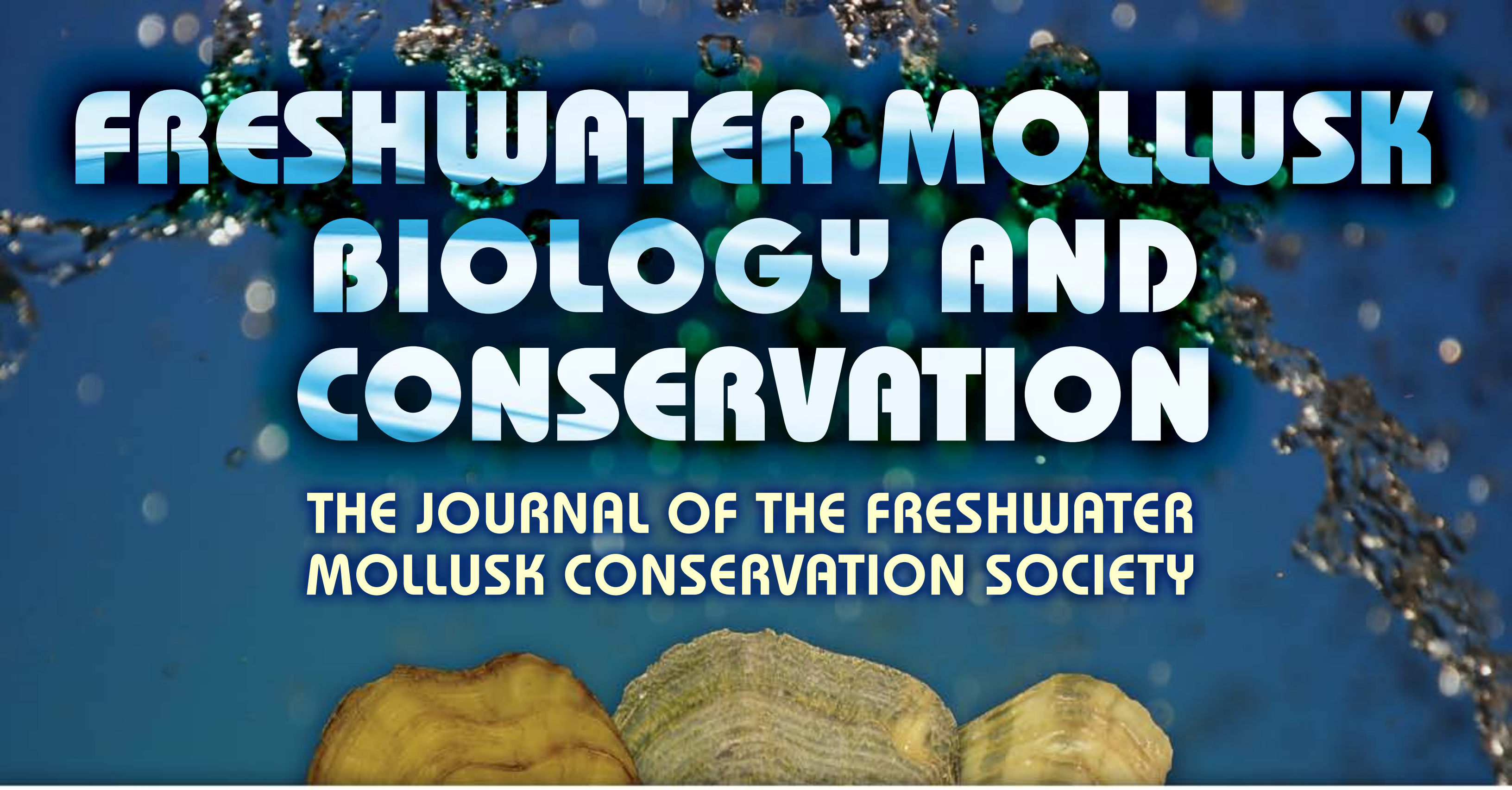


FRESHWATER MOLLUSK BIOLOGY AND CONSERVATION

THE JOURNAL OF THE FRESHWATER MOLLUSK CONSERVATION SOCIETY

VOLUME 21 NUMBER 1 APRIL 2018

Pages 1-18
Freshwater Mussels (Bivalvia: Unionida) of Vietnam: Diversity, Distribution, and Conservation Status
Van Tu Do, Le Quang Tuan, and Arthur E. Boga

Pages 19-27
A Survey of the Freshwater Mussels (Mollusca: Bivalvia: Unionida) of the Niangua River Basin, Missouri
Stephen E. McMurray, Joshua T. Hundley, and J. Scott Faiman

Freshwater Mollusk Biology and Conservation 21:1–18, 2018

REGULAR ARTICLE

FRESHWATER MUSSELS (BIVALVIA: UNIONIDA) OF VIETNAM: DIVERSITY, DISTRIBUTION, AND CONSERVATION STATUS

Van Tu Do[1], Le Quang Tuan[1], and Arthur E. Bogan[2]*

[1] *Institute of Ecology and Biological Resources (IEBR), Vietnam Academy of Science and Technology, 18 Hoang Quoc Viet, Nghia Do, Cau Giay, Ha Noi, Vietnam, dovantu.iebr@gmail.com; penguin0343@gmail.com*

[2] *North Carolina Museum of Natural Sciences, 11 West Jones Street, Raleigh, NC 27601 USA*

ABSTRACT

Vietnam has the second highest diversity of freshwater mussels (Unionida) in Asia after China. The purpose of this paper is to compile an up-to-date list of the modern unionid fauna of Vietnam and its current conservation status. Unfortunately, there has been relatively little research on this fauna in Vietnam. Fifty-nine species of Unionida have been recorded from Vietnam based on literature, museum records, and our fieldwork. Fifty were assessed in the International Union for Conservation of Nature (IUCN) Red List 2016 in the IUCN categories of Critically Endangered (four species, 6.8%), Endangered (seven species, 12%), Vulnerable (one species, 1.7%), Near Threatened (two species, 3.4%), Least Concern (23 species, 39%), Data Deficient (11 species, 18.6%), and Not Evaluated (11 species, 18.6%). Considering the impacts of pollution, timbering, agriculture, and damming of rivers, research on the diversity and conservation status of freshwater mussels is very urgently needed to propose specific conservation measures for these species in Vietnam. If all taxa listed as Data Deficient are found to be threatened, with around 42% of species threatened, this fauna would be one of the most threatened freshwater molluscan faunas in Asia.

KEY WORDS: Unionidae, Margaritiferidae, IUCN Red List, extinct, endangered, citizen science

INTRODUCTION

Freshwater bivalves are widely distributed in the freshwaters of the world and are considered one of the most imperiled animal groups (Bogan 1993, 2008; Lydeard et al. 2004; Strayer and Dudgeon 2010; Graf 2013; Haag and Williams 2014). Two major diversity hotspots of unionid bivalves are the southeastern United States (Neves et al. 1997; Bogan 2008; Haag 2012) and east and southeastern Asia (Bolotov et al. 2017; Zieritz et al. 2017). Our understanding of the distribution of unionids in Asia is limited and the coverage of information is uneven and mostly historical (Dudgeon et al. 2006; Zieritz et al. 2017).

Overviews of the freshwater bivalve fauna across Asia, including Vietnam, were provided by Haas (1910a, 1910b, 1910c–1920, 1923). Compendia covering the Unionida of the world began with the *Synopsis* by Lea (1836, 1838, 1852, 1870) and were followed and expanded by Simpson (1900, 1914) and Modell (1942, 1949, 1964). Haas (1969a) wrote the last comprehensive survey of the Unionida, and followed it with a treatise (Haas 1969b) that covered both modern and fossil taxa to the generic level. Higher classification of the Unionida was overinflated by Starobogatov (1970). Brandt (1974) summarized the Thai and Southeast Asian unionids, but overlooked Haas (1969a, 1969b). Đặng et al. (1980) followed the classification proposed by Starobogatov (1970). The inflated taxonomy of the Unionidae erected by Starobogatov's classification was reduced by Graf (2007). A preliminary list of freshwater bivalve taxa from Vietnam from literature and museum data was included in the summary of the East and Southeast Asia freshwater bivalve fauna by Zieritz et al. (2017). Analyzing molecular data, the Unionidae has been confirmed as a monophyletic clade (Hoeh et al. 1998,

*Corresponding Author: arthur.bogan@naturalsciences.org

Table 1. Unionid taxa listed and/or figured by in the four volumes by Thach (2005, 2007, 2012, 2016b).

Species	2005	2007	2012	2016b
Anodonta harlandi Baird & Adams, 1867[1]				Fig.
Cristaria bialata (Lea, 1829)[2]	L/Fig.			
Cristaria discoidea[3]		L/Fig.	Fig.	
Cristaria truncata			L/Fig.	
Hyriopsis cumingii[4]			L/Fig.	
Hyriopsis schlegeli[5]	L/Fig.			
Hyriopsis sp.			L/Fig.	
Lamprotula leai	L/Fig.		Fig.	
Lanceolaria bilirata				L
Lanceolaria bogani				L/Fig.
Lanceolaria fruhstorferi				Fig.
Lanceolaria grayi			L/Fig.	
Lanceolaria grayana (Lea, 1834)				Fig.
Lanceolaria laevis	L	Fig.		
Lanceolaria yueyingae He & Zhuang, 2013				Fig.
Nodularia douglasiae				L
Oxynaia jourdyi		L/Fig.		
Oxynaia micheloti	L/Fig.			
Physunio inornatus		L/Fig.		
Physunio micropterus		L/Fig.		
Physunio modelli		L/Fig.		
Pilsbryoconcha exilis	L/Fig.		Fig.	
Pilsbryoconcha lemeslei		L/Fig.		
Pseudodon cambodjensis		L/Fig.		
Pseudodon contradens tumidula (Lea, 1856)[6]		Fig.		
Pseudodon mouhoti [sic][7]	L/Fig.			
Pseudodon vondembuschianus chaperi (Morgan, 1885)		L/Fig.		
Sinanodonta elliptica	Fig.			Fig.
Sinanodonta hunganhi				L/Fig.
Sinanodonta woodiana				Fig.
Trapezoideus exolescens		L/Fig.		
Uniandra contradens tumidula (Lea, 1856)[8]	L			

L = listed; Fig.= figured.
[1]*Anodonta harlandi* is a junior synonym of *Sinanodonta woodiana*.
[2]*Cristaria bialata* is a junior synonym of *C. plicata*.
[3]*Cristaria discoidea* is a junior synonym of *Pletholophus tenuis*.
[4]*Hyriopsis cumingii* moved to *Sinohyriopsis cumingii* (see Lopes-Lima et al. 2017).
[5]*Hyriopsis schlegeli* is misidentification of *Sinohyriopsis cumingii*.
[6]Misplaced species, belongs in *Contradens*.
[7]Incorrect spelling of *Pseudodon mouhotii*
[8]Correct genus is *Contradens*.

2001, 2002; Roe and Hoeh 2003; Graf and Cummings 2006; Breton et al. 2007, 2010; Doucet-Beaupré et al. 2010; Whelan et al. 2011; Pfeiffer and Graf 2015). The most recent phylogenetic classification within the modern Unionidae is that of Lopes-Lima et al. (2017) and Bolotov et al. (2017).

Early work on the Vietnamese molluscan fauna was typically performed by European malacologists describing freshwater bivalve species. These included the papers of Morelet (1865, 1866), Mabille (1887), Morlet (1886a, 1886b, 1891), Dautzenberg (1900), Bavay and Dautzenberg (1901), Martens (1902), Rochebrune (1904a, 1904b), Rolle (1904), Dautzenberg and Fischer 1906a, 1906b, 1908), and Haas (1910a, 1910b, 1910c-1920, 1913, 1923). Isaac Lea, living in the United States, also described some unionids from Southeast Asia (see Scudder 1885). The only comprehensive treatment of the freshwater invertebrates, including freshwater bivalves for northern Vietnam, is that by Đặng et al. (1980).

Thach, a retired physician and avocational shell collector has published four volumes providing information and pictures of marine, terrestrial, and freshwater mollusks of Vietnam, including some Unionidae (Thach 2005, 2007, 2012, 2016b) (Table 1). A total of 21 species of freshwater mussels from Vietnam were reported and figured in the 4 volumes by Thach. He also described two new species, *Lanceolaria bogani* Thach, 2016 (Thach 2016a) and *Sinanodonta hunganhi* Thach, 2016 (Thach 2016b). Thach divided the freshwater bivalves of Vietnam into Amblemidae and Unionidae, but did not comment on the Margaritiferidae. His report and figure of *Pilsbryoconcha lemeslei* is the first record of this species from Vietnam (Thach 2007).

We recently have been surveying the freshwater mussel fauna of Vietnam (Bogan and Do 2011, 2013a, 2013b, 2014a, 2014b, 2016). The objective of the present paper is to develop an up-to-date list of the unionid fauna reported for Vietnam and their distribution (Table 2; see also Supplemental Species Range Maps). The modern unionid fauna of Vietnam is divided between two families, Margaritiferidae and Unionidae. Margaritiferidae is represented by a single species. The Unionidae fauna of Vietnam is represented by 28 genera and 58 species (Table 2).

METHODS

Study Area

Vietnam lies on the eastern side of the Indochina Peninsula encompassing 331,210 km^2 (Fig. 1). The northern part of the country is mountainous and contains the Red River basin, which drains to the east, emptying into the Gulf of Tonkin. The rivers draining to the west are tributaries of the Mekong River basin, draining into the Gulf of Thailand. Southern Vietnam is home to the Annamite Range, the Central or Western Highlands and the extensive Mekong River delta and its numerous distributaries. The major rivers of Vietnam are shown on Figure 1.

Historical literature was used to document species described from Vietnam and was compared with the list published by Đặng et al. (1980). Taxonomy of these species was challenging because Đặng et al. (1980) based their taxonomy on Starobogatov (1970), but see Graf's (2007) revision of Starobogatov's taxonomy. Taxonomy used in this paper is based on available literature, as presented by Lopes-Lima et al. (2017) and is the same as used by Zieritz et al. (2017). Additional information was collected from photographs of specimens from various museum collections available on the Internet, which were checked and identifications verified (Graf and Cummings 2017). Dates of publication were verified and resulted in minor changes (Bogan and Do 2011; Bogan 2015).

Our fieldwork was carried out at the following times: July 2010 in northern Vietnam; November 2012 across 12 northern provinces of Vietnam; March 2014 beginning in Hanoi, including the Central Highlands and the Mekong Delta area of southern Vietnam; and October–November 2016, concentrating on 7 northern provinces (Bogan and Do 2013a, 2013b, 2014a, 2014b, 2016). During each field trip, markets were visited in the early morning and people selling freshwater bivalves and gastropods were asked about where the animals had been collected (Fig. 2). Other residents and fishermen were asked about local freshwater mussels. We searched streams and lakes crossed during our trips by wading and feeling for mussels or using hand dredges. Collection methods varied by location; some shell harvesters used handheld wire baskets on a rope to collect mussels and gastropods in northern Vietnam (Fig. 3). Long bamboo-handled rectangular wire frame nets were used to collect mussels from stream and lake bottoms in southern Vietnam (Fig. 4). One shell collector used a surface-supplied-air diving apparatus to dive and collect freshwater mussels.

The Vietnam Red Book was first developed in 1992, and it was a collaboration of the Institute of Ecology and Biological Resources (IEBR) and the International Union for Conservation of Nature (IUCN) with financial support from Sweden. The criteria used in the book were built on the IUCN Red List standards. The 1992 list was later revised and contained 13 species of freshwater mussels (Red Data Book of Vietnam 2000). This was expanded by the Institute of Science and Technology of Vietnam. A country-wide assessment of the conservation status of 416 species of animals in Vietnam resulted in the publication of the Vietnam Red Data Book (2007). This assessment included 11 species of freshwater mussels; 1 species was added and 3 species were dropped from the earlier lists: *Cristaria herculea*, *Lamprotula liedtkei*, and *Pilsbryoconcha suilla* and was conducted using the IUCN conservation assessment protocol in place at the time. The Vietnam Red Data Book (2007) lists six Rare; four Vulnerable, and a single indeterminate mussel species (Table 2).

Conservation assessments of all species listed here were based upon the application of the criteria laid out in the IUCN Red List Categories and Criteria (2012) and explained in the IUCN Assessment Process (IUCN 2017) The categories of threatened status include Extinct, Extinct in the Wild, Critically Endangered, Endangered, Vulnerable, Near Threatened, Least Concern, Data Deficient, and Not Evaluated (see Table 2). Each category is based on five criteria: (1) reduction in population size, (2) geographic range, (3) population size estimated to number at listed level for each threatened status, (4) population size estimated to number less than a given level for the threatened status, and (5) quantitative analysis showing probability of extinction in the wild. The guidelines for the application of these criteria are carefully explained by the IUCN Standards and Petitions Subcommittee (2016). The standards and an explanation of required data is presented in tabular form based on the IUCN data entry format for assessing the conservation status of each species (IUCN 2013). The threatened species assessed by the IUCN from the Indo-Burma region were initially listed in Köhler et al. (2012). The conservation status of all the species listed in Table 2 and supporting information can be found on the IUCN Red List website (IUCN 2016).

This work has been registered with ZooBank and a copy has been archived at Zenodo.org.

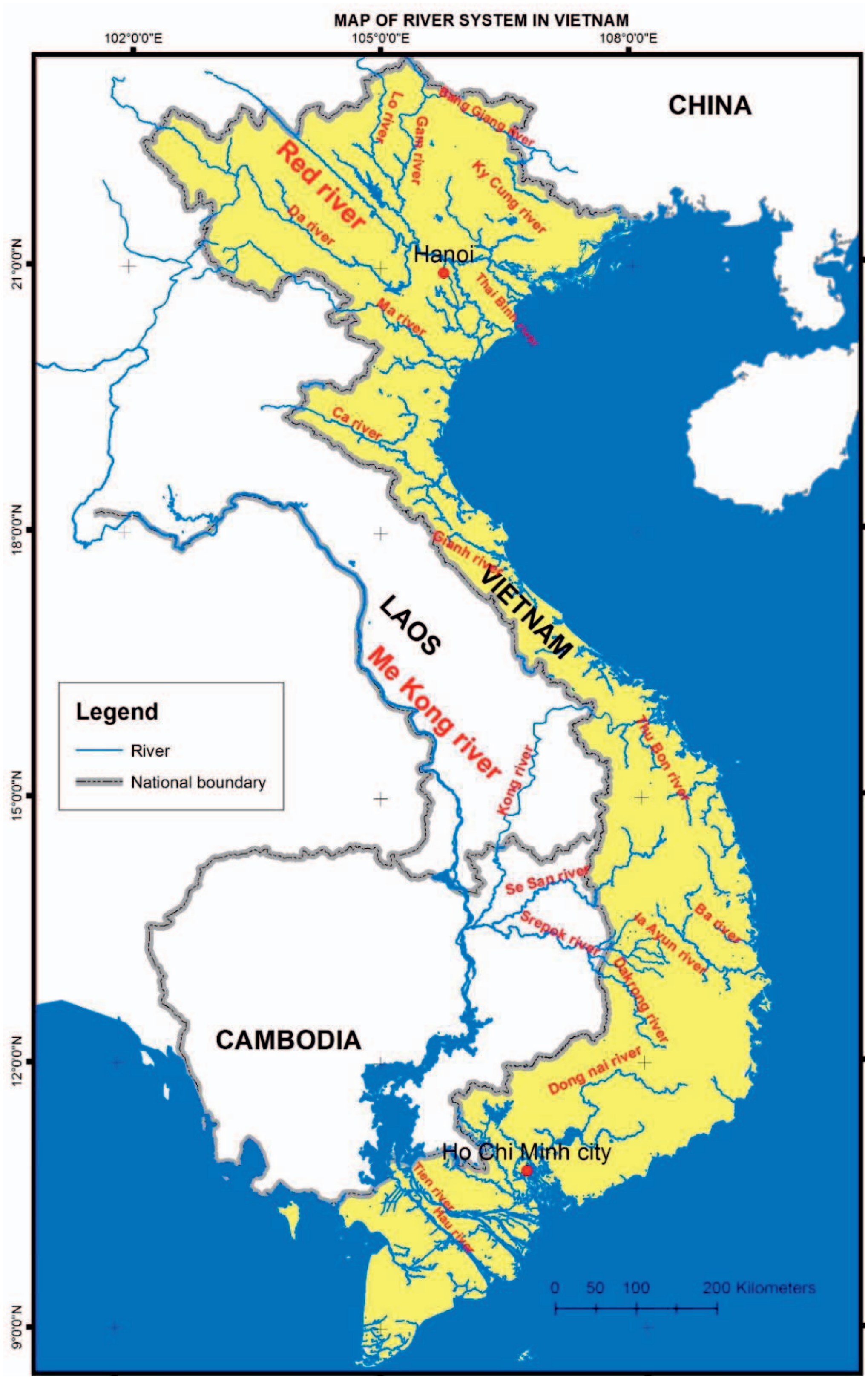


Figure 1. Map of the major rivers of Vietnam.

RESULTS

Margaritiferidae Henderson, 1929

Recent molecular studies of the Margaritiferidae have considered it consists of a single genus, *Margaritifera* Schumacher, 1816 (Bolotov et al. 2016b; Araujo et al. 2017). Bolotov et al. (2016b) recognized three clades, which are treated as subgenera. *Margaritifera laosensis* is the only species belonging to the subgenus *Margaritanopsis* Haas, 1910. Historically, *M. laosensis* was known from Dien Bien Province in northwest Vietnam and in the adjacent part of Lao People's Democratic Republic (PDR). During recent fieldwork in West Central Vietnam (Bogan and Do 2014a), a local stated to have found similar shells but we did not procure any. Phuong (2011) provided an IUCN conservation assessment. The ecology and conservation of *M. laosensis* was detailed by Bolotov et al. (2014), who listed three known viable populations in the Lao PDR.

Unionidae Rafinesque, 1820

Aculamprotula nodulosa was reported from Cao Bang area of northern Vietnam by Đặng et al. (1980). Graf and Cummings (2007) continued to place this species in *Lamprotula*. However, Pfeiffer and Graf (2013) confirmed the split of *Lamprotula* and *Aculamprotula*. *Unio nodulosa* was placed in the genus *Aculamprotula* by He and Zhuang (2013) and Graf and Cummings (2017). Live specimens have been recently collected in northern Vietnam (Bogan and Do 2016).

Photographs presented by Graf and Cummings (2017) and a photograph provided by S. Schneider (University of Cambridge, Cambridge, UK, personal communication) are identified as *A. nodulosa*, but these shells are much rounder than the type figure of *A. nodulosa*.

Per Haas (1969a) *Chamberlainia hainesiana* [+ *Simpsonia demangei* Rochebrune, 1904 is listed as occurring in Thailand, Cambodia, and the Tonkin region of Vietnam. *Simpsonia demangei* is listed from "Rivière Claire entre Vietri et Tuyen-Quas, (Tonkin)" (Rochebrune, 1904). *Simpsonia demangei* was listed in the synonymy of *C. hainesiana* by Brandt (1974) and Graf and Cummings (2017). Such a disjunct distribution may suggest that the animal from Tonkin may be a separate and distinct species from *C. hainesiana*. New live specimens are needed to test the placement of this species described from Vietnam using molecular methods.

Uniandra Haas, 1912 was used as a senior synonym of *Contradens* Haas, 1913 by Brandt (1974). *Contradens* Haas, 1911 has priority over *Uniandra* Haas, 1912, based on the dates of publication of the sections of Haas (1910c–1920) (Bogan 2015).

Contradens contradens was listed by Brandt (1974) from Thailand, Lao PDR, Cambodia and southern Vietnam [+ *Uniandra contradens tumidula* (Lea, 1856)]. However, it was not reported by Đặng et al. (1980). This species has been collected from southern Vietnam (Bogan and Do 2014). Graf and Cummings (2017) figured lots identified as *Unio semidecoratus* Morlet, 1889, Tonkin Muséum national d'Histoire naturelle, Paris (MNHN MP) 3861; *Unio dautzenbergi* Morlet, 1889, Tonkin; and *Physunio crossei* Deshayes, 1879, from Cochinchine MNHN MP 3774. All specimens were identified as *Contradens contradens* by Graf and Cummings (2017).

Considering that the type locality for *Contradens semmelincki* (Martens, 1891) is Borneo and the type locality for *Contradens fultoni* is Manson, Tonkin (Mau Son, Lang Son), *C. fultoni* is here considered a valid separate species. Graf and Cummings (2017) treat *C. fultoni* as a junior synonym of *C. semmelincki*.

Cristaria plicata is viewed as a valid, wide-ranging species (Lopes-Lima et al. 2017). Đặng et al. (1980) recognized four species of *Cristaria* in Vietnam: *Cristaria bellua* Morelet, 1866; *Cristaria bialata* Lea, 1829; *Cristaria herculea* Middendorff, 1847; and *Cristaria truncata* Đặng, 1980. Klishko et al. (2014, 2016) determined that *C. herculea* and *Cristaria tuberculata* Schumacher, 1817 are synonyms of *C. plicata*. *Cristaria bellua,* a misspelling of *Anodonta bellus*, and *Symphynota bialata* were listed by Brandt (1974) and He and Zhuang (2013) as synonyms of *C. plicata*.

Cristaria truncata is recognized as a valid species by Graf and Cummings (2017) but is poorly known and its relationship to *C. plicata* is unknown.

Cuneopsis demangei was described from Tonkin and recognized by Haas (1969a), Đặng et al. (1980), and Graf and Cummings (2017). This species is restricted to northern Vietnam but has not been collected in the last several decades.

Cuneopsis pisiculus (Heude, 1874) was illustrated by Graf and Cummings (2017) as University of Michigan Museum of Zoology (UMMZ) 110095, purportedly from Tonkin, Vietnam. The accompanying original label listed it from Ningpo and not from Tonkin. This is considered a spurious record and not part of the fauna of Vietnam.

Diaurora aurorea was listed by Đặng et al. (1980), but has not been collected recently. Early specimens identified as *Diaurora* are housed in the Vietnam National University, Hanoi University of Science, Museum of Biology, Hanoi, but were not available for examination.

Ensidens sagittarius was reported by Brandt (1974) as a synonym of *Ensidens ingallsianus*, but Graf and Cummings (2017) treated *E. ingallsianus* as a separate species and illustrated specimens from Cochinchine. However, the specimens listed as *E. sagittarius* from Cochinchine all appear to be specimens of *E. ingallsianus*.

Gibbosula Simpson, 1900 was described containing only *Mya crassa* Wood, 1815. Haas (1969a, 1969b) included *Gibbosula* as a junior synonym of *Lamprotula* Simpson, 1900. He and Zhuang (2013) and Graf and Cummings (2017) recognized *Gibbosula* as a valid genus. Pfeiffer and Graf (2013) recognized two clades in *Lamprotula* but did not address the status of *Gibbosula* because the type species of *Lamprotula* is poorly understood. *Gibbosula* is retained here recognizing its uncertain status and placement.

Gibbosula crassa was listed as occurring in northern

Table 2. Complete list of freshwater mussel species found in Vietnam: 59 species, 28 genera, 2 families. The species conservation statuses are based on the International Union for Conservation of Nature (IUCN) Red Listing (2016) and the Red Data Book of Vietnam (1992, 2000) and Vietnam Red Data Book (2007).

Species	IUCN Red List	Vietnam Red Data Books	Distribution Area (Province) in Vietnam, Comments
Aculamprotula nodulosa (Wood, 1815)*	CR	R	Northeast (Bang Giang River in Cao Bang, Ky Cung River in Lang Son, Thuong River in Bac Giang, Tuyen Quang (IUCN listed as *Lamprotula nodulosa*)
Chamberlainia hainesiana (Lea, 1856)	DD	V	Northeast (Phu Tho, Lo River in Tuyen Quang)
Contradens contradens (Lea, 1838)	LC		Mekong River delta (An Giang, Long An) IUCN listed as *Uniandra contradens*)
Contradens fultoni Haas, 1939 *	DD	R	Northeast (Mau Son in Lang Son) (IUCN Listed as *Uniandra semmelincki*)
Cristaria plicata (Leach, 1815)	DD	V	Northeast, Northwest, Red River delta
Cristaria truncata Đặng, 1980	EN		Northeast (Cao Bang, Bac Giang), Red River delta (Hai Duong, Ha Nam, Ninh Binh, Nam Dinh)
Cuneopsis demangei Haas, 1929	CR	K-inderminate	Northeast (Da River in Phu Tho)
Diaurora aurorea (Heude, 1883)	DD		Northeast (?)
Ensidens ingallsianus (Lea, 1852)	LC		Central Highlands, South Central Coast, Southeast, Mekong River delta
Gibbosula crassa (Wood, 1815)	CR	R	Northeast (Bang Giang River in Cao Bang, Ky Cung River in Lang Son) (IUCN listed as *Lamprotula crassa*)
Harmandia somboriensis (Rochebrune, 1882)	DD		Southeast, Mekong River delta
Hyriopsis gracilis Haas, 1910	LC		Southeast, Mekong River delta
Hyriopsis delaportei (Crosse & Fischer, 1876)	LC		Mekong River delta (An Giang)
Lamprotula bazini (Heude, 1877)	DD		Northeast (Ha Noi)
Lamprotula blaisei (Dautzenberg & Fischer, 1905)*	VU	R	Northeast (Cao Bang, Lang Son, Bac Giang)
Lamprotula contritus (Heude, 1881)	EN		Northeast (Cao Bang, Bac Kan, Thai Thuyen)
Lamprotula leai (Gray in Griffith & Pidgeon, 1833)	LC	V	Northeast
Lamprotula quadrangulosa (Heude, 1881)	LC		Northeast (Bang Giang River) (IUCN treated as synonym of *L. leai* not listed)
Lamprotula salaputium (Martens, 1902)*	DD		Northeast (Tuyen Quang)
Lanceolaria bilirata (Martens, 1902)*	CR		Northeast (Cao Bang, Lang Son)
Lanceolaria bogani Thach, 2016*	NE		North Central Coast (Thua Thien Hue)
Lanceolaria fruhstorferi (Bavay & Dautzenberg, 1901)*	NE	R	Northeast (Cao Bang, Lang Son) (IUCN lists as synonym of *Lanceolaria grayana*)
Lanceolaria gladiola (Heude, 1877)	LC		Northeast, Northwest, Red River delta
Lanceolaria grayi (Gray in Griffith & Pidgeon, 1833)	DD		Northeast, Northwest, Red River delta
Lanceolaria laevis (Martens, 1902)*	NE		Northeast (Cong River in Thai Nguyen)
Margaritifera laosensis (Lea, 1863)	EN		Northwest (Dien Bien Phu)
Nodularia dorri (Wattebled, 1886)*	LC		Northeast, Northwest, Red River delta
Nodularia douglasiae (Gray, 1833)	LC		Northeast, Northwest, Red River delta, North Central Coast
Nodularia nuxpersica (Dunker, 1848)	NE		Northeast (IUCN listed as *Unio douglasiae*)
Oxynaia diespiter (Mabille, 1887)*	EN		Northeast (Bac Kan, Thai Nguyen)
Oxynaia gladiator (Ancey, 1881)*	DD		Northeast
Oxynaia jourdyi (Morlet, 1886)*	NT		Northeast (Ha Noi, Vinh Phu, Phu Tho, Hoa Binh)
Oxynaia micheloti (Morlet, 1886)*	EN		Northeast (Cao Bang, Phu Tho, Vinh Phuc)
Physunio cambodiensis (Lea, 1856)	LC		Central Highlands (Serepok River in Dak Lak), Mekong River delta (An Giang)

Table 2, continued.

Species	IUCN Red List	Vietnam Red Data Books	Distribution Area (Province) in Vietnam, Comments
Physunio micropterus (Morelet, 1866)	LC		Central Highlands (Dak Bla River tributary of Se San River in Kon Tum), Southeast (Dong Nai), Mekong River delta
Physunio modelli Brandt, 1974	LC		South Central Coast (Binh Thuan)
Physunio superbus (Lea, 1843)	LC		Mekong River delta (Can Tho)
Pilsbryoconcha compressa (Martens, 1860)	LC		Southeast, Mekong River delta (IUCN listed as synonym of *P. exilis*)
Pilsbryoconcha exilis (Lea, 1839)	LC		South Central Coast (Ninh Thuan), Southeast, Mekong River delta (Can Tho)
Pilsbryoconcha lemeslei (Morelet, 1875)	LC		Central Highlands (Dak Bla River tributary of Se San River in Kon Tum, Khanh Hoa)
Pletholophus sp.*	NE		Northeast, Red River delta
Pletholophus tenuis (Gray in Griffith & Pidgeon, 1833)	LC		Throughout the country (IUCN listed as *Cristaria tenuis*)
Protunio messageri (Bavay & Dautzenberg, 1901)*	EN		Northeast (Bang Giang River in Cao Bang)
Pseudobaphia sp.	NE	R	Northeast (Bang Giang River in Cao Bang)
Pseudodon cambodjensis (Petit, 1865)	DD		Southeast, Mekong River delta
Pseudodon inoscularis (Gould, 1844)	LC		Southeast (Dong Nai), Mekong River delta
Pseudodon mouhotii (Lea, 1863)	LC		Southeast, Mekong River delta
Pseudodon resupinatus Martens, 1902*	EN		Northeast (Vinh Phuc, Lang Son)
Pseudodon vondembuschianus (Lea, 1840)	LC		Southeast, Mekong River delta
Ptychorhynchus pfisteri (Heude, 1874)	NT		Northeast (Vinh Phuc, Phu Tho), Northwest (Hoa Binh)
Scabies crispata (Gould, 1843)	LC		Northwest (Hoa Binh), Mekong River delta (An Giang)
Sinanodonta hunganhi Thach, 2016*	NE		North, Nghe An Province
Sinanodonta jourdyi (Morlet, 1866)*	NE		Northeast, Northwest, Red River delta
Sinanodonta lucida (Heude, 1878)	NE		Northeast, Northwest, Red River delta
Sinohyriopsis cumingii (Lea, 1852)	LC	V	Northeast (Bac Giang, Ha Noi, Ha Nam, Nam Dinh, Ninh Binh) (IUCN listed as *Cristaria cumingii*)
Solenaia oleivora (Heude, 1877)	NE		Northeast (Phan River in Vinh Phuc, Day River in Ha Noi and Ha Nam, Thuong River in Bac Giang)
Trapezoideus exolescens (Gould, 1843)	LC		Southeast, Mekong River delta
Trapezoideus misellus (Morelet, 1865)	DD		Northeast (Bang Giang River in Cao Bang, Vinh Phuc)
Unionetta fabagina (Deshayes in Deshayes & Julien, 1874)	LC		Central Highlands (Sa Thay River in Kon Tum)

CR = Critically Endangered; DD = Data Deficient; EN = Endangered; IUCN = International Union for Conservation of Nature; K = Indeterminate; LC = Least Concern; NE = Not Evaluated; NT = Near Threatened; R = Rare; VU = Vulnerable; V = Vulnerable.

*Endemic to Vietnam.

Figure 2. Pan with several unionid species for sale in a market, Ha Noi, Vietnam, Photograph by Arthur Bogan. November 18, 2014.

Vietnam by Đặng et al. (1980). Haas (1969a), Đặng et al. (1980), and He and Zhuang (2013) all placed *Lamprotula mansuyi* (Dautzenberg and Fischer, 1908), described from northern Vietnam in the synonymy of *Lamprotula crassa*. Live specimens of this species were recently collected from the Bang River, Cao Bang Province, Vietnam, for anatomical and molecular analyses (Bogan and Do 2016).

Harmandia somboriensis has been reported from the Mekong and Mun rivers, but not mentioned as occurring in Vietnam (Brandt 1974). Pfeiffer (personal communication) found in it in shallow water around boulders. There are type specimens collected from "Cochinchine" preserved in the MNHN, Paris. This species collected from "Cochinchine" are assumed to be part of the Vietnamese fauna.

The genus *Hyriopsis* Conrad, 1853 has some taxonomic issues. *Limnoscapha* Lindholm, 1932 was proposed for a group of bivalve species occurring from the Miocene to Pliocene in what was, in 1978, the southern Soviet Union; these species became extinct at the end of the Pliocene (Gozhik 1978). This generic name was placed as a subgenus of the modern *Hyriopsis* and has been used as a modern subgenus (Modell 1950; Brandt 1974). Haas (1969b) and Graf and Cummings (2006) listed *Limnoscapha* as a synonym of *Hyriopsis*. *Limnoscapha* represents, in our opinion, an extinct fossil group not related to the modern *Hyriopsis* species of Asia.

Hyriopsis bialatus was listed from Malaysia, Thailand, Cambodia, southern Vietnam, and Tonkin (Brandt 1974) and recently confirmed from the Mekong Delta in Vietnam by Bogan and Do (2014b). However, *Hyriopsis bialatus* has been shown to be three separate species based on mitochondrial DNA sequence data with *H. bialatus* being described from the "in Songi flumine Malaccae" (Sungi River, Malacca, Malaysia) (Zieritz et al. 2016, 2017). Sungi is the Malay

Figure 3. Small clam rake used by local fishermen to collect freshwater mussels from the local rivers. Photograph by Van Tu Do. Ca Lo River, Soc Son District, Ha Noi, Vietnam. Photograph by Van Tu Do. November 23, 2012.

word for river, so the locality is unclear and Malaccae referred to the southern side of peninsular Malaysia. An available name for the species occurring in the Mekong River basin is *Hyriopsis gracilis* Haas, 1910 (Haas 1910b). We are using *H.*

Figure 4. Long-handled rake with basket from southern Vietnam. Photograph by Van Tu Do. April 4, 2014.

gracilis for what has been historically listed as *H. bialatus* only for the Mekong River basin populations.

Hyriopsis cumingii has been recognized by numerous authors including Haas (1969a, 1969b), Brandt (1974), and He and Zhuang (2013). Starobogatov (1970) described *Sinohyriopsis* with the type species *Unio cumingii* Lea, 1852 and simultaneously described *Nipponihyria* Starobogatov, 1970 type species *Hyriopsis schlegeli* Martens, 1861. Đặng et al. (1980) used the combination *Sinohyriopsis cumingii*. No use of the name *Nipponihyria* has been found in the literature since it was described. *Sinohyriopsis* is here given priority over *Nipponihyria* based on usage since both names were published in the same original work. *Hyriopsis cumingii* and *H. schlegeli* have been placed in *Sinohyriopsis* based on recent phylogenetic work that separated them from the type species of *Hyriopsis*, *Hyriopsis bialatus*, (Froufe et al. 2015; Lopes-Lima et al. 2017). *Sinohyriopsis cumingii* is used here.

Hyriopsis delaportei was reported for the first time in An Giang Province, Vietnam (Bogan and Do 2014b).

Lamprotula Simpson, 1900 was first divided by Wu (1998) into *Lamprotula* and *Aculamprotula* based on differences in shell shape, anatomy, and glochidial morphology. This distinction was confirmed with molecular sequence data by Zhou et al. (2007). Pfeiffer and Graf (2013) confirm this division but raise questions about the other generic names available for parts of this polyphyletic group.

Lamprotula bazini was reported from northern Vietnam by Đặng et al. (1980) and recognized as valid by He and Zhuang (2013) and Graf and Cummings (2017). This species has not been collected in several decades.

Lamprotula blaisei was listed from northern Vietnam by Đặng et al. (1980) and recognized as a valid by He and Zhuang (2013) and Graf and Cummings (2017). This species has not been collected in several decades.

Lamprotula contritus was reported from northern Vietnam by Đặng et al. (1980). He and Zhuang (2013) and Graf and Cummings (2017) consider this a synonym of *Lamprotula caveata* (Heude, 1877). This species has not been collected recently. Animals of this species from Vietnam do not appear to be the same as *L. caveata,* as they lack the characteristic depressions in the shell. We treat it here as a valid species pending further genetic analysis.

Lamprotula leai was reported from northern Vietnam by Đặng et al. (1980) and recognized as a valid species by He and Zhuang (2013) and Graf and Cummings (2017). This species is the most common species of this genus in northern Vietnam.

Lamprotula liedtkei (Rolle, 1904) was listed from northern Vietnam by Đặng et al. (1980) and recognized as a junior synonym of *Aculamprotula nodulosa* by He and Zhuang (2013) and Graf and Cummings (2017). However, the specimen of *Quadrula liedtkei* sp., with a Rolle manuscript name figured by Graf and Cummings (2017) is from Tonkin (United States National Museum, Smithsonian Institution [USNM] 187462) and is much rounder than the figure of the type of *Unio liedtkei* Rolle, 1904 and pictured by He and Zhuang (2013). This USNM specimen resembles the shell shape of *Lamprotula similaris* (Simpson, 1900) from China (He and Zhuang 2013).

Lamprotula ponderosa (Dautzenberg and Fischer, 1905) was recognized as a variety separate from *Lamprotula leai*. However, it was listed as a junior synonym of *Lamprotula leai* by Haas (1969a). He and Zhuang (2013) and Graf and Cummings (2017) listed *Unio* (*Quadrula*) *leai* var. *ponderosa* Dautzenberg and Fischer, 1905 as a primary junior homonym of *Unio ponderosa* Rossmässler, 1842. It is also a junior homonym to *Unio ponderosa* Hanley, 1842 and *Unio ponderosa* Gray, 1825. The shell illustrated by Đặng et al. (1980) may be a separate species or variation of *L. leai*.

Lamprotula quadrangulosa was described from China and placed by Simpson (1914) as a junior synonym of *L. caveata* (Heude, 1877) also described from China. Đặng et al. (1980) viewed *L. quadrangulosa* as a valid species, separate from both *L. leai* and *L. caveata*. Haas (1969a), He and Zhuang (2013), and Graf and Cummings (2017) listed *L. quadrangulosa* as a synonym of *L. caveata*. *Lamprotula quadrangulosa* from Vietnam does not appear to be the same as *L. caveata,* lacking the characteristic depressions in the shell characteristic of *L. caveata*. We treat *L. quadrangulosa* as a valid species pending further genetic analysis.

Lamprotula salaputium described from Thuyen-Quan, Annam, was not figured by Martens. Martens (1902) noted he had a single specimen, making the specimen a holotype by monotypy. Graf and Cummings (2017) do not provide a picture of this species, but recognize it as a valid species. The mollusk collections in Berlin and Frankfurt museums have been queried and neither has this specimen. This species is an unknown species described from Vietnam.

Đặng et al. (1980) reported four species of *Lanceolaria* from northern Vietnam, *Lanceolaria bilirata*, *Lanceolaria fruhstorferi, Lanceolaria grayii* and *Lanceolaria laevis*. Graf and Cummings (2017) recognized three valid species from Vietnam: *L. bilirata*, *Lanceolaria gladiola*, and *L. grayii*. This genus needs a careful revision.

Lanceolaria bilirata was described from Tonkin, Vietnam, and is apparently restricted to northern Vietnam. Haas (1969a) placed this taxon as a subspecies of *Lanceolaria oxyrhyncha* (Martens, 1894) and Kondo (2008) listed it as a synonym of *Lanceolaria grayana* (Lea, 1834). The authors recognize this species.

Lanceolaria bogani was recently described from Thura Thien-Hue Province, Vietnam, and placed in the Unioninae by Thach (2016a).

Lanceolaria fruhstorferi was recognized as a valid species by Haas (1910c) but listed by He and Zhuang (2013) and Graf and Cummings (2017) as a junior synonym of *L. grayii*. This species was recognized as a separate valid species from Vietnam by Thach (2016a).

Lanceolaria gladiola was described from China but Haas (1911) and Graf and Cummings (2017) report it from Vietnam and figure specimens that appear to be *Lanceolaria grayii*. This is a doubtful record for Vietnam.

Lanceolaria grayii is the senior synonym for *Unio* *grayanus* Lea, 1834 described from China (Bogan and Do 2011). Graf and Cummings (2017) include *L. fruhstorferi*, *L. laevis* and *Lanceolaria gracillimus* Rolle, 1904 as synonyms of *L. grayii*. All three were described from Tonkin. This group needs revision.

Lanceolaria laevis was originally described from Tonkin. It has been recognized and figured by Đặng et al. (1980) and Thach (2005, 2007). It was listed by He and Zhuang (2013) and Graf and Cummings (2017) as a junior synonym of *L. grayii*.

Nodularia Conrad, 1853 was erected with *Unio douglasiae* Griffith & Pidgeon, 1833 as the type species. Simpson (1900, 1914) and Starobogatov (1970) used *Nodularia* as a valid genus. However, *Nodularia* was considered a junior synonym of *Unio* Retzius, 1788 (Haas 1969a, 1969b). Đặng et al. (1980) included two taxa from northern Vietnam in *Nodularia*. Graf and Cummings (2007) recognized the genus and included four species, while Graf and Cummings (2017) included only three species. *Nodularidia* Cockerell, 1901, was an unnecessary replacement name for *Nodularia* when it was considered preoccupied. *Nodularidia* was used by He and Zhuang (2013) for a single species in China. *Nodularia* and *Unio* represent separate clades and may belong in separate tribes (Lopes-Lima et al. 2017). We recognize three taxa in *Nodularia* from Vietnam.

Nodularia dorri was reported by Đặng et al. (1980). Graf and Cummings (2017) also used this species and noted its distribution from the Gulf of Tonkin to the Mekong. It appears to be restricted to northern and central Vietnam.

Nodularia douglasiae crassidens Haas, 1910 (Haas 1910a) appeared in Simpson (1914) as a *Nodularia* (*Nodularia*) *douglasiae* var. *crassidens* and was recognized by Đặng et al. (1980). Haas (1969a) placed this taxon as a synonym of *Unio douglasiae douglasiae* but listed it as occurring in China and questionably in Cambodia. Graf and Cummings (2017) synonymize this subspecies under *Nodularia douglasiae*. *Nodularia douglasiae* is used here but it is recognized that *Nodularia* needs extensive revision.

