MALACOLOGICAL INVESTIGATION OF THE FULLY OPERATIONAL NAM THEUN 2 HYDROELECTRIC DAM PROJECT IN KHAMMOUANE PROVINCE, CENTRAL LAO PDR

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Abstract. We conducted a malacological investigation in four districts of the Nam Theun 2 (NT2) hydroelectric dam project area, Khammouane Province, central Lao PDR (Nakai, Gnommalath, Mahaxai and Xe Bang Fai), after the first and second years of full operation in March 2010 and November 2011 to determine health risks for humans. A total 10,863 snail specimens (10 families/23 species) from 57 sampling stations and 12,902 snail specimens (eight families/21 species) from 66 sampling stations were collected in 2010 and 2011, respectively. *Neotricula aperta* (gamma race), the intermediate host for *Schistosoma mekongi*, was found in large numbers (5,853 specimens) in 2010 in Nam Gnom (downstream) at Station 25 (Mueang Gnommalath: Gnommalath District) and in fewer numbers (170 specimens) at Station 26 (Ban Thathod: Gnommalath District). In 2011, significantly fewer numbers (434 specimens) of *N.aperta* were found at Station 25. No snails were found to be infected with *S. mekongi*; however, 3.6% and 0.45% of *Bithynia* (*D.*) *s. goniomphalos* specimens collected were found to be infected with *Opisthorchis viverrini* (human liver fluke) during 2010 and 2011, respectively. *Pomacea canaliculata*, the rice crop pest, the intermediate host of *Angiostrongylus* (*Parastrongylus*) *cantonensis*, was found in the greatest numbers during 2010 and 2011; the prevalence increased significantly from 1.3% in 2010 to 53.3% in 2011. We also found seasonal variation in snail populations in terms of abundance and diversity. The snail fauna and risk for transmission of parasitic diseases need to be monitored continuously to evaluate the long-term impact of the dam project.

Keywords: malacological investigation, hydroelectric dam, *Neotricula aperta*, *Bithynia* (*D.*) *s. goniomphalos*, *Pomacea canaliculata,* Lao PDR

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INTRODUCTION

The Nam Theun 2 (NT2) hydroelectric power project is located on the Nam Theun River, a tributary of the Mekong River, in Khammouane Province, central Lao PDR. Dam construction began in 2005 and was completed in 2009. The reservoir was filled by 2008, and the 1,070-megawatt trans-basin hydroelectric power station commenced electricity production in 2009. The 39 meter high dam has caused a 450-km^2 reservoir containing $3,910 \times 10^6$ m^3 of water. A tunnel transfers water to the powerhouse, 350 meters below the reservoir surface level. There is a regulating pond below the power station and a 27 kilometer long channel from the regulating pond to the Xe Bang Fai River, a tributary of the Mekong River (World Bank, 2004).

Dam projects can dramatically changes riverine environments, resulting in an increase in mollusk populations (Attwood, 1999), some of which may be carriers of human parasitic helminths. Abdel-Wahab *et al* (1979) reported an increase in the prevalence of *Schistosoma mansoni* after construction of the Aswan Dam in Egypt. Possible transmission of *S. japonicum* in areas newly affected by construction of the Three Gorges Dam on the Yangtze River in China has also been reported (McManus *et al*, 2010).

The increase in snail intermediate host populations associated with dams is a concern for disease transmission and important scientifically for the diversity and number of mollusk species. Babko and Kuzmina (2009) found loss of protected mollusk species was an important effect of damming the Dnieper River basin in the Ukraine.

