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REGULAR ARTICLE

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

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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,

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

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

⁶Misplaced species, belongs in *Contradens*.

⁷Incorrect spelling of *Pseudodon mouhotii*

⁸Correct 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 km² (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.

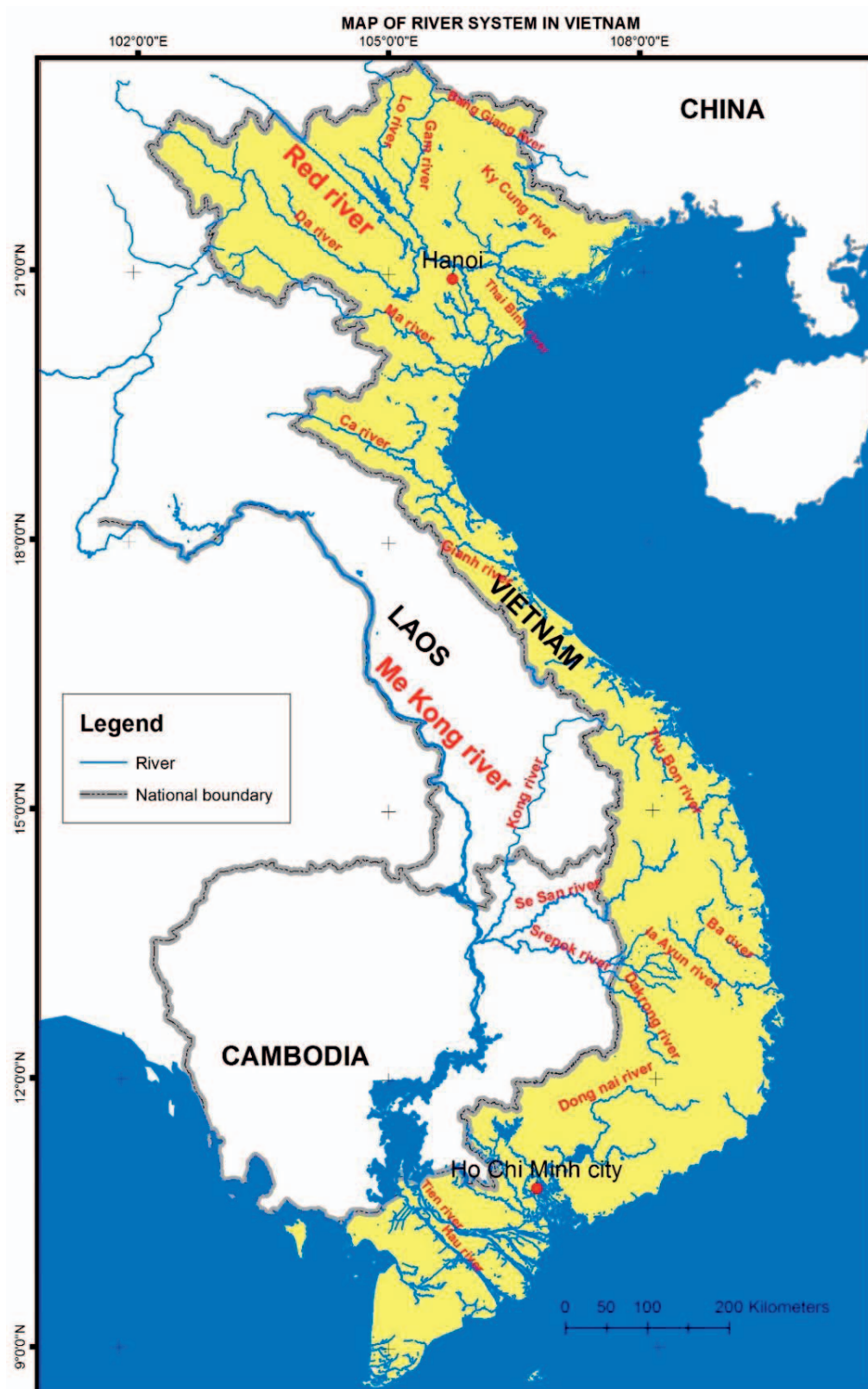


Figure 1. Map of the major rivers of Vietnam.