Nodularia nuxpersica is a new addition to the fauna of Vietnam based on recent collections from markets in northern Vietnam. He and Zhuang (2013) figured and included *Unio nuxpersica* in the synonymy of *Scabies crispata* (Gould, 1843) and *Scabies chinensis* Liu et al., 1991 (He and Zhuang 2013). The Vietnam samples were shown to belong in *Nodularia* based on DNA sequence data (Lopes-Lima et al. 2017).

Oxynaia was described by Haas, but the date of publication has been confused. Haas (1969a) recorded it as 1911 but Haas (1969b) used 1913. Starobogatov (1970) used *Oxynaia* Haas, 1912. Graf and Cummings (2017) noted the generic name was associated with a figure in 1911 as a nomen nudum and only described in 1913 (Haas 1913) and subsequently redescribed in Haas (1913b). Based on the dates of publication for Haas (1910c–1920) reported by Bogan (2015), plates 14, 15, 16 in Haas (1911) are the first appearance of the generic name *Oxynaia* associated with four described species published in 1911. Thus, the generic name *Oxynaia* was available from the date of publication of the plates. This is considered an indication for a genus named before 1931 under the International Commission on Zoological Nomenclature (ICZN 1999) Code Article 12.11.2.2. The generic name *Oxynaia* takes the date of publication as Haas, 1911 (see Bogan 2015). The type species of *Oxynaia* was designated as *Unio jourdyi* Morlet, 1886 by Haas (1913).

Oxynaia diespiter was described from Tonkin, and known from the single type specimen and conchologically is very close to *Oxynaia jourdyi*. Đặng et al. (1980) reported this species from northern Vietnam. Graf and Cummings (2017) illustrated a single specimen from Tonkin, MNHN_MO_2998, which may be the unmarked holotype.

Oxynaia gladiator was described from Tonkin and recognized as valid by Haas (1969a) and Graf and Cummings (2017). Haas (1969a) listed this species from Tonkin and Annam, Vietnam. However, it looks very much like *Oxynaia micheloti* (Morlet, 1886). Adding this to the fauna of Vietnam would bring the total *Oxynaia* species to four.

Oxynaia jourdyi is listed by Haas (1969a) as the type species for the genus; it was described from Bac Hat etang de la riviere Claire. Đặng et al. (1980) also listed this species.

Oxynaia micheloti was described from "Tonkin." Haas (1969a) mentions this species is only known from the original description. Đặng et al. (1980) recognized the species. Based on the figures provided by Graf and Cummings (2017), *O. micheloti* does not have a very long shell and has a taller shell than many of the lots figured as that species. Some of the other figured lots appear to represent *Nodularia* species.

Physunio cambodiensis is listed from Cambodia, Lao PDR, and Thailand by Haas (1969a), Brandt (1974), and Graf and Cummings (2017). Davidson et al. (2006) collected this species from a site on the Serepok River in Dak Lak Province, and the Mekong River, An Giang and Long An Provinces, Vietnam. These are the first records for this species in Vietnam.

Physunio micropterus was reported by Brandt (1974) and Graf and Cummings (2017) from Cambodia and Thailand. Two specimens were reported from "Cochin China" or southern Vietnam (Graf and Cummings 2017). Davidson et al. (2006) collected this species from a site on the Dak Bla River tributary of the Se San River, Kon Tum Province, Vietnam. This species has been reported from Luy River, Binh Thuan province.

Physunio modelli was described from north central Thailand and reported from Thailand and Lao PDR (Brandt 1974). It has been reported from the Ham Tan district, Binh Thuan Province by Thach (2007:190, plate 61, fig. 1057).

Physunio superbus was described from New Holland in error and Brandt (1974) listed the distribution as possibly including southern Vietnam. Đặng et al. (1980) did not report this species. Graf and Cummings (2017) figure specimens from Cochinchine or the Mekong Delta area of southern Vietnam. There are specimens in the IEBR collections, Hanoi, with the only locality data recorded as Vietnam.

Pilsbryoconcha compressa was recognized as a subspecies of *Pilsbryoconcha exilis* by Brandt (1974). Graf and Cummings (2017) listed *P. compressa* as a separate species. This species was reported from An Giang Province, Vietnam (Bogan and Do 2014b).

Pilsbryoconcha exilis was reported from southern Vietnam (Brandt 1974). Graf and Cummings (2017) figured specimens from Vietnam.

Pilsbryoconcha lemeslei was not mentioned by Đặng et al. (1980). Haas (1969a) listed it only from Thailand and Cambodia and Brandt (1974) did not mention this species from Vietnam. Thach (2007) mentions this species from Khanh Hoa, Vietnam, and figured a specimen that resembles specimens figured by Graf and Cummings (2017).

Pilsbryoconcha suilla von Martens, 1902 was not originally figured and was placed in the genus *Pilsbryoconcha* by Simpson (1914). Simpson remarked that Martens thought this species reminded him of *Pilsbryoconcha*. Đặng et al. (1980) used the combination *Pilsbryoconcha suilla* but did not figure this species. *Anodonta suilla* has been used as a junior synonym of *Sinanodonta woodiana* by Haas (1969a) and Graf and Cummings (2017). If it has a shell shape close to *Sinanodonta jourdyi* Morlet, it would become a synonym of *S. jourdyi* of Vietnam (Lopes-Lima, personal communication).

Cristaria discoidea (Lea, 1834) has been placed in *Cristaria* (*Pletholophus*) by Simpson (1900, 1914) and Haas (1969a). *Unio tenuis* Gray in Griffith and Pidgeon, has been dated as 1834 and listed as a junior synonym of *Unio discoidea* Lea, 1834 by Lea (1836, 1838, 1852, 1870), Simpson (1900, 1914) and Haas (1969a). Petit and Coan (2008) determined the date of publication of the figure of *Unio tenuis* Gray in Griffith and Pidgeon as 1833, and noted *Unio tenuis* has priority over the later name *Unio discoidea* Lea, 1834. This case does not meet the requirements of the Code 23.9 (ICZN 1999) for usage and the older name has date priority and must prevail. The correct name for *Cristaria discoidea* is *Cristaria tenuis* (Gray in Griffith and Pidgeon, 1833). *Cristaria tenuis* was used by He and Zhuang (2013) and Graf and Cummings (2017). Đặng et al. (1980) elevated *Pletholophus* to generic level and included three species: *Pletholophus swinhoei* (Adams, 1866); *Pletholophus inangulatus* (Haas, 1910a), and *Pletholophus discoideus* (Lea, 1834). All of them are considered synonyms under *Cristaria tenuis* (He and Zhuang 2013; Graf and Cummings 2017). Placement of *C. tenuis* in *Pletholophus* and separate from *Cristaria* was confirmed by Lopes-Lima et al. (2017).

DNA sequence analyses of *Pletholophus* samples from Vietnam revealed a second distinct species, here assumed to represent a new species, *Pletholophus* sp. (Lopes-Lima, personal communication).

Protunio Haas, 1912 was described by Haas but various dates have been listed for its publication. Haas (1969a, 1969b), Starobogatov (1970), and Graf and Cummings (2017) all listed 1913 (Haas 1913) as the date of publication of *Protunio*. Graf and Cummings (2017) cited Haas 1912 (plate 32) for *Protunio* but used 1913 as the date for the generic description (Haas 1913). Based on the dates of publication for Haas (1910c–1920) reported by Bogan (2015), plate 32 is the first appearance of the generic name *Protunio* associated with a described species published in 1912 (Bogan 2015). Thus, the generic name *Protunio* was available from the date of publication of the plate and since *Protunio* was published in association with a single species, *Unio messageri* Bavay and Dautzenberg, 1901 is the type species by monotypy. This is considered an indication for a genus named before 1931 under ICZN Code Article 12.112.2. The generic name *Protunio* takes the date of publication as Haas, 1912 (see Bogan 2015). *Protunio* was subsequently redescribed by Haas with the date on the signature of 1914 and the date on the cover of the Lieferung containing the four signatures of 1919 (Bogan 2015).

Protunio messageri was recognized by Haas (1969a, 1969b) and Graf and Cummings (2017) as restricted to northern Vietnam. Đặng et al. (1980) reported this species from around Cao Bang and Lang Son. However, the specimen illustrated by Đặng et al. (1980) and Đặng and Hồ (in press) is not *Protunio messageri* when compared with the original figures (Heude 1877) and figures provided by Graf and Cummings (2017). The specimen figured by Đặng et al. (1980) and Đặng and Hồ (in press) represents a different species. The figured shell shape is very similar to *Pseudobaphia biesiana* (Heude, 1877) figured by Haas (1910c–1920), He and Zhuang (2013), and Graf and Cummings (2017) but represents an undescribed species, *Pseudobaphia* sp. *Pseudobaphia* sp. is known from only three lots of specimens, one lot in IEBR, Hanoi, one lot in the North Carolina Museum of Natural Sciences, Raleigh, and a large lot in the Vietnam National University, Hanoi University of Science, Museum of Biology, Hanoi. This species has not been collected since 1971.

Pseudodon inoscularis is the type species of *Pseudodon* and has been reported from throughout Southeast Asia. Brandt (1974) recognized one species as a Rassenkreis or a ring species with a variety of subspecies. This group is in dire need of a taxonomic revision. Graf and Cummings (2017) claimed the range of *P. inoscularis* from South Vietnam but did not illustrate any specimens.

Pseudodon callifer (Martens, 1860) was listed by Brandt (1974) as subspecies of *P. inoscularis callifer* and reported from Thailand, Cambodia and southern Vietnam.

Pseudodon cambodjensis was not reported by Brandt (1974) or Đặng et al. (1980) from Vietnam, but Graf and Cummings (2017) list a specimen (Museum of Comparative Zoology, Harvard [MCZ] 37431) from Cochinchine and mapped it in southern Vietnam.

Pseudodon ellipticus Conrad, 1865 was listed by Graf and Cummings (2017) from Thailand, Cambodia, and southern Vietnam but they did not figure any specimens. It was described from Cambodia. Brandt (1974) used it as a subspecies of *Pseudodon vondembuschianus*.

Pseudodon inoscularis was recognized by Graf and Cummings (2017), who listed it from southern Vietnam. Haas (1969a) listed this species from Tenasserim, Myanmar [+

Burma], only. Brandt (1974) treated the species as a ring species ranging from Myanmar, Thailand, Malaysia, Lao PDR, Cambodia, and southern Vietnam. This wide-ranging species appears to grade from one form to another across its range and should be carefully examined with molecular techniques.

Pseudodon mouhotii was recognized and listed from Vietnam by Brandt (1974) and Graf and Cummings (2017), but was not discussed by Đặng et al. (1980). *Pseudodon exilis* (Morelet, 1866) was considered by Brandt (1974) a junior synonym of *Pseudodon mouhotii*.

Pseudodon resupinatus was described from Than Moi, Tonkin, but was not originally figured. It is recognized as a valid species by Simpson (1914), Haas (1920), Đặng et al. (1980), and Graf and Cummings (2017). This species is endemic to northern Vietnam.

Pseudodon vondembuschianus, as used by Brandt (1974), contained three subspecies including *Pseudodon vondembuschianus ellipticus* Conrad, 1865, reported from southern Vietnam. Đặng et al. (1980) and Graf and Cummings (2017) do not list this species from Vietnam. It is found in southern Vietnam.

Ptychorhynchus pfisteri was reported by Đặng et al. (1980) from northern Vietnam. The species was not listed from Vietnam by Haas (1969a, 1969b), He and Zhuang (2013), or Graf and Cummings (2017). Recently specimens have been collected by the authors in Hanoi.

Scabies crispata was reported by Đặng et al. (1980) and Brandt (1974) from Vietnam. Graf and Cummings (2017) report this species from Cochinchine and Tonkin, Vietnam, but some of the specimens figured appear to be specimens of *Nodularia*. Recently, a field survey conducted by L. A. Prozorova and N. X. Quang (personal communication) recorded this species from Bung Binh Thien, An Phu, An Giang (southern Vietnam).

Sinanodonta hunganhi was described from around Vinh City, Nghê An Province, in northern Vietnam and reported it living "along rivers" [sic] (Thach 2016b). Based on the published figure, this species appears to fit within the shell variation of *S. jourdyi*.

Sinanodonta jourdyi and *Sinanodonta elliptica* (Heude, 1878) were identified from northern Vietnam (Đặng et al. 1980). Specimens collected from Vietnam were identified as both species and were examined genetically. These specimens represent a single species, distinct from *Sinanodonta woodiana* of China (Lopes-Lima, personal communication). The name available for the Vietnamese species is *S. jourdyi*. Because *S. elliptica* was described from China, it is likely a synonym of *S. woodiana* and was not found in Vietnam (Lopes-Lima, personal communication).

Sinanodonta lucida was reported from North Vietnam (Đặng et al. 1980). Graf and Cummings (2017) treated *S. lucida* as a junior synonym of *S. woodiana*. Bolotov et al. (2016a) reported it as a separate, valid species but from China.

Sinanodonta woodiana has been assumed to be a wide-ranging and plastic species, with 103 synonyms listed for this species (Graf and Cummings 2017). Haas (1969a) treated all three taxa reported from Vietnam as synonyms of *Anodonta* (*Anodonta*) *woodiana* (Lea, 1834). Đặng et al. (1980) recognized three species in the genus *Sinanodonta* in northern Vietnam, *S. jourdyi* (Morlet, 1886), *S. elliptica* (Heude, 1878), and *S. lucida* (Heude, 1878). He and Zhuang (2013) and Graf and Cummings (2017) listed all three taxa as synonyms of *S. woodiana*. Preliminary DNA sequence analyses have separated *S. jourdyi* from *S. woodiana* occurring in China. Because the type locality for *S. elliptica* is China, it is not recognized in Vietnam and is considered part of the greater *S. woodiana* complex (Lopez-Lima, personal communication). The complexity of *S. woodiana* has been documented for Asia and the species invading Europe (Bolotov et al. 2016a). Bolotov et al. (2016a) documented seven separate lineages within what has been named *Sinanodonta woodiana*. These analyses also separate *Sinanodonta lucida* as a separate linage within the *S. woodiana* complex. This taxonomic puzzle will require further analyses to resolve this group.

Solenaia oleivorus has been collected from the Phan River (Vinh Phuc Province), Day River (Ha Noi and Ha Nam provinces), and Thuong River (Bac Giang province) in Vietnam. This species was synonymized by He and Zhuang (2013) under *Solenaia iridinea* (Heude, 1874) in China, but determined to be a separate and valid species by Ouyang et al. (2011). The authors recognize it as a valid species.

Trapezoideus was recognized as containing a single species with three subspecies by Brandt (1974). He remarked *Trapezoideus* might occur in southern Vietnam. Đặng et al. (1980) recognized *Trapezoideus misellus*. Graf and Cummings (2017) placed *T. misellus* as a junior synonym of *Trapezoideus excolescens* (Gould, 1843). Preliminary genetic analyses have suggested *Trapezoideus* is not a monotypic genus, but may harbor several cryptic species (Lopes-Lima, personal communication). Now, we have chosen to recognize the wide-spread species *T. exolescens* in southern Vietnam and *T. misellus* from northern Vietnam.

Unionetta fabagina was listed by Haas (1969a) from Cambodia and Lao PDR. Brandt (1974) reported *Unionetta fabagina* from the Mekong River, but not from Vietnam. A shell of *U. fabagina* has been collected from Sa Thay River, Kon Tun and Gia La provinces (Central Highlands), Vietnam.

DISCUSSION

Distribution of the Fauna

The unionid fauna of Vietnam can be divided along the major river basins draining the country (Fig. 1). The Red River basin is the major basin in the north, passing through Hanoi. There are representatives of the fauna in the far north of Vietnam that have relationships with the fauna of the Zhu River basin and the Yangtze River basin farther north in southern China (e.g., *Lamprotula* species). The western border areas of Vietnam, including Dien Bien Province and rivers of the Central Highland and southern Vietnam, are drained by tributaries to the Mekong River basin in the north. The Mekong River fauna described by Brandt (1974) for Thailand, Lao PDR, and Cambodia extends into southern Vietnam in the distributaries in the Mekong Delta. The unionid fauna in the eastern rivers of the Central Highland is still poorly known.

Seventeen species are considered endemic to Vietnam and comprise 28.8% of the total species found in Vietnam (Table 2). Forty species were found in the north while 18 species were reported from the south and only one species (*Sinanodonta jourdyi*) is widely distributed throughout the country (Table 2; see also Supplemental Individual Species Maps).

Our recent surveys demonstrated that the northeastern area of Vietnam possess the highest diversity of freshwater mussels in Vietnam. Se San and Serepok, tributaries of the Mekong River, can be ranked as a second hotspot of diversity of this group. It is necessary to conduct more surveys in the northwest of Vietnam in Dien Bien Province and the Central Highlands where data are quite scarce. We have only spent part of a single field trip in southern Vietnam and need to spend more time in the Mekong Delta area of Vietnam.

Conservation Assessment

The IUCN hosted a training session in Phenom Penh, Cambodia, and a workshop in Vientiane, Lao PDR, to assess the conservation status of the freshwater fauna of the Indo-Burma area, including Vietnam (Allen et al. 2012). Freshwater bivalves and gastropods were a part of this program (Köhler et al. 2012). Our current conservation assessment began with the information from IUCN Red List (2016) and is supplemented with our recent field data and museum records. The IUCN conservation status of the freshwater bivalves of Vietnam is summarized in Table 2.

Based on the 59 species recorded in Vietnam (Table 2), those taxa assessed in the IUCN Red List (2016) included 4 species (6.8%) assessed as Critically Endangered, 7 species (12%) assessed as Endangered, 1 species (1.7%) assessed as Vulnerable, 2 species (3.4) assessed as Near Threatened, 23 species (39%) assessed as Least Concern, 11 species (18.6%) assessed as Data Deficient, and 11 species (18.6%) that were not evaluated.

Based on our survey results beginning in 2010 and using the IUCN Red List categories and criteria (IUCN 2012), we herein recommend that the conservation status of following four species should be changed and we will submit a revised species assessment to the IUCN:

(1) *Solenaia oleivora* should be assessed as Vulnerable. It was found only in the Phan, Day, and Thuong rivers; population reduction was estimated about 50% over 10 yr; extent of occurrence was estimated as smaller than 20,000 km^2. This species is assessed only on the Vietnamese portion of its range.
(2) *Lamprotula quadrangulosa* should be assessed as Vulnerable. It was found only in the Bang River; population reduction was estimated about 50% over 10 yr; extent of occurrence was estimated as smaller than 20,000 km^2. This species is assessed only on the Vietnamese portion of its range.
(3) *Trapezoideus misellus* should be assessed as Vulnerable. It was found only in the Bang River; population reduction was estimated about 50% over 10 yr; extent of occurrence was estimated as smaller than 20,000 km^2. This species assessed only on data from northern Vietnam.
(4) *Contradens fultoni* should be assessed at least as Endangered. It was found in only the Mau Son River, Lang Son Province, based on an early record from 1930; extent of occurrence was estimated as smaller than 5,000 km^2. This species is endemic to Vietnam.

We are particularly concerned about the status and continued survival of four species in the Bang River basin and tributaries of Li Chiang in northeastern Vietnam and China: *Aculamprotula nodulosa*, *Lamprotula contritus*, *Lamprotula quadrangulosa*, and *Gibbosula crassa*. These species have been very scarce in the past several decades. *Lamprotula blaisei*, *Contradens fultoni*, *Pseudobaphia* sp., and *Cuneopsis demangei* have not been seen or collected since the early 1970s. No shells or live specimens of these last four taxa were collected during our fieldwork, strongly suggesting that these taxa are extirpated from their former range in Vietnam. The first three species are endemic to Vietnam and they may already be extinct.

Impacts

Freshwater mussels are long-lived animals (10 to 200 yr) and have a unique life cycle with a parasitic larval stage on the gills or fins of fish, so negative impacts on the species may not be immediately apparent (Bogan 1993, 2006; Vaughn and Taylor 1999; Vaughn 2010; Haag 2012). Mussels provide a variety of ecosystem services that directly and indirectly impact the local human populations including biofiltration, food source for animals and humans, and resource materials (e.g., inlay materials) (Vaughn 2017). Negative impacts on freshwater mussels are numerous, including channel modification and habitat destruction from dredging; sedimentation; clear-cutting of watersheds; monoculture cropping; loss of riparian buffers along streams; pollution in many forms including fertilizers, pesticides, industrial effluents, and domestic sewage; mining; urbanization and damming of rivers; commercial exploitation; introduced species; expansion of nonnative parasite hosts; and the loss of native host fish (e.g., Dudgeon et al. 2006; Gillis 2012; Haag 2012; Vaughn 2012; Sousa et al. 2014; Zieritz et al. 2016). There is no research on the impacts of current agricultural and forestry practices on the unionid fauna of Vietnam; however, research in Malaysia (Zieritz et al. 2017) has indicated that such activities have had a negative effect on the distribution of freshwater mussels.

Many impacts on the freshwater environment were visible during our surveys including deforestation, road construction (Fig. 5), in-stream sand and gravel mining (Fig. 6), open-pit

Figure 5. Road construction and disposal of debris over the edge of the road and the impact on the local river; the river is the same color as the earth being dumped. Lang Son Province, Vietnam. Photograph by Arthur Bogan. November 11, 2012.

Figure 7. Open-pit mining, Cao Bang Province, Vietnam. Photograph by Arthur Bogan. November 13, 2012.

mining runoff (Fig. 7), harvesting for food (Fig. 2), domestic pollution, and construction of various dams and hydroelectric projects (Fig. 8). Streams have been locally modified by restriction of channels, diversion of water for rice fields, and terracing of flood plains for rice production. Most of the large trees have been cut from the mountains, affecting the rain runoff patterns and thus affecting water temperature and clarity and increasing runoff (see Naiman and Dudgeon 2011; Zieritz et al. 2016). These modifications are impacting freshwater mussels and gastropod populations. A few species are doing well in disturbed habitats and show up in the markets as food items, including *Sinanodonta* spp., *Cristaria plicata*, *Pletholophus tenuis*, and *Nodularia* spp. (V.T. Do, personal observations).

Current and planned dams in the Mekong River basin and their impacts have been summarized by Winemiller et al. (2016). Dams and reservoirs not only impact the mussel and fish fauna in the footprint of the reservoir but also below the reservoir. Downstream of the dam (Fig. 8) water flow patterns, water temperature, and chemistry are changed and can dramatically impact mussels, their biology, and native host fish (Vaughn and Taylor 1999).

Mussels are used a food item and are intensively collected in some areas of Vietnam. A local mussel harvester commented that currently he is only able to collect about 100 kg per day where in the past he was collecting 500 to 800 kg per day to sell in local markets. This decline in harvest may be due to overharvesting or mussel population declines due to a combination of overharvesting, disturbance, and pollution. Consider the number of people across Vietnam collecting mussels each day and this impact on a yearly basis is staggering. Decline in the mussel fauna of Vietnam can be considered on a local scale as well as considering the national impact on the freshwater bivalve fauna. These impacts will also impact those species that range beyond Vietnam's borders.

Figure 6. In-stream gravel mining, Dien Bien Province, Vietnam. Photograph by Arthur Bogan. November 19, 2012.

Figure 8. Dam in central Vietnam with the riverbed downstream dewatered. Photograph by Arthur Bogan. November 18, 2014.

Conservation Recommendations

In addition to established national parks and conservation areas, beginning in 2008 and extending to 2020, Vietnam will establish 45 areas for protection of inland water bodies. Some parts of the Red and Da rivers (in northern Vietnam) will be included in protected areas. However, conservation activities for freshwater bivalves have never been mentioned. About 60% of the Vietnamese freshwater bivalve fauna is currently imperiled. Some freshwater bivalve species already appear to have disappeared from northern Vietnam and the future is bleak for endangered freshwater bivalve species.

New outreach materials need to be developed for distribution to local people, aquaculture agencies, primary and high schools, and universities which illustrate the Vietnamese freshwater bivalve fauna and their unique life cycle. Aquaculture programs can be encouraged to develop captive propagation programs that will identify the native host fish for species to assist in conservation. Public activities and education on the importance and role of freshwater bivalves have not been mentioned. Some of freshwater bivalve species already seem to have disappeared from northern Vietnam and there is reason to be pessimistic about the future of endangered freshwater bivalve species.

Knowledge of the taxonomy of marine mollusks is actively expanding due to activities of the amateur shell collectors who are regularly contributing to the description of new species (see Bouchet et al. 2016). Developing a public program not only to provide information on freshwater mollusks of Vietnam, but also a website to provide free information or assist with identifications, is needed. This would stimulate more public involvement in examining the local freshwater fauna. Shell clubs are common in the United States and Europe and there are already shell dealers and people interested in shells in Vietnam (see Thach 2005, 2007, 2012, 2016b). These people would be a great source of information and local knowledge about these animals and should be encouraged to participate. A template might be the Cornell FeederWatch project.

Future Research Needs

Our understanding of the phylogenetic relationships of the freshwater mussels of Vietnam is only beginning to be explored (e.g., Lopes-Lima et al. 2017). Using results of our expanding molecular analyses, we have recognized a small-sized species, *Nodularia nuxpersica*, new to Vietnam, and one undescribed new species, *Pletholophus* sp. By comparing photographs and museum collections, we have recognized a misidentified species as new, *Pseudobaphia* sp. If the results of the work in Malaysia are any indication, some of the currently recognized Vietnamese unionid species may be overturned as some species are being recognized as a species complex (e.g., *Hyriopsis bialatus*) (Zieritz et al. 2016). This effort will require continued collaboration with colleagues throughout Asia.

ACKNOWLEDGMENTS

We want to express our gratitude for the support of the Institute of Ecology and Biological Resources (IEBR), Vietnam Academy of Science and Technology (VAST), and North Carolina Museum of Natural Sciences for their support of this collaborative research. We also acknowledge the help of our assistants, Mr. Quoc Toan Phan, Nguyen Tong Cuong, Nguyen Dinh Tao, and our drivers, Mr. Nguyen Ngoc Quyen, who was our driver for three trips, and Mr. Dang Thanh Ha, who was our driver for the 2016 trip. We also appreciate the Nagao Natural Environment Foundation support for Do Van Tu's research project "The study of Unionoida biodiversity and conservation status in Bang and Ky Cung River basins in Northeast Vietnam." Ms. Jamie M. Smith and Mrs. Heather B. Leslie have been instrumental in databasing specimens deposited in the North Carolina Museum of Natural Sciences Mollusk Collection from Vietnam. Mrs. Cynthia M. Bogan and Ms. Jamie M. Smith have reviewed the manuscript for content and English composition. We thank our anonymous reviewers for their very helpful and thorough comments and suggestions; they have been very helpful.

LITERATURE CITED

Allen, D. J., K. G. Smith, and W. R. T. Darwall (compilers). 2012. The Status and Distribution of Freshwater Biodiversity in Indo-Burma. IUCN, Cambridge, United Kingdom, and Gland, Switzerland. 158 pp.

Araujo, R., S. Schneider, K. J. Roe, D. Erpenbeck, and A. Machordom. 2017. The origin and phylogeny of Margaritiferidae (Bivalvia, Unionoida): A synthesis of molecular and fossil data. Zoologica Scripta 46:289–307. doi: 10.1111/zsc.12217

Bavay, A., and P. Dautzenberg. 1901. Description de deux Unio et d'un Corbicula nouveaux, provenant de l'Indo-Chine. Journal de conchyliologie 49:5–9, plate 1, figures 1–7.

Bogan, A. E. 1993. Freshwater bivalve extinctions: Search for a cause. American Zoologist 33:599–609.

Bogan, A. E. 2006. Conservation and extinction of the freshwater molluscan fauna of North America. Chapter 30. Pages 373–383 *in* C.F. Sturm, T. A. Pearce, and A. Valdes, editors. The Mollusks: A Guide to Their Study, Collection, and Preservation. American Malacological Society, Universal Publishers, Inc., Boca Raton, Florida.

Bogan, A. E. 2008. Global diversity of freshwater mussels (Mollusca, Bivalvia) in freshwater. Global diversity of freshwater animals. Hydrobiologia 595:139–147.

Bogan, A. E. 2015. Determining the date of publication for *Contradens* Haas and *Uniandra* Haas (Bivalvia; Unionidae). The Nautilus 129:175–178.

Bogan, A. E., and V. T. Do. 2011. Research note: Clarification of the authorship and date of publication of three Asian species of Unionidae (Bivalvia): The Nautilus 125:171–172.

Bogan, A. E., and V. T. Do. 2013a. Field research on the distribution of freshwater bivalves in northern Vietnam, November 2012. Ellipsaria 15:13–14.

Bogan, A. E., and V. T. Do. 2013b. Conservation assessment of freshwater bivalves in northern Vietnam, 2012. Tentacle 21:10–20.

Bogan, A. E., and V.T. Do. 2014a. Freshwater bivalve survey of Vietnam, Part II: Central Highlands and the Mekong Delta area. Ellipsaria 16:29–31.

Bogan, A. E., and V. T. Do. 2014b. Two freshwater bivalve species new to the fauna of Vietnam (Mollusca: Bivalvia: Arcidae and Unionidae), Tropical Natural History 14:113–116.

Bogan, A. E., and V. T. Do. 2016. Fieldtrip to northern Vietnam, 2016. Ellipsaria 18:27–29.

Bolotov, I. N., Y. V. Bespalaya, M. Y. Gofarov, A. V. Kondakov, E. S. Konopleva, and I. V. Vikhrev. 2016a. Spreading of the Chinese pond mussel, *Sinanodonta woodiana*, across Wallacea: one or more lineages invade tropical islands and Europe. Biochemical Systematics and Ecology 67:58-64.

Bolotov, I. N., I. Vikhrev, Y. Bespalaya, V. Artamonova, M. Gofarov, J. Kolosova, A. Kondakov, A. Makhrov, A. Frolov, S. Tumpeesuwan, A. Lyubas, T. Romanis, and K. Titova. 2014. Ecology and conservation of the endangered Indochinese freshwater pearl mussel, *Margaritifera laosensis* (Lea, 1863) in the Nam Pe and Nam Long rivers, Northern Laos. Tropical Conservation Science 7:706–719.

Bolotov, I. N, I. V. Vikhrev, Y. V. Bespalaya, M. Y. Gofarov, A. V. Kondakov, E. S. Konopleva, N. N. Bolotov, and A. A. Lyubas. 2016b. Multi-locus fossil-calibrated phylogeny, biogeography and a subgeneric revision of the Margaritiferidae (Mollusca: Bivalvia: Unionoida). Molecular Phylogenetics and Evolution 103:104–121.

Bolotov, I. N., I. V. Vikhrev, A. V. Kondakov, E. S. Konopleva, M. Y. Gofarov, O. V. Aksenova, and S. Tumpeesuwan. 2017. New taxa of freshwater mussels (Unionidae) from a species-rich but overlooked evolutionary hotspot in Southeast Asia. Scientific Reports 7:11573. doi:10.1038/s41598-017-11957-9

Bouchet, P., S. Bary, V. Héros, and G. Marani. 2016. How many species of molluscs are there in the world oceans and who is going to describe them? Pages 9–24 *in* V. Héros, E. Strong, and P. Bouchet, editors. Tropical Deep-Sea Benthos 29. Muséum national d'Histoire naturelle, Paris.

Brandt, R. A. M. 1974. The non-marine aquatic Mollusca of Thailand. Archiv für Molluskenkunde 105:1–423.

Breton, S., H. Doucet-Beaupré, D. T. Stewart, W. R. Hoeh, and P. U. Blier. 2007. The unusual system of doubly uniparental inheritance of mtDNA: Isn't one enough? Trends in Genetics 23:465– 474. doi: 10.1016/j.tig.2007.05.011

Breton, S., D. T. Stewart, S. Shepardson, R. J. Trdan, A. E. Bogan, E. G. Chapman, A. J. Ruminas, H. Piontkivska, and W. R. Hoeh. 2010. Novel protein genes in animal mtDNA: A new sex determination system in freshwater mussels (Bivalvia: Unionoida)? Molecular Biology and Evolution 28:1645–1659. doi: 10.1093/molbev/msq345

Đặng N. T., and T. H. Hồ (in press). Freshwater Bivalves and Snails of Vietnam (Mollusca: Gastropoda, Bivalvia). Publishing House for Science and Technology, Hanoi, Vietnam.

Đặng, N. T., T. B. Thái, and V. M. Pham. 1980. Identification of freshwater invertebrates of North Vietnam. Sciences and Technology Publishing Co., Ha Noi, Vietnam. 573 pp. In Vietnamese: Định loại động vật không xương sống nước ngọt Bắc Việt Nam.

Dautzenberg, P., 1900. Diagnose d'une nouvelle espèce d'Unio provenant de l'Indo-Chine. Journal de conchyliologie 48:429.

Dautzenberg, P., and H. Fischer. 1906a. Contribution a la fauna malacologique de l'Indo-Chine. Journal de conchyliologie. 54:145–226, plates 5–7.

Dautzenberg, P., and H. Fischer. 1906b. Liste des Molluques récoltés par M. H. Mansuy en Indo-Chine et au Yunnan et description d'espèces nouvelles. Journal de conchyliologie 53:343–471, plates 8–10.

Dautzenberg, P., and H. Fischer. 1908. Liste des Molluques récoltés par M. Mansuy en Indo-Chine et description d'espèces nouvelles II. Journal de conchyliologie 56:169–217, plates 4–8.

Davidson, S. P., T. Kunpradid, Y. Peerapornisal, T. M. L. Nguyen, B. Pathoumthong, C. Vongsambath, and A. D. Pham. 2006. Biomonitoring of the Lower Mekong and selected tributaries. MRC Technical Paper No. 13. Mekong River Commission, Vientiane, Lao PDR. 100 pp.

Doucet-Beaupré, H., S. Breton, E. G. Chapman, P. U. Blier, A. E. Bogan, D. T. Stewart, and W. R. Hoeh. 2010. Mitochondrial phylogenomics of the Bivalvia (Mollusca): Searching for the origin and mitogenomic correlates of doubly uniparental inheritance of mtDNA. BMC Evolutionary Biology 10:50. doi:10.1186/1471-2148-10-50

Dudgeon, D., A. H. Arthington, M. O. Gessner, Z.-I. Kawabata, D. J. Knowler, C. Lévêque, R. J. Naiman, A.-H. Prieru-Richard, D. Soto, M. L. J. Stiassny, and C. A. Sullivan. 2006. Freshwater biodiversity: Importance, threats, status and conservation challenges. Biological Reviews 81:163–182.

Froufe, E., H. M. Gan, Y. P. Lee, J. Carneiro, S. Varandas, A. Teixeira, A. Zieritz, R. Sousa, and M. Lopes-Lima, 2015. The male and female complete mitochondrial genome sequences of the endangered freshwater mussel *Potomida littoralis* (Cuvier, 1798) (Bivalvia: Unionidae). Mitochondrial DNA 27:3571–3572. doi:10.3109/19401736.2015.1074223

Gillis, P. L. 2012. Cumulative impacts of urban runoff and municipal wastewater effluents on wild freshwater mussels (*Lasmigona costata*). Science of the Total Environment 431:348–356.

Gozhik, P. F. 1978. Fossil limnoscaphs in the southern Ukraine. Malacological Review 11:147–148.

Graf, D. L. 2007. Palearctic freshwater mussel (Mollusca: Bivalvia: Unionoida) diversity and the Comparatory Method as a species concept. Proceedings of the Academy of Natural Sciences of Philadelphia 156:71–88.

Graf, D. L. 2013. Patterns of freshwater bivalve global diversity and the state of phylogenetic studies on the Unionoida, Sphaeriidae, and Cyrenidae. American Malacology Bulletin 31:135–153.

Graf, D. L., and K. S. Cummings. 2006. Palaeoheterodont diversity (Mollusca: Trigonioida + Unionoida): What we know and what we wish we knew about freshwater mussel evolution. Zoological Journal of the Linnean Society, London 148:343–394.

Graf, D. L., and K. S. Cummings. 2007. Review of the systematics and global diversity of freshwater mussel species (Bivalvia: Unionoida). Journal of Molluscan Studies 73:291–314.

Graf, D. L., and K. S. Cummings. 2017. Musselp. The Freshwater Mussels (Unionoida) of the World (and other less consequential bivalves). Available at http://mussel-project.uwsp.edu/ (accessed January 3–May 10, 2017).

Griffith, E., and E. Pidgeon, [1833]–1834, The Mollusca and Radiata. Vol. 12, *in* E. Griffith, editor [1824]–1835, The Animal Kingdom Arranged in Conformity with its Organization, by the Baron Cuvier, member of the Institute of France, &c. &c. &c. with supplementary additions to each order, by Edward Griffith, F.L.S., A.S., corresponding member of the Academy of Natural Sciences of Philadelphia, &c. and others. Whittaker and Co., London.

Haag, W. R. 2012. North American Freshwater Mussels: Natural History, Ecology and Conservation. Cambridge University Press, Cambridge, United Kingdom. 505 pp.

Haag, W. R., and J. D. Williams. 2014. Biodiversity on the brink: An assessment of conservation strategies for North American freshwater mussels. Hydrobiologia 735:45–60.

Haas, F. 1910a. New Unionidae from East Asia. The Annals and Magazine of Natural History (8th series) 6:496–499.

Haas, F. 1910b. Neue Najaden. Nachrichtsblatt der Deutschen Malakozoologischen Gesellschaft 4:97–103.

Haas, F. 1910c–1920. Die Unioniden. Neubearbeitung und Fortsetzung der Küsterschen und Clessinschen Monographien von *Unio* und *Anodonta*. Volume 9 (pt. 2, section 2), pages 1–344, plates 1–73, 12a; 15 text figures *in* H. C. Küster, editor. Systematisches Conchylien-Cabinet von Martini und Chemnitz. Bauer und Raspe, Nürnberg.

Haas, F. 1913. Neue Najadengattungen. Nachrichtsblatt der Deutschen

Malakozoologischen Gesellschaft 45:33–38. Date published January 27, 1913 *fide* Solem 1967:83

Haas, F. 1923. Bieträge zu einer Monographie der asiatischen Unioniden. Sonderabdruck aus den Abhandlungen der Senkenbergischen Naturforschenden Gesellschaft 38:129–203, plates 15–16.

Haas, F. 1969a. Superfamilia Unionacea. Das Tierreich (Berlin). Lieferung 88:i–x,1–663.

Haas, F. 1969b. Superfamily Unionacea. Pages N411–N471 *in* R. C. Moore, editor. Treatise on Invertebrate Paleontology. Part N, Volume 1. Mollusca 6. Bivalvia. Geological Society of America and the University of Kansas, Lawrence, Kansas.

He, J., and Z. Zhuang. 2013. The Freshwater Bivalves of China. ConchBooks, Harxheim, Germany. 198 pp.

Heude, P. 1874. Diagnoses Molluscorum in fluminibus provinclae Nankingensis collectorum. Journal de conchyliologie 22:112-118.

Heude, P. 1875–1885. Conchyliologie fluviatile de la province de Nanking et de la Chine centrale. Librairie F. Savy, Paris. 10 Fascicules, plates and unnumbered pages.

Hoeh, W. R., M. B. Black, R. Gustafson, A. E. Bogan, R. A. Lutz, and R. C. Vrijenhoek. 1998. Testing alternative hypotheses of *Neotrigonia* (Bivalvia: Trigonioida) phylogenetic relationships using cytochrome C oxidase subunit 1 DNA sequences. Malacologia 40:267–278.

Hoeh, W. R., A. E. Bogan, K. S. Cummings, and S. I. Guttman. 2002. Evolutionary relationships among the higher taxa of freshwater mussels (Bivalvia: Unionoida): Inferences on phylogeny and character evolution form analyses of DNA sequence data. Malacological Review 31/32:123–141.

Hoeh, W. R., A. E. Bogan, and W. H. Heard. 2001. A phylogenetic perspective on the evolution of morphological and reproductive characteristics in the Unionoida. Pages 257–280 *in* G. Bauer and K. Wächtler, editors. Ecology and Evolutionary Biology of Freshwater Mussels, Unionoida. Ecological Studies Vol. 145. Springer Verlag, Berlin.

ICZN (International Commission on Zoological Nomenclature). 1999. International Code of Zoological Nomenclature. 4th ed. Incorporating Declaration 44, amendments of Article 74.7.3, with effect from December 31, 1999, and the Amendment on e-publication, amendments to Articles 8, 9, 10, 21 and 78, with effect from January 1, 2012. International Trust for Zoological Nomenclature, London. 306 pp. Available at http://www.nhm.ac.uk/hosted-sites/iczn/code/ (accessed September 11, 2015).

IUCN (International Union for Conservation of Nature and Natural Resources). 2012. IUCN Red List Categories and Criteria: Version 3.1. 2nd ed. IUCN, Gland, Switzerland and Cambridge, United Kingdom. 32 pp. Available at http://cmsdocs.s3.amazonaws.com/keydocuments/Categories_and_Criteria_en_web%2Bcover%2Bbckcover.pdf (accessed November 18, 2016).

IUCN. 2013. Documentation standards and consistency checks for IUCN Red List assessments and species accounts. Version 2. Adopted by the IUCN Red List Committee and IUCN SSC Steering Committee. IUCN, Gland, Switzerland and Cambridge, United Kingdom. 65 pp. Available at http://cmsdocs.s3.amazonaws.com/keydocuments/RL_Standards_Consistency.pdf (accessed November 18, 2016).

IUCN. 2016. Red List of threatened species. Edition 2016-2. Available at http://www.iucnredlist.org/ (accessed June–November 2016).

IUCN. 2017. IUCN Assessment Process for adding species to the IUCN Red List. Edition 2017-3. Available at http://www.iucnredlist.org/technical-documents/assessment-process (accessed December 21, 2017).

IUCN Standards and Petitions Subcommittee. 2016. Guidelines for using the IUCN Red List Categories and Criteria. Version 12. Prepared by the Standards and Petitions subcommittee. International Union for Conservation of Nature and Natural Resources. Gland, Switzerland and Cambridge, United Kingdom. 101 pp. Available at http://cmsdocs.s3.amazonaws.com/RedListGuidelines.pdf (accessed November 19, 2016).

Klishko, O., M. Manuel Lima-Lopez, E. Froufe, and A. E. Bogan. 2014. Are *Cristaria herculea* (Middendorff, 1847) and *Cristaria plicata* (Leach, 1815) (Bivalvia, Unionidae, Unioninae, Anodontini) separate species? Zookeys 438:1–15. doi:10.3897/zookeys.438.7493

Klishko, O., M. Lopes-Lima, E. Froufe, A. E. Bogan, and V. Y. Abakumova. 2016. Systematics and distribution of *Cristaria plicata* (Bivalvia, Unionidae) from the Russian Far East. Zookeys 580:13–27. doi:10.3897/zookeys.580.7588

Köhler, F., M. Seddon, A. E. Bogan, V. T. Do, P. Sri-Aroon, and D. Allen. 2012. The status and distribution of freshwater molluscs in the Indo-Burma region. Pages 66–88 *in* D. J. Allen, K. G. Smit, and W. R. T. Darwall, compilers. The Status and Distribution of Freshwater Biodiversity in Indo-Burma. IUCN, Cambridge, United Kingdom, and Gland, Switzerland.

Kondo, T. 2008. Monograph of Unionoida in Japan (Mollusca: Bivalvia). Special Publication of the Malacological Society of Japan, Tokyo. No. 3, 69 pp.

Lea, I. 1836. A Synopsis of the Family of Naïades. Cary, Lea and Blanchard, Philadelphia; John Miller, London. 59 pp., 1 plate, colored.

Lea, I. 1838. A Synopsis of the Family of Naïades. 2nd ed., enlarged and improved. Carey, Lea and Blanchard, Philadelphia. 44 pp.

Lea, I. 1852. A Synopsis of the Family of Naïades. 3rd ed., greatly enlarged and improved. Blanchard and Lea, Philadelphia. 88 pp.

Lea, I. 1870. A Synopsis of the Family Unionidae. 4th ed., very greatly enlarged and improved. Henry C. Lea, Philadelphia. 184 pp.

Lopes-Lima, M., E. Froufe, V. T. Do, M. Ghamizi, K. E. Mock, Ű. Kebapçi, O. Klishko, S. Kovitvadhi, U. Kovitvadhi, O. S. Paulo, J. M. Pfeiffer III, M. Raley, N. Riccardi, H. Şereflişan, R. Sousa, A. Teixeira, S. Varandas, X.-P. Wu, D. T. Zanatta, A. Zieritz, and A. E. Bogan. 2017. Phylogeny of the most species-rich freshwater bivalve family (Bivalvia: Unionida: Unionidae): Defining modern subfamilies and tribes. Molecular Phylogenetics and Evolution 106:174–191. doi 10.1016/j.ympev.2016.08.021

Lydeard, C., R. H. Cowie, W. F. Ponder, A. E. Bogan, P. Bouchet, S. A. Clark, K. S. Cummings, T. J. Frest, O. Gargominy, D. G. Herbert, R. Hershler, K. E. Perez, B. Roth, M. Seddon, E. E. Strong and F. G. Thompson. 2004. The global decline of nonmarine mollusks. BioScience 54:321–330.

Mabille, J. 1887. Sur quelques Mollusques du Tonkin. Bulletins de la Société Malacologique de France 4:73–164, plates 1–4.

Martens, E. V. 1902. Neue Unioniden aus Tonkin und Anam. Nachrichtsblatt der Deutschen Malakozoologischen Gesellschaft 34:130–135.

Modell, H. 1942. Das natürliche system der Najaden. Archiv für Molluskenkunde 74:161–191.