At our study site in Lao PDR, a preliminary malacological investigation was conducted in 1996 prior to the dam being built (Lohachit, 1996). That investigation revealed the dam site was rich in freshwater mollusks. Twenty-six species of freshwater gastropods and bivalves were found; their distribution and abundance recorded (Lohachit, 1996). *Neotricula aperta* (gamma race), an intermediate host for schistosomiasis with normal or reduced pigmentation, was first found in two habitats (Nam Gnom of Ban Thathod and Mueang Gnommalath) downstream to the project site (Lohachit, 1996). Attwood and Upatham (1999) confirmed the findings of Lohachit (1996) and reported high laboratory infection rates with *S. mekongi* (33%) in the *N. aperta* from Xe Bang Fai River, Khammouane Province, central Lao PDR. Attwood and Upatham (1999) suggested that the increase in snail numbers could be related to environmental changes brought about by the dam projects in central Lao PDR.

It is important that during hydroelectric power projects that malacological investigation be conducted to identify snail species, population densities and determine the presence of human parasites of major importance. The aim of this study was to survey the freshwater mollusk population for snail-mediated disease in the vicinity of the NT2 hydroelectric dam project, Khammouane Province, central Lao PDR, during the early operational phases in 2010 and 2011.

MATERIALS AND METHODS

Study area

Sampling was carried out in four districts of the NT2 hydroelectric dam project area, Khammouane Province, central Lao PDR: Nakai (NK), Gnommalath (GL), Mahaxai (MX) and Xe Bang Fai (XF) Districts with 57 sampling stations in March 2010 and 66 sampling stations in November 2011. The 66 stations sampled in 2011 included the 57 stations from the March 2010 survey along with 9 sites. The sampling stations were located at the watershed, reservoir, resettlement and downstream sectors of the NT2 dam project. Watershed areas in the Nakai Nam Theun National Protected Area (NPA) were: Nam Xot (3), Nam Theun (9), and Nam Noy (3). The reservoir area encompassed 15 stations along the littoral zone of the NT2 reservoir in the NK District. The resettlement area had 15 sampling stations in 15 villages in the NK district. The downstream areas in 2010 consisted of 12 sampling stations: six in GL and six in MX. In 2011, four new samplings stations were added at GL, one at MX and four at XF (Fig 1).

Mollusk collection methods

A scoop net was used to collect snails living among the roots of trees along the banks, on submerged and floating aquatic plants, in leaf litter and in pebbles, sand, clay, silt and humus. Larger snails were picked up by hand, especially those living on the upper or lateral surfaces of boulders and rocky outcrops and on the under-surfaces of solid substances, such as stones, twigs, tree bark and household debris. In very turbid water, the scoop net was more efficient than hand-picking. In temporary habitats, where desiccation had occurred, soil was excavated, sieved through a series of screens and carefully examined for aestivating snails.

Screening snails for infection in the field laboratory

Each evening after collection, snails of medical importance were examined in a field laboratory by the shedding method for parasitic infections (Sri-aroon *et al*, 2005). In brief, 5 to 10 snails of medical importance were placed in small plastic vials, which were half-filled with dechlorinated tap water and exposed to a 60-Watt light for 2 hours. The snails were then examined under a stereomicroscope for the emergence of cercariae. If no cercariae were found, the snails were left overnight and then re-examined the next morning. If cercariae were found in any of the vials, they were placed individually in separate vials to ascertain the cercaria type and prevalence of infection isolated from the snails.

Snail identification

All snails were transported to the laboratory in Bangkok, numbered and identified to family, genus and species, if possible, using morphological characteristics with the aid of the identification keys of Temcharoen (1971), Brandt (1974), Upatham *et al* (1983), Keawjam (1987) and Chitramvong (1992) and compared with the snail collections in the Mollusk Museum of the Department of Social and Environmental Medicine, Faculty of Tropical Medicine, Mahidol University. Voucher specimens were also deposited in this museum.

