about five days later, and spawning is completed before the end of the second week of March, at the southernmost latitudes of the species' range (Groffen et al., 2022). This phenology is delayed by three weeks when reaching mid-latitude of the Korean Peninsula, and three more weeks at Vladivostok latitude. In addition, climate change is creating disturbances for this explosive breeder, and a delay of about a week at a given location in R Korea was observed over the last five years. Finally, young males can be found for a few weeks at the breeding site after spawning is completed. Mate selection is done through scrambling competition (Cheong et al., 2008), resulting in the death of some females through drowning (Shin et al., 2020a). Eggs are deposited in two strands containing about 4000 eggs, weaved through the vegetation, between 50 cm and 1.5 m underwater (Ambu et al., 2022). Hatching takes about a week, and the tadpoles stay in the vegetation close to the surface until they are able to swim freely and form schools in the water body. It takes four weeks for tadpoles to develop and emerge from the water, in synchrony, on wet days (Fig. 2.6). The toadlets will stay close to the breeding area until dispersion, and migration to woodlands for hibernation. In R Korea, the species stops being active from mid-November, hibernating until late

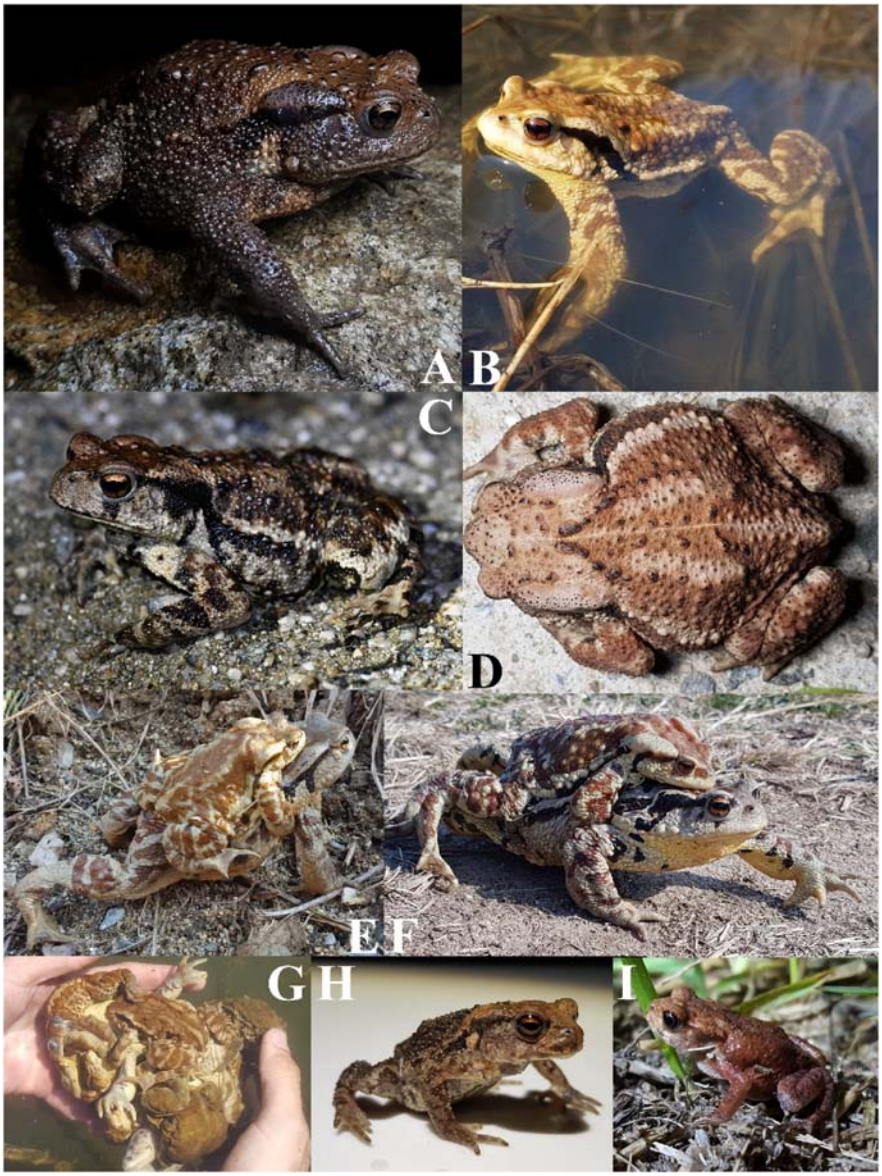

FIG. 2.5

Adult *Bufo sachalinensis*. The species does not show as great a variation in colour as *B. gargarizans* (A to D). Smaller males wait for females outside of water bodies to amplex them before they reach the water (D and E) and overcome competition with larger males, although they may be dislodged once reaching the water, and may me drowned with females in case of scramble competition (G). Toadlets can be found in the vicinity of the breeding ground (H and I).

From Amaël Borzée.

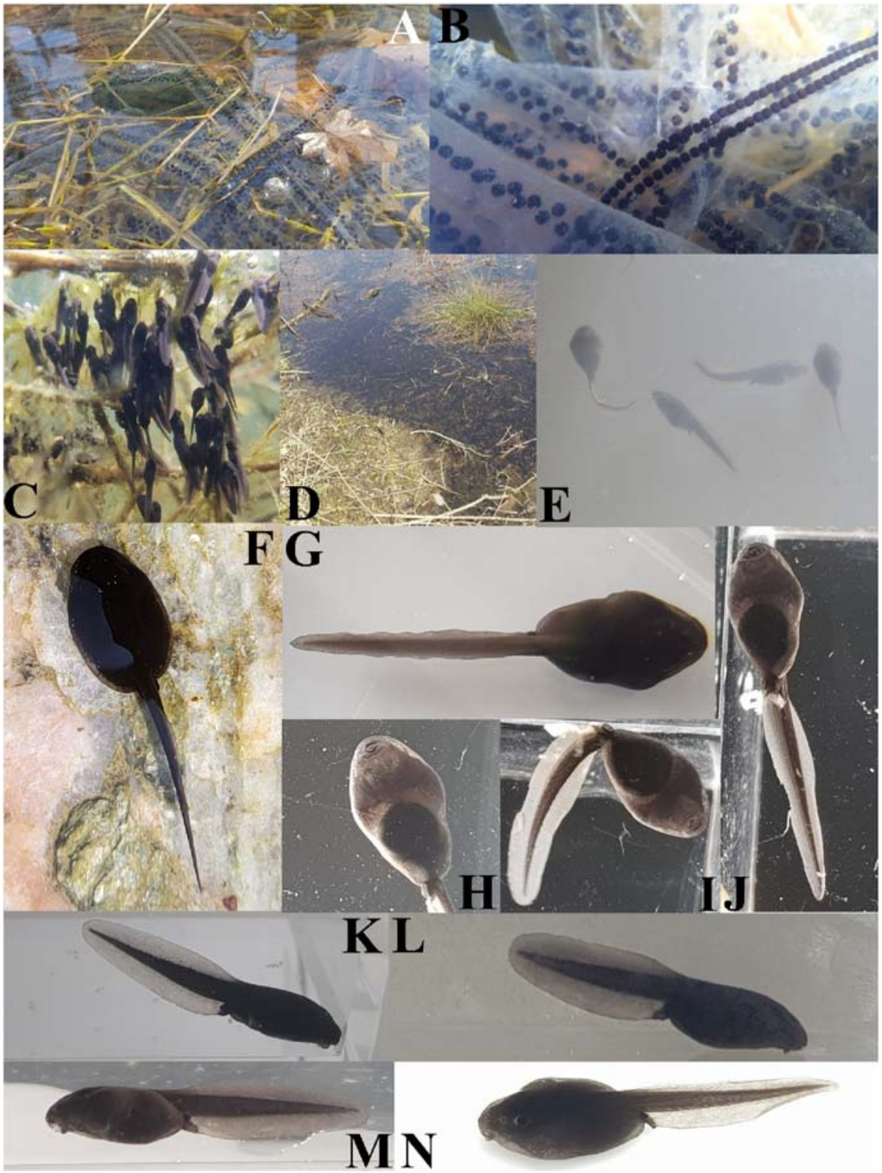

FIG. 2.6

Eggs and tadpoles of *Bufo sachalinensis*. The eggs are spawned in two long strings attached to the vegetation (A and B), where tadpoles stay until being free swimming (C), and before schooling in large groups (D and E). The tadpoles are very dark, with a specific labial tooth row formula (F to N).

From Amaël Borzée.

February the next year to breed. Hibernation starts earlier, from mid-October, at high latitudes. It takes three to four years for *B. sachalinensis* to reach sexual maturity, and young males at the breeding sites are unlikely to access mates due to their small sizes. The species is long-lived, and a captive female was recorded to have reached 16 years old.

2.1.2.4 Threats and conservation

Bufo sachalinensis has not been assessed by the IUCN Red List of Threatened Species following the split with *B. gargarizans* (Kuzmin et al., 2004), although the current assessment as Least Concern is likely to be valid despite the decrease in population size, due to the wide distribution of the species, its tolerance for a broad range of habitats, and its ability to cope with a relative degree of habitat change (Groffen et al., 2022). In R Korea the species is principally impacted by habitat loss, following urban development and clear cutting. It is also within the top ten amphibian species impacted by roadkills (Shin et al., 2022), and climate change models for suitable habitat predict a decrease by 2030, 2050 and 2080 under different RCP scenario (Kim et al., 2021). In addition, climate change is impacting the breeding phenology of the species, even within a few years (Jang et al., 2023). Finally, the species is used for traditional medicine in China and DPR Korea, but such use has now almost stopped in R Korea. The species is locally abundant in R Korea, and common within its range in Russia. It occurs in protected areas in all range countries, and infections by the Chytrid fungus do not seem to have an impact on the survival of the species (Bataille et al., 2013).

2.1.2.5 Identification

Adults of the species are easily differentiated from the other sympatric Bufonidae, the closest one being *B. stejnegeri*, which is distinguishable through the absence of exposed tympanum. The absence of comparative studies with *B. gargarizans*, and the absence of knowledge regarding range boundaries, makes the morphological identification of these two species more difficult. *Bufo sachalinensis* colouration is however more consistent, with a brown dorsum and black non-continuous lateral stripes segregated by white stripes, and a white venter (Matushkina et al., 2022). The release calls of the two species are also expected to be different, but no study on the subject is available yet. The tadpoles' labial tooth row formula is 2(2)/3 (Park et al., 2009).

2.1.3 *Bufo stejnegeri*

2.1.3.1 Origin and distribution

Bufo stejnegeri, or the Water Toad, a name based on the behaviour of the species, was described from Kaesong, in DPR Korea (Schmidt, 1931). The species emerged from the radiations within East Asian *Bufo* that started about 8.9 million years ago, with the species being between 2 and 4 (Yang et al., 2000; Othman et al., 2022b) and 7.3 million years old (Fong et al., 2020), without specific sub-clade arrangement linked to the topography.

FIG. 2.7

Distribution of *Bufo stejnegeri*, the Water Toad.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

The species ranges from Jiri Mountain in the south, and along the Baekdudaegan Mountain range, being generally restricted to high elevations (Andersen et al., 2022b). The continuity of the species' presence along the mountainous range is however not demonstrated, and the southernmost subpopulation may be isolated. It is present in the eastern half of R Korea, and some populations are now extirpated, such as the one in the area of Seoul. The presence of the species in DPR Korea follows a line starting in the southeast and heading to the northeast, along the mountain ranges, without reaching the highest altitudes and latitudes (Andersen et al., 2022b). In China, the species occurs in eastern Liaoning, and extreme west Jilin (Fei and Ye, 2016), without reaching northern DPR Korea or Russia (Fig. 2.7).

2.1.3.2 Habitat

The species ranges from 20 to 1250 m in R Korea (Andersen et al., 2022a), although rare at the lower range of elevations, and from 200 to 700 m in China (Fei et al., 2012). In contrast with the other Bufonidae in northeast Asia, *B. stejnegeri* has some very specific ecological requirements, differing quite importantly from that of sympatric amphibians, with the exception of *Rana huanrenensis*. The species is present in riparian mixed and deciduous forests outside of the hibernation and breeding period, when it is present in fast-flowing high elevation streams. The species migrates between the two habitats, when it can be found in unhospitable environments like cliffsides.

2.1.3.3 Behavioural ecology

The behavioural ecology of *B. stejnegeri* is unique in the region, and has independently evolved in the species (Fong et al., 2020). Amplexed pairs and single males and females enter streams from September in China (Fei et al., 2012) and early October and November in R Korea. Mate selection is based on size-assortative pairing (Lee and Park, 2009), and the pair will stay amplexed under the ice until spawning in late March and April in R Korea (Lee and Park, 2009; Chen et al., 2012; Groffen et al., 2022) and April in China (Ji, 1987). The skin of the toads will change structure within a few days of being submerged, switching from a warty to a smooth skin with flaps, likely to increase oxygen intake when underwater (Fig. 2.8). Females deposit about 800 eggs in two long filaments, generally under rocks or in cracks between rocks. The development of eggs has not been studied, but hatching can be as quick as five days (personal observations), likely to prevent the eggs from being flushed. Tadpoles can be observed in April and May, they have a long fusiform body adapted to lotic habitats, and they are able to adhere to the substrate through a body arrangement that provides benefits similar to those of a ventral sucker (Fig. 2.9). Toadlets emerge in June, and they can be found in the non-breeding habitat in October. As toadlets have not been recorded hibernating underwater like breeding adults, they are likely hibernating underground before reaching sexual maturity, although they can breed from the following year (Lee and Park, 2009). In the non-breeding habitat, the species is generally nocturnal (Fei et al., 2012)

2.1.3.4 Threats and conservation

For now, the Water Toad is mistakenly listed as a Least Concern on the IUCN Red List of Species (IUCN SSC Amphibian Specialist Group, 2020). The species does not occur across a wide distribution, its population is not large, and it is decreasing fast, albeit hardly documented. Based on maps provided by Fei et al. (1999), Fei et al. (2009), Fei et al. (2012) and Fei and Ye (2016) for China, and by Yang et al. (2000) for R Korea, follow-up surveys, in 2020 in R Korea and 2021 in China, failed to document the occurrence of the species at these sites, leading to the conclusion that the species became locally extirpated at most sites located within 20 km of urban areas. Similarly, the subpopulations at other localities are now extirpated, such as the one in the mountains south of Seoul (Shin et al., 2020b). In addition, population densities such as the ones described by Lee and Park (2009) are increasingly rare.

Furthermore, the species was historically uncommon on the Korean Peninsula, and due to its habitat requirements, the population is suspected to be fragmented (Do et al., 2017). The reasons for these declines and local extinctions are mostly linked to habitat destruction and degradation at the breeding sites, caused by urban development, timber crops, development of recreational activities, dams, and water pollution. Specific threats also include roadkills in R Korea, where it is within the top five amphibian species impacted by the threat (Shin et al., 2022), collection for traditional medicine in DPR Korea, sensitivity to habitat changes (Groffen et al., 2022), and sensitivity to climate change through the loss of suitable habitat, as shown by landscape models predicting a drastic decrease of suitable habitat by 2030, 2050 and 2080 under different RCP scenario in R Korea (Kim et al., 2021). The

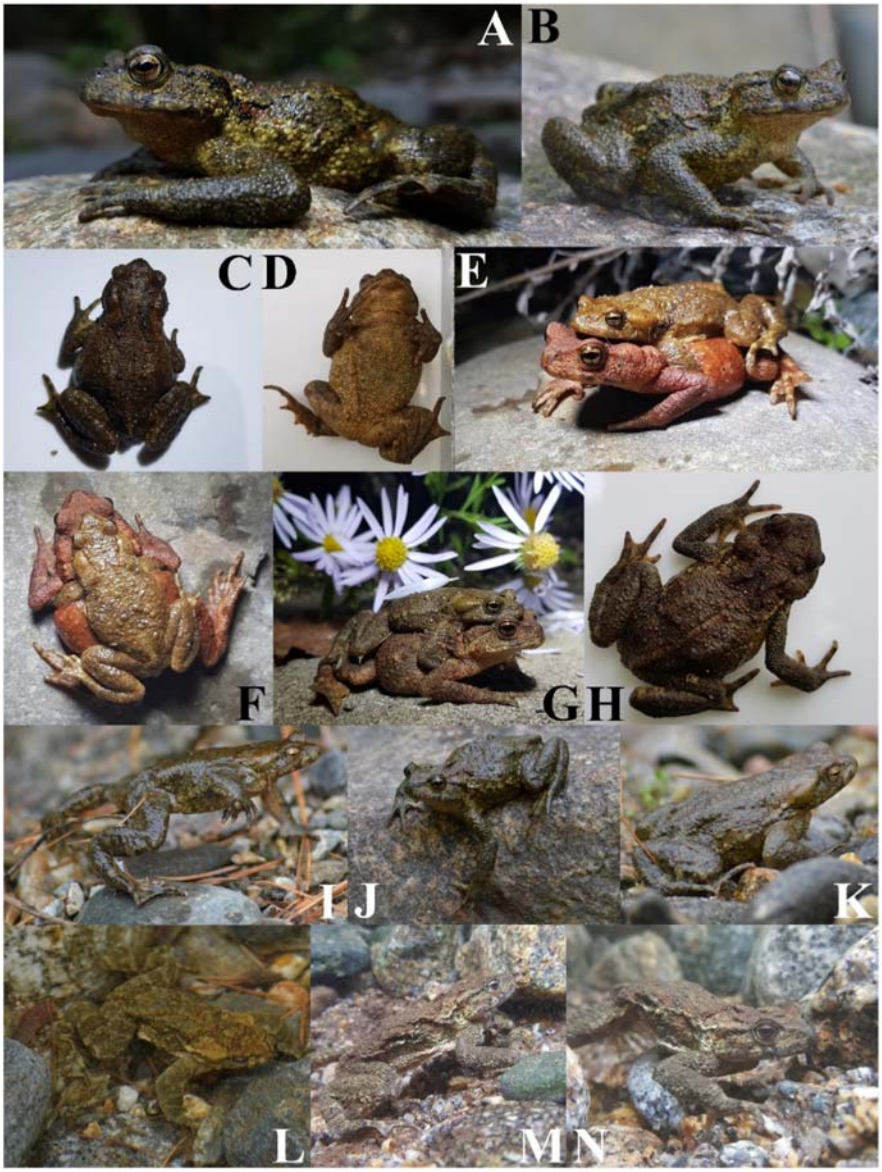

FIG. 2.8

Adult *Bufo stejnegeri*. The species is constant in colouration (A to D and H), but females change colour during the breeding season (E), when the sexual dimorphism is made even more visible (F). Amplexus starts in fall (G) and the pair will stay under water until spawning in spring (L, M and N), resulting in a smoothing of the skin (I and J) and extension of skin flaps (L, M and N). The lateral line is clearly visible in some individual of the species (K).

From Amaël Borzée.

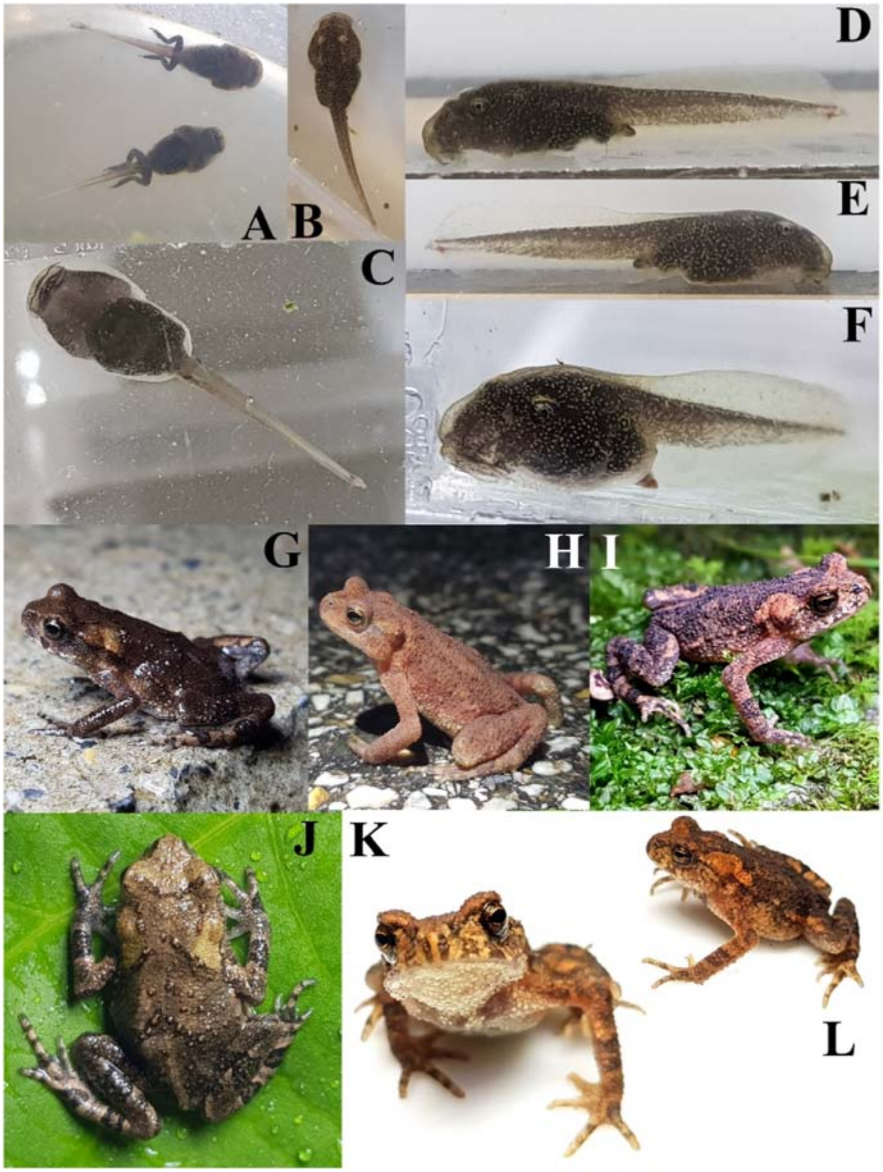

FIG. 2.9

Tadpoles and juveniles of *Bufo stejnegeri*. Tadpoles live in fast flowing streams and are adapted to the water flow through the shape of their bodies and the presence of a ventral suction-like arrangement of the body (A to F). The tadpoles are darker with yellow speckles (B, D and E). After metamorphosis, on fall warm rainy nights, the toadlets can be found a few 100 m away from the stream where the eggs were spawned (J to L).

From Amaël Borzée.

destruction of hibernation sites for first-winter juveniles may also be a threat, although the lack of data prevents clear conclusions.

In contrast, the species is found in several protected areas, including the Baekdudaegan Mountains Reserve and several National Parks in R Korea, and it is also protected from collection in China, and it is specifically protected in Liaoning through different legislations (ASG, 2020). The species has also been found to be positive for the Chytrid fungus, but it is not considered to be a threat (Bataille et al., 2013).

2.1.3.5 Identification

Adult *B. stejnegeri* are easily identifiable in comparison with sympatric *Bufo* through the absence of visible tympanum and the parotid glands being parallel. The species is also more slender than sympatric *Bufo*, with smooth skin during the breeding season, and a clearly marked equivalent of a lateral line in most individuals. The release calls of the species are higher than that of sympatric *Bufo*. Eggs strands are thinner in *B. stejnegeri* than in sympatric *Bufo*, and the species breeds in lotic habitat. The tadpoles are slender and less dark than that of sympatric *Bufo,* rather streamlined like that of other lotic breeding Bufonidae, such as *Ansonia,* and the labial tooth row formula is 2(2)/3 in Korea (Park et al., 2009) but potentially different in China (Li et al., 2010).

2.2 *Strauchbufo*

The genus emerged with its sister clade about 10.8 million years ago (Othman et al., 2022b). It used to have a Palearctic distribution, until disappearing from the western parts of its range during the ice ages (Litvinchuk et al., 2020).

2.2.1 *Strauchbufo raddei*

2.2.1.1 Origin and distribution

Strauchbufo raddei, the Mongolian toad (Strauch, 1876), a name based on the centrality of its range, emerged more than 11.6 million years ago, when the two main clades within this species diverged. A northern clade became established in the central Asian steppes about 7.8 million years ago while a southern clade emerged after the next glacial cycle, about 6.8 million years ago, dispersing north later on (Othman et al., 2022a). In addition to the north-south distinction, a latitudinal barrier isolates the pre-Tibetan Plateau population from other populations (Othman et al., 2022a).

The species has a very extensive range (Litvinchuk et al., 2020), occurring in an isolated population in Shandong in China in the south-east (Ding et al., 2022), an isolated population in northern Henan, and across northern Hebei to reach northern Shaanxi (north of Xi'an), Gansu, and the lowest elevations of eastern Qinghai. The species is not present in the Gobi desert in Inner Mongolia, China, and southern Mongolia, but it ranges north of the Gobi desert. It is present across the landscapes until the southern bank of the Baikal Lake in Russia, with an isolated population

FIG. 2.10

Distribution of *Strauchbufo raddei*, the Mongolian Toad.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

northwest of the Baikal Lake. The species is then present eastward, in northern Heilongjiang and parts of Jilin, from where it ranges into Far Eastern Russia along the Amur River Basin, with an isolated population in northern Sakhalin Island. It is not present on the high elevation of the Paektu/Changbai Mountain, but reaches a few kilometres away from the Russian border into extreme northern DPR Korea (Borzée et al., 2021b). The species is also present in North Pyongan in the northwest of DPR Korea (Kuzmin et al., 2017), ranging north-westward around the Yellow Sea from there (Fig. 2.10).

2.2.1.2 Habitat

The altitudinal range of the species is variable, starting from sand dunes at sea level in DPR Korea (Borzée et al., 2021b), a weakly saline landscape, reaching a maximum of 3300 (Fei et al., 2012) or 3800 m of elevation (Kuzmin et al., 2017) in the western part of its range. The largest population densities in the species are however found a medium elevations, between 1100 and 1700 m (Kuzmin et al., 2017). Across these elevations, the species is found in a variety of landscapes, including extremes such as semideserts and saline marshes, where its presence is linked to springs and streams. The Mongolian toads more generally occur in coniferous, mixed and deciduous forests, bushland, steppes, grassland, meadows and wetland, including streams and river banks (Fei et al., 2012).

The use of landscapes is also clade-specific, with deserts and grasslands in Eastern Siberia, Mongolia and western China, and river basins and forested landscapes in northeastern China, DPR Korea and Russia (Othman et al., 2022a). All clades can however cope with habitat modification and the species is not uncommon in agricultural landscapes and moderately urbanised habitats (Kuzmin et al., 2004). The species relies on lentic habitats to breed, including large and oxbow lakes, marshes and bogs but also modified habitats such as rice fields, and it is occasionally found breeding in weakly brackish habitats (Kuzmin et al., 2017; Borzée et al., 2021a).

2.2.1.3 Behavioural ecology

Adults of both sexes can move across large distances in the landscape (Fig. 2.11). The breeding season of the species is latitude-dependent, with individuals spawning as early as March at lower latitudes in China, where development from spawning to metamorphosis takes about 80 days (Fei et al., 2012). Hibernation can however last until late May in Eastern Mongolia, and eggs have not hatched by early June in the northernmost areas of the range even if males can start calling when the water temperature is between 4 and 5°C (Kuzmin et al., 2017). Exceptionally, amplexus can be found in late June in Mongolia, although females are generally done breeding by that time, and spawning can take place until early July in Buryatia Republic in Russia and at high elevation in Gansu in China. The females lay two egg strings that are 3 to 6 m long, containing about 2000 eggs, that they disperse between the surface and 50 cm below the surface in deep lakes as well as shallow and temporary wetlands (Kuzmin et al., 2017). Hatching takes about two weeks, and then tadpoles hold to the egg string until the free-swimming development stage, when they congregate in warmer areas of the water body (Fig. 2.12). Tadpoles metamorphose between June and August, moving out of the water before total tail absorption, and they have been reported to be able to overwinter as tadpoles when the water is deep enough to avoid freezing (although evidence is scarce, and it may not be a common behaviour). Youngs of the year will disperse during rainy days in late summer, and the species can exhibit both diurnal and nocturnal activity when the temperature allows. Hibernation starts from mid-September at northern latitudes and early November in the south, and overwintering is generally underground, sometimes as deep as 2 m to reach below the frost line, with individuals hibernating in groups or alone (Kuzmin et al., 2017). Exceptions to this behaviour are found close to hot springs, where individuals can be found active even when the air temperature reaches −20°C (Kuzmin et al., 2017). The species reaches sexual maturity between two and four years, for an eight to ten years lifespan (Kuzmin et al., 2017).

2.2.1.4 Threats and conservation

The Mongolian Toad is listed as Least Concern, with a stable population size, by the IUCN Red List of Threatened Species (Kuzmin et al., 2004), and in Mongolia (Terbish et al., 2006b). It is widely distributed, and can tolerate a broad range of habitats, including partially modified environments. In addition, the species occurs across numerous protected areas in all range countries, including 8% of its range in Mongolia (Terbish et al., 2006a), and it is protected in Buryatia and Irkutskaya Provinces in Russia.

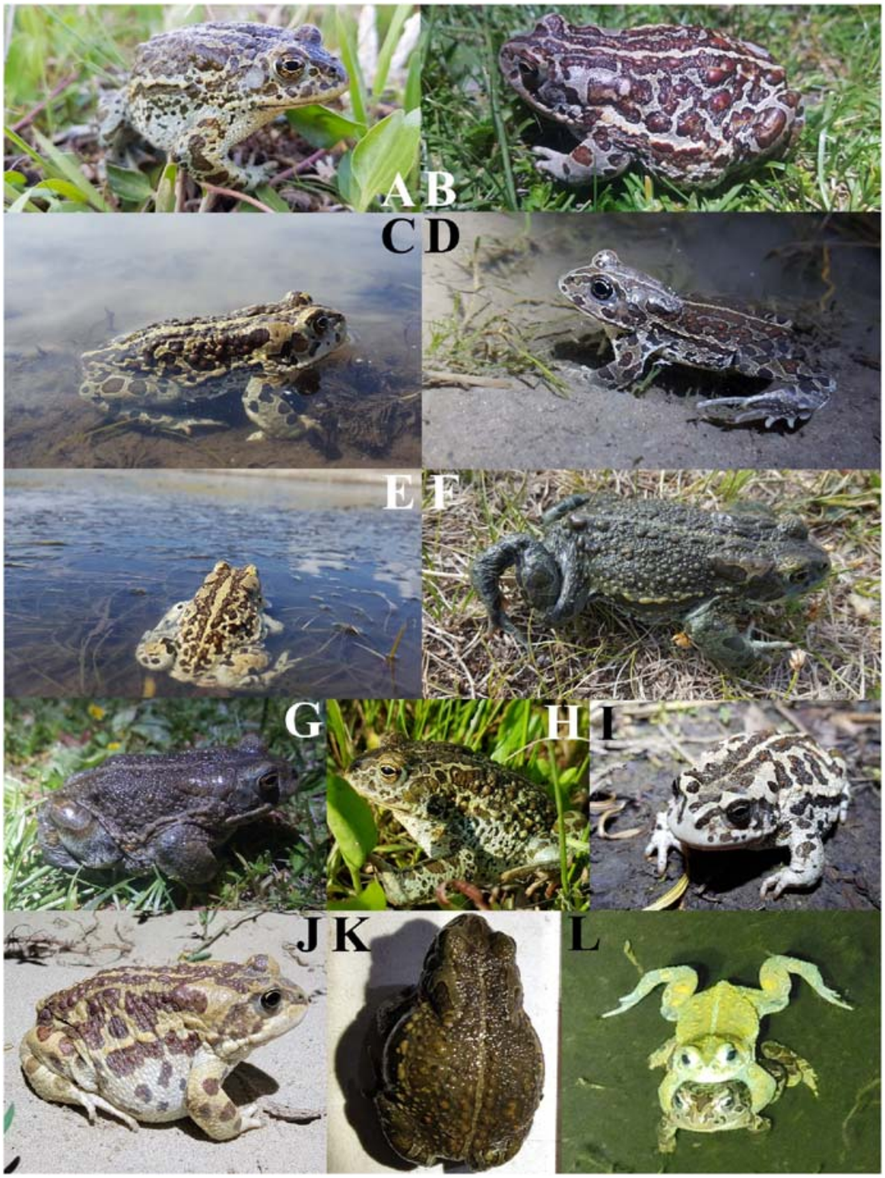

FIG. 2.11

Adult *Strauchbufo raddei*. The species is variable in colouration (A to K), but females are generally more contrasted (A, B and I). Breeding takes place between April and July, based on the latitude (L).

From Amaël Borzée.

FIG. 2.12

Eggs, tadpoles and juveniles of *Strauchbufo raddei*. Eggs (A) are spawned in non-flowing water bodies, where tadpoles will develop (B to I). Toadlets stay in the vicinity of the water body (J), and take comparatively long to become tail-less (K) and show the same colour as adults (L).

From Amaël Borzée.

The threats to the species include locally abundant roadkills and collection for traditional medicine in China (Kuzmin et al., 2004), water pollution (Borzée et al., 2021a) as metal pollution can delay development in the species (Zhang et al., 2007) and climate change is impacting the distribution and abundance of the species at the southern edge of its range (Duan et al., 2016). Potential additional threats need to be considered, as for instance about half of the toadlets in 2008 had incompletely developed hindlimbs at a site in Mongolia for undetermined reasons (Kuzmin et al., 2017). In addition, isolated populations, including the ones depending on hot springs for overwintering, are under higher threat of habitat alteration through development and pollution from mining.

2.2.1.5 Identification

Strauchbufo raddei is the only Bufonidae in large parts of its range, but when it is sympatric with *Bufo* species, it is easily identifiable through dorsal patterns that are green or brown, delineated by a white or dark network of lines, sometimes fading out on the dorsum. Generally, females have more contrasted patterns, with very light line networks between patches of colours, while males are dark green with brown line networks (Fig. 2.11). This sexual dimorphism is not definitive, and exceptions are numerous. The calls of the species are soft whistles (Kuzmin et al., 2017), unlike that of other sympatric amphibians, but release calls are generally similar to that of Bufonidae, although different between the southern and northern clades of the species (Othman et al., 2022a). The labial tooth formula is 1:1 + 1/3 (but also 1:1 + 1/1:2, although rarely) similar to *Bufotes pewzowi* (Kuzmin et al., 2017).

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CHAPTER

Hylidae (*Dryophytes*)

3

3.1 *Dryophytes*

Northeast Asian Hylidae are relatively recent on the Asian continent. The first Hylids, from the *Hyla* genus, arrived in Asia between 28 and 23 million years ago (Smith et al., 2005), migrating across the Bering Pass when sea levels were lower. Species of the *Hyla* genus did not only stay in northeast Asia, but dispersed across most of Eurasia. Population in central Asia were however extirpated over time, likely through the desertification of the landscapes. Populations in southern Asia are now found in China, Vietnam, India and Myanmar.

The Hylid species currently present in northeast Asia belong to the *Dryophytes* genus, and dispersed into Asia following the route used by *Hyla*, but between 22 and 17 million years ago (Li et al., 2015). The genus is now found in eastern and northern China, eastern Mongolia, east of the Baikal lake and in the Amur basin in Russia, on the Korean peninsula and on the main islands of the Japanese archipelago. The genus first split around 13 million years ago (Borzée et al., 2020b), resulting in the *Dryophytes immaculatus* complex and the *Dryophytes japonicus* complex. The *D. japonicus* complex is divided into two species, one of them in need of taxonomic description and restricted to the Japanese archipelago and the Sakhalin Island and the other one subdivided into two subspecies, with *D. j. japonicus* restricted to the southern islands of the Japanese archipelago and *D. j. stepheni* ranging across mainland northeast Asia (Boulenger, 1887). The *D. immaculatus* complex diversified about one million years ago, resulting in three species occurring on the Korean Peninsula and eastern China (Borzée et al., 2020b).

Over evolutionary times, the stable habitat for the *D. japonicus* complex was consistently present across the southernmost island of the Japanese archipelago, the Korean peninsula and the Amur Basin, while the stable habitat for the *D. immaculatus* complex was along the Yangtze River basin in China, the Korean peninsula, and the bed of the Yellow Sea when sea levels were lower and the land was emerged (Andersen et al., 2022c).

Continental northeast Asian hylids rely on similar habitats throughout their range, having adapted to human activities and breeding in large numbers in agricultural wetlands when available. This also resulted in the species being subjected to similar threats, namely habitat loss and fragmentation. A significant difference

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between clades is that *D. j. stepheni* can cope with the anthropisation of the environment, while all three species from the *D. immaculatus* complex are now restricted to the vicinity of agricultural wetlands such as rice paddies.

3.1.1 *Dryophytes japonicus*

3.1.1.1 *Origin and distribution*

The two *Dryophytes japonicus* clades diverged around 2 million years ago (Dufresnes et al., 2016). Here, the focus is on *D. japonicus*, and especially *D. j. stepheni*, the Northeast Asian Treefrog, as it is the only clade present on the mainland, and the definition of subspecies is a fluid human concept changing with our understanding of the relationship between clades.

D. j. stepheni is found all the way south to Jeju island in R Korea, and as far north as the northern Amur River Basin in Russia. The habitat on the Korean Peninsula and the Amur Basin has been relatively suitable over the last 130,000 years (Andersen et al., 2022c), although gene flow was restricted within several regions and three weakly divergent clades have formed. The westernmost population is along the Selenge River in Mongolia (Kuzmin et al., 2017), and the easternmost one in the region of Komsomolsk-on-Amur in the Russia Far East, facing the Sakhalin island where the sister species occurs. The three weakly divergent clades of *D. j. stepheni* are distributed such as the southern one includes Jeju island and most R Korea, the central one includes the northern boundaries of R Korea, DPR Korea, Liaoning and Jilin in China and the northern one includes Heilongjiang in China, the region between the Russian Far East and the Baikal Lake in Russia, and the extreme north in central-eastern Mongolia (Fig. 3.1). This last northern clade was described as an independent species under the epithet “ussuriensis” before being synonymised (Li et al., 2015). Finally, an isolated population is present at the boundary between Henan and Inner Mongolia in China, along the Chaogedu’er river bordering the west of the Yudaokou Grassland Forest Scenic Park (Stone, 1899).

3.1.1.2 *Habitat*

The habitat used by *D. j. stepheni* is generally clade specific, with some exceptions. The southern lineage has adapted to human activities (Roh et al., 2014), and likely benefitted from the early development of rice agriculture. Surveys at more than 3200 independent rice paddies during the breeding season resulted in presence records for the species. It is however not present in agricultural landscapes only, and individuals are breeding in slow-flowing creeks and isolated pools in forested hills in the natural wetlands left in R Korea, but also, and in contrast, in water fountains in urban areas. The population in Jeju islands is particular in that it also breeds in basaltic formations resulting from volcanic activity, and at sites with brackish water (Heo et al., 2019). The central clade, centred on DPR Korea and Liaoning and Jilin in China, also breeds in rice paddies when available, but the species is equally relying on the natural environment, including larger water bodies than those where the southern clade is found. The northernmost “ussuriensis” clade is rarely found breeding in

FIG. 3.1

Distribution of *Dryophytes japonicus*, the Northeast Asian Treefrog, on continental Asia and parts of western Japan. The range of the candidate species is shown with *dashed lines*.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

agricultural landscapes, and principally relies on natural wetlands in forested areas as well as floodplains, and it is present in isolated but densely populated pockets centred around oxbow lakes and other large lentic wetlands, at the edge of forests, in Mongolia and the adjacent regions in Russia (Borzée et al., 2019b), but not in the steppes areas (Kuzmin et al., 2017). The clade can be found from sea level and up to 1500 m of elevation in R Korea (Andersen et al., 2022a), but around 600 m in Mongolia (Kuzmin et al., 2017).

3.1.1.3 Behavioural ecology

The behavioural ecology of *D. j. stepheni* is region and clade-specific, especially in regard to the breeding phenology. The first males can be heard calling in late March at the southern latitudes of the range, with the peak breeding activity in May and June (Groffen et al., 2022). In opposition, breeding starts in late May and does not last more than a few weeks in northern locations. Males generally call from the edge of water bodies and will amplex with any female passing by. Once amplexed, the female will lay eggs in small clusters throughout the water body. Hatching, and tadpole development, are temperature dependent, and individuals can take up to several months to reach metamorphosis in cold areas that are not impacted by droughts. In warm habitats, the first metamorphs can be seen emerging from late May, with the latest ones observed metamorphosing in September. In Mongolia, individuals emerge from the water between late July and early August (Kuzmin et al., 2017). The date of emergence is linked to the time period available to forage before hibernation, a late emergence is unlikely to be beneficial to the fitness of individuals.

The divergence in habitat use for breeding also results in differences in breeding ecology as subpopulations that rely on rice paddies or isolated water bodies for breeding at northern latitudes need to migrate to forested areas for hibernation (Kuzmin et al., 2017; Borzée et al., 2019a) while subpopulations breeding in creeks in forests can hibernate in the vicinity of the breeding site. An interesting behaviour found in the clade is that males climb up trees in fall, and especially chestnut trees, and call from the upper canopy. The reason for this behaviour is not yet understood but could be related to the development of call muscles in young individuals, or the selection of hibernation partners through MHC-influenced call properties to attain herd immunity. This behaviour stops when the temperature reaches around 10°C, and individuals start brumating and then hibernating (Borzée et al., 2018a). Individuals start hibernating in mid-November in R Korea, but from as early as September in Mongolia (Kuzmin et al., 2017).

3.1.1.4 Threats and conservation

Threats are also clade-specific, with individuals the southernmost clade present in large numbers and the northernmost clade being regionally threatened in Mongolia (Kuzmin et al., 2017). In contrast, the two clades centred on the Korean peninsula are likely to have seen their population increase over the last millennia in areas where the frogs breed in rice paddies. The trend has however inverted since the beginning of industrialisation, and despite the very large number of individuals over a large area, the population size is decreasing due to habitat loss and widespread anthropogenic changes to the landscape. Threats to the central clade are less easy to categorise as a large section of the population is found in DPR Korea, where surveyed amphibian species are thriving in the lowlands (Borzée et al., 2021b), but deforestation may have had a negative impact on the species present at higher elevations. The northern "ussuriensis" clade is the one under the highest level of threat because of climate change-induced droughts and habitat loss (Duan et al., 2016; Kim et al., 2021). For instance, populations in Mongolia are declining because of the combined impact of threats, including water pollution from domestic, agricultural and mining facilities (Terbish et al., 2006; Kuzmin et al., 2017; Borzée et al., 2021a). In addition, droughts related to human activities have resulted in the decline of some populations (Kuzmin et al., 2017). As a result, the species is listed as threatened in Mongolia (Munkhbayar and Terbish, 1997). A general point for all three clades is that they may not be as strongly impacted by the salinisation of the environment as a result of climate change as both the southern and northern clades can cope with brackish habitat during tadpole development (Heo et al., 2019; Borzée et al., 2021a), and the species can cope with some degree of habitat changes (Groffen et al., 2022). However, the species is among the top five amphibian species impacted by roadkills in R Korea (Shin et al., 2022) and there is a risk of increase in Ranavirus because of climate change (Roh et al., 2023).

3.1.1.5 Identification

The identification of the species is straightforward for most of its range as it is the only Hylid occurring in the area (Fig. 3.2). Tadpoles of *D. j. stepheni* are between 2 and 3 cm long, with a mottled caudal musculature pattern and they are characterised by a 2(2)/3 labial tooth row formula in Korea (Fig. 3.3; Park et al., 2009). The formula, however, is different in Mongolia: 1:1 + 1/3 or rarely 1:1 + 1/1:1 + 1:1 (Kuzmin et al., 2017). So far, *D. j. stepheni* tadpoles have not been found to express red pigments like tadpoles of the *D. immaculatus* group do (Fig. 3.3). A clear distinction from the *D. immaculatus* group is the general presence of dark markings on the body (blotches or stripes) and back legs, although some individuals are sometimes immaculate green, especially at the beginning of the breeding season (Fig. 3.2). In addition, adults *D. j. stepheni* are more plumb and stouter than *D. suweonensis* and *D. flaviventris*. This difference is not always visible in juveniles, which are morphologically difficult to identify. The easiest way to ensure the identity of the species, however, is to listen to the advertisement calls as *D. j. stepheni* calls at a comparatively low frequency with repeated patterns sounding like "bep" to the human ear, with a short inter-note interval but phrases that can last several minutes.

3.1.2 *Dryophytes immaculatus*

3.1.2.1 Origin and distribution

Dryophytes immaculatus, the Chinese Immaculate Treefrog is the basal clade in the species complex, having diverged from the two other species around 1 million years ago (Borzée et al., 2020b). The species has been isolated on the western side of the Yellow Sea, with a stable area since the last glacial maximum matching with the basin of the Yangtze River (Andersen et al., 2022c). The current range of the species has likely contracted over the last 21,000 years, following the increase in sea level and the flooding of the Yellow Sea. The species density has however likely become more uniform in the landscape following the development of rice agriculture over the last 10,000 years, and the conversion of all habitats in the area into agricultural wetlands (Huan et al., 2021). While the species was reported to be widespread between Nanjing and Shanghai a few decades ago, the population has drastically decreased since then. Datapoints outside this range have been reported, and surprisingly all the way north to "Beijing area", which are now attributable to "immaculate coloured" *D. japonicus* individuals (Stone, 1899), a likely adaptation to the grasslands of the area. Other datapoints out of this range have been reported (e.g., see AmphibiaChina.org), but they regularly turn out to be miss-identifications, confirmed through pictures or molecular analyses (Borzée et al., 2017a). Currently, all known remaining populations are between the Yangtze and Huai River, with a small isolated population in rice fields west of the Dabie Mountains. The remaining potential populations of interest that needs to be elucidated are the ones at the feet of Tianmu Mountain, for which museum vouchers morphologically match some of the characters present in *D. immaculatus*, individuals reported from Yangjifeng, Jiangxi Province (Wang et al., 2010) and individuals reported from Hunan Province (Shen, 2014), although all of these sites originate from landscape very different from the one where *D. immaculatus* is currently found (Fig. 3.4).

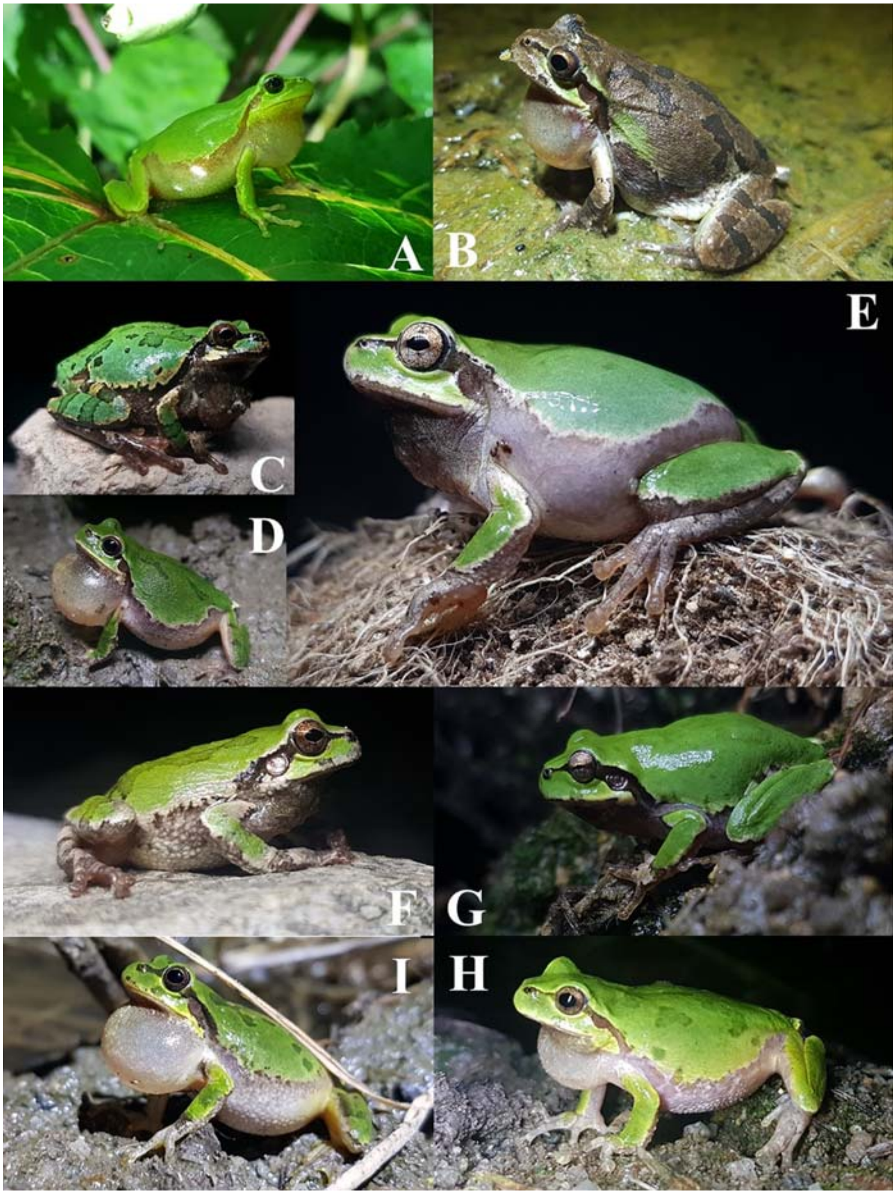

FIG. 3.2

Adult *Dryophytes japonicus stepheni*. Males generally call from the ground or flat surfaces (A to D and I), and are green during the breeding season, with black patterns that are individual specific (B to H).

From Amaël Borzée.

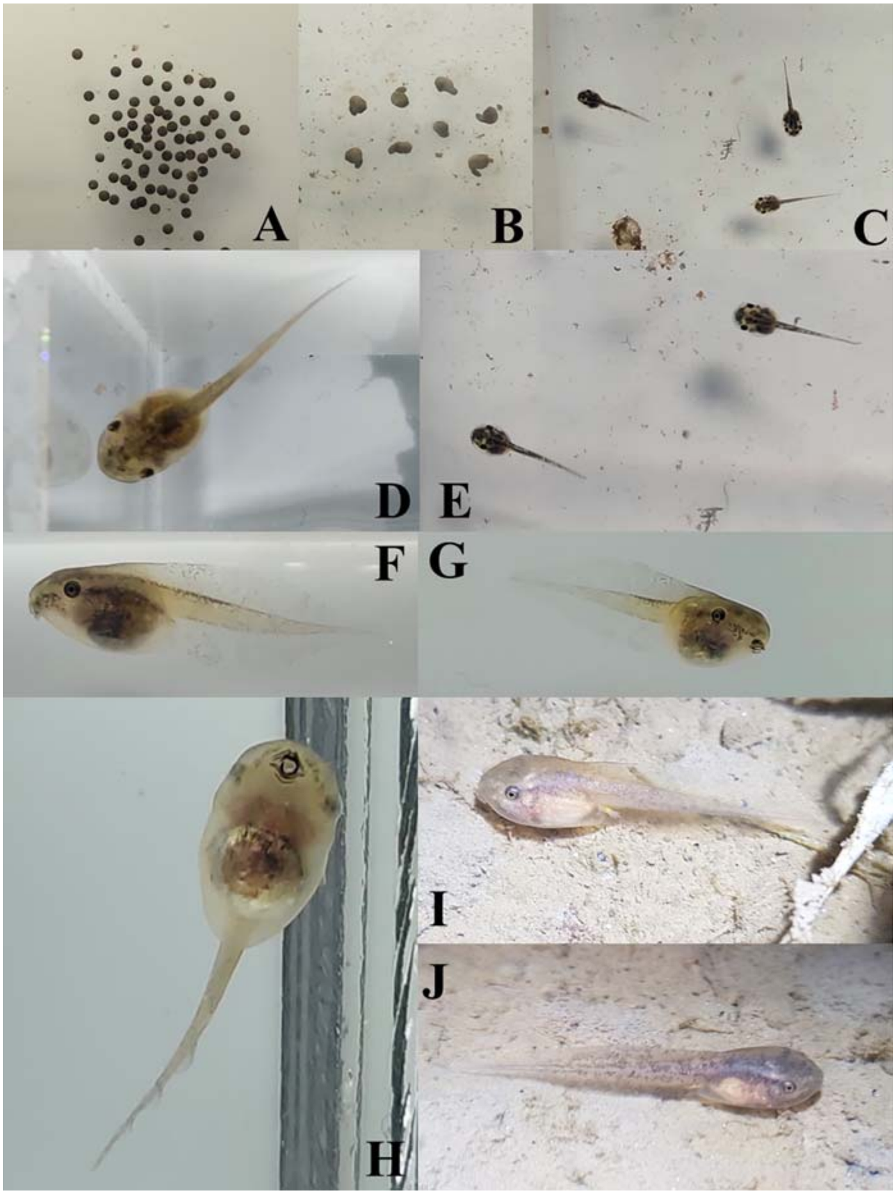

FIG. 3.3

Eggs and tadpoles of *Dryophytes japonicus stepheni*. The eggs are spawn in small clutches (A) and develop into embryo (B) and then tadpoles (C) within a week of development. Tadpoles can develop faster in warmer environment, circa two weeks old tadpoles (D to H) compared with tadpoles within a week of development (E). The leg buds will develop a few weeks before metamorphosis (I and J).

From Amaël Borzée.

FIG. 3.4

Predicted ancestral distribution of *Dryophytes immaculatus*, the Chinese Immaculate Treefrog. Some remnant isolated populations are likely present slightly out of this range.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

3.1.2.2 Habitat

Dryophytes immaculatus, as well as the other species in the group, were originally found in low-elevation wetlands such as alluvial floodplains. Records for *D. immaculatus* are blurred by widespread misidentification and include a wide range of habitats in regions where the species is now known not to have occurred. Current extant populations, supported by molecular identification, are now restricted to low and mid-elevation agricultural wetlands, from general areas best characterised by an original vegetation that should have been composed of reedbeds and other low-height semi-aquatic vegetation (Andersen et al., 2022c). The species is however found at relatively higher elevation than *D. suweonensis* and *D. flaviventris* (Borzée et al., 2020b).

3.1.2.3 Behavioural ecology

The behaviour and the ecology of *D. immaculatus* have not been the focus of specific research and they are mostly unknown. Based on ecophylogeographic consistency among Hylid clades and weather patterns, it is however possible to expect the species to be breeding from late April, although the breeding phenology may be regulated by agricultural flooding, and in this case, may start later and extend until mid-July. Males of the species, similarly to the other species in the group, call from emergent vegetation above water, holding on plant stems while maintaining a vertical position (Fig. 3.5). The calls have a higher frequency than that of *D. japonicus*, likely because this type of call reaches further in the landscape where the species occur. In addition, the number of independent pulses before the connected pulse within each note is

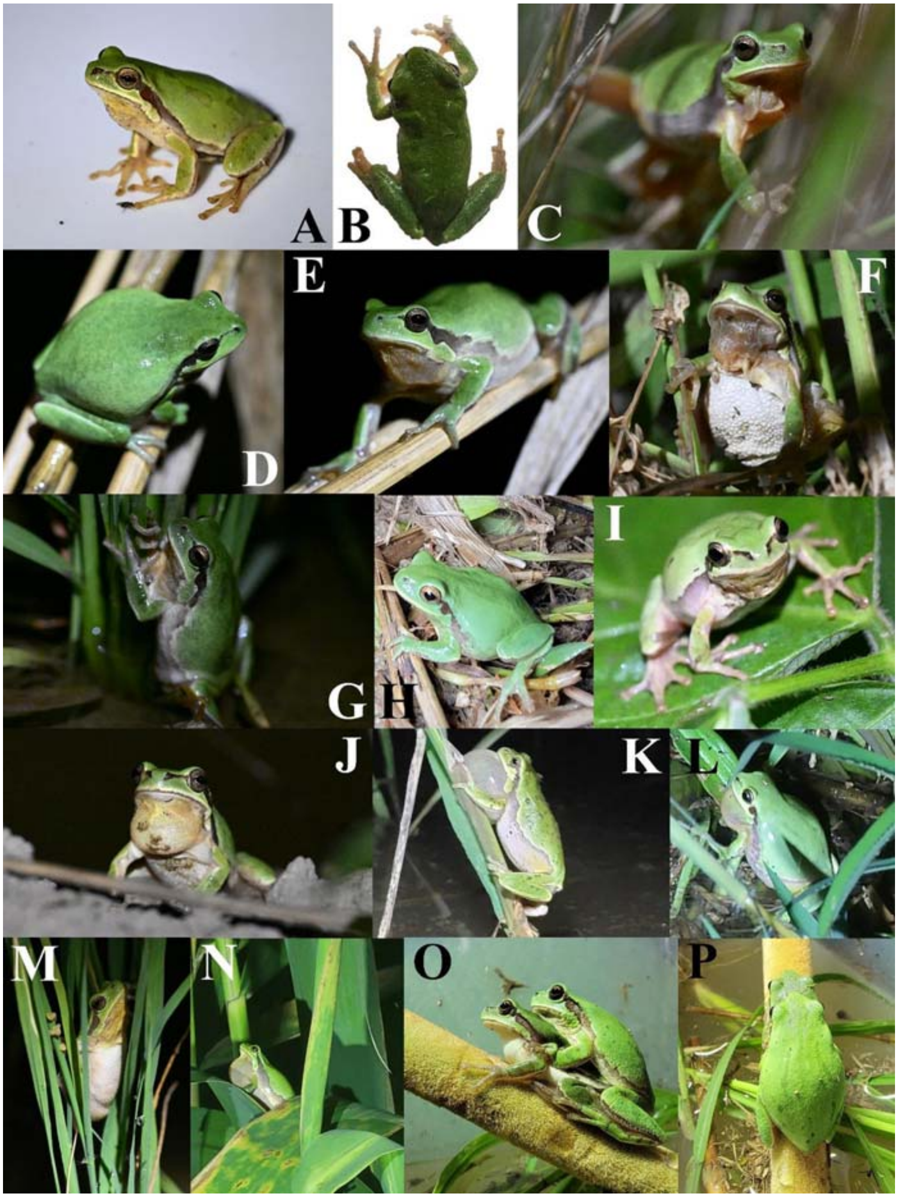

FIG. 3.5

Adult *Dryophytes immaculatus*. The species is generally spotless (A to E, H and I) and move above ground level (C and E). Males call from an emerged substrate above the water level (F to M) but can also be found more than 2 m above ground in rare occasions (N). Females initiate the amplexus, which can last several hours (O and P).

From Amaël Borzée.

higher for *D. immaculatus* than for *D. suweonensis* and *D. flaviventris* (Borzée et al., 2020b). Males have been recorded producing advertisement calls early in the evening. The species is expected to hibernate in the vicinity of the breeding sites, within the floodplain, and not to migrate towards forested hills over winter.