Modell, H. 1949. Das natürliche system der Najaden. 2. Archiv für Molluskenkunde 78:29–46.

Modell, H. 1950. Tertiäre Najaden IV. Archiv für Molluskenkunde 79:25–36.

Modell, H. 1964. Das natürliche system der Najaden. 3. Archiv für Molluskenkunde 93:71–126.

Morelet, A. 1865. Rectifications et additions à la fauna malacologique de l'Indo-Chine. Journal de conchyliologie 13:19–23, 225–228.

Morelet, A. 1866. Description d'espèces appartenant à la fauna malacologique de l'Indo-Chine. Journal de conchyliologie 14:62–64.

Morlet, L. 1886a. Diagnoses Molluscorum novorum Tonkini. Journal de conchyliologie 34:75–78.

Morlet, L. 1886**b.** Liste des Coquilles recueillies, au Tonkin, par M. Jourdy, chef d'escadron d'artillerie, et description d'espèces nouvelles. Journal de conchyliologie 34:257–295, plates 12–15.

Morlet, L., 1891. Contributions à la faune malacologique de l'Indo-Chine. Journal de Conchyliologie 39:230–254, plates 5, 7.

Naiman, R. J., and D. Dudgeon. 2011. Global alteration of freshwaters:

Influences on human and envirnomental well-being. Ecological Research 26:865–873.

Neves, R. J., A. E. Bogan, J. D. Williams, S. A. Ahlstedt, and P. D. Hartfield. 1998. Status of aquatic mollusks in the southeastern United States: A downward spiral of diversity. Pages 43–86 *in* G. W. Benz and D. E. Collins, editors. Aquatic Fauna in Peril: The Southeastern Perspective. Special Publication 1. Southeast Aquatic Research Institute, Lenz Design & Communications, Decatur, Georgia. 554 pp.

Ouyang, J. X., X.-P. Wu, S. Ouyang, S. Li, and D. Zhao. 2011. Phylogenetic analysis of some Chinese freshwater Unionidae based on mitochondrial COI sequences. Journal of Conchology 40:543–548.

Petit, R. E., and E. V. Coan. 2008. The molluscan taxa made available in the Griffith and Pidgeon (1833–1834) edition of Cuvier, with notes on the editions of Cuvier and on Wood's *Index Testaceologicus*. Malacologia 50:219–264.

Pfeiffer, J. M. III, and D. L. Graf. 2013. Re-analysis confirms the polyphyly of *Lamprotula* Simpson, 1900 (Bivalvia: Unionidae). Journal of Molluscan Studies 79:249–256.

Pfeiffer, J. M. III, and D. L. Graf. 2015. Evolution of bilaterally asymmetrical larvae in freshwater mussels (Bivalvia: Unionoida: Unionidae). Zoological Journal of the Linnean Society 175:307–318. doi: 10.1111/zoj.12282

Phuong, T. D. N. 2011. *Margaritifera laosensis*. IUCN 2011. 2011 IUCN Red List of Threatened Species. Version 2011.2. Available at http://www.iucnredlist.org (accessed July 3, 2016).

Red Data Book of Vietnam. 1992. Volume 1. Animals. Science and Technics Publishing House, Ha Noi. 396 pp. In Vietnamese.

Red Data Book of Vietnam. 2000. Volume 1. Animals. Publishing House for Science and Technology, Ha Noi, 408 pp. In Vietnamese.

Rochebrune, A.-T. 1904a. Monographie du genre *Harmandia*. Bulletin du Muséum d'Histoire Naturelle 10:138–141.

Rochebrune, A.-T. 1904b. Essai monographique sur le Genre *Chamberlainia* Simpson. Bulletin du Muséum d'Histoire Naturelle 10:463–466.

Roe, K. J., and W. R. Hoeh. 2003**.** Systematics of freshwater mussels (Bivalvia: Unionoida). Pages 91–122 *in* C. Lydeard and D. R. Lindberg, editors. Molecular Systematics and Phylogeography of Mollusks. Smithsonian Series in Comparative Evolutionary Biology. Smithsonian Books, Washington, D.C.

Rolle, H. 1904. Drei neue Najadeen aus Tonkin. Nachrichtsblatt der Deutschen Malakozoologischen Gesellschaft 36:25–26, plates 1–4.

Scudder, N. P. 1885. The Published Writings of Isaac Lea, LL.D. Biographies of American Naturalists II. Bulletin of the U.S. National Museum, Number 23. Government Printing Office, Washington, DC. 278 pp.

Simpson, C. T. 1900. Synopsis of the naiades, or pearly freshwater mussels. Proceedings of the U.S. National Museum 22:501–1044.

Simpson, C. T. 1914. A Descriptive Catalogue of the Naiades, or Pearly Fresh-Water Mussels. Parts I–III. Bryant Walker, Detroit. 1,540 pp.

Solem, A. 1967. New molluscan taxa and scientific writings of Fritz Haas. Fieldiana: Zoology 53:71–144.

Sousa, R., A. Novais, R. Costa, and D. L. Strayer. 2014. Invasive bivalves in fresh waters: Impacts from individuals to ecosystems and possible control strategies. Hydrobiologia 735:233–251. doi 10.1007/s10750-012-149-1

Starobogatov, Ya. I. 1970. Fauna Mollyuskov i Zoogeograficheskoe Raionirovanie Kontinental'nykh Vodoemov Zemnogo Shara [Mollusk Fauna and Zoogeographical Partitioning of Continental Water Reservoirs of the World]. Nauka, Leningrad. 372 pp., 39 figures, 12 tables. In Russian.

Strayer, D. L., and D. Dudgeon. 2010. Freshwater biodiversity conservation: Recent progress and future challenges. Journal of the North American Benthological Society 29:344–358.

Thach, N. N. 2005. Shells of Vietnam. ConchBooks, Hackenheim, Germany. 338 pp., 91 color plates.

Thach, N. N. 2007. Recently Collected Shells of Vietnam. L'Informatore Piceno and N.N.T, Ancona, Italy. 384 pp., 118 color plates.

Thach, N. N. 2012. New Records of Molluscs from Vietnam. 48HrBooks Company, Akron, Ohio. 276 pp., 151 color plates.

Thach, N. N. 2016a. *Lanceolaria bogani* (Bivalvia: Unionidae), a new species from Vietnam Novapex 17(1):9–11.

Thach, N. N. 2016b. Vietnamese New Mollusks, Seashells, Landsnails, Cephalopods with 59 New Species. 48HrBooks Company, Akron, Ohio. 205 pp., 81 color plates.

Vaughn, C. C. 2010. Biodiversity losses and ecosystem function in freshwaters: Emerging conclusions and research directions. BioScience 60:25–35.

Vaughn, C. C. 2012. Life history traits and abundance can predict local colonization and extinction rates of freshwater mussels. Freshwater Biology 57:982–992.

Vaughn, C. C. 2017. Ecosystem services provided by freshwater mussels. Hydrobiologia. doi 10.1007/s10750-017-3139-x

Vaughn, C. C., and C. M. Taylor. 1999. Impoundments and the decline of freshwater mussels: A case study of an extinction gradient. Conservation Biology 13:912–920.

Vietnam Red Data Book 2007. Part I. Animals. Publishing House for Science and Technology, Ha Noi. 515 pp. In Vietnamese.

Whelan, N. V., A. J. Geneva, and D. L. Graf. 2011. Molecular phylogenetic analysis of tropical freshwater mussels (Mollusca: Bivalvia: Unionoida) resolves the position of *Coelatura* and supports a monophyletic Unionidae. Molecular Phylogenetics and Evolution 61:504–514.

Winemiller, K. O., P. B. McIntyre, L. Castello, E. Fluet-Chouinard, T. Giarrizzo, S. Nam, I. G. Baird, W. Darwall, N. K. Lujan, I. Harrison, M. L. J. Stiassny, R. A. M. Silvano, D. B. Fitzgerald, F. M. Pelicice, A. A. Agostinho, L. C. Gomes, J. S. Albert, E. Baran, M. Petrere, Jr., C. Zarfl, M. Mulligan, J. P. Sullivan, C. C. Arantes, L. M. Sousa, A. A. Koning, D. J. Hoeinghaus, M. Sabaj, J. G. Lundberg, J. Armbruster, M. L. Thieme, P. Petry, J. Zuanon, G. Torrente Vilara, J. Snoeks, C. Ou, W. Rainboth, C. S. Pavanelli, A. Akama, A. van Soesbergen, and L. Sáenz. 2016. Balancing hydropower and biodiversity in the Amazon, Congo and Mekong. Science 351:128–129.

Wu, X.-P. 1998. Studies on freshwater Mollusca in mid-lower reaches of the Yangtze (Chang Jiang) River. Doctoral Dissertation in Science. Institute of Hydrobiology, Chinese Academy of Sciences. Wuhan, Hubei Province, China. 197 pp.

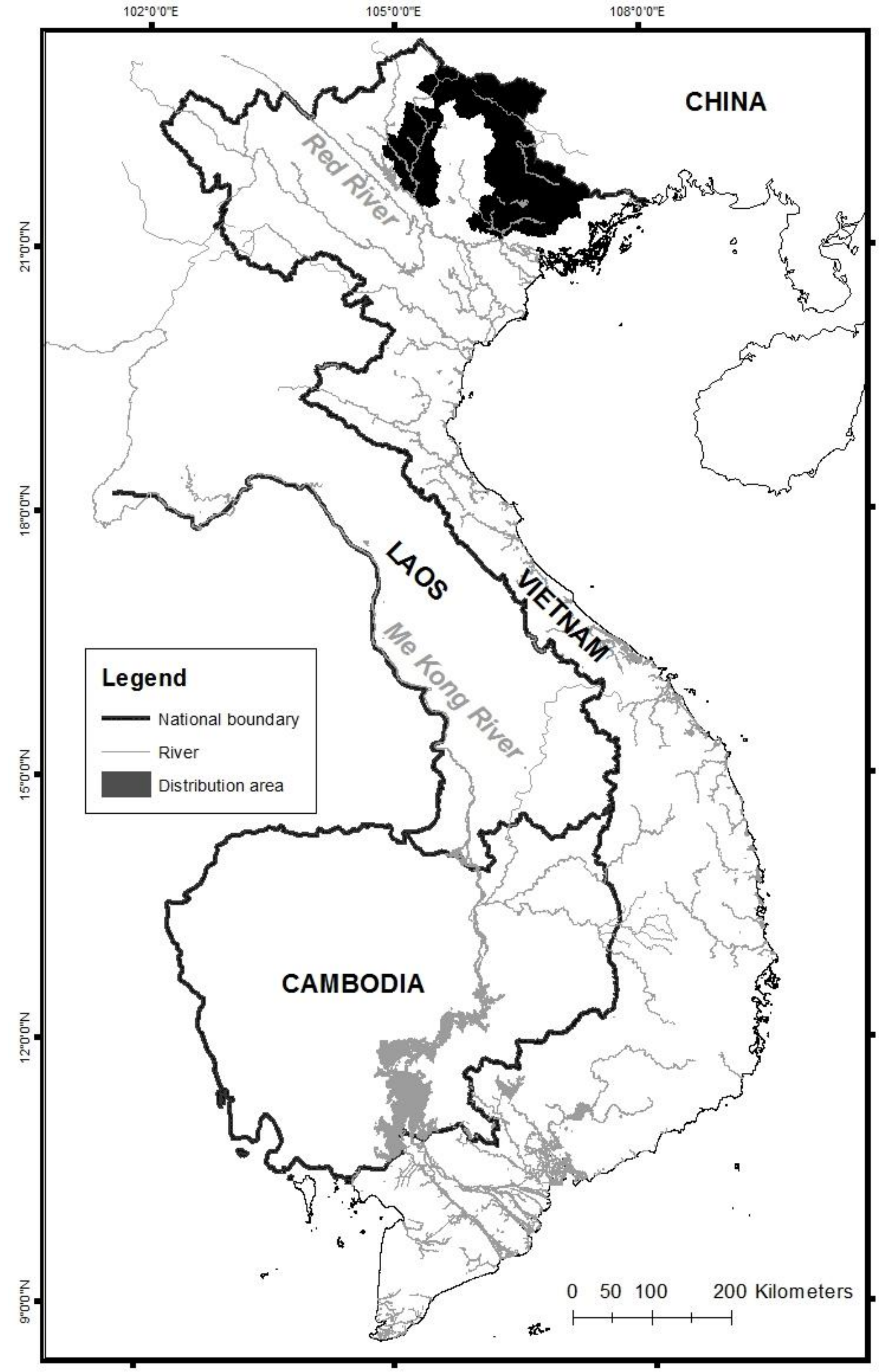
Zhou, C.-H., S. Ouyang, X.-P. Wu, and M. Li. 2007. Phylogeny of the genus *Lamprotula* (Unionidae) in China based on mitochondrial DNA sequences of 16S rRNA and ND1 genes. Acta Zoologica Sinica 53:1024–1030.

Zieritz, A., A. E. Bogan, E. Froufe, A. Klishko, T. Kondo, U. Kovitvadhi, S. Kovitvadhi, J. H. Lee, M. Lopes-Lima, J. M. Pfeiffer, R. Sousa, V. T. Do, I. Vikhrev, and D. T. Zanatta. 2017. Diversity, biogeography and conservation of freshwater mussels (Bivalvia: Unionida) in East and Southeast Asia. Hydrobiologia. doi 10.1007/s10750-017-3104-8

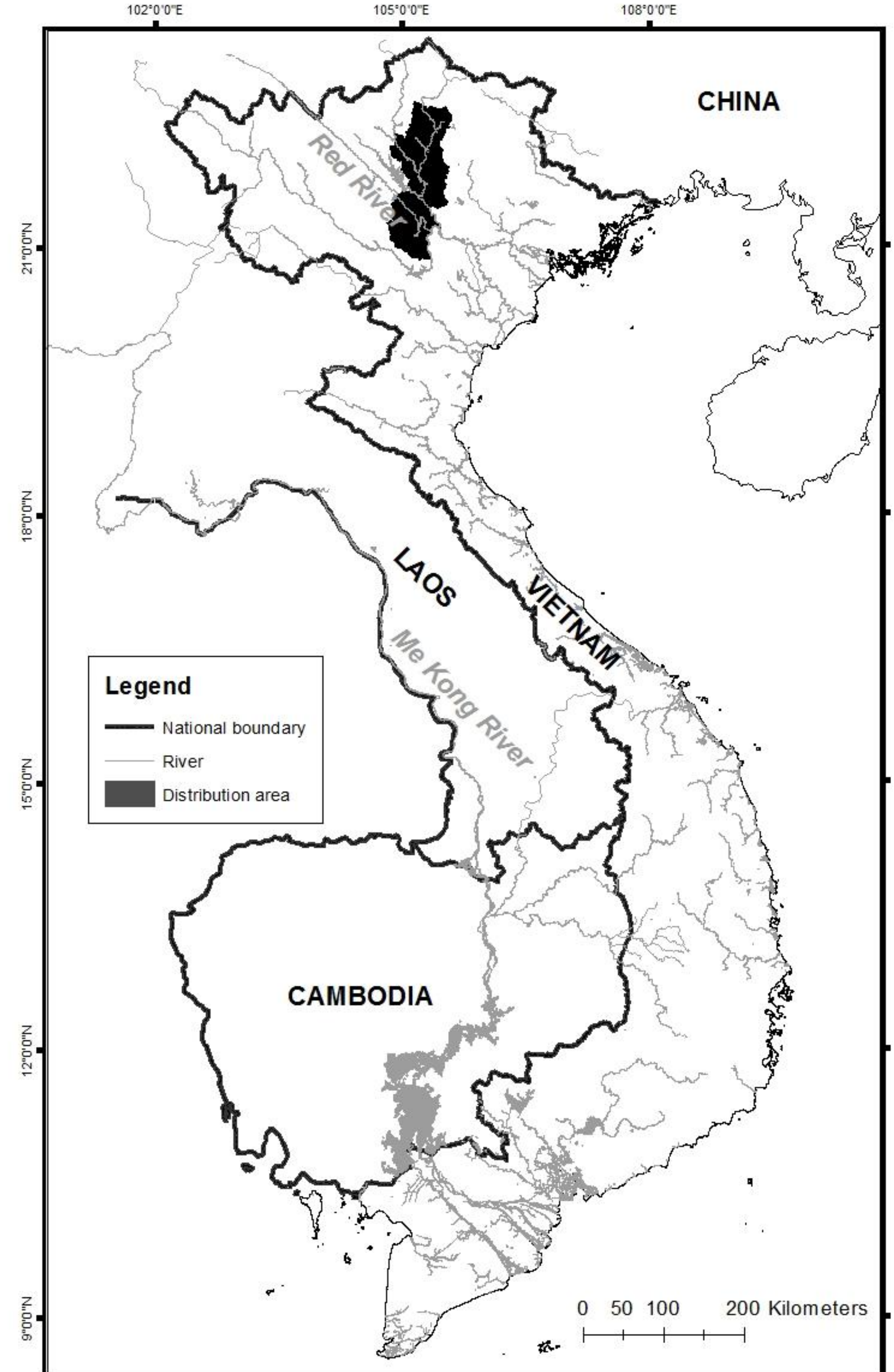
Zieritz, A., M. Lopes-Lima, A. E. Bogan, R. Sousa, S. Walton, K. A. A. Rahim, J.-J. Wilson, P.-Y. Ng, E. Froufe, and S. McGowan. 2016. Factors driving changes in freshwater mussel (Bivalvia, Unionida) diversity and distribution in Peninsular Malaysia. Science of the Total Environment. 571:1069–1078. doi 10.1016/j.scitotenv.2016.07.098

Supplemental Species Range Maps for Individual Species.

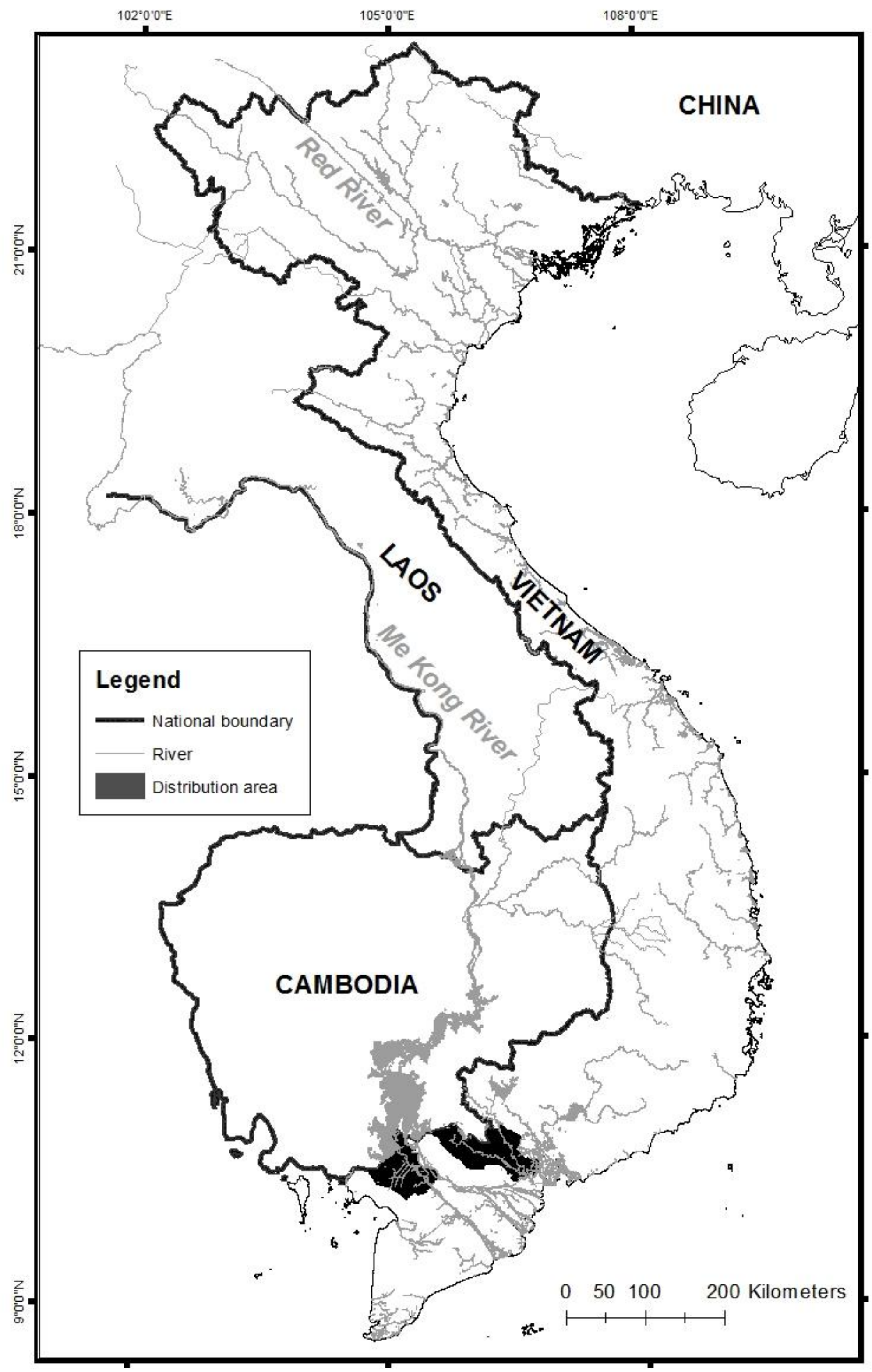
Aculamprotula nodulosa (Wood, 1815)



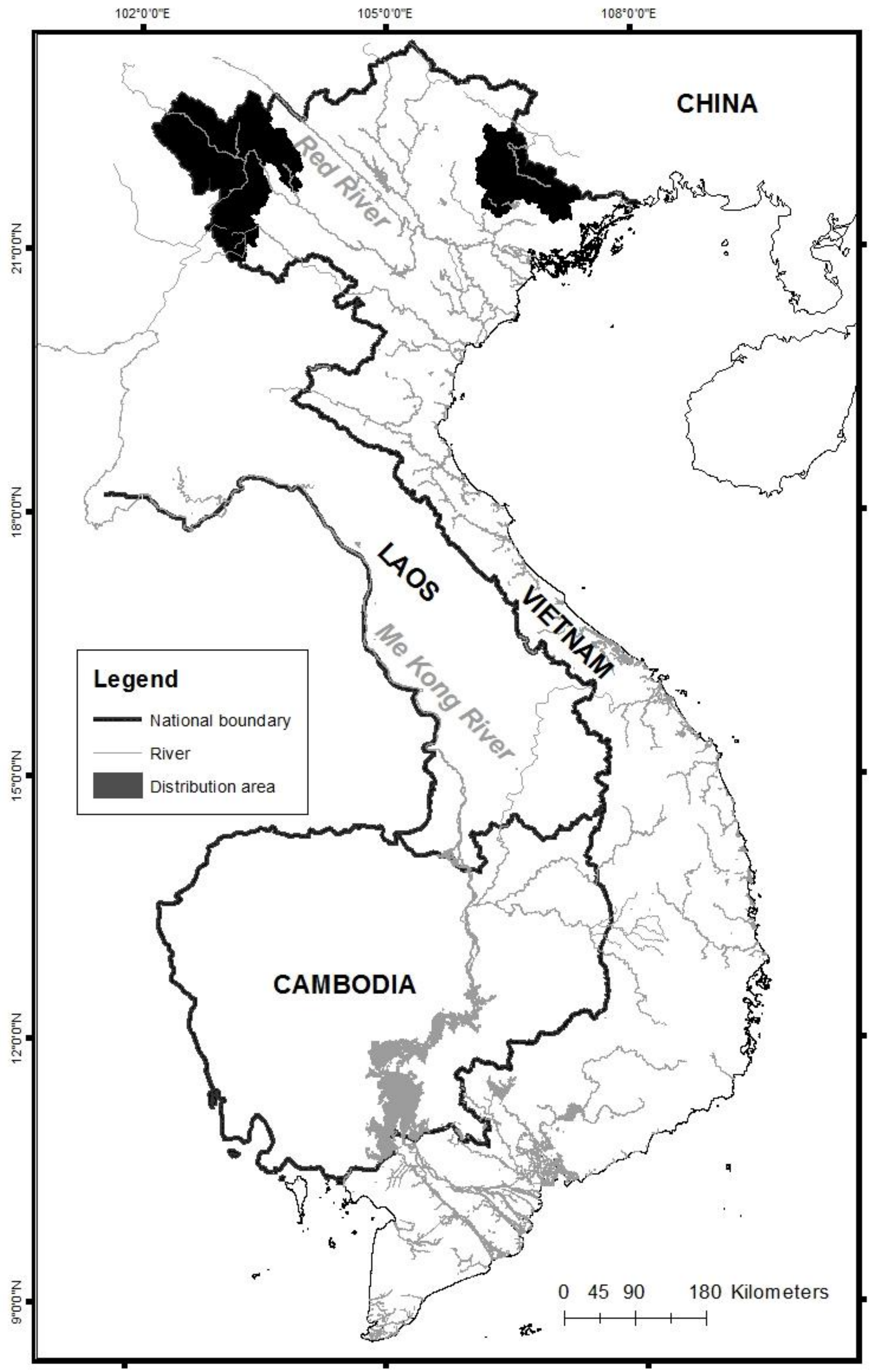
Chamberlainia hainesiana (Lea, 1856)



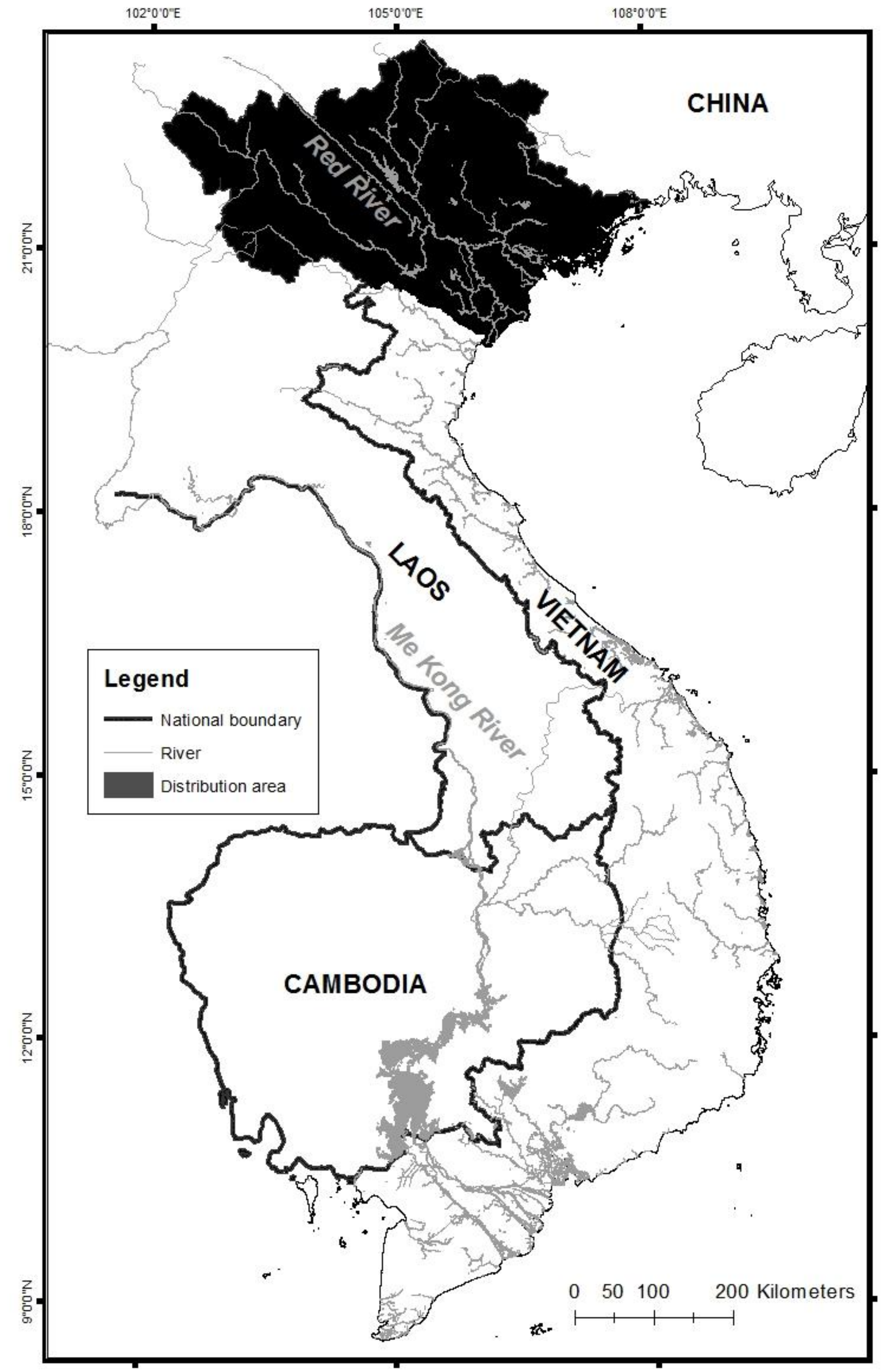
Contradens contradens (Lea, 1838)



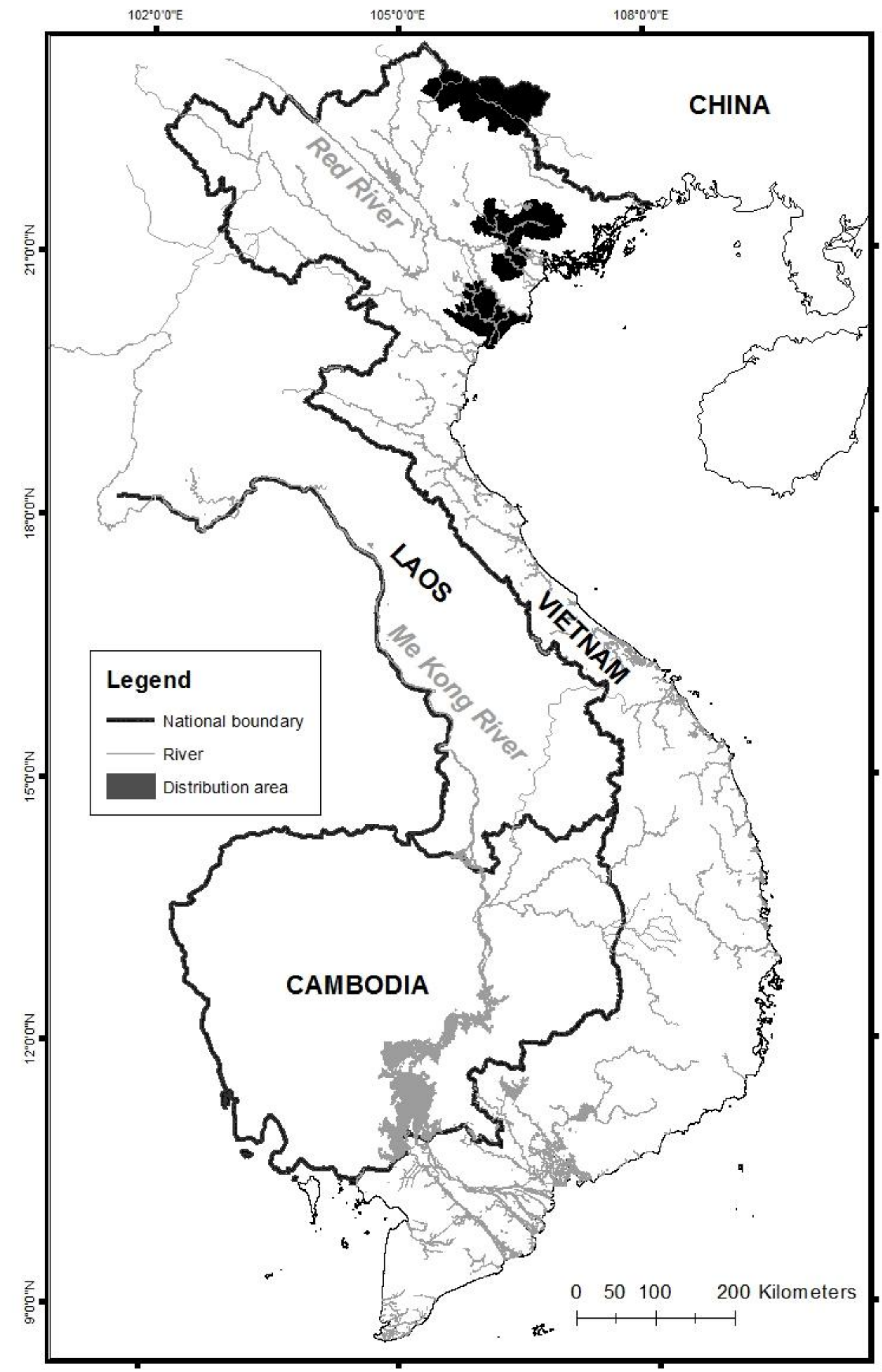
Contradens fultoni Haas, 1939



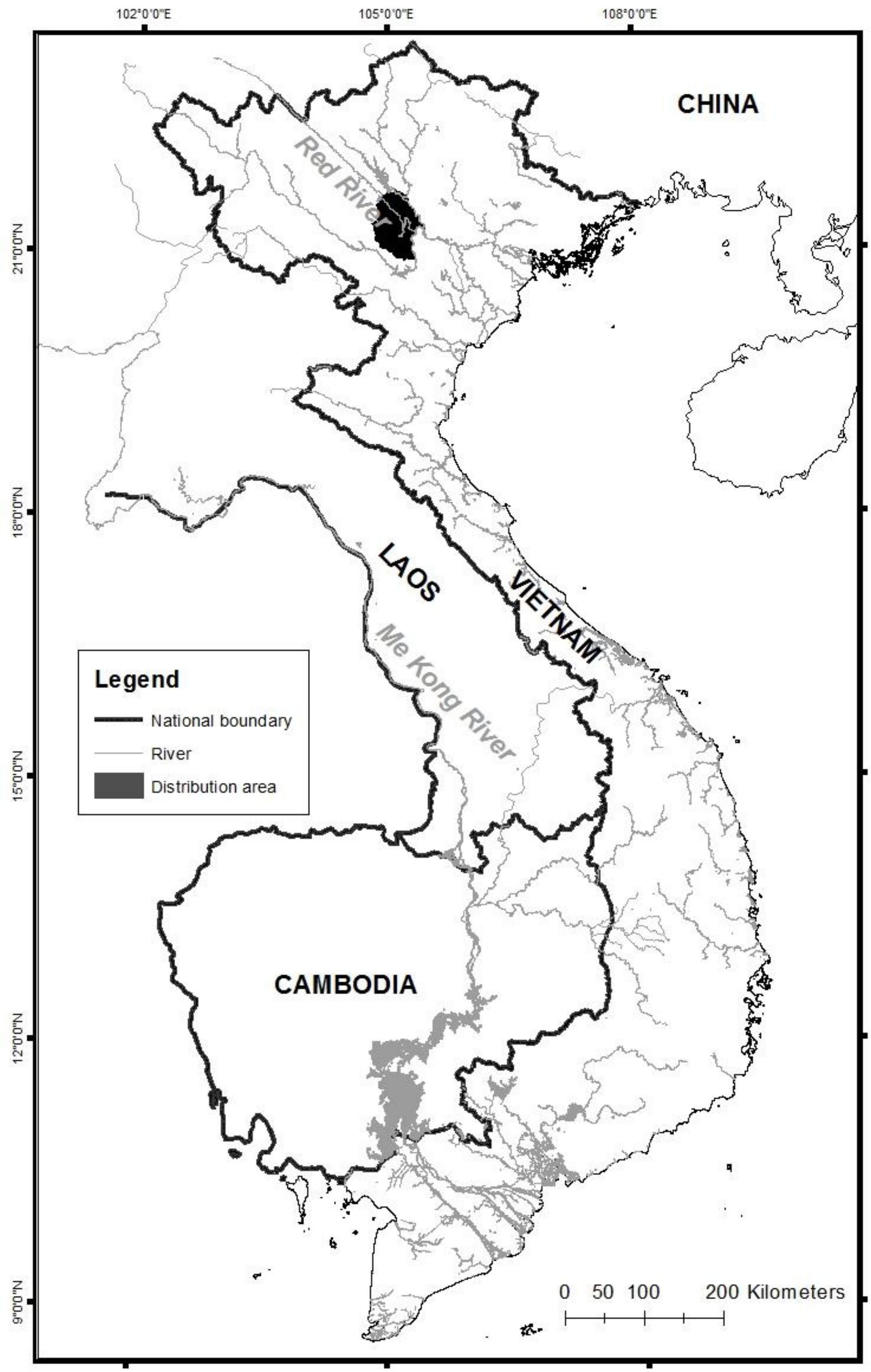
Cristaria plicata (Leach, 1815)



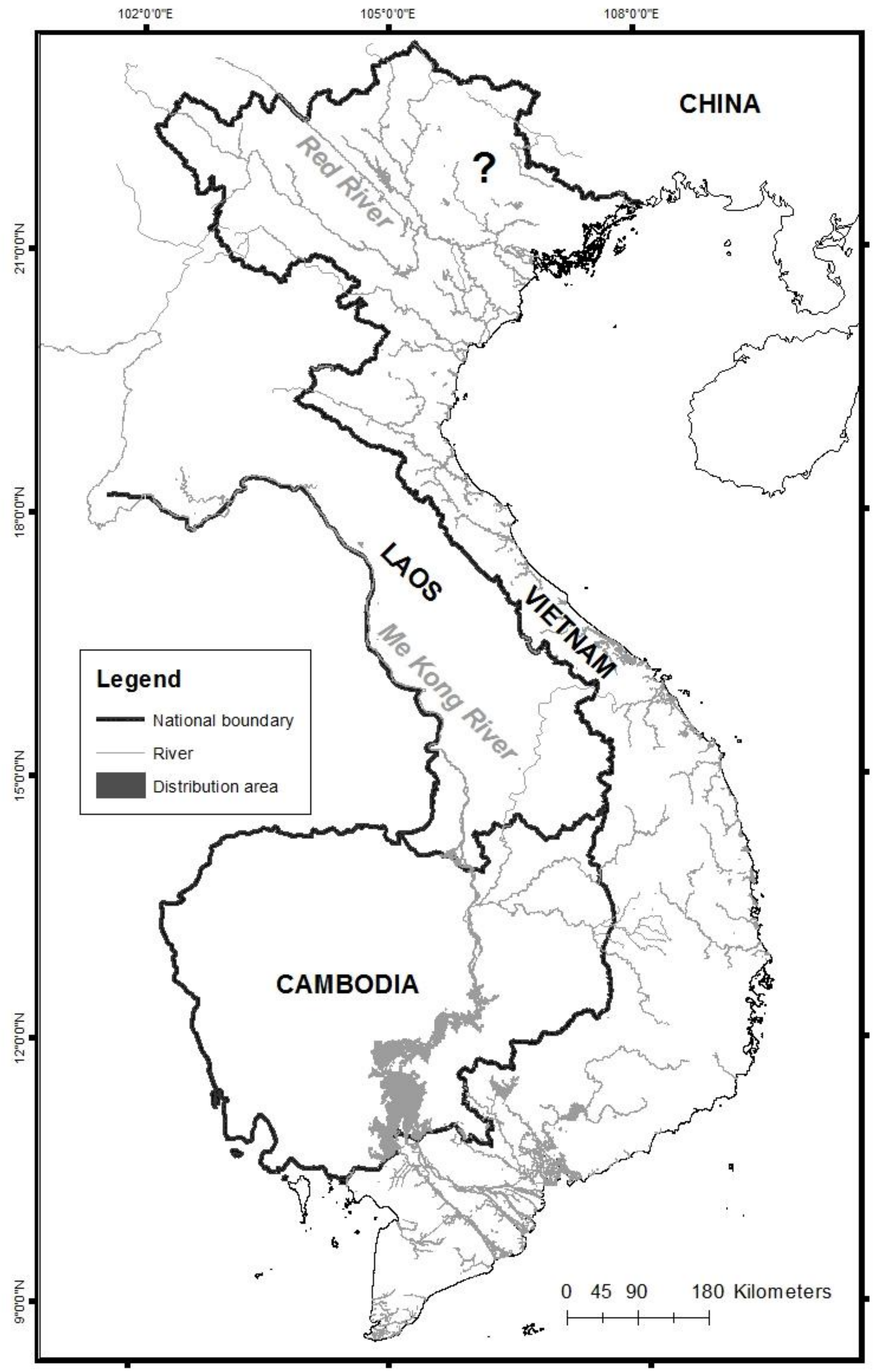
Cristaria truncata Đặng, 1980



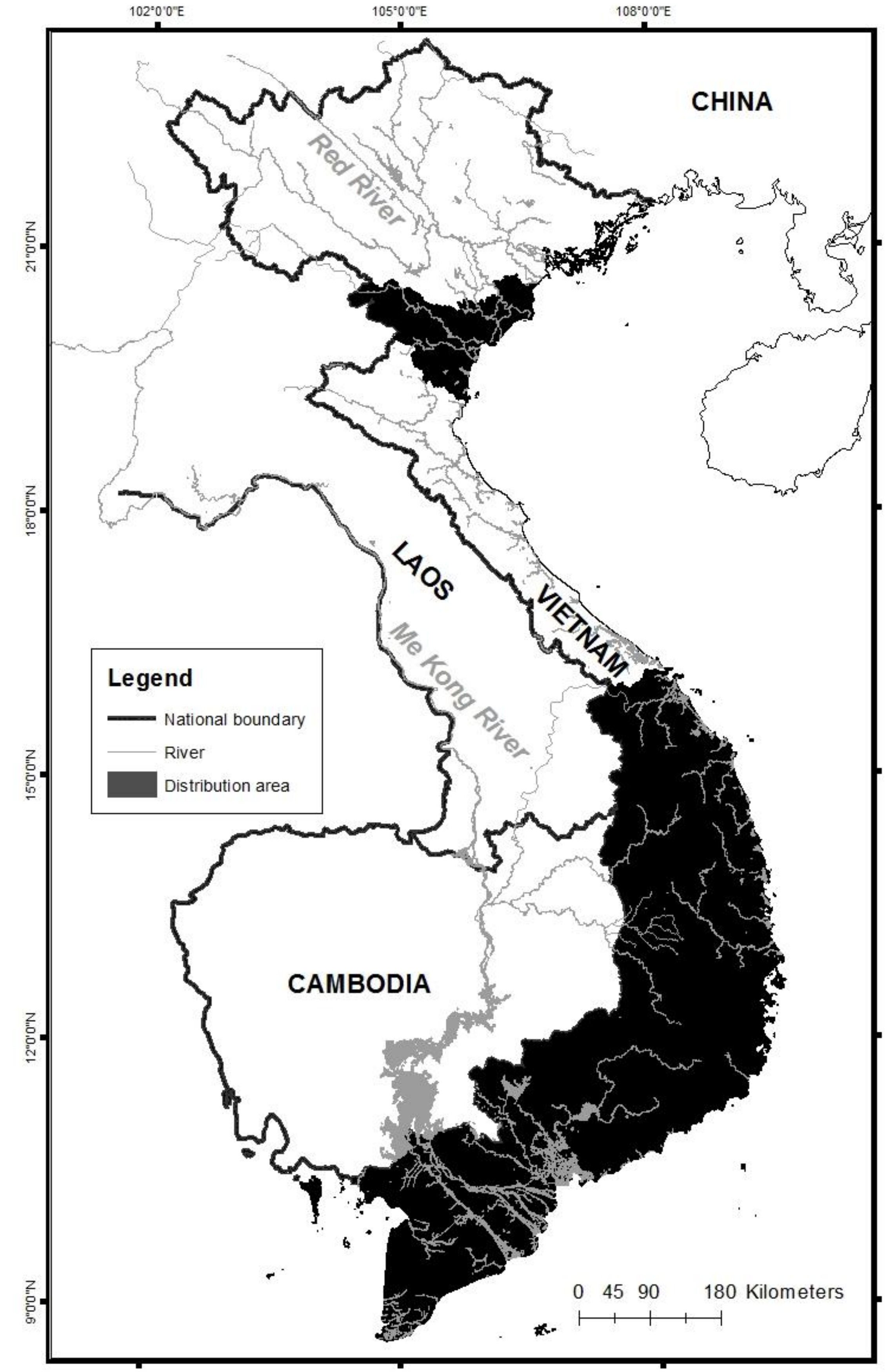
Cuneopsis demangei Haas, 1929



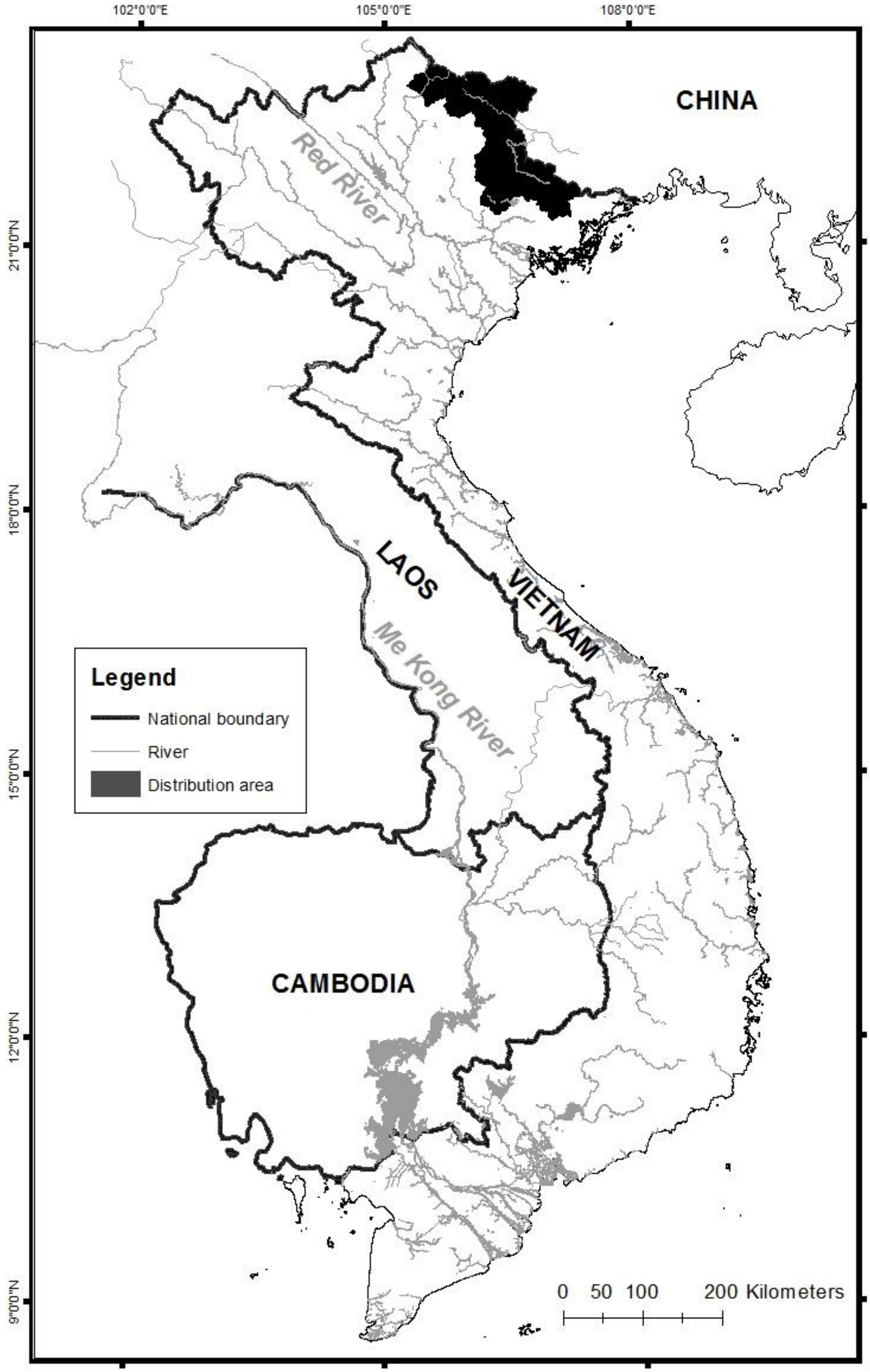
Diaurora aurorae (Heude, 1883)