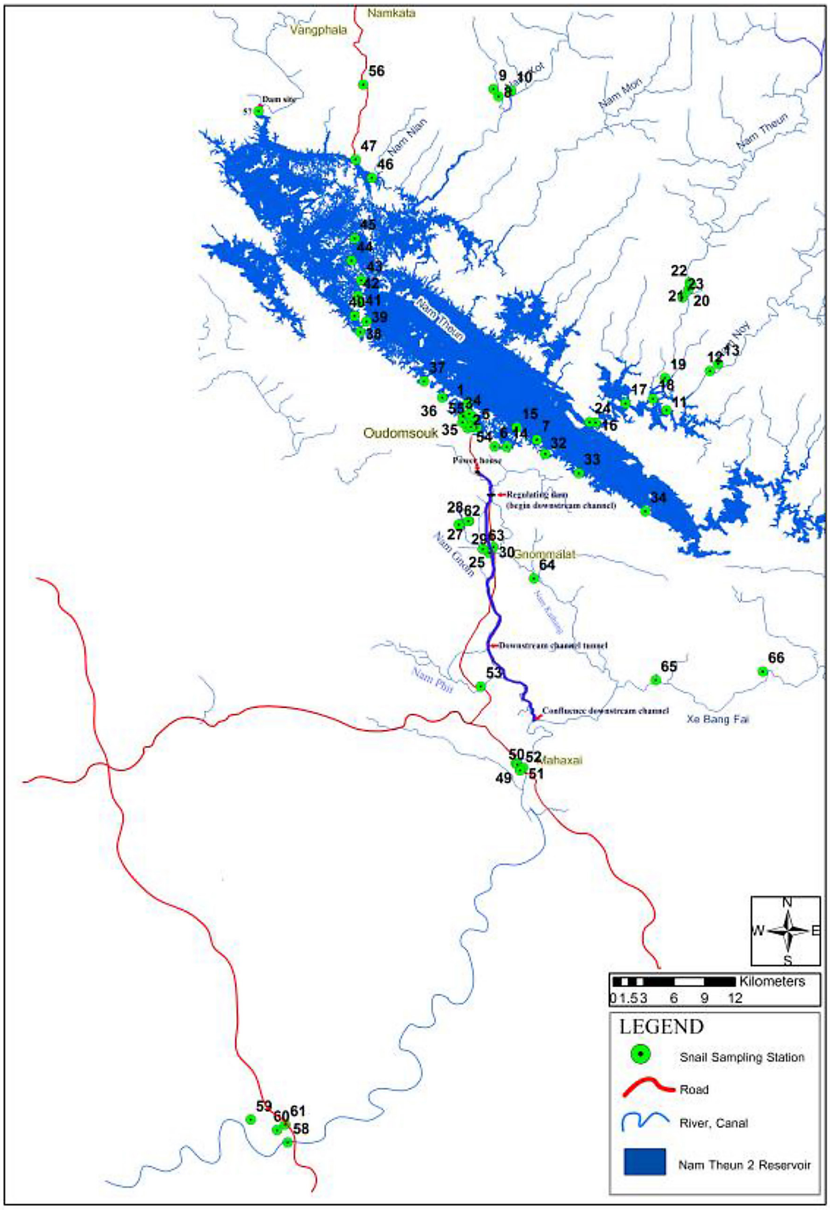
Snails of medical importance were identified according to Brandt (1974), Burch and Lohachit (1983), Tropmed Technical Group (1986), Burch and Upatham (1989) and Sri-aroon (2010).

Abiotic factors of snail habitats in the NT2 project area

At each sampling stations, air and water temperatures were monitored as an indicator of snail habitat and distribution. Physical and ecological characteristics were also recorded to identify snail habitats at the NT2 site.