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 pisciculus (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 aurea 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	
<i>Aculamprotula nodulosa</i> (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 <i>Lamprotula nodulosa</i>)	
<i>Chamberlainia hainesiana</i> (Lea, 1856)	DD	V	Northeast (Phu Tho, Lo River in Tuyen Quang)	
<i>Contradens contradens</i> (Lea, 1838)	LC		Mekong River delta (An Giang, Long An) IUCN listed as <i>Uniandra contradens</i>	
<i>Contradens fultoni</i> Haas, 1939 *	DD	R	Northeast (Mau Son in Lang Son) (IUCN Listed as <i>Uniandra semmelincki</i>)	
<i>Cristaria plicata</i> (Leach, 1815)	DD	V	Northeast, Northwest, Red River delta	
<i>Cristaria truncata</i> Đặng, 1980	EN		Northeast (Cao Bang, Bac Giang), Red River delta (Hai Duong, Ha Nam, Ninh Binh, Nam Dinh)	
<i>Cuneopsis demangei</i> Haas, 1929	CR	K-indeterminate	Northeast (Da River in Phu Tho)	
<i>Diawora aureora</i> (Heude, 1883)	DD		Northeast (?)	
<i>Ensidens ingallsianus</i> (Lea, 1852)	LC		Central Highlands, South Central Coast, Southeast, Mekong River delta	
<i>Gibbosula crassa</i> (Wood, 1815)	CR	R	Northeast (Bang Giang River in Cao Bang, Ky Cung River in Lang Son) (IUCN listed as <i>Lamprotula crassa</i>)	
<i>Harmandia somborensis</i> (Rochebrune, 1882)	DD		Southeast, Mekong River delta	
<i>Hyriopsis gracilis</i> Haas, 1910	LC		Southeast, Mekong River delta	
<i>Hyriopsis delaporteii</i> (Crosse & Fischer, 1876)	LC		Mekong River delta (An Giang)	
<i>Lamprotula bazini</i> (Heude, 1877)	DD		Northeast (Ha Noi)	
<i>Lamprotula blaisei</i> (Dautzenberg & Fischer, 1905)*	VU	R	Northeast (Cao Bang, Lang Son, Bac Giang)	
<i>Lamprotula contritus</i> (Heude, 1881)	EN		Northeast (Cao Bang, Bac Kan, Thai Thuyen)	
<i>Lamprotula lei</i> (Gray in Griffith & Pidgeon, 1833)	LC	V	Northeast	
<i>Lamprotula quadrangulosa</i> (Heude, 1881)	LC		Northeast (Bang Giang River) (IUCN treated as synonym of <i>L. lei</i> not listed)	
<i>Lamprotula salaputium</i> (Martens, 1902)*	DD		Northeast (Tuyen Quang)	
<i>Lanceolaria bilirata</i> (Martens, 1902)*	CR		Northeast (Cao Bang, Lang Son)	
<i>Lanceolaria bogani</i> Thach, 2016*	NE		North Central Coast (Thua Thien Hue)	
<i>Lanceolaria fruhstorferi</i> (Bavay & Dautzenberg, 1901)*	NE	R	Northeast (Cao Bang, Lang Son) (IUCN lists as synonym of <i>Lanceolaria grayana</i>)	
<i>Lanceolaria gladiola</i> (Heude, 1877)	LC		Northeast, Northwest, Red River delta	
<i>Lanceolaria grayi</i> (Gray in Griffith & Pidgeon, 1833)	DD		Northeast, Northwest, Red River delta	
<i>Lanceolaria laevis</i> (Martens, 1902)*	NE		Northeast (Cong River in Thai Nguyen)	
<i>Margaritifera laosensis</i> (Lea, 1863)	EN		Northwest (Dien Bien Phu)	
<i>Nodularia dorri</i> (Wattebled, 1886)*	LC		Northeast, Northwest, Red River delta	
<i>Nodularia douglasiae</i> (Gray, 1833)	LC		Northeast, Northwest, Red River delta	
<i>Nodularia nuxpersica</i> (Dunker, 1848)	NE		Northeast (IUCN listed as <i>Unio douglasiae</i>)	
<i>Oxyaia diespiter</i> (Mabille, 1887)*	EN		Northeast (Bac Kan, Thai Nguyen)	
<i>Oxyaia gladiator</i> (Ancey, 1881)*	DD		Northeast	
<i>Oxyaia jourdyi</i> (Morlet, 1886)*	NT		Northeast (Ha Noi, Vinh Phu, Phu Tho, Hoa Binh)	
<i>Oxyaia micheloti</i> (Morlet, 1886)*	EN		Northeast (Cao Bang, Phu Tho, Vinh Phuc)	
<i>Physunio cambodiensis</i> (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
<i>Physunio micropterus</i> (Morelet, 1866)	LC		Central Highlands (Dak Bla River tributary of Se San River in Kon Tum), Southeast (Dong Nai), Mekong River delta
<i>Physunio modelli</i> Brandt, 1974	LC		South Central Coast (Binh Thuan)
<i>Physunio superbus</i> (Lea, 1843)	LC		Mekong River delta (Can Tho)
<i>Pilsbryoconcha compressa</i> (Martens, 1860)	LC		Southeast, Mekong River delta (IUCN listed as synonym of <i>P. exilis</i>)
<i>Pilsbryoconcha exilis</i> (Lea, 1839)	LC		South Central Coast (Ninh Thuan), Southeast, Mekong River delta (Can Tho)
<i>Pilsbryoconcha lemeslei</i> (Morelet, 1875)	LC		Central Highlands (Dak Bla River tributary of Se San River in Kon Tum, Khanh Hoa)
<i>Pletholophus</i> sp.*	NE		Northeast, Red River delta