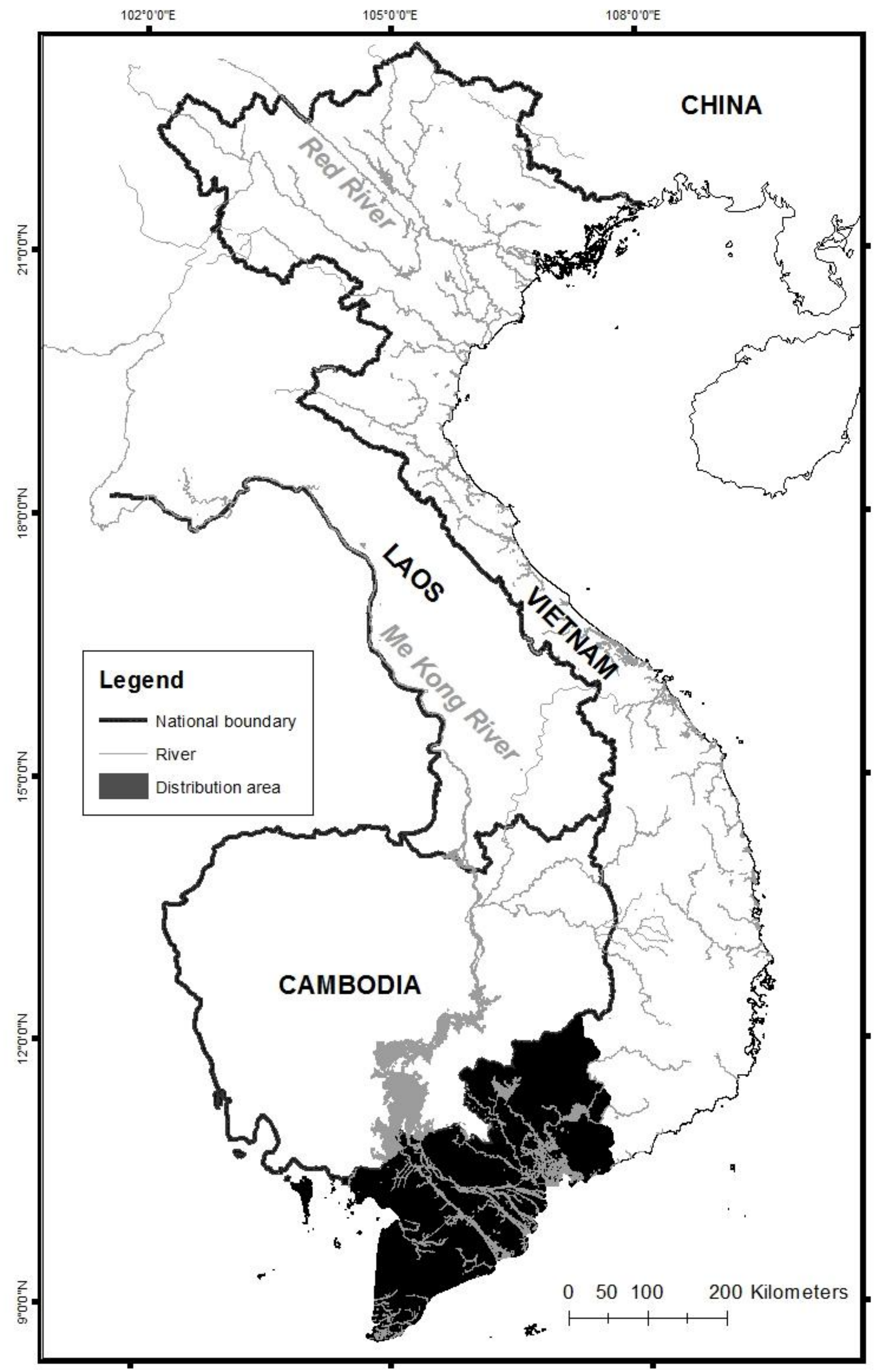
Ensidens ingallsianus (Lea, 1852)



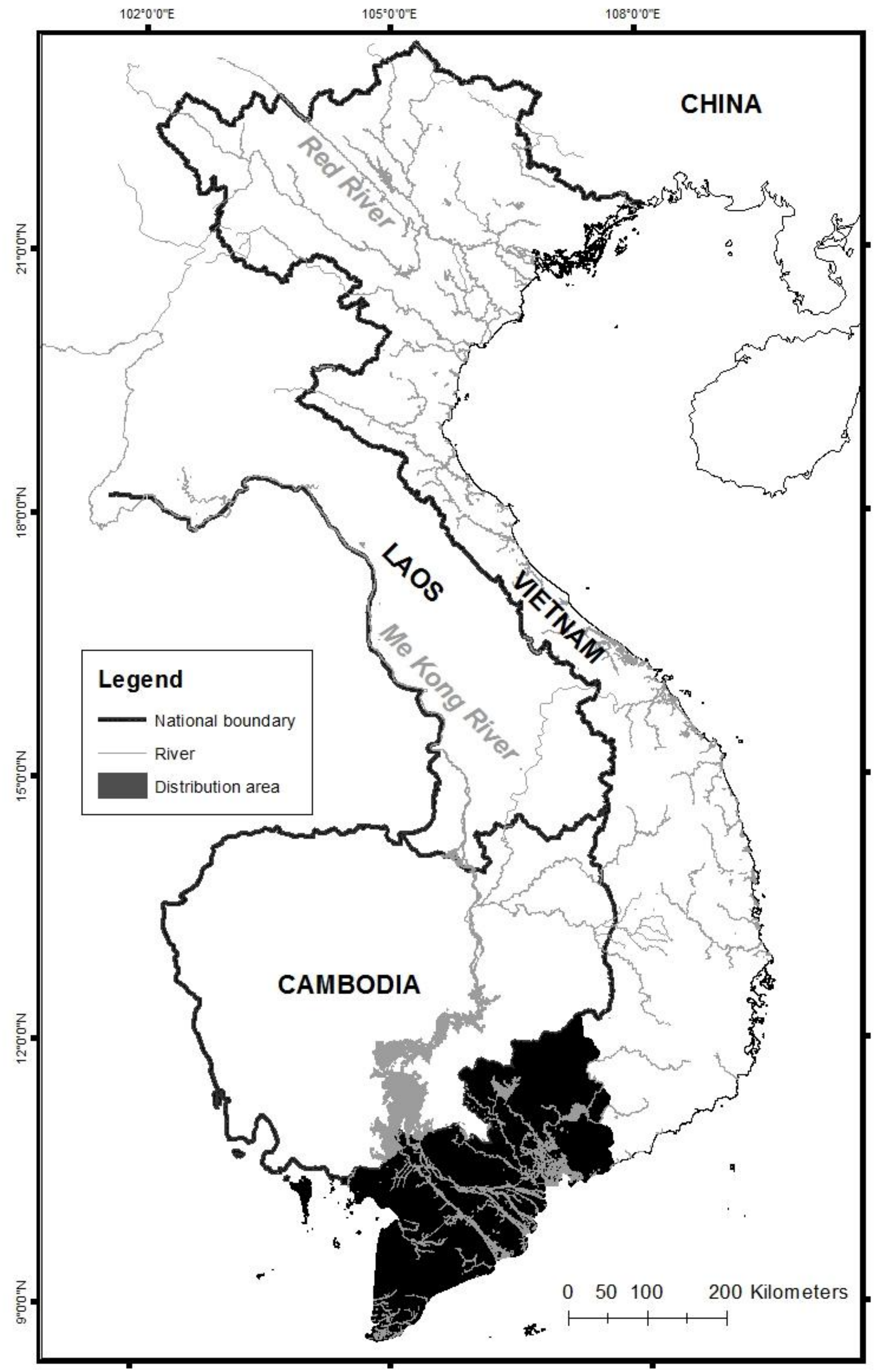
Gibbosula crassa (Wood, 1815)



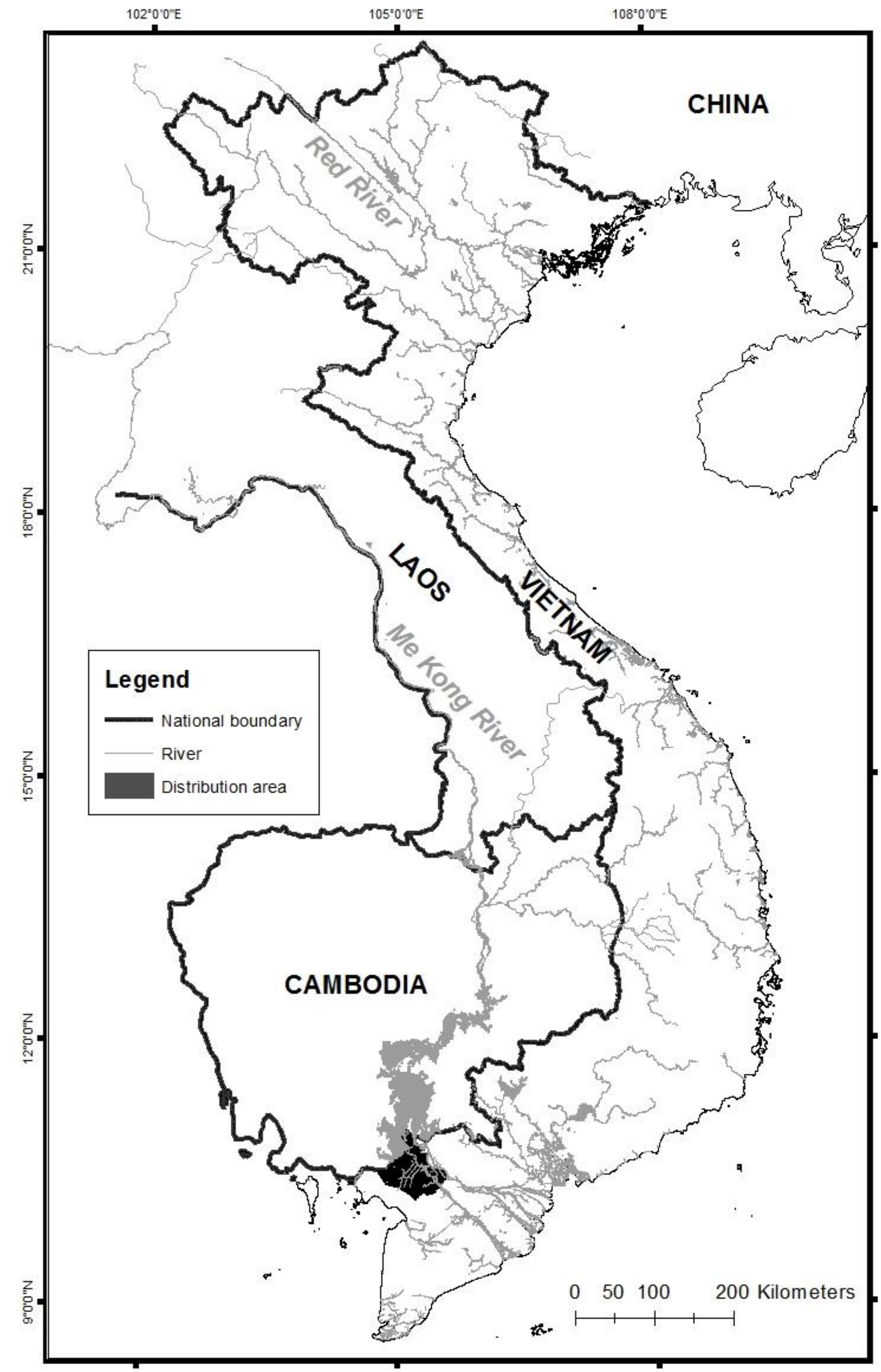
Harmandia somboriensis (Rochebrune, 1882)



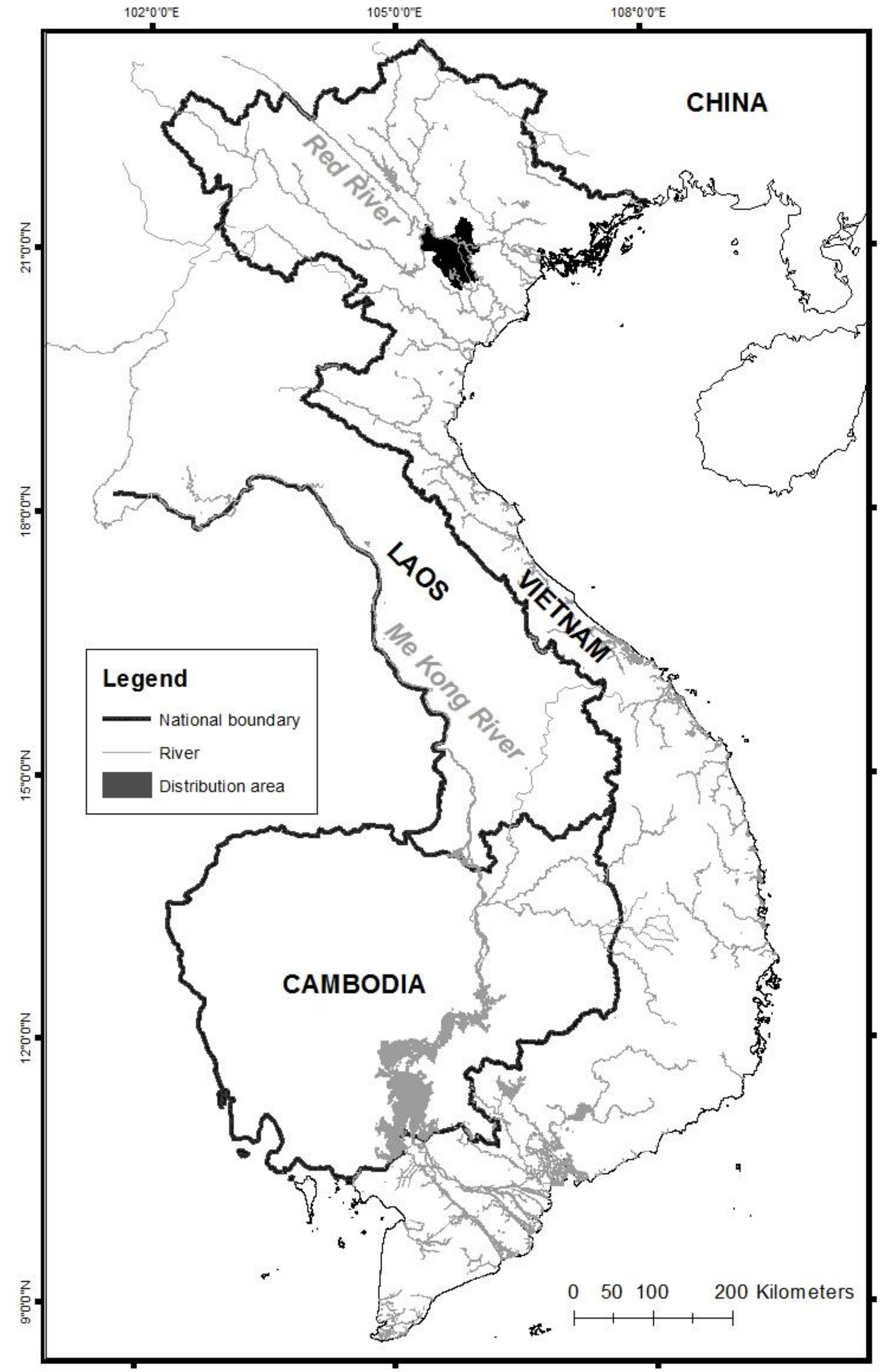
Hyriopsis gracilis Haas, 1910



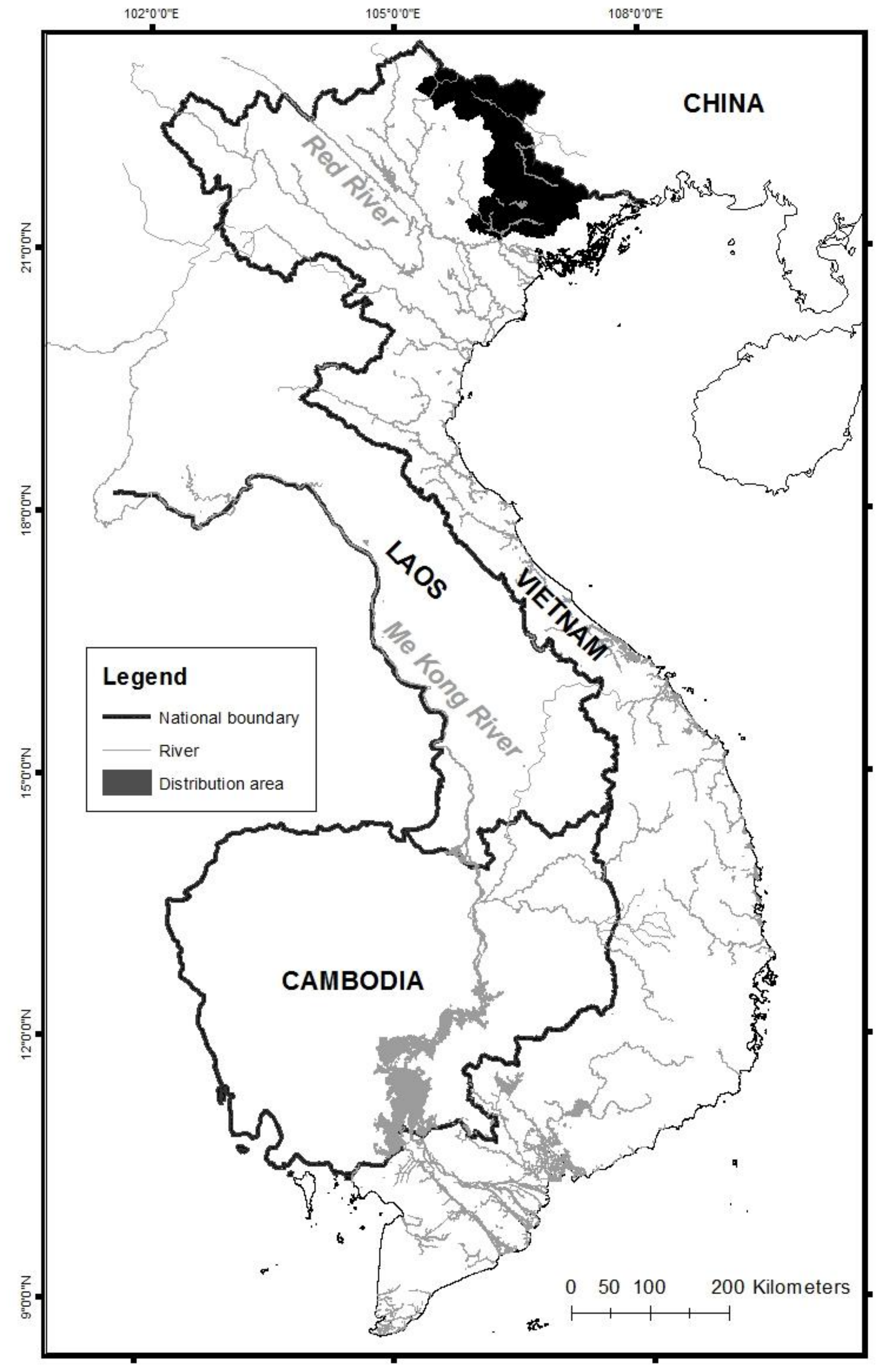
Hyriopsis delaportei (Crosse & Fischer, 1876)



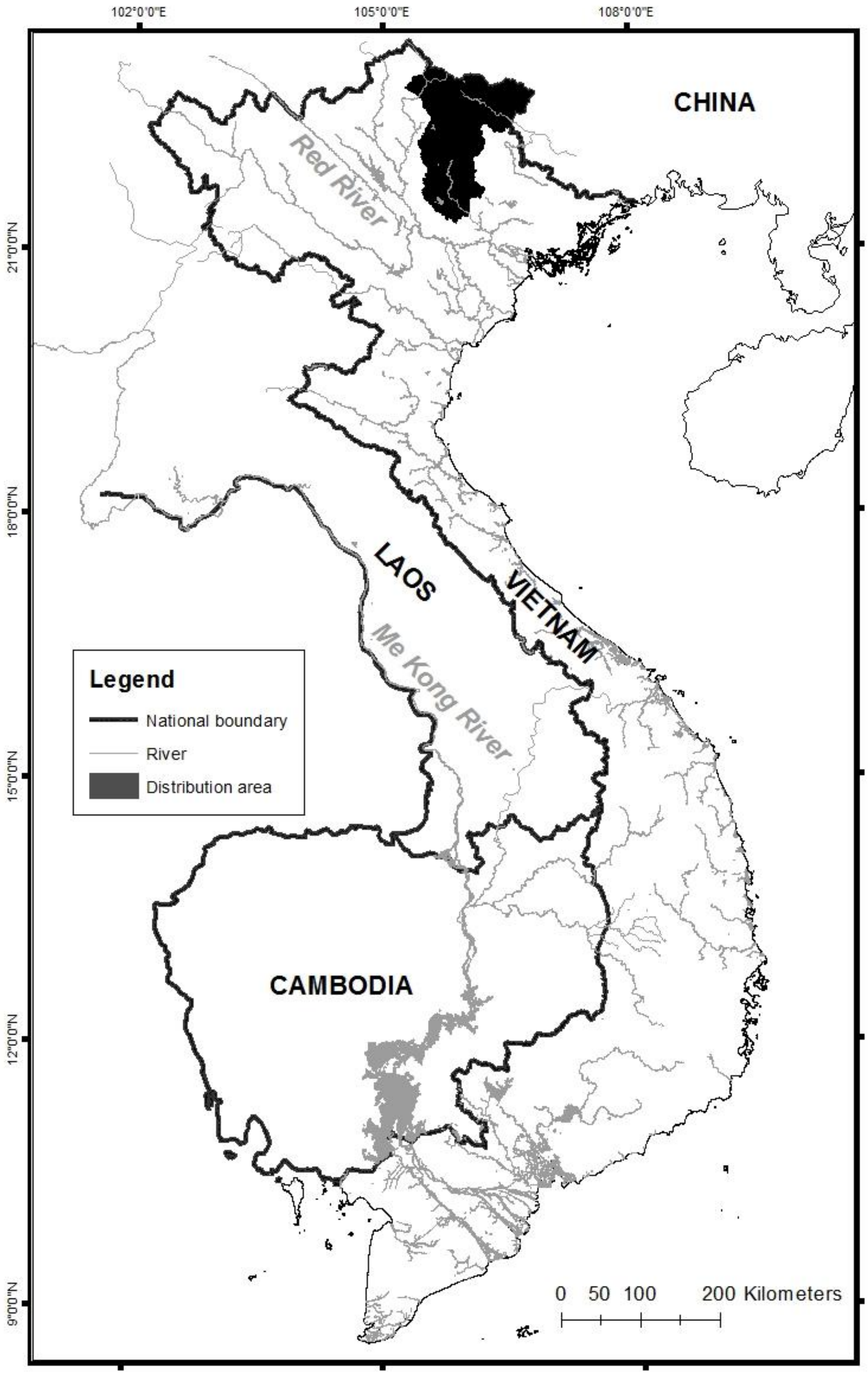
Lamprotula bazini (Heude, 1877)



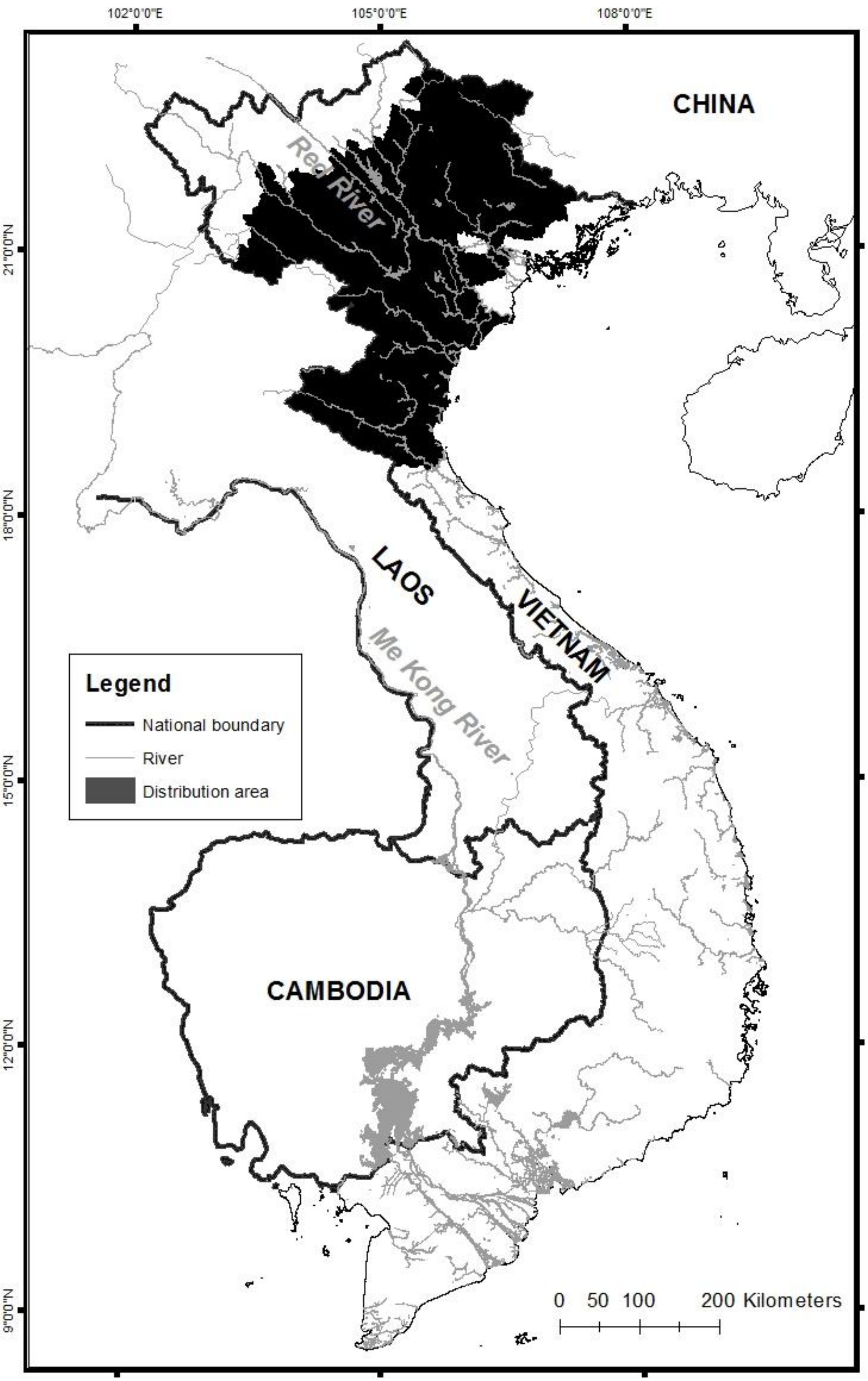
Lamprotula blaisei (Dautzenberg & Fischer, 1905)



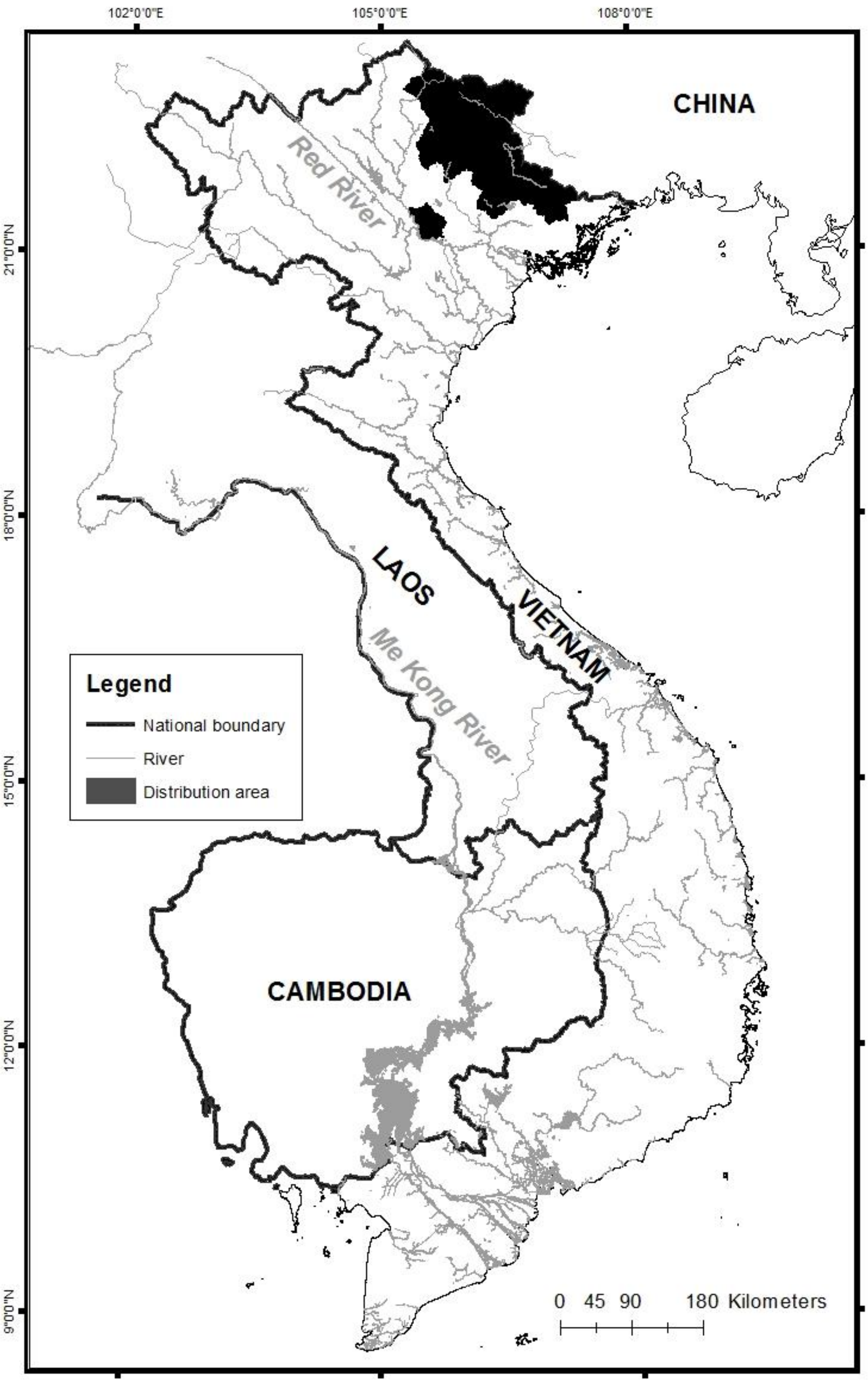
Lamprotula contritus (Heude, 1881)



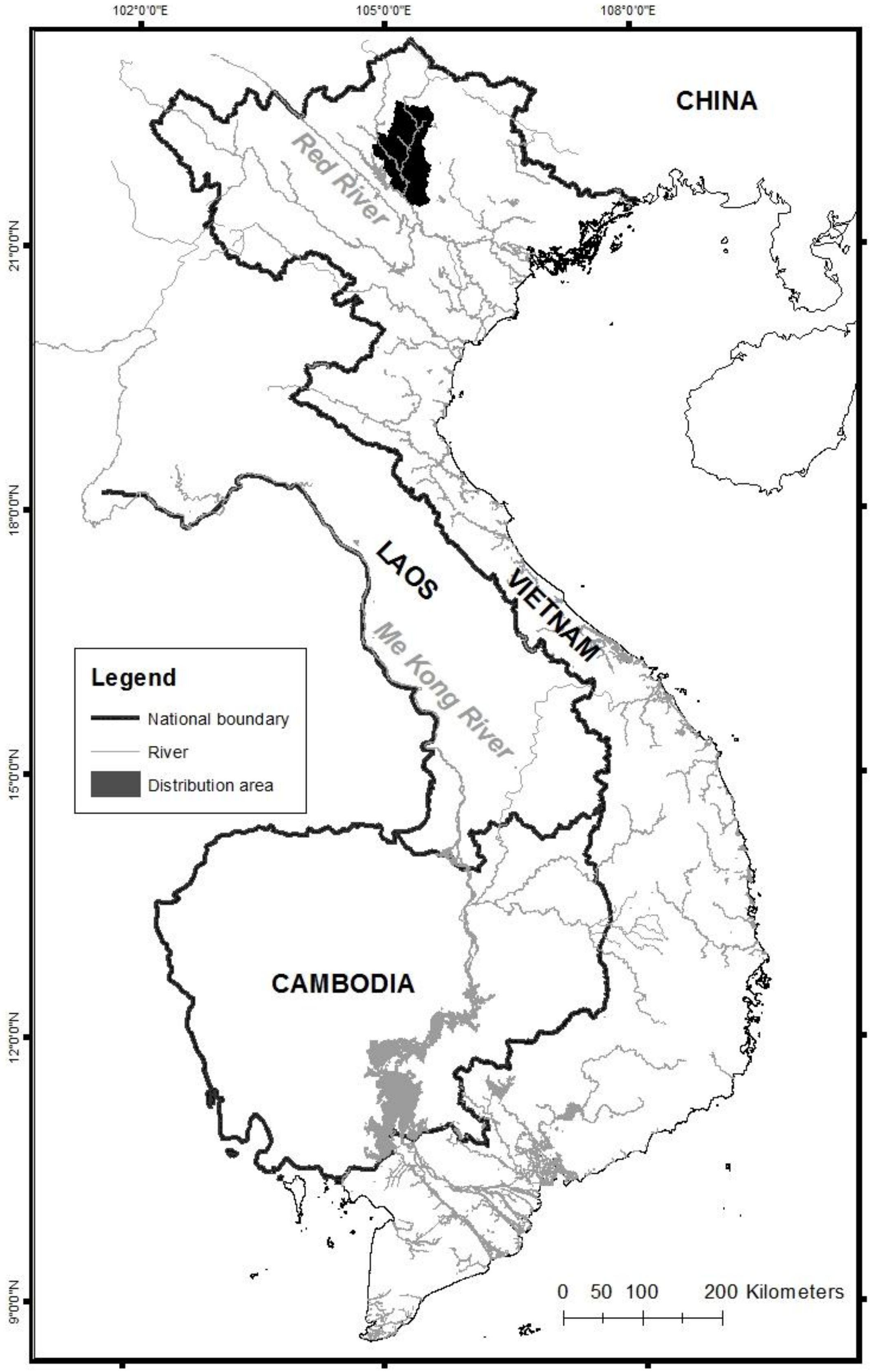
Lamprotula leai (Gray in Griffith & Pidgeon, 1833)



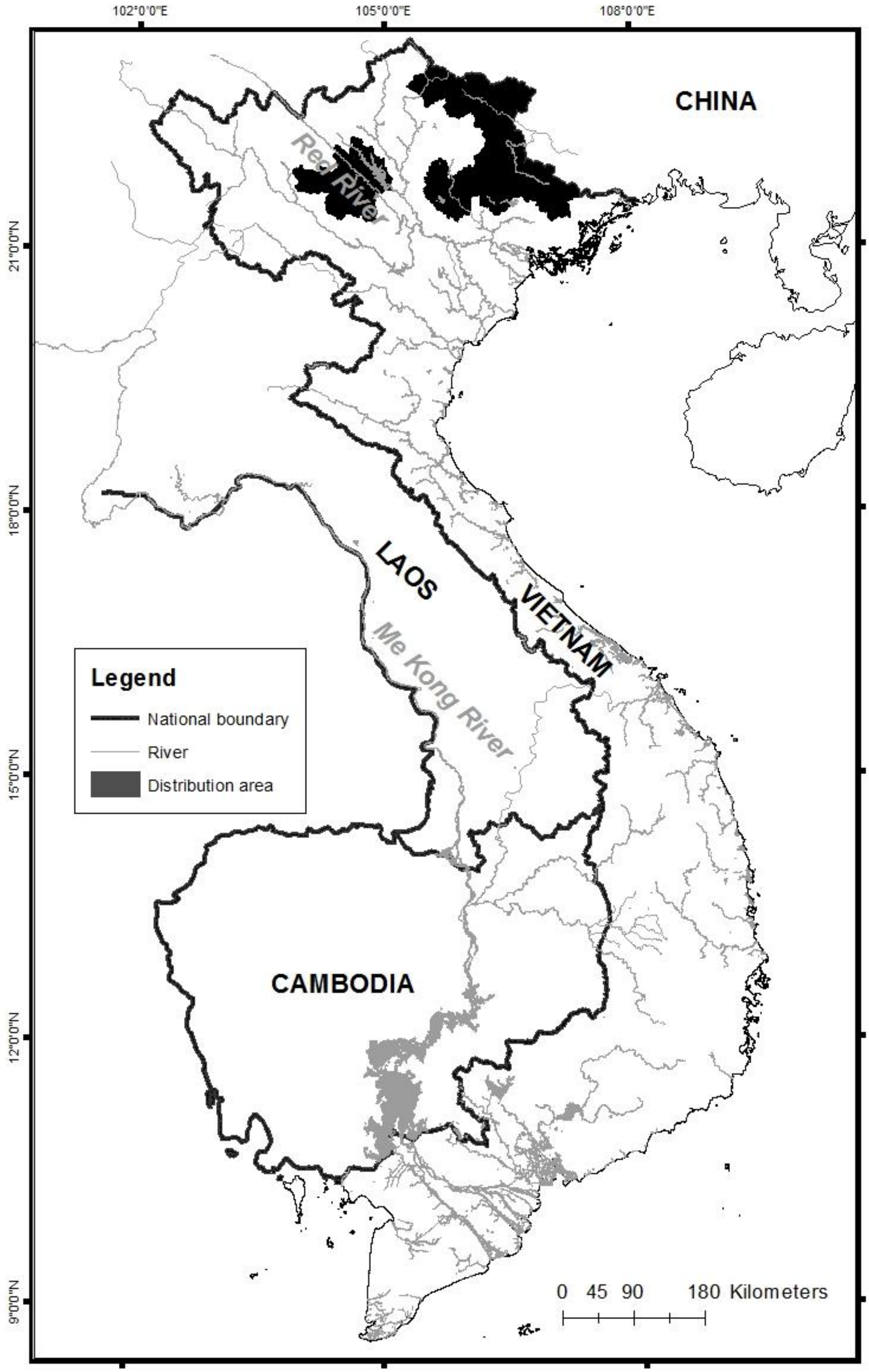
Lamprotula quadrangulosa (Heude, 1881)



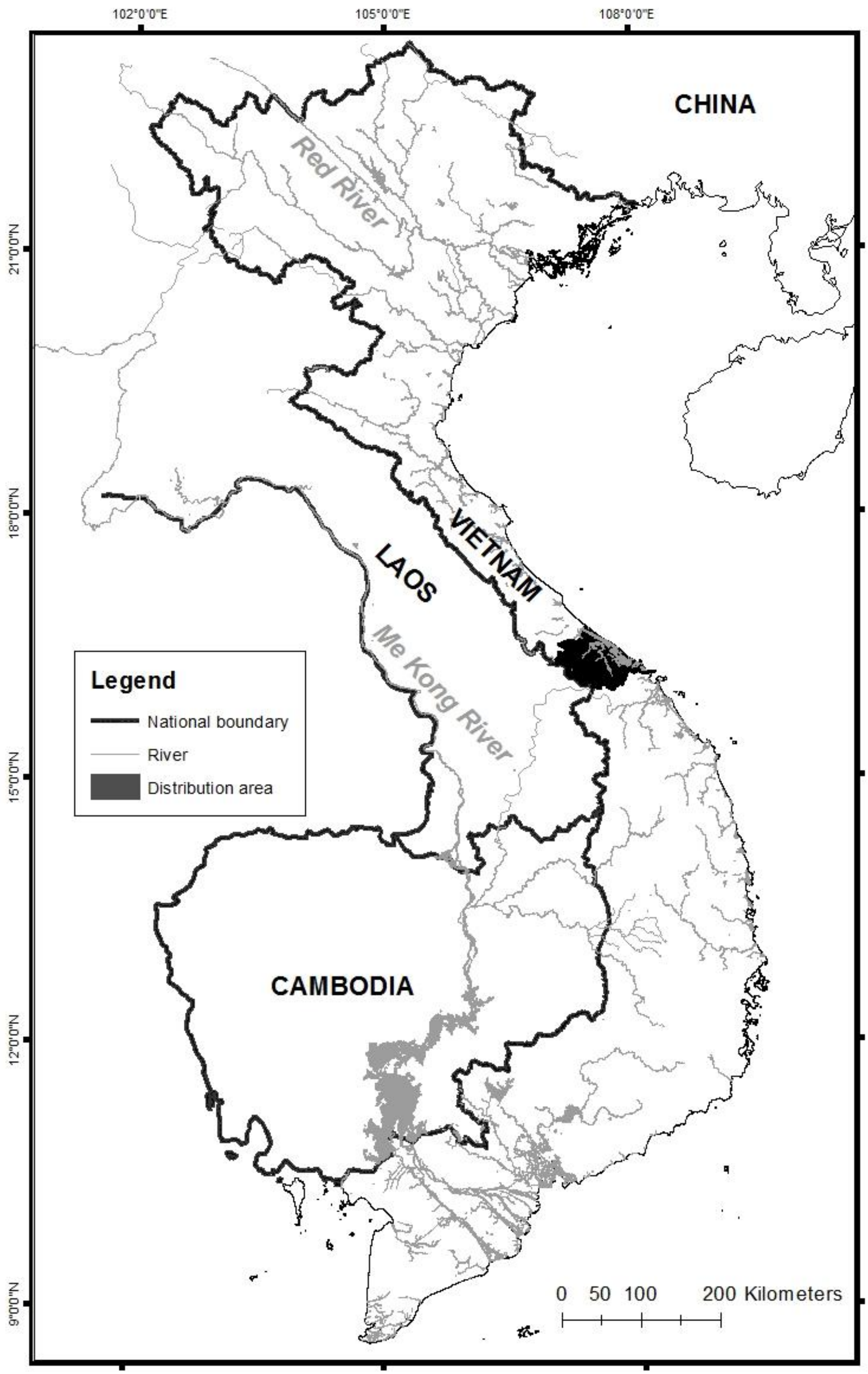
Lamprotula salaputium (Martens, 1902)