RESULTS

A total 10,863 specimens from 10 families and 23 species, and 12,324 from nine families and 21 species of live freshwater snails (Table 1) were collected from 57 stations (Station Nos. 1-57 in Fig 1) in 2010 and 2011, respectively. An additional nine stations were sampled in 2011 (Station



Area	District	Sector	No. of stations	Station nos.
Watershed	Nakai	Nam Xot	3	8, 9, 10
		Nam Noy	3	11, 12, 13
		Nam Theun	9	16, 17, 18, 19, 20, 21, 22, 23, 24
Reservoirs	Nakai		15	1, 2, 3, 4, 5, 6, 14, 31, 44, 45, 46, 47, 54, 55, 57
Resettlements	Nakai		15	7, 15, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 56
Downstream	Gnommalath	Nam Gnom	6	25, 26, 27, 28, 29, 30
		Nam Katang	3	62, 63, 64
		Xe Bang Fai	1	66
	Mahaxai	Xe Bang Fai	7	48, 49, 50, 51, 52, 53, 65
	Xe Bang Fai	Xe Bang Fai	4	58, 59, 60, 61

Fig 1–Map of the 66 snail-sampling stations in the NT2 hydroelectric dam project area.

Table 1
The gastropoda collected by study year at the 57 original sampling stations.

Gastropoda	2010 March			2011 November		
	Total individuals	Abundance[a] %	Total frequency	Total individuals	Abundance[a] %	Total frequency
Ampullariidae						
Pomacea canaliculata	143	1.3	38	6,568	53.3	37
Bithyniidae						
Bithynia (D.) s. goniomphalos	1,086	10.0	5	1,152	9.3	6
Wattebledia crosseana	104	1.0	4	265	2.1	4
Buccinidae						
Clea helena	2	0.02	2	2	0.02	1
Viviparidae						
Sinotaia mandahlbarthi	531	4.9	32	46	0.4	8
Filopaludina (F.) zilchi	60	0.5	7	262	2.1	15
Filopaludina (S.) m. martensi	52	0.5	5	96	0.8	9
Filopaludina (S.) m. munensis	11	0.1	4	2	0.02	1
Idiopoma umbilicata	262	2.4	18	95	0.8	9
Idiopoma dissimilis	2	0.02	1	-	-	-
Idiopoma ingallsiana	-	-	-	130	1.0	15
Pachychilidae						
Sulcospira dakrongensis	28	0.3	1	-	-	-
Stenothyridae						
Stenothyra spp	133	1.2	1	19	0.1	1
Pomatiopsidae						
Neotricula aperta	6,287	57.9	2	170	1.4	1
Lacunopsis conica	1,087	10.0	2	17	0.1	2
Halewisia expansa	-	-	-	7	0.1	1
Thiaridae						
Melanoides tuberculata	128	1.2	3	177	1.4	3
Tarebia granifera	30	0.3	1	30	0.2	2
Thiara scabra	14	0.1	1	2	0.02	1
Planorbidae						
Indoplanorbis exustus	528	4.9	26	763	6.2	31
Gyraulus convexiusculus	11	0.1	2	77	0.6	15
Polypylis hemisphaerula	1	0.01	1	1	0.01	1
Trochotaia trochoides	1	0.01	1	-	-	-
Camptoceras jiraponi	2	0.02	1	-	-	-
Lymnaeidae						
Radix rubiginosa	360	3.3	16	2,443	19.9	23
Total	10,863	100		12,324	100	

[a]Abundance was calculated from total number of live snails (10,863 in 2010; 12,324 in 2011).

Table 2
Gastropoda collected at the 9 sampling stations added for the November 2011 survey.

Gastropoda	Total	%	Frequency
Bithyniidae			
Bithynia (D.) s. goniomphalos	83	14.4	3
Wattebledia crosseana	3	0.5	1
Buccinidae			
Clea helena	21	3.6	3
Viviparidae			
Filopaludina (S.) m. martensi	11	1.9	1
Pomatiopsidae			
Lacunopsis coronata	11	1.9	2
Lacunopsis conica	8	1.4	2
Halewisia expansa	1	0.2	1
Pachydrobia prasongi	107	18.5	2
Stenothyridae			
Stenothyra sp	18	3.1	3
Thiaridae			
Melanoides tuberculata	187	32.3	5
Tarebia granifera	114	19.7	4
Thiara scabra	9	1.6	4
Planorbidae			
Indoplanorbis exustus	1	0.2	1
Gyraulus convexiusculus	4	0.7	1
Total	578	100	

Table 3
Snails of medical importance detected during the study and their potential diseases.