3.1.2.4 Threats and conservation

Recent surveys have shown the species to have been extirpated over most of its range, and it is now likely to be functionally extinct in most of Jiangsu and Shanghai, the core habitat and the type locality of the species, where surveys have failed to detect viables populations between 2018 and 2023, with a few potential exceptions. A viable population still occurs north of Hefei (Borzée et al., 2020b). The reason for this decline is principally linked to habitat loss. While the development of agriculture and the regulated hydroperiod about 10,000 years ago may have helped the species in terms of range and population size, the more recent mechanisation, followed by the incremental switch from rice agriculture to dry agriculture and other production has strongly impacted the species through habitat loss and the inability to exploit agricultural landscapes. New protected areas need to be dedicated to the species. Some conservation efforts are now showing, especially around the type locality in Shanghai greater area. As a result, the species should not be listed as Least Concern as it is now on the IUCN Red List of Species (Xie, 2017), but likely as Critically Endangered in view of the speed of the decline. The species is not used for human consumption, but it may be found in pet shops, although so far all individuals verified were misidentified and none of them was *D. immaculatus*.

3.1.2.5 Identification

The range of *D. immaculatus* may overlap with *Hyla chinensis* in the southern parts of its range, and the adults of the two species can be differentiated by the black patterns on the body and the dorsolateral line (Fei et al., 2012). The body of *D. immaculatus* is also slenderer than that of *Hyla* species (Fig. 3.5). Each note of the advertisement calls can be characterised by the sound “kink”, similar to *D. immaculatus* and *D. flaviventris*, but with fewer independent pulses before the connected pulse within each note. Tadpoles of *D. immaculatus* are characterised by a 1/3(1) labial tooth row formula (Borzée et al., 2020b), a divergence from the labial tooth row formula of other Hylid species that needs to be confirmed (Fig. 3.6).

3.1.3 *Dryophytes suweonensis*

3.1.3.1 Origin and distribution

The Suweon treefrog, *Dryophytes suweonensis*, originates from the split with *D. flaviventris* about one million years ago. The species has been distributed on the eastern edge of the Yellow Sea since the last interglacial 130,000 years ago, although it is also likely it occurred on the Yellow Sea basin 21,000 years ago when the land was emerged and most northeast Asian paleorivers merged into a broad river in the area, maintaining an isolation barrier between the three species

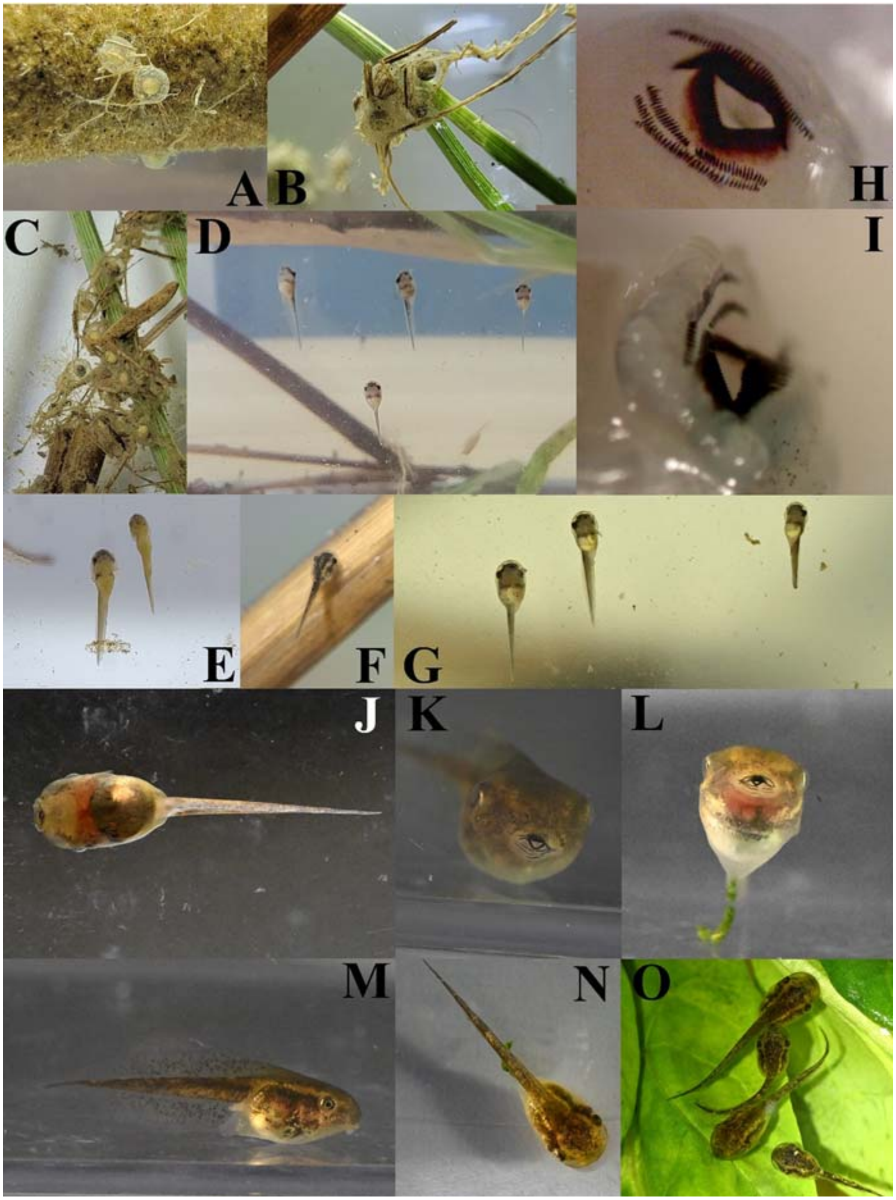

FIG. 3.6

Eggs and tadpoles of *Dryophytes immaculatus*. The eggs are laid in very small clutches spread around the water body (A to C). Once hatched, tadpoles will stay on a vertical substrate without feeding for a few days while absorbing the nutrients provided by the eggs (C to G); and they have visible gills at the very first stages of development (E). Once the mouthparts develop (H to L) to feed principally on vegetal matter (O here eating spinach leaves). Tadpoles have variable spots on their tails and a reddish colouration is most common (M and N).

From Amaël Borzée.

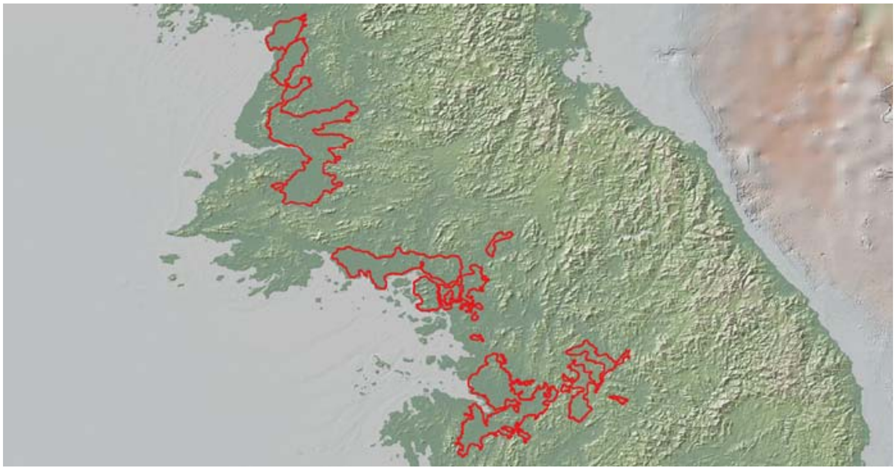

FIG. 3.7

Distribution of *Dryophytes suweonensis*, the Suweon Treefrog.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

of the *D. immaculatus* complex (Borzée et al., 2020b). The species is now restricted between the Chilgap Hills in R Korea and the Taeryong River in DPR Korea (Borzée, 2020). While *D. suweonensis* could be present further north in DPR Korea, surveys were not successful in detecting the species in Liaoning in China (Fig. 3.7).

3.1.3.2 Habitat

Dryophytes suweonensis is now restricted to agricultural wetlands in R Korea, as the last site with a semi-natural habitats where the species' presence was confirmed was destroyed in the late 2010s (Borzée and Jang, 2015). The species was recorded from rice paddies only in DPR Korea, but it was observed in the vicinity of natural wetlands, and it is expected to also occur in natural habitat in the nation. The natural habitat of the species is restricted to alluvial floodplains, with a high proportion of reedbed cover, and only very little vertical structures such as trees or low hills. The species is found between 1 and 320 m of elevation (Andersen et al., 2022a), but the median elevation of sites is 1 m above sea level.

3.1.3.3 Behavioural ecology

In terms of behavioural ecology, the Suweon treefrog is comparatively well understood (Fig. 3.8). Males call to attract females from the centre of rice paddies in May and June, with the peak activity is early June, and some males calling as late as early July (Groffen et al., 2022). The calling behaviour is typical of the species group, with males holding on vertical structures above the water levels, and females climbing up and initiating contact to start the amplexus (Borzée et al., 2016). Once amplexed, females lay eggs in small clutches across about a dozen square metres to decrease the risk of predation on eggs and embryos (Fig. 3.9). The eggs hatch within a few

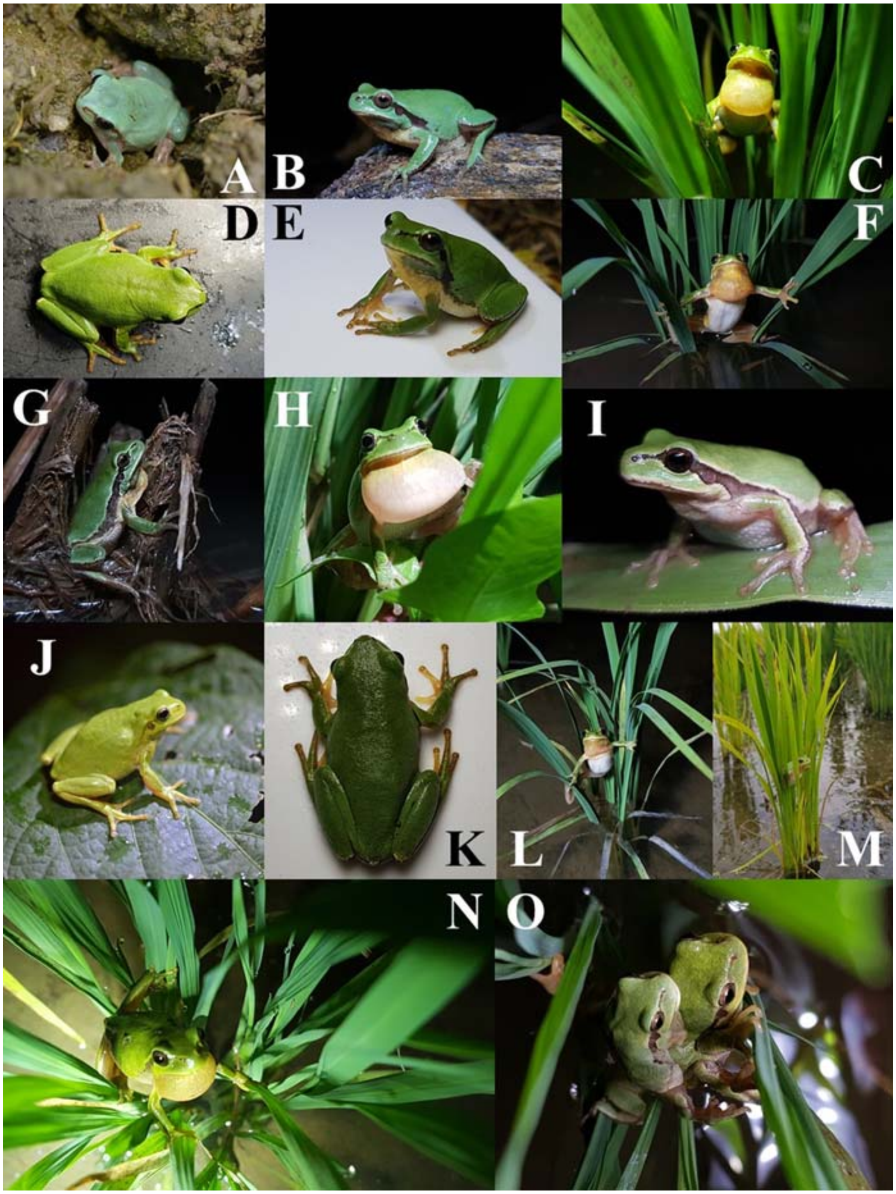

FIG. 3.8

Adult *Dryophytes suweonensis*. As individual emerge from hibernation (A) they will directly head to the breeding sites (B) to start calling (C to N). Females initiate amplexus above the water line (O), and they do not stay more than a few hours in the water, generally foraging on vegetation, and especially broad leaved plants before hibernation (J).

From Amaël Borzée.

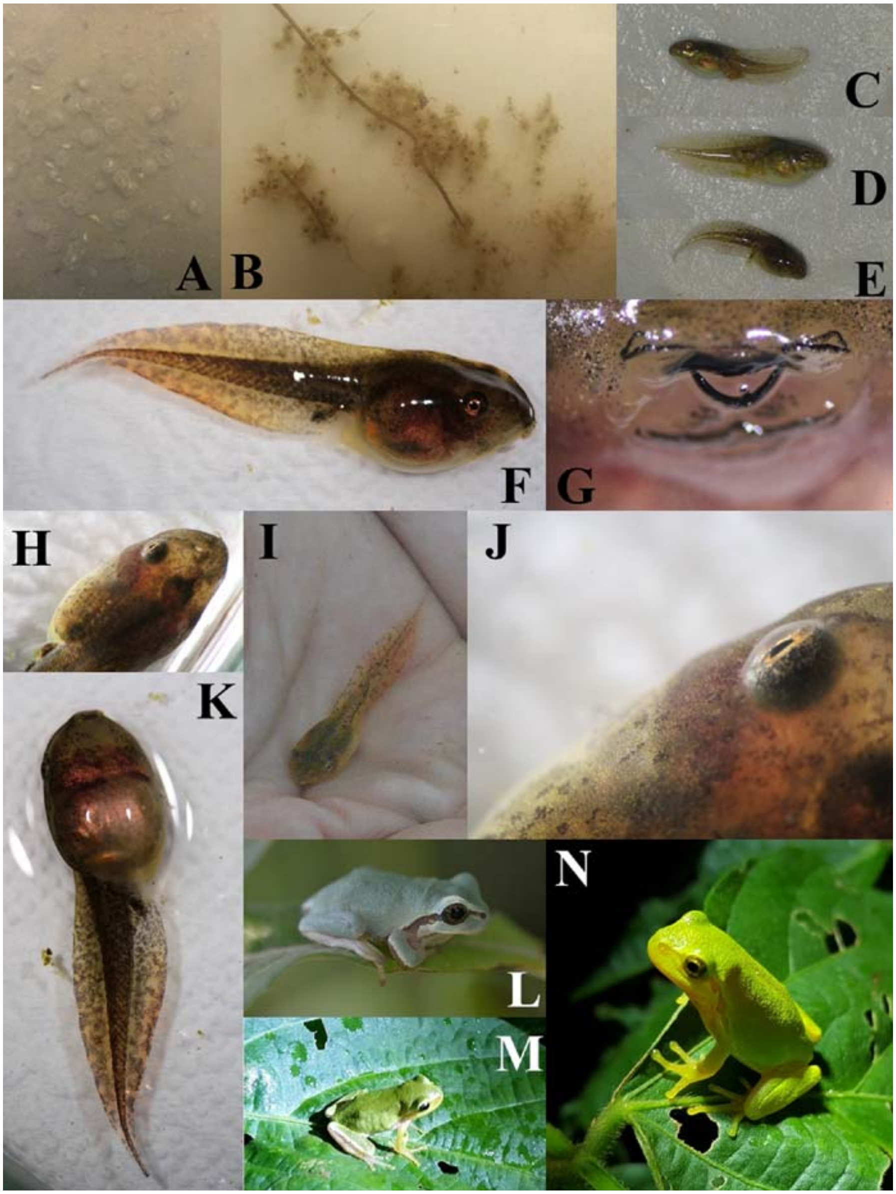

FIG. 3.9

Egg, tadpoles and juvenile *Dryophytes suweonensis*. Eggs are laid in small clutches (A and B). Once hatched, tadpoles of the species show red pigments (D to K), even after translation for translocation (I). Froglets will stay in the vicinity of the breeding habitat after metamorphosis (L to N).

From Amaël Borzée.

days, based on the temperature, and the tadpoles are first hanging vertically in the water column, unable to swim or feed. A few days later, tadpoles acquire locomotion and start feeding, first on decaying matters, but they are also able to feed on small preys once large enough. It takes a few weeks for individuals to reach the right size for metamorphosis, at which point the tadpoles find a substrate with a gentle slope into the water, from which they walk up and away from the water over the course of a few hours to a day while the tail is lost through apoptosis and the individual goes through the last steps of metamorphosis. The earliest metamorphs can be found in late June, and the latest ones in mid-July.

Juveniles stay in the vicinity of rice paddies during the first months of development, with a preference for large-leaved vegetation, such as beans traditionally planted around rice paddies. The young frogs can be found in the vicinity of rice paddies, with a preference for reed beds at this stage in life, until the temperature becomes too low, and the frogs disappear from sight to hibernate between late October and early November. The Suweon treefrog does not hibernate far from its breeding habitat, sometimes even within the same wetland, as the frogs burry themselves in soft ground along cracks or other substrate allowing them to go deep enough to overwinter below the frost line. The species has not been found hibernating in water. Suweon treefrogs are not active throughout winter, and they emerge from mid-April to mid-May, heading directly towards the centre of the water body to start calling.

Males as young as a year old can be found calling (Borzée et al., 2018b), although the size of calling individuals suggests that most males are two to three years old when becoming sexually active. Males will spend up to two months calling from the vegetation, and at the difference with most other treefrog species, some males are calling from the exact same perches almost every night of the breeding season, and from the very same area, every breeding season, throughout their lives. They are however not consistently calling through the night as they will feed between bouts of calls, especially during the emergence of mayflies as they can feed from the calling perches. The species generally preys on small-winged insects over land arthropods. Males are active between dusk and until 2:00 to 4:00 a.m., with a peak activity early in the evening, when amplexus generally occurs. After advertising, males will move towards grassy habitats for a few hours, before spending time in shrubs, and moving back towards the calling habitat the next day, a move linked to the arrival of *D. j. stepheni* in the microhabitat (Borzée et al., 2016). While males stay within a few dozen metres of their calling sites, females are more active and can be found up to a few 100 m away. At the end of the breeding season, adults can be found in the same microhabitat as juveniles, and the absence of seasonal migration makes the detection of the species rather consistent throughout seasons.

3.1.3.4 Threats and conservation

Dryophytes suweonensis is currently listed as Endangered on the IUCN Red List of Species (IUCN SSC Amphibian Specialist Group, 2017). Threats to the Suweon treefrogs are multiple, but the main threat is by far habitat loss (Borzée et al., 2017b). As a result of the current rate of habitat loss, the species may become extinct within decades in R Korea if nothing is done (Andersen et al., 2022b). The situation is not as severe in DPR Korea where large continuous wetlands are present, with a lower rate of mechanisation and chemical use, therefore making landscapes such as alluvial plains, more amphibian friendly. Climate change is a threat to the species across its range (Borzée, 2020), especially in places where breeding is linked to rice agriculture as farmers plant rice later every year as it grows faster, and thus also flood rice paddies later and delay the breeding season of the species.

Other discrete threats are also present throughout the life cycle of the species, starting with pollution of the water bodies where tadpoles develop, as pollution resulting from agrochemicals is linked to the absence of the species. Later, metamorphs and adults are impacted by the harvest of rice, but also beans surrounding rice paddies, as their number is significantly lower after harvests (Borzée, 2020). Hibernation in the vicinity of rice paddies is not safe either as some farmers burn the remaining rice straws in early winter, burning the frogs sheltering in the area, or desiccating the habitat more than the frogs can cope with. In addition, recent policies have led to the addition of soil layers in rice paddies during winter in many areas where the species occurs, effectively preventing individuals from emerging from hibernation. The modification of the habitat and the canalisation of ditches with cemented U-shaped water-drain also impacts the species, both through the removal of access to hibernation sites and adequately humid microhabitats, but also because calling frogs will avoid calling in the side of the wetland where concrete ditches have been installed (Groffen et al., 2018).

During the breeding season, the main threat comes from the competition with *D. j. stepheni*, a species whose presence has increased because of human activities. Competition is shaping the daytime behaviour of *D. suweonensis* as the presence of *D. j. stepheni* results in the displacement of *D. suweonensis* towards other microhabitats, but also its calling behaviour, with *D. suweonensis* individuals prevented from using physical calling space in presence of *D. j. stepheni*. In addition, *D. j. stepheni* calling males create a barricade around the rice paddies that needs to be crossed by *D. suweonensis* females, often resulting in cross-species amplexus with *D. j. stepheni* males indiscriminately amplexing with *D. suweonensis* females. As a result, hybridisation is a threat to *D. suweonensis* as most populations in R Korea are reaching a state of hybrid swarm (Borzée et al., 2020a). Finally, the introduced American bullfrog (*Lithobates catesbeianus*) is also a threat to *D. suweonensis*, both through direct predation, but also the non-lethal spread of batrachochytrid fungi (*Batrachochytrium dendrobatidis*; Borzée et al., 2017c).

The most efficient action that can be taken to protect the species is the protection of sites, as a single well-selected site can prevent the extinction of the species in R Korea for the next 100 years (Andersen et al., 2022b). Discrete actions can also make a difference, such as for instance maintaining a minimum height at which to cut weeds around rice paddies so that the day-time habitat of the species is maintained, and frogs are not cut down during the process, or exposed to predation and desiccation afterwards (Borzée and Jang, 2019). In addition, maintaining a few square metres flooded after rice paddies are drained in late June or early July will help a large number of tadpoles complete their life cycle as they are nearing metamorphosis at that time, and even 24 h of hydric stress, in opposition to direct drainage, can speed up the metamorphosis process and help maintain the population (Pers. Com. Mr. Yu Sanghong). It is, however, important to note some benefits from rice agriculture, such as the lower predation rates due to the drainage of the rice paddies during the fallow phase, and the regulated hydroperiod that guarantees flooding every year. In addition, the species can respond adequately to translocation and conservation programs, as seen by the now-discontinued conservation programme in the city of Suwon (Borzée et al., 2018b). Finally, the Suweon treefrog is only weakly impacted by roadkills (Shin et al., 2022) and it can cope with some degrees of habitat change (Groffen et al., 2022).

3.1.3.5 Identification

Tadpoles of *D. suweonensis* are characterised by the 2(2)/3 labial tooth row formula (Park et al., 2009), a mottled caudal musculature pattern and they and they have been observed with red pigment on the tail (Borzée et al., 2018b, Fig. 3.9). Adult *D. suweonensis* are almost always immaculate green, and thus distinguishable from *D. j. stepheni*. It is however interesting to point out that many individuals do have dorsal stripes when emerging from hibernation, and the observers need to take the season into account for easy identification. Another difference is that *D. suweonensis* is slenderer and less plump than *D. j. stepheni*. The most visible point of morphological difference with *D. flaviventris* is the length of the webbing, but identification based on range is easier as the two species do not overlap (Borzée et al., 2020b, Fig. 3.7). In comparison to the calls of *D. j. stepheni*, the calls of *D. suweonensis* are characterised by a higher frequency and a longer note duration. Each note could be characterised by the sound “kink”, similar to the other species of the *D. immaculatus* group, but with a slightly shorter note duration than *D. flaviventris* and a slightly longer note than *D. immaculatus* due to the number of pulses before the connected pulse.

3.1.4 *Dryophytes flaviventris*

3.1.4.1 Origin and distribution

Dryophytes flaviventris, the Yellow-bellied Treefrog, is restricted to a very narrow area on the west lowlands of R Korea, ranging between the Mangyeong river and the Chilgap Hills. The Chilgap hills are outside of the ecological requirements of the species and create a barrier with *D. suweonensis*. To the south, the Mangyeong River would seem to be a porous barrier because its width is narrower than what is expected to be the limit for the species to disperse, but intense surveys in the habitat south of the river were not successful in detecting the presence of the species. It is likely that *D. flaviventris* is not able to cross the river and establish a new population, thus requiring a revisit of what is determined to be a dispersion barrier for Hylids, as the habitat south of the river matches the ecological requirements of the species (Andersen et al., 2022c, Fig. 3.10).

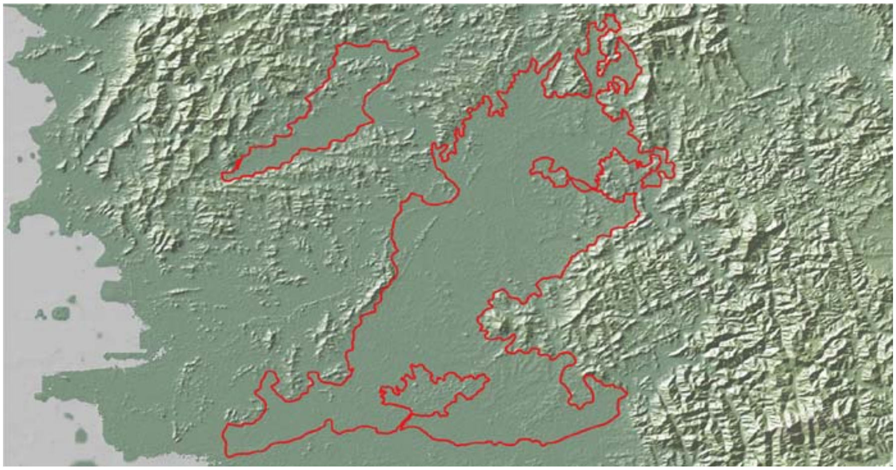

FIG. 3.10

Distribution of *Dryophytes flaviventris*, the Yellow-bellied Treefrog.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

3.1.4.2 Habitat

The species occurs in three disconnected populations, in the regions of Buyeo, Nonsan and Iksan. At all sites, *D. flaviventris* is found in rice paddies only, and intensive survey efforts have shown that viable populations are unlikely to be found at new localities. The three populations are segregated by habitat unsuitable for the species, and the conversion of rice paddies for dry agriculture or tertiary production, especially in Nonsan, has resulted in a decrease in suitable habitat for the species. The noticeable difference in habitat with *D. suweonensis* is that the habitat of *D. flaviventris* is not in the proximity of forested areas, and as a result, there are fewer *D. j. stepheni* occurring in syntopy with *D. flaviventris*. The species is present between 2 and 13 m above sea level only (Andersen et al., 2022a).

3.1.4.3 Behavioural ecology

The behavioural ecology of the species is similar to that of *D. suweonensis* and *D. immaculatus*. The main difference with *D. suweonensis* is that the species start breeding one to two weeks earlier, likely in relation to the lower latitude of the range, but the breeding season ends at the same period, with the last males calling during the first week of July (Fig. 3.11). In addition, individuals start calling much earlier during the day, with the earliest call around mid-day, and choruses reaching peak activity around 4—5:00 p.m., well before sunset. As a result, amplexus is easily observed during daytime, with an unknown impact on visibility to predators. The behaviour and phenology of tadpoles and metamorphs has not been studied so far, but it is expected to follow the same pattern as that of *D. suweonensis*, likely being a few days ahead of time in the season, similar to the calling phenology (Fig. 3.12).

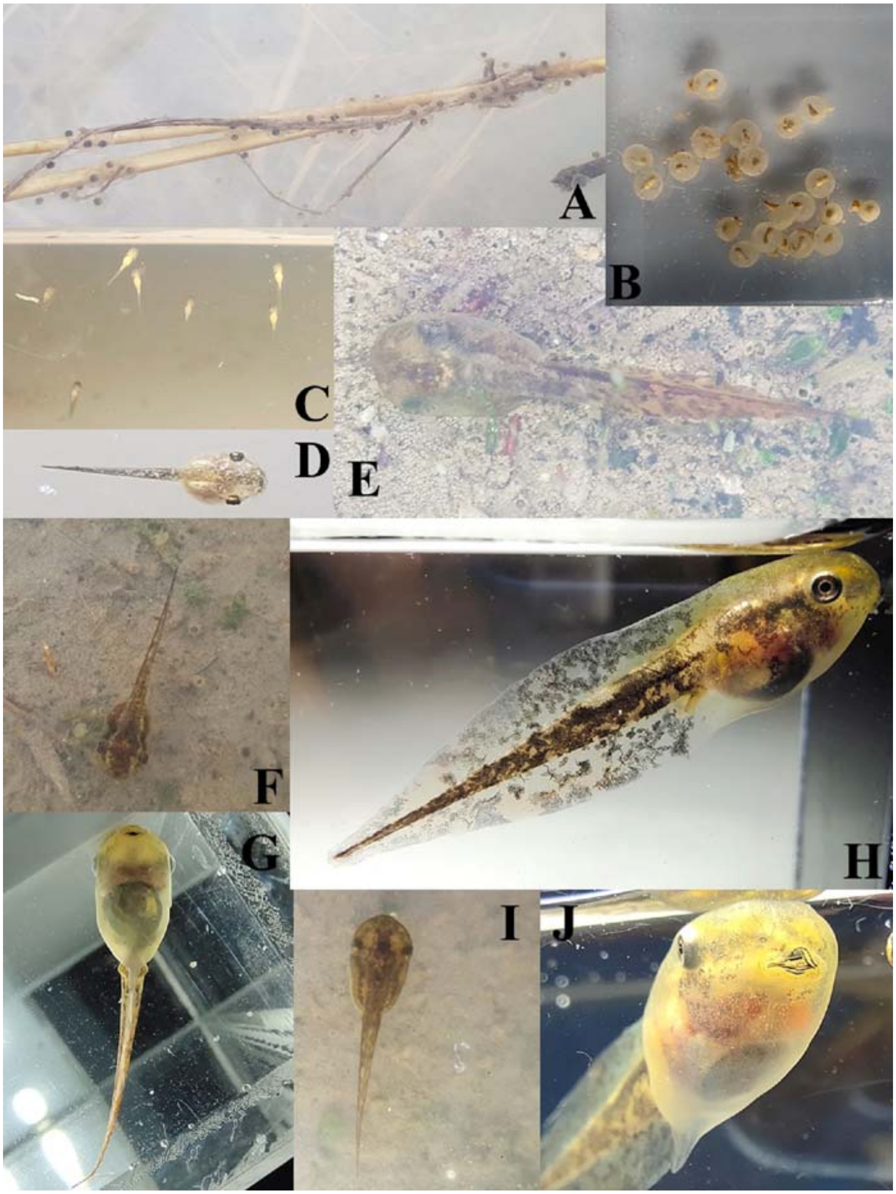

FIG. 3.11

Egg and tadpoles of *Dryophytes flaviventris*. The eggs are spwan in small clusters (A to B), and once hatched the larvae are vertical and immobile in the water column for a few days (C). Some of the tadpoles have red pigments, especially in the tail, similarly to other species of the complex (D to J).

From Amaël Borzée.

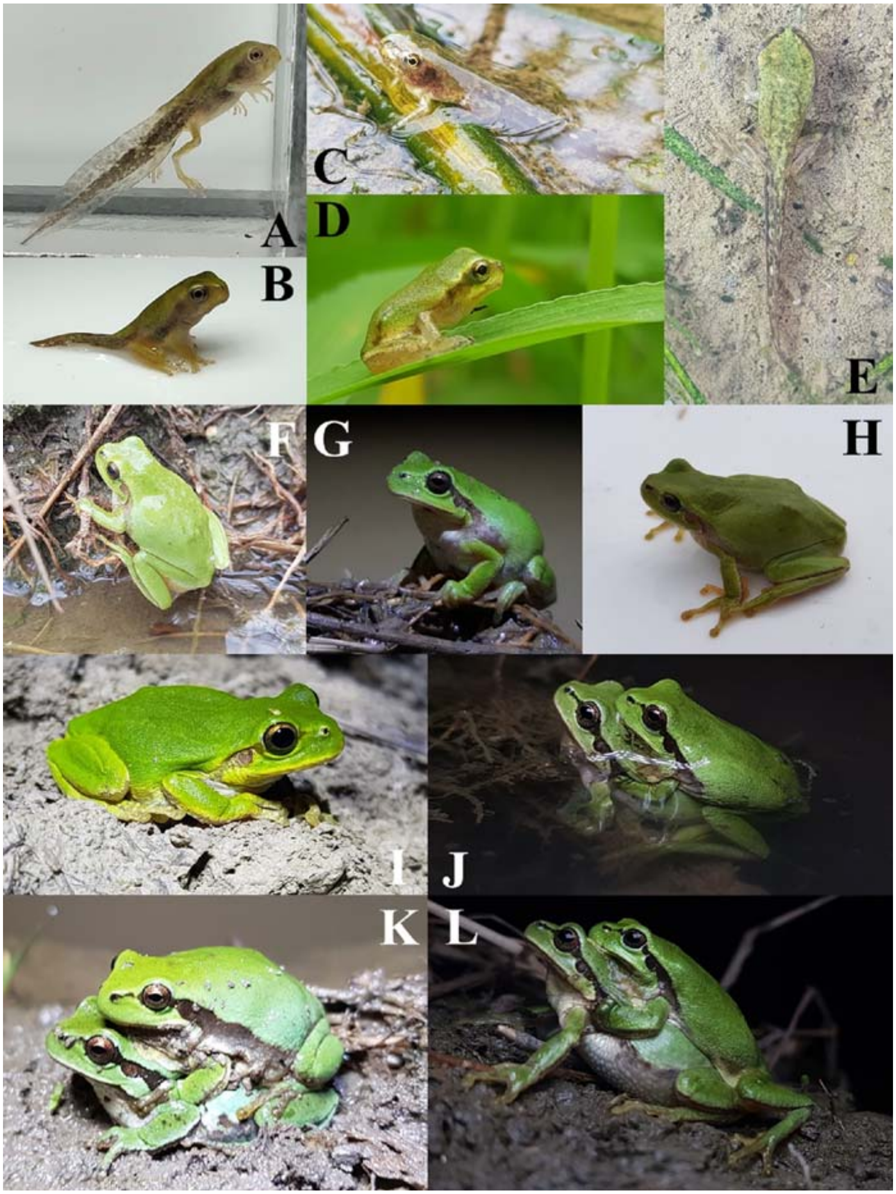

FIG. 3.12

Juvenile and adult *Dryophytes flaviventris*. The larvae are still fully aquatic until the total development of their limbs and metamorphosis takes about a day (A to E). Adults are present at the breeding site from the first year, calling from mid-afternoon (F to I). The amplexus is initiated by the female (J to L), which will spawn in small clusters.

From Amaël Borzée.

3.1.4.4 Threats and conservation

Dryophytes flaviventris is listed as Critically Endangered on the IUCN Red List of Species (in press). The species is also restricted to agricultural wetlands, and habitat loss is the main threat as rice paddies are transformed for dry agriculture (especially watermelons) and tertiary production, especially in Nonsan and Buyeo. The population in Iksan is however less threatened by habitat conversion as rice paddies in the area have the highest yield for the nation, but the development of cattle farms has resulted in habitat loss nonetheless, and the growth of the city and its transportation system is consistently encroaching on the habitat of the species (Borzée, 2020). The difference in behavioural ecology with *D. suweonensis* is beneficial in terms of competition with *D. j. stepheni* as the species has not been found to be as critically impacted, but it may also be mitigated by the fact that fields are used for barley agriculture before rice, and therefore providing an alternative diurnal habitat at the onset of the breeding season. Namely, breeding earlier during the day results in decreased competition for breeding resources, and barley fields may provide alternative non-breeding habitats. The species is however under another threat: predation by the invasive American bullfrog (*L. catesbeianus*; Seo et al., 2023) is likely the reason why *D. flaviventris* was extirpated from at least two locations over the last decades (Borzée et al., 2020b). Similarly to *D. suweonensis*, modelling has shown that the protection of a single site would prevent the extinction of the species within the next 100 years and that without changes to the current dynamics, the species will go extinct within that time period (Andersen et al., 2022b), partly because the species cannot cope with extensive habitat changes besides agricultural wetlands (Groffen et al., 2022).

3.1.4.5 Identification

Tadpoles of *D. flaviventris* have not been formally described, but they have also been observed with red pigment on the tail (Fig. 3.12). Adult *D. flaviventris* are also almost always immaculate green, and distinguishable from *D. j. stepheni* based on this trait. Adults emerging from hibernation are also sometimes showing dorsal stripes and present the same identification challenges as *D. suweonensis*. Within the *D. immaculatus* group, *D. flaviventris* is the slenderest of all species in the species group (Fig. 3.11). The comparison of call with *D. j. stepheni* is similar to that of *D. suweonensis* and *D. immaculatus*, characterised by the sound “kink”, and *D. flaviventris* has the longest note duration of the *D. immaculatus* group. The distinction between *D. suweonensis* and *D. flaviventris* is easier to make based on range.

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CHAPTER

4

Bombinatoridae (*Bombina*)

Bombinatoridae are divided into a Palearctic and an Indo-Malayan clade, with the later clade being the most distant from the species in northeast Asia (5.9–28.6 million years divergence; Zheng et al., 2009).

4.1 *Bombina*

The Palearctic *Bombina* split between 5.1 and 20.9 million years ago (Zheng et al., 2009), or more precisely around 17.17 million years ago (8.56–26.15 million years ago; Fong et al., 2020). While there are several species in the western Palearctic, there is so far only one species described in the eastern Palearctic.

4.1.1 *Bombina orientalis*

4.1.1.1 *Origin and distribution*

The Eastern Fire-Bellied Toad was described from an isolated population in Yantai on the Shandong Peninsula in China, with syntypes across its main range on the Korean Peninsula, northeast China and Far Eastern Russia (Boulenger, 1890). The species, *Bombina orientalis*, originated about 14.8 million years ago (6.5–23.52 Ma; Fong et al., 2016) and includes four clades, one restricted to the Shandong Peninsula, and introduced in Beijing, estimated to be about 5.01 million years old, a second one across Russia, China and the Korean Peninsula about 6.31 million years old, one known to be only in northern R Korea (likely due to the absence of samples from DPR Korea) about 3.12 million years old, and a last one on Jeju Island, about 4.32 million years old (noting a mismatch with the island being about 2 million years old; Fong et al., 2016). Each clade is a distinct evolutionary lineage, but their taxonomic status needs to be determined as they were delineated through mtDNA only (Fong et al., 2016), and so far only the clade in Jeju Island is known to be ecologically distinct (Kang et al., 2017). Other geographic features impacted the genetic structure of the species, such as the Yilan-Yinong fault within the northern Chinese lineage (Yu et al., 2021).

The species is distributed in extreme northern Jiangsu in the southwest, and across the Shandong Peninsula, following the boundaries of the mountainous landscapes. Further north, a population was introduced in Beijing. The closest population is in Liaoning, south of the Yilan-Yinong fault, with the species extending across

Continental Northeast Asian Amphibians. https://doi.org/10.1016/B978-0-323-91857-2.00001-4

FIG. 4.1

Distribution of *Bombina orientalis*, the Eastern Fire-Bellied Toad.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

northeast China into Jilling and southern Heilongjiang on both side of the fault. The species ranges further north across suitable landscapes into a (potentially) isolated population in northern Heilongjiang, reaching into Inner Mongolia (Fei et al., 2012), and further east in Russia. The population in Jilin extends into the Amur Basin river, reaching into Khabarovsk, and it is present some areas of the Primorye. The species is present throughout DPR Korea, except at the highest elevations (Borzée et al., 2021), and it is present across most landscapes in R Korea, including some islands along the southern coast (Fig. 4.1).

4.1.1.2 Habitat

Bombina orientalis is present from sea level, and reaches 500 m above sea level in Russia (Kuzmin, 1999), 900 m in China (Fei et al., 2012) and 1400 m in R Korea (Andersen et al., 2022). It breeds in a broad range of shallow wetlands, including small mountain streams, grassy hills with isolated springs, swamps, small and shallow ponds, tyre tracks and rice paddies. Outside of the breeding season, the species is present in the same landscapes, with a higher population density in mixed coniferous and broad-leaf forested areas surrounding rice paddies (Fong et al., 2016). It can be present in most natural landscapes with freshwater, including coniferous, grassy, sandy and other coastal landscapes. The landscape used by the clade restricted to Jeju island is different as it is often found in dark basaltic ponds.

4.1.1.3 Behavioural ecology

Bombina orientalis emerges from hibernation from late April at northern latitude (Kuzmin, 1999), and from mid-March in the south. Individuals will not breed directly, and the breeding season is prolonged, starting from mid-March and peaking in June but with eggs spawned until late September in R Korea (Groffen et al., 2022). Once at the breeding site, males will emit feeble calls, not amplified by vocal sacs, to attract females (Fig. 4.2). The amplexus will result in about 200 large eggs deposited in the vegetation in small patches of a few dozen eggs. The duration to hatching is temperature dependent, being as short as three days in shallow and warm water bodies (Zou et al., 1991) and hence prone to drying out, and metamorphosis can be completed in as little as three weeks in the right conditions, but generally taking two months from spawning to metamorphosis (Kuzmin, 1999). The froglets will stay in the vicinity of the water body until dispersing in late summer (Fig. 4.3). The species overwinters underground or under thick substrates but rarely underwater, starting from late September at northern latitudes (Kuzmin, 1999) and early November in R Korea (Groffen et al., 2022). *Bombina orientalis* can exhibit the unken reflex when threatened, exposing the bright colours of their throats and venters. Both males and females can emit release calls when grasped.

4.1.1.4 Threats and conservation

The species is currently listed as Least Concern by the IUCN Red List of Species, although the population size is decreasing (IUCN SSC Amphibian Specialist Group, 2020). The rationale for the assessment is the wide distribution and the tolerance to habitat change, a point especially adequate for the clade on the Korean Peninsula as the population is estimated to have benefited from rice agriculture and increased in size since then (Fong et al., 2016). Finally, despite being tested positive for the Chytrid fungus, the fungus is not known to have negative effects on the fitness of the species (Bataille et al., 2013).

The population size of the species is however decreasing due to several factors, primarily habitat loss as despite tolerating habitat modifications there is a threshold that cannot be crossed (Groffen et al., 2022). In addition, climate change models for the suitable habitat of the species predict a drastic decrease of suitable habitat by 2030, 2050 and 2080 under different climate change scenarios (Kim et al., 2021), the species is within the ten amphibian species the most impacted by roadkills in R Korea (Shin et al., 2022), and it is caught for the international pet trade and traditional medicine. Finally, populations close to human settlements are affected in their development, resulting in multiple limb abnormalities (Kang et al., 2016), and tadpole survival is linked to water quality close to urban areas (Park et al., 2015). The species has some use for human medicine as it produces Bombinins (Simmaco et al., 2009).

4.1.1.5 Identification

The morphology of the species is very different from that of other amphibians of the region, making it easy to identify due to its blotched red venter and red nails, with a generally green and black patterned back. In addition, the species does not have a tympanic membrane, and the pupils are triangular. The calls are very soft, giving it the name of "bell toad" in many languages and places around its range. Males have nuptial pads on two fingers only, generally not conspicuous, and the fact that females also emit release calls has made some sex identification erroneous. The tadpoles' labial tooth row formula is 2/3[1] in R Korea (likely the widespread clade, Park et al., 2009), and 2/1 + 1[2] in China (Fei et al., 2012). The formula is not known for the two other clades.

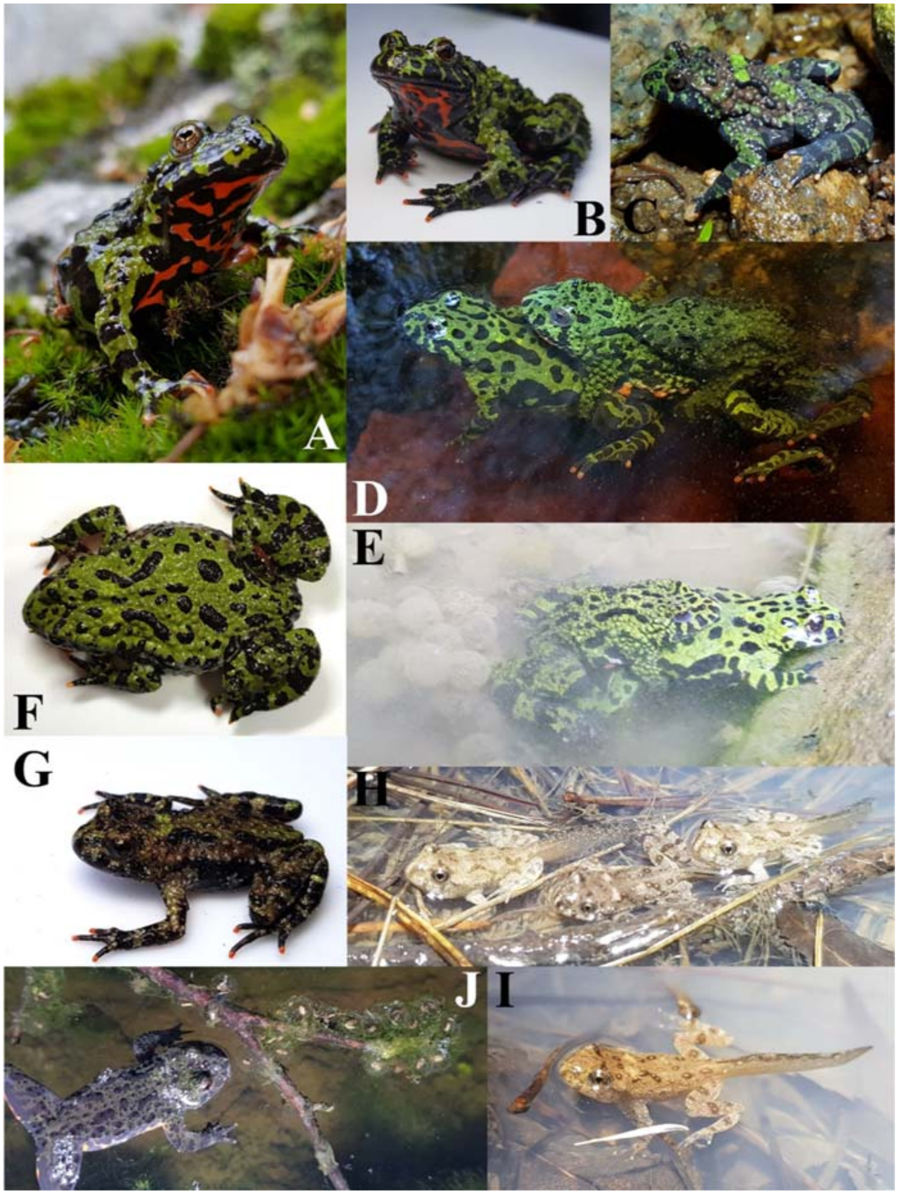

FIG. 4.2

Adult *Bombina orientalis*. The amount of green on the dorsum and red on the venter of the species is variable (A, B and C), but all toes are red (F). Amplexus is in the water (D and E), before spawning (J). The larvae develop in the water, and retain the tail for a relatively long period (H and I) before metamorphosing (G).

From Amaël Borzée.

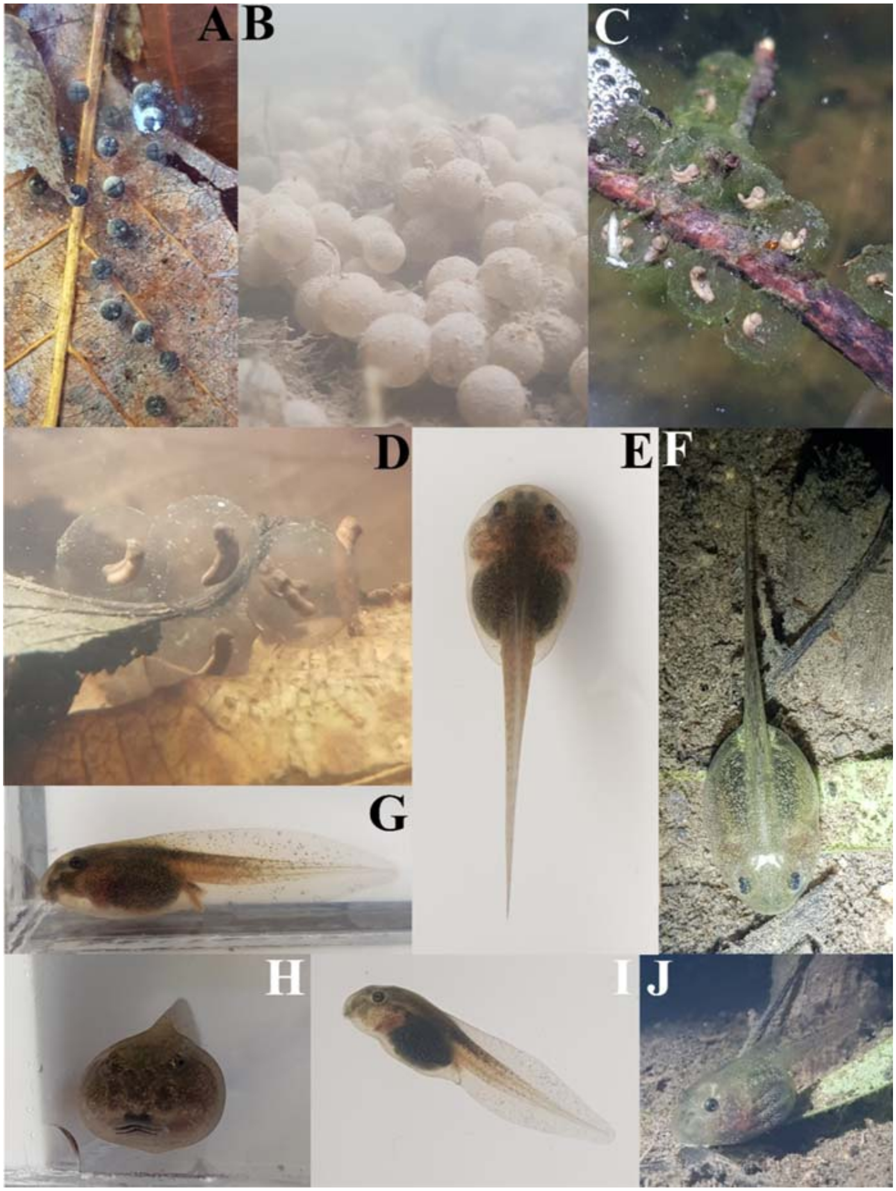

FIG. 4.3

Eggs and tadpoles of *Bombina orientalis*. The eggs are attached to the substrate, and they are among the largest for northeast Asian amphibians (A, B, C and D). Tadpoles have a unique shape with an enlarged heads (E, F, G, I and G), and unique labial tooth row formula (H).

From Amaël Borzée.

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CHAPTER

Microhylidae (*Kaloula*)

5

The Microhylidae family in northeast Asia, as defined here, includes only the *Kaloula* genus (but see the introduction for a few words about *Microhyla fissipes*). Asian Microhylids radiated from the Indian continental place after the Gondwana break up and the collision between the Indian plate and southern Asia 52 to 70 million years ago (van der Meijden et al., 2007; Garg and Biju, 2019). The common ancestor to *Kaloula* species emerged about 38 million years ago and diversification took place about 20 million years ago, in relation with the orogeny of the Qinghai-Tibetan Plateau (Othman et al., 2021). The genus ranges across east Asia, including Java in Indonesia in the south, the Philippines to the East, the edges of the Qinghai plateau in the west, and all the way to Heilongjiang, China, in the north.

5.1 *Kaloula*

5.1.1 *Kaloula borealis*

5.1.1.1 *Origin and distribution*

The Boreal Digging Frog, or Boreal Narrow-Mouthed Frog, *Kaloula borealis*, was described from Dandong, Liaoning China in 1908 (Barbour, 1908). The species represents a monophyletic lineage that diverged about nine million years ago (3.66 to 15.29; Othman et al., 2021), an estimate comparatively old age that could be found to be younger through new tools. The species shows a low genetic diversity (Yang et al., 2000), highlighting widespread genetic exchanges across its large range, and multiple crossings of the Yellow Sea, over land north of the sea outside of ice ages, or across it during low sea level periods (Othman et al., 2021). Finally, the species split again about 6.3 million years ago, with one clade present in China and the other one in northern China and the Korean Peninsula (Othman et al., 2021). The distribution of *K. borealis* has been shaped by glaciations, and it is now present over one of the largest ranges in east Asia, extending from Zhejiang in the south (Huang, 1990), Sichuan in the west, across Shanxi and Gansu (Fei et al., 2012), and as far north as Heilongjiang (Zhang et al., 2015). The species is also present on the western coast of the Korean Peninsula, with some populations isolated in southern Hamgyong Province on the east coast of DPR Korea (Borzée et al., 2021), and a cosmopolitan distribution in R Korea, with the exception of the highest elevation (Fig. 5.1).

Continental Northeast Asian Amphibians. https://doi.org/10.1016/B978-0-323-91857-2.00002-6

FIG. 5.1

Distribution of *Kaloula borealis*, the Boreal Narrow-Mouthed Frog.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

5.1.1.2 Habitat

Kaloula borealis occurs over a broad range of landscapes, although restricted from 0 to 600 m of elevation in R Korea (Andersen et al., 2022) but present up to 1200 m of elevation in China (Fei et al., 2012). Adult individuals can be found in most types of landscapes, from green spaces in urban landscapes, to dry steppes, shrubs, broad-leaved, mixed and coniferous forests. The species is however restricted to wetlands, even temporary, for breeding, and it can breed in a broad range of lentic water bodies, including modified landscapes such as rice paddies or ditches. The species is however extremely rarely found breeding in flowing water bodies.

5.1.1.3 Behavioural ecology

Kaloula borealis emerges from hibernation from mid-April, but the peak breeding season is in June and July (Groffen et al., 2022). Males wait for heavy rains, generally with the onset of the monsoon to chorus in large groups from temporary pools, and they float while producing advertisement calls (Fig. 5.2). The eggs are the only amphibian eggs floating on the water surface as a single layer in northeast Asia, and each female lays about 600 eggs, reportedly several times a year (Fei et al., 2012). The eggs can hatch in about 24 to 48 h, and tadpoles sink to the bottom of the water body upon hatching, and start swimming a day later (Fig. 5.3). The development period is the shortest for northeast Asian amphibians, lasting as little as two weeks, and rarely lasting more than three. After metamorphosis, the froglets are highly fossorials and can be found in the area around the breeding ground, sometimes sharing shelters with adults, and generally feeding at night only. Interestingly, *K. borealis* adults can be found up to a few metres of elevation in trees in fall

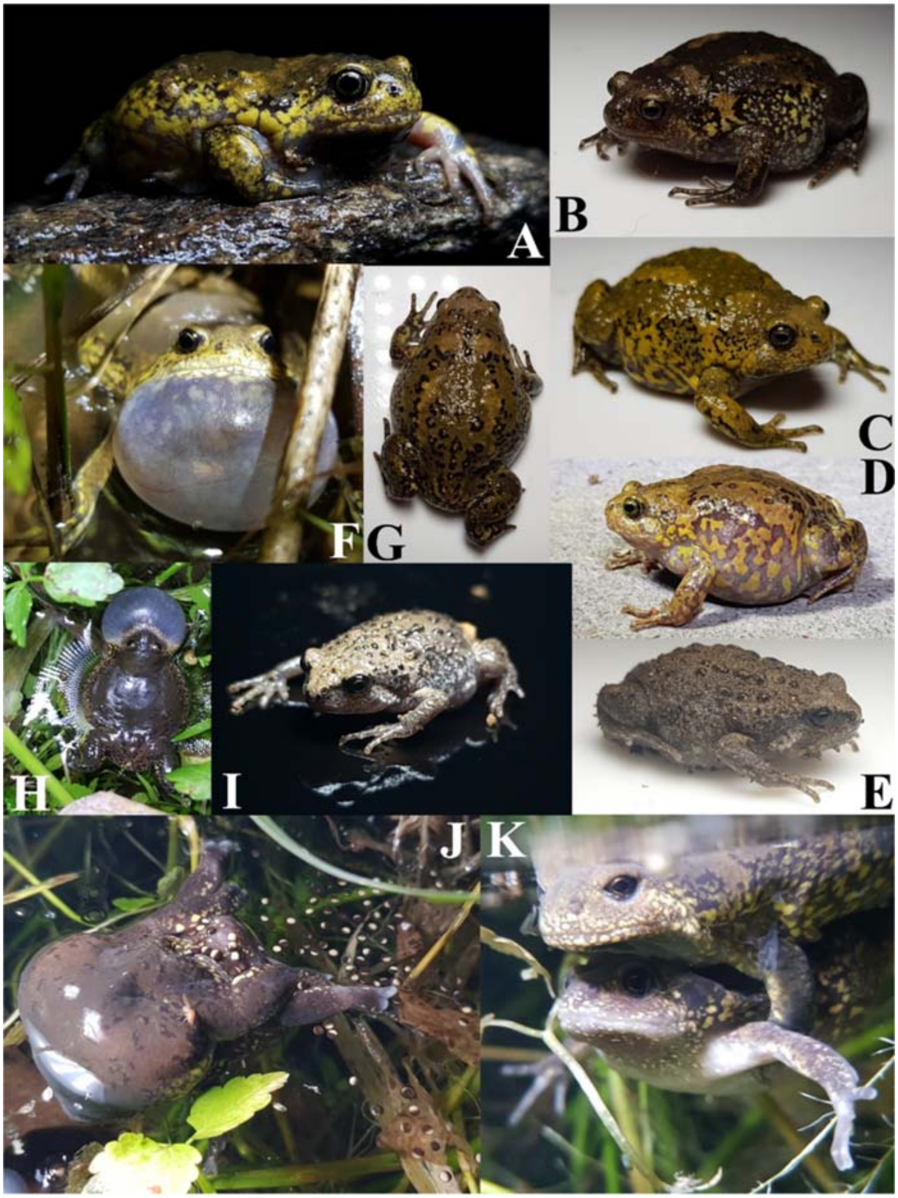

FIG. 5.2

Adult *Kaloula borealis*. The species is greatly variable in colouration, from bright *yellow* (A), through *brown* and *black* (B, C, D, E and I). The body is characterised by a round shape (G and H). Males call from the water body (F and H), where they spawn (J and K).

From Amaël Borzée.