<i>Pletholophus tenuis</i> (Gray in Griffith & Pidgeon, 1833)	LC		Throughout the country (IUCN listed as <i>Cristaria tenuis</i>)
<i>Protunio messageri</i> (Bavay & Dautzenberg, 1901)*	EN		Northeast (Bang Giang River in Cao Bang)
<i>Pseudobaphia</i> sp.	NE	R	Northeast (Bang Giang River in Cao Bang)
<i>Pseudodon cambodjensis</i> (Petit, 1865)	DD		Southeast, Mekong River delta
<i>Pseudodon inoscularis</i> (Gould, 1844)	LC		Southeast (Dong Nai), Mekong River delta
<i>Pseudodon mouhotii</i> (Lea, 1863)	LC		Southeast, Mekong River delta
<i>Pseudodon resupinatus</i> Martens, 1902*	EN		Northeast (Vinh Phuc, Lang Son)
<i>Pseudodon vondembuschianus</i> (Lea, 1840)	LC		Southeast, Mekong River delta
<i>Ptychorhynchus pfisteri</i> (Heude, 1874)	NT		Northeast (Vinh Phuc, Phu Tho), Northwest (Hoa Binh)
<i>Scabies crispata</i> (Gould, 1843)	LC		Northwest (Hoa Binh), Mekong River delta (An Giang)
<i>Sinanodonta hunganhi</i> Thach, 2016*	NE		North, Nghe An Province
<i>Sinanodonta jourdyi</i> (Morlet, 1866)*	NE		Northeast, Northwest, Red River delta
<i>Sinanodonta lucida</i> (Heude, 1878)	NE		Northeast, Northwest, Red River delta
<i>Sinohyriopsis cumingii</i> (Lea, 1852)	LC	V	Northeast (Bac Giang, Ha Noi, Ha Nam, Nam Dinh, Ninh Binh) (IUCN listed as <i>Cristaria cumingii</i>)
<i>Solenia oleivora</i> (Heude, 1877)	NE		Northeast (Phan River in Vinh Phuc, Day River in Ha Noi and Ha Nam, Thuong River in Bac Giang)
<i>Trapezoideus exolezens</i> (Gould, 1843)	LC		Southeast, Mekong River delta
<i>Trapezoideus misellus</i> (Morelet, 1865)	DD		Northeast (Bang Giang River in Cao Bang, Vinh Phuc)
<i>Unionetta fabagina</i> (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 somborensis has been reported from the Mekong and Mun rivers, but not mentioned as occurring in Vietnam (Brandt 1974). Pfeiffer (personal communication) found 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 Malacca” (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 Malacca 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 delaporteii 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 similis* (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.

Pilsbryconcha compressa was recognized as a subspecies

of *Pilsbryconcha 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).

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

Pilsbryconcha 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).

Pilsbryconcha suilla von Martens, 1902 was not originally figured and was placed in the genus *Pilsbryconcha* by Simpson (1914). Simpson remarked that Martens thought this species reminded him of *Pilsbryconcha*. Đặng et al. (1980) used the combination *Pilsbryconcha 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 messengeri* 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 messengeri 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 messengeri* 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, Nghệ 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 lineage within the *S. woodiana* complex. This taxonomic puzzle will require further analyses to resolve this group.

Solenia 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 *Solenia 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. excolescens* 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 Tum 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) *Solenia 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 km². 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 km². 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 km². This species assessed only on data from northern Vietnam.

- (4) *Conradens 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 km². 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*, *Conradens 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.

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



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



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

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 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.

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