Gastropoda	Potential disease
Neotricula aperta (gamma race)	Schistosomiasis (*Schistosoma mekongi*)
Bithynia (D.) s. goniomphalos	Opisthorchiasis, echinostomiasis
Indoplanorbis exustus	Cercarial dermatitis, echinostomiasis
Radix rubiginosa	Cercarial dermatitis, echinostomiasis, fascioliasis
Polypylis hemisphaerula	Fasciolopsiasis
Melanoides tuberculata	Paragonimiasis, echinostomiasis, heterophyiasis
Thiara scabra	Paragonimiasis, echinostomiasis
Tarebia granifera	Paragonimiasis, echinostomiasis
Gyraulus convexiusculus	Echinostomiasis
Trochorbis trochoideus[a]	Fasciolopsiasis
Pomacea canaliculata	Angiostrongyliasis, echinostomiasis
Filopaludina (S.) m. martensi	Angiostrongyliasis, echinostomiasis

[a]Not recorded in 2011.

Table 4
Distribution of snails by the 7 study locations.

Gastropoda	Study locations 1	2	3	4	5	6	7
Pomacea canaliculata	Found in 2010 and 2011	Found in 2010 and 2011	Found in 2010 and 2011	Found in 2010 and 2011	Found in 2010 and 2011	Found in 2010 and 2011	Found in 2010 and 2011
Bithynia (D.) s. goniomphalos				Found in 2011 only	Found in 2010 only	Found in 2010 and 2011	Found in 2010 and 2011
Wattebledia crosseana						Found in 2010 and 2011	Found in 2011 only
Clea helena			Found in 2011 only			Found in 2010 and 2011	
Sinotaia mandahlbarthi	Found in 2010 only	Found in 2010 and 2011	Found in 2010 and 2011	Found in 2010 and 2011	Found in 2010 and 2011	Found in 2010 only	Found in 2010 only
Filopaludina (F.) zilchi	Found in 2011 only			Found in 2010 and 2011	Found in 2010 and 2011	Found in 2010 and 2011	Found in 2011 only
Filopaludina (S.) m. martensi				Found in 2010 and 2011	Found in 2010 and 2011	Found in 2011 only	
Filopaludina (S.) m. munensis				Found in 2010 only	Found in 2010 only	Found in 2011 only	
Idiopoma umbilicata		Found in 2010 only	Found in 2010 and 2011	Found in 2010 and 2011	Found in 2010 and 2011	Found in 2011 only	Found in 2010 only
Idiopoma ingallsiana		Found in 2011 only	Found in 2011 only	Found in 2011 only	Found in 2011 only	Found in 2011 only	Found in 2011 only
Idiopoma dissimilis						Found in 2010 only	
Sulcospira dakrongensis		Found in 2010 only					
Stenothyra spp						Found in 2010 and 2011	
Neotricula aperta						Found in 2010 and 2011	
Lacunopsis conica						Found in 2010 and 2011	
Halewisia expansa						Found in 2011 only	
Melanoides tuberculata	Found in 2010 only				Found in 2011 only	Found in 2010 and 2011	Found in 2011 only
Tarebia granifera						Found in 2010 and 2011	Found in 2011 only
Thiara scabra						Found in 2010 and 2011	Found in 2011 only
Indoplanorbis exustus		Found in 2011 only	Found in 2010 and 2011	Found in 2010 and 2011	Found in 2010 and 2011	Found in 2011 only	
Gyraulus convexiusculus		Found in 2011 only	Found in 2011 only	Found in 2011 only	Found in 2010 and 2011	Found in 2011 only	Found in 2010 only
Polypylis hemisphaerula						Found in 2010 and 2011	
Trochorbis trochoides					Found in 2010 only		
Camptoceras jiraponi						Found in 2010 only	
Radix rubiginosa	Found in 2010 only	Found in 2010 and 2011	Found in 2010 and 2011	Found in 2010 and 2011	Found in 2010 and 2011	Found in 2011 only	