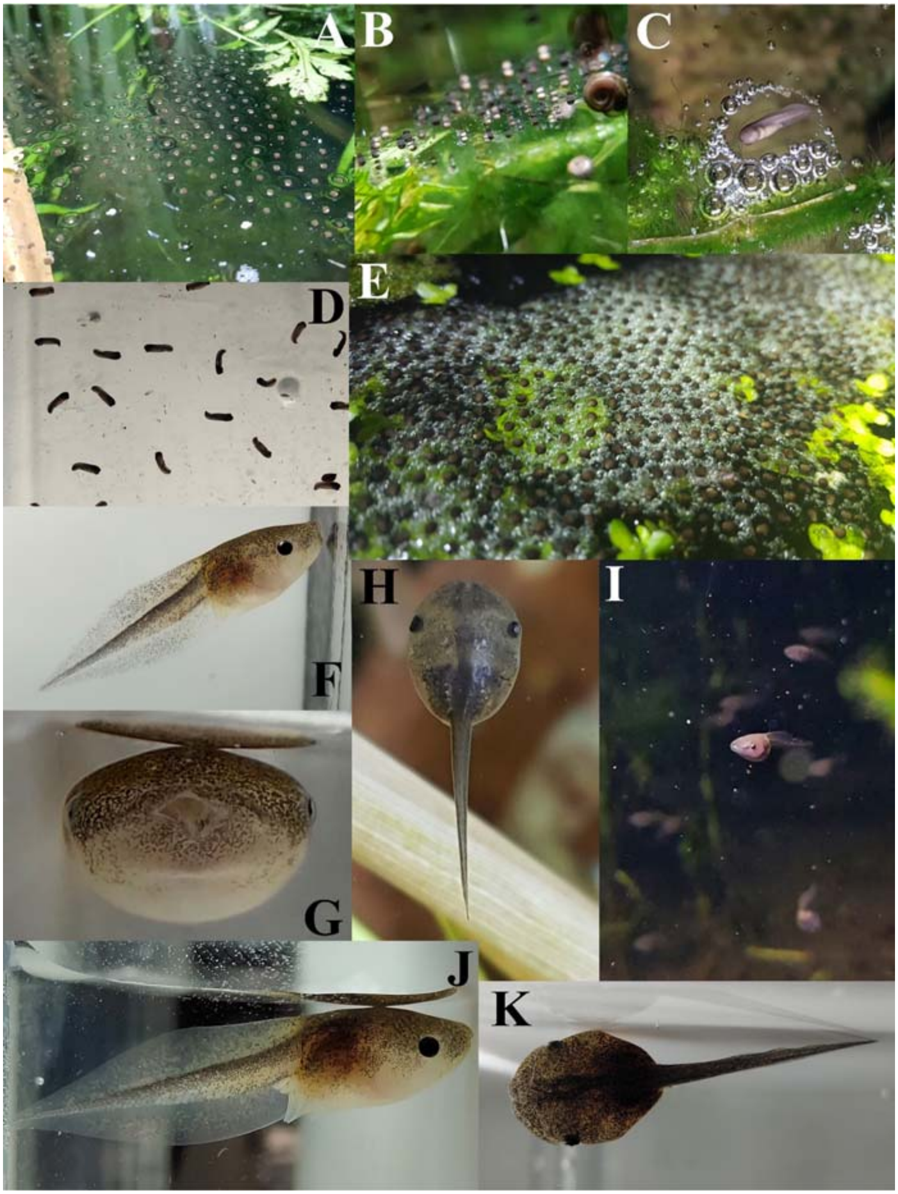

FIG. 5.3

Eggs and tadpoles of *Kaloula borealis*. The eggs are floating on the water surface (A, B and E), also while the embryo is developing (C and D). Tadpoles are active in the whole water column (H), feeding on floating particles as they do not have labial teeth (F and G). The body of the species is typical of Microhylidae with a large round body and a dark tail (H, J and K).

From Amaël Borzée.

(Borzée et al., 2016), for undefined reasons, a behaviour shared by other species in the genus. The species is among those with the longest continuous overwintering period in R Korea, generally hibernating from early November to early April (Groffen et al., 2022; noting that the data originates from citizen science data, is about a fossorial species, and therefore may be incomplete).

5.1.1.4 Threats and conservation

Kaloula borealis is listed Least Concern but decreasing in population size (ASG, 2020). The species is not threatened in China, abundant in DPR Korea, but listed as threatened in R Korea (NIBR, 2019), noting that the behaviour of the species is not well understood, with bouts of activity only when it rains, and thus likely creating a bias in population estimates. It is widely distributed and tolerates a broad range of habitats, including modified habitats and urban environments as long as clean temporary water is available to breed (Groffen et al., 2022). However, the population density for the species is likely declining along with its habitat (ASG, 2020). Accordingly, the principal threat to the species is habitat destruction and degradation, but it is also moderately affected by roadkills in R Korea (Shin et al., 2022), and the low genetic diversity could be a threat in the long term (Othman et al., 2021). In contrast, climate change models for suitable habitat predict an increase in suitable habitat by 2030, 2050 and 2080 under different climate change scenarios (Kim et al., 2021), however, connectivity between the current range and predicted suitable habitat is unknown. The species also occurs in several protected areas in all range countries, and its status of 'Endangered category II species' in R Korea (NIBR, 2019) results in increased protection and translocation when occurring in areas designated for urban development.

5.1.1.5 Identification

The identification of the species is easy as they have a clearly distinct morphology shaped by their fossorial lifestyle. Colours can, however, be variables, ranging from dark yellow to sandy grey and deep dark (Fig. 5.2). The calls of the species are also distinct, and males commonly duet when calling in groups, alternating notes, and giving a dual-tone to the calls. Eggs are floating as a single layer on the water surface and tadpoles have a dark tail sticking out of a round and transparent body, a morphological features exclusive to the species in northeast Asia, but similar to other Microhylidae, such as *Microhyla fissipes*, a sympatric species in the southern latitudes of its range. The species can be differentiated from the *Kaloula* species with a geographically close range, *K. rugifera*, through its larger body when tadpole (Zhou et al., 2011). The tadpoles do not have a labial tooth row formula as they do not have a complex oral disk (Park et al., 2009), but *K. rugifera* is characterised by 12 to 19 papillae, and *K. borealis* has 9 to 16 (Zhou et al., 2011).

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CHAPTER

6

Ranidae (*Rana*, *Glandirana*, and *Pelophylax*)

The Ranidae family is monophyletic (Wiens et al., 2009) of Mesozoic origin (Bossuyt and Roelants, 2009), and represented by three native and one invasive genera in northeast Asia. It is the family with the largest number of genera and species in the region. Among the three native genera, *Rana* originated in East Asia and diverged in the region starting 25 million years ago (Yuan et al., 2016). *Glandirana* emerged about 30 million years ago (Chen et al., 2017), and is restricted to East Asia although across a very wide latitudinal range. *Pelophylax* in East Asian diverged about 6.2 million years ago (Liu et al., 2010) but heavily hybridise across their whole range. Finally, *Lithobates* has been invasive in the region for a few decades (Groffen et al., 2019b). The three native genera range across a widely divergent landscape, resulting the in the presence of the family in all landscapes where amphibians are present, and none of the species is in imminent risk of extinction.

6.1 *Rana*

The Brown Frog genus, *Rana*, is widespread in the northern hemisphere, ranging across Eurasia and into Southeast Asia, and in western North America. The genus originated in East Asia, and subsequently dispersed towards other regions (Yuan et al., 2016). The Asian monsoonal system and the Baekdudaegan/Changbai mountain range (Yang et al., 2017) played important roles in restricting gene flow and driving speciation in *Rana* in Northeast Asia (Yuan et al., 2016). The resulting *Rana* clades restricted to East Asia diverged between 25 and 20 million years ago, with all described clades for which information is available having speciated two million years ago (Yuan et al., 2016). Even now, the taxonomy of the clades in the region is in need of clarification, with species still waiting to be described at the time of writing (Che et al., 2007; Shen et al., 2022). The genus occurs in almost all types of habitats across its range (Hillis and Wilcox, 2005), but many species are threatened, and a few even became extinct recently (Yuan et al., 2016). A specificity of the Eastern Asian *Rana* is the multiple adaptive strategies against the cold, including hypothermia endurance.

Continental Northeast Asian Amphibians. https://doi.org/10.1016/B978-0-323-91857-2.00004-X

6.1.1 ***Rana amurensis***

6.1.1.1 Origin and distribution

Rana amurensis, the Amur Brown Frog, described from Kazakevichevo in Khabarovsk, Russia, diverged from the *Rana* clade about 20 million years ago (Zhou et al., 2017) and it is closely related to *Rana coreana* in terms of phylogeography and morphology. The species includes multiple divergent clades, including old and recent radiations due to the changing landscape and cooling of the northern edge of its range across evolutionary times (Zhou et al., 2017). The species is best characterised by a very extensive range, making it one of the most widespread amphibian species of the Palearctic. The species ranges from the area north of Kumya in southern Hamgyong Province on the east coast of DPR Korea in the south, and the low mountainous area north of Pyongyang is likely to be the southern boundary to the west (Borzée et al., 2021c). In China, the species is present in the mountainous area of eastern Liaoning, throughout Jilin, and in the northern half of Inner Mongolia, at a latitude matching with Heilongjiang. In Mongolia, the species is distributed in the northern and extreme eastern areas, away from the desertic landscapes and along valleys, with its distribution limited by dry steppes to the south, and by the valley of the Tuul River to the west (Kuzmin et al., 2017). Finally, the species covers a large area in Russia, although it is not present in the Chernye Mountains, where it is present in most landscapes at southern latitudes, and becomes less common further north, in isolated populations along river valleys, but reaching as far north as the coast of the East Siberian and Chukchi Seas (Fig. 6.1).

FIG. 6.1

Distribution of *Rana amurensis*, the Amur Brown Frog.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima" with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

6.1.1.2 Habitat

The habitat requirements of the species are significantly different across the latitudinal gradient of its range, with the southern populations in DPR Korea being restricted to mountainous landscapes, specifically mountain streams and isolated stream pools (Kim and Han, 2009). In southern Russia, the species lives only in open landscapes and not in forests (Pers. Com. Dr. Maslova). The species becomes more generalist as latitude increases, reaching the broadest ecological niche at the median latitude of its range where it occurs in lentic or slow-flowing water bodies in both plains and mountain woodlands in northern China, Mongolia and further north in Russia. The ecological niche restricts again as latitude increases, and *R. amurensis* becomes associated with river valleys, in relation to wintering microhabitats. In China, the species ranges from 50 to 650 m of elevation (Fei et al., 2012), and it is associated with both forested and open landscapes, in the vicinity of wetlands. In Mongolia, the species is mostly present in meadows without canopy cover, or in valleys with wooded areas, but between 580 and 1500 m of elevation (Kuzmin et al., 2017).

6.1.1.3 Behavioural ecology

The life cycle of the *R. amurensis* and the length of the hibernation period is dependent on the latitude. At northern latitudes, the species hibernates from early September until late May, while it is active until October and from mid-April in the central parts of its range (Kuzmin et al., 2017). The species can exceptionally be active in November in southern latitudes, and breeding from late March (Kim and Han, 2009). The long hibernation is made possible by physiological adjustments involving oxygen-deprived fat storage, and the ability to survive in hypoxic conditions (Berman et al., 2019). The species generally hibernates underwater, including in waterbodies that are a few metres deep, and frogs can generally be found in groups in Mongolia and Transbaikalia (Kuzmin et al., 2017). In contrast, the species overwinters underground in Far Eastern Russia (Kuzmin and Maslova, 2005). While the species hibernates in flowing water or underground, it needs lentic water to spawn, and adults migrate over a considerable distance in fall and spring to migrate between breeding and overwintering sites (Fig. 6.2). The breeding habitat includes lentic water bodies such as lake shores, ponds and swamps, close to abundant vegetation at the median latitude of its range, but it is generally associated with lentic or slowly flowing water bodies at southern and northern latitudes, generally surrounded by woodlands.

The Amur Brown Frog breeds in late April to May at mid-latitudes, but until mid-July further north, although eggs can be found as late as early August. The eggs are spawned attached to the vegetation, generally clustered in groups of 720 to 2000 in the vegetation a few dozen centimetres deep but close to the banks (Kuzmin et al., 2017). The species generally avoids water bodies that are too shallow, when possible, likely to avoid freezing, and it can spawn comparatively deep for the genus. The eggs hatch within a few weeks to a month, based on temperature, and metamorphosis takes place about a month later at mid-range latitude, in early

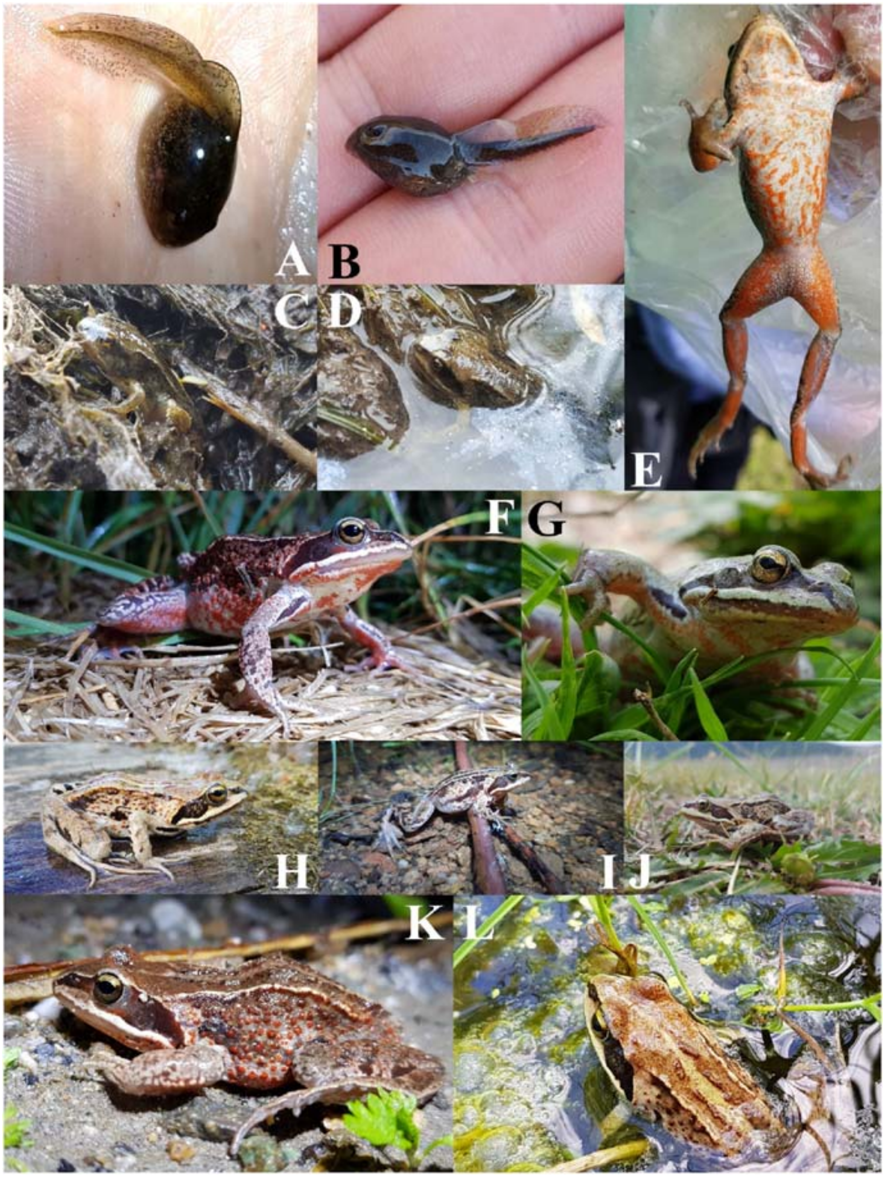

FIG. 6.2

Tadpole and adult *Rana amurensis*. The tadpoles are darker than other Anura larvae at high latitudes (A and B) and metamorphosis takes place in late June and early July (C and D). The species can be identified through the ventral patterns (E and F), the continuous white upper lip (F and G), and the red glands on the lateral sides of the body (H—L).

From Amaël Borzée.

July, but as late as early August further north (Fig. 6.2). Froglets disperse once tail retention is complete (Fig. 6.2), and adults stay in the vicinity of the wetland to feed before migrating to their overwintering habitat starting from mid-August at central latitudes (Kuzmin et al., 2017). The species is sexually mature from the second or third year at mid-range latitude.

6.1.1.4 Threats and conservation

Due to its distribution over a very large geographic area, the species faces a large number of threats, which can be described as localised even if the threat is reaching a national scale, in comparison with the range of the species. As a result, and because *R. amurensis* can tolerate weakly degraded habitats, the species is listed as Least Concerned by the IUCN Red List of Threatened Species (ASG, 2020c). However, the population size is decreasing across the whole range of the species due to several factors linked to general habitat degradation and related human activities, such as roadkills related to road development, drought related to climate change and mass collection for education. Specifically, the main geographically restricted threats are the loss of forested areas in DPR Korea (Borzée et al., 2021c), the loss of forested areas and overharvesting for food, traditional medicine and trade in China (Othman et al., 2022), poaching since the 1990s in Russian regions close to the Chinese border, dams construction in Siberia (ASG, 2020c), and overharvesting for research and education and water pollution in Mongolia (Kuzmin et al., 2017; Borzée et al., 2021b). The largest documented declines are in Mongolia where population sizes are decreasing and multiple local extirpations have been documented in relation to droughts (Kuzmin, 2010), despite 11% of the range of the species being included in protected areas (Terbish et al., 2006). As a result, the species is listed in the Red Data Books of the Middle Urals (Permskaya and Sverdlovskaya provinces, Russia) and the Yamal-Nenets Autonomous County (Russia). In contrast, the species is farmed (Borzée et al., 2021a), and it occurs in protected areas throughout its range, although climate change is likely impacting its distribution and abundance in the southern edge of its range through a shift in suitable habitat (Duan et al., 2016).

6.1.1.5 Identification

Morphologically wise, the species the most closely related to *R. amurensis* is *R. coreana*, and the two species share a large number of characteristics that distinguish them from other *Rana* species in the region. Principally, they show a white continuous stripe covering the totality of the upper lip, and red smooth spots on their ventral side during the breeding season (see details reviewed by Borzée et al., 2023). In the parts of the range outside of DPR Korea, *R. amurensis* has two clearly visible and prominent dorsolateral stripes and black spots on the tubercles on the back that *R. coreana* does not (Song et al., 2006; Wang et al., 2017a), and more rough red-brown spots on the flanks than *R. coreana*. Finally, the webbing between the toes of *R. amurensis* is moderately developed compared to *R. coreana*, likely an adaptation to colder habitats (Song et al., 2006; Zhao et al., 2017; Othman et al., 2022).

The vocal sacs in the species are comparatively reduced, but the release calls of the species are similar to a duck babbling. The eggs of the species, and egg clutches, are smaller than that of sympatric species, and floating. The tadpoles of this species are light brown with light grey dots on the body and dark brown spots on the tail. The tadpoles' labial tooth row formula is 1(1)/3, both in China (Li et al., 2005b) and Mongolia (Kuzmin et al., 2017).

6.1.2 *Rana coreana*

6.1.2.1 Origin and distribution

The Korean Brown Frog, *Rana coreana*, was described in 2006 based on genetic and morphological comparisons (Song et al., 2006), and the type locality is presumed to be in Incheon (Songdo) or Suweon (Seungnam), R Korea (Okada, 1928). The species split with *R. amurensis* about 10 million years ago (Zhou et al., 2017, but see Lee et al., 1999 for earlier divergence time), and *Rana kunyuensis* was synonymised with *R. coreana* based on genetic and morphological data (Zhou et al., 2015). The species ranges across R Korea, although it is not on Jeju Island and other islands off the coast of the Korean mainland. It occurs northwards up to the western lowlands of DPR Korea, as far north as the southern banks of the Taeryong River (Borzée et al., 2021c). In addition, there is an isolated population in Kumya area in southern Hamgyong Province (Kim and Han, 2009); and an isolated population in Shandong Peninsula, China, including on Mount Kunyu (Fig. 6.3).

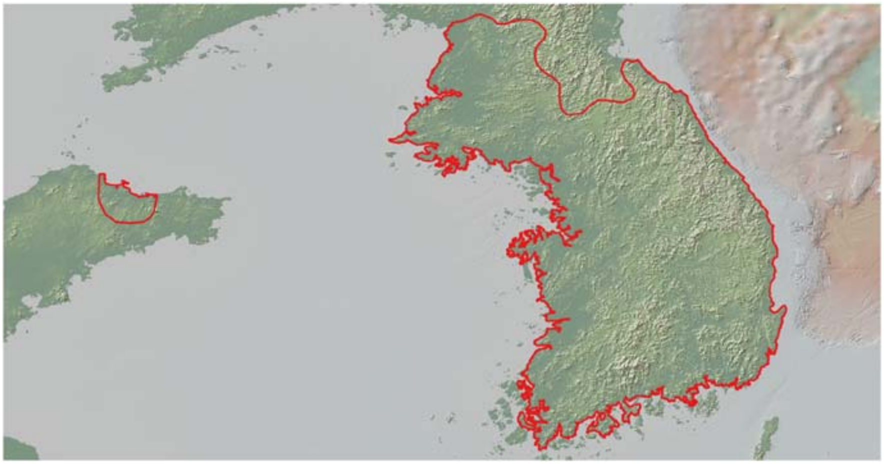

FIG. 6.3

Distribution of *Rana coreana*, the Korean Brown Frog.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

6.1.2.2 Habitat

The species is generally restricted to low and medium elevations, with a peak abundance around 300 m but individuals are found as high as 400 m in China (Fei et al., 2012) and about 850 m in R Korea (Andersen et al., 2022). As a result, the natural habitat of *R. coreana* mostly includes alluvial valleys, plains and hills of conifer and deciduous forests, at these elevations. When in these habitats, the presence of *R. coreana* is associated with wetlands, and the species will require the presence of both types of environments to occur. It therefore occurs in isolated populations, where density can be relatively high. In addition, the large-scale landscape transformations because of human activities across the Korean peninsula have resulted in the conversion of most natural wetlands, and as a result the species heavily relies on rice paddies for breeding, before rice plantation. Rice agriculture also provides a substitute habitat for hibernation as the species can be found in water holes and reservoirs used to flood rice paddies in winter, or under the ice on ditches around rice paddies if they are deep enough (Macias et al., 2018). The species can cope with some degree of landscape modification, and it can be found in agricultural wetlands in the vicinity of urban areas, despite some form of pollution (IUCN SSC Amphibian Specialist Group, 2019a).

6.1.2.3 Behavioural ecology

The peak spawning period of the species is in mid-March, but the species can breed from mid-February to mid-April in R Korea (Groffen et al., 2022), and April in China (Fei et al., 2012). Males are organised in breeding choruses to attract females, but the calls are not loud, due to the absence of vocal sacs, and sound like a krrrrr rasping (Fig. 6.4). The females lay small clusters of eggs in lentic water bodies, but not in lotic environments, ranging from 250 to 900 eggs (Fei et al., 2012). The eggs of the species are spawned the furthest away from the bank in comparison with other sympatric *Rana* species (Ambu et al., 2022). The eggs can hatch within four days if the weather and water temperature are high for the season. Tadpoles will take between one and two months to metamorphose, with most individuals having metamorphosed by mid-May, when the rice paddies are ploughed and flooded (Fig. 6.5). The froglets will stay in the area surrounding the water body where they hatched for a few weeks, before dispersing to the surrounding forested areas over summer. Hibernation will start in November, depending on the temperature, and it is generally done underwater. Emergence can be as early as late January based on the weather (Groffen et al., 2022).

6.1.2.4 Threats and conservation

While being widespread and listed as Least Concerned by the IUCN Red List of Threatened Species (IUCN SSC Amphibian Specialist Group, 2019a), *R. coreana* is dependent on the use of rice paddies for breeding in most of its range due to the loss of natural habitat, and the populations are disconnected and scattered, with a decreasing number of individuals. Therefore, while the species can tolerate some degree of habitat modification, it is declining faster, and present in

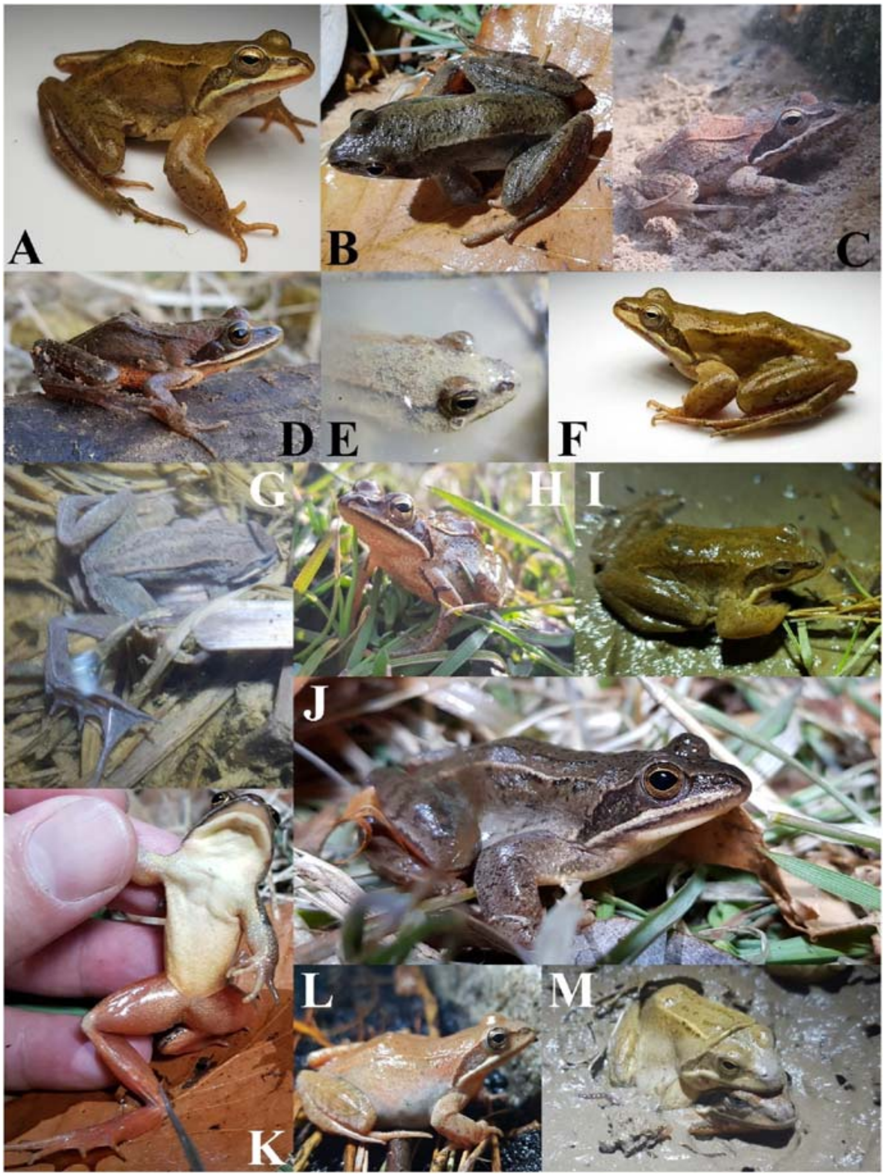

FIG. 6.4

Adult *Rana coreana*. The species is best identified through the continuous white upper lip (A—J), with a red marbled throat and venter during the breeding season (D and H), but not outside of the breeding season (K — note that J is the same individual). The webbing is also species-specific (G and K). Females start producing eggs before winter (L) and amplexus takes place in early spring (M).

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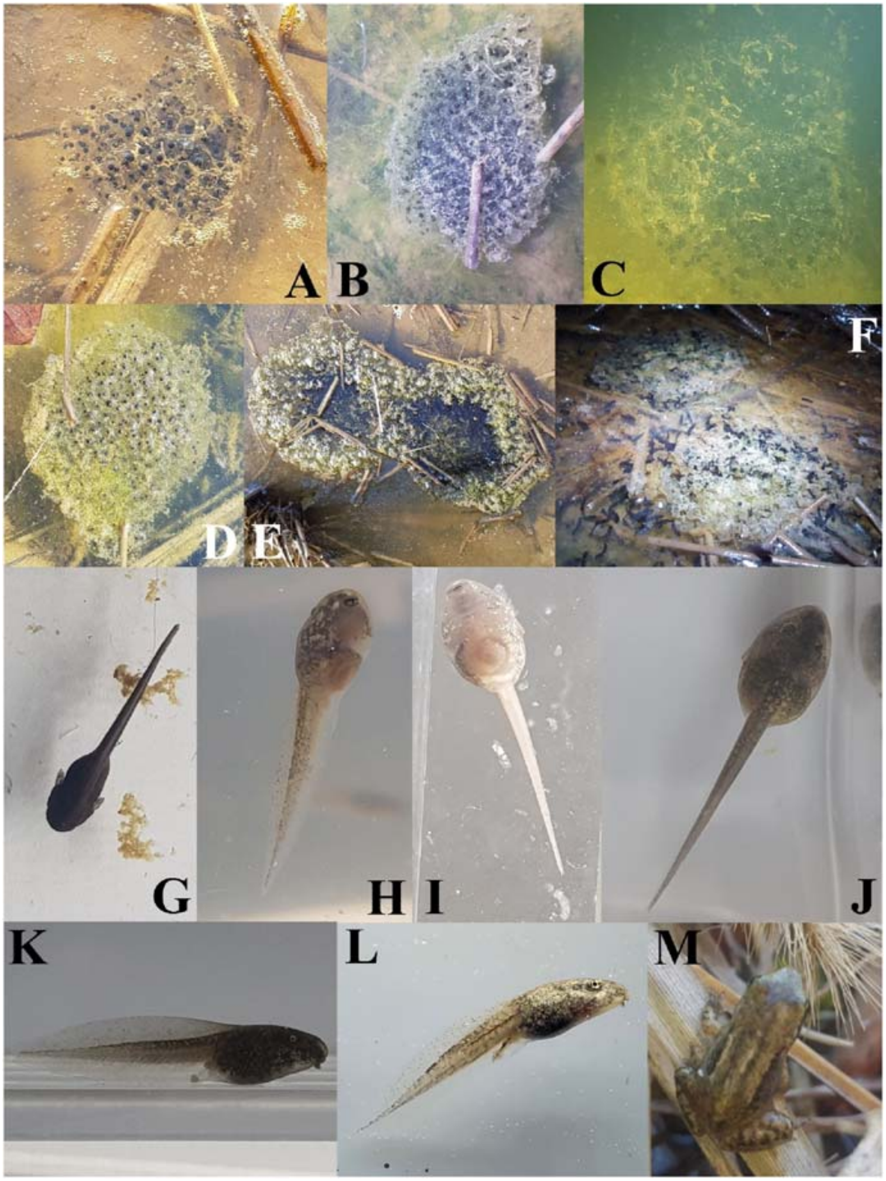

FIG. 6.5

Egg, tadpole and froglet *Rana coreana*. The eggs are spawned in late spring in non-flowing waterbodies, and they are not attached to the substrate (A—D). The egg clutches are smaller than that of sympatric *Rana* species, with fewer eggs. Once hatched, the larvae use the egg mass for shelter until they are free swimming (E and F). The development takes a few weeks (G—L) and metamorphosis takes place in early summer (M).

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comparatively lower numbers, than the sympatric *Rana* species. Specifically, it is declining in abundance in DPR Korea (Borzée et al., 2021c), it is moderately affected by roadkills as it ranks within the top 15 amphibian species impacted in R Korea (Shin et al., 2022), where it cannot cope with extensive habitat changes (besides agricultural wetlands; Groffen et al., 2022), and it is impacted by pollution from pesticides and fertilizers in China (Fei et al., 2012). In addition, climate change models for suitable habitat for the species predict a drastic decrease by 2030, 2050 and 2080 under different climate change scenarios (Kim et al., 2021). However, the species occurs in some protected areas in all three range nations, and while some individuals have been found to be infected by the Chytrid fungus (Fong et al., 2015), the pathogen is not known to have a negative impact on the species.

6.1.2.5 *Identification*

This species is the smallest of all Brown Frogs found in the region. In terms of morphological variations, *R. coreana* is most similar to *R. amurensis,* and the key to discriminating these two species from other *Rana* of the region is the white continuous stripe covering the totality of the upper lip and the red smooth spots on their ventral and lateral sides during the breeding season (see details of review in Borzée et al., 2023). In the parts of the range outside of DPR Korea, *R. coreana* does not have clearly prominent dorsolateral stripes, in opposition to *R. amurensis* (Song et al., 2006; Wang et al., 2017a), and not as many clearly marked rough red-brown spots on the flanks. Finally, the toes of *R. coreana* are only half webbed, and the toes are underdeveloped (Song et al., 2006; Zhao et al., 2017; Othman et al., 2022). Another key morphological variable is that the ratio of foot length to tibia length is higher in *R. coreana* than in *R. amurensis* (Song et al., 2006). The tadpoles' labial tooth row formula is: 2(2)/3[1] (Park et al., 2009), and the eggs of the species, and egg clutches, are smaller than that of sympatric species, and floating.

6.1.3 *Rana dybowskii*

6.1.3.1 *Origin and distribution*

Dybowski's Brown Frog, *Rana dybowskii*, was described from Abrek Bay, near Vladivostok in Russia and it is part of the *R. dybowskii* complex which also includes *Rana pirica* and *Rana uenoi*. The species complex branched off from the *Rana chensinensis* species complex about 11.7 million years ago (Zhou et al., 2017) and *R. dybowskii* split with *R. pirica* about 8.55 million years ago (Yang et al., 2017). The species ranges from Pyongyang latitude in DPR Korea in the south, where it is restricted to the higher elevation landscapes, before increasing in occurrence and density as latitude increases (Kim and Han, 2009; Borzée et al., 2021c). The species then ranges through northeast China, including the eastern regions of Liaoning, Jilin and Heilongjiang, where the mountainous landscape matches its ecological needs. The species is also present across the Russian Far East (excluding the Sakhalin and the Kurile Islands) all the way to Yakutsk's latitude (about 63° N; Kuzmin et al., 2017, Fig. 6.6).

FIG. 6.6

Distribution of *Rana dybowskii*, the Dybowski's Brown Frog.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

6.1.3.2 Habitat

The habitat of the species changes with latitude, with the species restricted to higher elevations and vernal pools in the southern part of its range (Kim and Han, 2009). In China and southern regions of the Russian Far East *R. dybowskii* can be found in a variety of landscapes, including lowlands, and until 900 m of elevation. In the northern areas of its range, the species is restricted to lower elevation landscapes, and to areas close to wetlands. Although generally in the vicinity of broadleaf and mixed coniferous forests (Fei et al., 2012), the species breeds in lentic habitats, such as the shallow edge of lakes, ponds, and modified landscapes such as rice paddies (Kuzmin et al., 2004a).

6.1.3.3 Behavioural ecology

Males of the species gather in breeding choruses to advertise for females, and spawning takes place in April and May (Fig. 6.7). Each egg clutch floats independently and includes about 1000 eggs. The calls of the species can be compared to children laughing in the distance, and it is the only *Rana* producing advertisement calls within the area of occurrence. Females rarely attend the choruses more than once, and they will migrate back to the woodlands soon after spawning. Males can stay up to a month at the breeding site, but they will migrate back to the woodlands before summer as well. Eggs take about a week to hatch in good weather conditions, but can take up to three weeks if the weather becomes cold again (Maslova, 2000). Once hatched, tadpoles generally cluster close to the edge of the water bodies to increase body temperature and speed up development (Fig. 6.8). The tadpoles will

FIG. 6.7

Adult *Rana dybowskii*. Adults are very variable in terms of colours and patterns (A—L), although generally more colourful during the breeding season (A), a period when females show brightly coloured venters (M) while males have milky white venters (N). The webbing is species-specific free-swimming and can be used for species identification (O).

From Amaël Borzée.

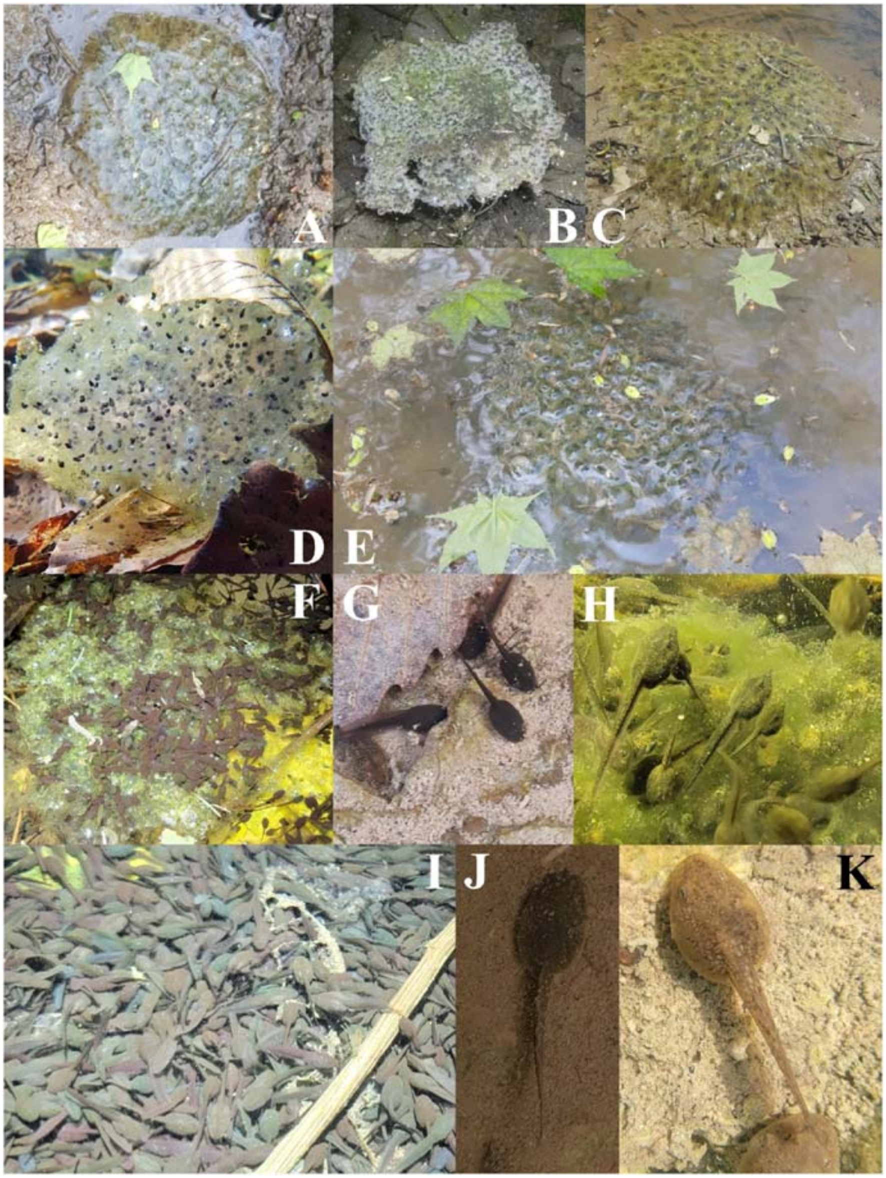

FIG. 6.8

Egg and tadpole *Rana dybowskii*. The eggs are spawned in non-flowing water bodies (A—E), and they are floating and not attached to the substrate (D). When hatching, tadpoles stay at the centre of the egg mass to shelter, before being free swimming (G—K) and sometimes aggregating in large groups (I).

From Amaël Borzée.

metamorphose between late May and early July, and they will stay close to the breeding site until late August to early October depending on latitude, when they will migrate to the overwintering area. Overwintering is generally underground, or under rocks underwater. The species relies on specific physiological adjustments such as fat storage oxygen to overwinter (Xiao et al., 2008).

6.1.3.4 Threats and conservation

The species is listed as Least Concern by the IUCN Red List of Threatened Species, despite the assessment being in need of an update and dating from prior to the split with *R. uenoi* (Kuzmin et al., 2004a). The assessment was made based on the wide distribution of the species across multiple landscapes and habitat types. However, the species is now declining throughout the range of the species despite still being widespread and locally abundant.

Specifically, the species is abundant but declining in DPR Korea (Borzée et al., 2021c), and it is used for human consumption. It has importantly declined in China due to harvest for human consumption (Wei et al., 2010), trade for farming (Borzée et al., 2021a), and habitat loss, and it is exported to other countries for human consumption (Othman et al., 2022). Similarly, it is declining in Russia because of landscape change and poaching (Maslova, 2002). In addition, abundant roadkills in fall are found on most of the range of the species where human populations are present and it is likely to be impacted by climate change, similarly to other *Rana* species in the region for which modelling has been conducted. In contrast, the species is found in several protected areas across its range, and infections by Ranavirus in the wild are not known to have a negative impact on the species (Xu et al., 2010).

6.1.3.5 Identification

The traits used for the identification of the species outside of the breeding season when in sympatry with *R. huanrenensis* are not the easiest, although *R. dybowskii* generally, but not always, shows an inverted V on its upper back, while *R. huanrenensis* has not been reported with this morphological feature yet. During the breeding season, male *R. dybowskii* show a milky white throat and venter, and females have a reddish yellow throat and venter (Kim et al., 2002). The species is also sympatric with *R. amurensis*, but size and colours are generally sufficient to distinguish adults of both species (but see Borzée et al., 2023 for a detailed morphological comparison with other *Rana* of Northeast Asia). The contact zone between *R. dybowskii* and *R. uenoi* should be in the latitude of Pyongyang in DPR Korea, and morphological traits to distinguish the two species (when not in sympatry, i.e., R Korea and Russia) should include well-developed toes in *R. dybowskii*, with a webbing almost linear (no angle) between the first and second toes (Matsui, 2014; Othman et al., 2022). Differences in call properties between *R. dybowskii* and *R. uenoi* are not known. The eggs of *Rana dybowskii* are relatively easy to identify as the eggs are floating, and the egg clutches are relatively bigger than that of other sympatric *Rana* species. Tadpoles can also be identified using the labial tooth row formula 3(3)/1(1), which is different from that of other sympatric *Rana* (Fei et al., 2009; Li et al., 2010).

6.1.4 ***Rana uenoi***

6.1.4.1 Origin and distribution

The Korean Large Brown Frog, *Rana uenoi*, described from Tsushima Island in Japan, is divided into two distinct clades: one on the Korean Peninsula and Tsushima Island, and one on Jeju Island, likely originating from the mainland during the Pleistocene (Jeon et al., 2021). The species diverged from *R. dybowskii* about 11 million years ago, a Miocene divergence that sets this pair of species apart from other species pairs in the region as they generally split during the Pleistocene (Yang et al., 2017). The species is also present in DPR Korea, where it is restricted to southern latitudes and low elevations, with the northernmost recorded individual located in Pyongyang area (Borzée et al., 2021c, Fig. 6.9).

6.1.4.2 Habitat

In R Korea, the species is recorded until 1300 m of elevation (Andersen et al., 2022) although it is most generally present at lower elevations, with large breeding concentrations found around 300 m a.s.l. The species is restricted to lentic water bodies for breeding, and the large habitat alterations resulting from human activities have caused the species to rely on rice paddies, before plantation, as substitute breeding habitats. In the remaining natural habitat, the species is generally associated with broadleaf vegetation, such as chestnut trees, mixed woodlands, and wet meadows. The species breeds in lentic water bodies such as rice paddies partially flooded by rainwater, shallow ponds and the shallow edges of some lakes, ditches, and disconnected pools close to streams. The species can be found close to urbanised areas, and it can breed in cemented pools if no other options are available.

FIG. 6.9

Distribution of *Rana uenoi*, the Korean Large Brown Frog.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

6.1.4.3 Behavioural ecology

Male *R. uenoi* congregate between mid-January and late April (Groffen et al., 2022) for about four weeks, with the beginning of the breeding season being delayed with the shift in latitude, and produce calls in breeding choruses (Kim et al., 2020) to attract females (Fig. 6.10). The calling activity of males in the species is affected by temperature, relative humidity and one-day lag rainfall (Yoo and Jang, 2012). During spawning, which may involve necrophilia (Groffen et al., 2019a), about 700 eggs are deposited. Adults leave the breeding site to migrate back to wooded areas, where they will stay until the next breeding season. The eggs float and they are generally spawned in shallow water (about 30 cm deep) closer to the bank in comparison with other sympatric *Rana* species breeding in lentic environments (Ambu et al., 2022). Hatching is temperature dependent, taking generally about ten days, but ranging between one and four weeks (Fig. 6.11). Tadpole development is also fast, with most individuals having metamorphosed by mid-May, when the rice paddies are ploughed and flooded. The young individuals will migrate to the forested areas between late October and early November in R Korea (Shin et al., 2022), where they will hibernate. Hibernation can start very late at low latitudes, with some individuals seen active in mid-December in central R Korea, and the first individuals are found calling during the first week of January on Jeju Island (Groffen et al., 2022). Hibernation is generally done underground, but cold spells can result in some individuals hibernating under the ice on ditches around rice paddies if they are deep enough (Macias et al., 2018). It takes two to three years for an individual to reach sexual maturity.

6.1.4.4 Threats and conservation

The species has not been assessed by the IUCN Red List of Threatened Species, but it is likely to be listed as Least Concern due to the large population size, broad range, connected populations, and ability to cope with some degree of habitat change (Groffen et al., 2022). However, some populations have declined due to habitat destruction and degradation, pollution, urbanisation and the mass collection of adult individuals, especially females, for human consumption in late winter. This practice has however stopped, but the import of other species from northeast Asia, and their subsequent release in the wild in R Korea presents risks of hybridisation and pathogen transmission (Othman et al., 2022).

In addition, the species is within the top five species impacted by roadkills in R Korea (Shin et al., 2022). Further, climate change models for habitat suitability predict a drastic decrease in suitable habitat by 2030, 2050 and 2080 under two different climate change scenarios (Kim et al., 2021), global warming is advancing the breeding season of *R. uenoi* by a large number of days (Jang et al., 2023). While some individuals have been found to be infected by the Chytrid fungus (Fong et al., 2015), the pathogen is not known to have a negative impact on the species. Finally, the species occurs in protected areas in both range countries, and no specific threats are known for the species in DPR Korea.

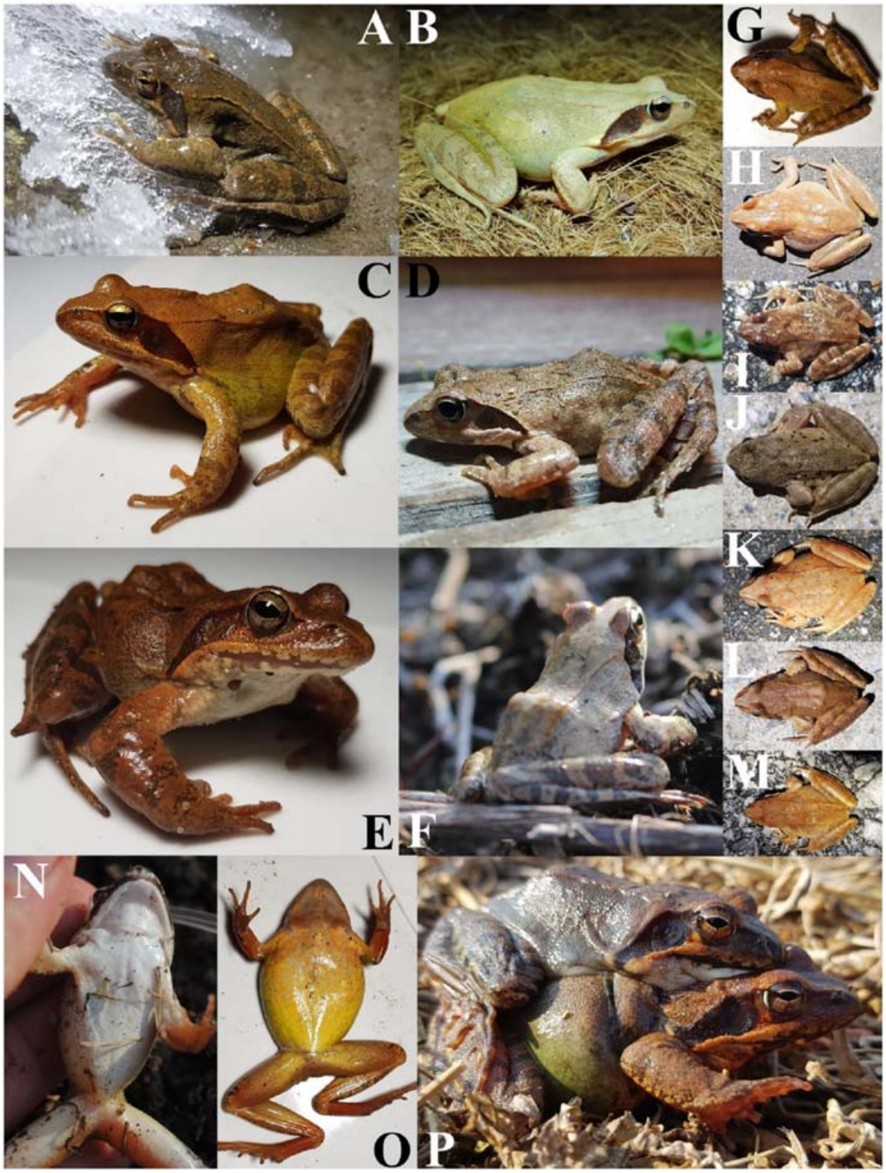

FIG. 6.10

Adult *Rana uenoi*. Adults are variable in colours but generally present an inverted V-shaped gland on their upper back (A—F). The species starts being active before the ice melts (A), and at that period the sexual dimorphism in colours is clearly noticeable with males showing white venters (N) while females are *orange* (O). Amplexus and spawning occurs in mid-winter (P).

From Amaël Borzée.

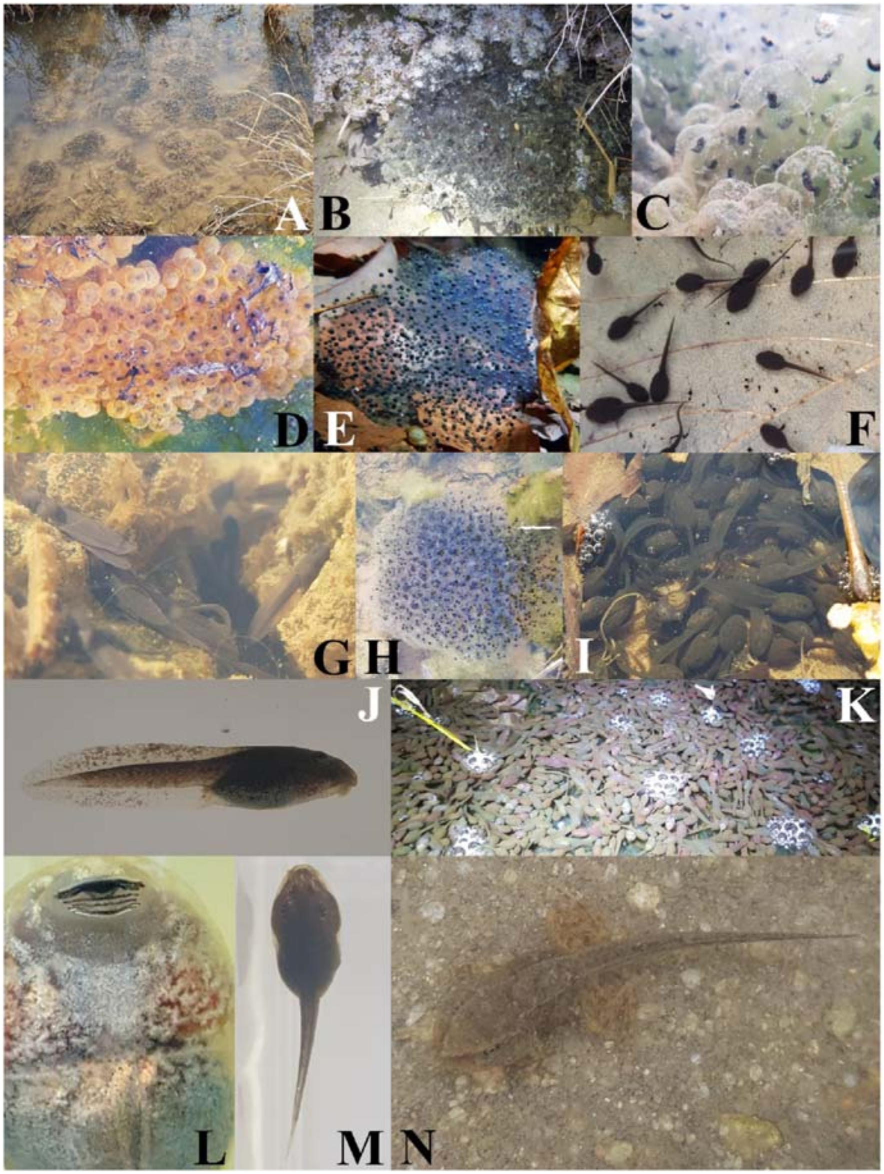

FIG. 6.11

Egg and tadpole *Rana uenoi*. The eggs are spawned before the end of winter in non-flowing water bodies (A) and susceptible to freezing (B), when they may sink under the water surface (C—E, D and H). Eggs are also susceptible to pollution, here originating from rusting equipment left in the water (D). Tadpoles (F, G and I—M) stay at the centre of the egg mass to shelter (G) and congregate for resources (K) before starting metamorphosis (N).

From Amaël Borzée.

6.1.4.5 Identification

The identification of *Rana* in the field outside of the breeding season is challenging. A key morphological character is the presence of an inverted V on the upper back of some individual *R. uenoi*, a character that is not yet known to be shared with *R. coreana* and *R. huanrenensis*, and not always present in *R. uenoi* either (see details of review in Borzée et al., 2023). During the breeding season, male *R. uenoi* present a smooth ventral skin with a milky-white throat and chest. Females in contrast have bright red throats and chests during the breeding season, with a smooth greyish ventral skin.

To differentiate *R. uenoi* and *R. dybowskii*, several characters are notable, but as the contact zone in DPR Korea has not been studied, these characters may not be perfectly adequate. *Rana uenoi* should be displaying weakly marked tubercles on the lower flanks and a few black spots between the scapular and the sacral region, in contrast with *R. dybowskii* (Matsui, 2014). In addition, the toe-tips of *R. uenoi* are blunt, and moderately webbed (Matsui, 2014; Othman et al., 2022).

The eggs of the species, and egg clutches, are larger than that of sympatric species, and floating, but similar to that of *R. coreana* and sometimes occurring in syntopy (Do et al., 2022). The tadpoles' labial tooth row formula is 4(2−4)/4[1] (Park et al., 2009). The calls of breeding choruses are peculiar, sounding like laughing children in the distance, and it is the only *Rana* which has calls that can be heard in the distance on the Korean Peninsula. The call properties in relation to that of *R. dybowskii* have not been analysed.

6.1.5 *Rana chensinensis*

6.1.5.1 Origin and distribution

The Chinese Brown Frog, *Rana chensinensis*, was described from Yinjiapo in the Qinling Mountains (Gee and Boring, 1929). This species complex includes *Rana chensinensis*, *Rana kukunoris, Rana huanrenensis* and the newly described *Rana taihangensis* on the Asian mainland (Zhou et al., 2012; Zhou et al., 2017; Yuan et al., 2016; Shen et al., 2022). The *R. chensinensis* complex split from the *R. dybowskii* complex about 11 million years ago (Zhou et al., 2017), and *R. chensinensis* and *R. kukunoris* split about 1.9 million years ago (Zhou et al., 2017).

The species is distributed across a large area, but the boundaries are still ill-defined. The clade that includes the type locality of *R. chensinensis* ranges as far south as the Wushan Mountains, then further north along the eastern ridge of the Chengdu Basin and southern Daba Mountains, along the Eastern Qinling mountains, but it does not distribute west towards Lanzhou. This clade is also present in the Dabie Mountains, and along the Funiu and Xiaoqinling Mountains connecting it to the main distribution. The boundary with *R. taihangensis* is north of the south-western Taihang Mountains, delineating a coherent geographic unit for *R. chensinensis* within the Yellow River Basin (Shen et al., 2022, Fig. 6.12). The species is unlikely to be present in Shandong as reported earlier, but discrete populations may have been established in Liaoning and Jilin by escaped individuals as a

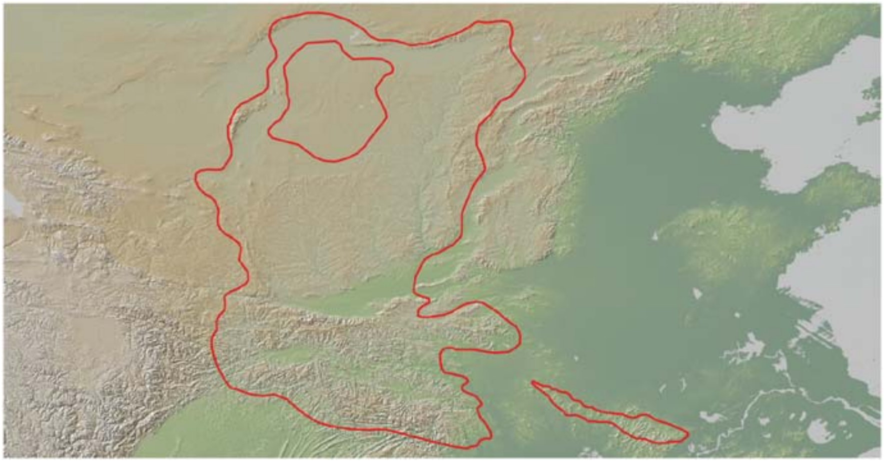

FIG. 6.12

Distribution of *Rana chensinensis*, the Chinese Brown Frog.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

result of the species being traded internationally and going through farms in the area (OTU 7 in Othman et al., 2022). In contrast, *R. kukunoris* is distributed to the west of *R. chensinensis*, on the edges of the Qinghai Tibet Plateau.

6.1.5.2 Habitat

The habitat used by the species is variable and *R. chensinensis*, is found in a broad range of habitats, but generally close to forested areas (Kuzmin et al., 2004d) and in larger numbers in mountainous landscapes, and at high elevations ranging up to 2100 m above sea level (Fei et al., 2012). This species is also found in habitats impacted by human activities, such as planted forests, cultivated fields and in the surrounding of cities. The breeding habitat includes both lentic waterbodies such as ponds and pools in wetlands, and flowing water bodies, where the species will also hibernate.

6.1.5.3 Behavioural ecology

The two clades in this species rely on breeding choruses for males to attract females, and males will stay in the water body for a few days to a few weeks (Fig. 6.13), while females come to breed only and will lay about 1000 eggs. The clade can breed from early February, but until June at high elevations (Fei et al., 2012), and egg development is temperature dependent, lasting from a few days to about two weeks (Fig. 6.14). Tadpoles will metamorphose from early April, and the froglets will stay in the vicinity of the water body until migration to the overwintering habitat. The species hibernates underwater, under rocks and other substrates at the bottom of the stream bed.