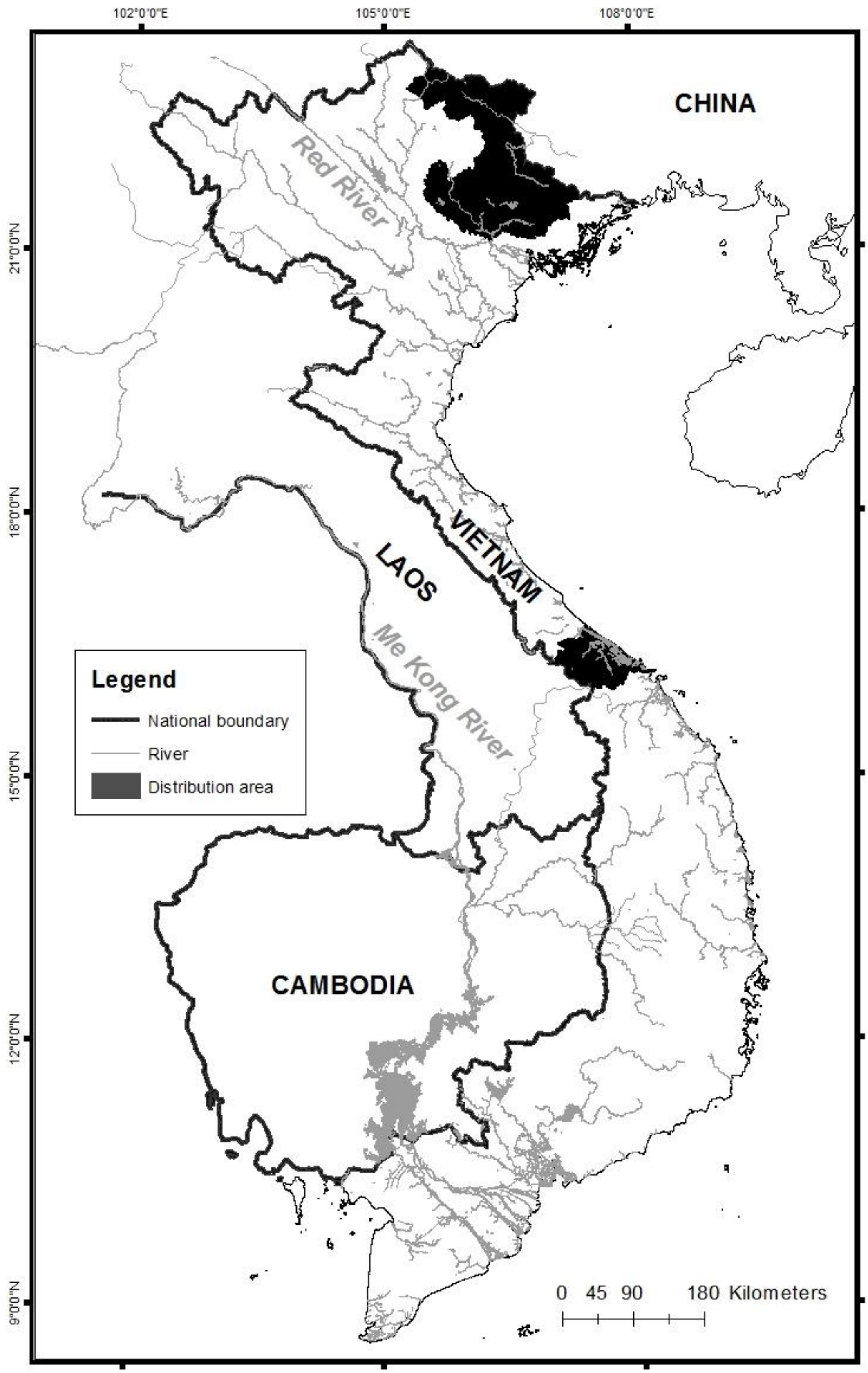
Lanceolaria bilirata (Martens, 1902)



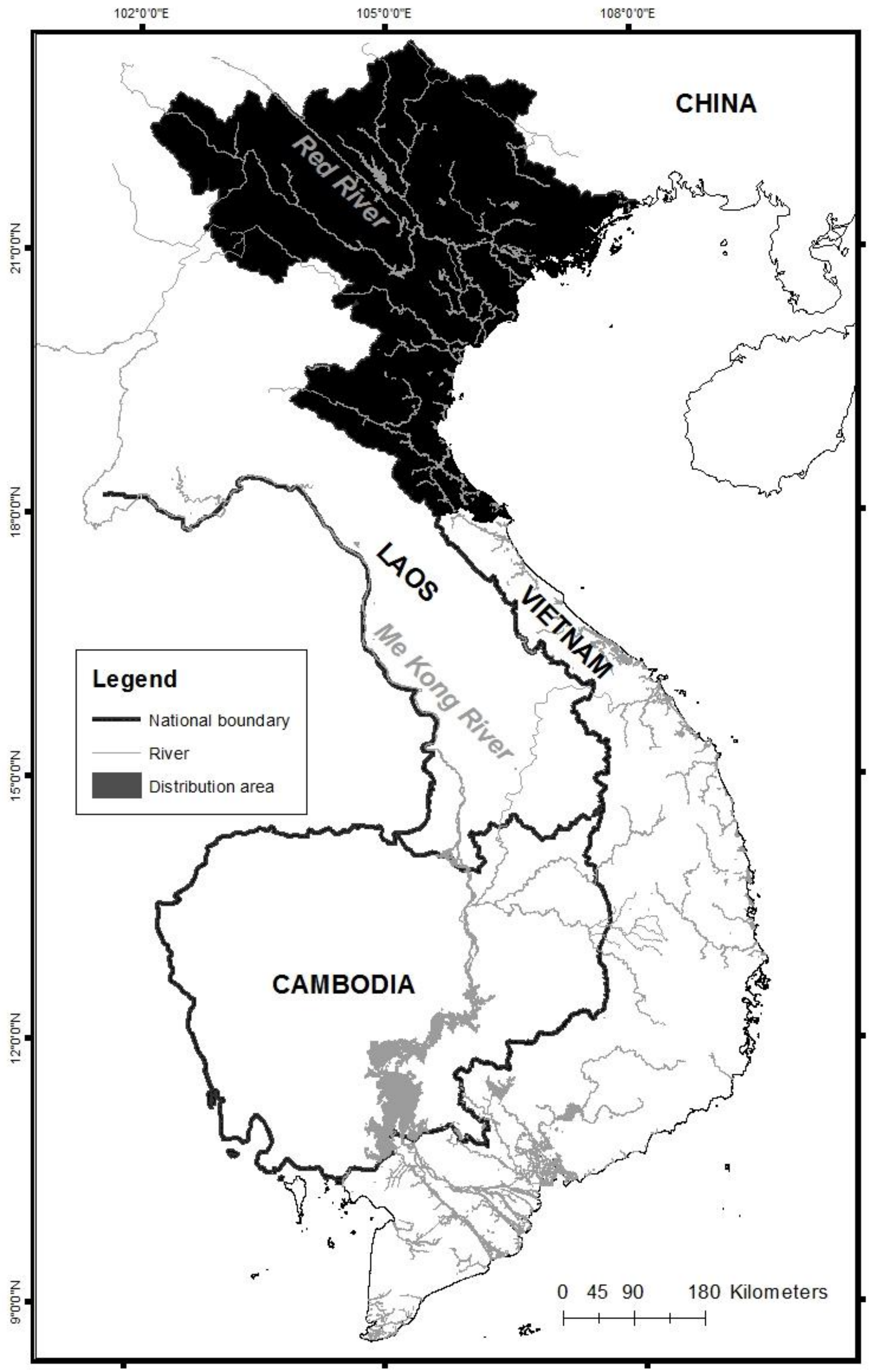
Lanceolaria bogani Thach, 2016



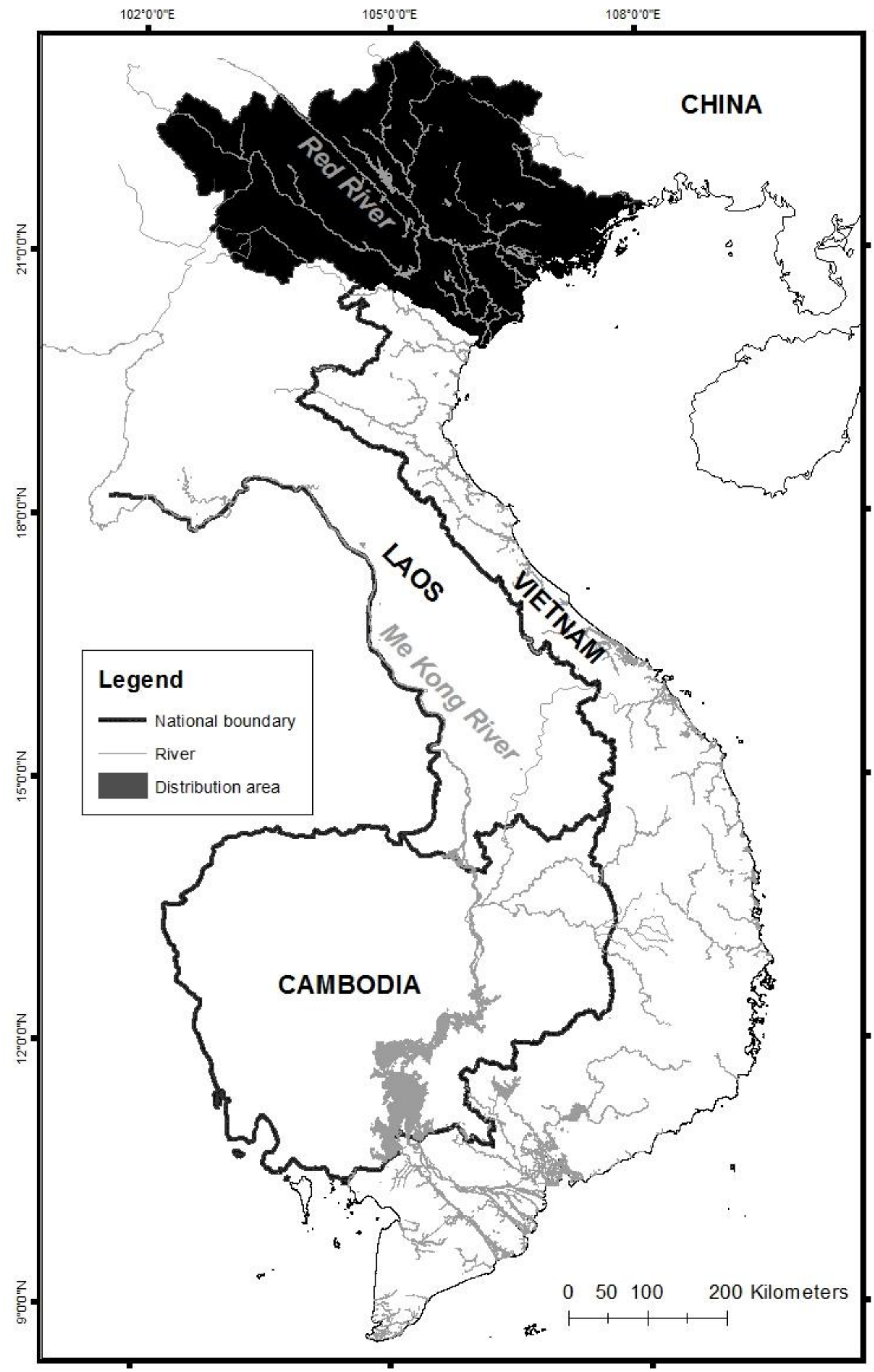
Lanceolaria fruhstorferi (Bavay & Dautzenberg, 1901)



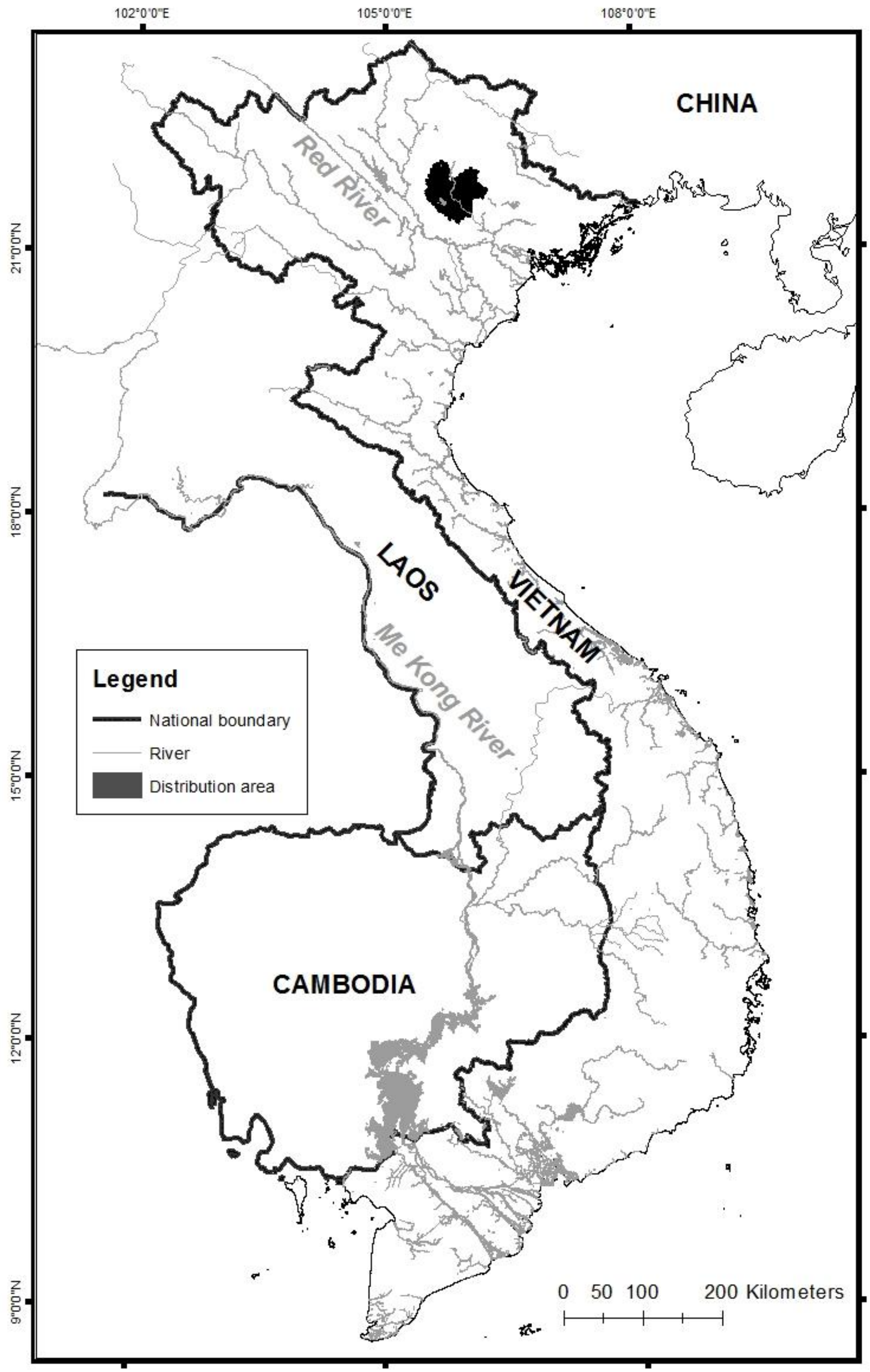
Lanceolaria gladiola (Heude, 1877)



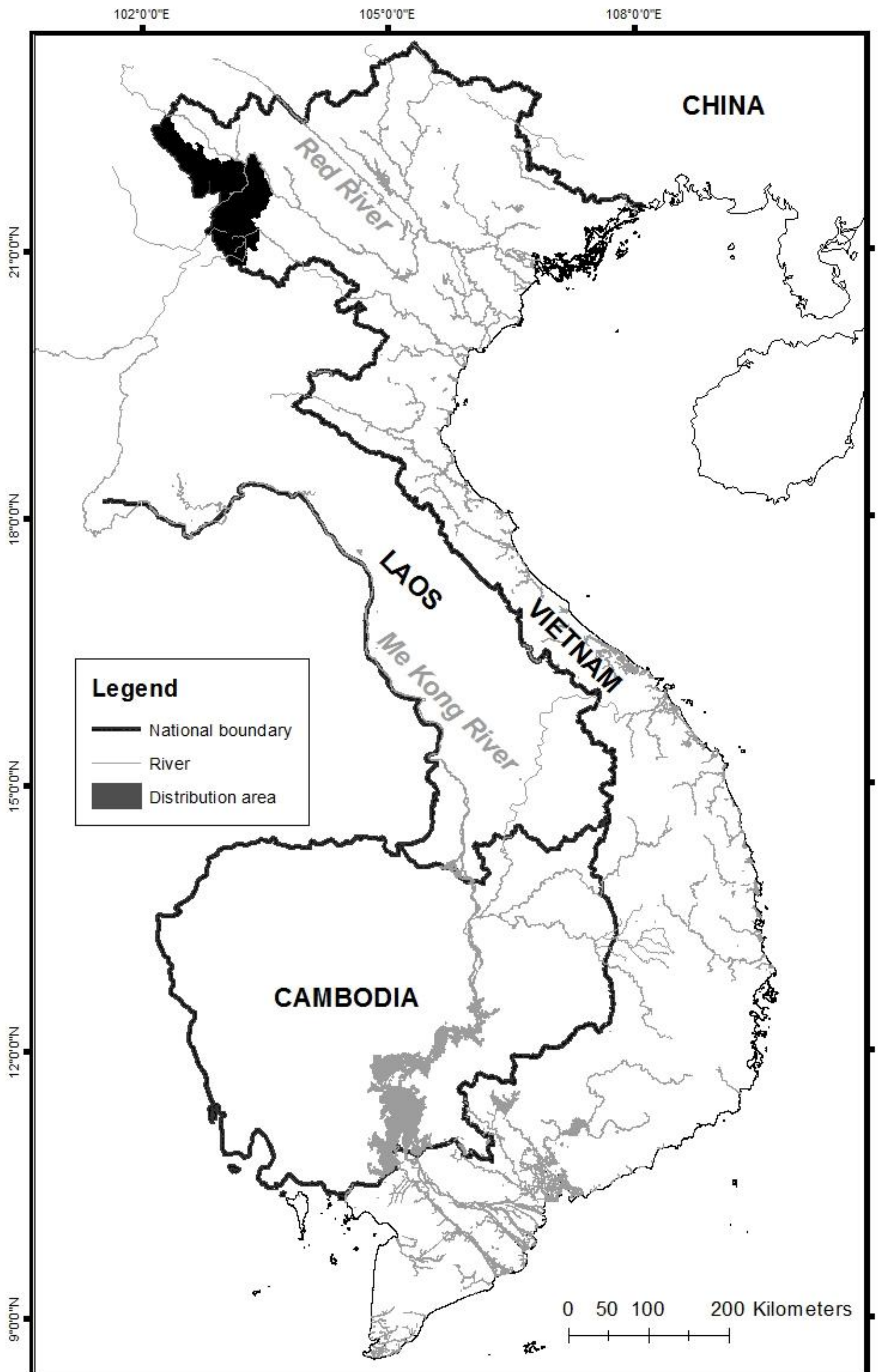
Lanceolaria grayi (Gray in Griffith & Pidgeon, 1833)



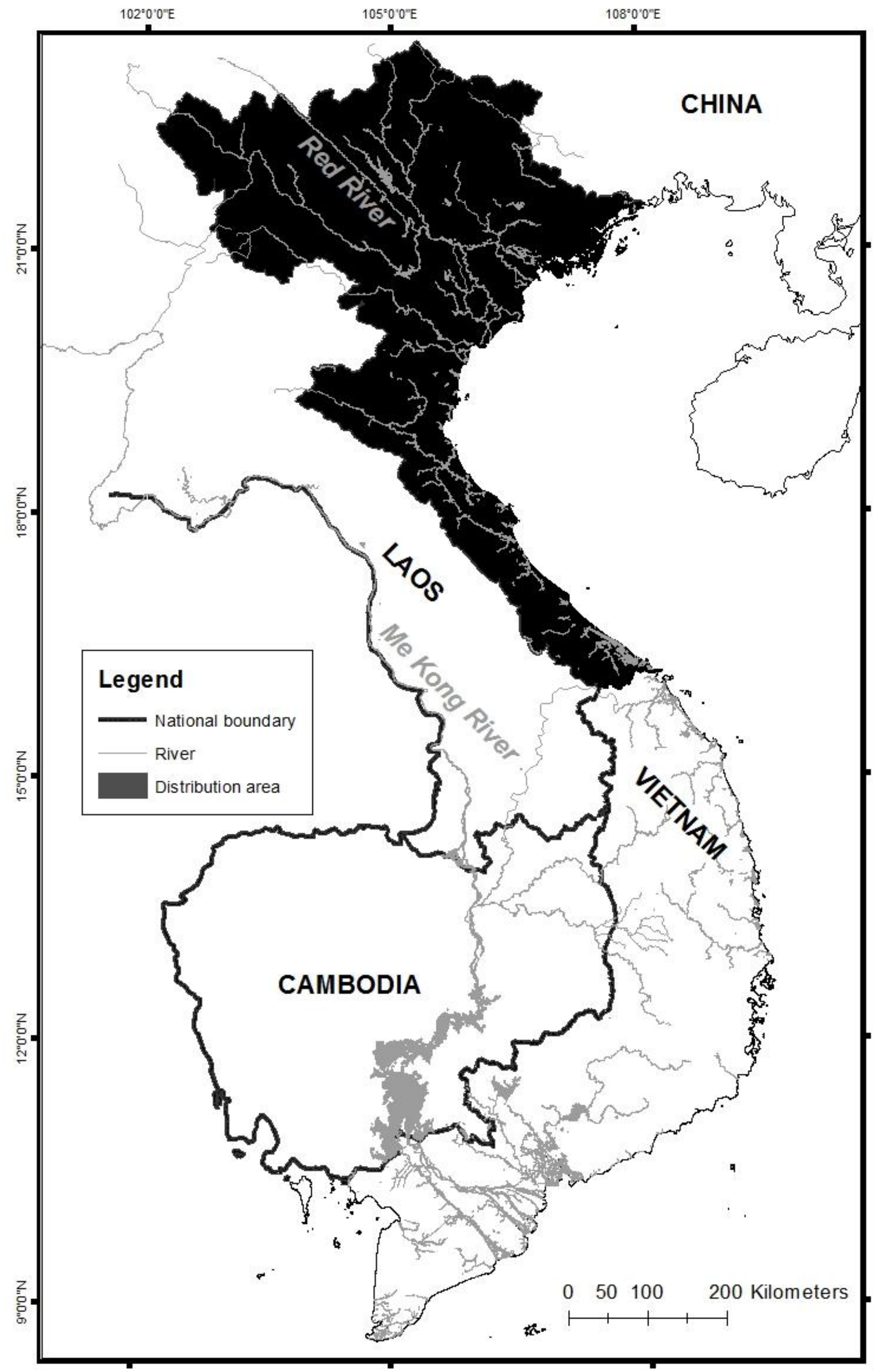
Lanceolaria laevis (Martens, 1902)



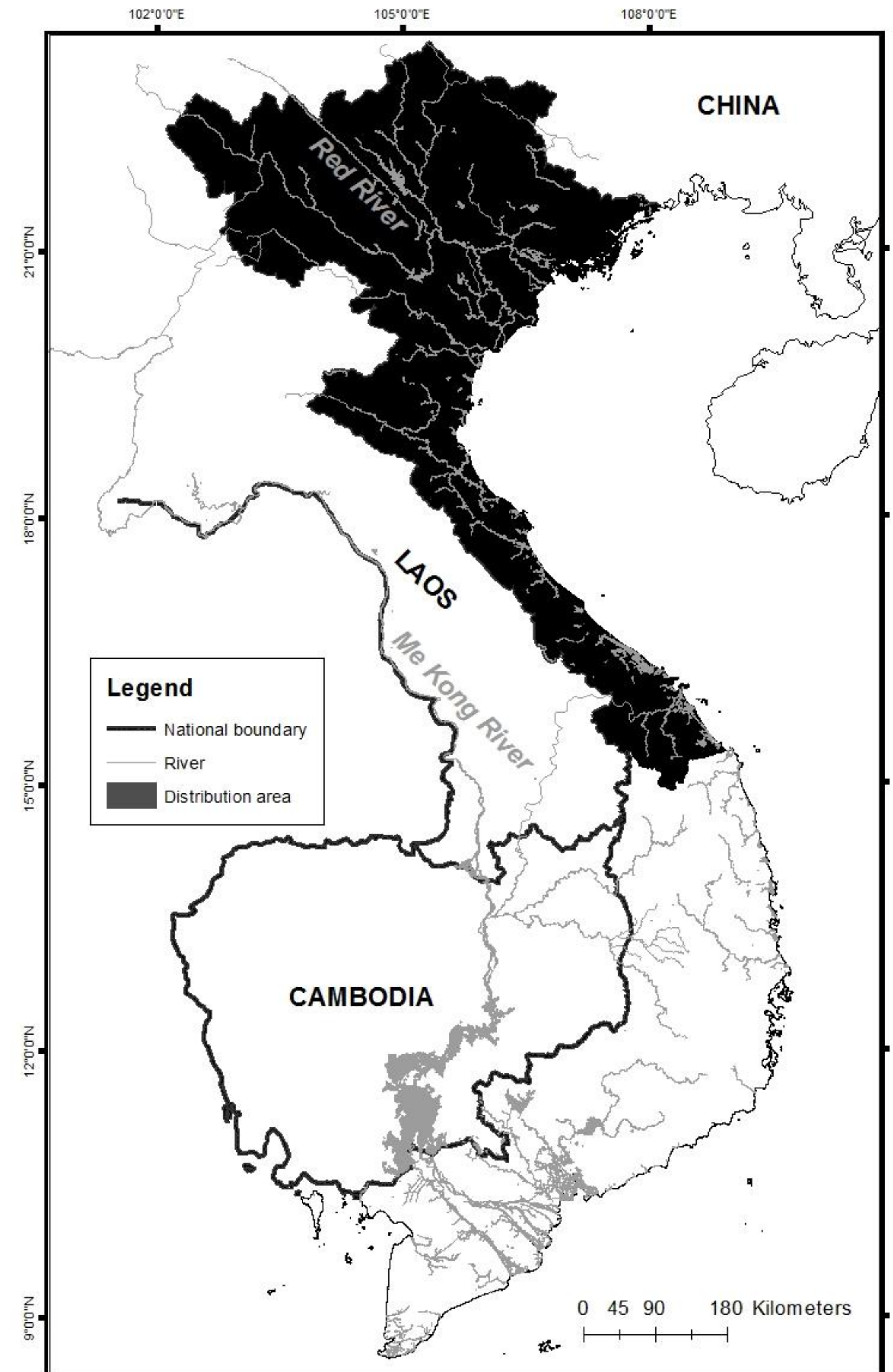
Margaritifera laosensis (Lea, 1863)



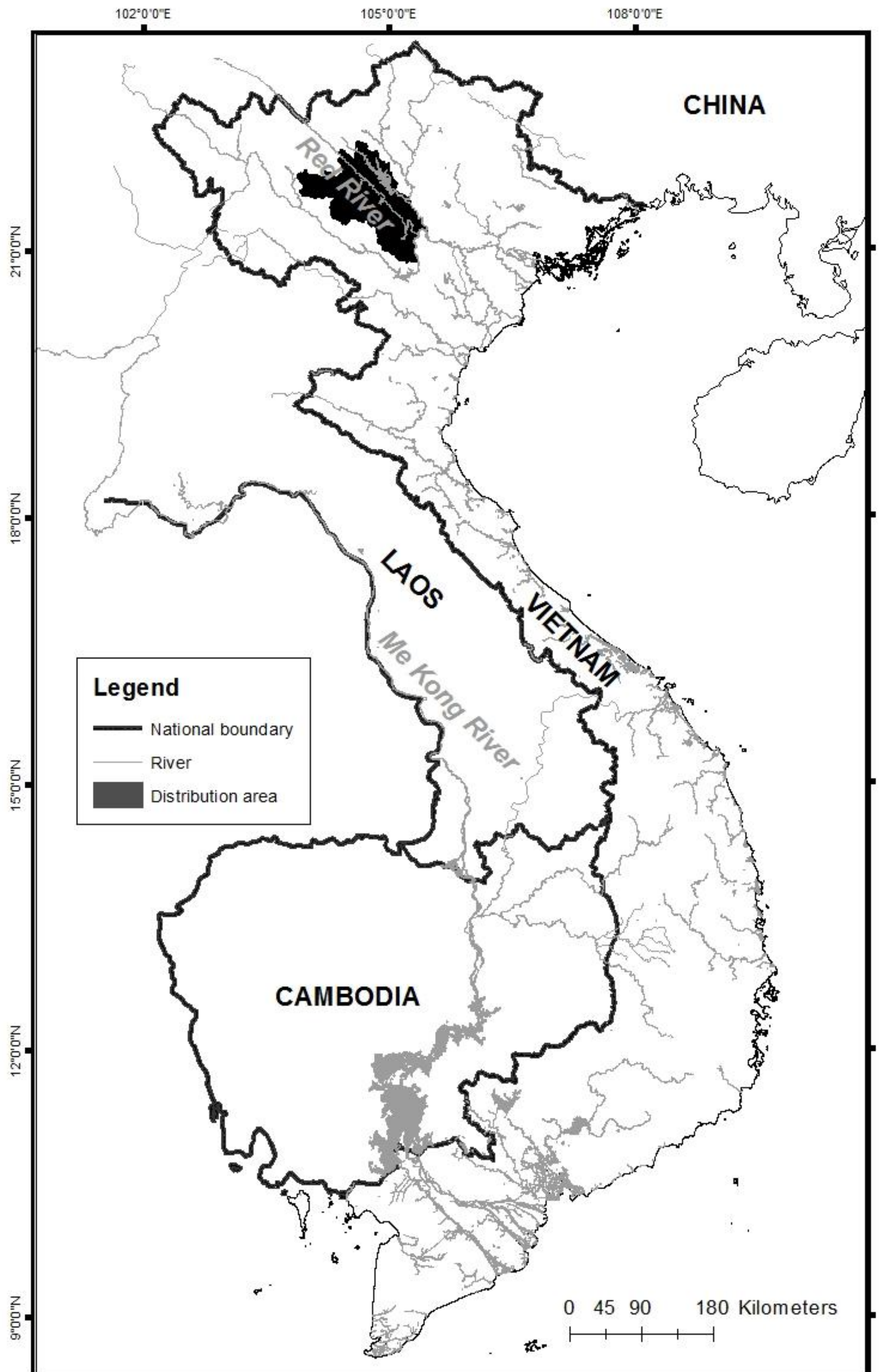
Nodularia dorri (Wattebled, 1886)



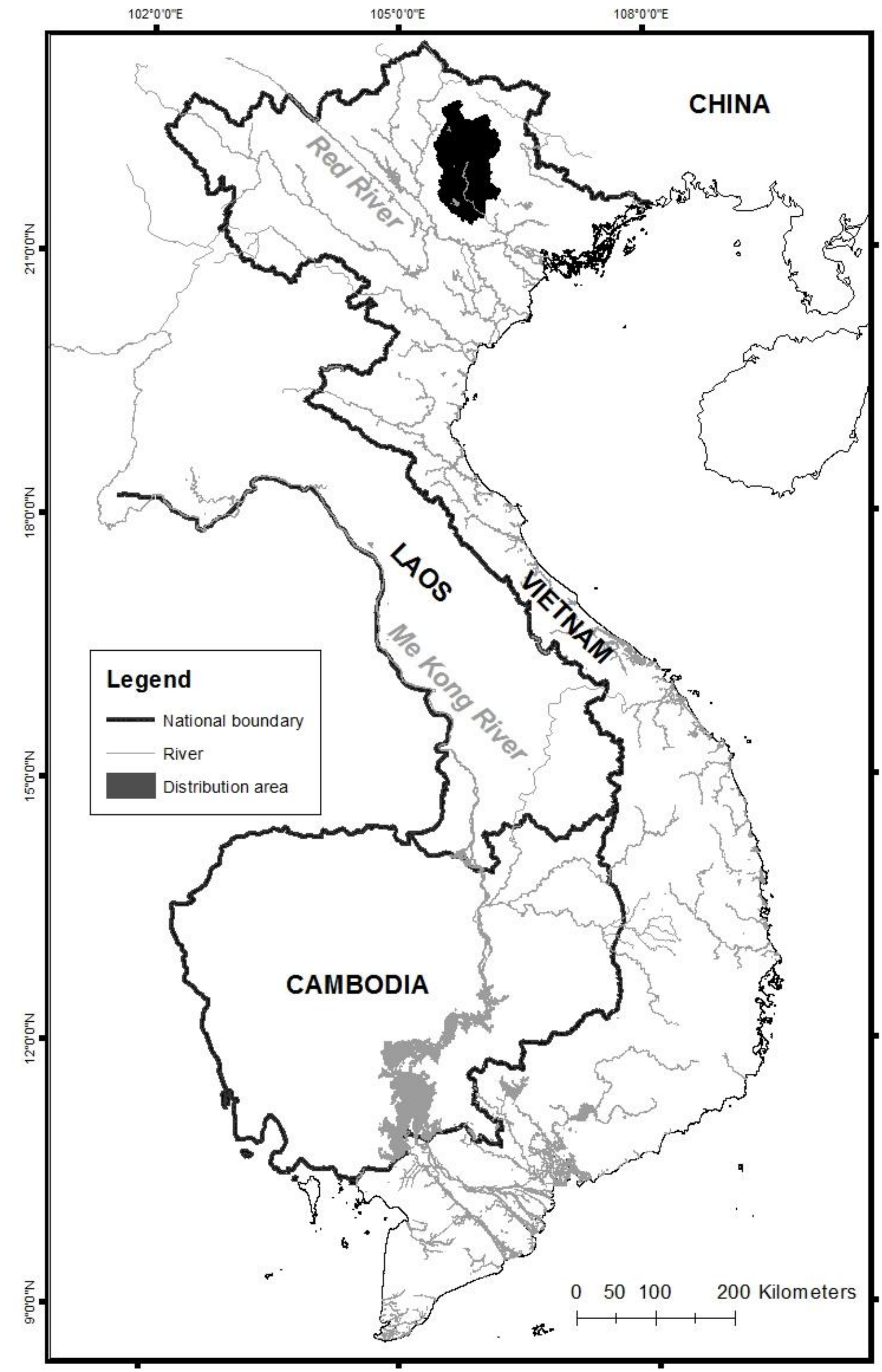
Nodularia douglasiae (Gray, 1833)



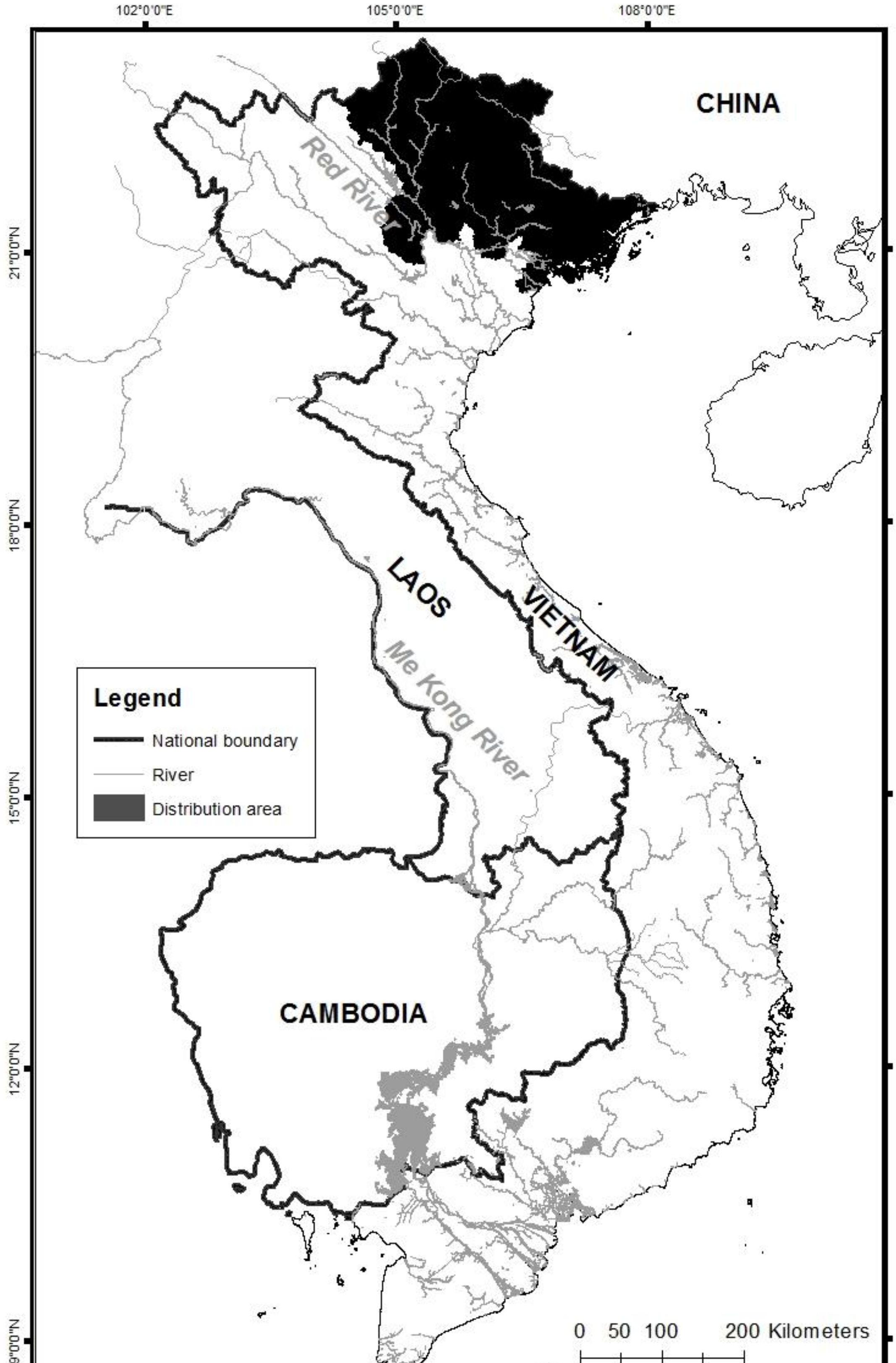
Nodularia nuxpersica (Dunker, 1848)



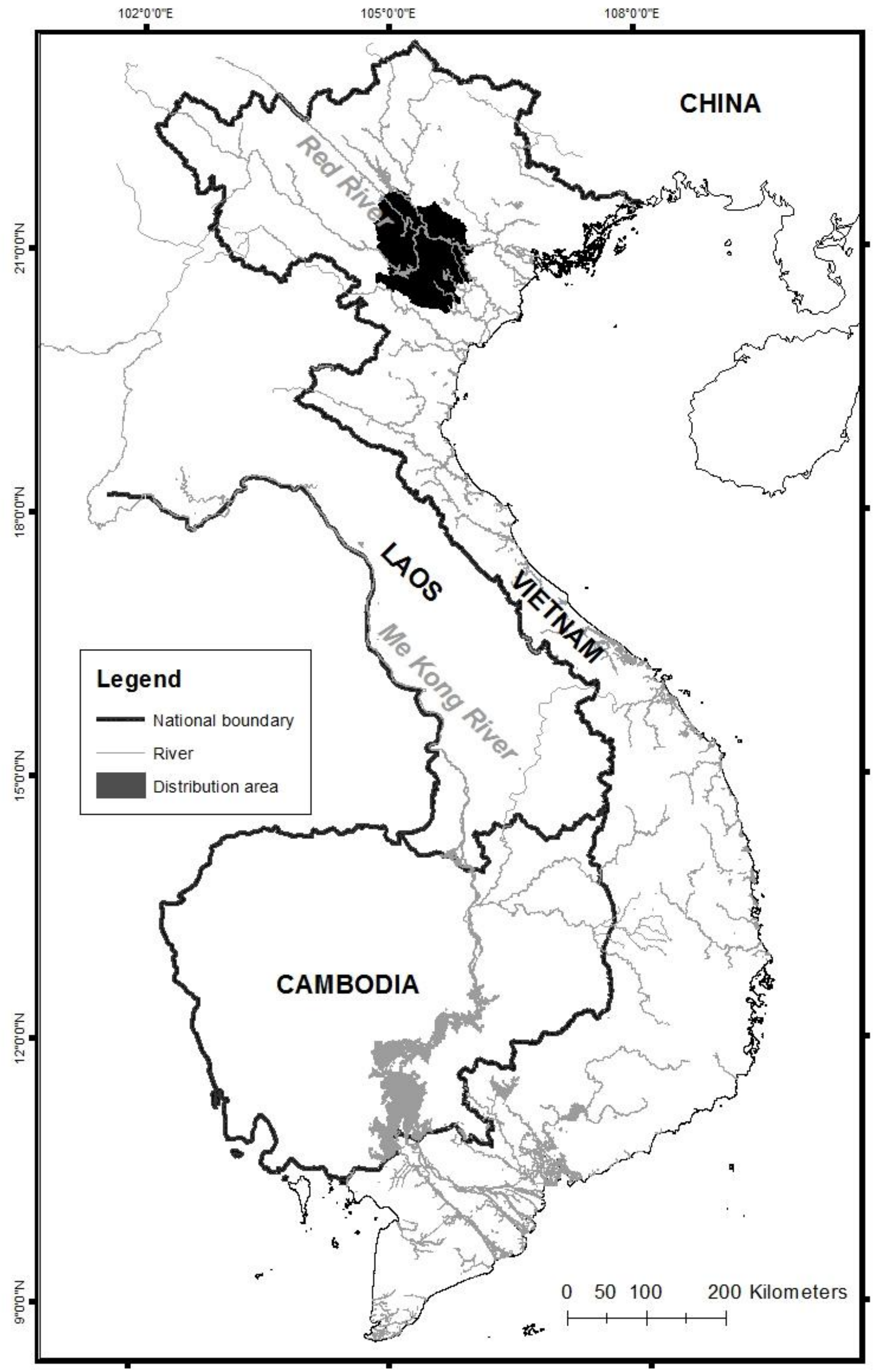
Oxynaia diespiter (Mabille, 1887)



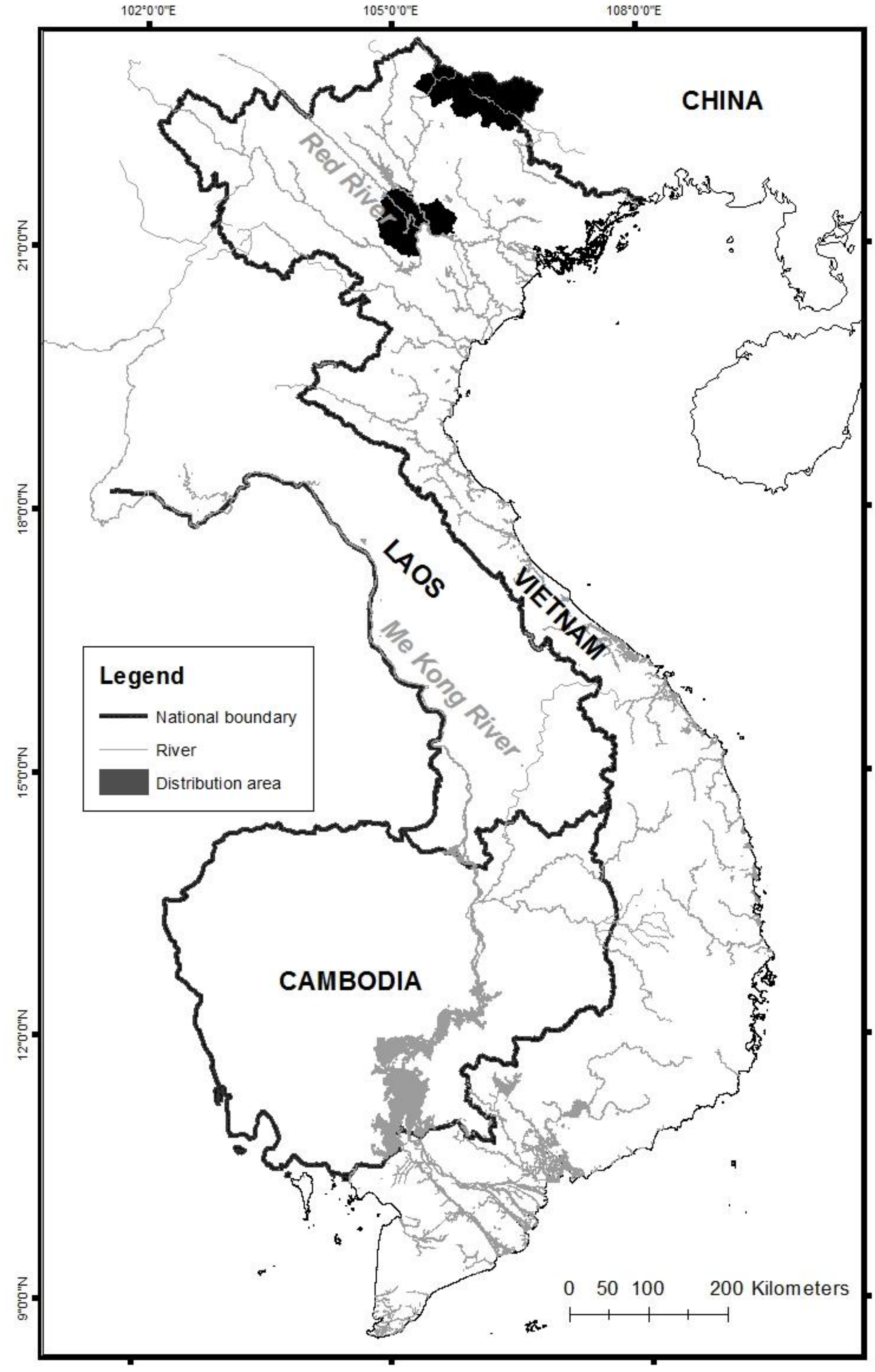
Oxynaia gladiator (Ancy, 1881)