Found in 2010 and 2011
Found in 2010 only
Found in 2011 only

(1) Nam Xot, watershed in NK, Nakai District; (2) Nam Noy, watershed in NK; (3) Nam Theun, watershed in NK (4) reservoirs, NK; (5) resettlement, NK; (6) downstream; GL, Gnommalath District; (7) downstream, MX, Mahaxai District.
NK, Nakai, GL, Gnommalath; MX, Mahaxai.

Nos. 58-66 in Fig 1) obtaining 578 snails from six families and 14 species (Table 2).

Overall, 12 and 11 species of medical importance were found in 2010 and 2011, respectively (Table 3).

Neotricula aperta (gamma race) with normal and reduced pigmentation, an intermediate host for *S. mekongi*, was found in large numbers in 2010 from two downstream habitats in Nam Gnom at Mueang Gnommalath (Station 25) and Ban Thathod (Station 26) in GL District (Fig 1), which are areas of human and animal activity. During the 2011 survey, *N. aperta* (gamma race) was found in low numbers at Station 25 and not at all at Station 26.

During 2010 and 2011, *Bithynia* (*Digoniostoma*) *siamensis goniomphalos*, the intermediate host of the human liver-fluke (*Opisthorchis viverrini*), was found in downstream rice fields and irrigation canals. In the 2011during survey, the rice fields were dry and the bithyniid snails aestivating. The numbers of snails were similar during both years (Table 1).

The golden apple snail (*Pomacea canaliculata*), the intermediate host of *Angiostrongylus* (*Parastrongylus*) *cantonensis* and a serious rice crop pest, was found in many areas of the NT2 dam project. This species was recorded in 38 of 57 sampled stations during 2010 and 37 of 57 sampled stations during 2011. The number of golden apple snails increased rapidly from 143 in 2010 to 6,568 in 2011, comprising 1.3% of the total in 2010 and 53.3% in 2011 (Table 1).

Table 4 shows the distribution of snail species at the two sampling periods. Twenty-five species of snails were found; two were not found in 2010 (*Idiopoma ingallsiana* and *Halewisia expansa*) and four were not found in 2011 (*Idiopoma dissimilis*,

Table 5
Snail types and numbers by study sites and years.

Gastropoda	1		2		3		4	
	2010	2011	2010	2011	2010	2011	2010	2011
Ampullariidae								
Pomacea canaliculata	4	42	*	93	5	30	28	5,343
Bithyniidae								
Bithynia (D.) s. goniomphalos	-	-	-	-	-	-	-	35
Buccinidae								
Clea helena	-	-	-	-	1	-	-	-
Viviparidae								
Sinotaia mandahlbarthi	5	-	54	1	98	5	168	22
Filopaludina (F.) zilchi	-	7	-	-	-	-	48	25
Filopaludina (S.) m. martensi	-	-	-	-	-	-	44	50
Filopaludina (S.) m. munensis	-	-	-	-	-	-	5	-
Idiopoma umbilicata	-	-	3	-	3	1	103	83
Idiopoma ingallsiana	-	-	-	7	-	21	-	61
Pachychilidae								
Sulcospira dakrongensis	-	-	28	-	-	-	-	-
Thiaridae								
Melanoides tuberculata	91	-	-	-	-	-	-	-
Planorbidae								
Indoplanorbis exustus	-	1	1	80	2	32	55	457
Gyraulus convexiusculus	-	-	-	4	-	23	-	25
Lymnaeidae								
Radix rubiginosa	7	-	19	100	19	46	65	2,177
Total	107	50	105	285	128	158	516	8,278
No. of species	4	3	6	6	6	7	8	9
Max no.	91	42	54	100	98	46	168	5,343

(1) Nam Xot, watershed in NK; (2) Nam Noy, watershed in NK; (3) Nam Theun, watershed in NK; (4) reservoirs; NK, Nakai District.
*Eggs found.