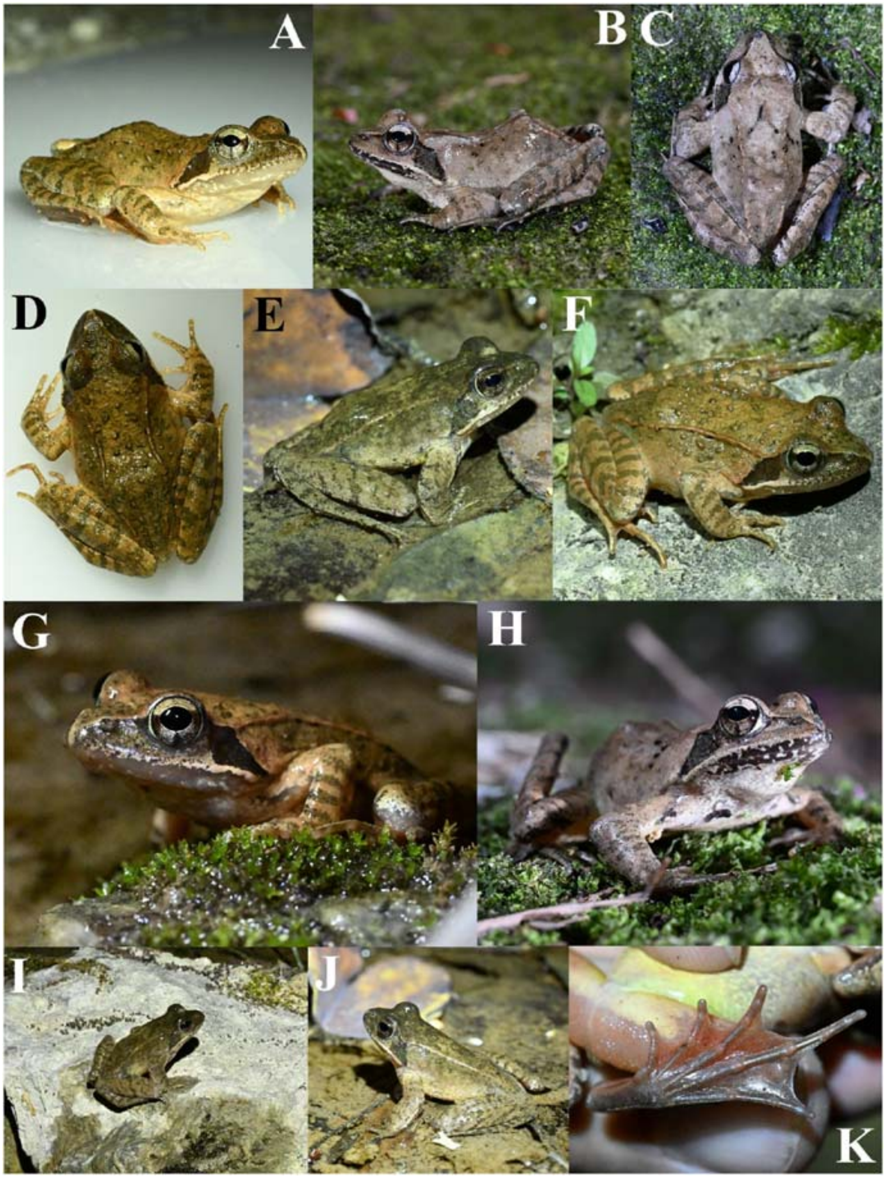

FIG. 6.13

Adult *Rana chensinensis*. Adults are active through the season in the vicinity of breeding sites, reaching high elevations (A—J). The species can be identified through several morphological cues, that may still need to be refined, but include the webbing of the hind toes (K).

From Amaël Borzée.

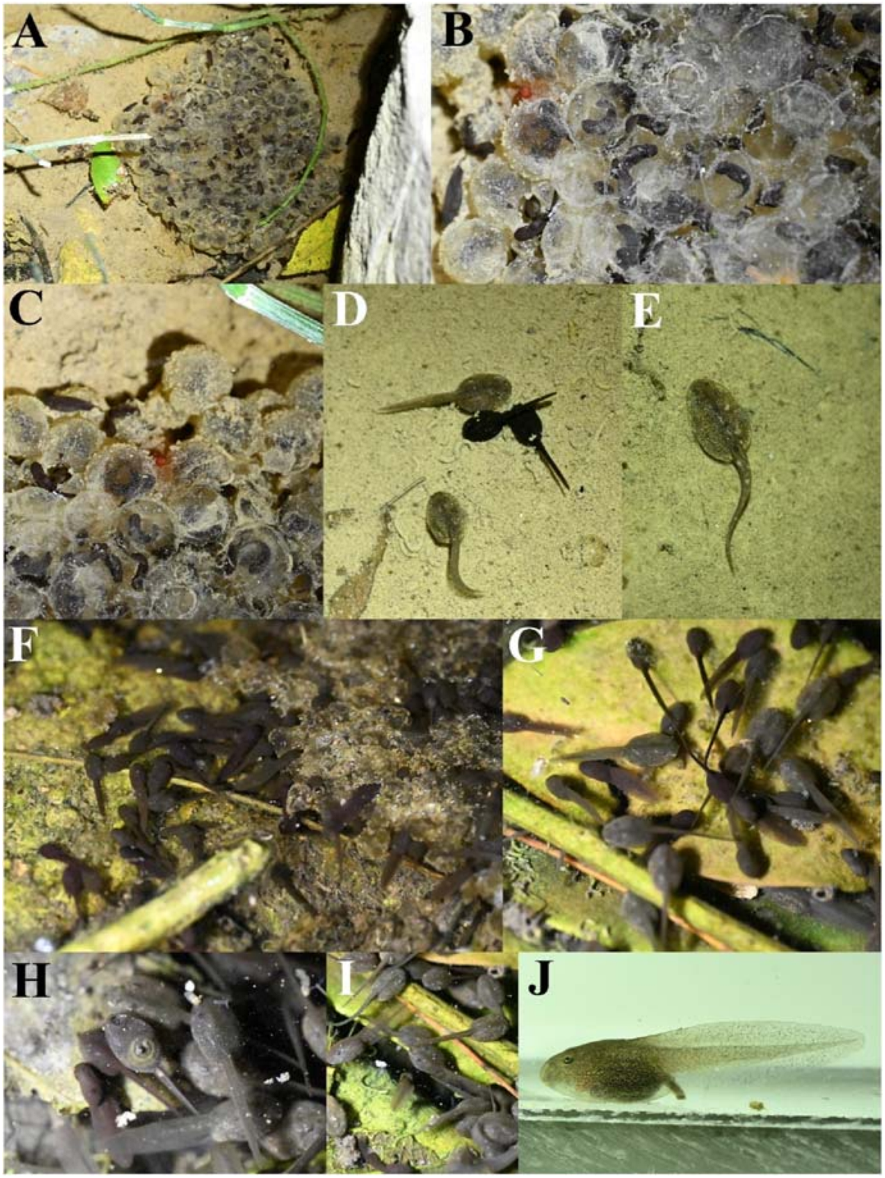

FIG. 6.14

Egg and tadpole *Rana chensinensis*. The eggs are spawned over a relatively long period of time (A—C), resulting in aggregation of tadpoles of different age (D, E and J). Tadpoles are feeding on decaying matter (E—I).

From Amaël Borzée.

6.1.5.4 Threats and conservation

The species is listed as Least Concern by the IUCN Red List of Threatened Species, despite a decreasing population size (Kuzmin et al., 2004d), and being assessed before the split with *R. taihangensis*. The species is subjected to harvests for human consumption, sometimes reaching the trade through laundering in *Rana* farms, and exported internationally under variable species names (OUT 7 in Othman et al., 2022). In addition, when considered together with *R. taihangensis*, the two species are likely impacted by climate change through a large shift in suitable habitat and altitude (Duan et al., 2016).

The species is widespread and common, and it can occur in moderately modified habitats, but it is exposed to roadkills due to its geographic distribution matching with higher human densities. This overlap with human activities also means that habitat destruction is a threat to the species, although of unknown impact on the population dynamics. The clade occurs in protected areas.

6.1.5.5 Identification

The species can be distinguished from the sympatric *Rana* through several morphological features, with uncertainties resulting from the taxonomic clarification needed for the species (morphological details in Borzée et al., 2023). The species is generally showing a while venter, with faint grey streaking, and reddish colouration on the inguinal area during the breeding season. Generally, the species complex can be discriminated from the *R. dybowskii* species complex through the presence of tubercles on the ventral side of the thighs (Song et al., 2006; AmphibiaChina, 2022). *Rana chensinensis* and *R. kukunoris* differ from *R. huanrenensis* in the shape and structure of the dorsolateral stripes (Song et al., 2006; Wang et al., 2017a), although *R. chensinensis* and *R. taihangensis* are similar in that the dorsal folds may not be straight, and sometimes interrupted (AmphibiaChina, 2022), and some individuals show an inverted V on their upper back, but the dorsolateral line is not prominent (Kuzmin et al., 2017). In addition, the *R. chensinensis* species complex has well-developed toe-webbing showing a wide angle between the first and second toe (noting here a similarity with *R. dybowskii*; Othman et al., 2022; AmphibiaChina, 2022). The forearms of *R. chensinensis* are considerably shorter than that of *R. kukunoris*, although similar to that of *R. huanrenensis* (Leung et al., 2021). The end of *R. chensinensis* fingers are round and blunt with comparatively fewer tubercles in comparison with *R. taihangensis.* Finally, the head morphology of *R. chensinensis* is also different from that of congeners, with a head length value higher than the head width (Matsui et al., 1993; AmphibiaChina, 2022), and *R. huanrenensis* shows an eye diameter larger than the inter-orbital distance, which are similar in *R. huanrenensis, R. dybowskii* and *R. amurensis* (Matsui, 2014), but opposite in *R. taihangensis*. Due to the habitat where eggs are deposited, they are expected to be sticking to the substrate, similar to *R. huanrenensis*. The tooth formula of tadpoles is 3+3 (or 4+4)/1+1 (Fei et al., 2009). No information on the vocalisations of the species is currently available.

6.1.6 *Rana taihangensis*

6.1.6.1 Origin and distribution

The Taihang Brown Frog, *Rana taihangensis*, was described in 2022 from Huixian in Henan Province, China (Shen et al., 2022), based on mitochondrial genes and matching with the Clade L from Zhou et al. (2012), and the OTU 1 and 2 from Othman et al. (2022). The species ranges northward from Xi'an in the western part of its range, across the northern Taihang Mountain arc, and reaching all the way to Northern Hebei across Eastern Gansu, Shaanxi, Shanxi, Inner Mongolia, Hebei, Henan and Beijing (Zhou et al., 2012; Shen et al., 2022), and further into extreme Eastern Mongolia (Terbish et al., 2013; Kuzmin et al., 2017). The boundary of the range to the southwest is restricted to the Haihe River system (Shen et al., 2022, Fig. 6.15). The species is also most unlikely to be in Liaoning and Jilin, although the species is traded internationally, going through farms in the area, and escaped individuals could have established discrete populations (OTU 1 and 2 in Othman et al., 2022).

6.1.6.2 Habitat

The species generally relies on habitat at comparatively lower elevations, despite records up to 2000 m, occurring in plains and lowlands rarely below 100 m of elevation at Beijing latitude and 200 m at the northern latitudes of its range (Shen et al., 2022). At higher latitudes and in drier landscapes, this species can also occurs in wetlands such as swampy areas near rivers and lakes surrounded by arid regions, including steppes and desertic landscapes, where it can spend extended periods of time in the water to cope with dry and hot conditions (Kuzmin et al., 2017). This

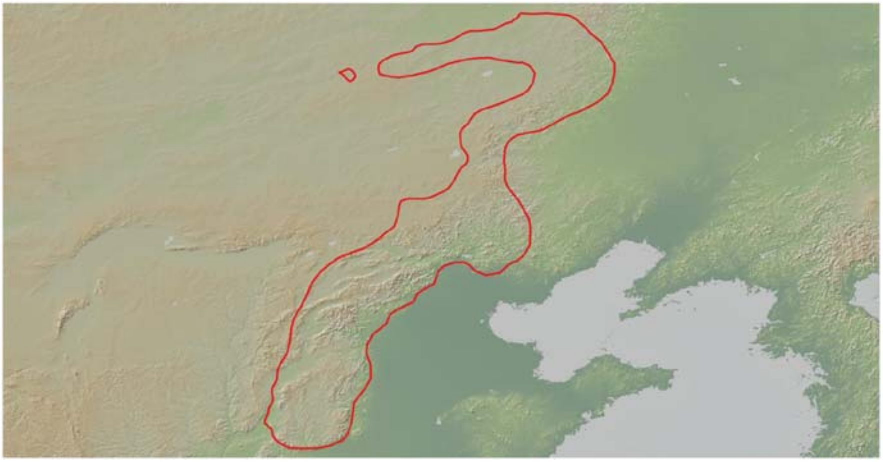

FIG. 6.15

Distribution of *Rana taihangensis*, the Taihang Brown Frog.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

species can breed in slow-flowing water bodies and wetlands such as the edge of slow rivers.

6.1.6.3 Behavioural ecology

The breeding behaviour of *R. taihangensis* is variable based on latitude and temperature, and breeding starts from late April at southern latitudes and low elevations (Shen et al., 2022), but eggs can be spawned as late as June, in shallow water in northern areas (Kuzmin et al., 2017). Egg development takes from a bit less than a week to several weeks, and tadpoles will metamorphose in mid-May at average range latitude, but as late as late July at northern latitudes. Adults of both sexes will stay in the vicinity of the breeding site, flowing or not flowing wetlands, which can also be the hibernating site, and they feed both on the ground and in water (Kuzmin et al., 2017). Hibernation can start from October at high latitudes, generally under the substrate at the bottom of lotic water bodies (Kuzmin et al., 2017, Fig. 6.16).

6.1.6.4 Threats and conservation

The species is more sporadically distributed at northern latitudes, and thus generally at lower density when the latitude increases. While abundant in some populations in China, it is rare and declining in Mongolia due to habitat alteration through pollution, urban development and cattle grazing. As a result, the species is listed in the Red Data Book of Mongolia (VuB1ab(iii)), and it occurs in protected areas (Kuzmin et al., 2017). The species is locally abundant in the south, but it is harvested for human consumption in China (OTU 1 and 2; Othman et al., 2022), and it is likely impacted by climate change through a large shift in suitable habitat and altitude when considered together with *R. chensinensis* (Duan et al., 2016). The range overlap with large cities is also likely to result in high mortality through roadkills, and habitat destruction is a threat to the species, although of unknown impact on the population dynamics. The species occurs in protected areas, including in parts of its range where it is not abundant.

6.1.6.5 Identification

Rana taihangensis generally has a white venter, with faint grey streaking, and reddish colouration on the inguinal area during the breeding season. Some individuals show an inverted V on their upper back, and the dorsolateral lines are not prominent. The species can be distinguished through several morphological features, noting that published descriptions of *R. chensinensis* do include *R. taihangensis*, resulting in some confusion (morphological details in Borzée et al., 2023). The species can be discriminated from the *R. dybowskii* species complex through the presence of tubercles on the ventral side of the thighs (Song et al., 2006; AmphibiaChina, 2022), and from *R. huanrensis* through the presence of vocal sacs. The dorsolateral folds in the species are not always straight, sometimes interrupted, in contrast with most other *Rana* species in the region, but similar to *R. chensinensis* (Song et al., 2006; Wang et al., 2017a). In addition, *R. taihangensis* has an interorbital distance lower than the internarinal distance, in opposition with *R. chensinensis*, and the finger of

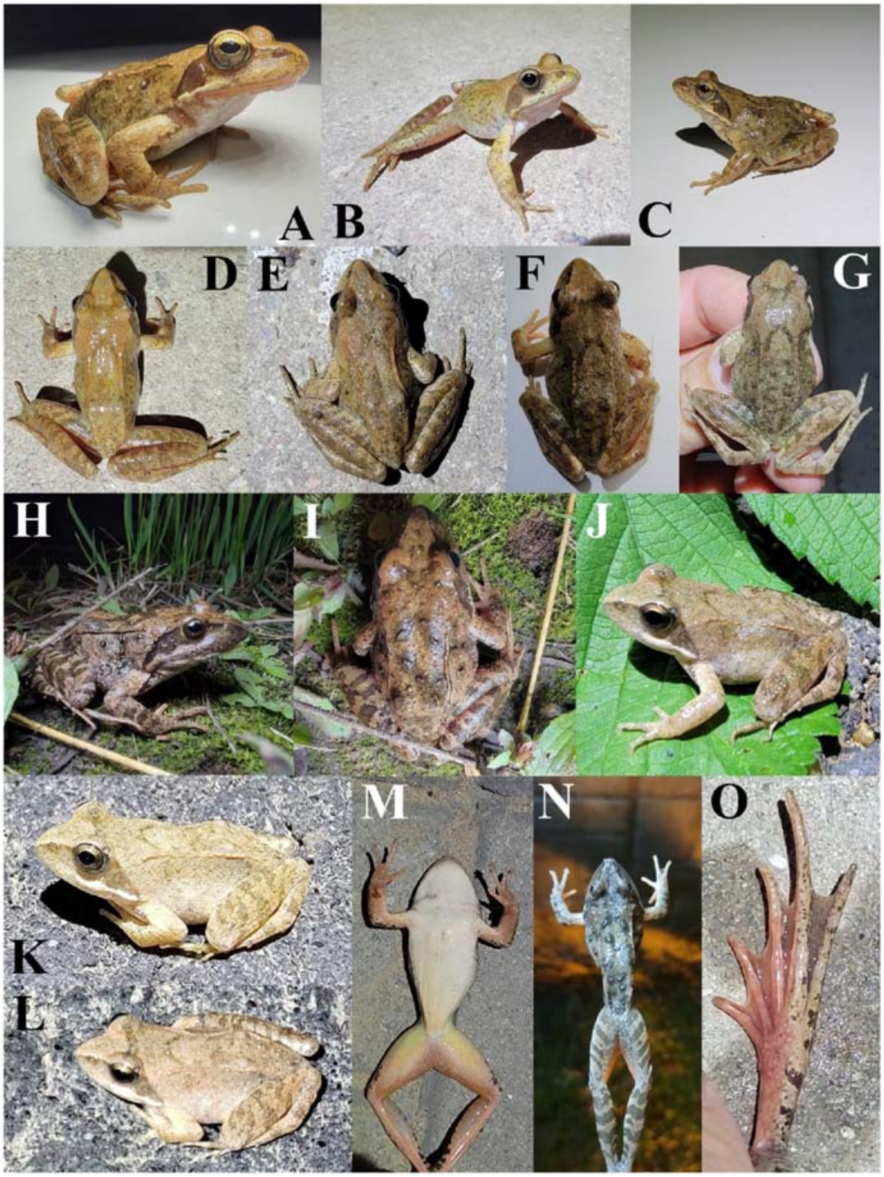

FIG. 6.16

Adult and juvenile *Rana taihangensis*. Adults are active from late winter, and migrate to and from the breeding sites before and after breeding (A—I). Juveniles can be found close to the breeding sites throughout summer (J—L). The species can be identified through several morphological cues, including the webbing of the hind toes (K).

From Amaël Borzée.

the upper limbs are blunt and round with visible palmar tubercles, while the tubercles are not as prominent and visible in *R. chensinensis*. Finally, *R. taihangensis* differs from *R. chensinensis* in having two versus four distinct nuptial pads (Shen et al., 2022). Due to the habitat where eggs are deposited, they are expected to be sticking to the substrate, similar to *R. huanrenensis*. The tooth formula of tadpoles of the southern clade is 3+3/1+1 (Shen et al., 2022) or 4+4/1+1 (Fei et al., 2009). No information is currently available about the vocalisations of the species.

6.1.7 *Rana huanrenensis*

6.1.7.1 Origin and distribution

The Huanren Brown Frog, *Rana huanrenensis*, was described from the eponymous city of Huanren in Liaoning, China (Liu et al., 1993), but mistakenly spelt 'huanrensis' in an earlier publication (Fei et al., 1990). Here I follow the spelling the authors wished to use and not the one used mistakenly before the intended description of the species, knowingly in disagreement with the Zoological code. The species split from the common ancestor or *R. chensinensis* and *R. kukunoris* about 3.3 million years ago (Zhou et al., 2017), and it is part of the *R. chensinensis* species complex.

Rana huanrenensis distributed from R Korea in the south, although its distribution excludes a part of southern Jeolla province and some of the islands surrounding the peninsula. It is present across the central areas of the peninsula, but it is not present in the northeast of DPR Korea (parts of South and North Hamgyong and Ryangang; Borzée et al., 2021c). The species occurs in China in southern Central Liaoning, from Shenyang and Baishan, around Huanren (Li et al., 2005a) and in the extreme south of Jilin (Lu et al., 2005, Fig. 6.17).

6.1.7.2 Habitat

The species is present from about sea level in the southern areas of the Korean Peninsula, ranging up to 1100 m in elevation (Andersen et al., 2022), but present in greater numbers at a few hundred metres above sea level, and it is among the species living at higher elevation in R Korea. In China, it occurs between 500 and 1000 m of elevation (Fei et al., 2012). The Huanren Brown Frog is mostly present along streams in areas surrounded by conifer, mixed and deciduous forests, including fast-flowing streams for its overwintering habitat and rocky pools disconnected from the steams, or at the edge of streams when the water speed is slow enough to breed. It is often found on the leaf litter outside of the breeding season, but adults can be found on the banks of water bodies and wetlands all year round, although rarely in areas where the habitat has been modified (Groffen et al., 2022).

6.1.7.3 Behavioural ecology

Adult *R. huanrenensis* can be found active from mid-January in southern Korea, but they generally emerge from hibernation from early March, and as late as

FIG. 6.17

Distribution of *Rana huanrenensis*, the Huanren Brown Frog.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

mid-April at higher latitudes and elevations. The species does not produce breeding choruses, but males aggregate and signal through both acoustic (through their larynx due to the absence of vocal sacs) and visual signals through hind-leg movements for mate attraction (Fig. 6.18). Spawning occurs between March and May (Groffen et al., 2022), and the eggs are deposited in sticky clutches on the substrate of generally slow-flowing streams and isolated stream pools at relatively high elevations in water between 50 and 70 cm deep (Ambu et al., 2022). The eggs take about ten days to a few weeks to hatch, and the tadpoles are found clustered at the edge of the water body where the water flow is lower and the temperature higher (Fig. 6.19). The tadpoles will metamorphose from mid-May to mid-June, and generally disperse along the stream once tail retention is finished. The male attendance to the breeding site is shorter than in the sympatric species, and similarly to other *Rana* species. Females do not stay at the breeding site after spawning, although adults of both sexes can be found foraging in the vicinity of the water body later in the season due to the proximity of breeding and overwintering sites. The species can be active until mid-December in southern Korea when the temperature is high enough (Groffen et al., 2022).

6.1.7.4 Threats and conservation

The species is listed as Least Concern by the IUCN Red List of Threatened Species (ASG, 2019b), despite a slow decline across the totality of its range. This decline is due to habitat loss and degradation resulting from the expansion of urban and agricultural areas, the loss of forested areas, harvests for human consumption for

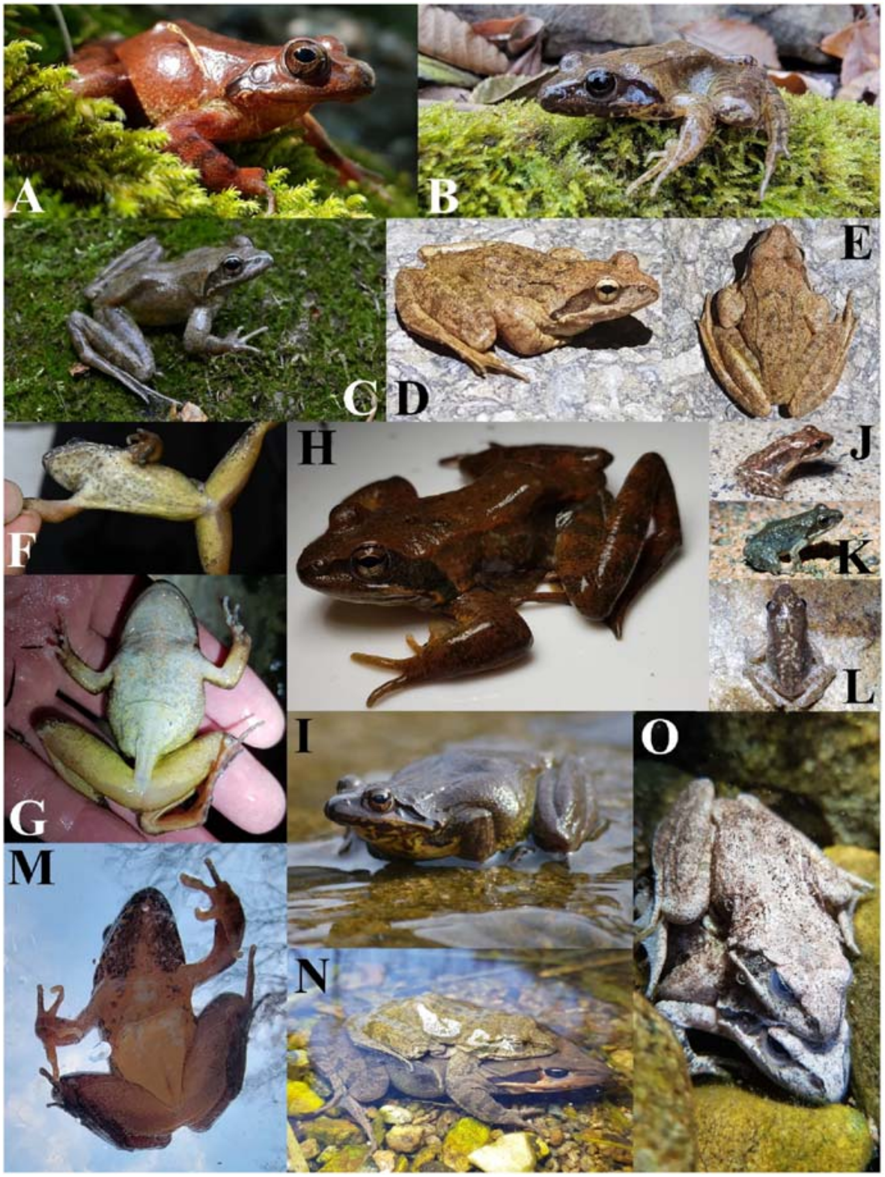

FIG. 6.18

Adult and juvenile *Rana huanrenensis*. The species is generally less variable and darker than the sympatric Rana species (A—F and H). The species can be identified through the species-specific ventral colouration during the breeding season (F, G and M) and juveniles can show reddish spots (J—L). The species overwinter underwater, and amplexus can last comparatively long (U—O).

From Amaël Borzée.

FIG. 6.19

Egg and tadpole *Rana huanrenensis*. The eggs are the only ones that stick to the substrate within the range of the species (A—D). Upon hatching the tadpoles stay within the egg mass until free swimming. The tadpoles are speckled with yellow, and adapted to slow flowing water (G—L).

From Amaël Borzée.

food and traditional medicine, water pollution and road kills (Shin et al., 2022). In addition, the species is traded under a different species identity, likely enhancing the risks due to overharvesting (Othman et al., 2022), and the risks resulting from the loss of genetic identity if the individuals sold in R Korea and originating from China escape and hybridise with the local clade (Borzée et al., 2023). Finally, climate change models for habitats suitable to the species predict a drastic decrease by 2030, 2050 and 2080 under different climate change scenarios (Kim et al., 2021).

In contrast, the species can cope with some degree of habitat changes (Groffen et al., 2022), and while knowing that some individuals have been found to be infected by the Chytrid fungus (Fong et al., 2015) the pathogen is not known to have a negative impact on the species. It also occurs in protected areas in all three range countries. However, due to the multiple ongoing pressures, additional knowledge on the speed of the decline may result in the species being listed as Near Threatened.

6.1.7.5 Identification

The eggs of the species, and egg clutches as a result, are the only ones among the sympatric *Rana* species to be sticky, and spawned affixed to the substrate, as an adaptation to flowing water. As a result, the species is the easiest to identify at the egg life stages, and when breeding as males do not call, and do not have air sacs (Yang et al., 2000b). In addition, the breeding colourations of the venters are clearly different from *R. uenoi* and *R. dybowskii*, the sympatric species with which confusion based on morphological identification is likely. Male *R. huanrenensis* have speckled yellowish-grey throats and venters, while it is milky white in male *R. uenoi* and *R. dybowskii.* Female *R. huanrenensis* have black speckled throats and chests and yellowish-green venters, while female *R. uenoi* and *R. dybowskii* have red throats and venters (see Kim et al., 2002 for additional illustrations). Outside of the breeding season, colourations are similar, and other characters are needed, such as the generally discontinued dorsolateral lines (see details in Borzée et al., 2023). It is interesting to note that the absence of an inverted V-shape is described as diagnostic for the species, despite the feature being present in all other species of the species complex. In addition, *R. huanrenensis* may show red non-tubercular glands on the back (Song et al., 2006; Wang et al., 2017a), visible an well-developed toe-webbing with a wide angle between the first and second toes and sub-articular tubercles visible on the toes (Othman et al., 2022; AmphibiaChina, 2022). They have front limbs of length similar to sympatric *Rana* species (Leung et al., 2021) but relatively shorter tibias femurs and feet than in species of the *R. dybowskii* complex (Yang et al., 2000b). Finally, the head morphology of the species is different, with the head generally longer than wide (Matsui et al., 1993), and the eye diameter is of size comparable with the inter-orbital distance (Matsui, 2014). The tadpoles' labial tooth row formula is: 4(2−4)/4[1] in R Korea (Park et al., 2009).

6.2 *Glandirana*

The genus *Glandirana* is nested within the Ranidae family, and restricted to East Asia, with the largest number of clades on the Japanese Archipelago, and it emerged about 30 million years ago (Chen et al., 2017). Three species are present on the mainland, with disconnected ranges. *Glandirana minima* in Fujian, *Glandirana tientaiensis* centred on Zhejiang and *Glandirana emeljanovi* on the Korean Peninsula and northeast China. The ecological requirements of these three species are greatly diverging due to their near-tropical to northern-temperate distributions.

6.2.1 *Glandirana emeljanovi*

6.2.1.1 *Origin and distribution*

The Wrinkled Frog, also called the Northeast China Rough-Skinned Frog or Imienpo Station Frog from Yimianpo, Shangzhi County, in Heilongjiang Province in China (Nikolskii, 1913), is closely related to *Glandirana rugosa* (Yang et al., 2000c). The common name of the species would benefit from being spelled following local spelling rules, and include the genus-specific common name, here suggesting Yimianpo Rough-Skinned Frog, to avoid colonial influence on spelling and limit regional political tensions (Frank and Ramus, 1995; Fei et al., 2009). Two clades are present within the Korean peninsula (Ogata et al., 2002; Eo et al., 2019; Kim, 2021), although none of them represents a distinct and named taxonomic lineage. The species ranges as far north as southern Heilongjiang (Fei et al., 2012), but it is unlikely to be present in Russia (Kuzmin and Maslova, 2003). The western boundary is in the coastal town of Dalian in Liaoning, and the species is common in DPR Korea (Borzee et al. Animals) and in R Korea, but it does not occur on Jeju Island (Yang et al., 2000a, Fig. 6.20).

6.2.1.2 *Habitat*

The species occurs over a broad range of habitats, including fast-flowing large rivers, estuaries with periodically brackish water (Pers. Com. Heo K), rice paddies, and small streams in forests. The species can therefore be found from sea level, until 1200 m of elevation with an average around 200 m of elevation (Andersen et al., 2022). While found on a broad range of landscapes, the species seems to be affected by anthropogenic changes to the landscapes as it is not present in as large numbers in the vicinity of urban areas, and when present closed to developed areas, it is in remnant forests and not in rivers or city parks.

6.2.1.3 *Behavioural ecology*

This species has a complex behavioural ecology in comparison with other species of the region. Females can spawn over a large time period, and they can be found in amplexus on the riverbeds from as early as late March (Fig. 6.21), spawning about 400 eggs in the vegetation (Fei et al., 2012). However, spawning has not been recorded before early May in R Korea (Groffen et al., 2022). The main spawning

FIG. 6.20

Distribution of *Glandirana emeljanovi*, the Yimianpo Rough-Skinned Frog. The type locality is among the northernmost sites where the species is known to occur.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

peak is in mid-June and the species can breed until late August (Groffen et al., 2022). Eggs that are spawned at the beginning of spring hatch within ten days, and tadpoles can go through metamorphosis by early August (Fig. 6.22). The young metamorphs will however be small, and comparatively disadvantaged for hibernation. The second and main development strategy is for hatchlings to grow slowly and spend the first winter underwater as tadpoles. They will then reach a comparatively large size (Kim et al., 2019). These tadpoles can metamorphose from April the following year if the weather is hot enough, and reach the same size as the individuals that had metamorphosed before winter by early summer. This dual strategy is beneficial in areas prone to droughts. Overwintering in adults is generally done at the bottom of water bodies, including slow-flowing reservoirs and large fast-flowing rivers, but individuals can be active in the habitat as late as mid-December and as early as mid-January when the temperature is high enough (Groffen et al., 2022). The species is mostly nocturnal (Fei et al., 2012), and spends the day in the same microhabitat as the one where it hibernates, i.e., generally under the substrate or rocks underwater.

6.2.1.4 Threats and conservation

Glandirana emeljanovi is currently listed as Least Concern on the IUCN Red List of Threatened Species, although its population size is decreasing (ASG, 2020a). As the species is characterised by a very large range, specific populations are affected by specific threats, although the main extinction risk comes from habitat changes,

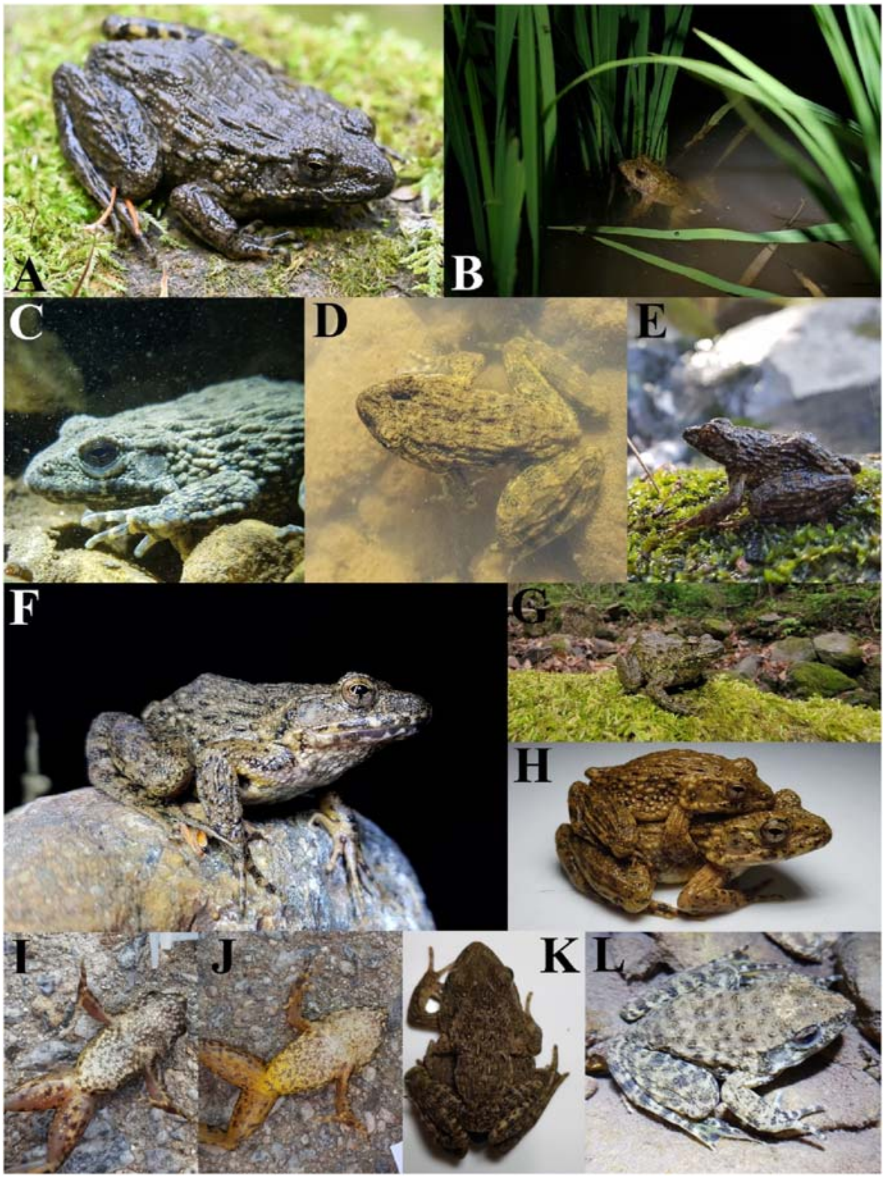

FIG. 6.21

Adult *Glandirana emeljanovi*. The species has a very distinct morphology with numerous glands (A—L). It spends a large amount of time underwater, from rice paddies to fast-flowing rivers, during but also outside of the breeding season (B—D and L). The ventral colourations (I and J) are species-specific and sexual dimorphism in size is important (H and K).

From Amaël Borzée.

FIG. 6.22

Egg and tadpole *Glandirana emeljanovi*. The eggs of the species are comparatively large, but there are not too many eggs in each egg mass (A—D). Tadpoles can overwinter, resulting in a large size at metamorphosis and they are the only native tadpoles found in winter within range (E—N).

From Amaël Borzée.

and the loss of adequate breeding and overwintering habitat. In addition, the species is listed within the top ten amphibian species impacted by roadkills in R Korea (Shin et al., 2022), and water pollution is a threat due to the species largely aquatic life. The species can be found in remnant forested landscapes within urbanised areas, but it is not found in water bodies in these landscapes as the species can only cope with some degree of habitat change (Groffen et al., 2022). *Glandirana emeljanovi* also occurs in agricultural wetlands throughout its range, and the conversion of rice paddies into dry crops or urban areas has resulted in the loss of suitable habitat. The population size of the species increased between 46,000 and 58,000 years ago (Kim, 2021), and in contrast climate change models predict a decrease of suitable habitat by 2030, 2050 and 2080 under different climate change scenarios (Kim et al., 2021), but in opposition to other amphibian species, the resulting salinisation of the landscapes may not be as much of a threat as the species has been recorded in weakly brackish waters in estuaries of R Korea. The species occurs in numerous protected areas in all three nations within its range. Finally, while some individuals have been found to be infected by the Chytrid fungus (Fong et al., 2015), the pathogen is not known to have a negative impact on the species.

6.2.1.5 Identification

The species is characterised by dorsal glands parallel to the snout-vent body axis, which are expected to help with oxygen intake when over-wintering underwater, a morphological feature that has given its name to the genus, *Glandirana*. It is the only species of the area with such glands, although *Pelophylax nigromaculatus* possess similar but thiner, shorter and less extensive structures. The species is generally brown, with yellow and speckled venters. When folded, the tarsal joint of the hind limbs extends to the eyes, and the species does not possess a subdigital tubercle (Fei et al., 2009). The species has several types of vocalisations, one repeated single note 'grrrrrr' for the mating calls, and one bird-like chirp sound used as a contact call, reminding of the mating calls of *Pelophylax chosenicus*. Tadpoles are generally easily identified as they typically show regular black spots on their back, they are the only tadpoles found in winter, and the largest tadpoles of the region, with the exception of the invasive *Lithobates catesbeianus*. The eggs are generally larger but less numerous than other Ranidae of the region. The tadpoles' labial tooth row formula is 1/3[1] (Park et al., 2009).

6.3 *Pelophylax*

The genus *Pelophylax* is widespread in Eurasia, likely originating from the western Palearctic, with the East Asian clades having diverged about 6.2 million years ago (Liu et al., 2010). The genus now shows an almost continuous distribution across the Palearctic as species are also found in the dry landscapes of central Asia. In northeast Asia, the two main clades, the *Pelophylax nigromaculatus* and *Pelophylax plancyi* complexes (following Liu et al., 2010), have diverged about 4.8 million years ago, but they have a history of hybridisation, with cytonuclear disequilibrium in numerous populations and even complete mitochondrial capture (Liu et al., 2010), likely in relation with glacial cycling (Komaki et al., 2015). The genus is widespread across landscapes as species have broad ecological requirements and some species are able to breed in most types of wetlands, despite a likely niche segregation between species complexes (Borzée et al., 2019). Recently, population expansions have been reported outward of all range boundaries, following natural or human-driven range extensions (e.g., Wang et al., 2016; Bae et al., 2022).

6.3.1 *Pelophylax nigromaculatus*

6.3.1.1 Origin and distribution

Pelophylax nigromaculatus, the Black-Spotted Pond Frog is found across a very large region of the eastern palearctic, with populations across the Japanese archipelago, as far north as northern Honshu, across the Korean peninsula and most of the related islands. It has also been introduced to Ulleung island between the Korean peninsula and Japan (Bae et al., 2022). The species ranges as far north as southern Khabarovsk Krai in Russia and Qiqihar in China, but its presence has not been confirmed in Mongolia. *Pelophylax nigromaculatus* is occurring in most of eastern and central China, as far west as Baoji in Shaanxi and the Sichuan Basin, and as far south as Guilin in Guangxi and northern Nanping in Fujian. Because the species is heavily traded for human consumption and mercy releases, many of the populations on the boundaries of the range are likely to be introduced, or escaped. This is for instance the case of the populations in Baiyin, Ningxia, in Yining, Xinjiang (Wang et al., 2016), Nyingchi and Lhasa in Tibet (Wang et al., 2017b), and maybe the one in Litang County in Sichuan (Fig. 6.23).

While all individuals within the *P. nigromaculatus* complex are currently assigned to a single species, two diverging clades have been identified (Zhang et al., 2008). The divergence started about 2.5 million years ago (Komaki et al., 2015), segregating the clade restricted to the west of the Yellow Sea in China with the one in northeast China, Russia, the Korean Peninsula and Japan. As the divergence is deep enough to suggest two segregated species, with different ecological requirements, further research is needed to clarify the taxonomic status of these clades. However, the name "*reinhardtii*" is already associated with the lineage east of the Yellow Sea (Peters, 1867) and the name "*nigromaculatus*" is associated with the lineage west of the Yellow Sea (Hallowell, 1861/1860). In addition, *P. nigromaculatus* populations heavily hybridise with species of the *P. plancyi* species complex, especially with *P. chosenicus* on the Korean Peninsula, and with *P. plancyi*, *P. hubeiensis* and *P. fukienensis* within their respective range in Eastern China (Liu et al., 2010; Komaki et al., 2015).

6.3.1.2 Habitat

On the Korean Peninsula, northeastern China and Russia, the species is associated with marshes and other lentic wetlands. In areas where rice agriculture is common

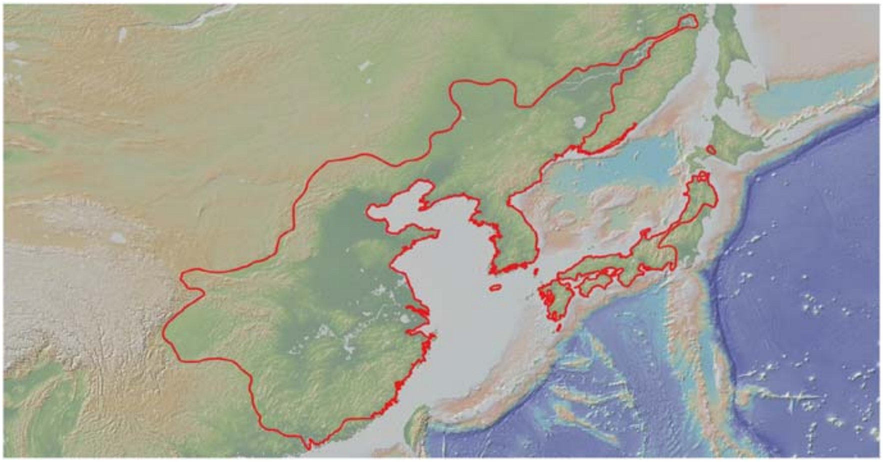

FIG. 6.23

Distribution of *Pelophylax nigromaculatus*, the Black-Spotted Pond Frog.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

within the range of the species, *P. nigromaculatus* also breeds in rice paddies, although their breeding season starts before the agricultural flooding in most southern regions, and the frogs start spawning in rain puddles that are later ploughed to prepare for rice plantation. The species is rare in large lakes but occurs in ponds, especially if there are no large fish and if floating vegetation is abundant. The species is found until a relatively high elevation, about 2200 m in China (noting a potential misidentification with *Pelophylax mongolius*; Fei et al., 2012) but only 1000 m in R Korea where the peak abundance is around 150 m of elevation (Andersen et al., 2022). The population west of the Yellow Sea is found in a broader diversity of habitats, including slow-flowing steams and small ponds and lakes. It is also found in semi-urban and urban areas, where the breeding season is elongated, likely due to the heat island effect.

6.3.1.3 Behavioural ecology

Male *P. nigromaculatus* start calling as early as early April in the southern regions of its range, both in China and R Korea, despite the temperature differences. The peak breeding season is however slightly different, with the number of calling males reaching a maximum in April southern China, early to mid-May in R Korea, and June in Russia, although the species can be heard calling until July in R Korea (Groffen et al., 2022). High temperature and relative humidity are the triggers for spawning in the species (Yoo and Jang, 2012). At the breeding sites, females are amplexed by males (Fig. 6.24) and lay all their eggs in a single egg mass (Fig. 6.25), typical of Ranidae, but with an egg size smaller than that of the *Rana* genus in general,

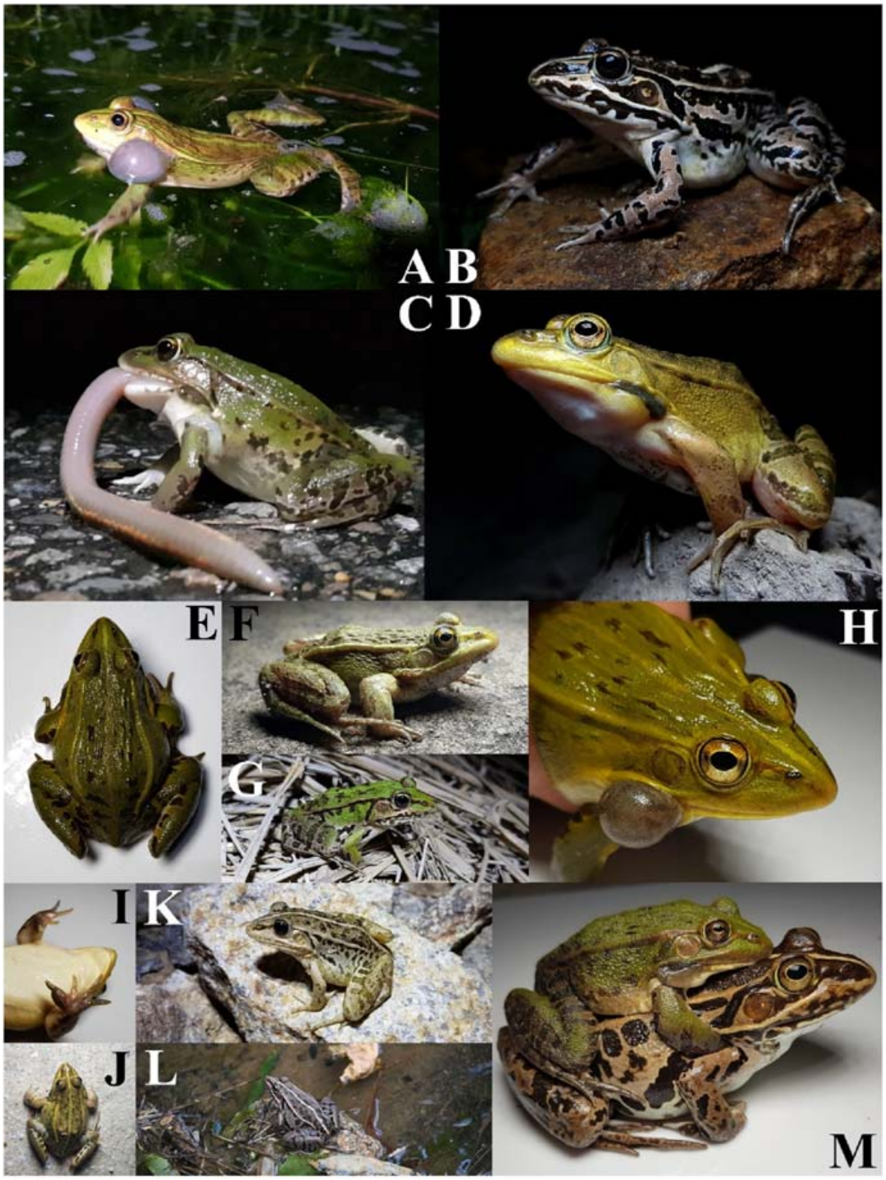

FIG. 6.24

Adult *Pelophylax nigromaculatus*. Males have clearly visible vocal sacs (A and H), also generally visible when they are not calling (D), and females can emit feable calls, with yet unknown functions, relatively similar to that of males even though they do not have vocal sacs. The species is quite variable in colours (A—M), but the ventral side is generally cream without speckles (I). *Pelophylax nigromaculatus* can feed on a wide variety of prey items, including some large-sized animals (C). Males are generally smaller than females (M).

From Amaël Borzée.

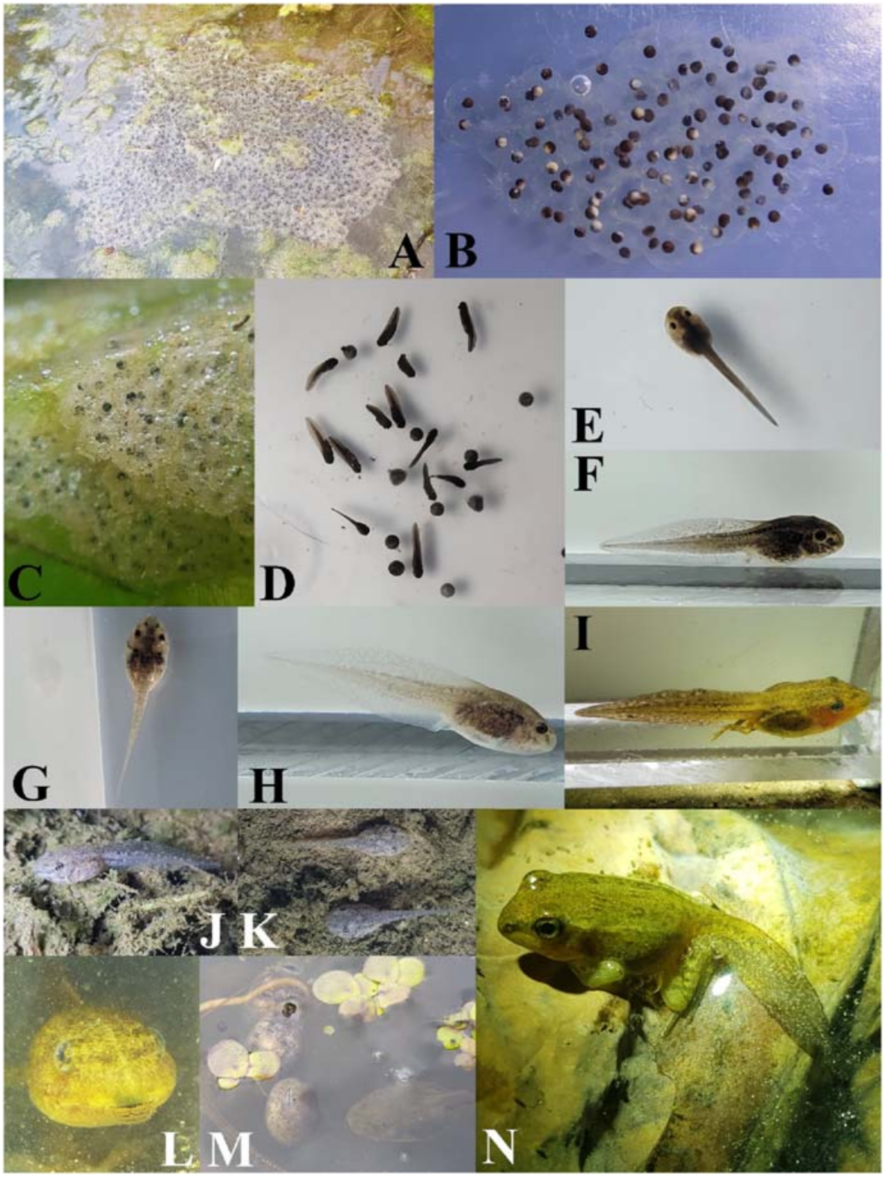

FIG. 6.25

Egg and tadpole *Pelophylax nigromaculatus*. Females lay eggs in large egg masses (A—C), and once hatched, the larvae leave the egg masses to finish their development on the substrate (D and E). Tadpoles of the species can be identified through the pale central dorsal stripe (I), and they live in large non-cohesive groups (F—M). Froglets can be active on the ground for short periods before tail retention (N).

From Amaël Borzée.

although a few 1000 eggs can be found in each egg clutch. Eggs take at least ten days but up to one month to hatch, and the tadpoles start feeding within a few days. Tadpoles can reach a few centimetres in length (Kim et al., 2019) and they will generally start metamorphosis about six weeks after the eggs have been laid, with variations due to environmental temperatures. Once metamorphosed, froglets will take three years to reach sexual maturity, and they will migrate yearly to forested areas for hibernation, generally avoiding coniferous forests. Hibernation is generally underground under the frost line, not in water, and it starts from October to November, until March to May, depending on latitude and temperature. The species may not rely on temperature to determine the onset of hibernation as it is consistently difficult to observe in winter (Groffen et al., 2022). *Pelophylax nigromaculatus* feeds on relatively large prey, including beetles with hard exoskeletons, but also on small amphibians and reptiles when available.

6.3.1.4 Threats and conservation

Pelophylax nigromaculatus is currently listed as Near Threatened by the IUCN Red List of Threatened Species, and it is declining globally (Kuzmin et al., 2004c). Threats are however geographically variable, and the species is stable in suitable habitats such as the agricultural wetlands of DPR Korea (Borzée et al., 2021c). While it is non-threatened in R Korea and China because of the large populations, and because it can cope with some weak habitat changes (Groffen et al., 2022), these still-large populations have declined in such a number that they warrant the species being listed as threatened globally. The main threat is habitat loss as the range of the species includes numerous large cities, with ever-expanding urban areas. In addition, natural wetlands have been transformed into agricultural wetlands over the last millennia, and the current shift away from rice agriculture is greatly impacting the species. Populations restricted to agricultural wetlands are impacted by agrochemical pollution, both in terms of tadpole development and loss of fitness (Huang et al., 2021) and in terms of gonadal development and feminisation of populations (Liu et al., 2017). Another noted threat is that of invasive species, with invasive fish preying on eggs (Fan et al., 2016) and adult *Lithobates catesbeianus* feeding on adults and juveniles (Groffen et al., 2019b). The species is also among the five species the most impacted by roadkills in R Korea (Shin et al., 2022).

In addition, due to its large size, the species is often the target of the trade for human consumption and mercy release. Human consumption is generally limited to the consumption of adult legs, although tadpoles are also sometimes cooked in broth or fried. Mercy releases pertain to traditions where animals are ‘released’ in return for favourable hospices. The ‘released’ species are most generally non-local species mass-produced or imported for this specific purpose. This is mostly affecting the ‘*reinhardtii*’ clade in China, and while source populations may see decreases in population size because of collection, the whole range of the species has expanded because of introductions, and for instance, frogs originating from Chongqing have been found in Xinjiang and Tibet (Wang et al., 2016, 2017b). It is also worth noting that climate change models predict a decrease of suitable habitat for the species in R Korea (Kim et al., 2021), and China (Duan et al., 2016). Finally, while some individuals have been found to be infected by the Chytrid fungus in R Korea (Fong et al., 2015), the pathogen is not known to have a negative impact on the species.

6.3.1.5 Identification

The body of adult individuals is characterised by linear dorsal glands, and most individuals have black stripes across their hind legs. The colouration is however very variable, with some individuals predominately green, and others black and white (Fig. 6.24). In opposition to individuals from the *P. plancyi* complex, the dorsolateral folds are not prominent and generally dark. Adult males have the characteristic, low frequency and repetitive call specific to the genus (graphic representation in Bae et al., 2022). When calling, a pair of lateral air sacs is clearly visible. The identification of tadpoles as belonging to *P. nigromaculatus*, in opposition to the *P. plancyi* complex is relatively easy for most individuals as they have a light-coloured central stripe on their dorsum, from the base of the tail to the centre of the head (Fig. 6.25). There is no known morphological difference between the "*reinhardtii*" and "*nigromaculatus*" clades. The tadpoles' labial tooth row formula is 2(2)/3[1] (Park et al., 2009).

6.3.2 *Pelophylax mongolius*

6.3.2.1 Origin and distribution

Pelophylax mongolius, the Yellow River Pond Frog ranges west of the Taihang Mountains, which create a boundary with *P. nigromaculatus* to the east. Here I do not recommend Mongolian Pond Frog as common name as the species is not found in current Mongolia. The species is distributed westward across Inner Mongolia, Ningxia, Shaanxi and eastern Gansu, with undefined clear boundaries likely reaching the feet of the mountainous plateau in Qinghai (Fig. 6.26). The clade was elevated to the species level in 2022, based on a holotype previously assigned to *P. nigromaculatus mongolia* (Schmidt, 1925), and synonymised with *Pelophylax tenggerensis* (Dufresnes and Litvinchuk, 2022; Zhou et al., 2022). The type locality is therefore in Meidaizhao in Inner Mongolia, and not Shapotou in Ningxia. The species diverged from the *P. nigromaculatus* complex a few million years ago (Dufresnes and Litvinchuk, 2022).

6.3.2.2 Habitat

The lowest elevations where *P. mongolius* is found is around 300 m above sea level, and likely up to 2200 m, based on earlier taxonomic definition (Fei et al., 2012). The species is associated with relatively dry habitat and occurs in disconnected subpopulations in adequate habitats, which include grasslands and forests around wetlands such as marshes, pools, oases, rivers and streams. It is the only species of the genus occurring in oases in this area, and it exploits waterbodies flowing generally faster than other *Pelophylax* of the region, diving when threatened, although breeding has been recorded so far in lentic habitat only.

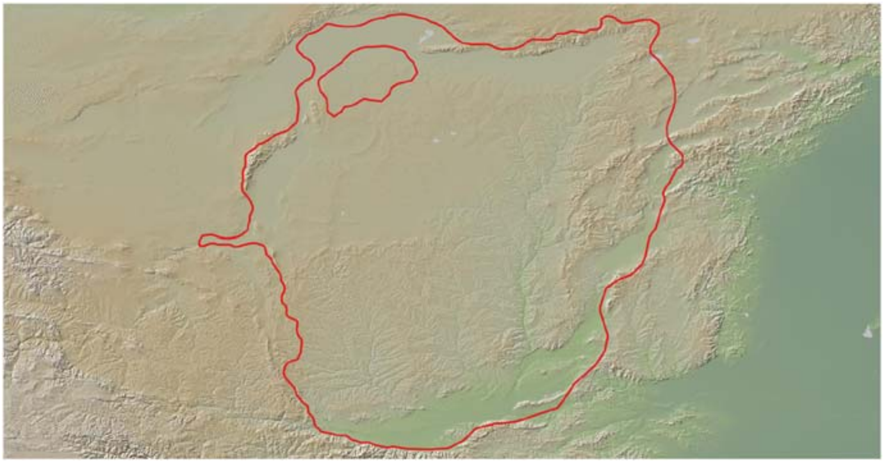

FIG. 6.26

Distribution of *Pelophylax mongolius*, the Yellow River Pond Frog.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

6.3.2.3 Behavioural ecology

The species emerges from hibernation in late April and males *P. mongolius* can be found calling from early May on warm days (Fig. 6.27). The peak breeding season is in June, although the species calls sporadically until mid-July. The egg masses are similar to that of *P. nigromaculatus* (Fig. 6.28), spawned in lentic water bodies, where males chorus and defend their calling microhabitat against competing conspecifics. Hatching takes one to two weeks, and tadpoles can finish their development and start metamorphosing by late June. Very little is known about the hibernation of the species, but it is likely to start in late October, when individuals move to underground shelters.