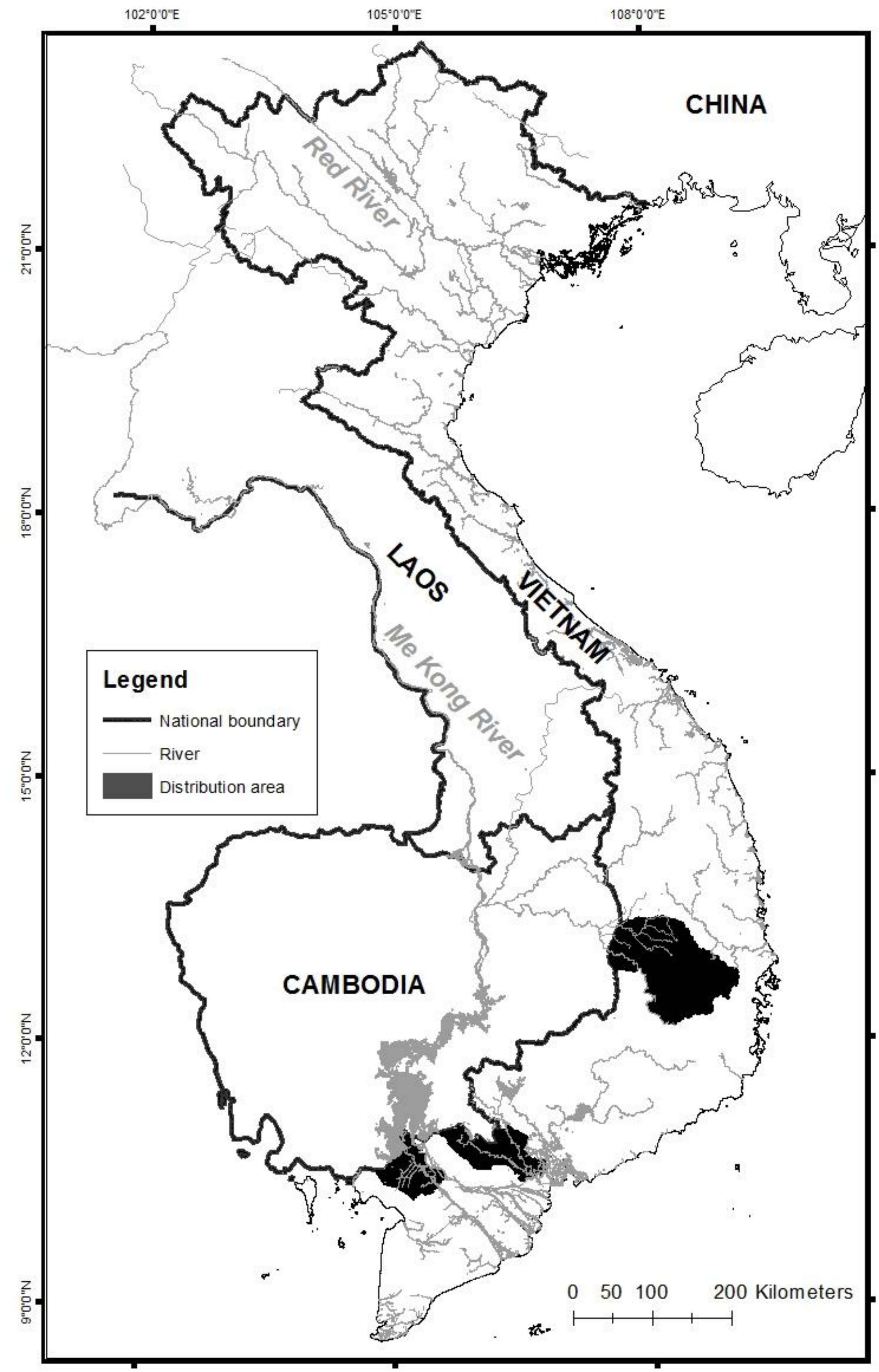
Oxynaia jourdyi (Morlet, 1886)



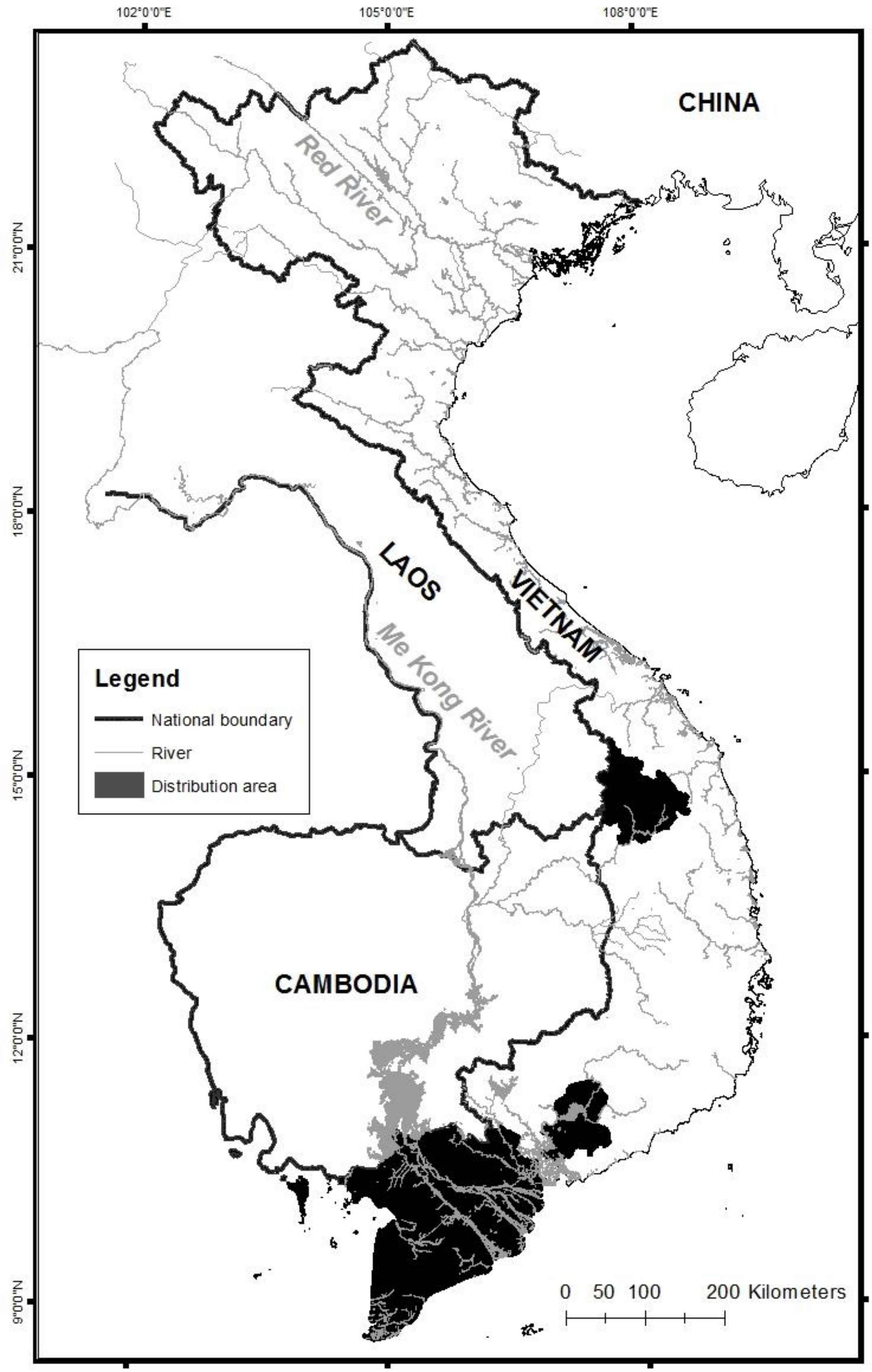
Oxynaia micheloti (Morlet, 1886)



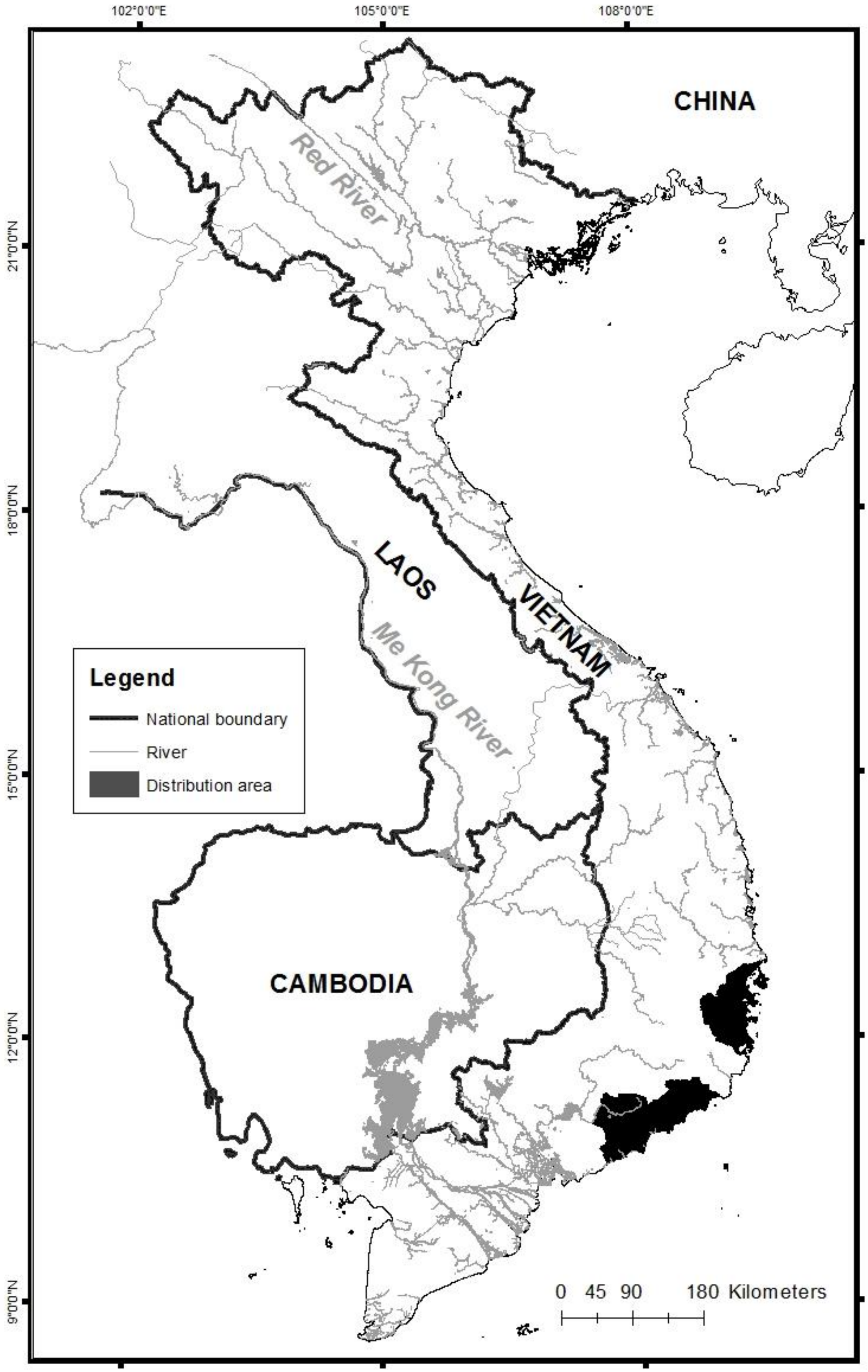
Physunio cambodiensis (Lea, 1856)



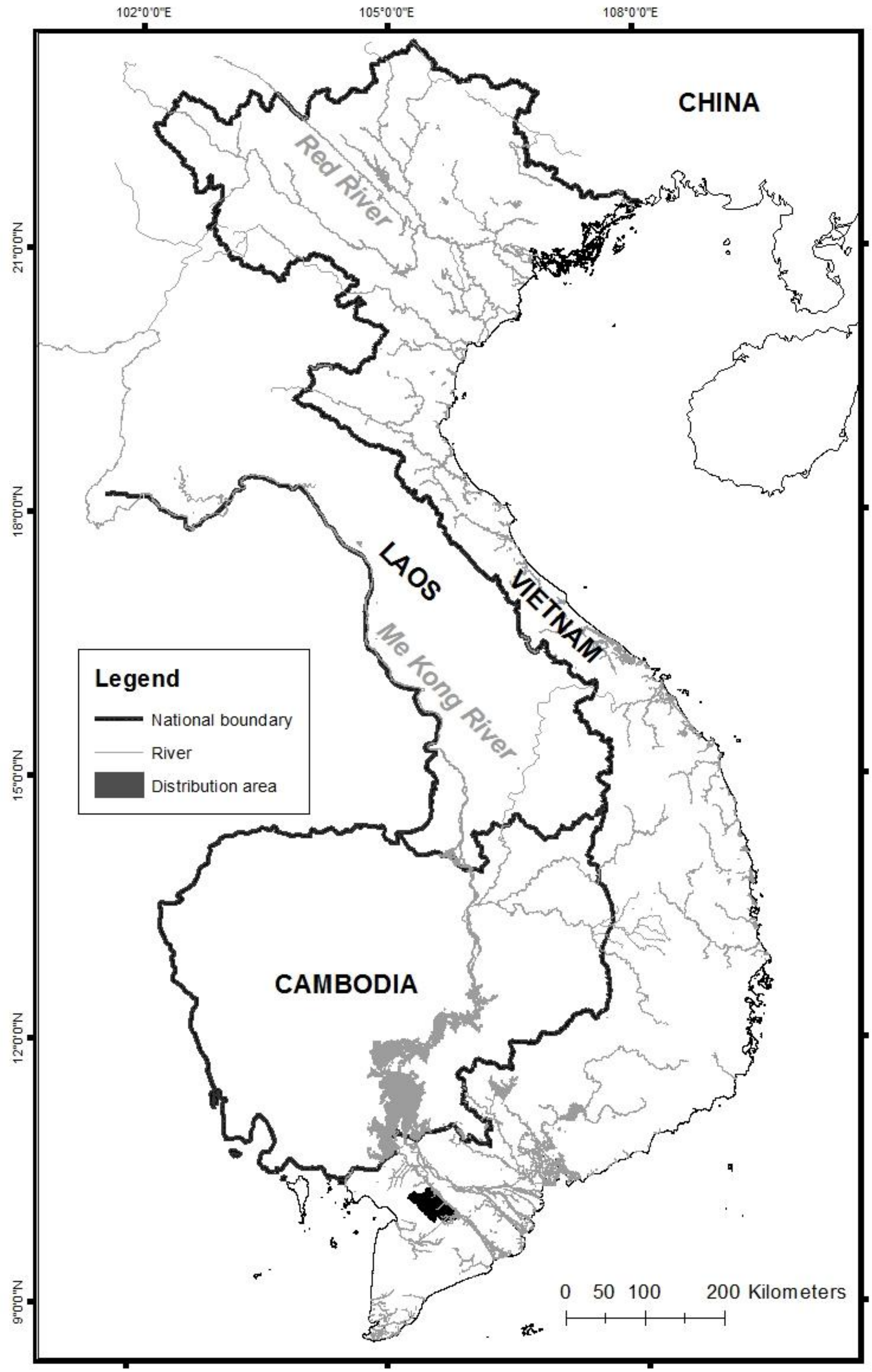
Physunio micropterus (Morelet, 1866)



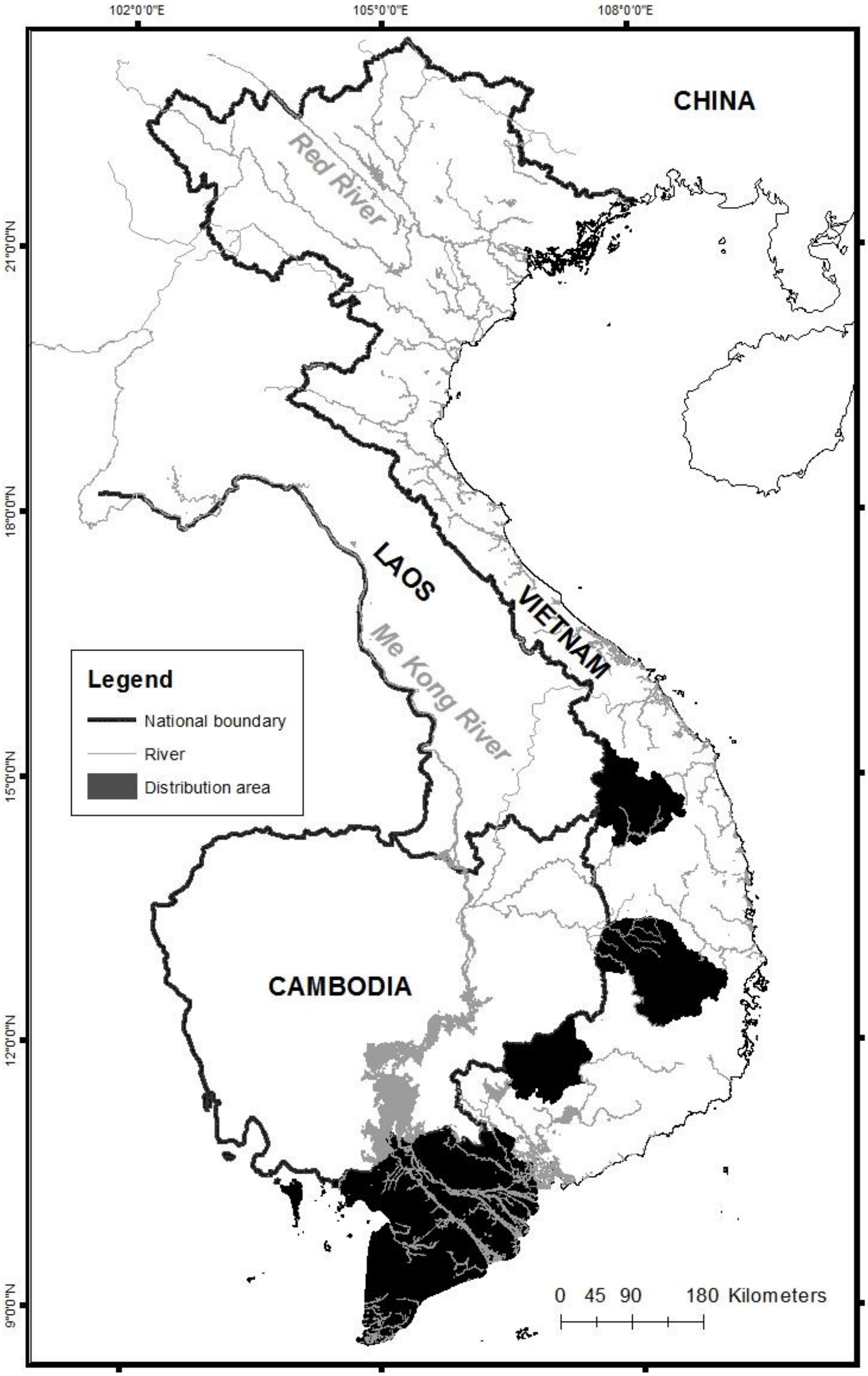
Physunio modelli Brandt, 1974



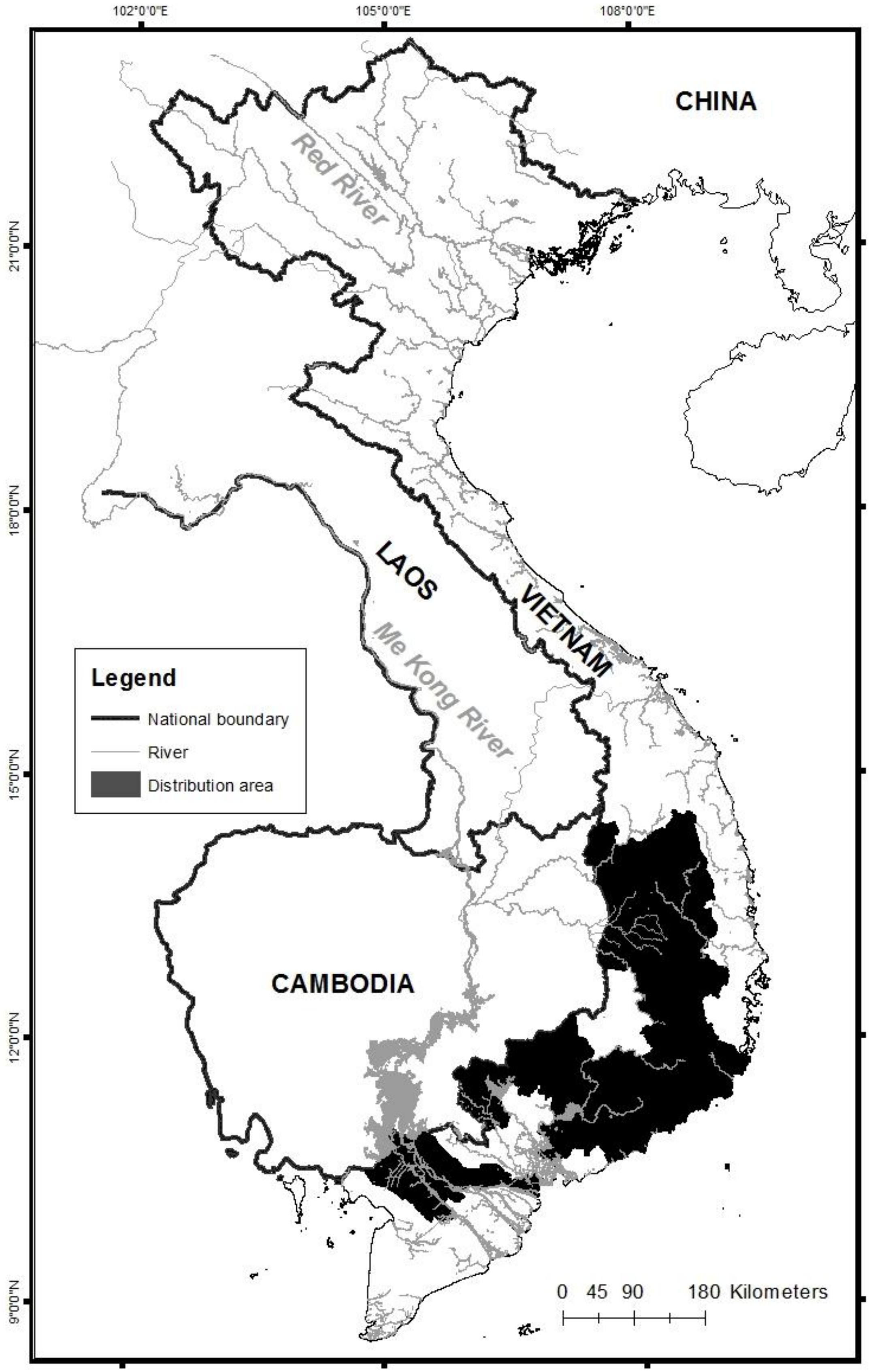
Physunio superbus (Lea, 1843)



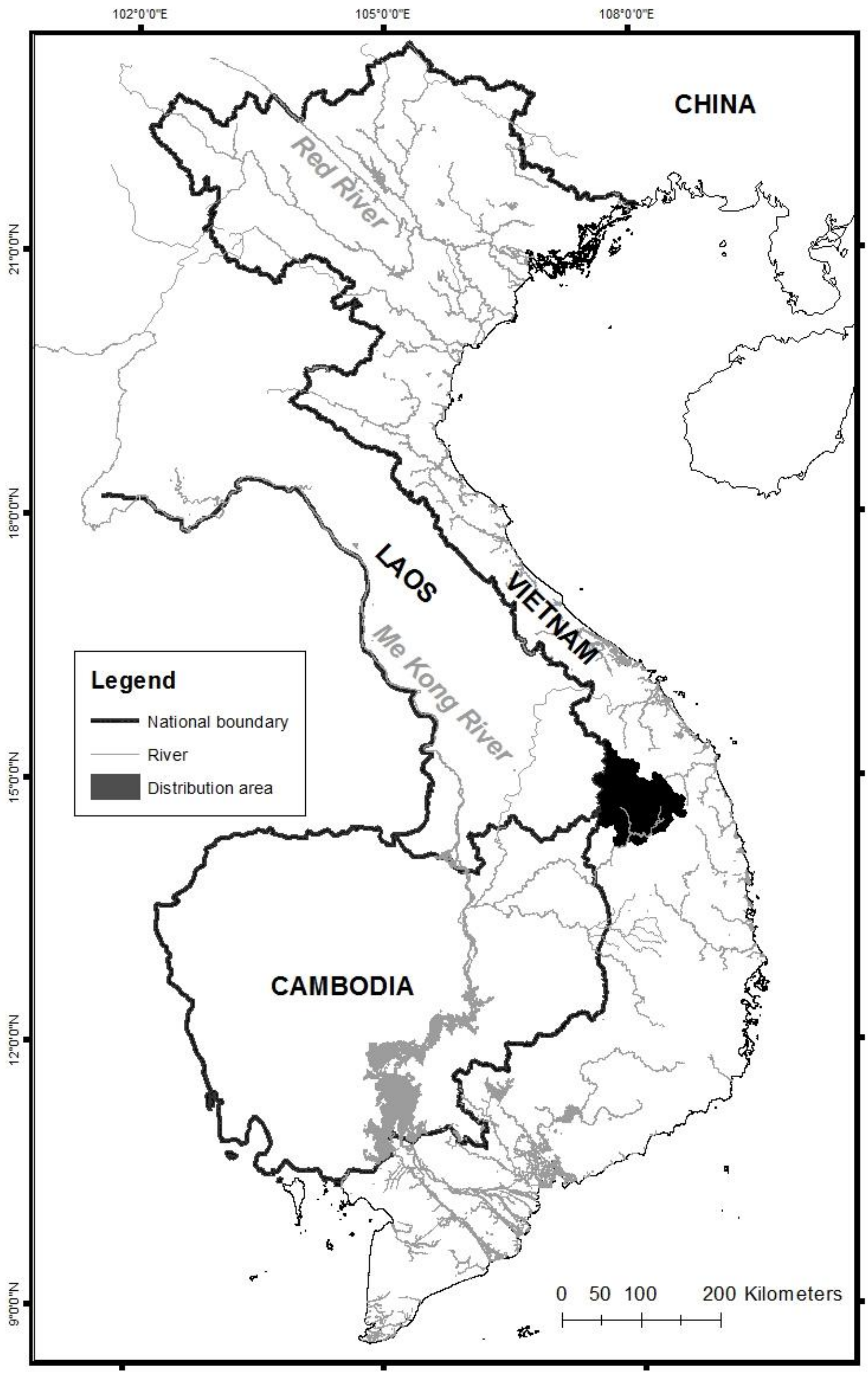
Pilsbryoconcha compressa (Martens, 1860)



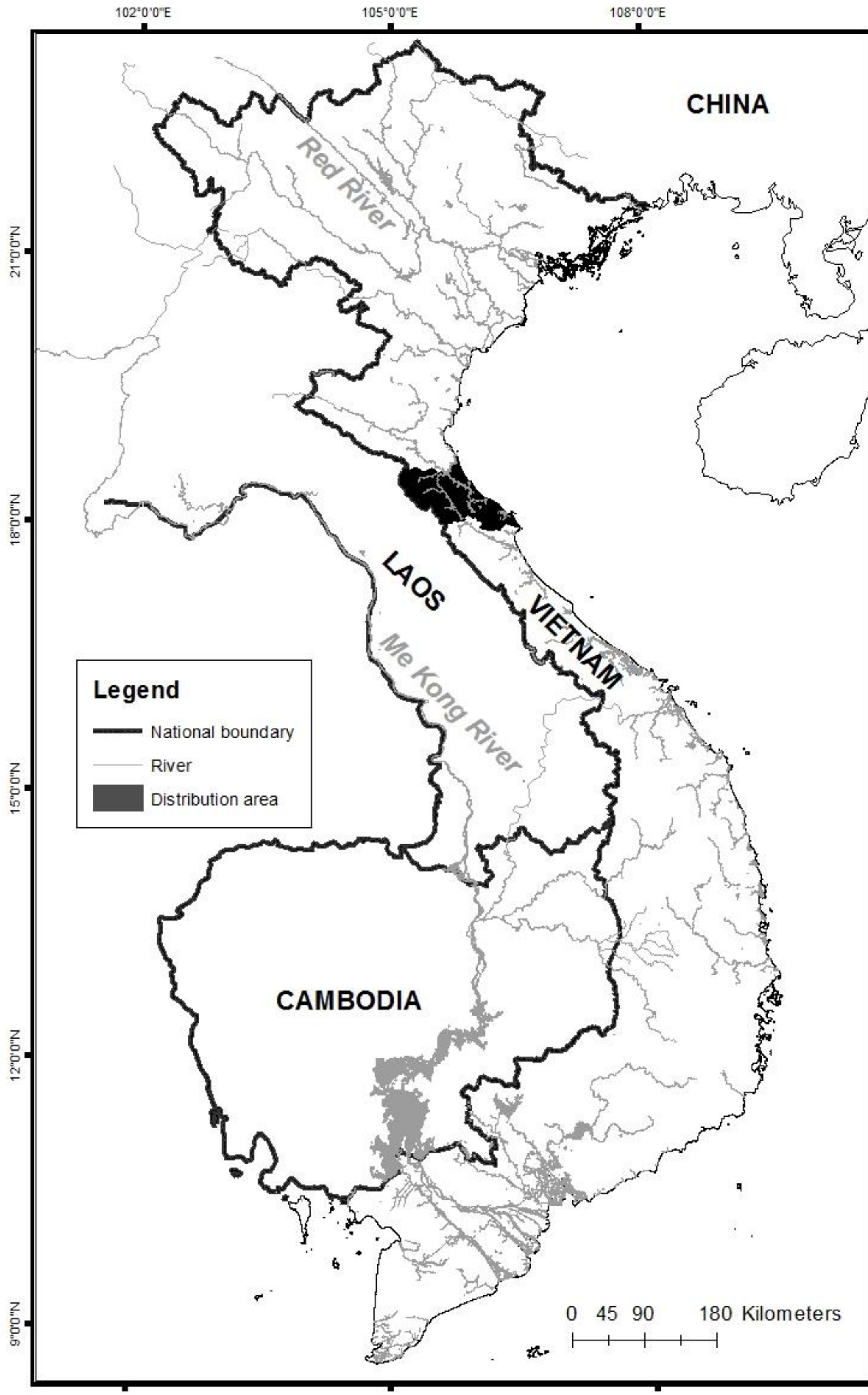
Pilsbryoconcha exilis (Lea, 1839)



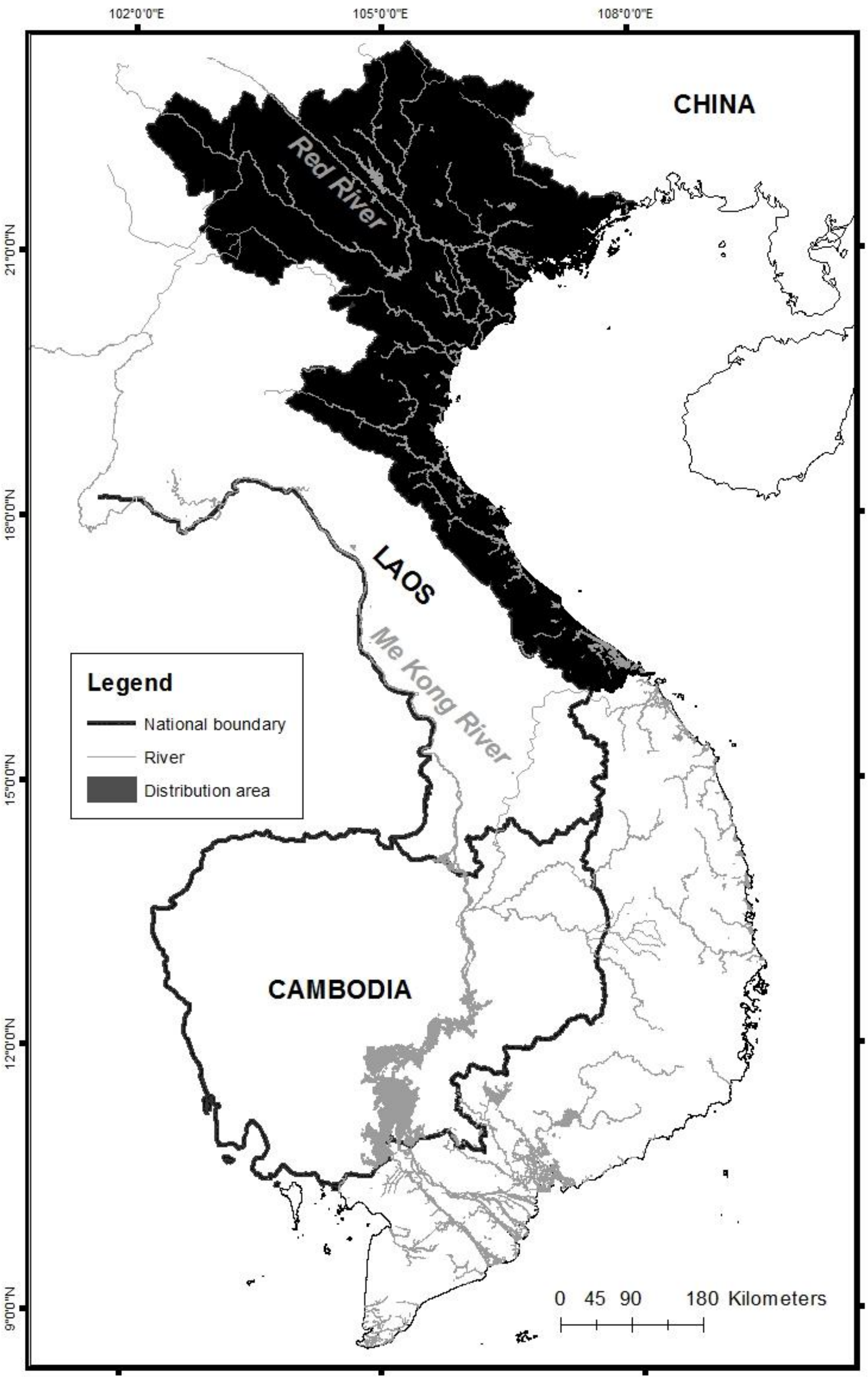
Pilsbryoconcha lemeslei (Morelet, 1875)



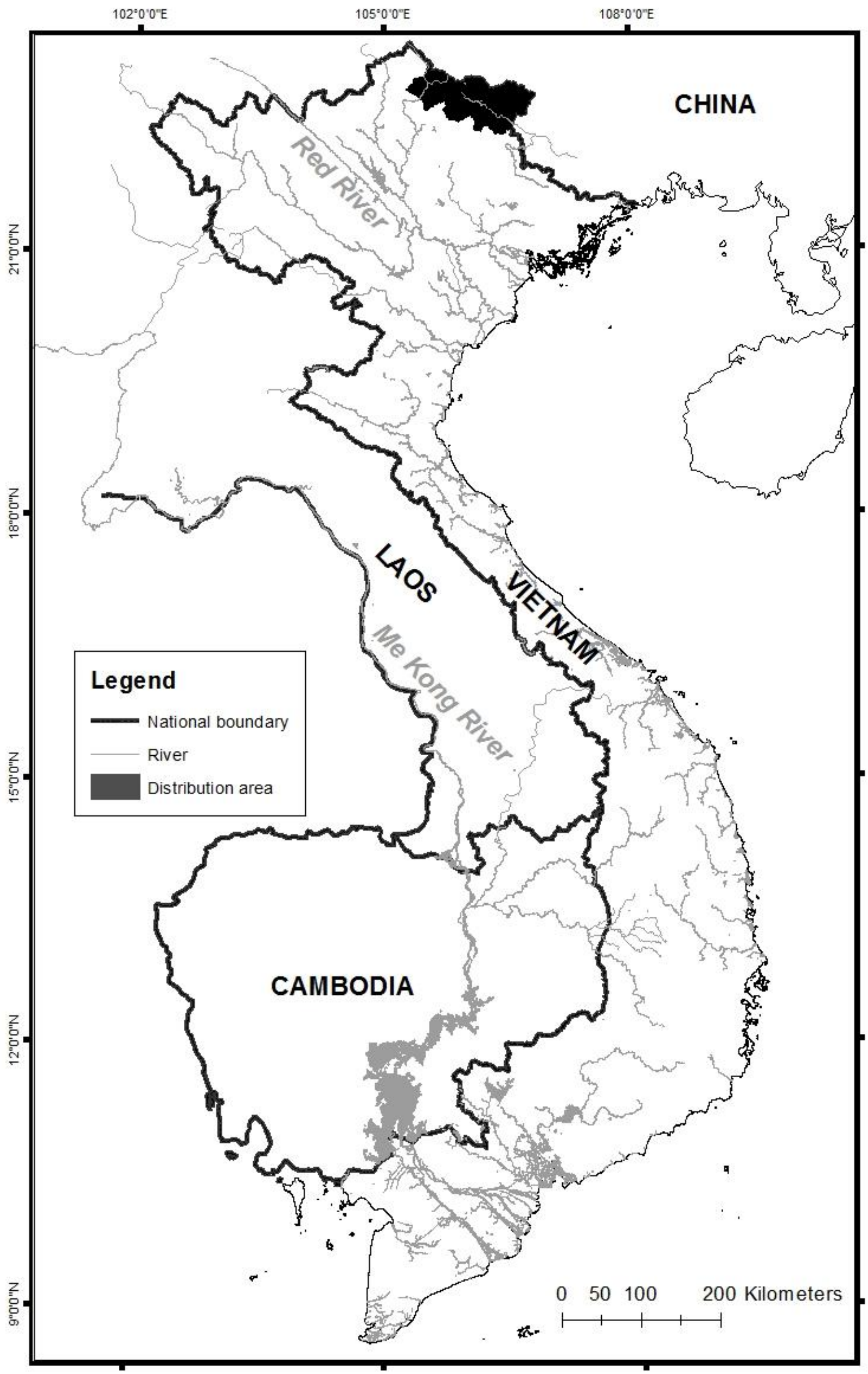
Pletholophus sp.



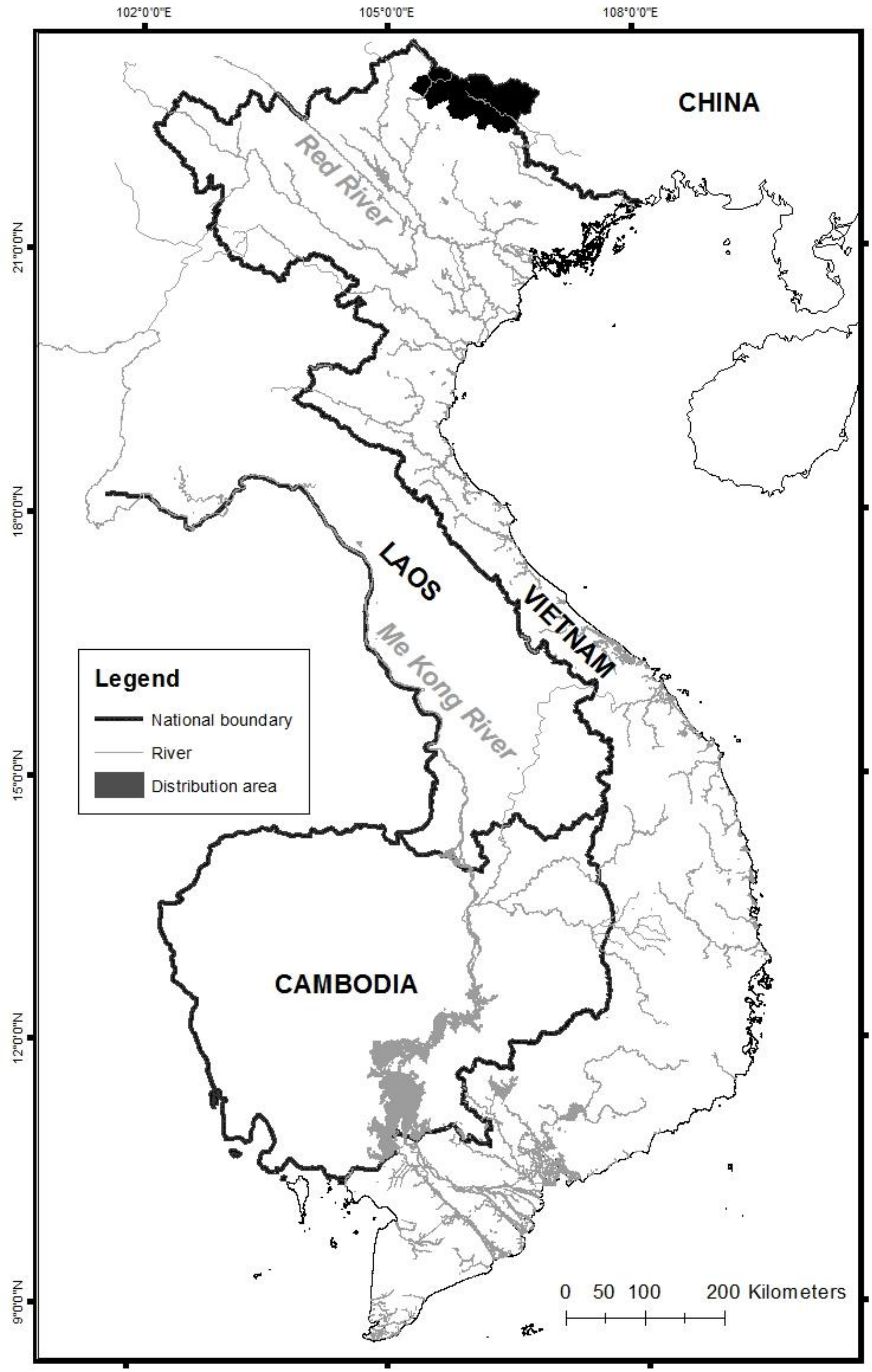
Pletholophus tenuis (Gray in Griffith & Pidgeon, 1833)



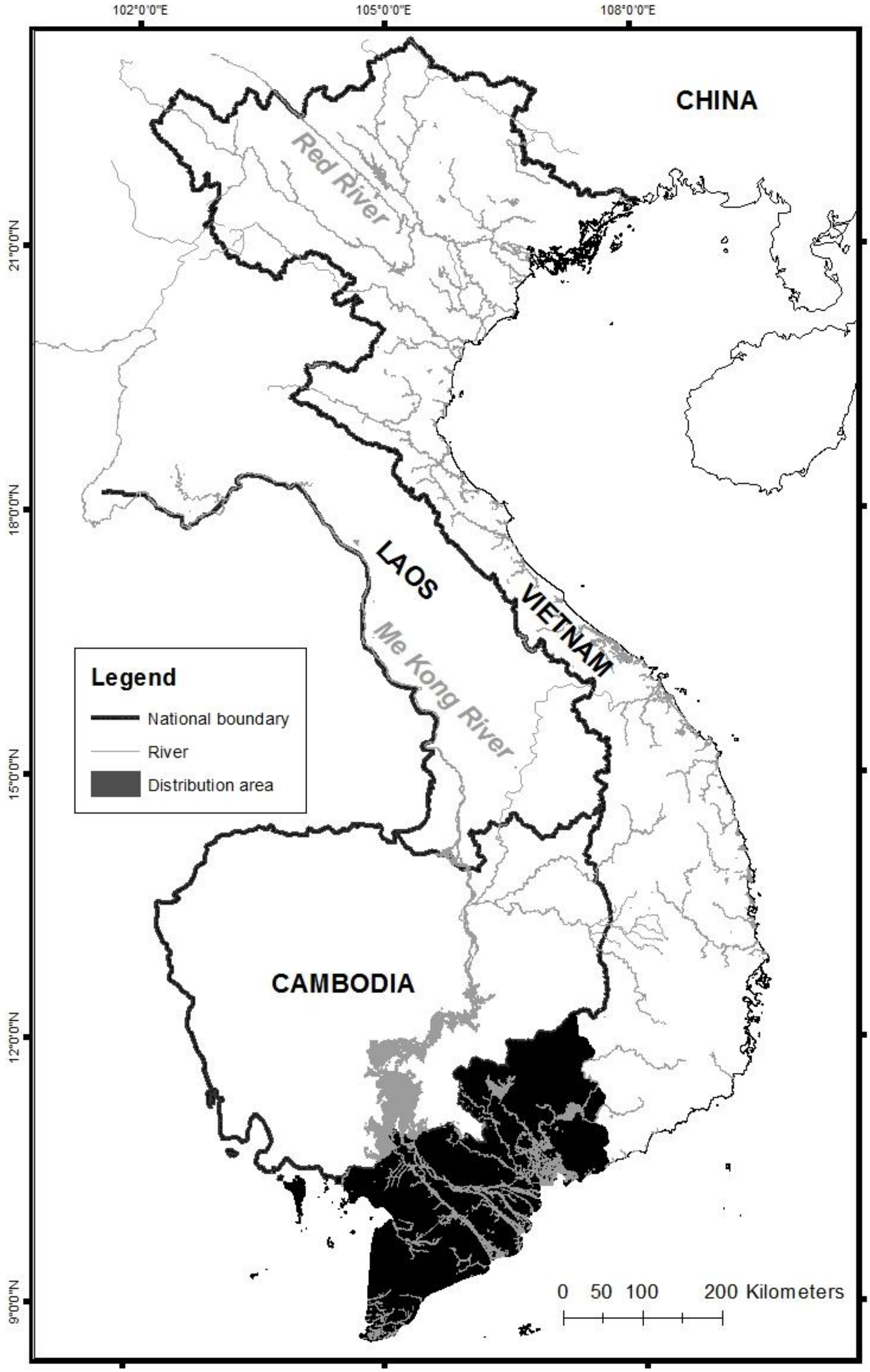
Protunio messageri (Bavay & Dautzenberg, 1901)



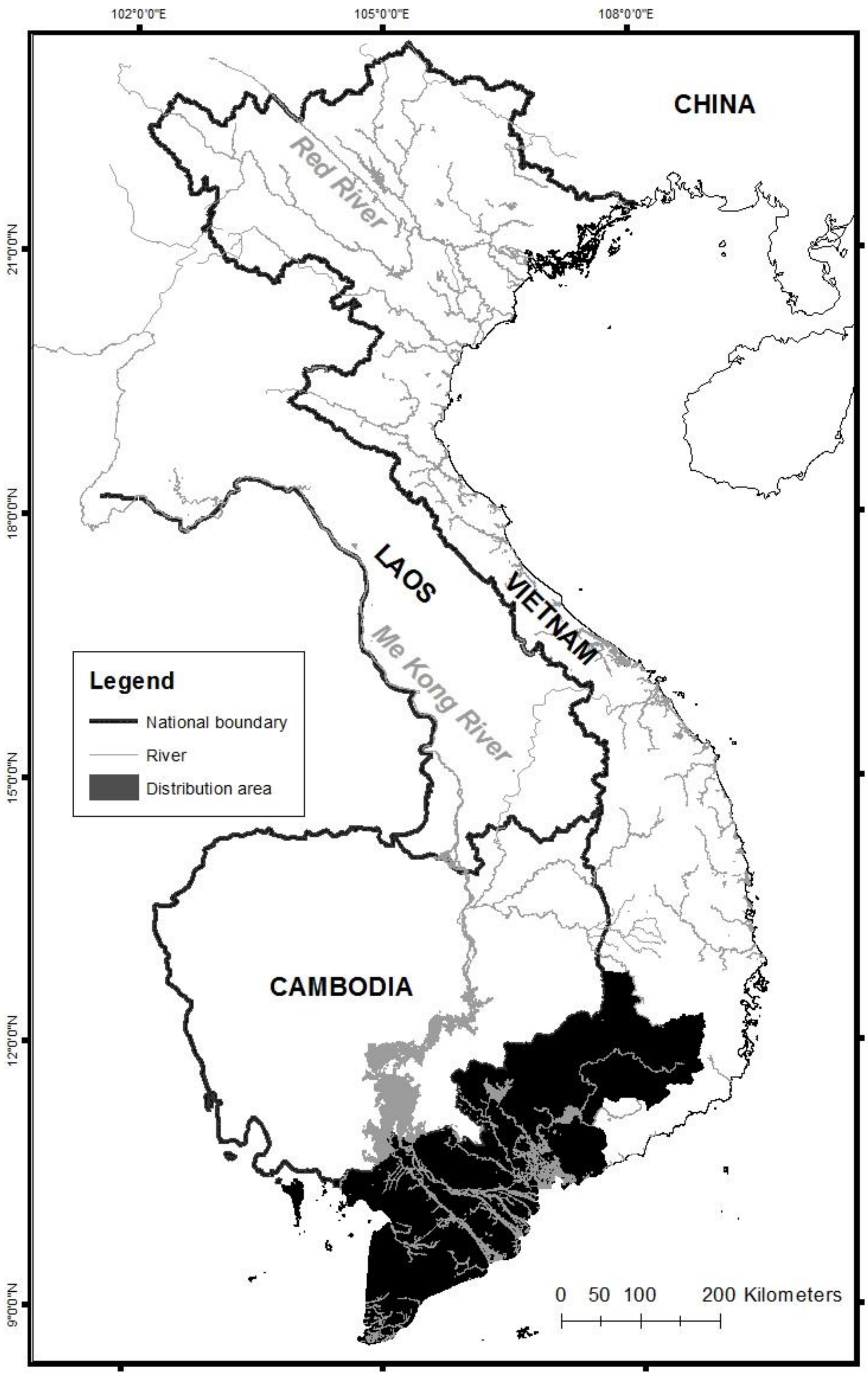
Pseuobaphia sp.