Sulcospira dakrongensis, *Trochotaia trochoides*, and *Camptoceras jiraponi*).

The species type and density by year are shown in Tables 5 and 6. The maximum number of individual snails (8,278) was collected from the reservoir areas in NK, and the maximum numbers of species (22) was collected in the downstream area at GL.

The snail species infected with cercaria and types of infection are shown in Table 7. In 2010, 3.6% of *B. s. goniomphalos* specimens collected were found to be infected with the human liver fluke (*O. viverrini*) in the rice fields at GL (Station 29 in Fig 1). The presence of *O. viverrini* cercariae was demonstrated by the shedding test and confirmed by specific hybridization probe-based real-time fluorescence resonance energy transfer (FRET) PCR (Sri-aroon *et al*, 2011). In 2011, no *O. viverrini*-infected *B. s. goniomphalos* were

Table 6
Snail types and numbers by study sites and years.

Gastropoda	5		6		7	
	2010	2011	2010	2011	2010	2011
Ampullariidae						
Pomacea canaliculata	75	936	1	86	30	38
Bithyniidae						
Bithynia (D.) s. goniomphalos	11	-	171	80	904	1,037
Wattebledia crosseana	-	-	104	250	-	15
Buccinidae						
Clea helena	-	-	1	2	-	-
Viviparidae						
Sinotaia mandahlbarthi	164	18	12	-	30	-
Filopaludina (F.) zilchi	6	115	6	83	-	32
Filopaludina (S.) m. martensi	8	17	-	29	-	-
Filopaludina (S.) m. munensis	6	-	-	2	-	-
Idiopoma umbilicata	152	1	-	10	1	-
Idiopoma ingallsiana	-	10	-	2	-	29
Idiopoma dissimilis	-	-	2	-	-	-
Stenothyridae						
Stenothyra spp	-	-	133	19	-	-
Pomatiopsidae						
Neotricula aperta	-	-	6,287	170	-	-
Lacunopsis conica	-	-	1,087	17	-	-
Halewisia expansa	-	-	-	7	-	-
Pachydrobia prasongi	-	-	-	-	-	4
Thiaridae						
Melanoides tuberculata	-	71	37	106	-	20
Tarebia granifera	-	-	30	30	-	2
Thiara scabra	-	-	14	2	-	2
Planorbidae						
Indoplanorbis exustus	470	138	-	55	-	-
Gyraulus convexiusculus	4	24	-	1	7	-
Polypylis hemisphaerula	-	-	1	1	-	-
Trochorbis trochoides	1	-	-	-	-	-
Camptoceras jiraponi	-	-	2	-	-	-
Lymnaeidae						
Radix rubiginosa	250	51	-	69	-	-
Total	1,147	1,381	7,888	1,021	972	1,179
No. of species	11	10	15	22	5	9
Max no.	470	936	6,287	250	904	1,037

(5) resettlement, NK, Nakai District; (6) downstream, GL, Gnommalath District; (7) downstream, MX, Mahaxai District.

Table 7
Infected snail species by year.