6.3.2.4 Threats and conservation

The species being named in 2022, it has not been assessed such as by the IUCN Red List of Threatened Species, but sections of the assessment for *P. tenggerensis* (IUCN SSC Amphibian Specialist Group, 2021b) are valid as the species are now merged, and sections for *P. nigromaculatus* are also valid as the distribution of *P. mongolius* was carved from its range (Kuzmin et al., 2004b). The species is stable in numbers, and its range is comparatively less impacted by human activities than that of conspecific species in the focal area, although the habitat of some populations is under threat because of desertification. In addition, *P. mongolius* is locally collected for human consumption, it is under threat of hybridisation with *P. nigromaculatus* through mercy releases, and climate change models predict a decrease of suitable habitat for the species, when analysed in

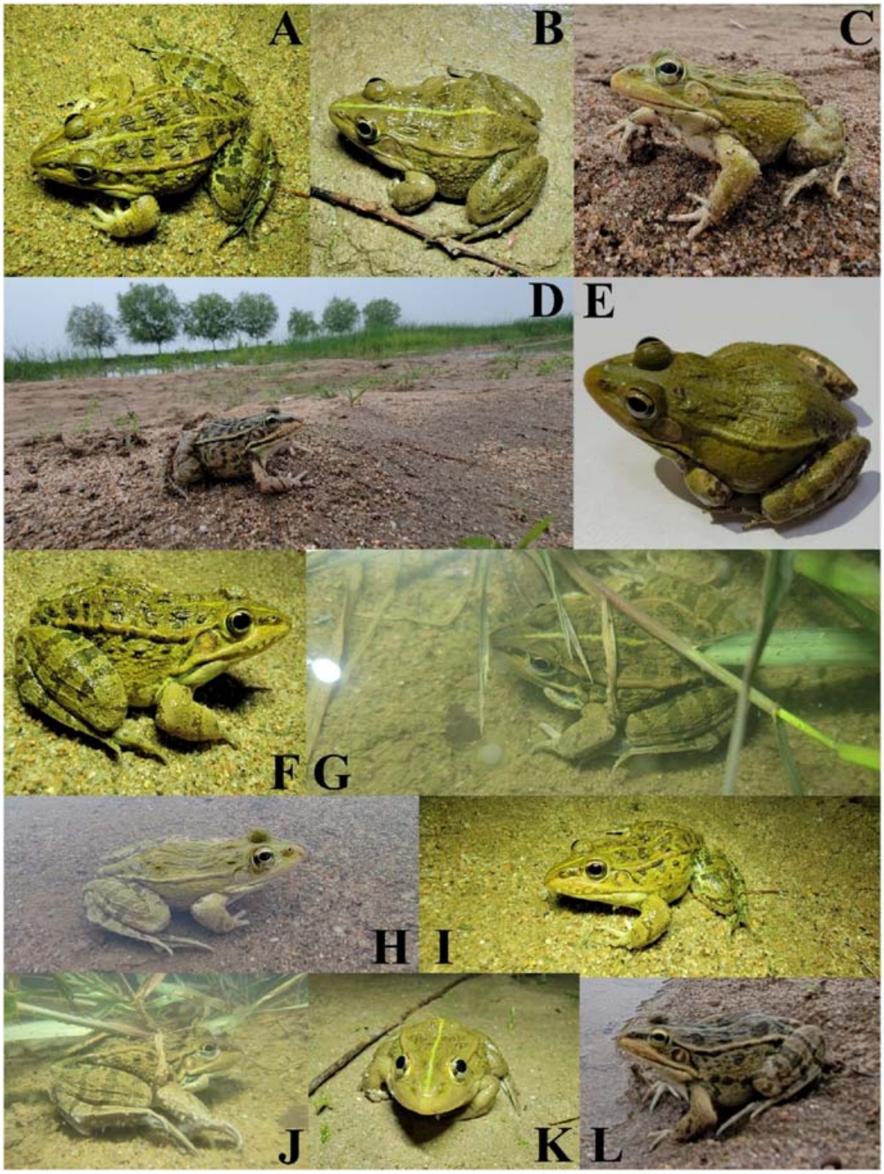

FIG. 6.27

Adult *Pelophylax mongolius*. Adults are restricted to wetlands within the range of the species, including slow flowing streams, and show a lower morphological variation than *P. nigromaculatus* and generally display a central dorsal stripe (A–L), of varying visibility (E).

From Amaël Borzée.

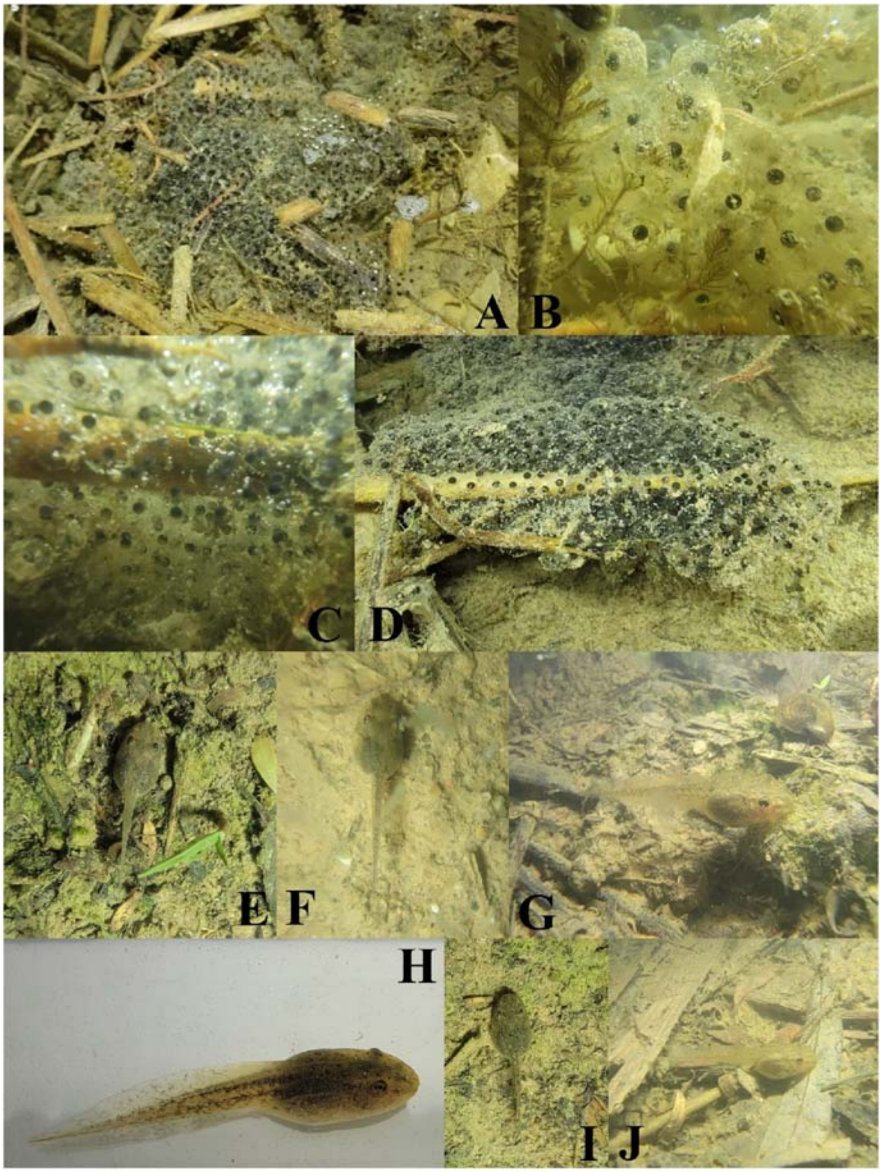

FIG. 6.28

Egg and tadpole *Pelophylax mongolius*. Eggs are spawned in large numbers in lentic water bodies (A—D), and tadpole development is temperature-dependent (E—I).

From Amaël Borzée.

combination with *P. nigromaculatus* (Duan et al., 2016). The species occurs in protected areas, including the one covering the type locality of *P. tenggerensis* before synonymy.

6.3.2.5 Identification

Pelophylax mongolius is so far considered the only species of the genus within its range, although areas of sympatry with *P. nigromaculatus* are expected in the valley around Xi'an. Adult *P. mongolius* can be identified through the combination of a few characters, including a head larger than long, nostrils closer to the eyes than to the edge of the snout, short hind limbs, and a species-specific toe formula representative or rudimentary webs (I 0- -1 II $^{1}/_{3}$ -1$^{1}/_{3}$ III $^{2}/_{3}$ -2- IV 2-$^{2}/_{3}$ V; Zhou et al., 2022). The species displays sexual dimorphisms, with females being larger than males, and males sporting large vocal sacs. As the western edge of the distribution of the species is unclear, morphological distinction with *Pelophylax persicus* is based on the dorsal glands, straight in *P. mongolius* but round in *P. persicus* (Safaei-Mahroo et al., 2023).

6.3.3 *Pelophylax chosenicus*

6.3.3.1 Origin and distribution

Pelophylax chosenicus, the Korean Golden Pond Frog, or Gold-Spotted Pond Frog, is closely related to *P. plancyi*. Although the time of divergence between the two clades is unresolved, it is likely to be relatively recent, similar to that of clades segregated by the Yellow Sea. The species is distributed along the western coast of the Korean Peninsula, and along the same coastline a few kilometres into China. A few inland populations have also been identified, especially in the southwest of R Korea (Fig. 6.29) and additional surveys may also reveal some inland populations in DPR Korea and China. The distribution starts from Gunsan and Jeonju in the south, noting an isolated population in Buan, and it is interrupted by low mountain ranges reaching the coastline such as the Chilgap hills, and in the Hwangae region in DPR Korea (Borzée et al., 2021c). The northernmost known population is in Liaoning in China (Zhou et al., 2022, 2023).

6.3.3.2 Habitat

Following the replacement of the natural habitat by agricultural wetlands on the Korean peninsula, the species became generally restricted to rice paddies, where it is still locally abundant. This association is however less strict than for species like *D. suweonensis* as the species is sometimes found in small and shallow ponds at low elevations (Ahn et al., 2021), especially if fishes are not present and both floating vegetation and reed beds are abundant. In addition, the species is restricted to relatively low elevations, starting from sea level and reaching about 500 m above sea level, with a mean elevation of around 200 m (Andersen et al., 2022). A difference in habitat with *P. nigromaculatus* is that *P. chosenicus* is generally occurring on the edges of the water bodies, or smaller and adjacent water bodies.

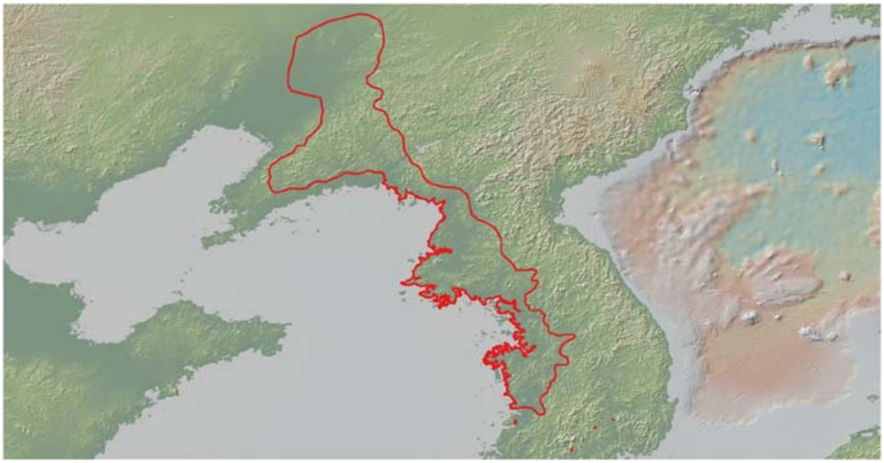

FIG. 6.29

Distribution of *Pelophylax chosenicus*, the Korean Golden Pond Frog, or Gold-Spotted Pond Frog.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

6.3.3.3 Behavioural ecology

The breeding season of the species starts in May, with males calling from water bodies, until late July if the water does not dry out (Groffen et al., 2022). The species has an extended repertoire of calls, generally thrill-like, with a relatively high diversity of notes, and a low note repetition in calls. Males occasionally defend their breeding range through calls, and by physically pushing other males (Fig. 6.30). Once amplexed, females lay a single egg mass of about 1000 eggs, generally similar to that of *P. nigromaculatus* in appearance, but smaller. Tadpole development is also generally around six weeks long, but temperature is important to slow or fasten development. Metamorphosis occurs along the bank of the rice paddies or other water bodies, with froglets moving out of the water body while their tail regresses (Fig. 6.31). Once metamorphosed, young individuals stay in the vicinity of the water body, and it takes about three years for individuals to reach sexual maturity. The species does not migrate away from the wetlands for overwintering, and individuals have a relatively small home range (Ra et al., 2008). They can be seen moving until mid-December, on warm days, but they are the latest amphibians to emerge from hibernation in R Korea, between late March and early April (Groffen et al., 2022).

6.3.3.4 Threats and conservation

The species is listed as Vulnerable by the IUCN Red List of Threatened Species, with a decreasing population trend (ASG, 2021a). The decline is expected to have reached 30% of the population size, mostly due to habitat loss and

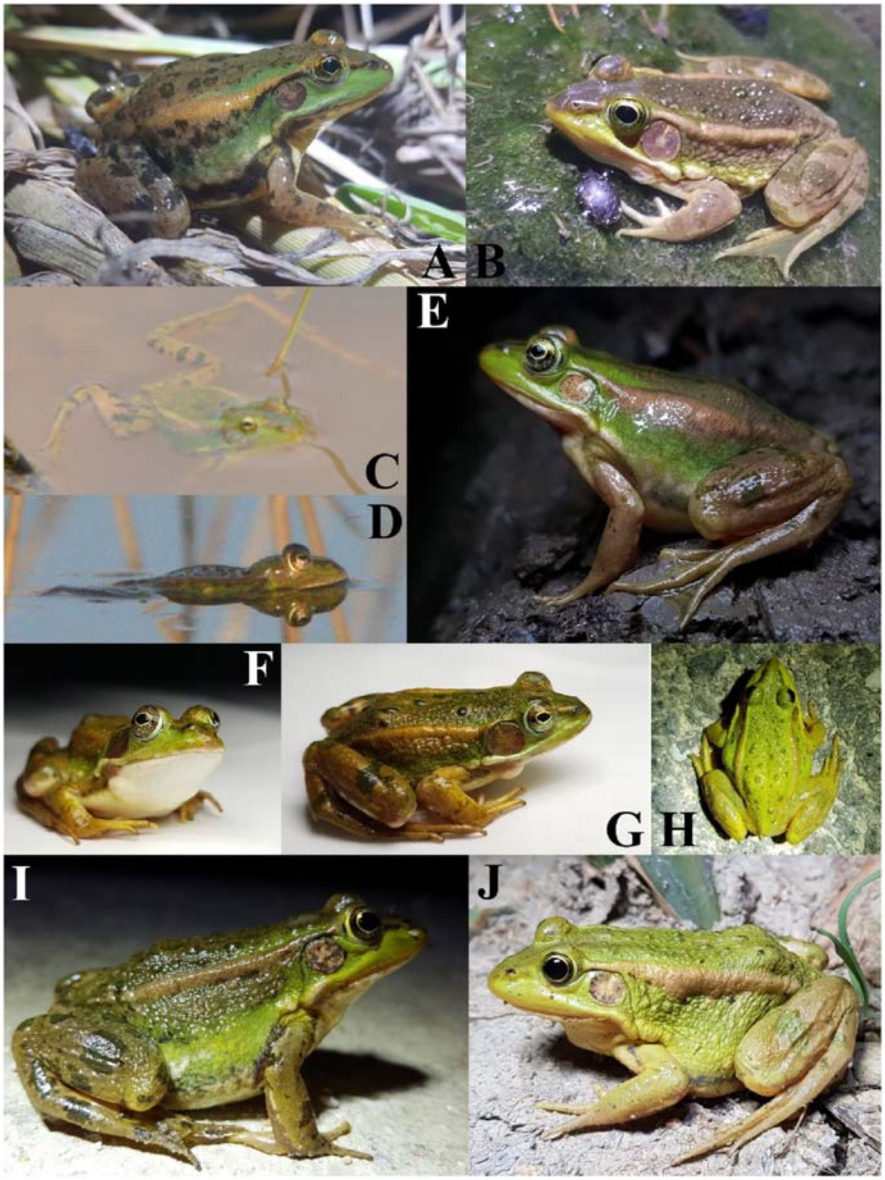

FIG. 6.30

Adult *Pelophylax chosenicus*. Males are characterised by the dorsolateral golden-coloured stripes and round dorsal glands (A—J) and they are among the latest ones to start calling in the season (D). A specificity of the species is that they do not have external vocal sacs (D).

From Amaël Borzée.

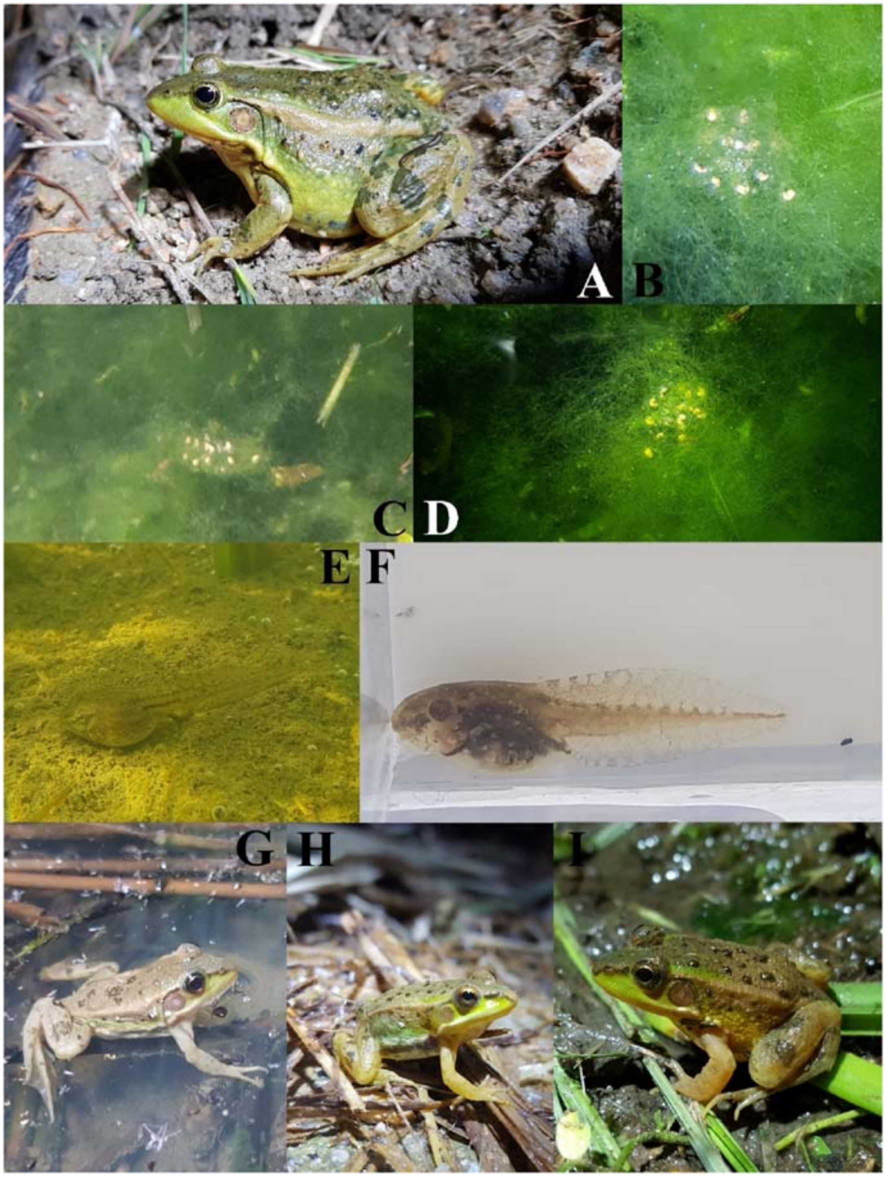

FIG. 6.31

Egg, tadpole, juvenile and adult female *Pelophylax chosenicus*. Females ready for oviposition show clearly visible budges in their abdomen (A). The eggs are spawned in small numbers in comparison to other *Pelophylax* species (B—D). Tadpoles can be identified at the species level in the later stage of development through the absence of the central dorsal stripe (E and F). Newly metamorphosed froglets show the dorsal glands specific to the species complex (G—I).

From Amaël Borzée.

degradation. In addition, the species has been extirpated from some sites in R Korea, and it is also declining in DPR Korea, including in North Pyongan province and Seoncheon because of droughts (Borzée et al., 2021c). The main threat to the species is habitat loss as most low-elevation wetlands have been converted to rice agriculture, which is now being transformed into dry agriculture or other production and cannot support the species. Populations that subsist in agricultural wetlands are impacted by agrochemical pollution, resulting in the decrease or even local extirpation of populations (Borzée et al., 2018). Populations in other types of wetlands are close to urban areas as prehistorical human ecological requirements resulted in the exploitation of habitats where amphibians were already present in large numbers, and non-agricultural sites are consistently being developed. The species cannot cope with extensive habitat changes (besides agricultural wetlands; Groffen et al., 2022), but it is only moderately affected by roadkills, being within the five species the least impacted by roadkills in R Korea (Shin et al., 2022). In addition, climate change models for the habitat suitable for the species predict a drastic decrease by 2030, 2050 and 2080 under different climate change scenarios (Kim et al., 2021). Climate change will also affect the timing of flooding of rice paddies where the species breeds. Some conservation efforts are however ongoing, with a translocation programme initiated by the National Institute of Ecology of Korea (Park et al., 2021), and conservation plans and recommendations available (Yoo et al., 2019), although it is currently too early to know if the translocations had a positive impact on the species. The range of this species overlaps with a few protected areas, although none is managed for wildlife, but to maintain water quality, and the species is listed as Endangered category II by the Ministry of the Environment of R Korea. Finally, some individuals were found to be infected by the Chytrid fungus (Fong et al., 2015), but the pathogen is not known to have a negative impact on the species.

6.3.3.5 Identification

The identification of the species in the field is relatively easy, despite the report of hybrids with *P. nigromaculatus*. Adults are characterised by prominent golden-coloured lateral lines, and round glands on their back, similar to *P. plancyi*. In comparison, *P. nigromaculatus* does not have prominent lateral stripes, but generally dark-coloured smooth stripes, and linear glands on its back. The main difference with *P. plancyi* is that male *P. chosenicus* generally have no external air sacs, with some exceptions possibly related to hybridisation with *P. nigromaculatus*. The mating calls of the species sound like that of small passerine birds, and the male-to-male contact calls are very specific chirps. No call property analyses have been conducted to determine the difference between *P. chosenicus* and *P. plancyi* so far. The tadpoles of the species are different from those of *P. nigromaculatus* in that they are characterised by the absence of a central dorsal stripe in the later development stages (Fig. 6.31). The tadpoles' labial tooth row formula is 1(1)/2 (Park et al., 2009), and the egg masses of *P. chosenicus* are generally smaller than that of *P. nigromaculatus*.

6.3.4 *Pelophylax plancyi*

6.3.4.1 Origin and distribution

Pelophylax plancyi, the Eastern Golden Pond Frog, is closely related to *P. chosenicus* (see section on *P. chosenicus*) but also to other species including *Pelophylax hubeiensis* to the east, and the morphologically similar *P. fukienensis* to the south. The segregation between *P. plancyi* and P *fukienensis* is more ancient than the one with other closely related species (Komaki et al., 2015), and noticeable variations in call properties and morphology clarify the segregation with *P. hubeiensis* (Mou and Zhao, 1992; Zhou et al., 2023). The species' distribution is centred around the low-elevation plains west of the Yellow Sea, where the density is the highest, although distributing as far south as Zhejiang and Jiangxi (where the type locality is located; Lataste, 1880) and to Hunan and Hubei to the west. The northern boundary in the distribution of the species is around Beijing, and it is also present in Hebei, east of Beijing (Fig. 6.32), although clear distribution boundaries and cryptic overlaps with *P. chosenicus* still need to be determined.

6.3.4.2 Habitat

Pelophylax plancyi distributes from sea level, occurring on reclaimed tidal flats in Jiangsu, up to a few hundred metres of altitude in the western areas of its range (Fei et al., 2009, 2012). At low elevation, the species is present in modified habitats

FIG. 6.32

Distribution of *Pelophylax plancyi*, the Eastern Golden Pond Frog.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

such as agricultural wetlands, as well as small ponds and lentic water bodies, with partial niche segregation with *P. nigromaculatus* (Borzée et al., 2019). When occurring in habitats that have been less damaged by human activities, the species can also occur at the edge of slow-flowing streams. The species is able to cope with a large amount of habitat degradation, and it is one of the few amphibian species also occurring at the heart of large urban areas, where it may have been translocated as part of mercy releases, and consequently the population is likely to be artificially maintained despite the absence of breeding events.

6.3.4.3 Behavioural ecology

Pelophylax plancyi emerges from hibernation from late March to early April in southern areas, and in May at the northern edge of its range. Males call from the water body, and defend a breeding range generally including submerged vegetation where the female will spawn after amplexus (Fig. 6.33). The vocal repertoire of the species is extensive, with males producing several types of calls to interact with other individuals, and females can also emit release calls. Males can vocalise until mid-October, although the mating calls are generally last heard in July. The egg mass is similar to that of other *Pelophylax* species, containing about 800 eggs, although smaller than that of *P. nigromaculatus* in terms of size and numbers, and slightly larger than that of *P. chosenicus* (Fig. 6.34). Tadpoles generally develop faster at lower latitudes due to the higher temperature, and development from hatching to metamorphosis can take up to eight weeks in the northernmost areas of its range. Young metamorphs do not disperse right away as they will hibernate in the area where they were spawned, and dispersion occurs over short distances. The hibernation period lasts from late October or November to April (Fei et al., 2012). It takes two to three years for an individual to reach sexual maturity and the species does not migrate between wetlands and wooded areas for hibernation, which starts from late October to late November depending on the latitude.

6.3.4.4 Threats and conservation

Similarly to other species distributed on the low-elevation plains around the Yellow Sea, the species is most threatened by habitat conversion and loss, although this species occurs over an area broad enough that it is listed as Least Concern by the IUCN Red List of Threatened Species, despite a decreasing population size (ASG, 2020b). The natural habitat of *P. plancyi* has been transformed, and while the species can adjust to substitute habitats in the form of rice paddies, the additional threats linked to agricultural practices (pollution, mechanised harvest, loss of hunting and resting habitat, canalisation …) do have a negative impact on the population dynamics of the species. As a result, despite being among the most numerous species occurring in rice paddies, the number of individuals has

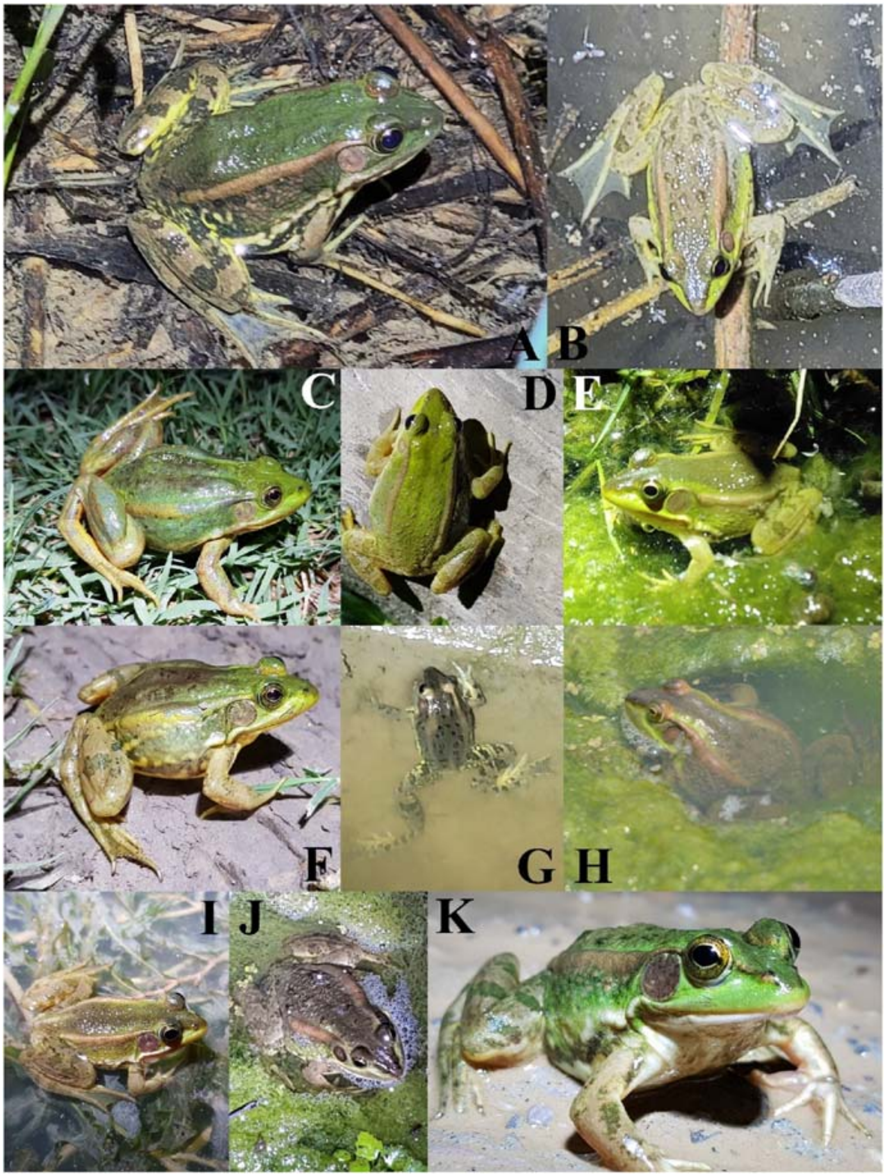

FIG. 6.33

Adult *Pelophylax plancyi*. Adults can be identified through the golden dorsolateral stripes and the round dorsal glands (A–K), a character shared within the species complex, although seemingly absent in this species in some defined geographic areas to the south and west (A and D). The species has small, but visible, vocal sacs (B, E and F).

From Amaël Borzée.

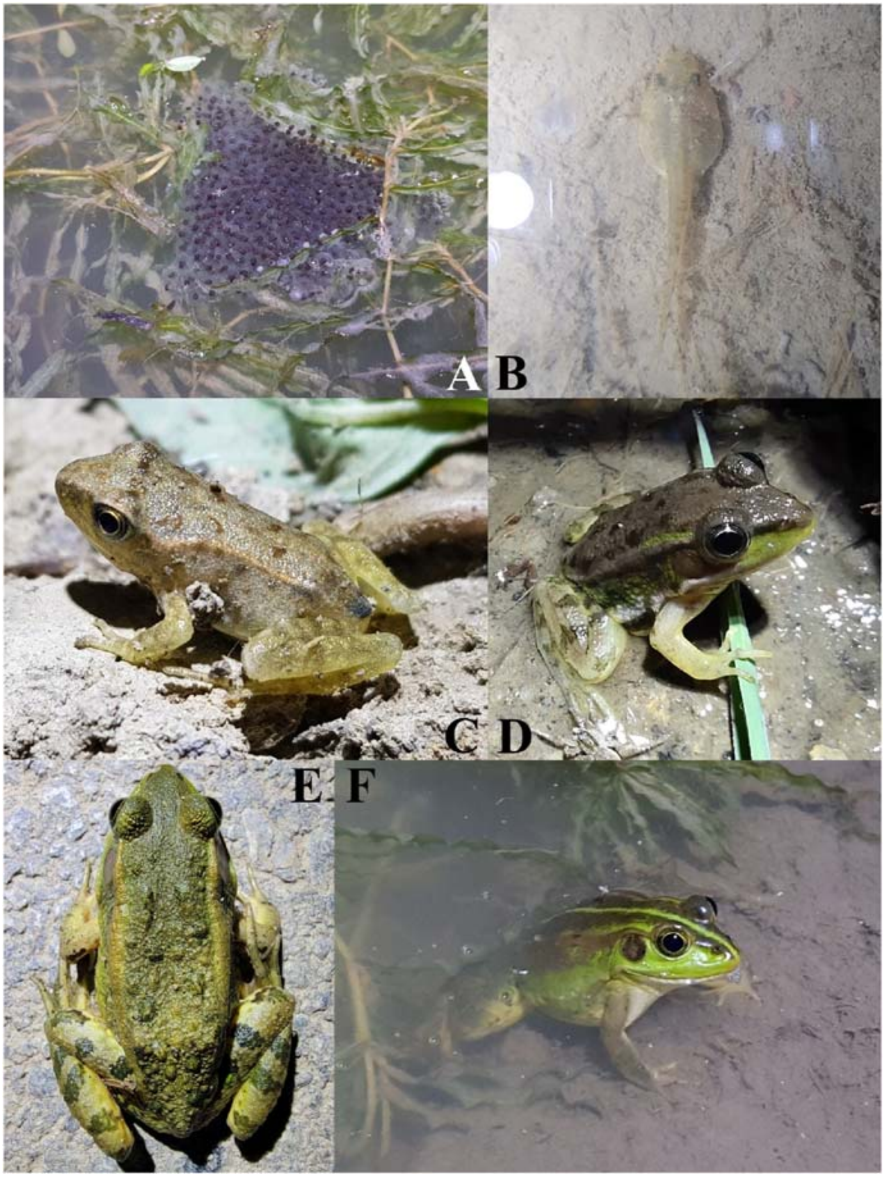

FIG. 6.34

Egg, tadpole and juvenile *Pelophylax plancyi*. Egg masses for the species are intermediate between that of *P. nigromaculatus* and *P. chosenicus* (A), and tadpoles can be identified at the species level by the absence of a dorsolateral stripe (B). Juveniles also have the round dorsal glands specific to the genus (C—E). Hybrid individuals with *P. nigromaculatus* can generally be identified through the presence of the specific dorsolateral stripes, but also a central stripe (F).

From Amaël Borzée.

significantly decreased and while an exact number is unlikely to be available, the population density is two to three times lower in agricultural wetlands than ponds. Climate change is also likely to impact the species' distribution and abundance at the southern edges of its range (Duan et al., 2016), and indirectly in agricultural habitats as it results in a shift in agricultural practices, and a shift in flooding regimes. Finally, the current changes in land use, away from rice agriculture, also result in the loss of substitute habitat used by the species, resulting in further decline in population size and range.

6.3.4.5 Identification

The identification of the species is similar to that of *P. chosenicus*, and similarly, the species hybridises with *P. nigromaculatus* and intermediate characters between the two species can be found. Adults are characterised by prominent golden-coloured lateral lines, and round glands on their back, similar to *P. plancyi*, but also to *P. fukienensis* and *P. hubeiensis* (Fei et al., 2012). The difference with *P. hubeiensis*, is in the length of the hindlimbs, reaching the tympanum in *P. hubeiensis* and the eye in *P. plancyi*. An additional difference in males is the presence of small but visible vocal sacs in *P. plancyi* but not in *P. hubeiensis* (they are internal), and the size of the tympanum, which is larger than the eyes in *P. hubeiensis* and smaller than the tympanum if *P. plancyi* (Fei and Ye, 1982). The species can be differentiated from *P. fukienensis* by a longer and higher metatarsal tubercle (Pope, 1929). The main difference with *P. chosenicus* is that male *P. plancyi* have clearly visible and extensive air sacs (Fei et al., 2009). In comparison, *P. nigromaculatus* does not have prominent dorso-lateral stripes, but generally dark-coloured smooth stripes, and linear glands on its back. Similarly to *P. chosenicus*, mating calls of the species sound like that of small passerine birds but differences between the two studies have not been studied, and the males can vocalise contact calls. The tadpoles of the species are different from that of *P. nigromaculatus* in that they are characterised by the absence of a central dorsal stripe (*P. plancyi* plate 1), but no morphological differences are known with the tadpoles of *P. fukienensis, P. hubeiensis* and *P. chosenicus*.

6.4 *Lithobates*

6.4.1 *Lithobates catesbeianus*

6.4.1.1 Origin and distribution

Lithobates catesbeianus, the American Bullfrog, was first introduced in R Korea in 1959, although the species became established in the 1970s. The population increased since then, with some successful population control methods in the late

2000s that were later abandoned (Groffen et al., 2019b). The species was introduced in China for human consumption, and the population in the wild is currently reinforced by escaped individuals from farms. The species is so far not found in all of the focal countries. In R Korea, *L. catesbeianus* occurs in the southern and western coastal areas, including islands, and in China it is present in numerous places across Jiangsu, Anhui, Henan and Hebei. Mongolia and Russia may be too cold for the species to be able to breed (Andersen et al., 2021), and for now it has not established populations in these countries. It is worth noting the disagreements regarding the taxonomy of the species, generally listed as *L. catesbeianus*, but described as *Rana catesbeiana* and sometimes referred to with this epithet, and more recently re-assigned to *Aquarana catesbeiana* (Dubois et al., 2021).

6.4.1.2 Habitat

The species is present until about 1000 m of elevation in R. Korea (Andersen et al., 2022), and regionally, it is present in lowlands, especially when there are numerous large canals connecting water bodies. The species breeds and disperses through these canals.

6.4.1.3 Behavioural ecology

The peak breeding activity of the species is June and July, when males can be heard calling (Fig. 6.35; Groffen et al., 2022). Once spawned, tadpoles will spend the first winter in the water, before dispersing during warm rainy nights (Fig. 6.36).

6.4.1.4 Threats and conservation

The species has a demonstrated negative impact on local species (Groffen et al., 2019b), through predation and competition. Specifically, it creates conservation risks for *P. nigromaculatus*, *P. chosenicus*, *D. suweonensis* and *D. flaviventris* in R Korea. In addition, the presence of *L. catesbeianus* is linked to the presence of the Chytrid fungus (Borzée et al., 2017), Saprolegniasis and Chromomycosis (Kim et al., 2008), and Ranavirus (Kwon et al., 2017).

6.4.1.5 Identification

The species is the largest one within the region of interest, superficially similar to *P. nigromaculatus* but different in the absence of clear coloured patterns. The calls are similar to the vocalisation of cattle, and the tadpoles are also visibly larger than that of other species, swimming in open water, with spotted dorsum superficially similar to that of *G. emeljanovi*, and a labial tooth row formula such as 3(2-3)/3 [1] (Park et al., 2009).

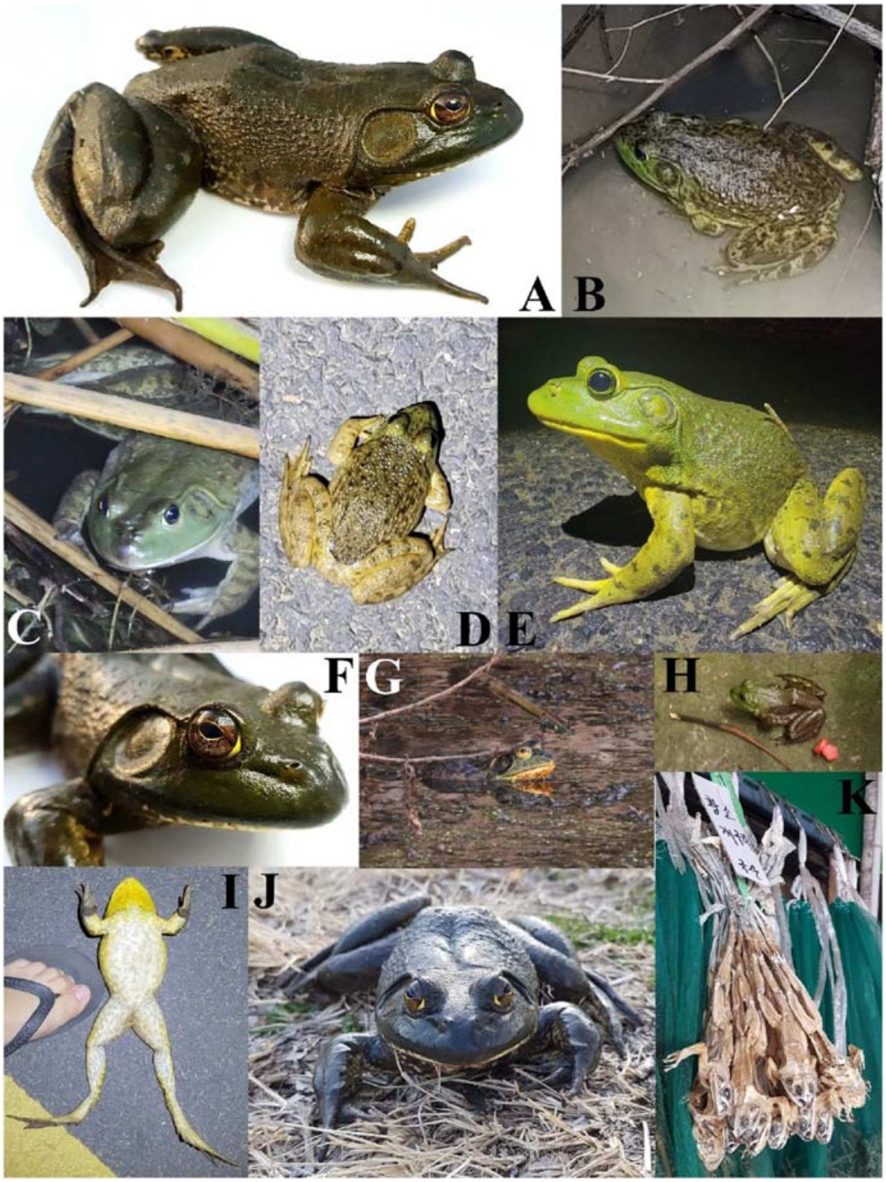

FIG. 6.35

Adult *Lithobates catesbeianus*. The species is active from late May, a bit later than other species in the region, and it is morphologically clearly different from all local species (A—J), through the dorsum colouration (A, B, D and H), the large tympanum (A, B and F), the ventral colour (I), and the large size (toes for scale; I). The species has replaced other local species in some of the traditional medicine systems, hopefully decreasing the harvest pressure on native and threatened species.

From Amaël Borzée.

FIG. 6.36

Egg and tadpole *Lithobates catesbeianus*. Eggs are tiny but incredibly numerous (A—D), although tadpoles reach very large sizes (E and G) while overwintering (F) prior to metamorphosis. The tadpoles can be misidentified with *G. emeljanovi* tadpoles during the first weeks of development (G—J). Tail retention during metamorphosis can take several weeks and individuals can move for extended periods on grounds (J). The species takes two to three years to reach sexual maturity (M).

From Amaël Borzée.

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CHAPTER

7

Dicroglossidae (*Fejervarya*)

The Dicroglossidae family diverged about 63.18 million years ago (Chen et al., 2017). In northeast Asia, it includes the *Fejervarya* and *Hoplobatrachus* genera, a clade about 54 million years old (Chen et al., 2017), although only a single species of *Fejervarya* spp. ranges far enough northwards to be included in this chapter. In East Asia, the other Dicroglossid frogs include the *Limnonectes* genus (Sanchez et al., 2018).

7.1 *Fejervarya*

The *Fejervarya* genus is about 40 million years old (Chen et al., 2017) and it is characterised by the presence of 'fejervaryan lines' on the venter of individuals (Sanchez et al., 2018). Importantly, the taxonomy of *Fejervarya* in East Asia is complicated and not fully resolved (Huang and Tu, 2016), with the names *Fejervarya multistriata* and *Fejervarya limnocharis* still used for Chinese populations of the genus, in agreement with the original range description of the species from Japan to India (Dubois and Ohler, 2000). This confusion is made despite the understanding that *F. limnocharis* is now restricted to southeast Asia, although with unclear species boundaries following diverging taxonomic accounts (Dinesh et al., 2015), and unclear geographic boudaries as *F. limnocharis* (Wiegmann, 1834) is expected to range from Myanmar (Zug and Mulcahy, 2020), and Mizoram and Manipur in India (Decemson et al., 2021), until southern China but does not reach the plains of the Yangtze river (Zhong et al., 2008; Yang et al., 2022). This genus is divided into multiple subclades with candidate species (Kotaki et al., 2010; Yang et al., 2022), and therefore, this chapter focuses on *Fejervarya kawamurai*.

7.1.1 *Fejervarya kawamurai*

7.1.1.1 *Origin and distribution*

The Rice Paddy Frog, *F. kawamurai*, ranges across the Japanese Archipelago and 'southern' continental northeast Asia, as defined here. The type locality of the species is in Hiroshima, Japan (Djong et al., 2011). The species diverged from a common ancestor in southern China about 5.8 million years ago and dispersed north (Yang et al., 2018). Later on, a subclade including Japan, the Zhoushan Archipelago, and some coastal regions in eastern and southern China diverged between 2.2 and

Continental Northeast Asian Amphibians. https://doi.org/10.1016/B978-0-323-91857-2.00010-5

FIG. 7.1

Distribution of *Fejervarya kawamurai*, the Rice Paddy Frog.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

1.8 million years ago (Yang et al., 2018), a divergence deep enough to consider the sister clade distributed in central and eastern coastal China (and two of the islands in the Zhoushan Archipelago) a candidate species (Yang et al., 2022). As currently understood, *F. kawamurai* is present in northern Taiwan Island and parts of the Japanese Archipelago (Zhong et al., 2008), and also the Yangtze River Basin, although it is not restricted to the basin and it occurs further south (Fig. 7.1; Djong et al., 2011).

For continental Asia specifically, the species ranges from northern Guangdong and Guangxi, it is present in eastern Guizhou and Sichuan, restricted north in the west by the Zhongnan Mountains part of the Qin Massif at Xi'an's latitude, reaching north-eastwards south of the Taihang Mountain Range, and northeastward to northern Hebei.

7.1.1.2 Habitat

This species is restricted to at least 2000 m in elevation, and it occurs in a wide range of habitats, from low plains at sea level (but not in saline environments) until high hills and low mountains (Fei et al., 2012). *Fejervarya kawamurai* breeds in a wide range of habitats, generally lentic, including marshes, ponds, small lakes, and associated waterways such as ditches, but also in modified habitats including garden pools and rice paddies, although it is not restricted to agricultural wetlands similarly to other species breeding in this type of landscapes. Outside of the breeding season, the species also tolerates a broad range of habitats, including heavily modified landscapes, and it can be found in parks at the heart of cities. The natural habitat of the species includes most open habitats with wetlands, such as river floodplains, marshes, and the edge of densely forested areas.

7.1.1.3 Behavioural ecology

The species emerges from overwintering between late January and early April, based on the latitude, and males congregate around and within shallow water bodies to call to attract females. They can modulate the frequency of their call to match the background noise of the environment (Lin et al., 2020). The breeding season is however the longest for the species of the region, with males found active at a breeding site from late March to mid-August at mid-latitude in Nanjing. It is interesting to note that some males can be calling until late September in urban settings. Females' attendance to the breeding sites is however more restricted and the spawning peak is between April and June, depending on the latitude (Fig. 7.2). The eggs of the species are especially small, with about 1000 eggs in each clutch, and the number being correlated with the size of the female (Fei et al., 2012). Eggs are laid in very shallow water, and take about a week to hatch, followed by about a month of development as tadpoles before metamorphosis (Fig. 7.3). The froglets will stay in the vicinity of the breeding pond until they are able to disperse before overwintering. Hibernation is reported to be under shelters, and males can call the following breeding season.

7.1.1.4 Threats and conservation

The species' assessment on the IUCN Red List of Threatened Species is not completed, and due to the taxonomic updates *F. kawamurai* is not listed, but *F. multistriata* includes some of the populations and it is listed as Data Deficient (Ohler, 2004). As a segment of the range was assessed under the name *F. limnocharis* (van Dijk et al., 2004), and despite the very large decrease in range size, the species is most likely to be listed as Least Concern as it has a broad distribution, it is present in a large number of habitats, including rice paddies, and the population size and density are comparatively high. The species is listed as harvested for human consumption (van Dijk et al., 2004), which is locally correct, but generally may result from misidentifications of *Hoplobatrachus* (or *Pelophylax*) due to similar morphologies, and because *Hoplobatrachus chinensis* is farmed. The small size of *Fejervarya* does not make them the primary target for human consumption in continental northeast Asia. Finally, the species can cope with modern rice agriculture practices, likely through its high fecundity and yearly recruitment (Izza et al., 2019).

Despite population expansion on exposed continental shelves over the last thousands of years (Yang et al., 2022), its large population size and likely stable population trend, the species is impacted by several threats. For instance, climate change is likely impacting its distribution and abundance at the southern edge of its range (Duan et al., 2016), and similarly, human activities resulting in the drainage of wetlands for urban expansion are locally impacting the presence of the species. The main threat to the species may be the use of agrochemicals as it is sensitive to the most commonly used pesticide (Dichlorvos) and herbicides (Butachlor) in

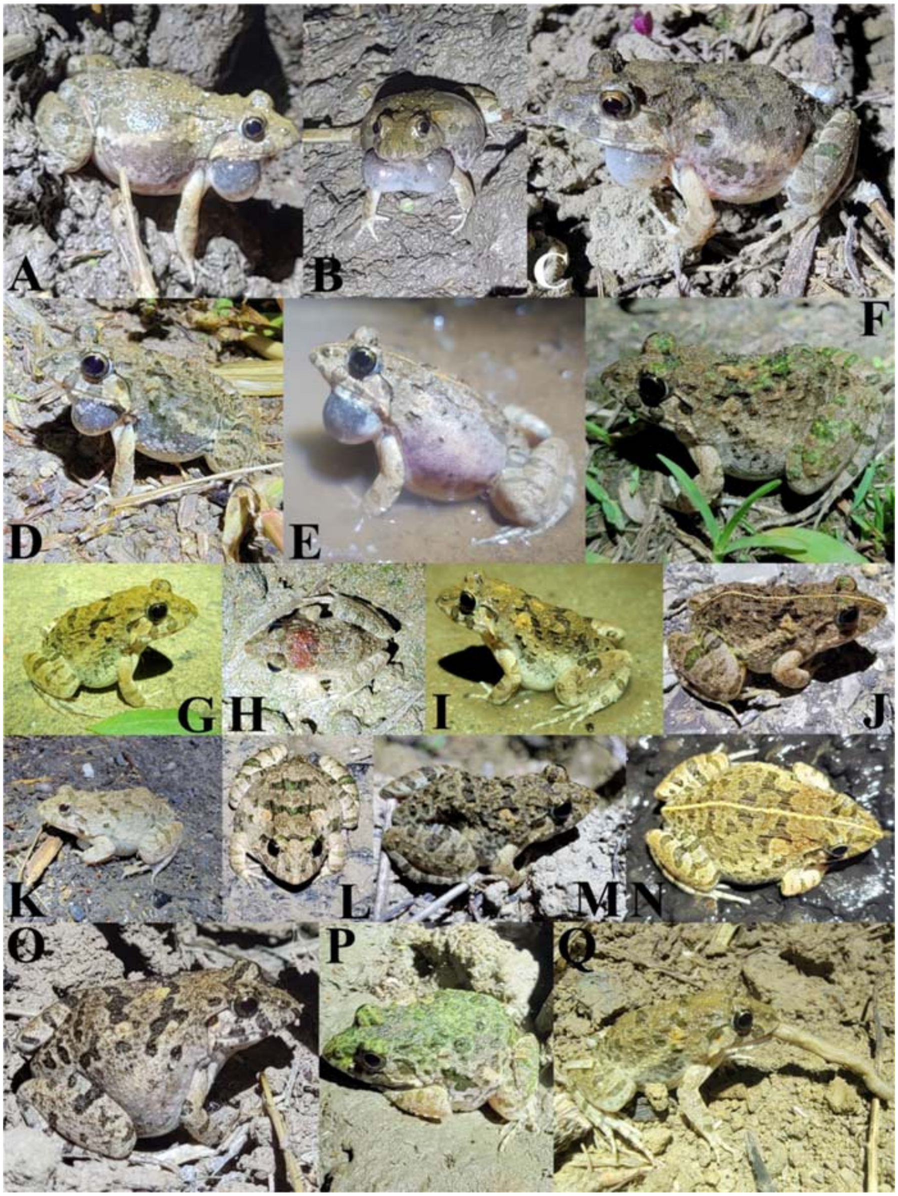

FIG. 7.2

Adult *Fejervarya kawamurai*. The vocal sac of the species is clearly split into two (A—E). The species is incredibly variable in morhology, colours, patterns, and shape (F—P), likley attributable to the absence of known morpholofical characters to discriminate between clades. The species can eat very large prey items (Q).

From Amaël Borzée.

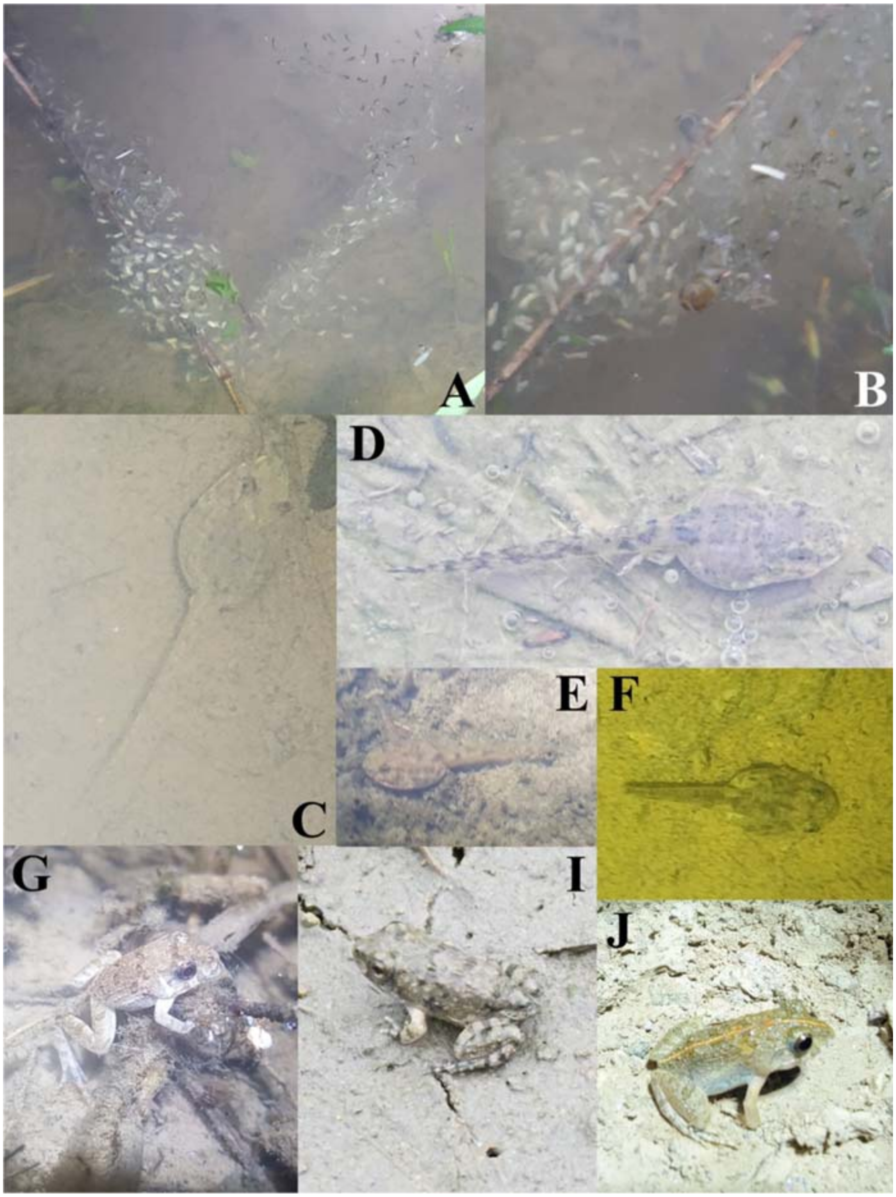

FIG. 7.3

Eggs, tadpoles and juveniles of *Fejervarya kawamurai.* The species lays eggs over an extended time period, and embryos are paler than that of other species in the region (A and B). Tadpoles can be identified through the alternated clear and dark patterns on the upper lips (C—F), which is maintained in juveniles and adults (G—J).

From Amaël Borzée.

China, and it is active when they are used (Geng et al., 2005). In addition, both malathion and carbaryl are pesticides frequently used in rice paddies, impacting the species by eliminating its food source, and being toxic to tadpoles. These chemicals impact survival during development and at metamorphosis, especially when used at the same time, such as in agricultural landscapes (Nataraj and Krishnamurthy, 2020). Specifically, butachlor affects the survival and development of tadpoles, even when found in concentrations below the recommended application rate (Liu et al., 2011). In addition, the species is sensitive to introduced western mosquitofish (*Gambusia affinis*; Fan and Lin, 2017). Finally, *F. kawamurai* has tested positive for the Chytrid fungus, but it is not known to have a negative impact (Bai et al., 2012).

7.1.1.5 Identification

Due to the multiple taxonomic changes related to the identity of the species, there is currently no published morphological identification key for *F. kawamurai*. Adults of the genus can be easily identified through their small size, and the Fejervaryan lines. In the south, *F. kawamurai* is likely in contact with *F. multistriata*, and morphological characters distinguishing the two species have not been studied. A key character, maybe shared with *F. multistriata*, is the almost total absence of marginal membrane on the fifth toe (Fei et al., 2009).

The calls of the species are highly variable, both in the number of notes and frequency (Lin et al., 2020), but they are distinct from that of other sympatric amphibians, except when overlapping with other *Fejervarya* species. The tadpole tooth formula of *F. kawamurai* at the type locality is (2)/3 or 2(2)/3(1), but differences with the mainland clade are not explicit.

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CHAPTER

8

Hynobiidae (*Onychodactylus*, *Salamandrella* and *Hynobius*)

The families Hynobiidae and Cryptobranchidae diverged from the other extant salamanders about 180 to 157 million years ago (Chen et al., 2015; Shen et al., 2016), and the divergence within Hynobiidae started in current northern China during the Cretaceous, with *Onychodactylus*, the most basal clade, diverging around 135 million years ago (Chen et al., 2015). The family was distributed in Eurasia before becoming restricted to Asia (Venczel, 1999a, 1999b). The sister clade to *Onychodactylus* diverged again during the tertiary (about 40 million years ago), with the split of *Ranodon*, *Paradactylodon* and *Pachyhynobius* from other younger Hynobiidae lineages around 60 million years ago (Malyarchuk et al., 2018), followed by the divergence of *Salamandrella* about 55 million years ago (Malyarchuk et al., 2018), and the younger divergence of the clade including *Hynobius*, *Liua*, *Batrachuperus* and *Pseudohynobius* about 50 million years ago (Malyarchuk et al., 2018). The Qinghai-Tibet Plateau orogenesis resulted in the emergence of the eastern *Batrachuperus*, and eastern *Liua* and *Pseudohynobius* (Chen et al., 2015) about 35 million years ago (Malyarchuk et al., 2018). In continental northeast Asia, The Korean Peninsula provided several refugia for *Hynobius, Onychodactylus* (Jeon et al., 2021) and *Salamandrella* (Poyarkov and Kuzmin, 2008) during the ice ages. The family is characterised by external fertilisation, the oviposition of two egg sacs, and the generally aquatic development of the larvae. All species have vomeral teeth, and lungs, except *Onychodactylus* species.