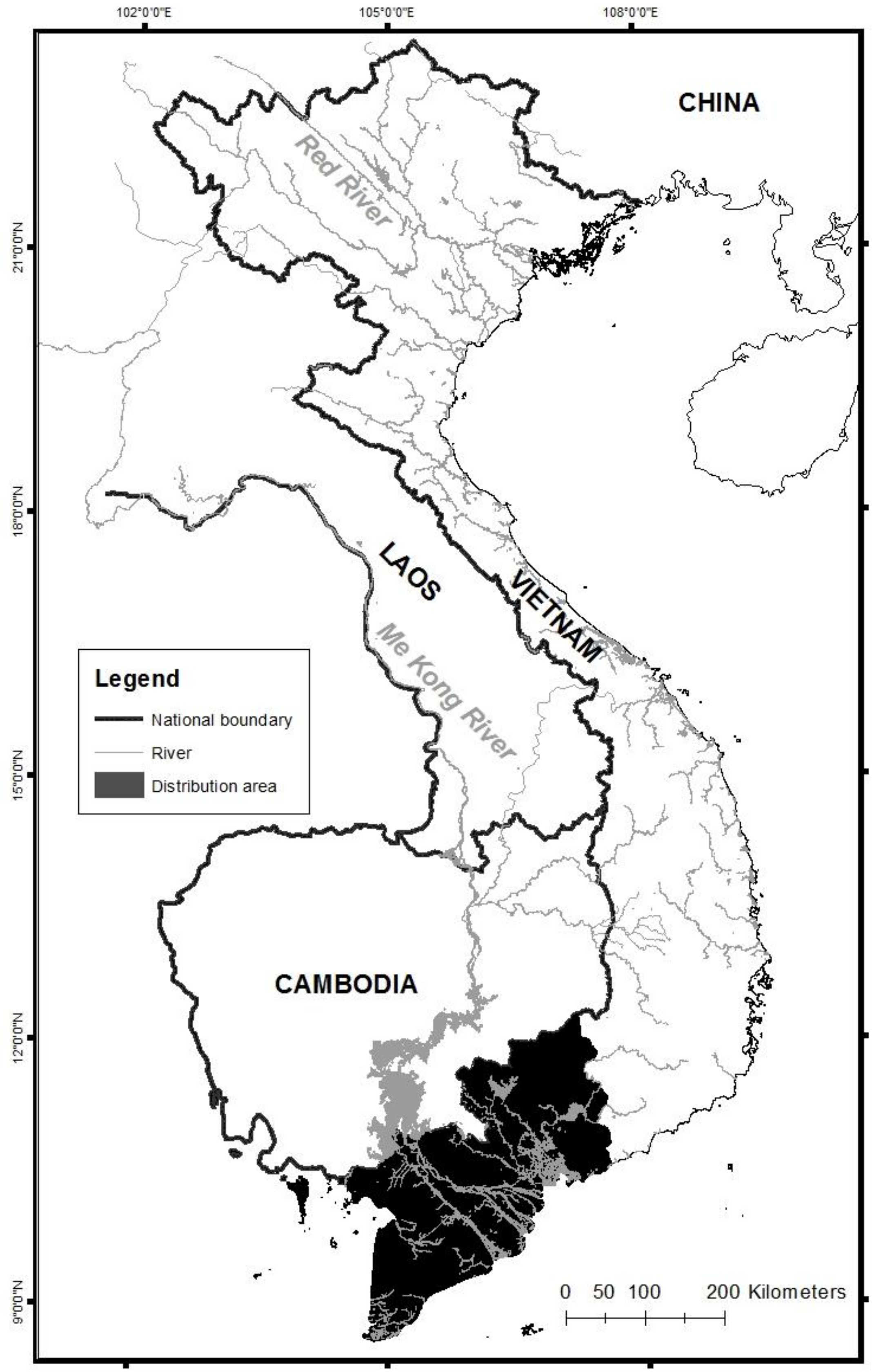
Pseudodon cambodjensis (Petit, 1865)



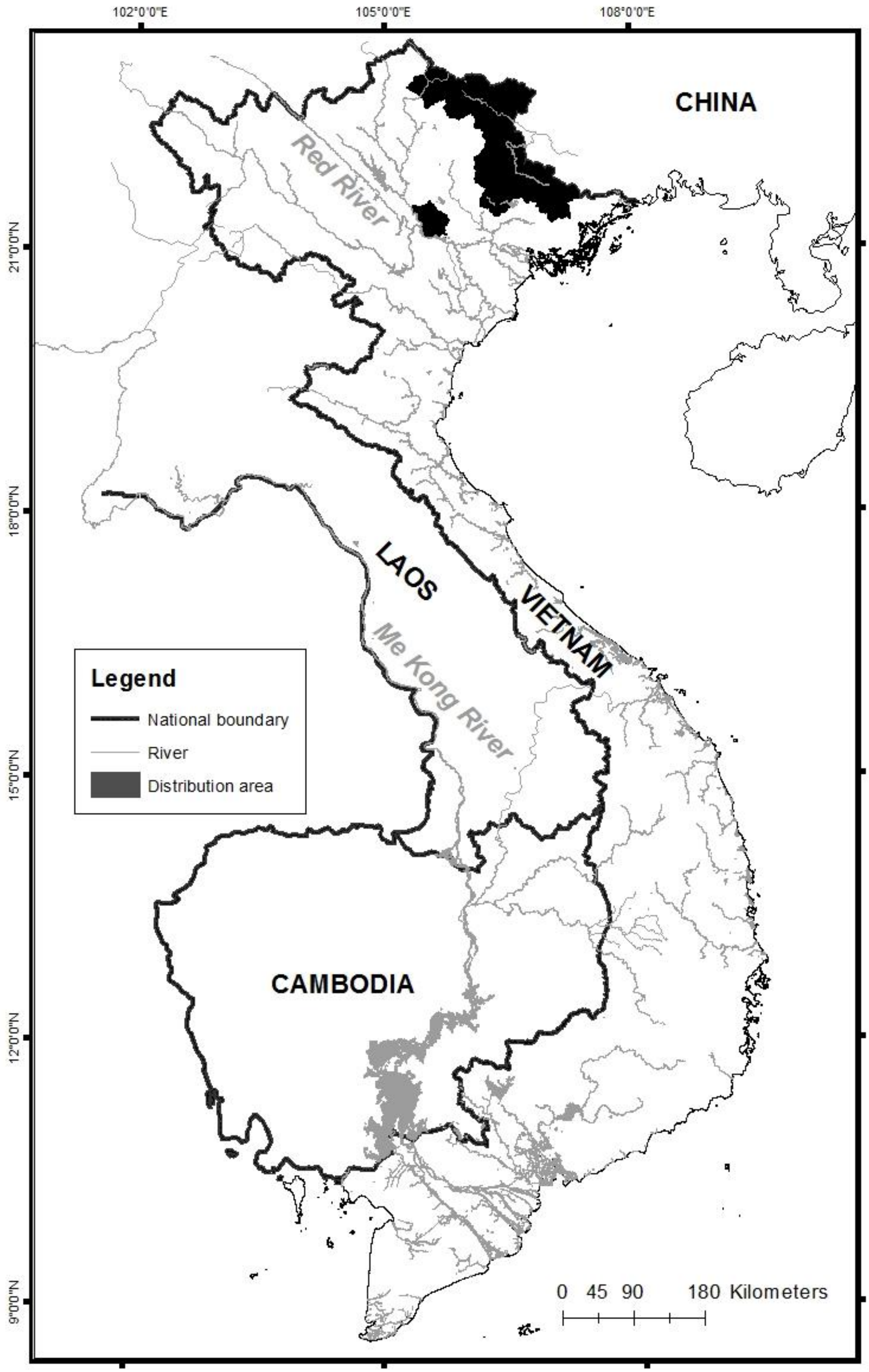
Pseudodon inoscularis (Gould, 1844)



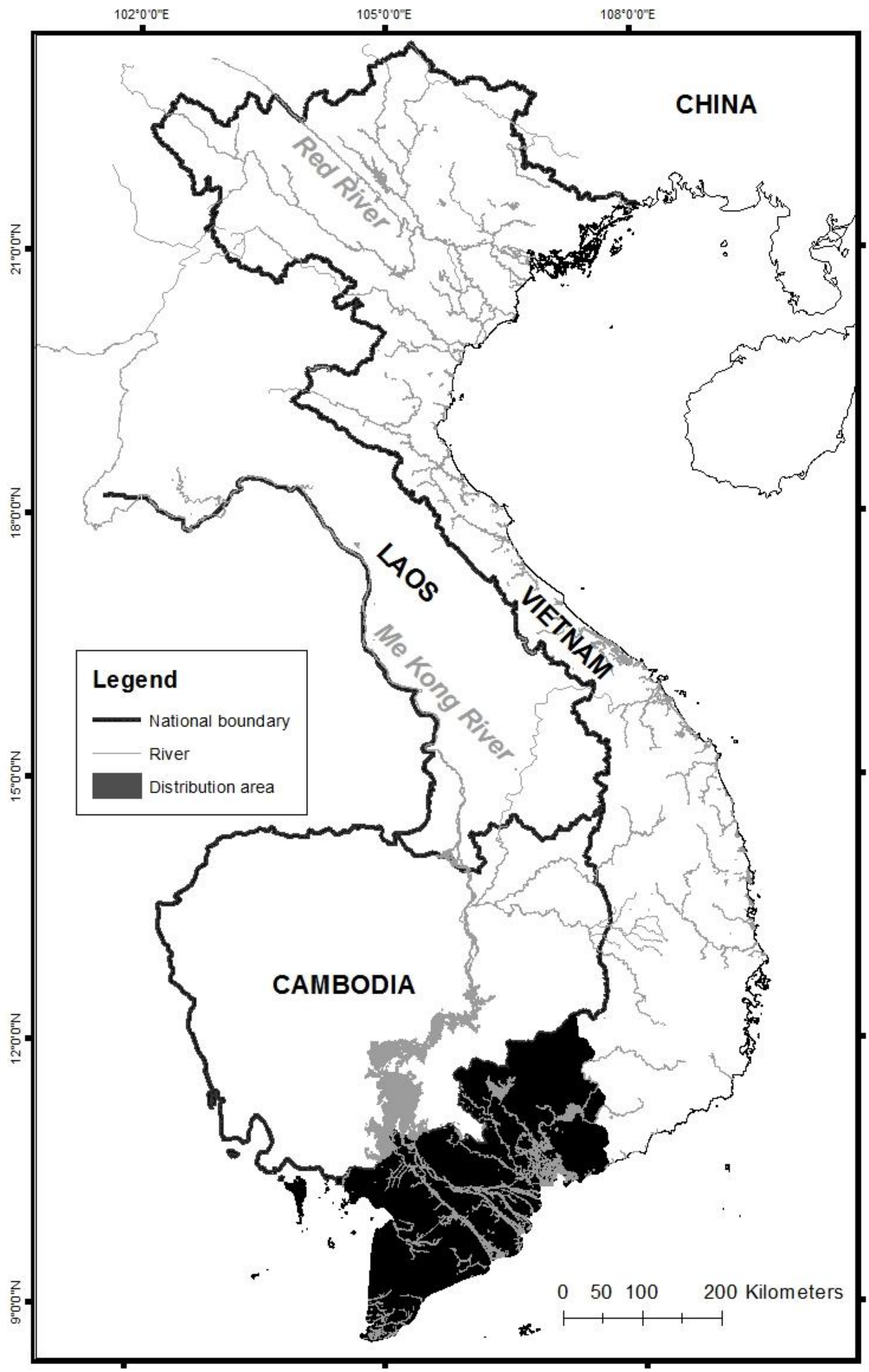
Pseudodon mouhoti (Lea, 1863)



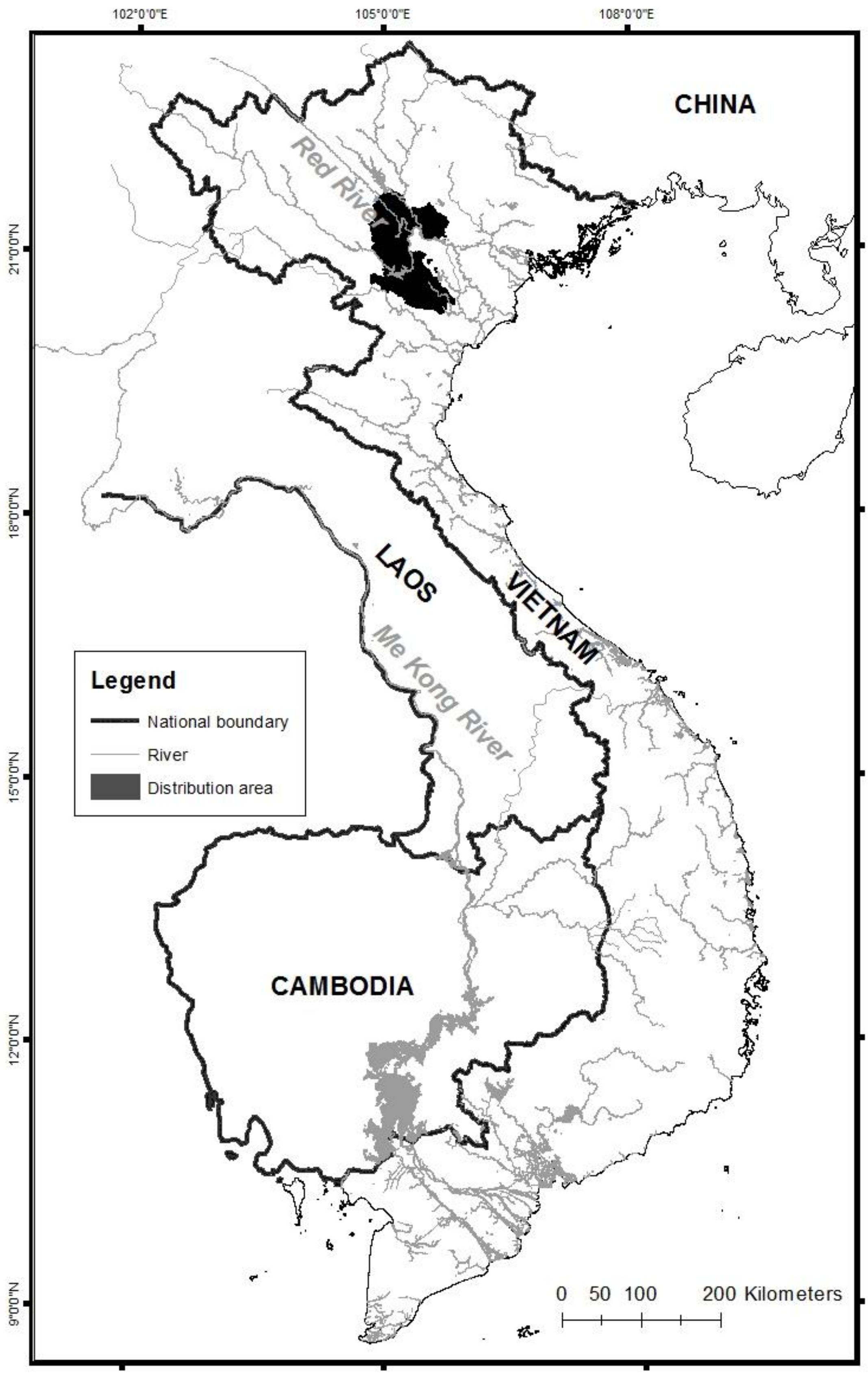
Pseudodon resupinatus Martens, 1902



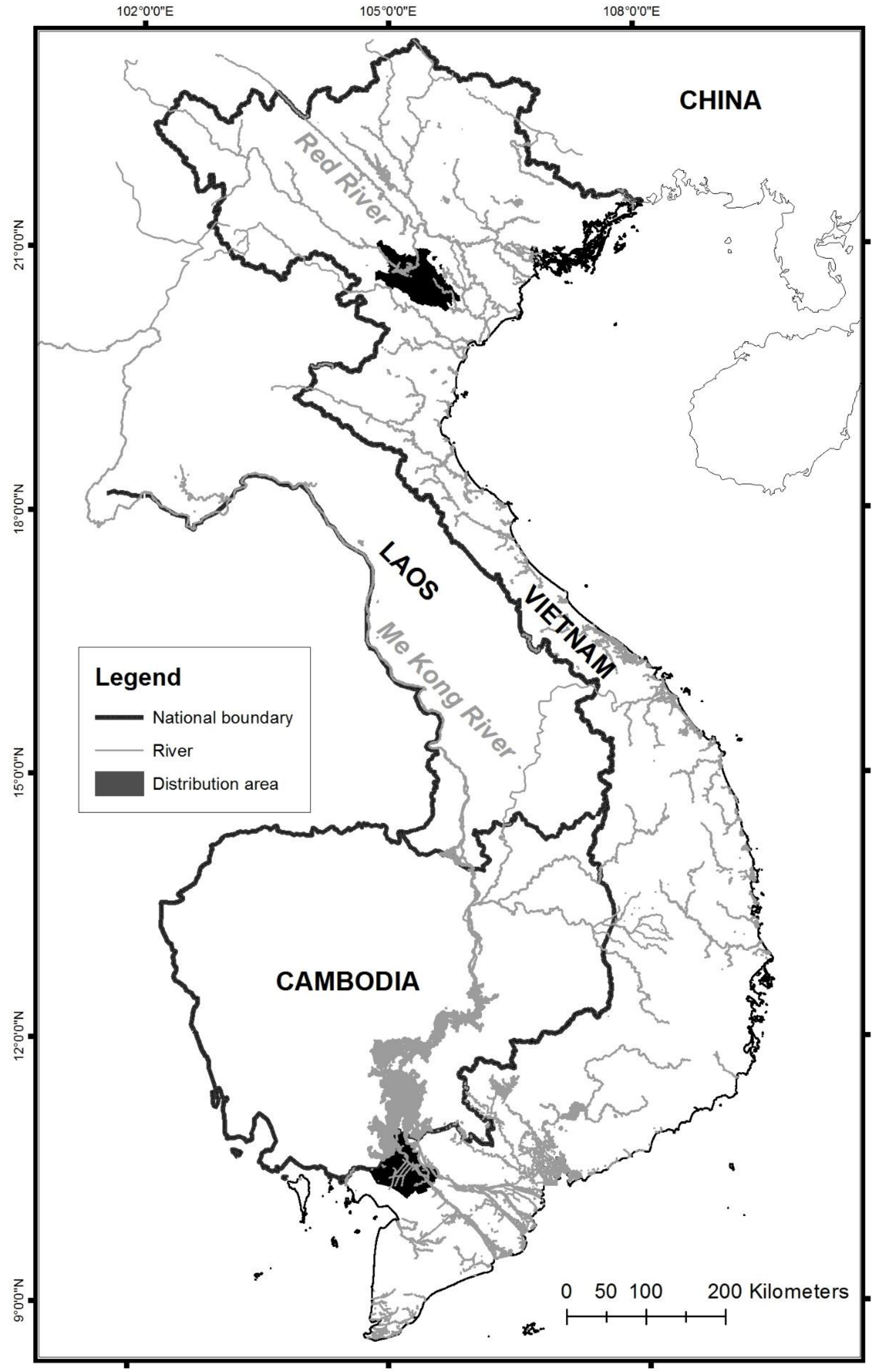
Pseudodon vondembuschianus (Lea, 1840)



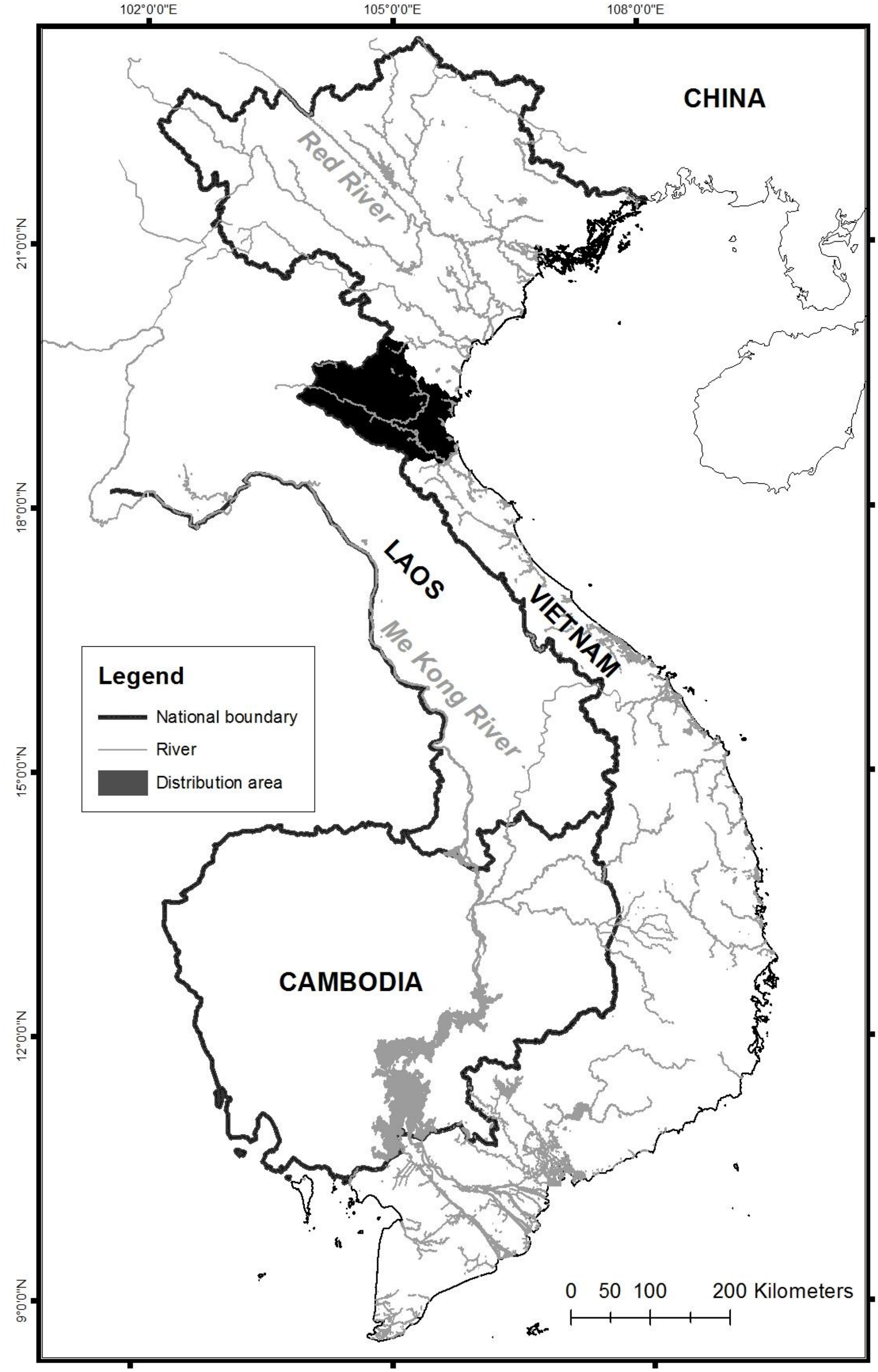
Ptychorhynchus pfisteri (Heude, 1874)



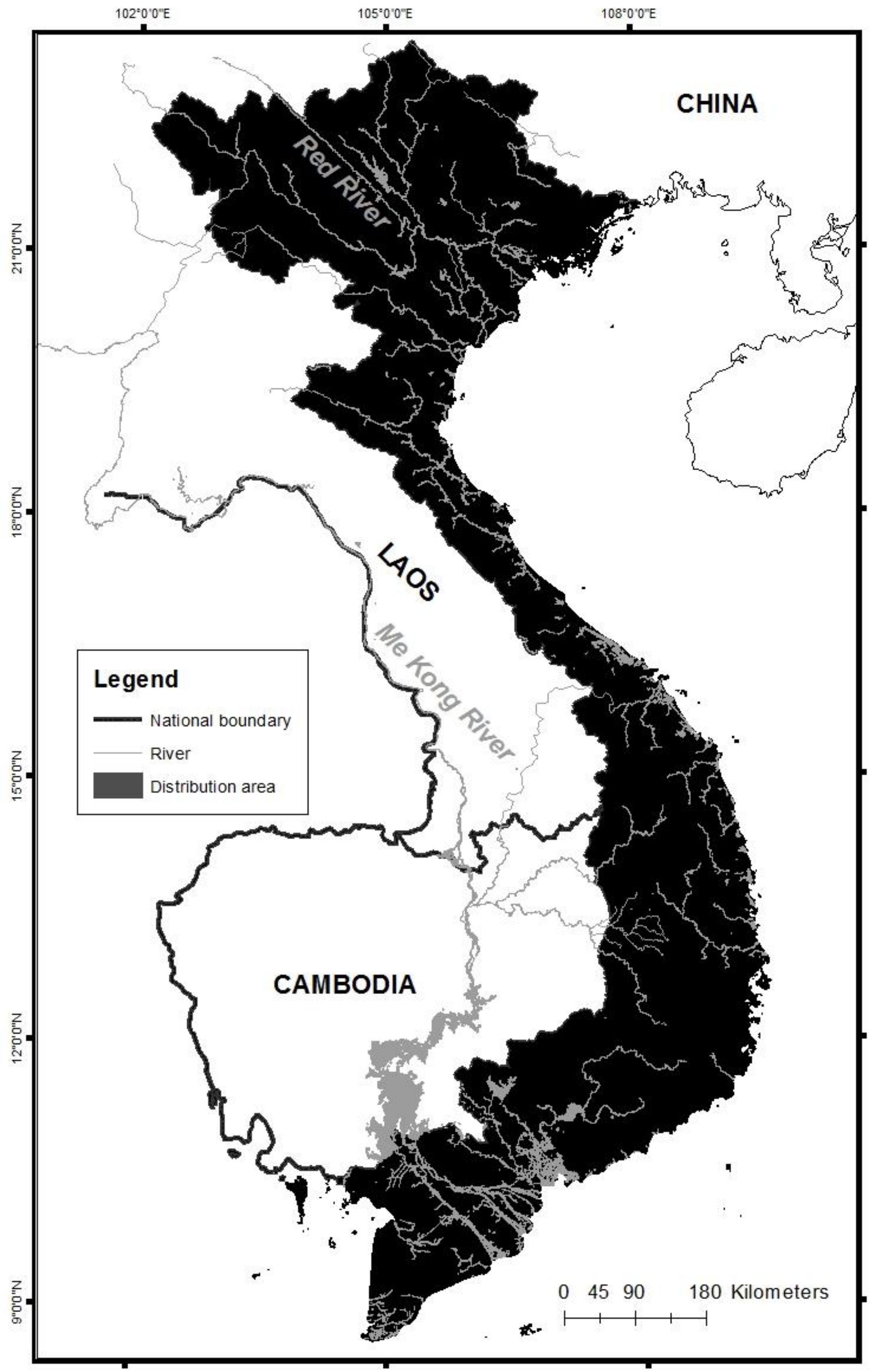
Scabies crispata (Gould, 1843)



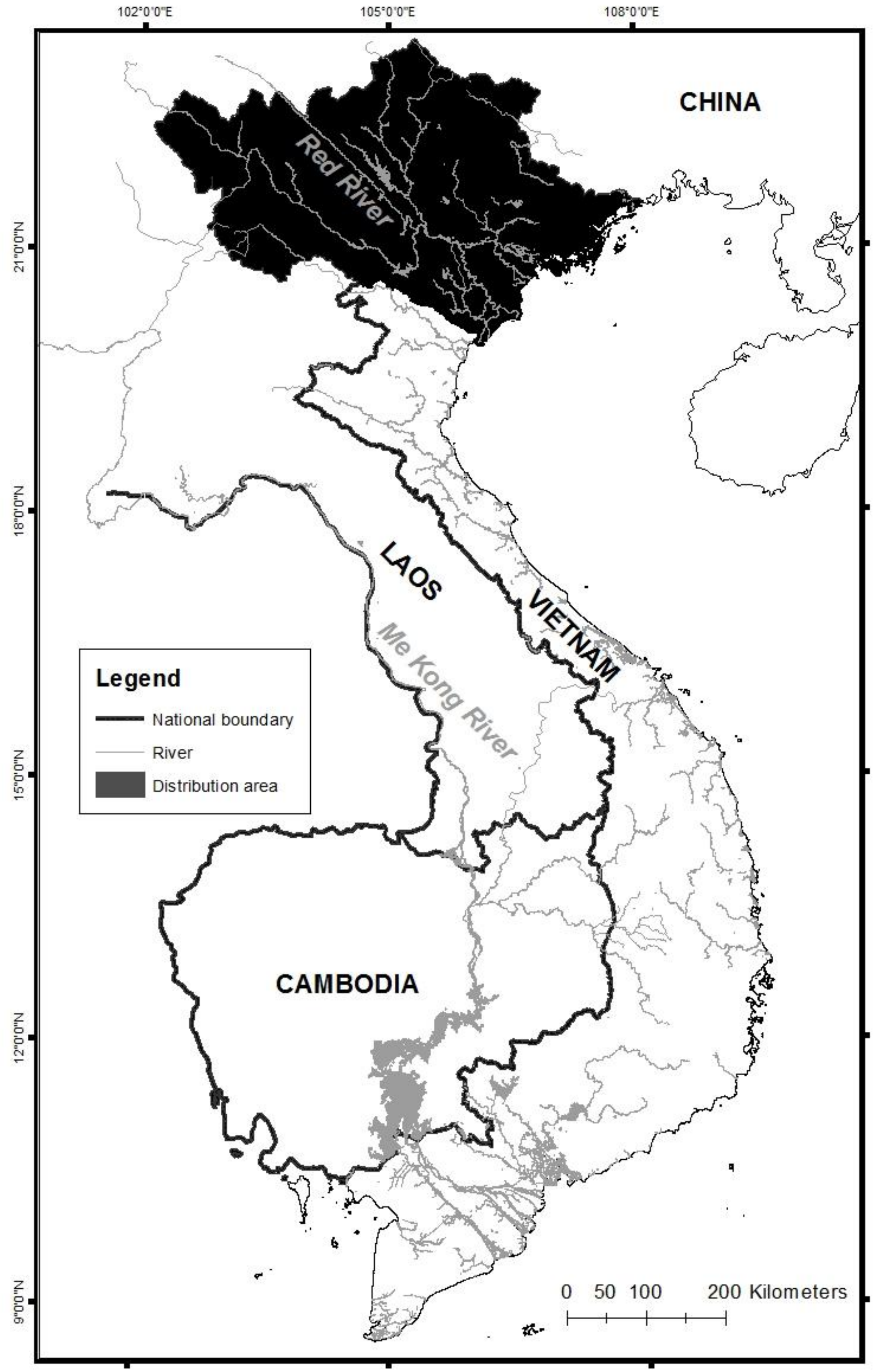
Sinanodonta hunganhi Thach, 2016



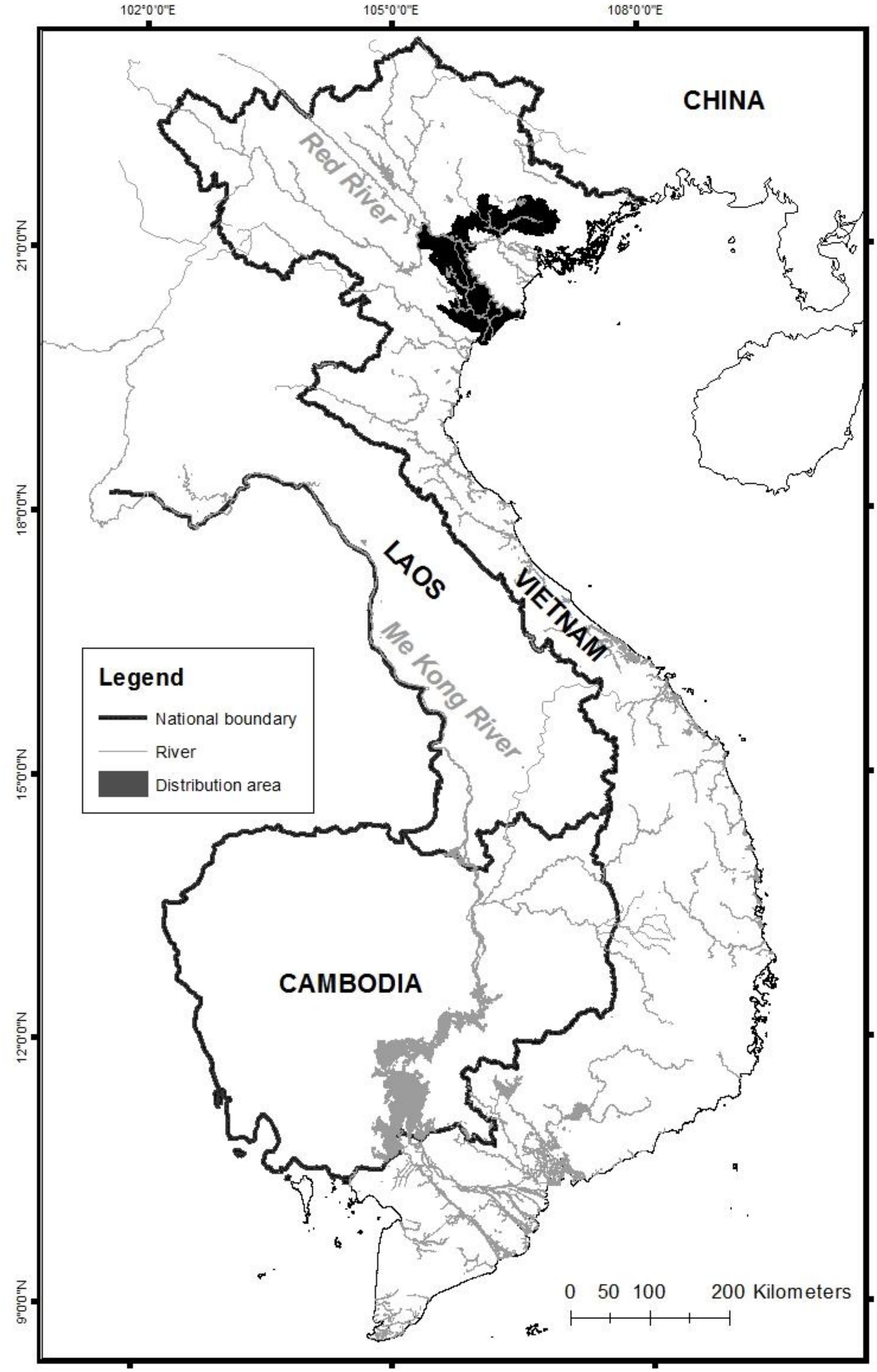
Sinanodonta jourdyi (Morlet, 1866)



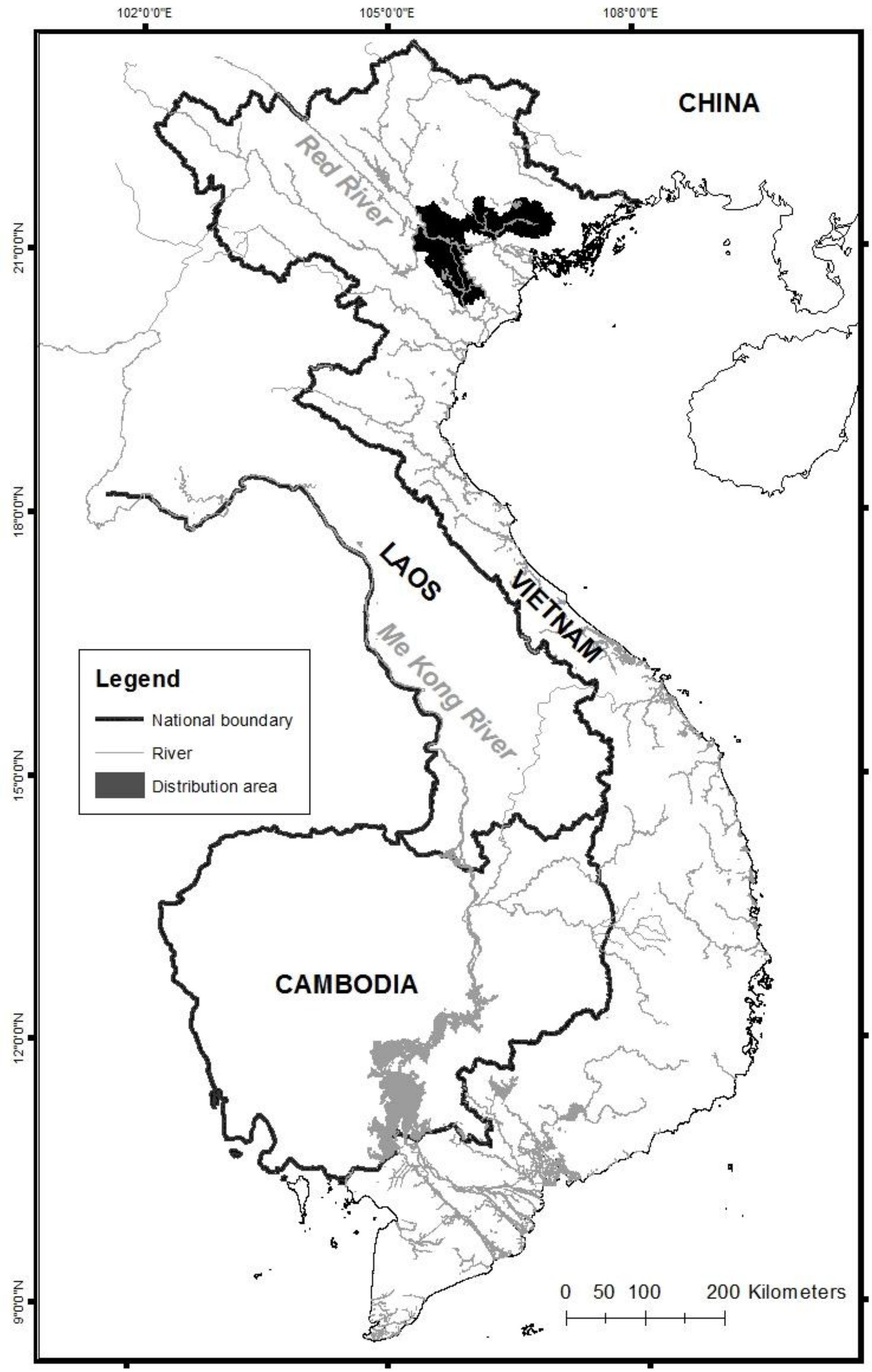
Sinanodonta lucida (Heude, 1878)



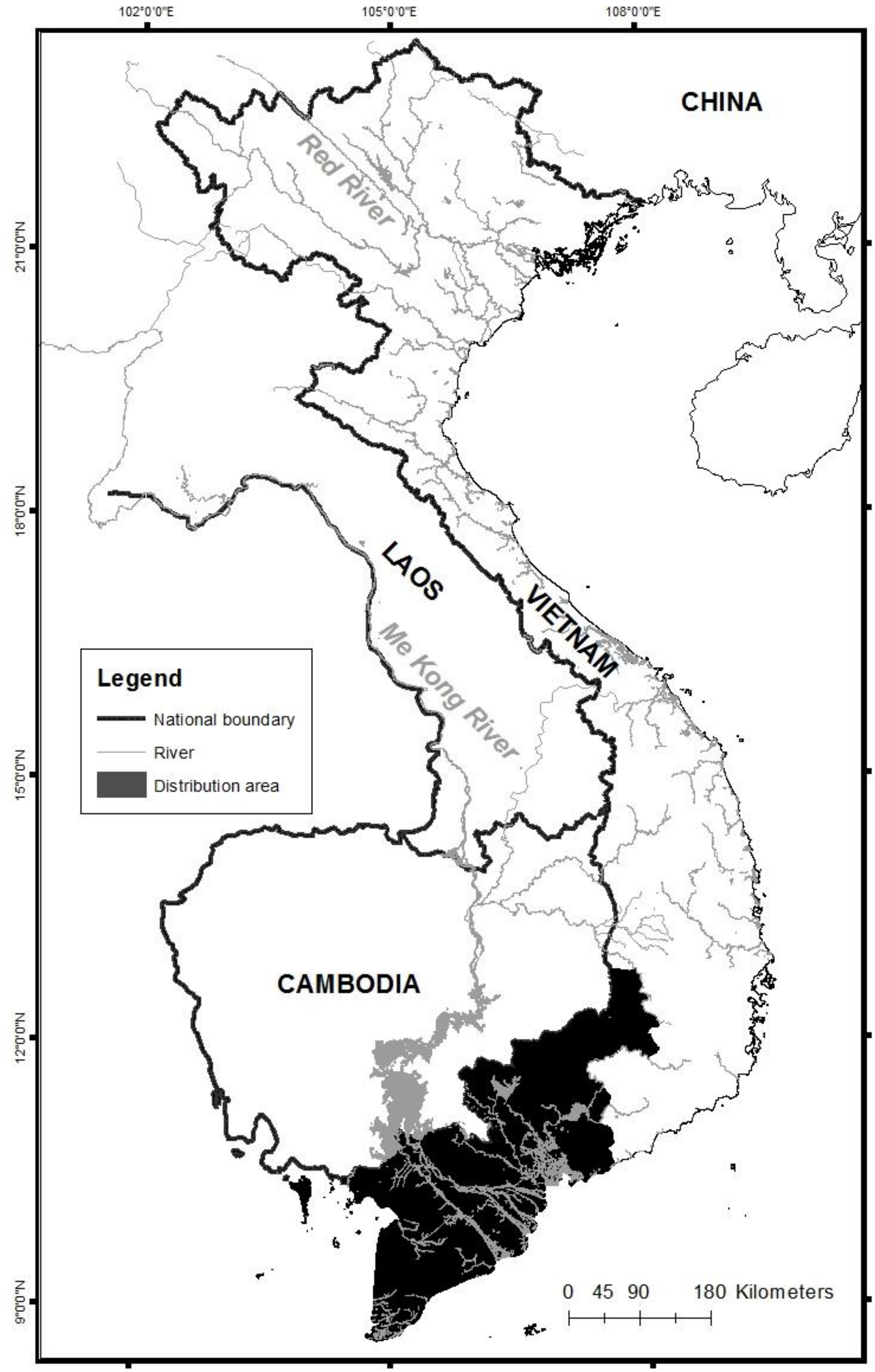
Sinohyriopsis cumingii (Lea, 1852)