8.1 *Onychodactylus*

The *Onychodactylus* genus is the most basal genus of the family, having diverged around 135 million years ago (Chen et al., 2015). It is composed of two main clades, one including *O. fischeri* only, and the other one composed of two subgroups, one including *O. zhangyapingi* and the Japanese species, and the other one including all other continental Asian species (Poyarkov et al., 2012; Suk et al., 2017). The genus is found in comparatively cooler areas, at higher elevations in the southern parts of the genus' range, or at lower elevations at high latitudes. The genus is lungless, long-lived, with aquatic larval development lasting several years. All species in

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the genus have smooth skin and a long slender body with a long tail when adult. The tail is longer in males in the genus (Poyarkov et al., 2012). The name of the genus comes from the keratinised black claw used to hold to the substrate in fast-flowing water, and maybe to climb for overground migration in adults. The genus was harvested for food and medicinal purposes in part of its range (Poyarkov et al., 2012), and it still is harvested in some uncommon instances.

8.1.1 *Onychodactylus fischeri*

8.1.1.1 Origin and distribution

Onychodactylus fischeri, or the Long-Tailed Clawed Salamander, or Russian Clawed Salamander, or Ussuri Clawed Salamander, was described from Khabarovsk, along the Ussuri River in Russia (Borkin, 1994; Kuzmin, 1995), but the collection locality is disputed and may be in the upper Ussuri basin, 450 km south-southwest of Khabarovsk (Frost, 2023). The species split from other *Onychodactylus* species about 7.5 million years ago (Chen et al., 2015) and it is characterised by a weak intraspecific phylogenetic structure (Poyarkov et al., 2012). The Russian Clawed Salamander is restricted to the Russian Far East, where it is only found in the southern part of the Sikhote-Alin Mountains (Primorsky Krai; Maslova et al., 2021; Maslova and Rogashevskaya, 2023). The northwestern border of the distribution of *O. fischeri* is located in the basin of the Pavlovka and Sokolovka rivers, tributaries of the Ussuri River, on the western slope of the Sikhote-Alin Range; while the northeastern border is located in the basin of the Zerkalnaya River, on the eastern slope of the Sikhote-Alin Range (Maslova, 2001; Kuzmin and Maslova, 2003). The western edge is in the basin of the Ilistaya and Razdolnaya/Suifen rivers, although only in the eastern tributaries. Reliable populations are from the Chuguevsky and Kavalerovsky Municipal Districts in the north and the Shkotovsky, Partizansky and Nakhodka City Districts to the south (Kuzmin and Maslova, 2021; Maslova et al., 2021). The westernmost presence record from the upper reaches of the Kedrovka River on the Borisov Plateau, northernmost from the Sikhote-Alinsky Nature Reserve and southernmost from the Kedrovaya Pad' Nature Reserve (Korotkov and Borkin, 1981) could not be confirmed recently (Kuzmin and Maslova, 2003; Glushchenko and Maslova, 2019). Reports of the species presence in DPR Korea (e.g., Song, 2016) refer to other *Onychodactylus* species (Borzée et al., 2021), and it has not been detected in China despite the very close geographic proximity (Fig. 8.1).

8.1.1.2 Habitat

The species is found in mountainous mixed coniferous – broad-leaved forest, which is most typical of this species (Kuzmin and Maslova, 2005, 2021; Emelianov, 2018). However, some populations are able to inhabit light broad-leaved forests where coniferous trees are absent (Sokolova et al., 2017; Maslova et al., 2018). The species is restricted to small and cold mountain streams (Maslova et al., 2021) and it is generally found close to the river heads, preferring streams and springs, and rarely found in the lower reaches of rivers due to the presence of fish and higher

FIG. 8.1

Distribution of *Onychodactylus fischeri*, the Long-Tailed Clawed Salamander, or Russian Clawed Salamander.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

temperatures as the optimum water temperature for adults and larvae is between 6 and 11°C (Solkin, 1993; Kuzmin, 1995; Glushchenko and Maslova, 2019). The streams are characterised by thick beds of pebbles, rocky banks, surrounded by humid vegetation with hides and shelters in the forms of fallen logs and large rocks (Kuzmin and Maslova, 2021), and nonfreezing deep pools for the survival of larvae during winter (Glushchenko and Maslova, 2019; Maslova et al., 2023). The species generally avoids open areas and favours heavy canopy covers, in relation to their physiological requirements, although partial canopy cover can also accommodate the species (Sokolova et al., 2017). The species is found between 180 and 1600 m (Maslova and Rogashevskaya, 2023).

8.1.1.3 Behavioural ecology

Adults *O. fischeri* can be found active out of the water between late summer and early autumn, while they are found in the water in spring, early summer and mid-autumn (Kuzmin, 2012). When on the ground, they are generally about 1.5 m away from the banks, before starting hibernation in October and early November (Glushchenko and Maslova, 2019). The species is found at densities reaching four adults and ten larvae per square metre, in optimal conditions (Maslova, 1998). Adults are expected to reenter the water in spring, and presumably spawning takes place between late spring and late summer (Glushchenko and Maslova, 2019; Yartsev et al., 2021), and larvae take more than one year to develop as they have been found once in a spring in winter (Maslova et al., 2021). The first egg clutch to be described for the species in the wild was collected attached to the upper side of a flat stone, likely unnaturally displaced, on 9 August 1989 (Kozik and Truberg, 1991). The first regular spawning site of *O. fischeri* was first discovered in May 2023. The site was located on the gravel-stony layer at the bottom of a small stream in the upper reaches of the Pravaya Sokolovka River, in the Sikhote-Alin Range, where 27 egg clutches were found. The eggs were about 35 mm long, with a mean number of 6.8 eggs, ranging from four to ten per sac, and thus a mean number of 13.6, ranging from nine to 17 per clutch (Maslova and Rogashevskaya, 2023). During courtship, males touch the cloaca of females with their snout, and then rub their bodies on the female. When the egg sacs start being oviposited, males grab the egg sacs with their back legs and deposit a “sperm clump”, in opposition to a spermatophore (Serbinova and Solkin, 1992; Yartsev et al., 2021), which will fertilise the eggs. The egg sacs are attached to the substrate by a gelatinous stalk, and each female lays two egg sacs containing between three and ten eggs (Serbinova and Solkin, 1992; Griffin and Solkin, 1995; Maslova and Rogashevskaya, 2023). The larvae will take three to four years to metamorphose, when reaching seven to nine cm, and they can be seen in the streams from late April to late October (Fig. 8.2). The species reaches sexual maturity between six and nine years of age, with a life expectancy reaching at least 18 years. The species is generally nocturnal, with larvae and adults in the water feeding on aquatic and semiaquatic invertebrates such as molluscs, insect larvae and small crustaceans, terrestrial adults feeding on terrestrial insects and arthropods (Kuzmin, 2012). The species can feed when the water temperature is close to 0°C (Raffaelli, 2022).

8.1.1.4 Threats and conservation

The species is decreasing in numbers but it is not currently up-to-date on the IUCN Red List (Kuzmin et al., 2004). Habitat loss and degradation are the main threats and habitat degradation includes water pollution, and deforestation of the upper reaches of rivers and streams and gravel extraction. The species is most sensitive to habitat degradation due to the lack of lungs, the long larval development, and the late sexual maturity, in relation to the need for cold clean waters and natural stream embankments (Kuzmin and Maslova, 2005; Sokolova et al., 2017; Emelianov, 2018). As a result of these specific ecological needs, the species is not continuously distributed across its range (Maslova et al., 2021), and logging of the upper reaches of the streams has a negative impact on the species in the whole downstream water system due to the increase in temperature, the decrease in canopy cover, and eutrophication (Kuzmin and Maslova, 2021; Maslova et al., 2021). In addition, the lack of lungs and the need for cold waters are most likely to make the species sensitive to climate change, similar to other *Onychodactylus* species (Shin et al., 2021; Borzée et al., 2022).

The species occurs in the Ussuriisky Nature Reserve and “Zov tigra” National Park (Maslova, 2016; Kuzmin and Maslova, 2021), and it is listed in the second category of

FIG. 8.2

Larvae of *Onychodactylus fischeri*. The larvae develop in streams over three to four years, spending winter in areas where the ice does not reach the bottom of the stream (A and B). Only larvae can be found in streams in winter as adults overwinter underground. Adults can be found in water in spring, early summer and mid-autumn (C–E).

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threatened species in the Red Book of the Russian Federation since 2001 (Kuzmin and Maslova, 2021), and in the first category of the Red Book of the Primorsky Territory since 2005 (Glushchenko and Maslova, 2019). However, it may have become locally extinct as the species was reportedly present in the upper reaches of the Kedrovka River on the Borisov Plateau (Korotkov and Borkin, 1981) but surveys in the early 2000s did not find the species (Glushchenko and Maslova, 2019).

8.1.1.5 Identification

The species is the only salamander within its range without lungs, and adults are characterised by 14 or 15 costal grooves; four fingers on the forelimbs and five fingers on the hindlimbs (Kuzmin, 2012; Poyarkov et al., 2012). Adults of the species have a long tail, slightly longer than the rest of the body, and a brown and grey body with dark, golden and brown patterns. Larvae have similar colours. The species is the only one within its range with keratinised black claws on all digits, for both adults (depending on the breeding status) and larvae. The species is the only one in the genus that does not show a contrast between dorsal and lateral colourations (Raffaelli, 2022).

Males have a relatively shorter tail than females, and a skin fold on the hind leg between the fifth toe and the tibia, especially developed during the breeding season. The male's vent is longer and more swollen in relation to a difference in cloacal glands (Yartsev et al., 2021).

8.1.2 *Onychodactylus zhangyapingi*

8.1.2.1 Origin and distribution

Onychodactylus zhangyapingi, the Jilin Clawed Salamander, was described from Heisonggou in Linjiang County, Jilin, China (Poyarkov et al., 2012). The species is a sister clade to all Japanese *Onychodactylus*, and it diverged from the common ancestor with *O. fischeri* about 7.5 million years ago (5.1—10.1; Chen et al., 2015). The Jilin Clawed Salamander is distributed on a narrow range around the Changbai Mountain in China (Poyarkov et al., 2012), and likely on its pendent, the Paektu Mountain, in DPR Korea, although the identity of the species in the nation has never been confirmed (Borzée et al., 2021). In China it is present in the Linjiang, Ji'an and Tonghua counties in Jilin (Che et al., 2012; Poyarkov et al., 2012; Xia et al., 2012), and Yanji area (Hou and Fei, 1964, Fig. 8.3).

8.1.2.2 Habitat

The Jilin Clawed Salamander, like other species in the genus, is restricted to the upper reaches of small mountain streams in mixed broad-leaved and conifer forests (Poyarkov et al., 2012). The species is only found close to cool flowing streams and their spring, overgrown with vegetation, although it can disperse over relatively large distances in humid habitats. The species occurs as low as 250 m (Fei et al., 2012; Poyarkov et al., 2012), although generally more abundant between 300 and 500 m of elevation, and it can also be found up to 1000 m (IUCN SSC Amphibian Specialist Group, 2020). The species is expected to be present on terrains characterised by slopes ranging between one and seven degrees, avoiding north and northeast slopes, up to 4800 m from water bodies, mainly surrounded by coniferous and broadleaf forests, although at least 6 km away from human construction and three km away from cropland (Peng et al., 2023). The species is generally present close to streams covered with pebbles and large rocks where larvae can shelter, with adults found in the vicinity of streams.

FIG. 8.3

Distribution of *Onychodactylus zhangyapingi*, the Jilin Clawed Salamander.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

8.1.2.3 Behavioural ecology

The ecology of the species is not well understood, but *O. zhangyapingi* is not generally found far from streams and adults hibernate in the area. They emerge from hibernation in early April, and reach the water once the ice has thawed for spawning with oviposition lasting until early June. Each female deposits two egg clutches, each including 12 to 24 eggs (IUCN SSC Amphibian Specialist Group, 2020), linked by a gelatinous stalk to the substrate, including rocks and vegetation. The eggs hatch before fall, and it takes three to four years for the juveniles to metamorphose. Both adults and larvae have keratinised claws, and larvae use them to maintain their position in the water body (Fig. 8.4). The larvae prey on aquatic and semiaquatic arthropods, and adults can also include worms and slugs in their diet (Fei et al., 2012).

8.1.2.4 Threats and conservation

Onychodactylus zhangyapingi is not generally common across its range, with populations relatively difficult to find and generally only found at low density (Fei et al., 2012), although the species has not experienced a genetic bottleneck (Luan, 2018). The ecology and threats to the species are not currently well understood and as a result, *O. zhangyapingi* is listed as Data Deficient, but declining, by the IUCN Red List (IUCN SSC Amphibian Specialist Group, 2020). The habitat used by the species is decreasing because of habitat degradation due to agricultural and urban development, and it may have become extirpated in the Yanji area (Hou and Fei, 1964). In addition, the species is strongly impacted by global warming (Wang et al., 2008) and predictions show a significant decline in habitat suitability in the future (Peng et al., 2023). The species is not known to occur in any protected

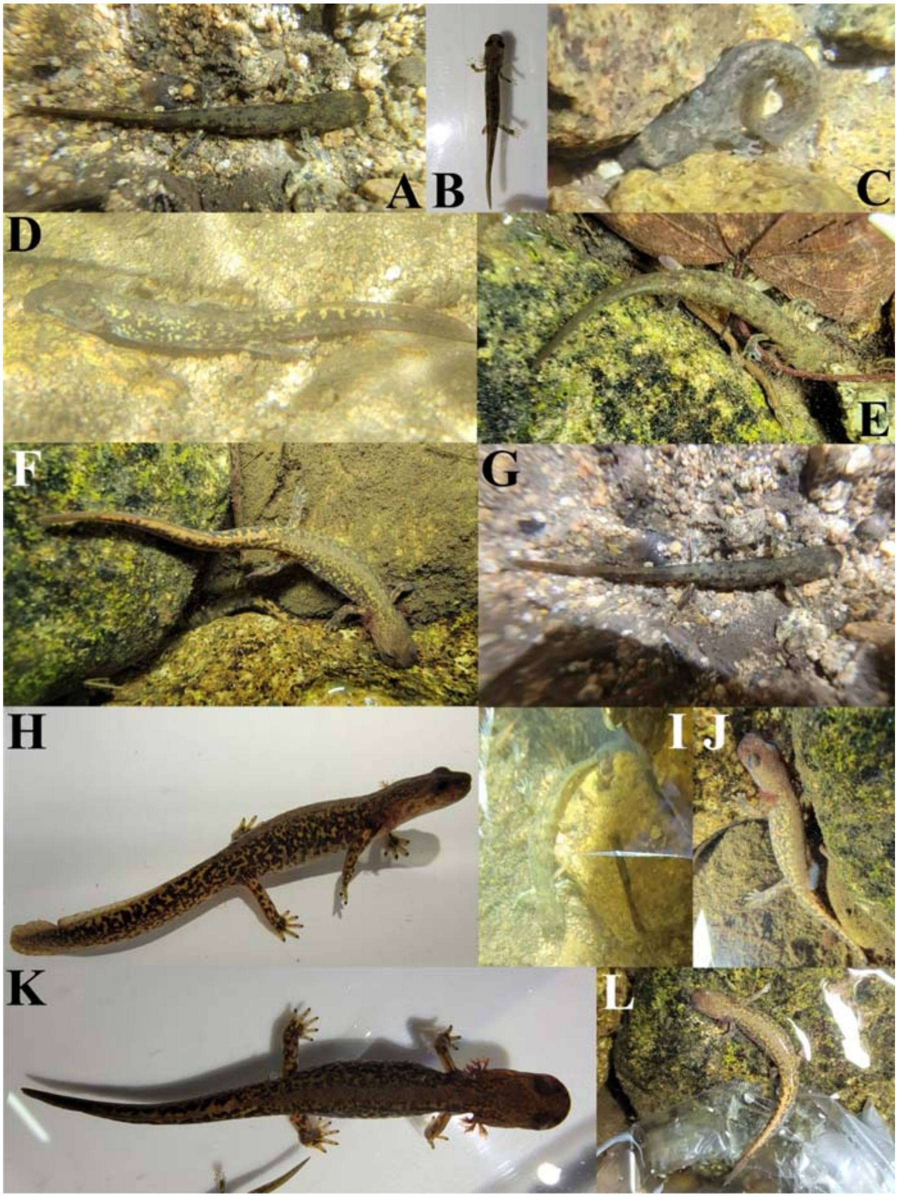

FIG. 8.4

Larvae of *Onychodactylus zhangyapingi*. The larvae of the species have black keratinised claws that they use to maintain their position in the flowing water (A—L). The colouration of larvae is variable (see G for variation), although generally following a species-specific pattern.

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area, and while no evidence of harvest is currently available, harvests in the past are most likely to have occurred as the other species of the genus in the same region was harvested (Poyarkov et al., 2012). The trade of the species is currently forbidden in China.

8.1.2.5 Identification

The distribution of the species is overlapping with that of other *Onychodactylus* species, but *O. zhangyapingi* is darker than the other continental *Onychodactylus* species, without any prominent dorsal band but dark brown patches (Poyarkov et al., 2012) that do not form a marbling or reticulated pattern (Raffaelli, 2022). The species has between 11 and 15 coastal grooves, and females can reach a larger size than males, based on a small dataset (Fei et al., 2012; Poyarkov et al., 2012). Males can be distinguished by the Y-shaped cloaca (Fei et al., 2012) and long tails (Xiong et al., 2016).

8.1.3 *Onychodactylus zhaoermii*

8.1.3.1 Origin and distribution

Onychodactylus zhaoermii, the Liaoning Clawed Salamander, was described from Huashan village in Xiuyan County, Liaoning, China (Poyarkov et al., 2012). The species is basal to the remaining continental *Onychodactylus* species distributed on the Korean Peninsula and its vicinity, having diverged about 7.93 (9.60−6.32) million years ago (Suk et al., 2017) and thus part of the *Onychodactylus koreanus* complex (Poyarkov et al., 2012). The Liaoning Clawed Salamander is present in southern Jilin (Ji et al., 1987; Fusong area; Xia et al., 2012) and Liaoning Provinces in China (Che et al., 2012). It is expected to range from the Laoling Mountains to the mountainous areas of the Liaodong Peninsula in Liaoning (Poyarkov et al., 2012), although the presence of the species has only been confirmed at a few localities in the Qian Mountain, Huashen, Xiuyan, Liaoyang and Benxi counties (Li, 2004; Zhou et al., 2021). The species' distribution crosses southwards over the border with DPR Korea until South Hamgyong. It is considered present in Northern Pyongan, Southern Pyongan, Chagang, Ryanggang (around Paektu Mountain) and Hamgyong provinces (Kim and Han, 2009; Borzée et al., 2021, Fig. 8.5).

8.1.3.2 Habitat

Onychodactylus zhaoermii is found close to non-disturbed rocky streams in densely vegetated areas, and both adults and larvae are more often close to the headwater and springs (Fei et al., 2012), with some rare individuals found downstream in small water reservoirs bordering streams. This *Onychodactylus* species is also a habitat specialist, adapted to both coniferous and mixed broad-leafed forests, located at least 10 km away from developed areas (Peng et al., 2023). The species is known to occur between 500 and 800 m in elevation, in water ranging from 6 to 14°C, in the

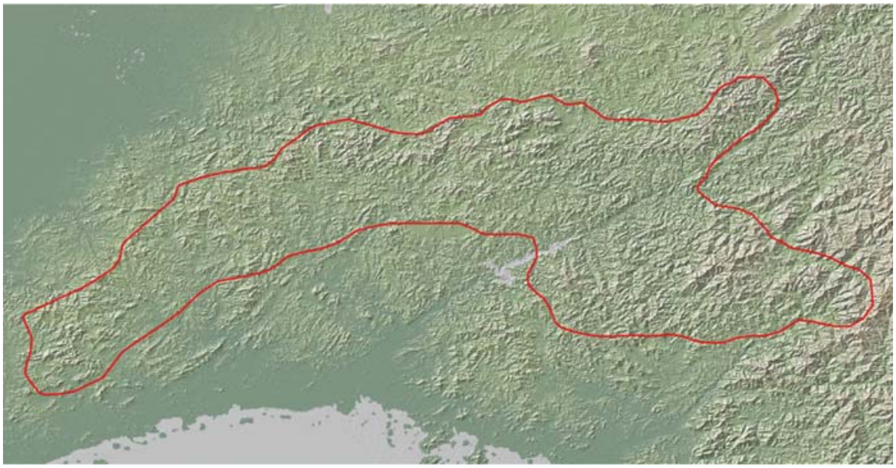

FIG. 8.5

Distribution of *Onychodactylus zhaoermii*, the Liaoning Clawed Salamander.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

permanent streams of the Qianshan Mountains and the mountainous areas of the Liaoning peninsula (Poyarkov et al., 2012). Despite the known and confirmed presence of the species in a protected area, there is so far very little data on the habitat preferences of the species.

8.1.3.3 Behavioural ecology

Adults emerge from hibernation in April (Li, 2004), and are known to be actively breeding in early and mid-May. However, breeding activities and morphological changes start when the water temperature reaches 6°C, which would result in the species starting spawning in late April (Zhou et al., 2021). In opposition with the other species of the genus in continental Asia, adults of the species are not often seen in the water after June, suggesting an earlier breeding season (Meng, 2013). Females seem to prefer rocky and not woody substrates to attach their double egg sacs with a gelatinous stalk, and each egg sac contains 12 to 17 eggs, although the number of eggs in ovaries was found to be between three and 24 (Fei et al., 2012). The species is generally not present at the centre of larger streams where the current is stronger and the temperature higher due to the absence of canopy cover (Fig. 8.6). After breeding, the species is mostly active under the substrate or heavy vegetation in the vicinity of streams, at night or after the rain, feeding on small invertebrates (Fei et al., 2012). This species seems to be the one with the shortest development period of the genus as metamorphosis is reported to take place two years after hatching (Fei et al., 2012). Adults of the species are active until late September to early October, when they start hibernating (Li, 2004).

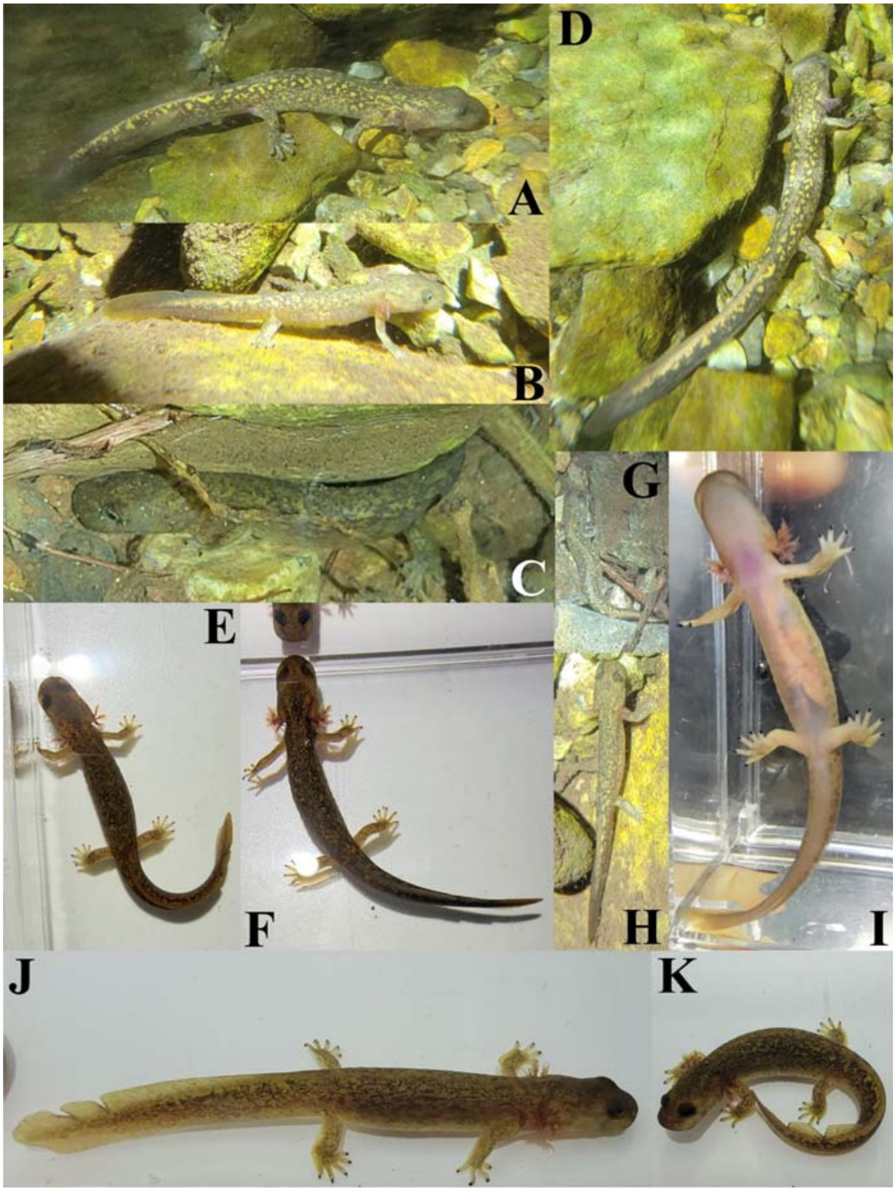

FIG. 8.6

Larvae of *Onychodactylus zhaoermii*. The species is identifiable through specific patterns and colours (A–K), although the full range of variation is not yet understood. Metamorphosis in this species can be done within two years of hatching, making it the *Onychodactylus* species with the shortest larval time in continental Asia.

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8.1.3.4 Threats and conservation

Onychodactylus zhaoermii is declining in numbers due to habitat loss, and while it has not been assessed by the IUCN Red List yet, threats have been documented. The Jilin Clawed Salamander is uncommon, occurring in disconnected populations that are hard to find (Kuzmin et al., 2004) and only represented by a low number of adult individuals (Fei et al., 2012), although it has not experienced a genetic bottleneck (Luan, 2018). In addition, the species is threatened and declining due to habitat degradation and loss, and especially past forest changes over the last centuries, with a modelled suitable habitat of 1438 km^2 divided into three disconnected regions (Zhou et al., 2021). An additional demonstrated threat is that of global warming (Wang et al., 2008). The breeding activities of the species in May are strongly regulated by the maximum temperatures, and the increase in temperature because of climate change is going to decrease the breeding potential in that season (Zhou et al., 2021). In addition, the genetic diversity of the Liaoning Clawed Salamander is ultra-low due to a drop in population 100,000 to 30,000 years ago, followed by an expansion in range over the last 25,000 years (Zhou et al., 2021).

As a result, the species is nationally listed as critically endangered in China (Jiang et al., 2016), and it is listed as level one species on the list of state-protected wildlife of the National Forestry and Grassland Administration and the Ministry of Agriculture and Rural Affairs (Zhou et al., 2021). The species is present in the "Natural Conservation Community for the Liaoning Clawed Salamander" in Xiuyan County, Liaoning (Han, 2015). While numerous individuals were collected for the pet trade in the Huashan region during the early 2010s (Li, 2004; Poyarkov et al., 2012), the trade of the species is currently forbidden in China.

8.1.3.5 Identification

Onychodactylus zhaoermii is morphologically differentiable from the other geographically close *Onychodactylus* species, although the full range of the colour variation is not understood yet and some patternless grey larvae are also found. The Liaoning Clawed Salamander has a lower number of costal grooves than *Onychodactylus koreanus* (although it is likely to be sympatric with the candidate species sister to *O. koreanus* and not *O. koreanus* itself), and it is darker in colour than *O. zhangyapingi*, with more orange and copper colours, sometimes resulting in marbling or reticulations that are not found in *O. zhangyapingi*. In addition, *O . zhaoermii* has a dark patch on both sides of the neck (Raffaelli, 2022). Males are slightly larger than females, and show extended skin flaps during the breeding season and a Y-shaped cloaca (Fei et al., 2012; Poyarkov et al., 2012).

8.1.4 *Onychodactylus sillanus*

8.1.4.1 Origin and distribution

Onychodactylus sillanus was described from Sasong, Yangsan, R Korea (Borzée et al., 2022) and it is called the Yangsan Clawed Salamander. The species is a sister clade to *O. koreanus*, having diverged 6.82 million years ago (8.20—5.38; Suk et al.,

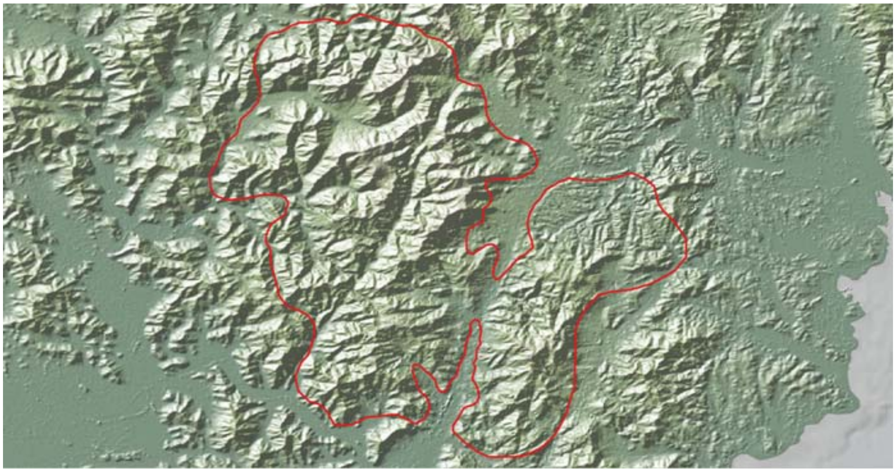

FIG. 8.7

Distribution of *Onychodactylus sillanus*, the Yangsan Clawed Salamander.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

2017). The Yangsan Clawed Salamander is restricted to the southeastern margin of R Korea, currently known from the cities of Yangsan and Miryang, including Unmun Mountain (Chang et al., 2009). The species is unlikely to be found far outside these localities as the habitat is not suitable (Borzée et al., 2022, Fig. 8.7).

8.1.4.2 Habitat

The species is restricted to moist, cool and shaded habitats in the broad-leafed and mixed forests of Yangsan and Miryang mountains, where it ranges between 80 and 900 m above sea level, although more abundant around 300 m above sea level. Larvae are found in the lower reaches of streams than adults. The species is found in the vicinity, or within, clean running streams, generally hiding under stones or dead logs in the streambed (Borzée et al., 2022).

8.1.4.3 Behavioural ecology

Onychodactlus sillanus seems to be opportunistically active all year round when the temperature allows, with individuals observed around 5°C in mid-December under a light rain. Males are showing their breeding phenotype from March (Fig. 8.8), and females have been observed with eggs in their ovaries in early March (Pers. Com. Kim Hapsu). Juveniles can start metamorphosing and moving out of the water from the first week of April (Pers. Com. Kim Hapsu; Fig. 8.9). Both juveniles and adults are more active at night, with adults climbing large boulders on the stream bank for foraging and they have been observed feeding on an adult Plecoptera. Juveniles and adults can be found away from streams, with juveniles recorded as far as 70 m from the closest stream, during wet warm nights of very late autumn. These

FIG. 8.8

Adults and juveniles of *Onychodactylus sillanus*. Adults are characterised by a very long tail (A—D), while shorter individuals (E—M) may not have reached sexual maturity yet. The venter of the species is not entirely opaque, and eggs can be seen easily when present (N). The sexual characters (O) in males in the species start being visible from March.

From Amaël Borzée.

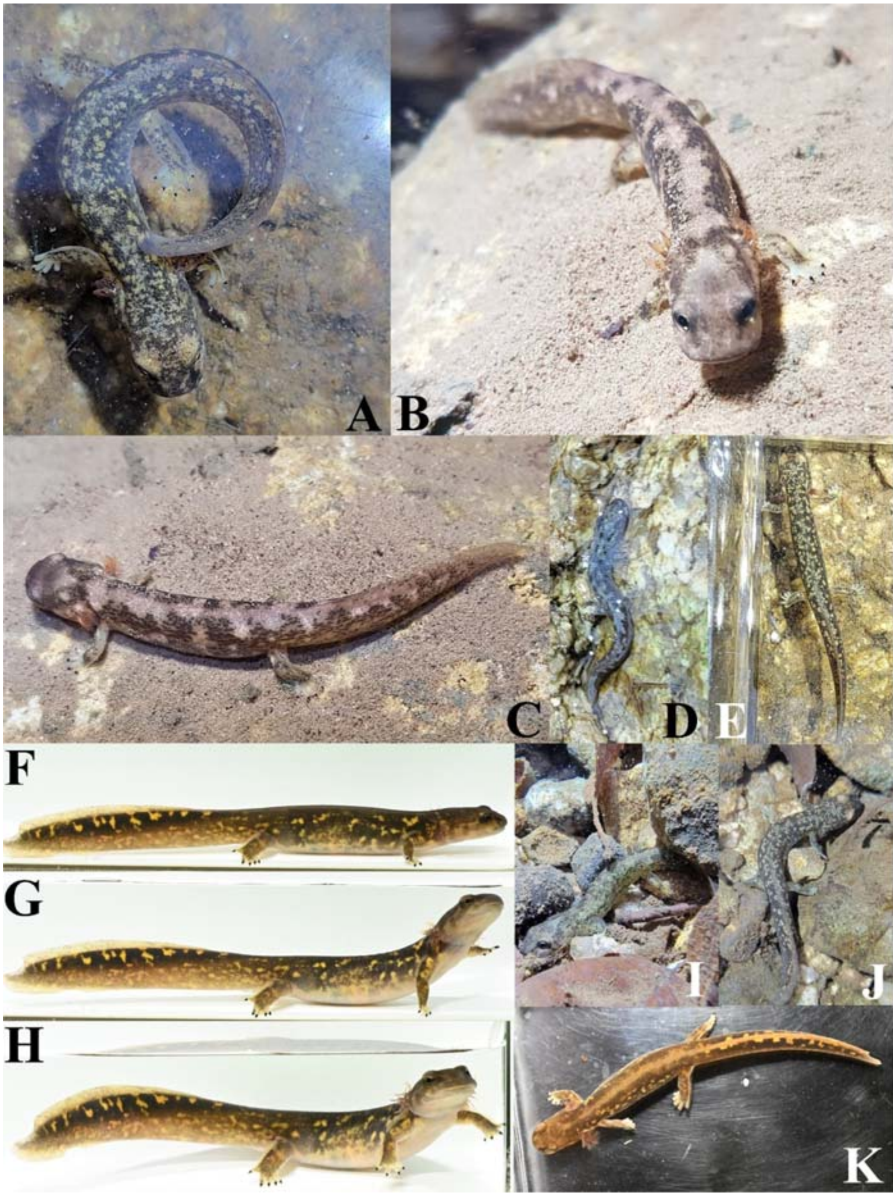

FIG. 8.9

Larvae of *Onychodactylus sillanus*. First-year larvae are visibly smaller (A–D) than older ones (E–K), and the gills get smaller the closer to metamorphosis.

From Amaël Borzée.

juveniles were likely dispersing along paths of least resistance, including streams and roads. In Yangsan area, the Yangsan Clawed Salamander is found in sympatry with *Hynobius yangi*, *Glandirana emeljanovi* and *Rana uenoi*, with larvae potentially feeding on other amphibian larvae and freshwater invertebrates. Similar to other species in the genus, breeding is likely taking place in streams or slow-moving subterranean water bodies, with egg sacs fixed against large boulders. The breeding ecology of the species is still mostly unknown (Borzée et al., 2022).

8.1.4.4 Threats and conservation

The species is not able to cope with extensive habitat changes (Groffen et al., 2022), and it is primarily threatened by habitat loss because of the development of human infrastructures (Borzée et al., 2022). Based on different landscape modelling approaches, the species' extent of occurrence is between 258 and 792 km^2. The species is however not present homogeneously across the habitat as it is restricted to streams for most of the year, and thus not present in most of this area. In addition, the small range of the species is predicted to shrink further as all forecasts show a drastic reduction in suitable habitat. The species is also sensitive to climate change, and climate change scenarios predict up to 97.3% decline in suitable habitat (Borzée et al., 2022).

Currently, citizen initiatives are attempting to protect the habitat of the species from urbanisation and groundwater development (Choi, 2020a, 2020b; Kim, 2021) as its presence in a protected area has not been demonstrated. It is however likely present in one of the five protected areas with suitable habitat within their boundaries (Borzée et al., 2022). Despite not being assessed by the IUCN Red List, *O. sillanus* is likely Critically Endangered following criterion A3(c), based on the projected population size reductions linked to the extent of occurrence decline and climate change predictions for 2050.

8.1.4.5 Identification

Onychodactylus sillanus is the only lungless salamander species within its range, although it is sympatric with *Hynobius yangi*. The distinction between the two species is easy as larvae of *O. sillanus* have black keratinised claws, and the adults of *O. sillanus* are larger, with yellow and orange hues that are not present in *Hynobius* species.

The Yangsan Clawed Salamander does not occur in sympatry with any other *Onychodactylus* species, but it can be diagnosed from other members of the genus by the presence of 11 to 12 costal grooves, a comparatively shallow series of 18 to 22 shallow vomerine teeth, a comparatively darker dorsum from head to tail with numerous medium-sized reddish-yellow elongated spots and ocelli, the absence of light dorsal band and large yellowish blotches on dorsum and tail (Borzée et al., 2022).

8.1.5 *Onychodactylus koreanus*

8.1.5.1 Origin and distribution

Onychodactylus koreanus, the Korean Clawed Salamander was described from Samcheok, in Gangwon Province in R Korea (Poyarkov et al., 2012). The species dispersed southwards from the ancestral lineage shared with *O. zhaoermii* (Suk et al., 2017) and it is composed of two main clades, one being *O. koreanus* and the other a candidate species (clade D1 in Poyarkov et al., 2012 and NE in Suk et al., 2017). The common ancestor to both clades diverged 6.3 million years ago (7.74−4.98; Suk et al., 2017).

The candidate species is restricted to northern R Korea, and southern DPR Korea, with an unknown distribution in the nation, but expected to range within Kangwon Province and maybe adjacent areas (Fig. 8.10; Kim and Han, 2009; Borzée et al., 2021). The southern clade diversified 2.31 million years ago (2.95−1.71), and then radiated into four subclades between 1.7 and 1.8 million years ago (Suk et al., 2017). The southern clade, the Korean Clawed Salamander, ranges from South Jeolla province in the south and across the nation along the Baekdudaegan range; and in other mountainous areas, such as Jiri, Deokyu, Songni, Taebaek, Odae, and Seorak mountains. It is also present on Chilgap Mountains despite the geographic discontinuity (Fig. 8.10).

8.1.5.2 Habitat

Habitat differences between the two clades have not been identified, and most of the knowledge available pertains to the southern clade merged with populations of the

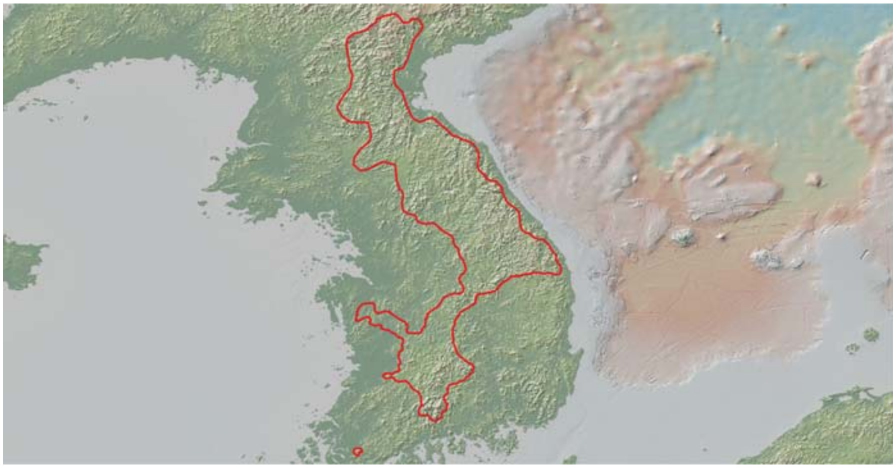

FIG. 8.10

Distribution of *Onychodactylus koreanus*, the Korean Clawed Salamander.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

northern clade in R Korea. This species is also a habitat and ecological specialist (Suk et al., 2017), adapted to cold (6–14°C; Raffaelli, 2022) and small flowing streams with rocks and pebbles in pristine and humid coniferous, broad-leafed and mixed forests. Larvae are generally found under rocks and in the leaf litter on the stream bed. The species is also found in underground habitats, such as large and deep caves, with the stream being about 2 m wide and 1 m deep and around 10°C at the only known breeding site (Hwansun cave; Park, 2005). The Korean Clawed Salamander is found at comparatively higher elevations, with the largest populations above 300 m, but present from 50 to 1300 m (Andersen et al., 2022).

8.1.5.3 Behavioural ecology

The behavioural ecology of the species is the best known for the genus in continental Asia, although based on data from a single breeding site (Park, 2005). Males arrive at the breeding site earlier than females, in late May, and they are present in large numbers throughout the breeding activities (Fig. 8.11). Once females arrive at the breeding site in June, a group of males creates a mating ball with that female, and the egg sacs are affixed on a vertical rock by the female a few dozen centimetres below the water surface. Females lay between 10 and 22 eggs, distributed into two egg sacs, and leave the breeding site after oviposition. No female was observed at the site in very late June. The breeding is communal, and a maximum of 173 pairs of egg sacs, likely originating from more than 100 individuals, were found at the only known breeding site (Park, 2005). Males then ventilate the sacs with the extended lateral folds on their hind legs and toes for a few weeks, and they were observed to be doing so for more than one pair of egg sacs, hinting at potential cooperative breeding; supported by the absence of antagonistic behaviour among males in this part of their life cycle (Park, 2005, Fig. 8.11). Sperm competition is likely to occur due to the mating balls, and the maintained amplexus of egg sacs by males even after the departure of the female. Hatching occurs in the following months, and the larvae take two to three years to metamorphose (Fig. 8.12). Recruitment occurs in November and mid-March, but only for larvae that have reached more than 3 cm in length (Lee et al., 2008). Data from captive individuals show that larvae may be able to reach between 7 and 10 cm before metamorphosis (Raffaelli, 2022).

The species is active over ground before winter, with mass migration observed in early October on rainy nights, when the temperature ranges between 10 and 15°C (Shin et al., 2020). At that period males already have fleshy hind-limb extensions, and most females are gravid, indicating that migration is potentially linked to reproduction, although all egg observations were eight months later. The species has not been seen active in late December and early January only (Groffen et al., 2022), although no individual has been found hibernating and individuals can be found feeding at temperatures as low as 6°C, and being active at a minimum of 3°C. In these conditions, the species reaches sexual maturity at five years old (Raffaëlli, 2013; Raffaelli, 2022).

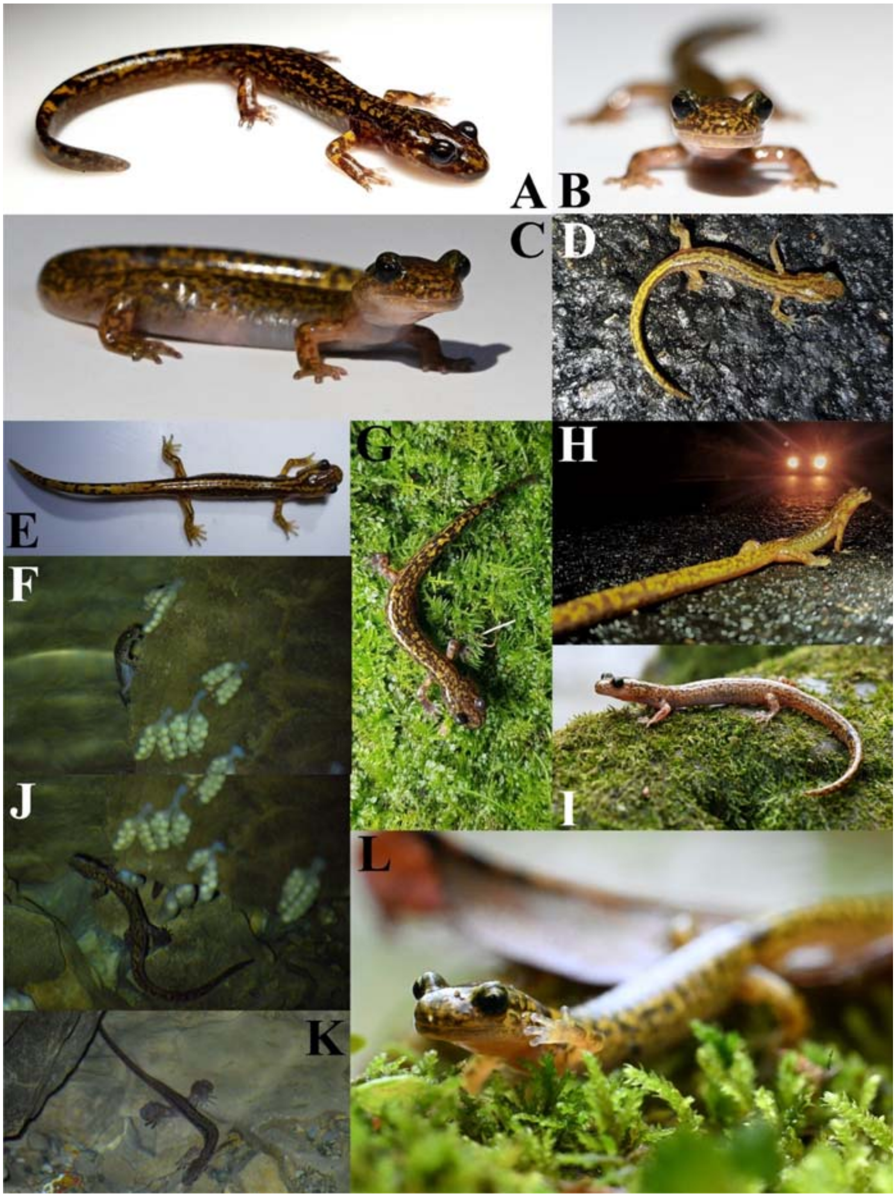

FIG. 8.11

Adults and eggs of *Onychodactylus koreanus*. Adults in the species do not generally show much colour variation (A—L), although other morphs, with more or less stripped patterns are sometimes found (D and E). The species is sensitive to roadkills when migrating overground (H). They breed in caves (F, J and K) where males fan the eggs with the skin flaps on their back legs.

From Amaël Borzée.

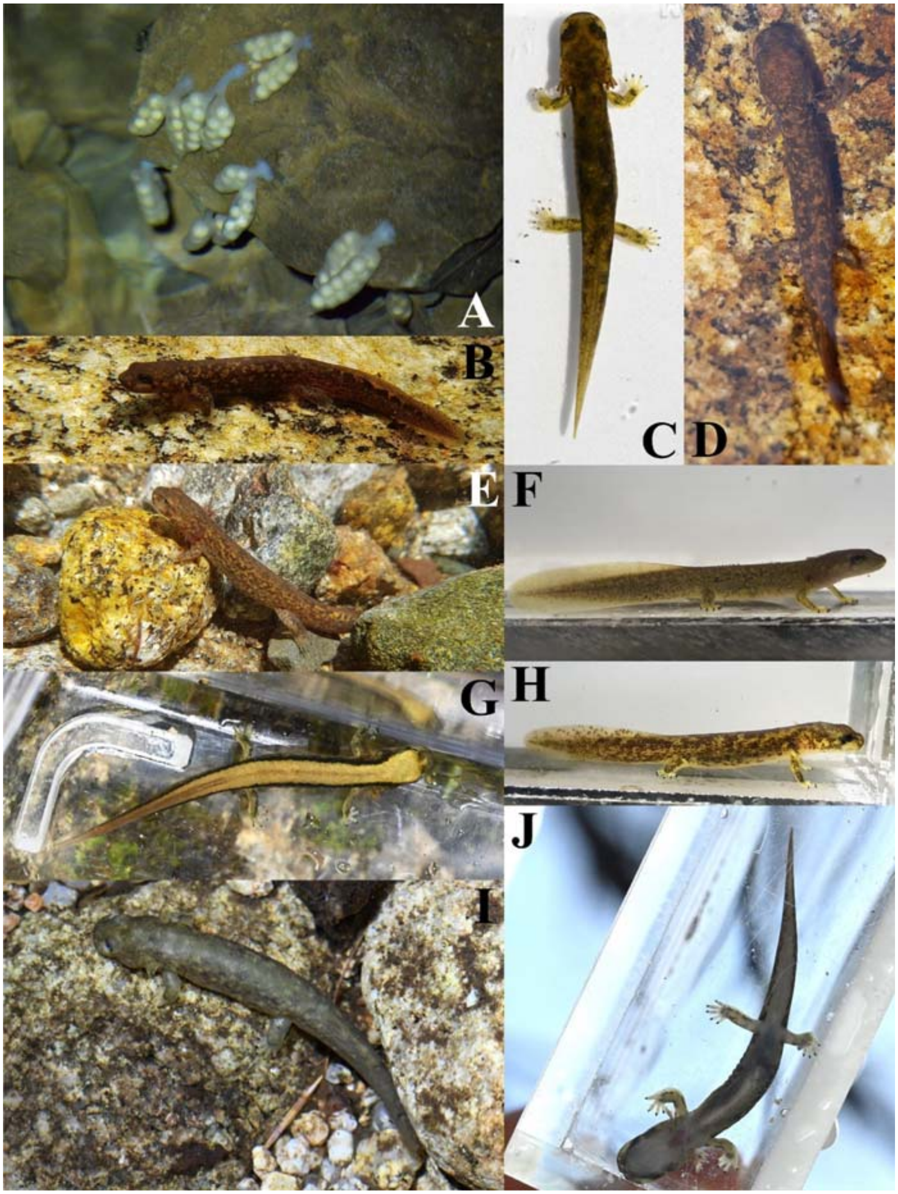

FIG. 8.12

Eggs and larvae of *Onychodactylus koreanus*. The eggs are spawned in slow-flowing streams in caves (A), and only one site breeding is openly known for this species, and genus, in continental northeast Asia. The larvae take two to three years to reach metamorphosis (B—F), and several morphs can be found (G—I). The keratinised claws are visible in larvae as well (J).

From Amaël Borzée.

8.1.5.4 Threats and conservation

The species is habitat-restricted and cannot cope with habitat change (Groffen et al., 2022). It is also severely impacted by climate change, with the current climatic conditions resulting in modelled drastic shifts in suitable habitat, generally resulting in a decrease in habitat availability in the near future (Shin et al., 2021). In addition, the species is impacted by roadkills, and especially breeding individuals (Shin et al., 2020, 2022). However, it is currently not harvested or used by humans. The species is not listed as threatened at the national level, but it has become absent or much less abundant from many populations, despite an increase in effective population size 25,000 to 30,000 years ago (Suk et al., 2017). The species is currently not assessed by the IUCN Red List, but based on the severity of the threats and the speed of the decline, it is a threatened species, despite being present in protected areas in R Korea.

8.1.5.5 Identification

The southern clade of *O. koreanus* is sympatric with several *Hynobius* species, but it is not sympatric with *O. sillanus* (Borzée et al., 2022). The two clades of *O. koreanus* are sympatric in the northern part of R Korea, and their parapatric or sympatric status is DPR Korea, within the species as currently defined and with *O. zhaoermii*, is not resolved (Borzée et al., 2021; Peng et al., 2023). Like other *Onychodactylus* species, *O. koreanus* has black claws in the larval and adult forms.

Korean Clawed Salamanders can be distinguished from other *Onychodactylus* species by a specific number of trunk vertebrae (18–20), costal grooves (12–14), and the typical colouration of juveniles and adults, which is a dark background with numerous bright, small round spots and no distinct dorsal band in adults (Poyarkov et al., 2012). The limbs of the species are shorter than that of *O. sillanus* (Borzée et al., 2022). The larvae of *O. koreanus* can be found under three different morphs, one being the typical morph with dark non-reticulated patterns on a yellowish background, the next most common is a yellowish body with a dark brown dorsal stripe, and finally, the rarest morph is a totally uniform grey body and it does not seem to be present in the southern clade (Fig. 8.12). The second morph with the stripe can also be found in adults. Adult males of the species generally have longer tails, and longer and narrower heads than females, which are generally smaller (Poyarkov et al., 2012).

8.2 *Hynobius*

Hynobius, within a clade that also includes *Salamandrella*, *Batrachuperus*, *Pseudohynobius* and *Liua*, diverged from the basal *Pachyhynobius* around 36.2 million years ago (31.1–41.7), before becoming an independent clade basal to *Salamandrella*, *Batrachuperus*, *Pseudohynobius* and *Liua* about 35.1 million years ago (30.1–40.5; Chen et al., 2015, here excluding the literature relying on less information for topology and datation). *Hynobius* started diversifying around 16.6 million years ago (13.9—19.7), with *Hynobius retardatus* having a basal position to all other *Hynobius* species. Two main groups diverged around 10.5 million years ago (8.6—12.6), resulting in the isolation of the Chinese mainland species, and the *Hynobius leechii* complex, which diverged 10.2 million years ago (8.3—12.3; Chen et al., 2015). *Hynobius* is the Hynobiidae genus with the largest number of species, currently including over 60 described taxa and a few remaining candidate species. Species in this genus generally become less speckled when ageing. The traditional lentic versus lotic arrangement of the species is weakly supported in view of field observations of typical lentic breeding species breeding in lotic environments when the habitat becomes available, and the plasticity of the tail morphology in changing environments. Males of the genus can develop a caudal fin during the breeding season, with an identifiable Y-shaped cloacal opening, in contrast with a straight opening in females (Raffaelli, 2022).

The topology of the *H. leechii* species complex still needs to be clarified, having diverged about 10.2 million years ago (8.3—12.3; Chen et al., 2015), and the topology based on multiple loci supports a basal lineage including *H. leechii* and *H. yangi* (Baek et al., 2011; Wang et al., 2023; but see Min et al., 2016 for an alternative topology).

8.2.1 *Hynobius leechii*

8.2.1.1 Origin and distribution

Hynobius leechii was described from Wonsan, DPR Korea (Boulenger, 1887). The species is a member of a clade with *Hynobius yangi*, having diverged around 9 million years ago (Baek et al., 2011), and basal to the other species of the species complex. *Hynobius leechii* diverged from its sister clade around 5.3 (Baek et al., 2011) to 4.3 million years ago (Kim et al., 2007), in the early Pliocene. The species is composed of several subclades with specific geographic distribution on the Korean Peninsula (Baek et al., 2011), and a low genetic diversity in northeast China (Zeng and Fu, 2004).

The Gensan Salamander (from the type locality of Wonsan and also called Wonsan Salamander), or Korean Salamander, ranges in the southwest of its distribution from the hills bordering the Iksan plains, north of the Jiri Mountain, and across the Korean Peninsula towards Ulsan, but it is not present in the southern coastal regions of the nation where other *Hynobius* species are present. The species occurs northwards throughout the Korean Peninsula, until the Hamhung area in DPR Korea, where it is limited to lower elevations (Kim and Han, 2009; Borzée et al., 2021). The species is then distributed across the peninsula to the northwest until the southern Chagang province, where it crosses into China. The Korean Salamander is present in southern Liaoning, southern and central Jilin, and southcentral Heilongjiang (Fei et al., 2012; Fei and Ye, 2016, Fig. 8.13). In the south, the species is sympatric with all *Hynobius* species it shares a boundary with.

FIG. 8.13

Distribution of *Hynobius leechii*, the Wonsan Salamander, or Korean Salamander.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

8.2.1.2 Habitat

The Korean Salamander occurs across a broad range of habitats, from low plains to low mountains, between 3 and 1250 m in R Korea (Andersen et al., 2022) and between 200 and 850 m in China (Fei et al., 2012). The species is also present across a variety of landscapes, ranging from agricultural areas to broad-leafed, conifer and mixed forests. The natural breeding habitat of the species is generally composed of disconnected stream pools, small and shallow stagnant water bodies, or other very slow-flowing water bodies (Yang et al., 2001; Ambu et al., 2022). However, the species also breeds in disturbed areas across its range, including cavities entirely made of concrete, such as irrigation ditches and sometimes in ornamental water bodies in city parks.

In the current landscapes, the species often resorts to breeding in agricultural areas such as rice paddies before they are flooded for rice agriculture in late winter and early spring. This substitute habitat is suitable for the species despite its degraded natural state in areas close to forests, generally in smaller rice fields at higher elevations with low chemical concentrations (Do et al., 2020).

8.2.1.3 Behavioural ecology

The species starts breeding from mid-January in southern latitudes (Groffen et al., 2022), but it can be found breeding in early May in the northern parts of its range. Males reach the breeding habitat first, and the sex ratio is skewed towards males during the whole breeding season, following daily variations due to the short attendance of females to the breeding sites (Sung et al., 2005, Fig. 8.14). Males can be found for a few weeks at the breeding site, or in its vicinity, but females stay in the water for

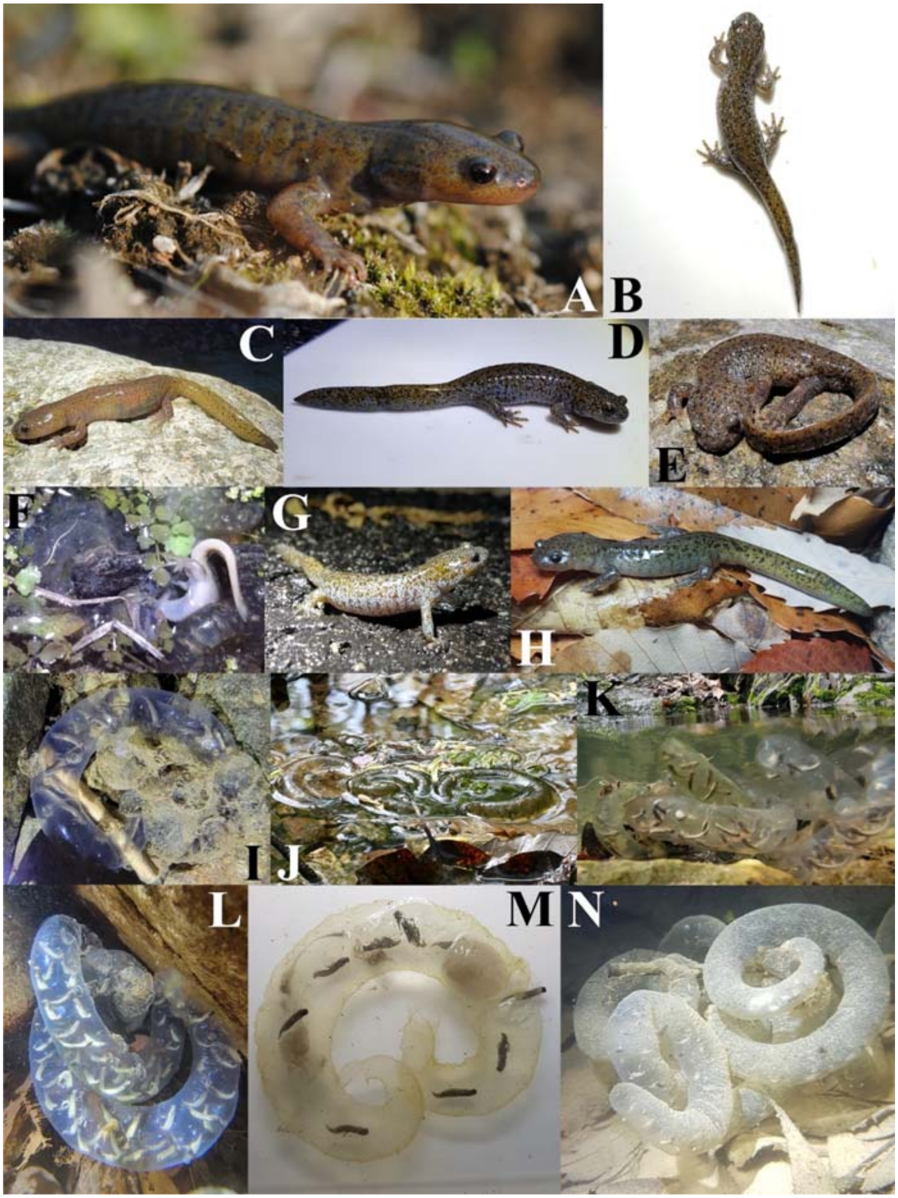

FIG. 8.14

Adults and eggs of *Hynobius leechii*. Adults are variable in colour (A—H). Scramble competition may occur when males are present in large concentration (F). The eggs are spawned into two egg sacs, one for each ovary (I—N), and attached to the substrate by a gelatinous stalk, or left at the bottom of the water body.