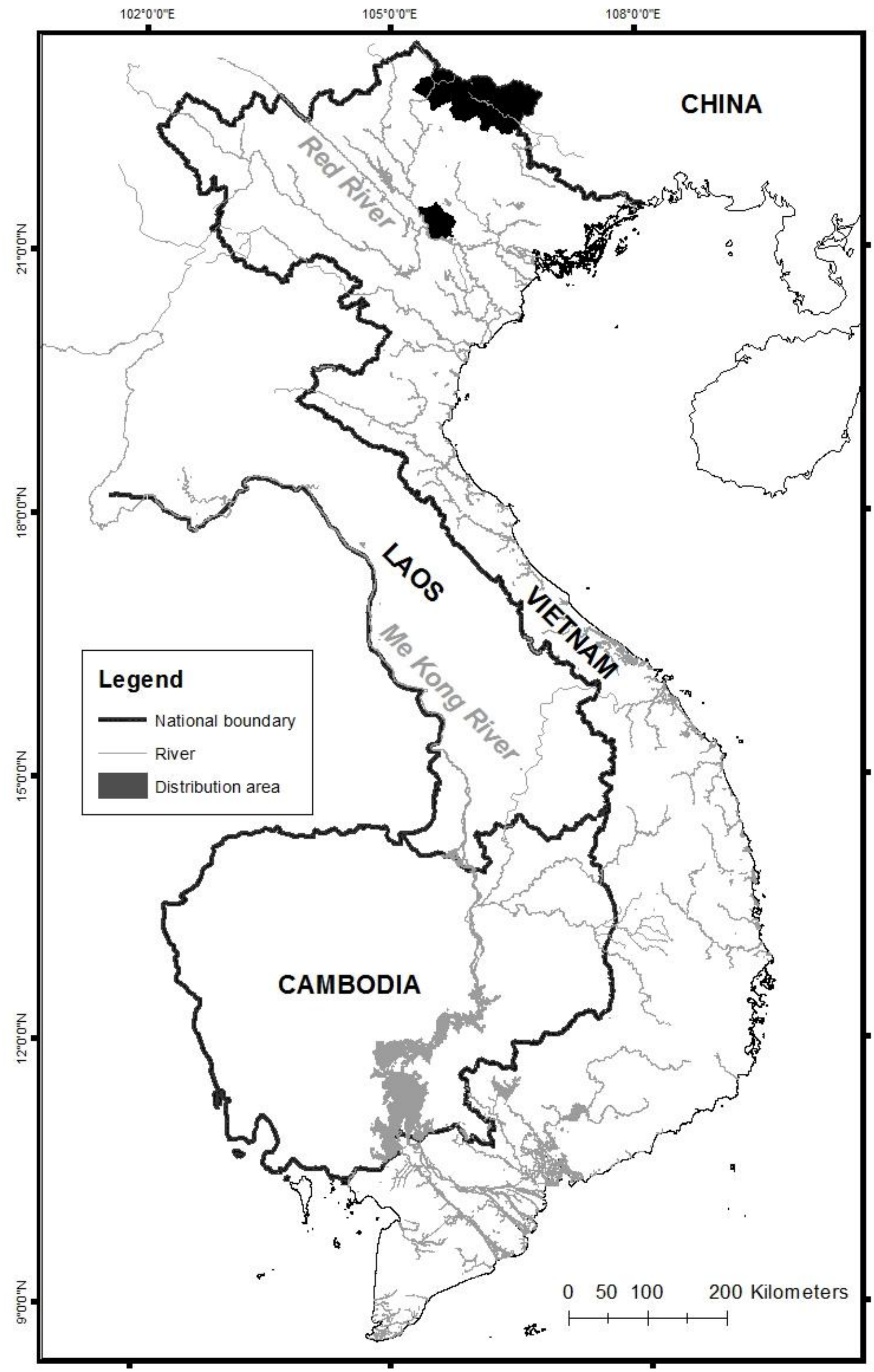
Solenaia oleivora (Heude, 1877)



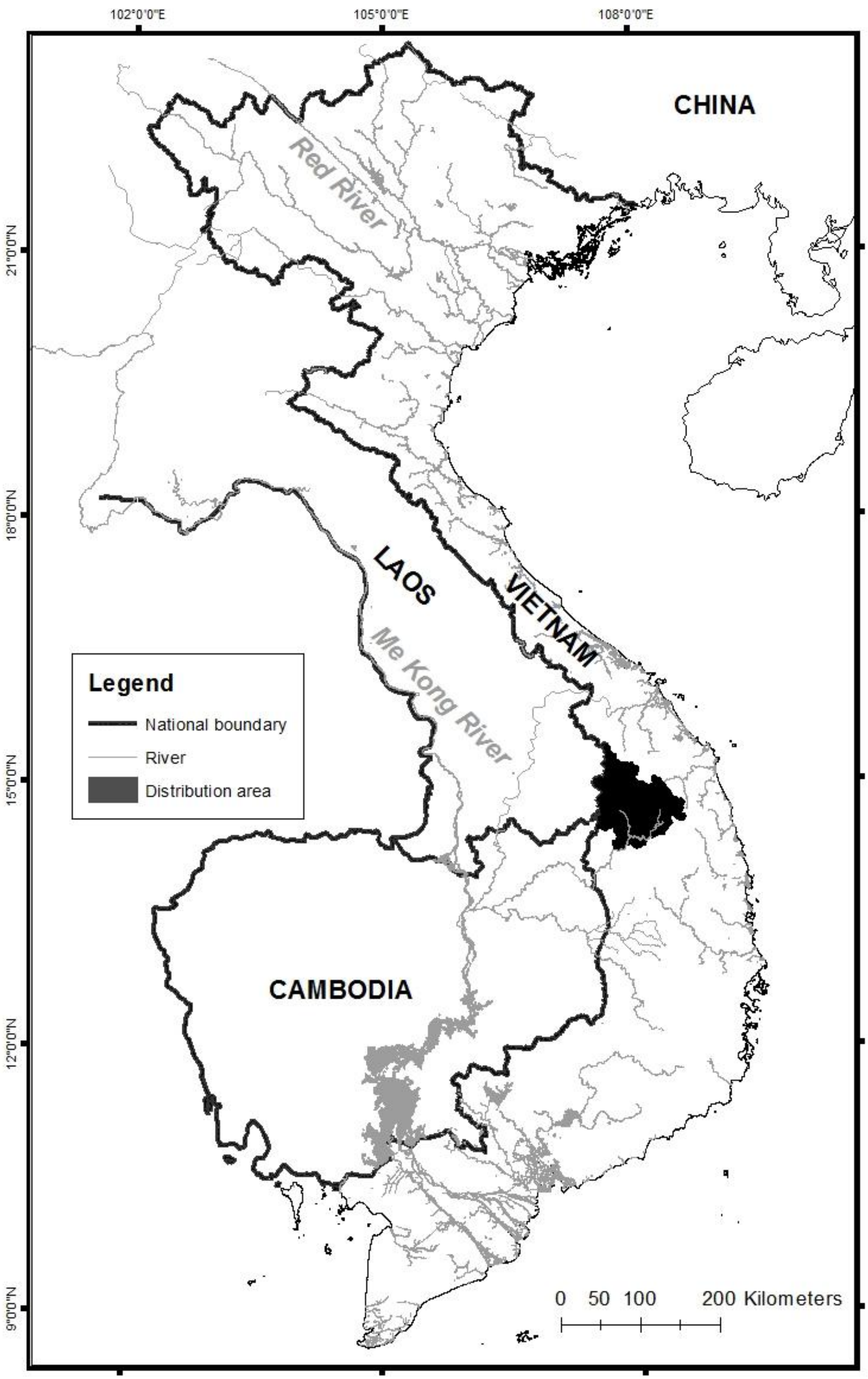
Trapezoideus exolescens (Gould, 1843)



Trapezoideus misellus (Morelet, 1865)



Unionetta fabagina (Deshayes in Deshayes & Julien, 1874)



Freshwater Mollusk Biology and Conservation 21:19–27, 2018

REGULAR ARTICLE

A SURVEY OF THE FRESHWATER MUSSELS (MOLLUSCA: BIVALVIA: UNIONIDA) OF THE NIANGUA RIVER BASIN, MISSOURI

Stephen E. McMurray*, Joshua T. Hundley[1], and J. Scott Faiman

Missouri Department of Conservation, Central Regional Office and Conservation Research Center, Columbia, MO 65201 USA

ABSTRACT

During 2007 and 2008, we surveyed freshwater mussels with timed searches at 35 sites in the Niangua River basin, an Osage River tributary in west-central Missouri. Our objective was to determine the distribution, species richness, and abundance of freshwater mussels in the basin. We observed a total of 714 live individuals from 20 species, including the Missouri endemic and species of conservation concern *Lampsilis brittsi*. The mean catch per unit effort (live mussels/person-hour) was 12 with values ranging from 0 to 144. *Eurynia dilatata* was the most abundant species (387 individuals observed, relative abundance = 54.2%), but all other species were present at much lower numbers. *Eurynia dilatata* and *Venustaconcha ellipsiformis* were the most commonly encountered species, both occurring at 24 sites. Our observation of 20 species is lower than historical richness in the basin (32 species), and nearly all species were formerly more widely distributed in the basin based on the occurrence of weathered and subfossil shells. Together with low catch per unit effort at most sites, these data suggest a sharp decline in mussel populations throughout the basin over the last few decades. This decline is cause for concern, but the causes are unknown.

KEY WORDS: freshwater mussel, Unionida, survey, Missouri

INTRODUCTION

The freshwater mussel fauna of Missouri is diverse but imperiled. Of the 69 species documented or reported from Missouri, 30 are Missouri species of conservation concern (SOCC), having state rankings of S1 (critically imperiled), S2 (imperiled), or S3 (vulnerable). Most of these SOCC are critically imperiled, and 15 are considered either state or federally endangered or threatened (McMurray et al. 2012; MDC 2018). Understanding the distribution, abundance, and diversity of mussels is crucial to the conservation of this ecologically important fauna (Haag and Williams 2014; FMCS 2016).

The Niangua River basin is part of the Upper Mississippi faunal province (Haag 2012). Thirty-two mussel species, including 5 Missouri SOCC and 1 federally and state endangered species (*Epioblasma triquetra*), are reported historically from the Niangua River basin (Table 1). *Cyprogenia aberti* is reported from the basin by 1 study (Schulz 2001), but its limited distribution in Missouri makes it likely that this record is erroneous (Oesch 1995; McMurray et al. 2012). The reports of *Ptychobranchus occidentalis* (Oesch 1995; Schulz 2001) are also doubtful based on its known distribution in Missouri (see also Hutson and Barnhart 2004).

Previous survey efforts in the Niangua River basin from 1915 to 2003 (Table 1) had limited geographic coverage, and the basin has never been systematically or quantitatively surveyed. Utterback (1915–1916) reported 3 species from a single location in the now impounded portion of the Niangua River in Lake of the Ozarks but did not report sampling effort or species abundances. Oesch (1995) reported 18 species from a 12 km reach of the Niangua River surveyed in 1969 and 10 species from a single location in the Little Niangua River surveyed in 1978 but did not describe sampling effort or report abundance or condition of the individuals collected. Addition-

[1]Current address: U.S. Fish and Wildlife Service, Missouri Ecological Services Field Office, Columbia, MO 65203

*Corresponding Author: Stephen.McMurray@mdc.mo.gov

Table 1. Freshwater mussel taxa reported from the Niangua River basin, Missouri.

Species	Utterback (1915–1916)	Oesch (1995)	Schulz (2001)	MDC (Unpubl. Data)	Present survey
Anodontini					
Alasmidonta marginata[A,B]		×	×		
Alasmidonta viridis[B]			×	×	
Lasmigona complanata		×	×	×	×
Lasmigona costata		×	×	×	×
Pyganodon grandis		×	×	×	×
Strophitus undulatus		×	×	×	
Utterbackiana suborbiculata[B]		×	×		
Amblemini					
Amblema plicata		×	×	×	×
Lampsilini					
Actinonaias ligamentina		×	×		×
Ellipsaria lineolata[A]				×	
Epioblasma triquetra[B]		×	×		
Lampsilis brittsi[B]	×	×	×	×	×
Lampsilis cardium		×	×	×	×
Lampsilis siliquoidea		×	×	×	×
Leptodea fragilis		×	×	×	×
Ligumia subrostrata		×	×		
Obliquaria reflexa		×	×	×	×
Potamilus alatus		×	×	×	×
Potamilus ohiensis		×	×		
Toxolasma parvum		×	×		
Truncilla donaciformis		×	×		×
Truncilla truncata		×	×	×	×
Venustaconcha ellipsiformis	×	×	×	×	×
Pleurobemini					
Eurynia dilatata	×	×	×	×	×
Fusconaia flava		×	×	×	×
Pleurobema sintoxia		×	×	×	×
Quadrulini					
Cyclonaias pustulosa		×	×	×	×
Cyclonaias tuberculata		×	×	×	×
Megalonaias nervosa		×	×		
Quadrula quadrula		×	×		
Theliderma metanevra			×		
Tritogonia verrucosa		×	×	×	×
Total native species[C]	3	29	31	21	20

[A]Only shells collected.
[B]Missouri species of conservation concern (MDC 2018).
[C]Excludes questionable taxa.

al species reported by Oesch (1995) were a summary of known collections. Schulz (2001) reported 31 species, but this was a summary of all available records in the basin, and specific collection information was not provided. Ecological Specialists, Inc. (2003) conducted surveys at 12 sites in the Little Niangua River in 2001 and reported 18 species but only 3 live individuals. Our objective was to document the current distribution, diversity, and abundance of mussels throughout the Niangua River basin.

METHODS

Study Area

The Niangua River is a sixth-order tributary of the Osage River, Missouri River basin, in west-central Missouri. The watershed is approximately 2,694 km^2, with the Little Niangua River draining approximately 829 km^2 (Schulz 2001; Sowa et al. 2007). The basin is located in the unglaciated Ozark Aquatic Subregion, which is characterized by older limestone bedrock and higher elevations than surrounding regions. Streams in the subregion tend to be spring influenced and cool and contain limited suspended solids (Sowa et al. 2007). The basin has a diverse fish fauna that includes the Missouri endemic *Percina cymatotaenia* and the endemic and federally threatened *Etheostoma nianguae* (Pflieger 1997; Schulz 2001).

The Niangua River flows north off the Springfield Plateau to its confluence with the Osage River (Fig. 1). The Little Niangua River flows north and east to its confluence with the Niangua River near river km 10. The lower 34 km of the Niangua River and the lower 16 km of the Little Niangua River are inundated by Lake of the Ozarks. Lake Niangua is an approximately 1.5 km^2 private hydropower reservoir that impounds approximately 3.7 km of the Niangua River. Springs are numerous in the basin, with 9 having a mean daily discharge > 0.03 m^3/s, including Bennett Spring (5.1 m^3/s) and Ha Ha Tonka Spring (1.4 m^3/s), the fourth and 12th largest springs, respectively, in Missouri (Schulz 2001). Water in the basin is generally well buffered due to the underlying limestone bedrock and influence of karst (Hauck and Nagel 2003; Owen and Pavlowsky 2011). Historically, the basin consisted of deciduous pine-oak and pine forests intermixed with glades, prairie, and savannah (Sowa et al. 2007). At present, savannahs are reduced in area and the basin is mainly in pasture, with mixed-hardwood forests confined to riparian areas and protected slopes (Nigh and Schroeder 2002).

Field Sampling and Data Analysis

We surveyed mussels with timed tactile or visual searches while wading or snorkeling at 35 sites in the Niangua and Little Niangua rivers in 2007 and 2008 (Fig. 1). Additional tributaries were not surveyed because they either were too small to support substantial mussel faunas or were intermittent. Surveys were conducted during low-flow conditions, usually in summer and autumn. We searched a mean of 1.25 person-hour (person-h)/site (range = 0.4–3.2). We searched all habitats at a site, and search time was roughly equivalent to the amount of available habitat; we searched additional time if live individuals were encountered. Visual and tactile searches tend to oversample large or sculptured individuals and undersample small or buried individuals, but these techniques maximize species richness (Strayer and Smith 2003). We chose survey sites based on the presence of suitable habitat (stable gravel or gravel-sand mixtures, bluff pools) or the presence of shell material on gravel bars and to provide relatively even spatial coverage throughout the basin. Survey sites encompassed approximately 143 km of the Niangua River and approximately 33 km of the Little Niangua River and included areas previously surveyed by Oesch (1995) and Ecological Specialists, Inc. (2003). Shell material was also collected and retained as voucher material in the Missouri Department of Conservation mollusk collection, Columbia. Shell material was classified as fresh dead (FD; intact periostracum and lustrous nacre), weathered dead (WD; intact periostracum but weathered, chalky nacre), or subfossil (SF; shell chalky with no periostracum) following Southwick and Loftus (2003). We made no attempt to quantify the abundance of shell material. Conservation status follows Williams et al. (1993) and MDC (2018); nomenclature follows Williams et al. (2017).

We determined species richness for each site in 2 ways: first, as the total number of species collected live and as FD shell material (Live + FD), and, second, as the total number of species collected live and shell material in any condition (Live + shell). We used the proportional difference in these 2 estimates [1 − (richness Live + FD/richness Live + shell)] to examine apparent recent changes in species richness. We computed relative abundance, catch per unit effort (CPUE, live mussels/person-h), and Shannon Diversity Index (SDI) from live collections only. We calculated SDI with the statistical package MVSP (Multi-Variate Statistical Package, ver. 3.12d, Kovach 1999). We used Mann-Whitney *U*-test in R (version 3.4.2, R Core Team 2017) to test for significant differences between species richness estimates, CPUE, and SDI values from the Little Niangua River and Niangua River.

RESULTS

A total of 714 live individuals representing 20 species were observed (Table 2). Live mussels were not found at 10 sites. Species richness based only on Live + FD shells averaged 2.8 species/site and ranged from 0 to 10. Mean CPUE across all sites was 12.0 live mussels/person-h and ranged from 0.0 to 144.0, but CPUE was > 25.0 live mussels/person-h at only 2 sites (Fig. 2). Site NR20 had the highest species richness (Live + FD) and CPUE. There were no obvious longitudinal patterns in species richness or CPUE (Fig. 2). Species richness and CPUE were highly variable among sites, and estimates of mean values were not significantly different between the Little Niangua River (mean richness/site = 1.9; mean CPUE/site = 1.8) and the Niangua River (mean richness/site = 3.1; mean CPUE/site = 14.9; richness: $U = 95.5$; CPUE: $U = 58.5$; both $P > 0.05$; Mann-Whitney *U*-test). Shannon Diversity Index values were low at all sites and were not significantly different between the Niangua River (mean SDI = 0.8) and Little Niangua River (mean SDI = 0.7; $U = 63$, $P > 0.05$; Mann-Whitney *U*-test).

In contrast to live mussels, shells were found at every site (Table 2) and were usually abundant. Species richness based on Live + shell averaged 6.2 species/site (range = 1–14). Live + shell richness was higher than Live + FD richness at 29 of 35 sites, and the 2 measures were equal at 6 sites; Live + FD richness was not greater than Live + shell richness at any site (Fig. 2). Species richness based on Live + shell was similar in the Little Niangua and Niangua rivers (6.0 and 6.3 species/site, respectively). The apparent proportional decline in species richness averaged 0.5 but was 1.0 at 7 sites and > 0.7 at 15 sites. The mean apparent proportional decline in species richness was 0.51 in the Niangua River and 0.68 in the Little Niangua River, and there was no significant difference between the rivers ($U = 135.5$, $P > 0.05$; Mann-Whitney *U*-test). The total number of occurrences in the basin was greater

Table 2. Results of mussel surveys in the Little Niangua River and Niangua River, Missouri. CPUE = catch per unit effort; SDI = Shannon Diversity Index. Numbers for each species represent the number of live individuals at a site; the presence of shell material is indicated as FD = Fresh Dead; WD = Weathered Dead; and SF = Subfossil. *Corbicula fluminea* presence noted as L (= Live) or shell material.

	Collecting Site														
	Little Niangua River								Niangua River						
Species	8	7	6	5	4	3	2	1	27	26	25	24	23	22	21
Lasmigona complanata								SF							
Lasmigona costata						1								5	
Pyganodon grandis															
Amblema plicata		1		WD	SF	1	SF	WD			WD				
Actinonaias ligamentina											WD			5	
Lampsilis cardium	1	SF	1		FD	13		SF			4	1	WD	4	WD
Lampsilis brittsi							SF		2	18	10	WD	WD	SF	
Lampsilis siliquoidea	1	WD	1	WD	SF	WD		SF					WD	WD	SF
Leptodea fragilis		WD													
Obliquaria reflexa		1													
Potamilus alatus		WD			WD			WD							
Truncilla donaciformis															
Truncilla truncata															
Venustaconcha ellipsiformis		WD	WD		WD	1		1		1	1	WD	WD	7	
Eurynia dilatata	SF		FD		WD			1		2	10	3	WD	189	8
Fusconaia flava	SF	WD			SF			SF			2	WD	WD	67	4
Pleurobema sintoxia		WD			WD		SF					WD			
Cyclonaias pustulosa															
Cyclonaias tuberculata			SF				SF	1						WD	WD
Tritogonia verrucosa							SF	SF						2	
Corbicula fluminea		L	L	L	L	L	L	L		L	L	FD	L	L	L
Species richness (live + shells, any condition)	4	9	5	2	8	5	5	10	1	3	7	7	6	10	5
Live species richness (live + FD shells)	2	2	3	0	1	4	0	3	1	3	5	2	0	7	2
Live total individuals	2	2	2	0	0	16	0	3	2	21	27	4	0	279	12
Person-hours	2.1	1.0	1.5	1.5	1.5	2.0	0.7	1.5	0.7	1.2	1.3	1	1.5	3.2	1.2
CPUE (mussels/person-h)	1.0	2.0	1.3	0.0	0.0	8.0	0.0	2.0	2.9	17.5	20.8	4.0	0.0	87.2	10.0
SDI	0.7	2.0	0.7			0.7		1.1	0.0	0.5	1.3	0.6		0.9	0.6

for Live + shell than Live + FD for all species except *Obliquaria reflexa* and *Truncilla donaciformis*, for which the 2 measures were equal, and the total number of occurrences overall was 2.4× greater for Live + shell (Table 3).

The live mussel fauna was dominated by *Eurynia dilatata*, which was found at 24 sites, with a mean CPUE of 8.7 live mussels/person-h, and representing 54.2% of live mussels (Table 3). *Fusconaia flava* was the second most abundant species (mean CPUE = 2.2 live mussels/person-h; relative abundance = 13.5%) and was observed at 21 sites. Along with *E. dilatata*, *Venustaconcha ellipsiformis* was the most widely distributed species, occurring at 24 sites, followed by *Lampsilis cardium* (22 sites) and *Lampsilis siliquoidea* (20 sites). Ten species had relative abundance values between 1.12 and 6.86%, and the remaining 8 species each had relative abundance values ≤ 0.84% (Table 3).

We observed no federal or state endangered or threatened species. One Missouri SOCC, *Lampsilis brittsi*, was observed live at 6 sites (mean CPUE = 1.1 live mussels/person-h), with shell material collected at 5 additional sites. The other SOCC previously reported from the basin were not observed. We did not count *Corbicula fluminea*, but it was abundant live at 24 sites throughout the basin; shell material was observed at 4 additional sites (Table 2). *Dreissena polymorpha* is reported from Lake of the Ozarks, including the downstream impounded reaches of the Niangua River (McMurray et al. 2012) but was not observed during this survey.

DISCUSSION

Historical species richness and faunal composition of the Niangua River basin are generally similar to other streams in

Table 2, extended.

Collecting Site																			
Niangua River																			
20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
																1			WD
1				SF		1													WD
							WD								3	1			WD
				WD	SF										WD	2	6	2	WD
8	5	SF	1	WD	WD	3	WD			WD			WD					WD	WD
4			1	WD	WD	1						SF	WD		WD		1	1	WD
				SF				1		11		7							
3	SF		WD	WD	WD	2	WD									2	2	1	
																7	13		WD
																4	2	1	FD
	SF			SF												4	6	FD	WD
																FD	1		
																4	2	FD	WD
8	1	1	1	SF	1		WD		WD	2	SF		WD	2	WD			SF	
165	1	1	WD	FD	2	4	WD		WD				WD	SF	WD			1	WD
16	1	WD	WD	WD	WD	6	WD			SF			WD		WD		SF		
5						1							WD				SF		WD
																	2	SF	
4			WD	WD													WD		WD
2	1	1		SF															WD
L	L	L	L		L	L	FD	WD	L	L		L	WD	L	L			L	
10	7	5	7	12	7	7	6	1	2	5	1	2	6	2	6	9	12	10	14
10	5	3	3	1	2	7	0	1	0	2	0	1	0	1	1	9	9	7	1
216	9	3	3	0	3	18	0	1	0	13	0	7	0	2	3	25	35	6	0
1.5	0.5	0.4	0.6	1.5	1.3	1.0	1.3	1	1.0	1.0	1.5	1.0	1.0	0.8	1.3	1.5	1.5	1.5	0.8
144.0	18.0	7.5	5.0	0.0	2.3	18.0	0.0	1.0	0.0	13.0	0.0	7.0	0.0	2.5	2.3	16.7	23.3	4.0	0.0
1.0	1.3	1.1	1.1		0.6	1.7		0.0		0.4		0.0		0.0	0.0	1.9	1.8	1.6	

the region. Excluding reported species of doubtful occurrence (see Introduction), the Niangua River basin had a historical mussel fauna of at least 32 species, which is similar to the Pomme de Terre (32 species), Sac (34 species), Marais des Cygnes (40 species), and lower Osage (33 species) rivers (Ecological Specialists, Inc. 2003; Hutson and Barnhart 2004; Angelo et al. 2009). However, we found only 20 live species.

Our survey results suggest a major recent decline in species richness throughout the Niangua River basin. Most species were represented only as WD or SF at many more sites than they were found Live + FD, indicating that they were previously more widely distributed throughout the basin. We do not know the time of death for WD and SF shells and cannot pinpoint when the decline began. Due to the well-buffered water in the Niangua River basin, we would expect shell material to persist on the order of decades, especially for species with thicker shells (Warren and Haag 2005; Strayer and Malcom 2007). We also cannot account for nondetection of live individuals at sites where a species was present only as WD or SF shells (Strayer and Smith 2003). Nevertheless, the consistently higher richness estimates including WD and SF shells at most sites suggests a severe decline in basin-wide richness.

There are few historical survey data from specific sites, but comparison of existing data with ours also supports a recent decline. Oesch (1995) reported 18 species in a 12 km reach of the Niangua River surveyed in 1969 that coincided with 2 of our survey sites (NR8 and NR9; Fig. 1). We observed only 3 species in that same reach, and only 1 was represented by live individuals (*L. brittsi*). Oesch (1995) reported 10 species, including *E. triquetra*, from a single site in the Little Niangua River (our site LN3) in 1978. Ecological Specialists, Inc.

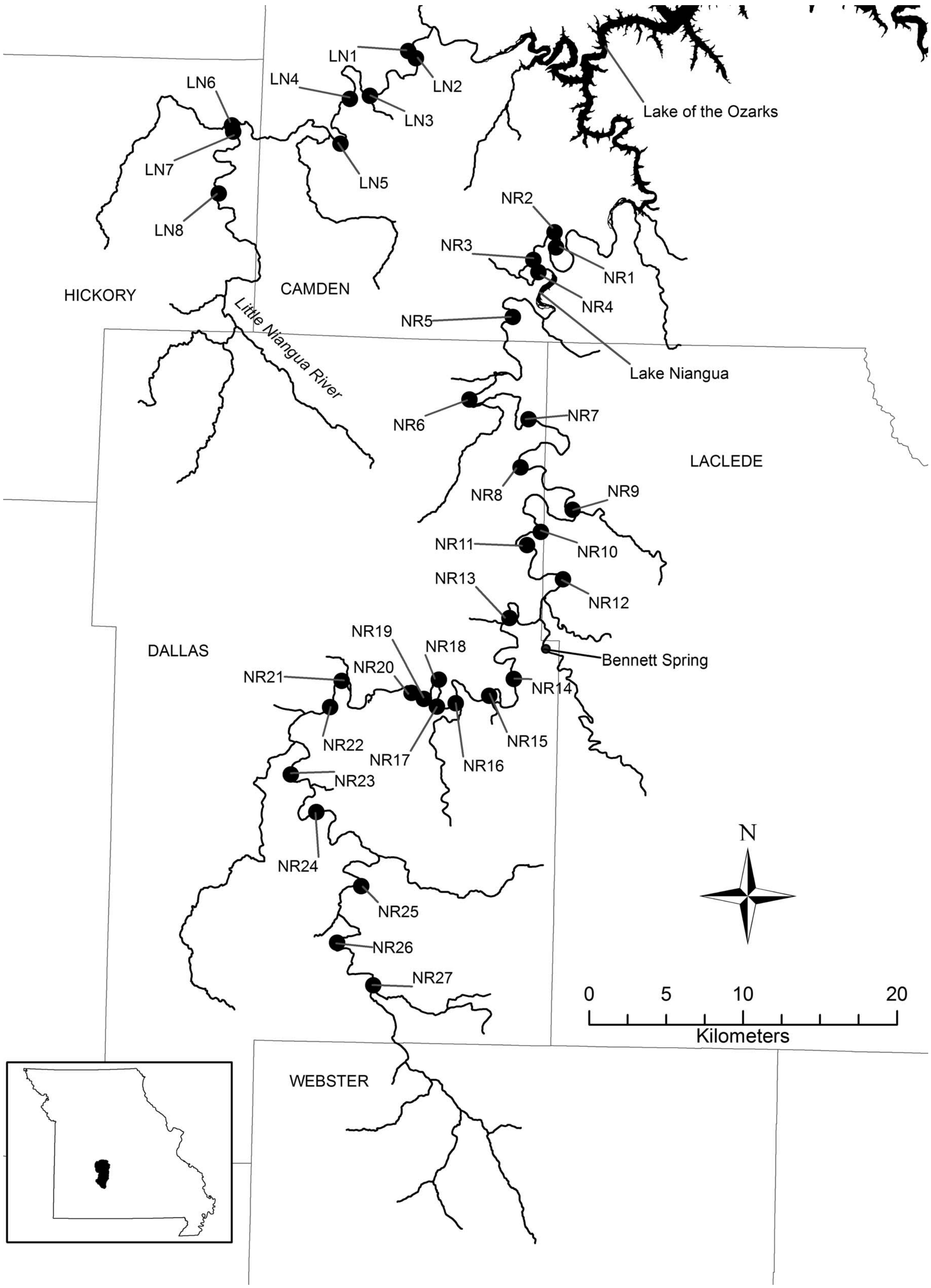


Figure 1. Niangua River Basin freshwater mussel collection sites (2007–2008). Inset shows the location of the basin in Missouri.

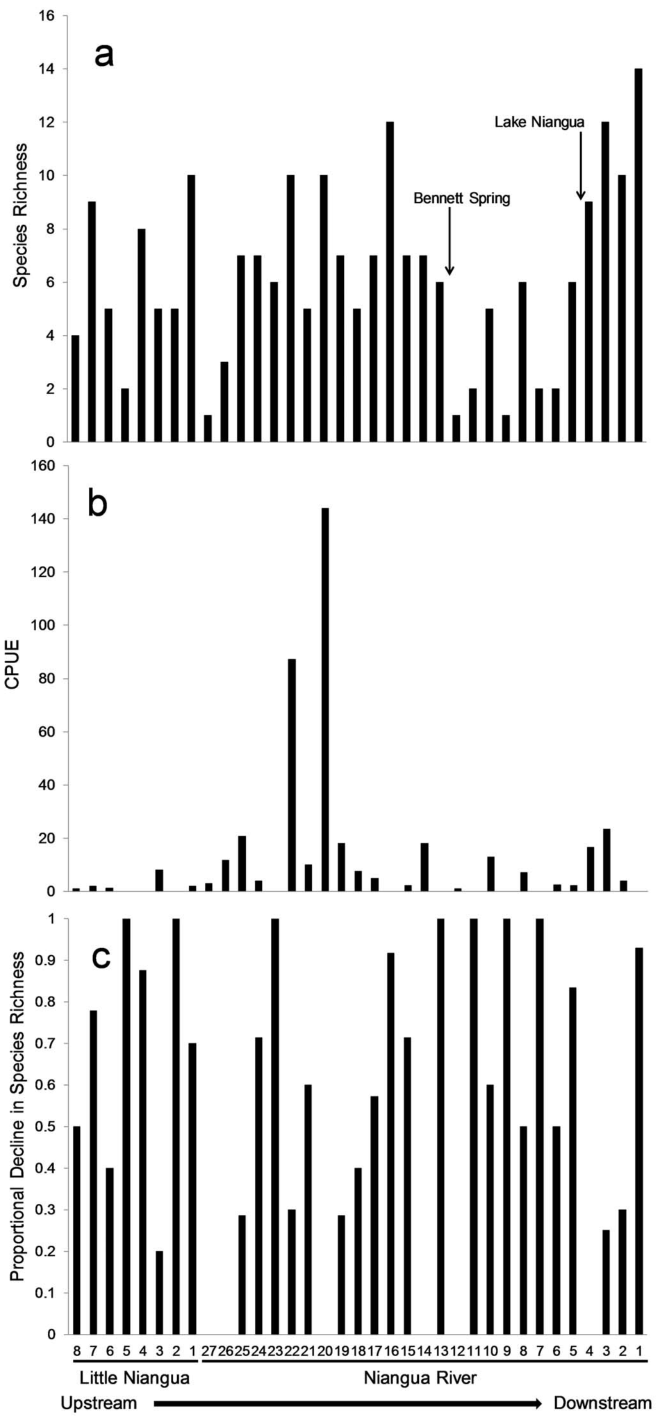


Figure 2. (a) Species richness (Live + shells), (b) catch per unit effort (CPUE, live mussels/person-h), and (c) apparent proportional decline in species richness at 35 sites in the Niangua River basin, Missouri, 2007–2008.

(2003) reported only 3 species (*Cyclonaias tuberculata*, *L. cardium*, and *L. siliquoidea*) as FD shell from that same site, and we observed only 4 live species and 1 species represented only by WD shell. No historical estimates of mussel abundance in the basin are available. However, our estimate of basin-wide mean CPUE (12.0 live mussels/person-h) was considerably lower than that reported from 2 other Osage River basin tributaries (Sac and Pomme de Terre rivers, 89.1 live mussels/person-h; Hutson and Barnhart 2004).

Table 3. Total number collected live, number of occurrences (live [L] + fresh dead [FD], and L + shells, any condition), and relative abundance of live freshwater mussels collected in the Niangua River basin, Missouri.

Species	No. Collected Live	No. Occurrences		Relative Abundance (%)
		L + FD	L + Shell	
Eurynia dilatata	387	14	24	54.20
Fusconaia flava	96	6	21	13.45
Lampsilis brittsi	49	6	11	6.86
Lampsilis cardium	32	12	22	4.48
Venustaconcha ellipsiformis	27	12	24	3.78
Actinonaias ligamentina	22	5	14	3.08
Leptodea fragilis	20	2	4	2.80
Amblema plicata	12	5	14	1.68
Lampsilis siliquoidea	12	7	20	1.68
Potamilus alatus	10	3	9	1.40
Lasmigona costata	8	4	6	1.12
Obliquaria reflexa	8	5	5	1.12
Pleurobema sintoxia	6	2	9	0.84
Tritogonia verrucosa	6	4	8	0.84
Truncilla truncata	6	3	4	0.84
Cyclonaias tuberculata	5	2	10	0.70
Pyganodon grandis	4	2	4	0.56
Cyclonaias pustulosa	2	1	2	0.28
Lasmigona complanata	1	1	3	0.14
Truncilla donaciformis	1	2	2	0.14

Apart from localized effects of hydropower operations and impoundment, several potential threats are present throughout the watershed (e.g., point source discharges, nonpoint source pollution, gravel mining), but the role of most of these factors in mussel declines is unknown (Schulz 2001; Haag 2012; Haag and Williams 2014), and we have no data on the distribution and magnitude of these potential threats. Lake Niangua could pose a barrier to *Aplodinotus grunniens* movement, the sole known host for *Leptodea fragilis* and *Potamilus alatus*, which could explain the apparent absence of these species upstream of the lake (Haag 2012; Sietman et al. 2018). However, reasons for the apparent assemblage-wide mussel decline throughout the Niangua River basin are unknown.

The Niangua River Basin has a growing threat from *D. polymorpha*, which is well established in Lake of the Ozarks, including the impounded portion of the lower Niangua River (McMurray et al. 2012). With boat traffic upstream to Lake Niangua, there will likely be further infestation of the lower Niangua River. *Corbicula fluminea* can pose a threat to native freshwater mussels in the basin through displacement or competition for juvenile habitat or by producing lethal concentrations of NH_3 during large die-offs (Yeager et al. 2000; Cherry et al. 2005; Cooper et al. 2005), but the importance of this threat is unknown.

Of the 12 previously reported species that we did not observe, some may survive in the Niangua River basin. *Alasmidonta marginata*, *Ellipsaria lineolata*, *Quadrula quadrula*, and *Theliderma metanevra* were reported within the last 10–40 years in the Niangua basin (Oesch 1995; Schulz 2001; MDC unpubl. data) and persist in other Osage River tributaries (Angelo et al. 2009; McMurray et al. 2012). Oesch (1995) reported *Utterbackiana suborbiculata*, *Potamilus ohiensis*, and *Toxolasma parvum* from an impounded portion of the Niangua River (Lake of the Ozarks); we did not survey impounded areas, but these adaptable, widespread species probably continue to occur in impounded portions of the basin. *Alasmidonta viridis*, *Strophitus undulatus*, *Ligumia subrostrata*, *E. triquetra*, and *Megalonaias nervosa* are reported from the basin only prior to 1980 (Oesch 1995; Butler 2007; McMurray 2015) and may be extirpated. With the exception of impoundment-tolerant species, other surviving species are rare in the basin, and most species we detected appeared to be present only as small populations. Our data provide a baseline for future monitoring and investigations of the cause of mussel declines in the Niangua River.

ACKNOWLEDGMENTS

Previously unpublished MDC data were collected by A. Buchanan, T. Grace, G. Stoner, and L. Trial. G. Stoner (MDC) assisted with survey efforts. K. Bataille, C. Fuller, and D. Novinger (MDC), R. McMurray, and B. Simmons (USFWS) provided helpful comments on this and an earlier version of this manuscript. We are grateful to W. R. Haag and 2 anonymous reviewers for their comments and improvement of this manuscript. This survey was funded by the Missouri Department of Conservation, and shell voucher material has been deposited in the Missouri Department of Conservation reference collection.

LITERATURE CITED

Angelo, R. T., M. S. Cringan, E. Hays, C. A. Goodrich, E. J. Miller, M. A. VanScoyoc, and B. R. Simmons. 2009. Historical changes in the occurrence and distribution of freshwater mussels in Kansas. Great Plains Research 19:89–126.

Butler, R. S. 2007. Status assessment report for the snuffbox, *Epioblasma triquetra*, a freshwater mussel occurring in the Mississippi River and Great Lakes basins. U.S. Fish and Wildlife Service, Asheville, NC.

Cherry, D. S., J. L. Scheller, N. L. Cooper, and J. R. Bidwell. 2005. Potential effects of Asian clam (*Corbicula fluminea*) die-offs on native freshwater mussels (Unionidae) I: water-column ammonia levels and ammonia toxicity. Journal of the North American Benthological Society 24:369–380.

Cooper, N. L., J. D. Bidwell, and D. S. Cherry. 2005. Potential effects of Asian clam (*Corbicula fluminea*) die-offs on native freshwater mussels (Unionidae) II: porewater ammonia. Journal of the North American Benthological Society 24:381–394.

Ecological Specialists, Inc. 2003. Osage hydroelectric project (FERC No. 459): naiad population assessment. AmerenUE, St. Louis, Missouri.

FMCS (Freshwater Mollusk Conservation Society). 2016. A national strategy for the conservation of native freshwater mollusks. Freshwater Mollusk Biology and Conservation 19:1–21.

Haag, W. R. 2012. North American Freshwater Mussels: Natural History, Ecology, and Conservation. Cambridge University Press, New York.

Haag, W. R., and J. D. Williams. 2014. Biodiversity on the brink: an assessment of conservation strategies for North American freshwater mussels. Hydrobiologia 735:45–60.

Hauck, H. S., and C. D. Nagel. 2003. Water resources data: Missouri water year 2002. Water-Data Report MO-02-1. U.S. Geological Survey, Rolla, MO. Available at https://pubs.usgs.gov/wdr/WDR-MO-02/pdf/wdrmo02.pdf (accessed March 7, 2018).

Hutson, C., and M. C. Barnhart. 2004. Survey of endangered and special concern mussel species in the Sac, Pomme de Terre, St. Francis, and Black River systems of Missouri, 2001–2003. Missouri State University, Springfield.

Kovach, W. L. 1999. MVSP—a multivariate statistical package for Windows, ver. 3.1. Kovach Computing Services, Pentraeth, Wales, U.K.

McMurray, S. E. 2015. Status assessments of *Cumberlandia monodonta*, *Alasmidonta viridis*, *Simpsonaias ambigua*, *Lampsilis rafinesqueana*, and *Quadrula cylindrica cylindrica* in Missouri. Missouri Department of Conservation, Columbia.

McMurray, S. E., J. S. Faiman, A. D. Roberts, B. Simmons, and M. C. Barnhart. 2012. A guide to Missouri's freshwater mussels. Missouri Department of Conservation, Jefferson City.

MDC (Missouri Department of Conservation). 2018. Missouri species and communities of conservation concern checklist. Missouri Department of Conservation, Natural Heritage Program, Jefferson City. Available at https://nature.mdc.mo.gov/sites/default/files/downloads/2018_SOCC.pdf (accessed February 2, 2018).

Nigh, T. A., and W. A. Schroeder. 2002. Atlas of Missouri ecoregions. Missouri Department of Conservation, Jefferson City.

Oesch, R. D. 1995. Missouri naiades: a guide to the mussels of Missouri. Missouri Department of Conservation, Jefferson City.

Owen, M. R., and R. T. Pavlowsky. 2011. Base flow hydrology and water quality of an Ozarks spring and associated recharge area, southern Missouri, USA. Environmental Earth Sciences 64:169–183.

Pflieger, W. L. 1997. The fishes of Missouri. Missouri Department of Conservation, Jefferson City.

R Core Team. 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at www.R-project.org/.

Schulz, R. G. 2001. Niangua River watershed inventory and assessment. Missouri Department of Conservation, Camdenton. Available at https://mdc.mo.gov/sites/default/files/watersheds/NianguaRiverWatershed270.pdf (accessed February 2, 2018).

Sietman, B. E., M. C. Hove, and J. M. Davis. 2018. Host attraction, brooding phenology, and host specialization on freshwater drum by 4 freshwater mussel species. Freshwater Science 37. doi: 10.1086/696382

Southwick, R. I., and A. J. Loftus, editors. 2003. Investigation and monetary values of fish and freshwater mussel kills. Special Publication 30. American Fisheries Society, Bethesda, MD.

Sowa, S. P., G. Annis, M. E. Morey, and D. D. Diamond. 2007. A GAP analysis and comprehensive conservation strategy for riverine ecosystems of Missouri. Ecological Monographs 77:301–334.

Strayer, D. L., and H. M. Malcom. 2007. Shell decay rates of native and alien freshwater bivalves and implications for habitat engineering. Freshwater Biology 52:1611–1617.

Strayer, D. L., and D. R. Smith. 2003. A guide to sampling freshwater mussel populations. Monograph 8. American Fisheries Society, Bethesda, MD.

Utterback, W. I. 1915–1916. The naiades of Missouri. American Midland

Naturalist 4:41–53; 4:97–152; 4:181–204; 4:244–273; 4:311–327; 4:339–354; 4:432–464.

Warren, M. L., Jr., and W. R. Haag. 2005. Spatio-temporal patterns of the decline of freshwater mussels in the Little South Fork Cumberland River, USA. Biodiversity and Conservation 14:1383–1400.

Williams, J. D., A. E. Bogan, R. S. Butler, K. S. Cummings, J. T. Garner, J. L. Harris, N. A. Johnson, and G. T. Watters. 2017. A revised list of the freshwater mussels (Mollusca: Bivalvia: Unionida) of the United States and Canada. Freshwater Mollusk Biology and Conservation 20:33–58.

Williams, J. D., M. L. Warren Jr., K. S. Cummings, J. L. Harris, and R. J. Neves. 1993. Conservation status of freshwater mussels of the United States and Canada. Fisheries 18:6–22.

Yeager, M. M., R. J. Neves, and D. S. Cherry. 2000. Competitive interactions between early life stages of *Villosa iris* (Bivalvia: Unionidae) and adult Asian clams (*Corbicula fluminea*). Pages 253–259 *in* R. A. Tankersley, D. I. Warmolts, G. T. Watters, B. J. Armitage, P. D. Johnson, and R. S. Butler, editors. Freshwater mollusk symposia proceedings. Proceedings of the First Freshwater Mollusk Conservation Society Symposium, March 1999, Chattanooga, Tennessee. Ohio Biological Survey, Columbus.

Freshwater Mollusk Biology and Conservation

ISSN 2472-2944