From Amaël Borzée.

oviposition for a few days only, and about a week in terrestrial microhabitats close to the breeding grounds (Sung et al., 2005). Attendance to the breeding site is generally regulated by the body condition and not the age of the individuals, which can be found breeding between one and nine years old for males and three and nine years old for females (Lee and Park, 2008). Males of the species have a specific courtship behaviour (Park and Park, 2000), maintaining an oviposition perch from which they attract females through body undulations (Kim et al., 2009), and detect the ovulation stage of females through chemical cues (Park and Sung, 2006). Females react to the undulation and the resulting water current by orientating towards the focal males until establishing contact with their snouts, at increasing frequency right before oviposition (Kim et al., 2010). Males also use body undulation to compete with other males, detecting the water movement through their lateral line (Park et al., 2008), and sometimes triggering a physical response in the form of snout contact or bites (Kim et al., 2009). Once the egg sacs are deposited, males maintain a post-insemination egg-guarding behaviour where they amplex with one of the egg sacs deposited by the female (Park et al., 1996). As a result, the eggs oviposited by a female can be fertilised by more than a single male (Park and Park, 2000).

A female lays between 60 and 120 eggs in R Korea and between 60 and 100 eggs in China, distributed in two sacs (Fig. 8.14), generally close to the bank of shallow water bodies, close to forests, with high vegetation cover, and in water bodies with *Rana* eggs (Ambu et al., 2022), likely for later predation by the larvae. The eggs take two to four weeks to hatch (Park and Park, 2000; Fei et al., 2012), and the larvae will metamorphose within two to three months based on food availability and temperature. Larvae generally feed on aquatic arthropods, other amphibian larvae, or through cannibalism (Fig. 8.15).

The species is not known to overwinter as larvae, and individuals start hibernating between early October in the north (Fei et al., 2006) and mid-December in the south (Groffen et al., 2022). Hibernation is generally done under the substrate, or deep under the ground in colder areas. Emergence is regulated by temperature and humidity, with the first emergence in mid-January but hibernation lasting until early April in the north (Fei et al., 2006; Groffen et al., 2022).

8.2.1.4 Threats and conservation

The species is comparatively little threatened by human activities as it can cope with relatively high degrees of habitat disturbance (Groffen et al., 2022). However, habitat change results in exposure to roadkills and the species is within the top ten amphibian species impacted by roadkills in R Korea (Shin et al., 2022). In addition, the species is threatened by landscape changes allowing the presence of predators in larger numbers than in natural habitats (Bae et al., 2017). Besides, climate change models for the suitable habitat of the species predict a decrease of suitable habitat for different timelines in the future, under different climate change scenarios, both in R Korea (Kim et al., 2021) and China (Duan et al., 2016), while also impacting the breeding phenology of the species (Jang et al., 2023). Finally, agricultural

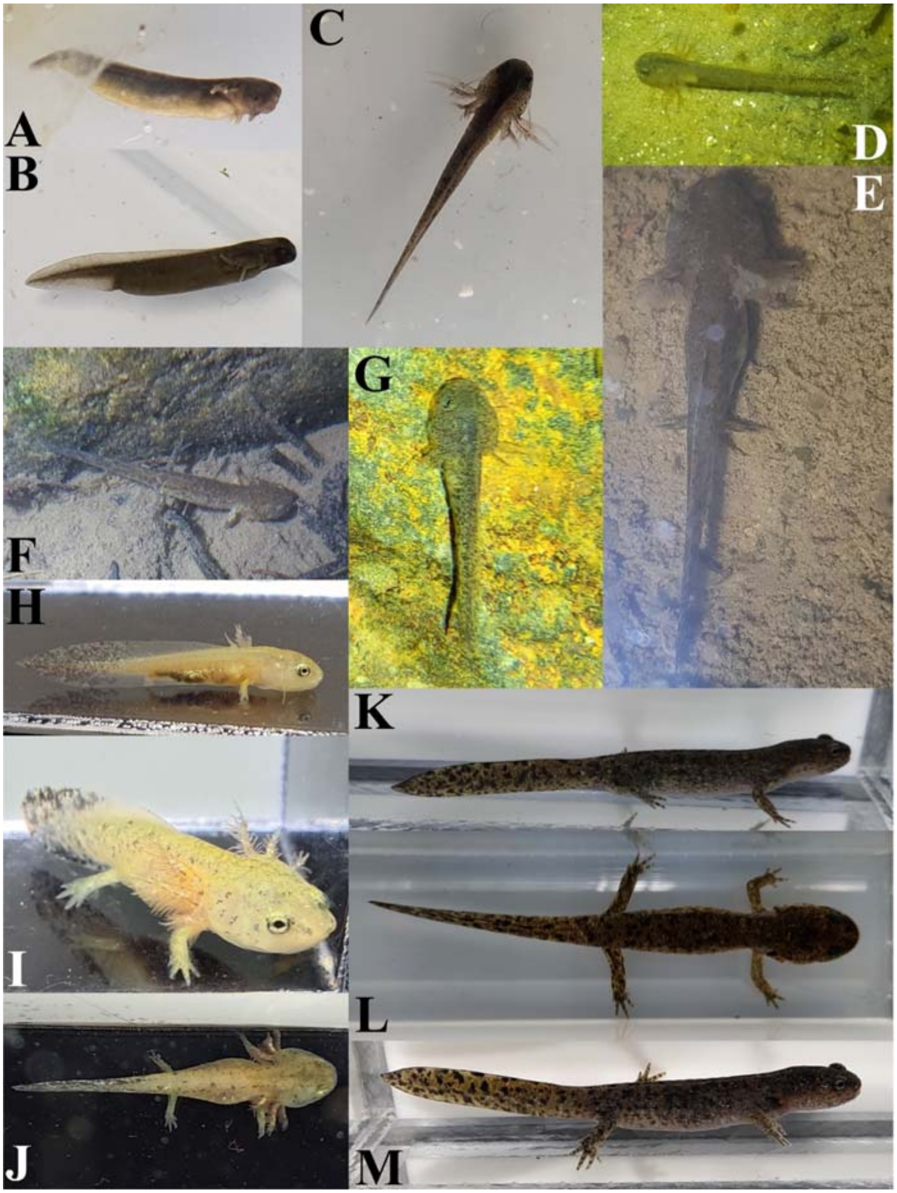

FIG. 8.15

Larvae of *Hynobius leechii*. Gills appear during development (A—C), when the larvae become free-swimming, and disappear before metamorphosis. Development takes a few months with metamorphosis during summer, and larvae can reach about 3 cm long before metamorphosis (D—M).

From Amaël Borzée.

chemicals have a strong impact on the development of *H. leechii*, resulting in the deformation and death of embryos and larvae (Park et al., 2010).

As a result of these threats, the species is listed as Least Concern, despite a decreasing population size, by the IUCN Red List (IUCN SSC Amphibian Specialist Group, 2019a). The decrease is principally linked to the ongoing decline in the extent and quality of habitat. Habitat destruction and degradation are mostly resulting from the expansion of urban areas, the intensification of agriculture and logging, and the decrease in water quality due to agricultural practices. The species is not used or harvested, but it is sometimes kept as pet in non-range countries, and it occurs in many protected areas, within all three range countries.

8.2.1.5 Identification

The species is the caudata species overlapping with the largest number of other species in the region. It is sympatric with four other *Hynobius* species, four *Onychodactylus*, two *Salamandrella* and one *Karsenia* species. Adults are easily discriminated from *Onychodactylus* due to the absence of black claws and yellow-orange patterns, from *Salamandrella* by the absence of a broad dorsal stripe (although a very thin yellowish stripe is sometimes but rarely visible in *Hynobius*) and from *Karsenia* by the absence of the broad dorsal stripe and clear pattern at the base of the tail. For the discrimination with the other *Hynobius* species, see the text for each species independently below. *Hynobius* tadpoles have three pairs of gills, and two balancers during the early stages of their development. Adults have 11 to 13 costal grooves, and males can be identified by the arrow shape of the cloaca, with an obvious bulge during the breeding season (Fei et al., 2006). Adults are highly variable in colouration, ranging from yellowish, to brown or black with light blue or dark brown speckles. Light-coloured speckles are more abundant in younger individuals.

8.2.2 *Hynobius yangi*

8.2.2.1 Origin and distribution

Hynobius yangi, or the Kori Salamander, was described from Jangan in Busan in R Korea (Kim et al., 2003). The clade in which the species is clustered diverged around 9 million years ago (Baek et al., 2011) and the species diverged from the sister clade *Hynobius leechii* around 5.3 (Baek et al., 2011) to 4.3 million years ago (Kim et al., 2007), in the early Pliocene.

The Kori Salamander occurs across a very restricted range (Borzée and Min, 2021) in the Miryang subbasin of the Gyeongsang Basin in the extreme southeastern R Korea (Kim et al., 2003, 2007). Its range is bordered by the metropolises of Busan, Yangsan and Ulsan, and it is regularly decreasing due to urban extension (Fig. 8.16).

8.2.2.2 Habitat

The species occurs across agricultural and natural landscapes, but it is generally more abundant in broad-leafed and mixed forests in hilly landscapes, ranging from sea level to 360 m of elevation (Andersen et al., 2022). The species is breeding

FIG. 8.16

Distribution of *Hynobius yangi*, the Kori Salamander.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

equally abundantly in isolated stream pools and small and shallow lentic water bodies such as fallow rice paddies before rice plantation. The habitat of the species is generally limited to the area between three metropoles, and as a result, heavily modified.

8.2.2.3 Behavioural ecology

Hynobius yangi is present at the breeding site between mid-February and mid-April, with a peak in spawning activity in mid-March (Groffen et al., 2022). The breeding behaviour of the species is generally similar to that of *H. leechii*, with males present at the breeding site earlier than females (Fig. 8.17), and competing for oviposition perches, and then for fertilisation through scramble competition (Park et al., 2015). Eggs are not always attached to the substrate, which includes a large proportion of underwater wooden structures, and some are left at the bottom of the water body in totally stagnant environments (Fig. 8.18). Females reach sexual maturity at three years old, while males can be sexually mature from two years old, and males and females reach a maximum of 11 and 10 years, respectively (Lee et al., 2010). The number of eggs per clutch is lower than in *H. leechii*, with an average of 66 eggs, and a maximum of 86 eggs (Kim et al., 2003; Lee et al., 2010), which take about three weeks to hatch, and up to three months for individuals to reach metamorphosis, based on food availability and water temperature (Fig. 8.18). The species is active until November, and emerges from hibernation from January (Groffen et al., 2022), depending on temperature and rain.

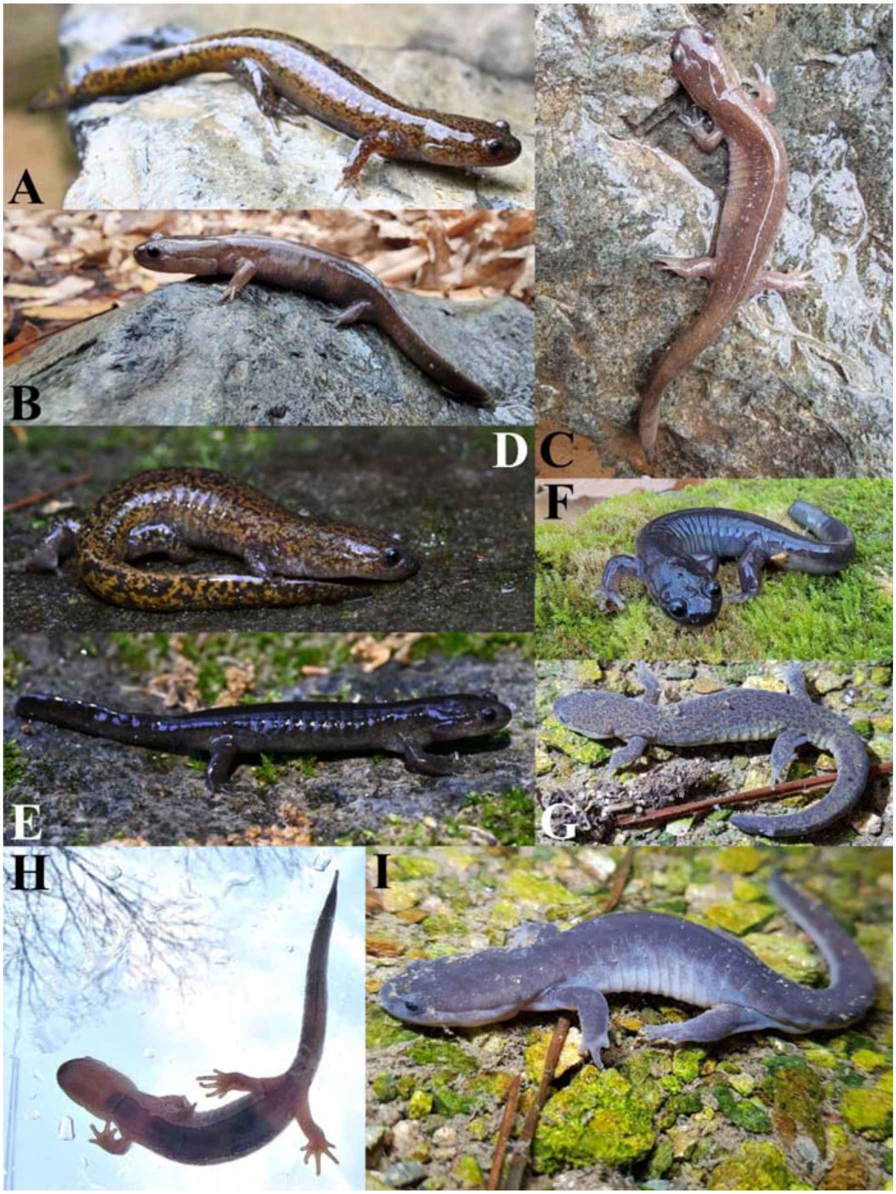

FIG. 8.17

Adult *Hynobius yangi*. Adults are variable in colours (A–I), but generally larger and broader than *H. leechii*, although visual identification requires several morphological cues. The species is not aquatic as adults, except during the breeding season when they can spend a few days or weeks in the water (I).

From Amaël Borzée.

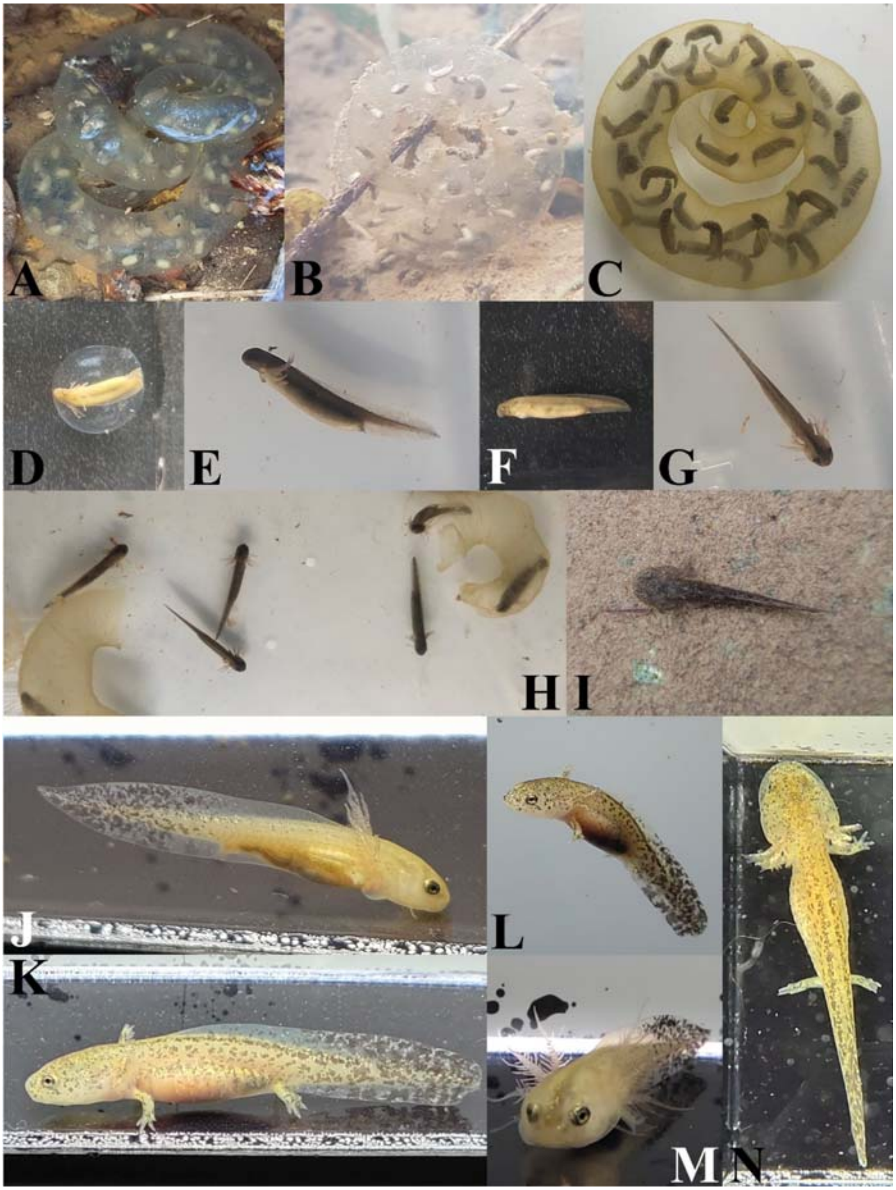

FIG. 8.18

Eggs and larvae of *Hynobius yangi*. The number of eggs per egg sacs is smaller than in *H. leechii* (A–D), although there are no morphological criteria known yet to identify larvae of the species (E–N).

From Amaël Borzée.

8.2.2.4 Threats and conservation

The species is threatened by habitat loss (Baek et al., 2011), and cannot cope with extensive habitat changes (Groffen et al., 2022), and when living in substitute agricultural habitats, the development of embryos is strongly and negatively impacted by chemicals resulting from agriculture, resulting in death and deformation (Park et al., 2010). In addition, the current habitat of the species is declining (Kim et al., 2003) and in the future, it is going to be strongly restricted by the development of the Busan, Ulsan and Yangsan metropoles, which are surrounding the range of the species and gradually merging into each other (the habitat is shared with *O. sillanus* for which habitat decline analyses are available; Borzée et al., 2022). In addition, a sharp decrease in habitat suitability is predicted because of climate change (noting the species misidentification in the analysis and potential bias; Kim et al., 2021).

As a result of these threats, the species is decreasing in population size, and listed as Endangered by the IUCN Red List (IUCN SSC Amphibian Specialist Group, 2019d), and at the national level (NIBR, 2019). The estimated extent of occurrence of the current known range is 512 km^2, divided into four threat-defined locations, with a severely fragmented population and a continuous decline in the extent and quality of habitat (IUCN SSC Amphibian Specialist Group, 2019d). The species is not used by humans, but it is kept as pet in a few rare cases, and it occurs in the Hoedong Water Source Protection Area. The construction of a nuclear plant has previously resulted in the translocation of the species (Kim et al., 2003; Baek et al., 2011). The species was anecdotally used for human consumption up to 40 years ago (Pers. Com. Mr Moon), a practice that has now stopped.

8.2.2.5 Identification

Hynobius yangi is sympatric with *O. sillanus*, although the two genera are easily discriminated through the claws and patterns as adults and larvae. The species is also in close geographic proximity with *H. leechii*, with some sympatric populations, where *H. yangi* can be identified, with difficulties, through its larger size, longer tail, and general blunter morphology (Kim et al., 2003), but not the number of costal grooves (Yang et al., 1997). The two sexes can be identified, with difficulties, by the larger heads of males and longer bodies of females (Kim et al., 2003). Males have a paddle-shaped tail (i.e., ovoid and not round in transection) during the breeding season, which is distinct from the cylindrical tail of females. No method is yet known to distinguish species in *Hynobius* tadpoles.

8.2.3 *Hynobius geojeensis*

8.2.3.1 Origin and distribution

Hynobius geojeensis, or the Geoje Salamander, was described from Geoje Island in South Gyeongsang Province in R Korea (34.850992°N, 128.590398°E; Borzée and Min, 2021). The species is clustered with *Hynobius perplicatus* (Suk et al., 2019), and the two species form a clade basal to the *Hynobius quelpaertensis* group. These

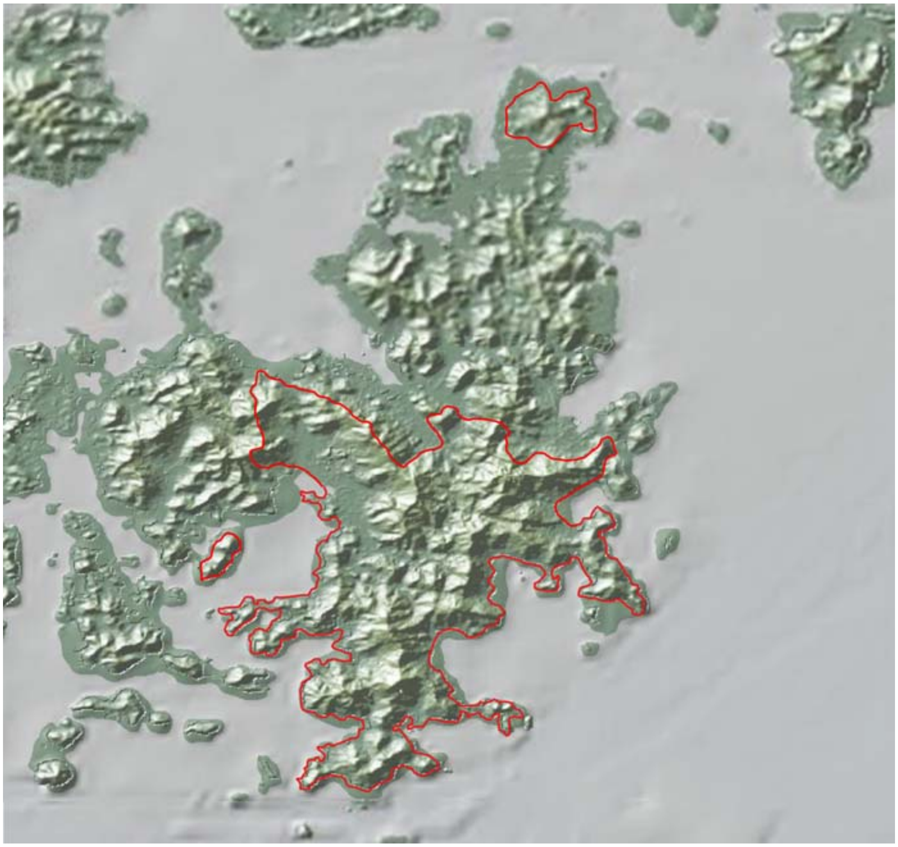

FIG. 8.19

Distribution of *Hynobius geojeensis*, the Geoje Salamander.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on Ahn (2023) and an updated IUCN Red List of Threatened Species distribution map.

five remaining species diverged from *H. leechii* and *H. yangi* about 5 million years ago (Baek et al., 2011).

The Geoje Salamander is a microendemic species restricted to Geoje Island, immediately off the southern mainland coast of R Korea (Borzée and Min, 2021, Fig. 8.19). The northern distribution of the species was recently resolved by involving citizen science participation, and providing key information (Ahn, 2023). It is sympatric with *Hynobius notialis* in the northern part of its limited range.

8.2.3.2 Habitat

The habitat of the species is much drier than that of other *Hynobius* species due to its distribution being restricted to an island, where is it mostly present in, or at the edge of, broad-leafed forests, between 20 and 250 m of elevation (Andersen et al., 2022).

The species breeds in very shallow water bodies only, although mildly flowing in some cases, on comparatively steep slopes, and in some cases in small cave-like cavities where the eggs are strongly anchored.

8.2.3.3 Behavioural ecology

The species is active at the breeding sites from late February, and oviposition is done between mid-March and mid-April, although adult males can be found at the breeding site until mid-May (Fig. 8.20; Groffen et al., 2022). Data on the behavioural ecology of the species is still uncommon although it is expected to follow the same pattern as that of other *Hynobius* in the region (see *H. leechii*), although some variation is to be expected due to the very shallow nature of some of the breeding sites, with the water reaching as low as one-third of the height of the egg sacs. For this reason, the egg sacs can have very sturdy egg stalks to anchor them under rocks in cavities, or unattached stalks in lentic habitats (Fig. 8.21). There is not much data available about hibernation in this species, but it is likely active on warm days as late as late November, and emerging in mid-January in warm and humid days.

8.2.3.4 Threats and conservation

The species cannot cope with extensive habitat changes (Groffen et al., 2022), but most of the known range where *H. geojeensis* is not occurring in sympatry with *H. notialis* is earmarked for the development of golf fields. In addition, the already restricted range of the species is impacted by the highly developed and industrialised shipyards on the island. The species is also impacted by climate change (Borzée and Min, 2021), and it likely to see a sharp decline in habitat suitability due to climate change (noting the limitation of the study due to species misidentifications; Kim et al., 2021). Finally, *H. geojeensis* is likely to be sensitive to pollution from agricultural chemicals (Park et al., 2010). The species has not yet been assessed by the IUCN Red List, but with a range estimated to be $<500\,\text{km}^2$, an area of occupancy $<100\,\text{km}^2$ and a declining population, the species is likely to be Critically Endangered following the criteria of the IUCN Red List (Borzée and Min, 2021). The species occurs in a National Park, and it is not currently used or harvested for human activities.

8.2.3.5 Identification

The species is sympatric with only one other caudata species, *H. notialis*, on the northern half of its range, north of the city of Geoje. However, *H. geojeensis* is generally broader and longer than *H. notialis*, although *H. geojeensis* limbs are shorter than that of *H. notialis* based on body size and body ratios. Although difficult to identify in the field, the combination of the following characters is diagnostic of the species: SVL $>$ 45.59, TL $>$ 32.67, GA $>$ 22.94, CW $>$ 7.58, HLL $>$ 7.97 and HL $>$ 10.70 (in mm; Borzée and Min, 2021). The is no method yet to distinguish *Hynobius* species in tadpoles.

FIG. 8.20

Adults and eggs of *Hynobius geojeensis*. The adults of the species are variable in colours, and they may have a thin line at the centre of their back (A–F). The habitat where the species occurs is comparatively dry, and spawning (G–K) is sometimes done in water less deep than the egg sac is thick (L).

From Amaël Borzée.

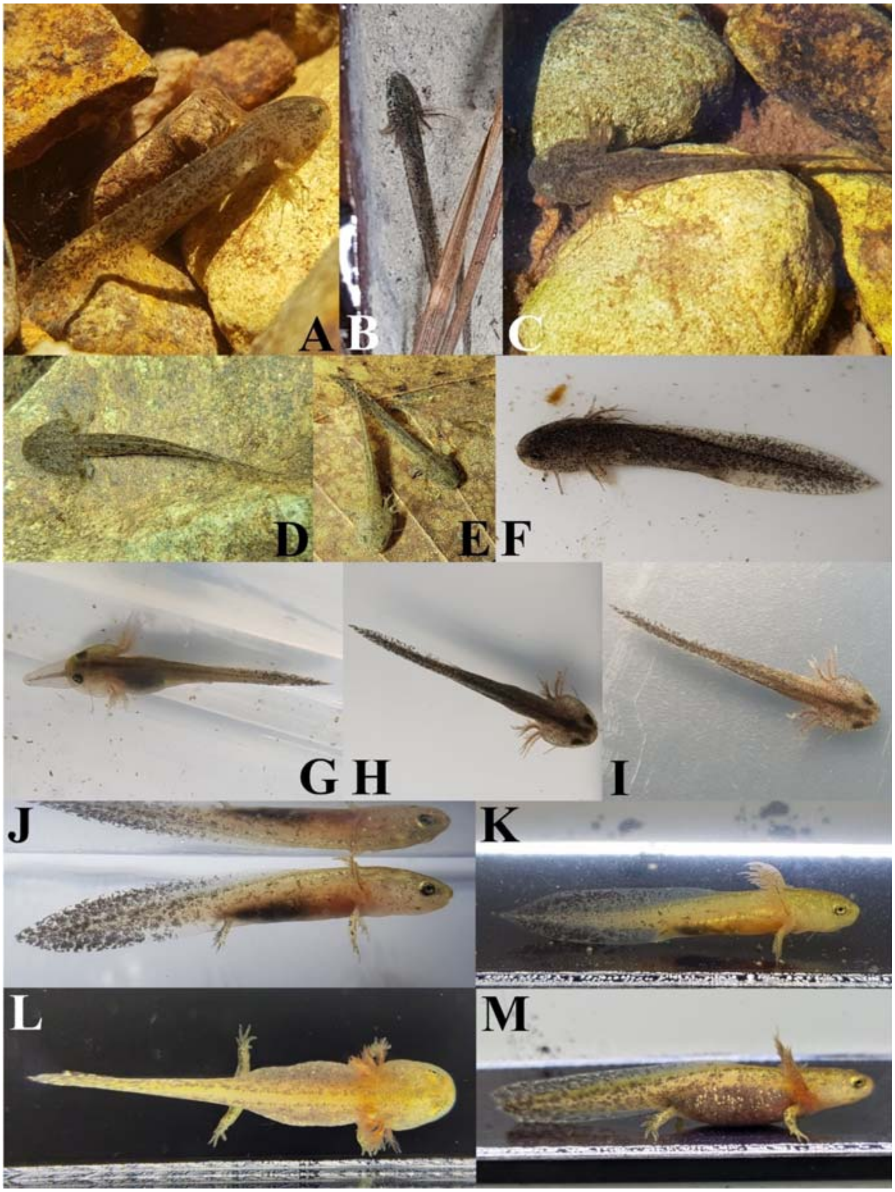

FIG. 8.21

Larvae of *Hynobius geojeensis*. Development in the species is temporally matching with that of other species in the region (A—M). Most *Hynobius* species are cannibalistic, but this species may be comparatively more reliant on this mode of predation (J) due to the isolated nature of the breeding sites.

From Amaël Borzée.

8.2.4 *Hynobius perplicatus*

8.2.4.1 Origin and distribution

Hynobius perplicatus, the Cryptic Uiryeong Salamander, or Uiryeong Salamander, was described from Uiryeong in R Korea (35.348198°N, 128.291133°E; Borzée and Min, 2021). The species is clustered with *Hynobius geojeensis* (Suk et al., 2019), and the two species form a clade basal to the *Hynobius quelpaertensis* group. These four remaining species diverged from *H. leechii* and *H. yangi* about 5 million years ago (Baek et al., 2011).

The Cryptic Uiryeong Salamander is not limited to the Uiryeong area as originally described (Borzée and Min, 2021), but it is also found further south, reaching 12 km north of Jinju to the west, Masan Happo-gu on the coast to the south and western Changwon to the west (Kim et al., 2023), where is it sympatric with *H. notialis*. Its northern boundary is on the southern bank of Hapcheon Reservoir, south of Hapcheon, as originally described (Fig. 8.22).

8.2.4.2 Habitat

The habitat of the species is different from that of other *Hynobius* species in R Korea in that it only weakly overlaps with rice agriculture, doing so only in the newly described southernmost populations, and as a result, the species is very rarely seen breeding in fallow rice paddies. It is generally found in slowly flowing streams, or isolated stream pools, in broad-leafed or mixed forests, from low to comparatively

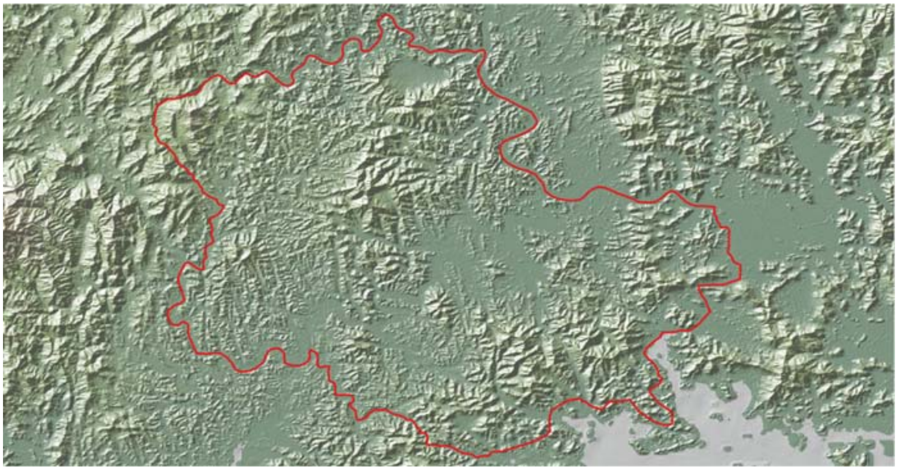

FIG. 8.22

Distribution of *Hynobius perplicatus*, the Cryptic Uiryeong Salamander or Uiryeong Salamander.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

high elevation. The species is found from near sea level up to 700 m of elevation, with most populations around 300 m (Andersen et al., 2022).

8.2.4.3 Behavioural ecology

Males of the species can be found active in the vicinity of the breeding site from late January on warm and humid days, but spawning actively starts from late February to early April, with a peak in March (Fig. 8.23). As the species is mostly breeding in slow-flowing water bodies, most egg sacs are strongly anchored under rocks, in shallow or relatively deep water, with the lowest found around 50 cm underwater. The breeding behaviour has not been studied in this species, but it is expected to be similar to that of other *Hynobius* species in the region (see *H. leechii*). Metamorphosis takes place from July, and individuals start hibernation from late November (Fig. 8.24).

8.2.4.4 Threats and conservation

The species is not able to cope with extensive habitat changes (Groffen et al., 2022), which also facilitates the presence of predators in larger numbers than in natural habitats (Bae et al., 2017). *Hynobius perplicatus* is also impacted by climate change (Borzée and Min, 2021), and likely to see a sharp decline in habitat suitability (noting the limitation of the study due to species misidentifications; Kim et al., 2021). In addition, the embryos and larvae of the species are likely to be sensitive to pollution from agricultural chemicals (Park et al., 2010). The species has not yet been assessed by the IUCN Red List, but with a declining population and a range <1000 km^2, it is likely to be Endangered following the criteria of the IUCN Red List.

8.2.4.5 Identification

The species is sympatric with either *H. leechii* or *H. notialis* over the totality of its range. It is the largest of all Korean *Hynobius* species (Borzée and Min, 2021), and it is difficult to morphologically identify it as there are no known discrete morphological traits. In general, *H. perplicatus* is larger in term or snout-vent-length, tail length, head length, head width and interorbital distance than both sympatric species. No method is yet known to distinguish species in *Hynobius* tadpoles.

8.2.5 *Hynobius quelpaertensis*

8.2.5.1 Origin and distribution

Hynobius quelpaertensis, or the Jeju Salamander, was first mentioned as a subspecies by Mori (1928), and it was elevated to the species level by Yang et al. (1997), although Yang et al. (1982) and Uh et al. (1992) already treated the population as an independent species. The species is clustered with *H. unisacculus* and *H. notialis* (Suk et al., 2019), and it is basal to both (Baek et al., 2011). The species is estimated to have diverged between 1.5 and 1.2 million years ago (Yang et al., 1997). Despite the mainland and island distribution, there is gene flow between

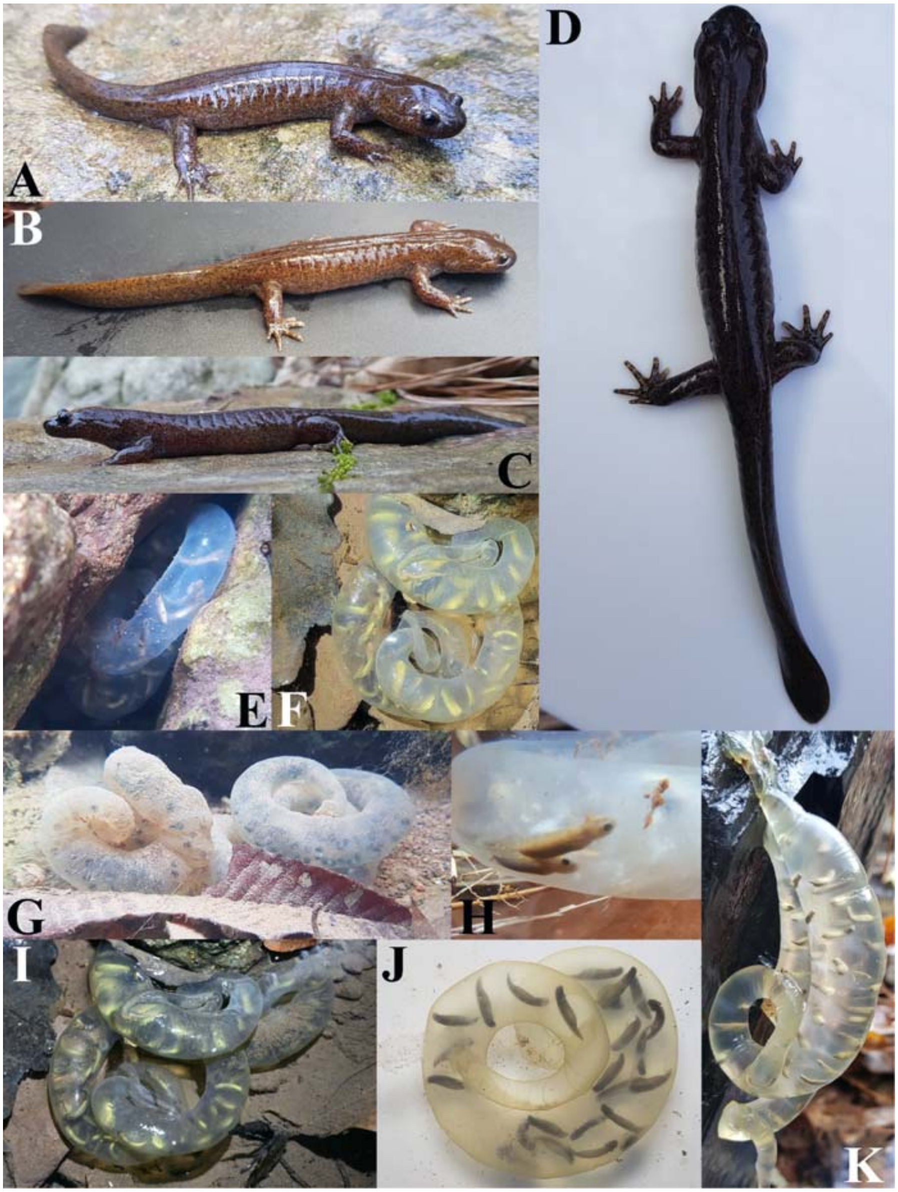

FIG. 8.23

Adults and egg sacs of *Hynobius perplicatus*. On average, the species is the largest of the genus in R Korea, although identification in the field is difficult (A–D). As the species generally breeds in flowing streams, most eggs are attached by gelatinous stalks under rocks (E–K).

From Amaël Borzée.

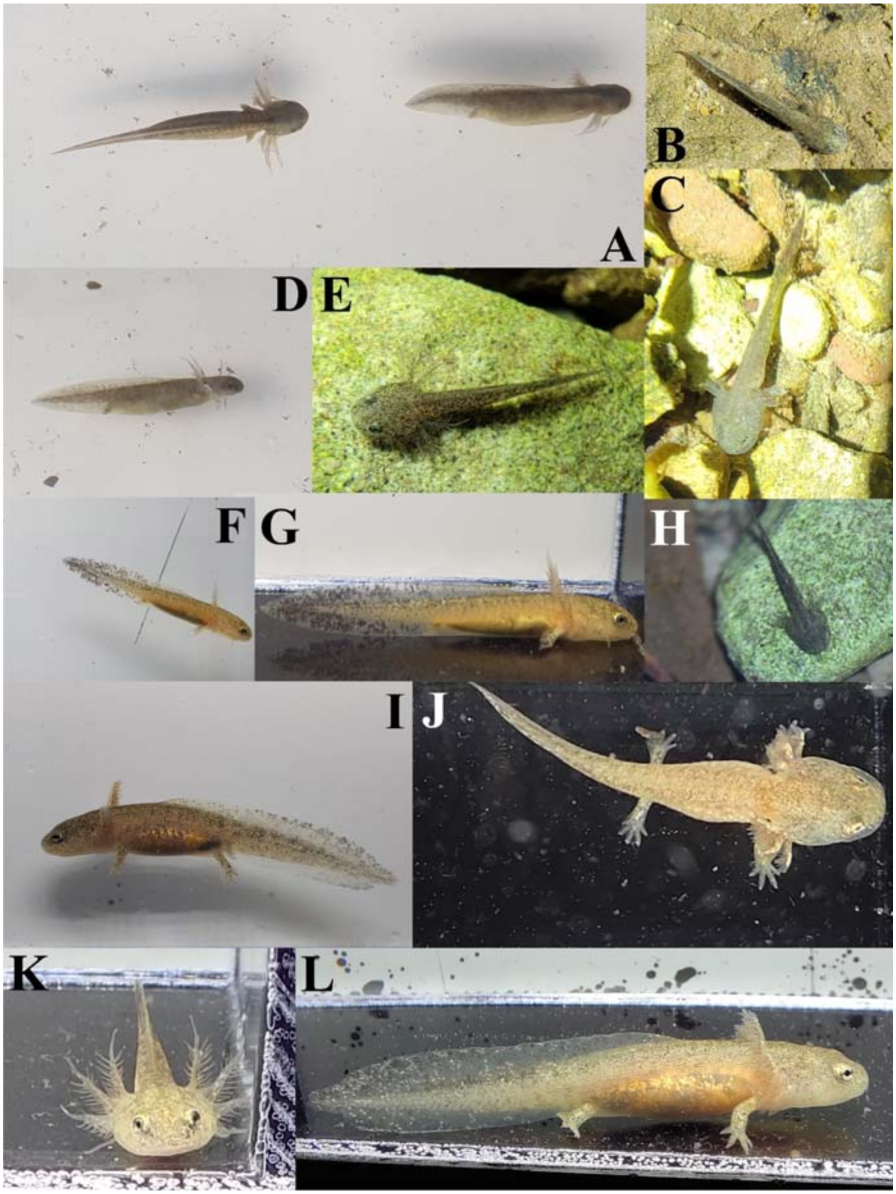

FIG. 8.24

Larvae of *Hynobius perplicatus*. Larvae swim out of the egg sacs once free swimming (A, B and D), and they stay in the section of the stream with the slowest flow. By the time the larvae are large, streams have generally slowed, and they continue their development in isolated stream pools (C and E–L).

From Amaël Borzée.

FIG. 8.25

Distribution of *Hynobius quelpaertensis*, the Jeju Salamander.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima'with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

populations, although to a lower extent for the subclade distributed on Jeju Island (Suk et al., 2019).

The Jeju Salamander (Yang et al., 2001) is distributed all the way north to Buan on the mainland, with some population north of Jiri Mountain overlapping with *H. leechii*. The species then distributes southwards towards Jangheung, and some of the larger islands further south, all the way to Jeju Island (Borzée and Min, 2021, Fig. 8.25).

8.2.5.2 Habitat

Hynobius quelpaertensis is found in a comparatively diverse habitats, as it is found on the mainland as well as on Jeju Island. On the mainland, it is found in the vicinity of isolated pool streams and shallow lentic water bodies in broad leaf, conifer and mixed forests. The species also commonly breeds in fallow rice paddies at the edge of forested hills. On Jeju Island, the habitat is different due to the geomorphological properties of the island and the species breeds in deeper water pools, with egg sacs recorded down to 1.50 m below the surface. The species also uses isolated and shallow pools in large riverbeds. Due to the scarcity of rice farming on the island, *H. quelpaertensis* is rarely found breeding in agricultural habitats there. The species is found from sea level to 1200 m of elevation (Andersen et al., 2022).

8.2.5.3 Behavioural ecology

The species starts breeding in late December on Jeju Island, but eggs can be spawned until late April on the mainland (Groffen et al., 2022). The species has been seen active throughout the year in Jeju, although it is inactive under rocks during the coldest period of winter, and shows a clearly marked hibernation period at higher latitudes. The species exhibits the same courtship behaviour as *H. leechii*, and males can be arduously competing to preserve access to specific wooden sticks for egg deposition, generally not in contact with any other substrate (Fig. 8.26). Males touch females with their snouts, and then females do the same shortly before oviposition. One, or several, males grab the female and/or one of the egg sacs, and maintain an "amplexed" position for several minutes. Other males sometimes dislodge the original male through scramble competition, and sperm competition is likely to occur. Females do not stay in the water body for more than a few days, while males can be there for several weeks for multiple mating. The eggs will take a few days to two weeks to hatch, depending on temperature, and the larvae will be ready to swim out of the egg sacs once fully developed (Fig. 8.27). Both male and female *H. quelpaertensis* have been reported to reach sexual maturity from three years old, and live a maximum of ten years (Lee et al., 2010), an interesting divergence from other *Hynobius* species in the area.

8.2.5.4 Threats and conservation

The species is impacted by habitat modification (Baek et al., 2011) and it cannot cope with extensive habitat changes (Groffen et al., 2022), which also enables increased predation pressure by fish (Bae et al., 2017). The species is also threatened by climate change, and models for suitable habitat for the species predict a weak decrease in suitable habitat by 2030, 2050 and 2080 under different climate change scenarios (for the population in Jeju; Kim et al., 2021). Climate change is also impacting the breeding phenology of the species (Jang et al., 2023). In addition, *H. quelpaertensis* is likely threatened by agricultural chemicals, resulting in the deformation and death of embryos (Park et al., 2010). Anecdotal observations link the inability of larvae to emerge from egg sacs that have become rigid because of polluted water. Finally, inland populations increased in size about 100,000 years ago, although not on Jeju Island, and the species does not show historical declines (Suk et al., 2019).

Despite being common within its range, the habitat of *H. quelpaertensis* is declining, and the species is listed as decreasing and Vulnerable by the IUCN Red List (IUCN SSC Amphibian Specialist Group, 2019b) because of its restricted extent of occurrence and its presence in between three and nine threat-defined locations. The habitat is degraded by deforestation and logging, the expansion of urban areas and water pollution. The species is not harvested or used for human activities in large numbers anymore, although there are some isolated reports of the species still being wild-caught for the pet trade, where it is abundant. The Jeju Salamander occurs in several protected areas, both on Jeju Island and on the mainland.

8.2.5.5 Identification

The species is sympatric with *H. leechii* in the northern parts of its range, and with *H. unisacculus* in the northwest. It can be discriminated from *H. leechii* through a combination of morphological characters (Yang et al., 1997), and a generally smaller

FIG. 8.26

Adult *Hynobius quelpaertensis*. The species is highly variable in colouration (A–M). During the breeding season, males and females can be identified by their cloaca (E and F) as well as their paddle-shaped tails. Eggs can be seen in the body cavity of females ready to spawn (L). Males compete to preserve access to specific structures for egg deposition (M).

From Amaël Borzée.

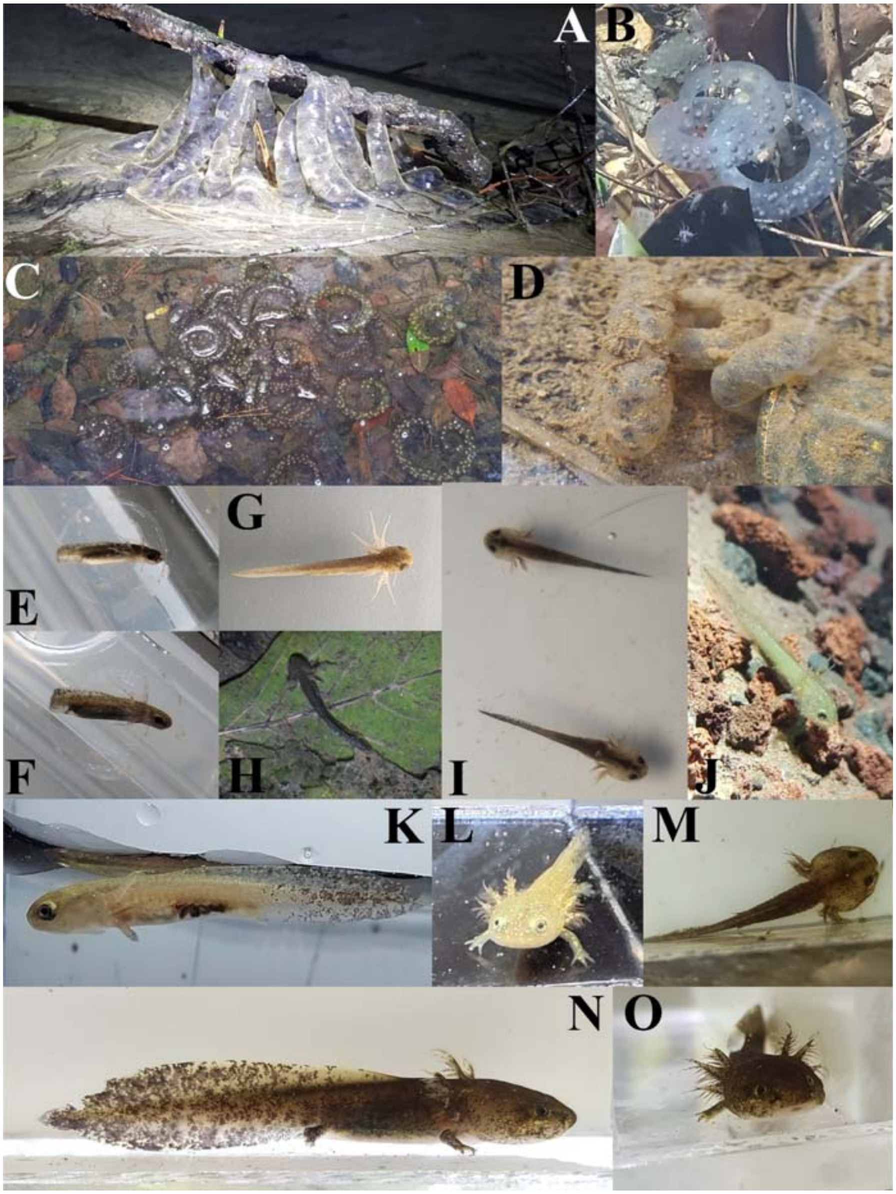

FIG. 8.27

Eggs and larvae of *Hynobius quelpaertensis*. Eggs on Jeju Island can be spawned from late January, and they can be attached to the substrate or left in the water (A—D). Development of the larvae in the species follows that of other *Hynobius* species (E—O), and some individuals can show a cannibalistic morph, identifiable through the much larger head (M).

From Amaël Borzée.

body size (Borzée and Min, 2021). The species can be distinguished from *H. unisacculus* through its much larger size, and specifically longer limbs and tail but shorter body (Min et al., 2016). There is no method yet to distinguish species in *Hynobius* tadpoles.

8.2.6 *Hynobius unisacculus*

8.2.6.1 Origin and distribution

Hynobius unisacculus, or the Korean Small Salamander, was described from Oenaro Island in Goheung, South Jeolla Province, R Korea (Min et al., 2016). The species is clustered with *Hynobius notialis*, but there is a large genetic variation between the two species (Min et al., 2016; Suk et al., 2019). The Korean Small Salamander was originally known to occur in Goheung, Suncheon, Boseong and Yeosu areas, which includes the type locality on Naero Island (Min et al., 2016). However, the species is now known to occur further north inland towards the base of Jiri Mountain. It is restricted to Boseong to the west, and eastern Suncheon, and almost reaches the Gwangyang area to the east, where it is sympatric with *Hynobius notialis* (Borzée and Min, 2021, Fig. 8.28).

8.2.6.2 Habitat

The species is found in the vicinity of broad-leafed and mixed forests, and it breeds almost exclusively in lentic water. Due to the development of landscapes, the species is now predominantly relying on fallow rice paddies and the surrounding ditches as

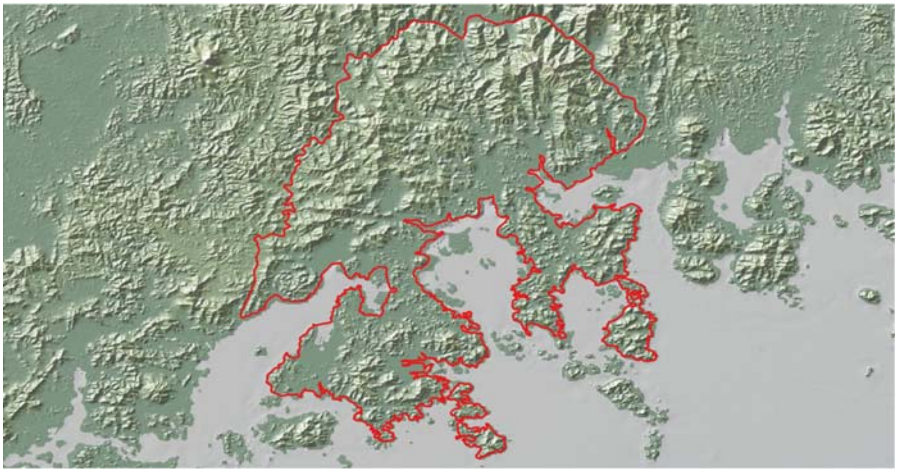

FIG. 8.28

Distribution of *Hynobius unisacculus*, the Korean Small Salamander.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

breeding habitats. Outside of the breeding season, the species is found in the leaf litter or under the substrate of the forested hills surrounding the breeding habitat (Min et al., 2016). The species is generally restricted to lower elevations, between sea level and 550 m of elevation (Andersen et al., 2022).

8.2.6.3 Behavioural ecology

Hynobius unisacculus can be found breeding from late January, until mid-April (Fig. 8.29), but the peak activity is in early March (Groffen et al., 2022). The mating behaviour of the species is not as well described as the one of *H. leechii* but it follows the same generalities, although females lay smaller egg sacs that are generally less coiled than that of the other species (Fig. 8.30), and containing only 17 to 88 eggs each (Song and Koo, 2010). As the species almost exclusively breeds in lentic water bodies, the egg stalks are generally weak or absent, and the egg sacs are not attached to the substrate (Min et al., 2016), but deposited on top of it, with a potential preference for flooded leaf litter or soil. Hatching takes about ten days in adequate temperatures, and metamorphosis happens in July or August. The species starts hibernating from mid-November, and can be found active close to the breeding habitat from mid-January on warm and humid days (Groffen et al., 2022).

8.2.6.4 Threats and conservation

Similar to most *Hynobius*, the species faces habitat degradation (Baek et al., 2011) and it cannot cope with extensive habitat changes (Groffen et al., 2022), which in addition exposes the species to increased predation events by local fish (Bae et al., 2017). The species is also impacted by climate change as its habitat suitability has been modelled to drop in the future (noting the species misidentification in the analysis; Kim et al., 2021) and the breeding phenology of the species is shifting (Jang et al., 2023). In addition, the species is most likely to be impacted by agricultural chemicals, resulting in deformation and death in embryos (Park et al., 2010).

The species is decreasing in population size and it has been listed as Endangered by the IUCN Red List (IUCN SSC Amphibian Specialist Group, 2019c). Its extent of occurrence is 3402 km^2, divided into four threat-defined locations. The species has not been reported from any national park or protected area, but there are no records of the species being utilised for human consumption.

8.2.6.5 Identification

Hynobius unisacculus is sympatric with *H. quelpaertensis* and *H. notialis*, and in very close geographic proximity with *H. leechii*. The species is generally smaller with relatively slender and shorter limbs than other Korean *Hynobius* (Min et al., 2016), and significantly smaller than the species it is sympatric with. Specifically, the species can be distinguished from *H. quelpaertensis* by its much shorter tail, relatively shorter limbs but longer body (Min et al., 2016). Further, *H. unisacculus* can be discriminated from *H. leechii* by their relatively shorter tail length, shorter head, but longer body (Min et al., 2016). Finally, *H. unisacculus* can be discriminated from

FIG. 8.29

Adult *Hynobius unisacculus*. Adults in the species are variable in colour, but maybe not as extensively as the other *Hynobius* species in the region (A—K), and they are visibly smaller, which helps with identification in the field. The species can be active from very early in the season, although not spawning yet.

From Amaël Borzée.

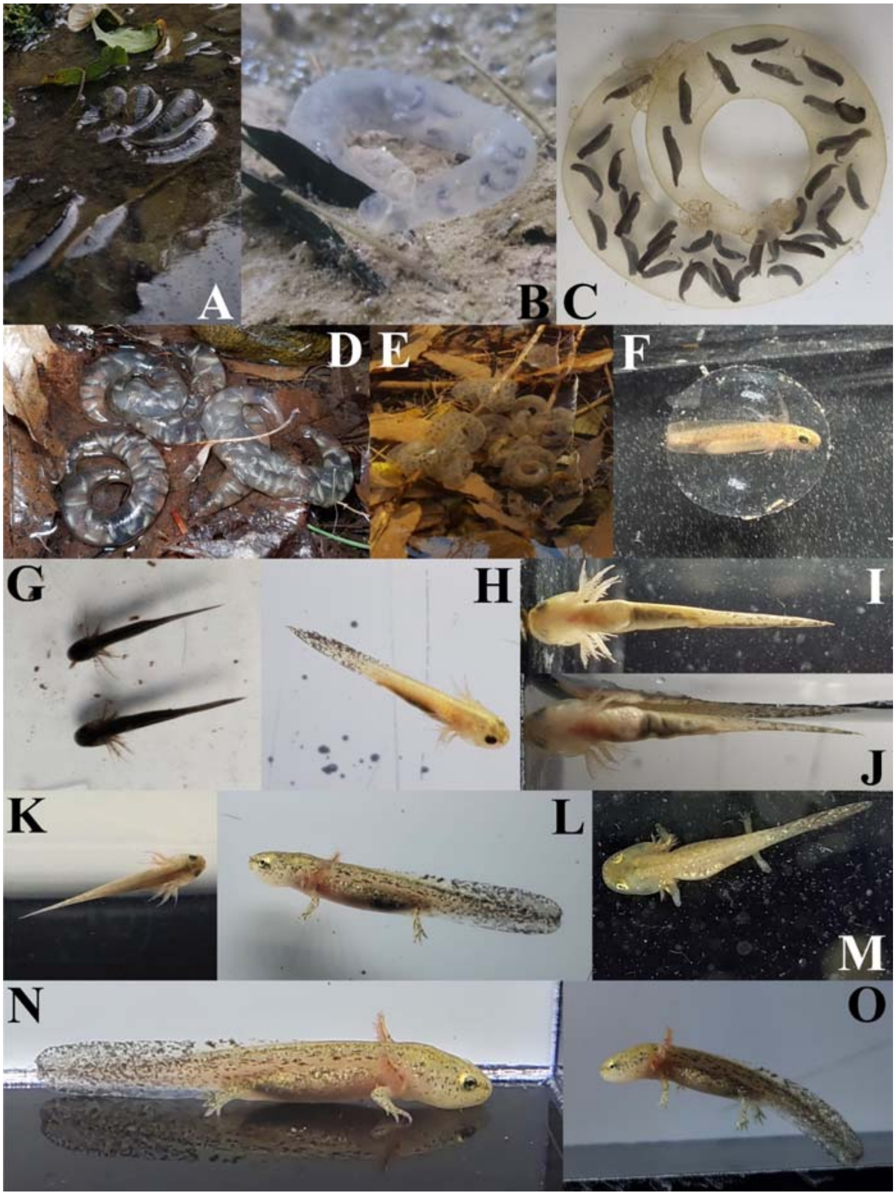

FIG. 8.30

Eggs and larvae of *Hynobius unisacculus*. Eggs can be spawned with a gelatinous stack linking them to the substrate, or not. (A–E) Hatching takes about ten days at adequate temperatures, and the larvae metamorphose from July (F–O).

From Amaël Borzée.

H. notialis by having a much shorter tail, shorter hindlimbs, and a comparatively smaller head and shorter eye-to-snout distance in males (Min et al., 2016; Borzée and Min, 2021). Sexes in adults can be distinguished, especially during the breeding season, as males have obviously swollen cloaca showing a Y-shaped slit, while females only have a longitudinal cloacal slit. Finally, males have thinner and higher tails that take a fin shape during the breeding season (Min et al., 2016). No method is yet known to distinguish *Hynobius* tadpoles.

8.2.7 *Hynobius notialis*

8.2.7.1 *Origin and distribution*

Hynobius notialis, the Southern Korean Salamander, was described from Jangmok from South Gyeongsang Province in R Korea (34.986877°N, 128.682033°E; Borzée and Min, 2021). The species is clustered with *H. unisacculus* and is characterised by a strong intraspecific barrier (Suk et al., 2019).

The Southern Korean Salamander is distributed from Gwangyang in the west, where it is sympatric with *H. unisacculus*, then along the coastal area, where it is sympatric with *H. perplicatus* in the area directly southeast of the range of this latter species, and to Masan to the east, where it is sympatric with *H. leechii*, and *H. geojeensis* on Geoje Island. The species is known to range as far as Haman in the northeast and to the feet of Jiri Mountain in the northwest. It also occurs on Namhae, Changseong, and Geoje Islands off the southern coast (Borzée and Min, 2021, Fig. 8.31). The range overlap on Geojae Island was recently resolved through the

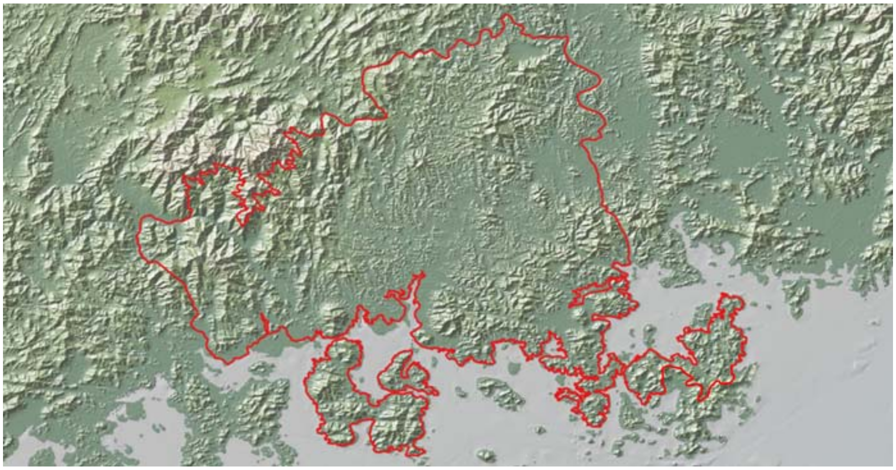

FIG. 8.31

Distribution of *Hynobius notialis*, the Southern Korean Salamander.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

help of citizen science (Ahn, 2023). Each water basin is inhabited by a clearly segregated clade (Pers. Com. Prof Min MS).

8.2.7.2 Habitat

The habitat of *H. notialis* includes broad-leafed, mixed, and conifer forests, in increasing relative proportions with the increase of elevation as the species is found from sea level to 1200 m of elevation (Andersen et al., 2022). Similarly, the species principally breeds in anthropogenically modified habitats in the lowlands, in fallow rice paddies and adjacent ditches or other man-made structures, but the habitat becomes increasingly more natural with the elevation, where the species is found breeding in slow-flowing streams, isolated stream pools and other lentic microhabitats.

8.2.7.3 Behavioural ecology

Hynobius notialis species can be found breeding from late February until mid-April, with a peak in activity in mid-March (Groffen et al., 2022, Fig. 8.32). As the species breeds from perfectly lentic to slowly flowing environments, the oviposition behaviour is variable, ranging from egg sacs deposited on the substrate without attachment, to eggs with a strong egg stalk attached to twigs or other wooden structures, to eggs attached underneath rocks (Fig. 8.33). There is no study on the breeding behaviour, or breeding phenology and development in this species, but hatching should not take more than two weeks, and metamorphosis should be done in early summer. Hibernation is likely to start around mid-November and emergence to take place in late-January, although lasting longer at higher elevations.

8.2.7.4 Threats and conservation

The distribution of the species overlaps with numerous large coastal cities, and developed areas, and as the species cannot cope with extensive habitat changes (Groffen et al., 2022), population size decreases are prevalent. In addition, changes to the habitat enable increased predation pressure by fish (Bae et al., 2017). Further, the suitable habitat for the species has been modelled to decrease under climate change scenarios (noting the analysis at the genus level on the mainland; Kim et al., 2021); and climate change is also impacting the breeding phenology of the species (Jang et al., 2023). Finally, the species is likely to be sensitive to pollution from agricultural chemicals (Park et al., 2010).

Hynobius notialis has not yet been assessed by the IUCN Red List. However, the range of the species is estimated to be $<5000\ \text{km}^2$ and the population size declining due to habitat loss and degradation, within four threat-defined locations. As a result, *H. notialis* is likely to fit the criteria to be listed as Endangered by the IUCN Red List.

8.2.7.5 Identification

Hynobius notialis shares areas of sympatry with *H. unisacculus*, *H perplicatus*, *H. geojeensis* and *H. leechii*. The species is generally larger than *H. unisacculus*

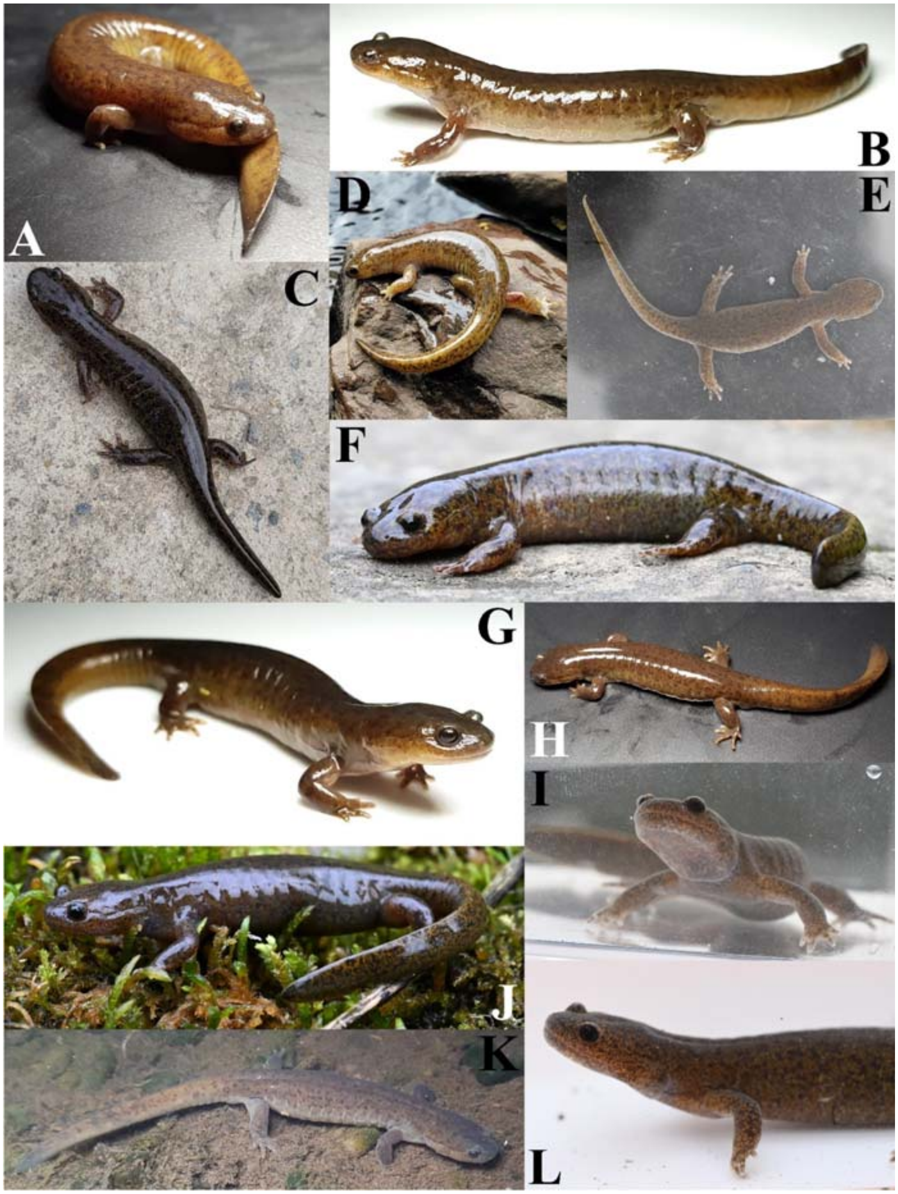

FIG. 8.32

Adult *Hynobius notialis*. Adults show a morphology intermediate to that of the species with contiguous or overlapping range, making them difficult to identify in the field (A—L). The species breeds from late February until mid-April but it can be found active almost throughout the year in warm and humid weather.

From Amaël Borzée.

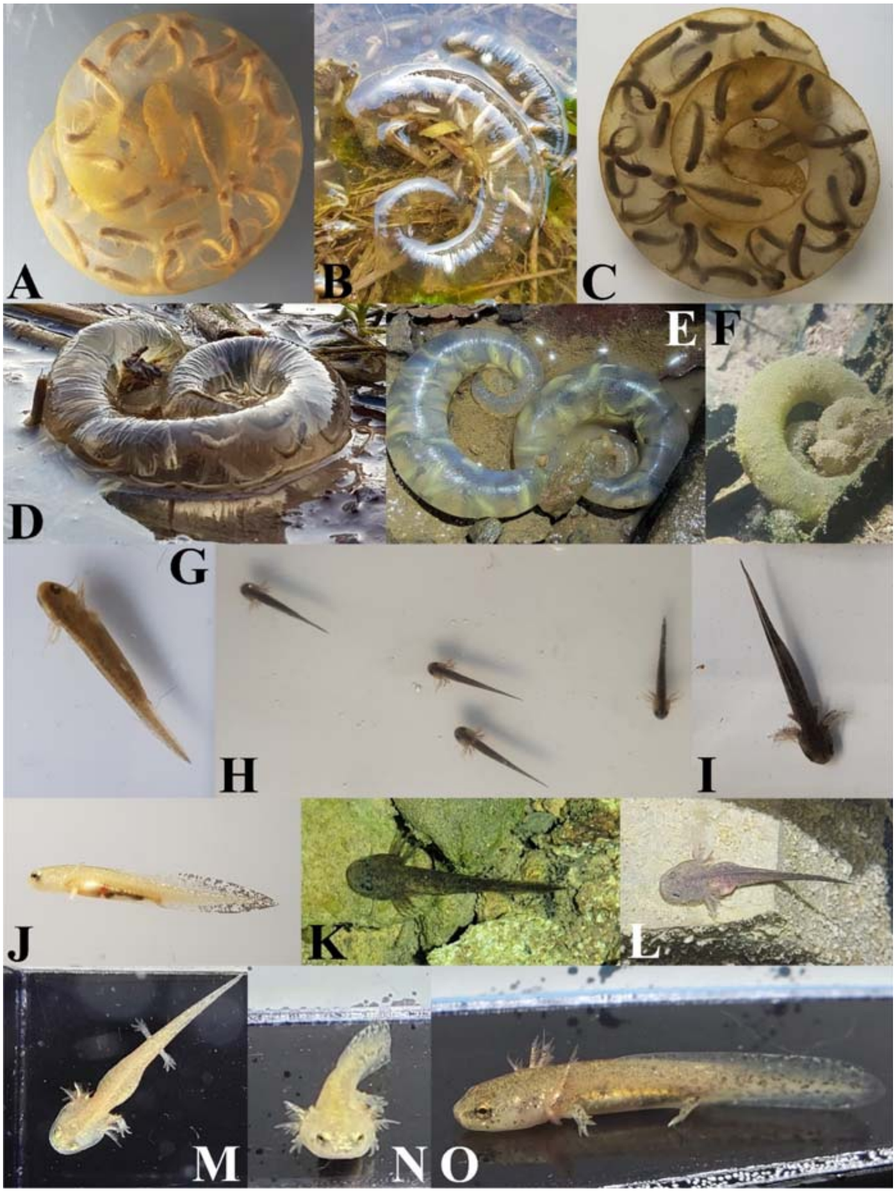

FIG. 8.33

Eggs and larvae of *Hynobius notialis*. The egg sacs can be spawned with or without the gelatinous stalks (A—F). Larval development is not known to be different to that of other *Hynobius* salamanders from the region (G—O).

From Amaël Borzée.

and smaller than *H. perplicatus* (see respective sections for additional details). However, the body size is generally similar to that of *H. geojeensis*, although the species has generally longer limbs than *H. geojeensis* (Borzée and Min, 2021). So far, there is no species identification key for *Hynobius* tadpoles.

8.3 *Salamandrella*

The *Salamandrella* genus is basal to the *Batrachuperus*, *Liua*, and *Pseudohynobius* genera, having diverged about 33.3 million years ago (28.4—38.6; Chen et al., 2015) from a shared common ancestor, or about 55 million years ago (33.6—81.2) based on the alternative tree topology of Malyarchuk et al. (2018), a radiation matching with the Paleo-Eocene thermal optimum (Poyarkov, 2010). The genus diverged through vicariance during the pre-Pleistocene glacial isolations in the southeastern parts of its current range, from a clade likely centred on Primorye Krai and the adjacent Manchu and Korean areas (Poyarkov and Kuzmin, 2008). The two species in the genus are generally not sympatric, with some exceptions (Poyarkov and Kuzmin, 2008; Malyarchuk et al., 2018).

8.3.1 *Salamandrella keyserlingii*

8.3.1.1 Origin and distribution

Salamandrella keyserlingii, or the Siberian Salamander, was described from the southwest of the Baikal Lake, close to the Kultuk Village (Dybowski, 1870). The two *Salamandrella* species diverged between 15.4 million years ago (10.7—20.2L; Malyarchuk et al., 2014) and 20.8 million years ago (10.2—35.7; Malyarchuk et al., 2018), and despite the deep divergence, the two species hybridise, for instance in the Jewish Autonomous Oblast (Malyarchuk et al., 2015). The species colonised northern latitudes, and western regions, via repeated expansions and retreats following climatic events (Poyarkov and Kuzmin, 2008), resulting in weak genetic diversity in the northern parts of its range (Malyarchuk et al., 2010). The species is characterised by intraspecific clades that radiated about 1.4 million years ago, with the southern clade about 780,000 years old, and the northern clades between 310,000 and 420,000 years old, although the youngest clades resulting from the northwest expansion into Northern Eurasia are only 150,000 and 80,000 years old (Malyarchuk et al., 2013).

The Siberian Salamander is the most widespread amphibian species of the Palearctic. In continental Asia, the species ranges from Krasnaya Rechka and Preobrazhenovka in Russia (Poyarkov and Kuzmin, 2008), Khailar area, Yichun area in Heilongjiang and central northern Inner Mongolia in China (Zhao and Bi, 1995; Fei et al., 2012), and the forested areas of northern Mongolia, with the largest population in the Selenge Basin and the southernmost population in Mongolia not far from Ulaanbaatar (Kuzmin et al., 2017). The species reaches Nizhegorodskaya Province, 45°E into European Russia to the east, and north across the polar circle,

FIG. 8.34

Distribution of *Salamandrella keyserlingii*, the Siberian Salamander.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

along the East Siberian Sea to the north. To the west, the Siberian salamander occurs on the Chukotka Peninsula, south along the Pacific coast, on Sakhalin Island, and northern and eastern Hokkaido (Goris and Maeda, 2004, Fig. 8.34).

8.3.1.2 Habitat

The species is present in a variety of landscapes and water bodies, all characterised by cold and long winters. In China, it is generally present in mountain streams and wetlands with good vegetation cover (Fei et al., 2012). In Mongolia and Russia, mountainous populations have the same requirements, however, most populations are present in plains, where they can also occur in floodplain wetlands surrounded by shrubs, and in Russia, the largest populations match with the north Palearctic taiga belt (Poyarkov and Kuzmin, 2008). Specifically, the species is generally found at the edge of the wet, coniferous, broad-leafed and mixed forests of the Taiga biozone, generally in shaded areas, close to lentic or slow-flowing water bodies (Kuzmin et al., 2008). The species can also cope with larger lentic water bodies, several metres deep, and in this case, it is restricted to areas with dense flooded vegetation that fish cannot access (Kuzmin et al., 2017). In terms of elevation, the species is present between 200 and 1800 m in China (Fei et al., 2012), while it is present between 200 and 2250 m in Mongolia (Kuzmin et al., 2017).

8.3.1.3 Behavioural ecology

Mating in the species occurs in small and isolated groups on the edge of wetlands. Both sexes are present in the vicinity of the breeding sites, under rocks and logs or at the edge of the water bodies before breeding (Kuzmin et al., 2017). Breeding starts in April in China and Mongolia (Fei et al., 2012; Kuzmin et al., 2017) but can occur until early June at higher altitudes and latitudes. Males produce body oscillations to attract females (Fig. 8.35), and during oviposition on vegetal structures, several males can form mating balls with a female, trying to fertilise the eggs through scramble competition. Each female can deposit between 50 and 200 eggs, generally attaching them to the substrate (Fei et al., 2012), and they can hatch within ten days to a few weeks based on temperature. The larvae are freely swimming by late June or early July (Fig. 8.36). Metamorphosis starts in July, occurring 80 to 100 days after spawning (Fei et al., 2012), and most individuals have metamorphosed by late July, when they first stay at the edge of the water bodies and then migrate in synchrony towards terrestrial habitats (Hasumi et al., 2014; Kuzmin et al., 2017). In extreme northern areas, hatching is reported to happen as late as August, with larvae sometimes overwintering (Raffaelli, 2022).

Once on land, juveniles and adults are mostly found under the substrate, such as rocks or logs, or deep underground to avoid water loss, on average 15 cm deep and 1 to 10 m away from the water (Kuzmin et al., 2017). Burrows are excavated by other species (Hasumi et al., 2009), and can contain aggregations of two to nine individuals (Hasumi et al., 2014). Metamorphosed individuals can move between 70 and 650 cm per day, with larger movement in young dispersing individuals recorded to move as far as 13 m in a day (Hasumi and Kanda, 2007). However, adult individuals can move about 20 m over several days after the breeding season to find a suitable microhabitat (Hasumi et al., 2009). Males migrate back to the nonbreeding habitat earlier or at the same time as females, with a preference for marshes, but females can migrate further and do not show habitat preference (Hasumi and Kanda, 2007).

Hibernation in the species starts in late September and lasts until mid-April the following year, in China (Fei et al., 2012), resulting in about 50% of the year spent hibernating. However, the time spent hibernating can reach 75% of a year at northern latitudes. Hibernation does not need to be below the frost line as adults are freeze tolerant and can survive freezing down to −30 to −40°C, and the species is also able to move at 0.5°C, with the eggs able to survive short-term freezing (Berman et al., 2016). Females are sexually mature from three to four years old, and males from two to three years old (Hasumi, 2010). Both males and females have a life expectancy of nine years, in Mongolia (Hasumi et al., 2009) and in Russia (Ishchenko et al., 1995).

8.3.1.4 Threats and conservation

The Siberian Salamander is common and widespread, living in natural landscapes, agricultural areas, and in the vicinity of urban areas, and while declining at the southern edge of its range, it is not threatened. As a result, the species is listed as Least Concerned, with a stable population by the IUCN Red List (Kuzmin et al., 2008). The threats are minor and localised, with for instance the decline of small and isolated populations in Mongolia because of droughts (Kuzmin et al., 2017). It is however important to note some local extinctions because of human activities (Munkhbaatar and Erdenetushig, 2013).

FIG. 8.35

Adult *Salamandrella keyserlingii*. Adults of the genus can be identified through the contrasting lateral and dorsal colours. The species has the broadest range for all amphibians of the Palearctic, the adults are freeze tolerant, and can spend more than half of the year in hibernation (A–G).

From Amaël Borzée.

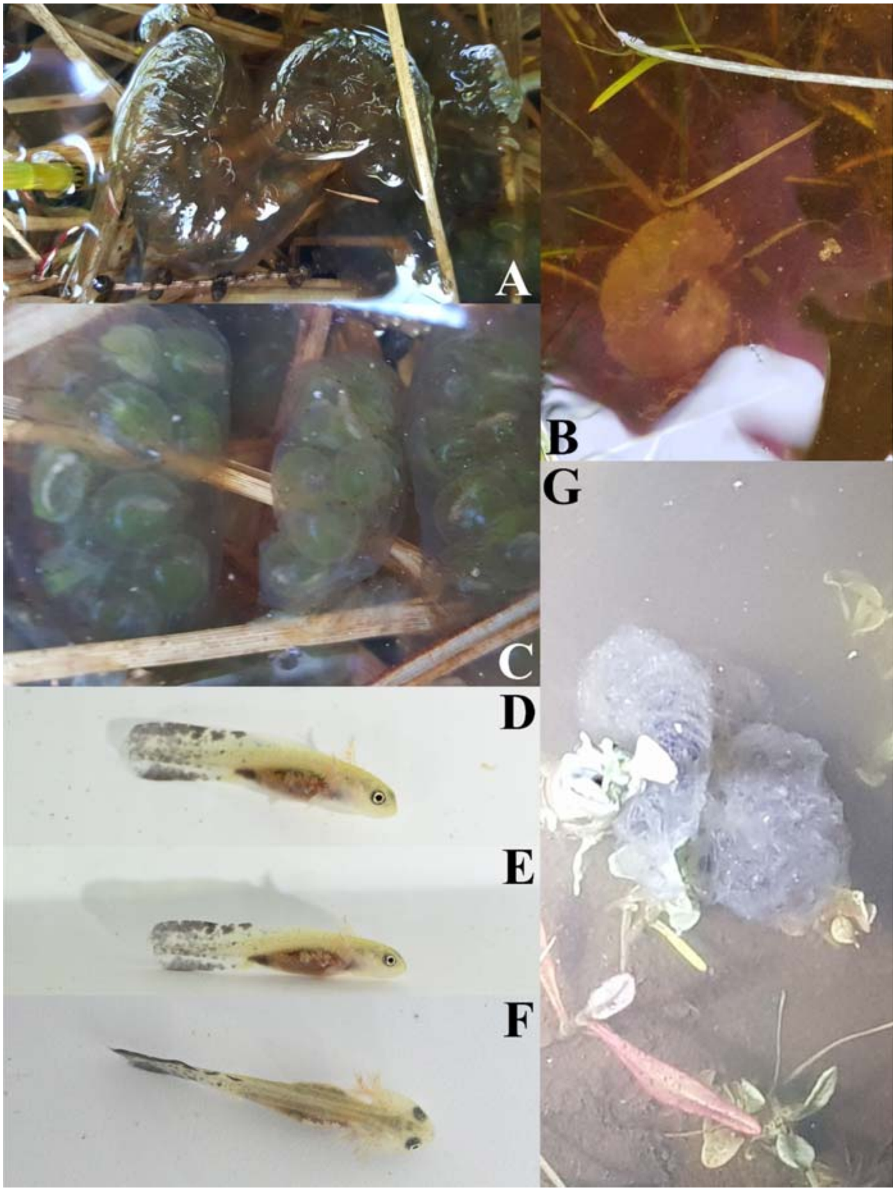

FIG. 8.36

Eggs and larvae of *Salamandrella keyserlingii*. The eggs of the species are broader than that of *Hynobius*, and reportedly able to withstand light freezing (A–C and G). The nutritive part of the egg can still be seen in the larvae after hatching, and a large part of its development (D–F).

From Amaël Borzée.

The species expanded in population size about 250,000 years ago, before contracting again during the Last Glacial Maximum around 25,000 ago and expanding again in recent years (Malyarchuk et al., 2013). Generally, some populations are impacted by habitat loss, pollution and urbanisation, and the low genetic diversity of some populations (Poyarkov and Kuzmin, 2008) may make them more sensitive to threats. The species is not exploited by humans, and it is present in multiple protected areas, across most of its range. In addition, it is listed in the Red Books of areas with low population sizes, such as the Altaiskii Region in Russia and Mongolia, and it is protected in Heilongjiang in China.

8.3.1.5 Identification

The species is sympatric with its sister species, *S. tridactyla*, with which it can also hybridise. It is also sympatric with *H. leechii* in Harbin area in China. *Salamandrella* salamanders generally have a dorsal stripe and dark flanks that are not present in *Hynobius*, and the body colouration is darker and more uniform. The species can be identified from the number of costal grooves, ranging from 12 to 15, instead of 11 to 12 in *S. tridactyla* (although Glushchenko and Maslova (2019) mention 12 to 14 costal grooves). In addition, *S. keyserlingii* has a broader body, and female body size, and egg sacs, are larger than that of *S. tridactyla* (Yartsev et al., 2016). Identifying sexes during the breeding season is easier as males have longer and higher tails, and larger cloaca, than females. *Salamandrella* larvae can reach 5 cm, while *Hynobius* larvae are generally smaller.

8.3.2 *Salamandrella tridactyla*

8.3.2.1 Origin and distribution

Salamandrella tridactyla, the Far East Salamander, was described from Vladivostok, Russia (Nikolskii, 1905), and despite its name, only about 37% of individuals have three toes, the others having four (Glushchenko and Maslova, 2019). The population was elevated to the species level based on several characters (Litvinchuk et al., 2004; Kuzmin and Maslova, 2005), although it was improperly referred to as *Salamandrella schrenckii* (e.g., Berman et al., 2005), following the taxonomic code (Poyarkov and Kuzmin, 2008), due to being named as a junior synonym of *Salamandrella keyserlingii*. The members of the *Salamandrella* genus are characterised by a deep divergence dated between 15.4 million years ago (10.7–20.2 L; Malyarchuk et al., 2014) and 20.8 million years ago (10.2–35.7; Malyarchuk et al., 2018), likely related to the drastic change in humidity of East Asia at that time (Guo et al., 2002). However, the two species can hybridise, for instance in the Jewish Autonomous Oblast (Malyarchuk et al., 2015).

The Far East Salamander (Fei and Ye, 2016) has a more narrow distribution than its sister species, present on the southern banks of the Amur River in Kabarovsk, and on both the north and south banks in the area contiguous to the Jewish Autonomous Oblast (Malyarchuk et al., 2010), but the exact distribution of the species is not yet determined (Glushchenko and Maslova, 2019). The species is distributed

FIG. 8.37

Distribution of *Salamandrella tridactyla*, the Far East Salamander.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

continuously between the Jewish Autonomous Oblast and Primorsky through Heilongjiang (northernmost location in the Harbin area), Jilin (northernmost in Changchun), and Liaoning (westernmost in Faku county) in China (Fei and Ye, 2016). Finally, the species reaches south into extreme northern DPR Korea (Borzée et al., 2021, Fig. 8.37).

8.3.2.2 Habitat

The species is present in a wide range of landscapes within its range, including broad-leaved, conifer and mixed forests, wet open meadows, and agricultural landscapes. The breeding habitat of the species is also variable, including both lentic and slow-flowing water bodies, as well as small permanent and temporary reservoirs and roadside ditches. It is also breeding in slow-flowing waters in China, but not in Russia (Glushchenko and Maslova, 2019). The species can also breed in large and relatively deep lakes in China, especially in high-elevation wetlands where fish are less common and in this case, the species stays in the vegetation close to the banks. The species seems to favour landscapes with fallen logs for hibernation, and it can be found from sea level to 1600 m of elevation.

8.3.2.3 Behavioural ecology

Salamandrella tridactyla emerges from hibernation in late March in Russia, and a bit later at higher elevations, right after the snow has melted, and both sexes migrate towards the breeding sides. Adults stay at the breeding site for three to four weeks, with spawning starting from early April (Fig. 8.38). Males undulate their bodies from a flooded vegetal perch to attract females, and competition can be high,

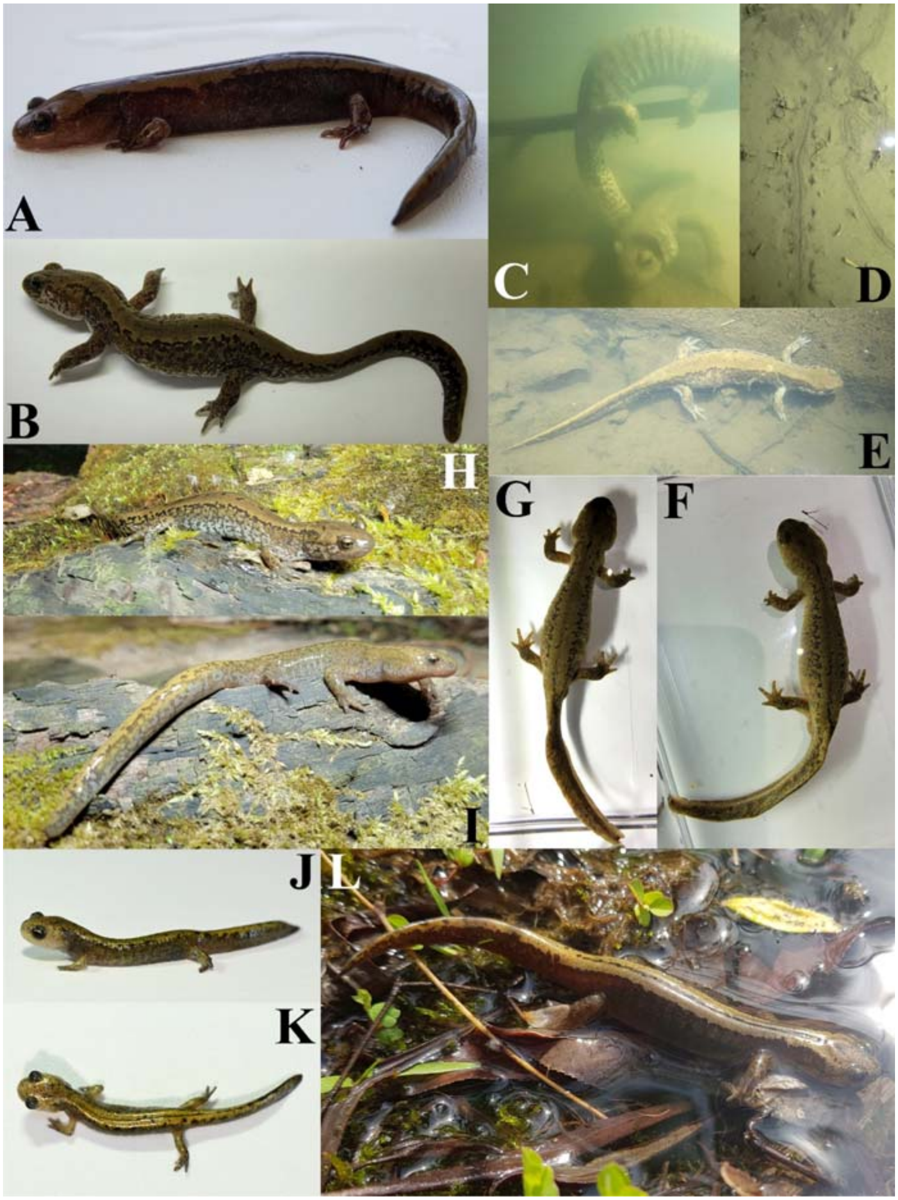

FIG. 8.38

Adult and juvenile *Salamandrella tridactyla*. Despite its name, only about 37% of individuals have three toes, the others having four (A—L). The species has a complex breeding behaviour, with males undulating their bodies from a flooded vegetal perch to attract females, and then wrapping themselves around females (C). The food print of the genus is clearly differentiable (D) and juveniles have the same colouration as adults from metamorphosis (J and K).

From Amaël Borzée.

resulting in physical aggressions (Glushchenko and Maslova, 2019). Once ready for oviposition, females approach the males, which will grab their body with their limbs and tail, and maintain contact until spawning is completed. If several males are present a mating ball can happen. The female attaches the egg sacs, each of which containing about 80 eggs, to the vegetal substrate with their stalks, between 5 and 50 cm deep (Yartsev et al., 2016; Glushchenko and Maslova, 2019). The eggs take 12 to 36 days to hatch in Russia, and the larvae swim out of the egg case between late May and early June. Development takes 41 to 51 days in Russia, depending on the water temperature, and metamorphosis generally takes place between late June and early July, but it can be delayed until September in colder areas (Fig. 8.39). On the ground, individuals generally shelter under fallen logs and they are active at night. It takes three years for individuals to reach sexual maturity, with a maximum life expectancy of 23 years (Glushchenko and Maslova, 2019). Hibernation in this species in Russia starts from October, under logs or deep in cracks underground, alone or in groups of up to ten individuals, generally close to the water body where they will breed the following spring (Kuzmin and Maslova, 2005). This is also a cold-tolerant species (Berman et al., 2005).

8.3.2.4 Threats and conservation

The species is locally abundant, including in the vicinity of some villages, and a high number of individuals can be observed spawning in forests and flood plains (Glushchenko and Maslova, 2019). However, in parts of its range, the habitat of the species is becoming degraded or lost, and water is becoming polluted through agricultural practices (Glushchenko and Maslova, 2019). The species has not been assessed by the IUCN Red List, but it is unlikely to be listed as threatened in the current situation due to its relatively large range, stable population and the current absence of important threats affecting the species. The species does not show a genetic signature of a recent increase in population size, in contrast with *S. keyserlingii* (Poyarkov and Kuzmin, 2008). The species is currently protected in all nature reserves and national parks of the Primorsky Krai (Maslova, 2016), and it is not used, or harvested, by humans.

8.3.2.5 Identification

Salamandrella tridactyla is sympatric with three *Onychodactylus* species and *H. leechii*. It is easily distinguishable from *Onychodactylus* at the larval and adult stages due to the absence of claws and the much stouter morphology. The clearest difference with *H. leechii* is the presence of a brown dorsal stripe and brown flanks, and a generally darker body. It can be distinguished from *S. keyserlingii* through its stouter but smaller body (Yartsev et al., 2016), with 11 to 14 costal groves instead of 12 to 15 (Glushchenko and Maslova, 2019). Sexes are more difficult to identify as males and females have a similar body size, although males have a higher tail fin and larger cloaca during the breeding season, and egg sacs can be identified as they are smaller in *O. tridactyla* than *O. keyserlingii* (Yartsev et al., 2016). The number of toes is not always reliable: only 37% of individuals have three toes

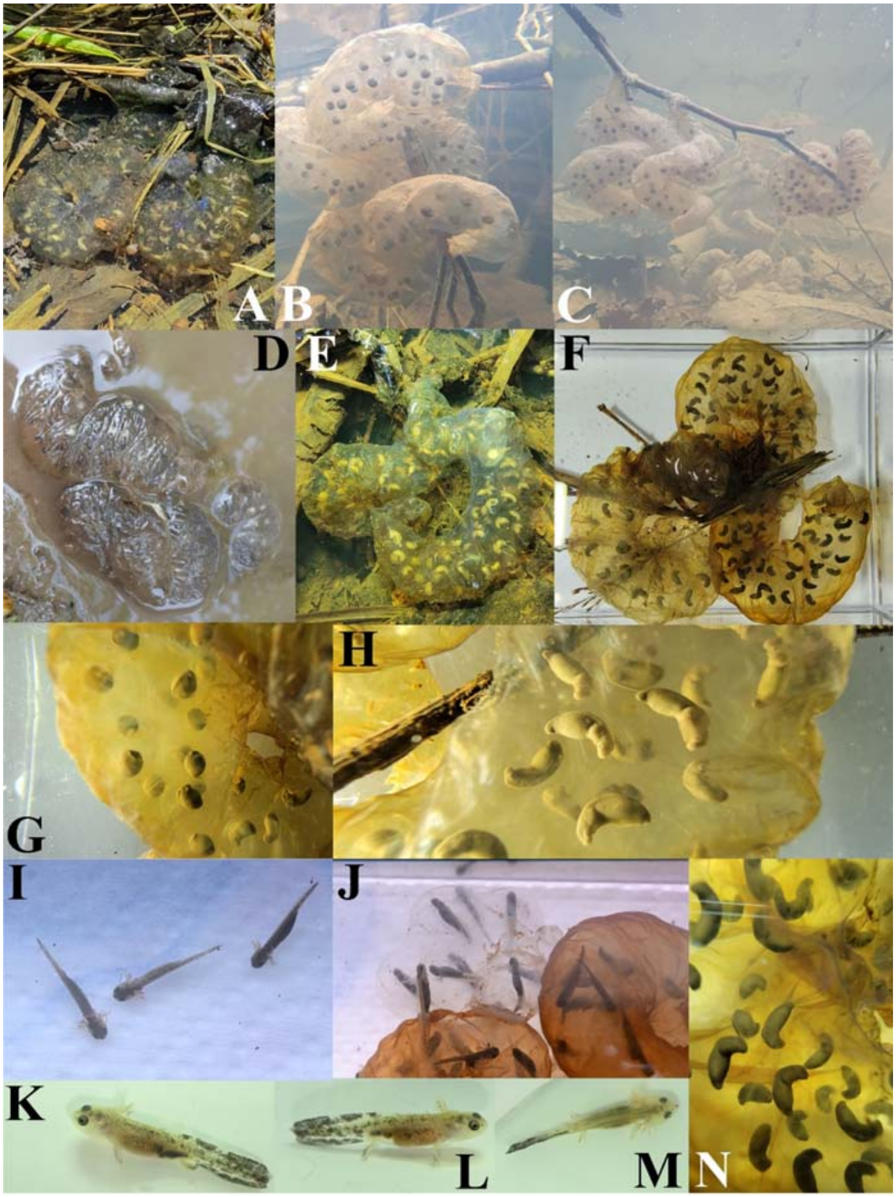

FIG. 8.39

Eggs and larvae of *Salamandrella tridactyla*. Egg sacs can be identified at the species level through their size as they are smaller in *O. tridactyla* than in *O. keyserlingii* (A–F). Egg and embryo development can be seen through the egg sacs (G, H and N), and the nutrients provided by the eggs can be seen throughout most of the development of the larvae (I–M).

From Amaël Borzée.

(Glushchenko and Maslova, 2019), and there are records of three toed individuals in *S. keyserlingii* (Kuzmin et al., 2017). There is no knowledge yet on morphological variations between the larvae of the two *Salamandrella* species.

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CHAPTER

Plethodontidae (*Karsenia*)

9

This family of Lungless salamanders originated from North America in the early Paleocene (Shen et al., 2016). It then divided into two subfamilies, the Hemidactyliinae and Plethodontinae, the latter including eight genera, among which the only Asian one, *Karsenia*. All other lungless salamanders are distributed on the American continent, ranging from Alaska in the USA to central Bolivia, and southern Europe (Frost, 2022). The family is about 130 million years old (clade Q in Zheng et al., 2011) or a bit more than 100 myo (clade 12 in Shen et al., 2016), and Plethodontinae are a bit less than 60 myo (clade S in Zheng et al., 2011) or about 40 myo (clade 14 in Shen et al., 2016). The family is the most speciose among salamander families, characterised by a broad range of behaviours and ecology, and many species show direct development where there is no aquatic larval phase and eggs hatch into miniature adults. In addition, the mating behaviour of the family is relatively well studied as it is highly stereotyped, including tail-straddle walks, spermatophore deposition and pheromones transfer through the mental gland.

9.1 *Karsenia*

9.1.1 *Karsenia koreana*

9.1.1.1 *Origin and distribution*

The Korean Crevice Salamander, *Karsenia koreana*, was described from Jangtae Mountain in 2005. The ancestor of *Karsenia* diverged from the clade shared with *Aneides* between 48.1 (37.5—58.9) and 40.5 million years ago (34.3—6.2; clade 15 in Shen et al., 2016), and dispersed from western North America to Eastern Asia either during the global warming events of the late Cretaceous and again during the Palaeocene-Eocene thermal optimum (Vieites et al., 2007) or during the late Eocene (about 42 million years ago; Shen et al., 2016). *Karsenia koreana* is about 31.00 million years old, with intraspecific splits as old as 2.30 my (1.74—2.92; Jeon et al., 2021). The species is superficially morphologically similar to the conservative *Plethodon*, despite differences in the morphology of the ankle bones (Min et al., 2005). The holotype was collected in Jangtae Mountain in South Chungcheong Province (R Korea; Min et al., 2005), but it is currently not possible to locate it (Shin et al., 2020a).

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FIG. 9.1

Distribution of *Karsenia koreana*, the Korean Crevice Salamander.

From Amaël Borzée. Map built in QGIS v. 3.32.1 'Lima' with the Global Multi-Resolution Topography (GMRT) synthesis layer and based on an updated IUCN Red List of Threatened Species distribution map.

The species is known to range from Baekun Mountain in the south (Shin et al., 2020b) and along the Baekdu mountain range crossing southern Korea north-eastward. Some populations are also found on weakly connected adjacent mountains (Fig. 9.1), and the species may be present in extreme southeastern DPR Korea (Borzée et al., 2021). *Karsenia koreana* is likely to have been present in other bordering regions in the geological past due to its North American origin, but these populations are most likely to be currently extirpated, likely following climatic oscillations. The range of the species has been expanding northward from a southernmost refugium population for the last million years (Jeon et al., 2021).

9.1.1.2 Habitat

Karsenia koreana is generally found between 200 and 400 m above sea level, with the holotype collected at 210 m (Min et al., 2005). However, it has been recorded between 50 and 850 m a.s.l (Andersen et al., 2022). The species is found in forested areas, more generally in deciduous or mixed forests, where its presence is strongly influenced by the amount of fallen wood and other substrate cover, such as moss cover on limestone rockslides. While the current populations are generally found in recently established forests, this may not reflect habitat preferences but the status of forested areas in R Korea, where trees were replanted after the Korean War (Lee and Miller-Rushing, 2014). At the microhabitat scale, individuals are found under smaller rocks among larger boulders, and the depth of the leaf litter, and the soil pH and condition are important factors for the presence of the species (Jung et al., 2019).

9.1.1.3 Behavioural ecology

Karsenia koreana is a secretive species that has not been seen breeding in the wild yet, and a lot of information regarding its breeding ecology is still missing (Fig. 9.2). In the wild, females were found to be seven years old on average, while males were five years old, with a sexual maturity of five and four years respectively. The oldest individuals recorded in the wild were nine years old in males, and ten years old in females (Song et al., 2017). The breeding sites are expected to be geographically proximate to the non-breeding area due to the general low dispersion capacity of plethodontids (Smith and Green, 2005). This assumption is supported by the direct development of the species, although observed in semi-natural conditions only (Moon and Park, 2016), where visibly ovulating females (eggs in the abdominal cavity) were captured in October and November and kept in a semi-natural outdoor enclosure with males under the leaf litter over winter. Overwintering was interrupted in April, and eggs were found on the side of a rock and mesh in June, in clusters of five and seven, providing potential data for clutch size in the wild (Moon and Park, 2016). While this is not necessarily accurate for all the details of the breeding ecology of the species, it provides a strong base to further understand the species.

9.1.1.4 Threats and conservation

Karsenia koreana can be locally abundant, but it is also affected by a large number of factors, including natural fluctuations. The population size of the species has been declining over the last 100,000 years, followed by a small rebound over the last 40,000 years, leaving the species with a current estimated effective population size so small that it is extremely vulnerable to environmental changes (Jeon et al., 2021). The current main threat to the known populations of *K. koreana* is habitat destruction and degradation due to urban expansion and timber exploitation. In addition, the species is unlikely to be able to cope with habitat degradation (Groffen et al., 2022). The second main threat is climate change, with most models predicting a decline in suitable habitat by 2070 (Borzée et al., 2019).

The species was listed as Least Concern by the IUCN Red List of Threatened Species (IUCN SSC Amphibian Specialist Group, 2019) due to its relatively wide distribution using a range smaller than the one known as of 2023 (extent of occurrence of 23,776 km^2) and relative abundance. The species is however extirpated at a few sites (Borzée et al., 2019), and its population size is expected to be decreasing, following a decline in the quality and extent of habitat available. While suitable habitat is available, including under several future climate change models, it is not within the known range, and the species does not possess the dispersal abilities needed to establish new populations (Borzée et al., 2019). Similarly, due to the lack of connectivity between populations, Jeon et al. (2021) recommended seven management units. In contrast, the species occurs in several protected areas, it is not used for human consumption, it is not known to be harvested in the wild, it has not been recorded to be infected by the salamander Chytrid Fungus, and it is one of the few Korean amphibians for which roadkills have not been recorded (Shin et al., 2022).

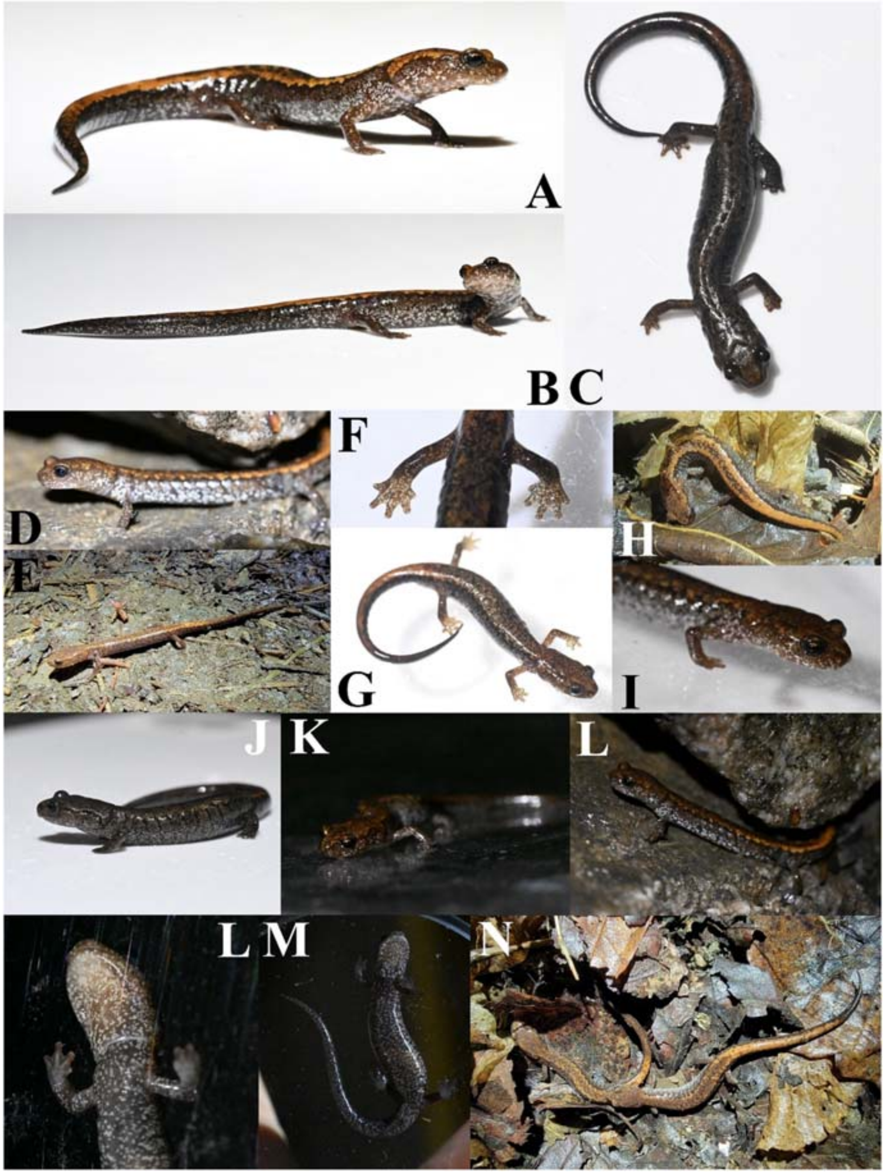

FIG. 9.2

Adult *Karsenia koreana*. The species is strikingly different from the other salamanders of the region (A—L), with quasi-webbed toes (F), proto-cirri (H and J) and reddish colouration at the base of the tail (A—N). Males (L) can be distinguished from females (M) through the presence of a mental gland, which is used by the male for the tail-straddling walk (N; Jangtae mountain in April 2023).

From Amaël Borzée.

9.1.1.5 Identification

The species is easy to identify in the field as it is morphologically distinct from sympatric species. Externally, easy features are the shape of the tail, and the nasolabial groove in the species (Min et al., 2005) which enhances chemoreception (Fig. 9.2). The species also possesses a large patch of paravomerine teeth, although visually confirming their presence is likely to prove lethal to the individual. The species is relatively small, generally 4 to 5 cm long when reaching maturity, with 14 to 15 costal grooves, and a clear gular fold separating head and body. Adults have a broad red to brown dorsal stripe that is not present in adult *Hynobius*, and a patternless round but tapered tail highly different from that of *Onychodactylus* individuals. Interestingly, the tail seems to be very weakly prehensile for some individuals that may try to hold on the vegetation when handled (Fig. 9.2). The tail can regenerate after autotomy (Lee and Park, 2016), and despite breeding through direct development, the species has small webbed toes. Females *K. koreana* have a more rounded snout (Min et al., 2005) but males have mental and caudal glands used for courtship (Sever et al., 2016).

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CHAPTER

Conclusions on continental northeast Asian amphibians

10

10.1 Conclusion

The knowledge shared in this book provides an overview of the origin, distribution, behavioural ecology, threats, conservation status and identification of all amphibian species currently described in continental northeast Asia, as well as cues for further development as some clades still need to be defined, as species or sub-species. In the same line of ideas, there is a need to characterise all amphibian evolutionary and conservation units in the region to understand their biodiversity values, functions in the ecosystems, and importance and uniqueness in terms of evolutionary background, and behavioural and ecological distinctiveness.

Continental northeast Asian amphibian species are on average 8.18 million years old, based on the clades for which data is available, with the extremes at 0.97 and 31 million years (Table 10.1). Some families such as Hynobidae and Ranidae are characterised by numerous species, although the earlier are generally microendemics and the latter wide-ranging, but both families would benefit from additional taxonomic research as some clades still need to be characterised. Other families such as Bombinatoridae and Plethodontidae are monophyletic, with large to medium range sizes, generally related to a single and old event of invasion. Interestingly, these monophyletic lineages are currently less threatened than the others.

In general, species are distributed on either side of the Yellow Sea, with a weak overlap. It would therefore be interesting to understand why species did not manage to colonise the habitat on the other side, and the hypotheses explaining this dichotomy include a shift in ecological landscapes, or competition with already established species. For instance, *D. japonicus* occurs across the Korean Peninsula and further north until the Baikal Lake, with an isolated population north of Beijing. At the same time, *F. kawamurai* ranges almost all the way to Beijing latitude, and thus two of the most widespread species are facing each other without coming into contact. In terms of range definition, the principal remaining unknown is the southern boundary of species ranging in the north of DPR Korea and the northern boundaries of species in the south of the nation.

The largest biodiversity hotspot in the region is on the mountain range separating China and DPR Korea, a landscape characterised by broad-lived temperate and conifer mixed forests. It is however interesting to note that none of the species in

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Table 10.1 Age of species in continental northeast Asia, averaged when discordant data is available from the literature, and based on the most recent publications or the publication with the largest number of genes analysed. All references are in the corresponding chapters. This table only includes native species.

Species	Clade age (my)	Age of known subclades (my)
Bufo gargarizans	5.2	2.8 and 2.7
Bufo sachalinensis	1.8	1.4 and 0.7
Bufo stejnegeri	4	
Strauchbufo raddei	11.6	7.8 and 6.8
Dryophytes japonicus	13.7	2
Dryophytes immaculatus	1.02	
Dryophytes suweonensis	0.97	
Dryophytes flaviventris	0.97	
Bombina orientalis	14.8	6.31, 5.01, 4.32 and 3.12
Kaloula borealis	9	6.3
Rana amurensis	20	
Rana coreana	10	
Rana dybowskii	8.55	
Rana uenoi	11	
Rana chensinensis	1.9	
Rana taihangensis	Unclear	
Rana huanrenensis	3.3	
Glandirana emeljanovi	Unclear	
Pelophylax nigromaculatus	Unclear	
Pelophylax mongolius	Unclear	
Pelophylax chosenicus	Unclear	
Pelophylax plancyi	Unclear	
Fejervarya kawamurai	2	
Onychodactylus fischeri	7.5	
Onychodactylus zhangyapingi	7.5	
Onychodactylus zhaoermii	7.93	
Onychodactylus sillanus	6.82	
Onychodactylus koreanus	6.3	6.3
Hynobius leechii	5	
Hynobius yangi	5	
Hynobius geojeensis	Unclear	
Hynobius perplicatus	Unclear	
Hynobius quelpaertensis	1.35	
Hynobius unisacculus	Unclear	
Hynobius notialis	Unclear	
Salamandrella keyserlingii	15.4	
Salamandrella tridactyla	15.4	
Karsenia koreana	31	2.3

the areas has a clearly defined distributions The lowlands around the Yellow Sea are generally inhabited by locally abundant species (e.g., *D. japonicus* and *F. kawamurai*) and range-restricted species, such as *D. immaculatus, D. suweonensis* and *D. flaviventris* (Fig. 10.1) on either side of the Yellow Sea. The area with the

FIG. 10.1

The first *Dryophytes flaviventris* I have encountered in the daytime, calling in mid-afternoon, in contrast with the other species of the complex. This picture is dedicated to Mr. Yu Sanghong without whom the species may not have been described.

From Amaël Borzée.

highest density of range-restricted species is the southern edge of the Korean peninsula where the *Hynobius* diversity is peaking for the area. The species with the widest-ranging distribution is *K. borealis*, an ecologically plastic species, except for the rain regulating its breeding behaviour.

The behavioural commonalities among continental northeast Asian amphibians are in their breeding requirements as all species but one lay eggs, as only *K. koreana* does not have an aquatic larval phase. Most species lay eggs at the onset of the warm season, although some variations may be found in *Onychodactylus* sp., the only genus known to be providing some level of parental care. The only native species overwintering as tadpoles in natural conditions is *G. emeljanovi*, and most species hibernate from the onset of the cold season, although ranging from September to December based on latitude.

10.2 Conservation considerations

The knowledge gathered here highlights that there are numerous conservation needs in the region, that the current protected areas do not geographically match with distribution hotspots, and that the most threatened species are not within protected areas, while abundant species do. Clearly, a conservation action plan at the regional scale is needed, and especially a transboundary plan to align conservation policies of all the neighbouring nations, and prioritise conservation needs and strengths as diverging landscapes have different strengths and weaknesses. This is perhaps especially true for *Rana* and Hynobiid species, two clades of Asian origin, both including threatened species that must be locally protected.

Generally, the species in the area are most threatened by habitat change, although climate change has a potentially strong, and generally negative, impact on all species. The presence of several large cities, including some of the fastest developing regions on earth has a clear impact on the survival of species. As a result, some species able to cope with human activities are extremely abundant in agricultural wetlands, and species unable to cope with any degree of human alteration to their habitat see their range shrink, sometimes unnoticed (e.g., *B. stejnegeri*).

As a result, the whole spectrum of threat levels is found, with species like *B. orientalis* listed as Least Concern, and species like *H. yangi* listed as Critically Endangered, by the IUCN Red List of Threatened Species. As most of the range-restricted species are in R Korea, the number of threatened species is the highest in the nation. However, all nations are characterised by threatened species, especially when considering salamanders.

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Index

‘*Note:* Page numbers followed by “f” indicate figures and “t” indicate tables.’

Continental Northeast Asian Amphibians

Origins, Behavioural Ecology, and Conservation

Synthesises research on evolutionary trends, ethology, and conservation for continental northeast Asian amphibians.

Continental Northeast Asian Amphibians: Origins, Behavioural Ecology, and Conservation is the only comprehensive compilation of knowledge on the amphibian species of continental northeast Asia. Along with accounts for each species, this book introduces the biogeographic history, behavioural patterns, ecological requirements, and threats to amphibians in the region. Written by a leading expert on Asian amphibians, this book delves into the details of the origin and life history of continental northeast Asian amphibians. It distinguishes variables that have been instrumental to the current distribution of populations, and what makes the amphibian biodiversity of this region unique. It also discusses each species and provides detailed accounts for field identification, range, and understanding of the species' behaviour during both the breeding and nonbreeding seasons. This book also provides in-depth accounts of the threats and trends for each species considering the current conservation pressure in the region. Each point is explained in relation to the very contrasted landscapes of the region that include two rather different species assemblages, one on the alluvial plains and the other at higher elevations on mountain ranges. *Continental Northeast Asian Amphibians: Origins, Behavioural Ecology, and Conservation* is an important resource for herpetological researchers and conservationists who want to understand the biodiversity, behaviour, and conservation of amphibians, and aid in their current and future protection efforts.

Key Features

- Provides the biogeographic history of each amphibian species in the region.
- Discusses the behavioural ecology of each species, along with differences and similarities between species.
- Addresses the ecological requirements and habitat information.
- Details the current threats and conservation efforts that can be made to protect vulnerable amphibians.

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