2010			2011		
Snail species	Cercaria type	No. infected/ Infection rate (%)	Snail species	Cercaria type	No. infected/ Infection rate (%)
B. s. goniomphalos	*O. viverrini*	6[a]/167[b] (3.6)	*B. s. goniomphalos*	*O. viverrini*	1/224 (0.45)
	Echinostome	2/167 (1.2)		Echinostome	24/984 (2.44)
	Xiphidio	1/167 (0.60)		Xiphidio	38/1,002(3.79)
				Furcocercus	1/224 (0.45)
			R. rubiginosa	Echinostome	1/3 (33.33)
				Xiphidio	1/62 (1.61)
			I. exustus	Echinostome	2/23 (8.70)

[a]Number of infected snails. [b]Total number of snails examined.

collected from Station 29, but were found in a dry rice field in Ban Pova (Station 52), MX. During drought, rice fields dry out and bithyniid snails aestivate; snails are induced out of this state by immersion in de-chlorinated tap water. One of 224 (0.45%) naturally aestivating *B. s. goniomphalos* specimen collected was found to be infected with *O. viverrini.* Other types of cercariae found were echinostome, furcocercous and xihpidio cercariae. There was no evidence of natural infection among *N. aperta*, the intermediate host of *S. mekongi*.

Snails were recorded from a wide range of habitats: rivers, swamps, ponds and reservoirs. All the sampling stations in the reservoir sectors were ecologically similar, where the body of water caused by the dam contained large amounts of dead wood, branches, roots, rocks and soil. Humans and domestic animals may frequent associated with these water bodies. The water level during the November 2011 survey was higher than during the March 2010 survey.

The average temperature at the dam site during the November 2011 survey was higher than during the March 2010 survey. In March 2010, the air temperature averaged 12.0-33.5°C and the water temperature averaged 19.0-33.0°C, while, in November 2011, the air temperatures averaged 20.0-38.0°C and the water temperature averaged 20.0-33.0°C.

DISCUSSION

Twenty-five species of freshwater snails were collected from 66 sampling sites at the NT2 hydroelectric dam project. The differences in species and numbers, during March 2010 and November 2011, may due to seasonal variations. A total 19 species were found during both years, 2 species were not found in 2010 and 4 species were not found in 2011.

Of the medically important snail species found, *N. aperta,* the intermediate host of *S. mekongi*, is the most concerning because of the potential for disease transmission. *N. aperta* appears to be restricted to the Mekong River and its tributaries in the lower Mekong basin (Attwood and Upatham, 2012). *N. aperta* with normal and reduced pigmentation (gamma race) was first reported in 1996 (Lohachit, 1996) from downstream areas of the NT2 power station on the Xe Bang Fai River within the MX District, in Khammouane Province, central Lao PDR. Attwood *et al* (2004) estimated the density of *N. aperta* in the Xe Bang Fai River to be 5,000 snails/m^2. In our study, *N. aperta* was not found in the Xe Bang Fai River downstream from the NT2 power station, possibly due to increased water velocity and high water levels resulting from discharge from the power station into the river. Attwood and Upatham (2012) suggested the increased flow rate and water depth in the Xe Bang Fai River after the dam became fully operational may have wiped out the snail population.

We found 2 habitats for *N. aperta* (Stations 25 and 26), both in Nam Gnom, GL District, Khammouane Province, similar to the finding of Attwood *et al* (2004).

Attwood and Upatham (2012) noted a significant decline in the *N. aperta* population in Xe Bang Fai at MX and in a spring flowing into the Nam Gnom at Ban Thathot (Station 26) in Khammouane Province after the NT2 dam became fully operational. The greater water flow rate, high concentration of suspended solids and the diversion of the Nam Theun River into the Xe Bang Fai River via a downstream discharge channel resulted in adverse conditions for *N. aperta* growth. The authors believe the snail population in the Xe Bang Fai River disappeared before 2010. The loss of the Xe Bang Fai *N. aperta* population was most likely caused by the dam; however, the disappearance of the Ban Thathod (Station 26) population appear to be unrelated to the damming operation even though the location is close to the regulation pond of NT2. Sampling Station 26 was not directly affected by the change in flow rate.

Many studies have found increased schistosomiasis transmission rates after damming operations (Abdel-Wahab *et al*, 1979; Malek, 1975; McManus *et al*, 2010); however, Attwood (2012) suggested the impact of damming in the Mekong region is not comparable to Africa because the habitat ecology of the intermediate hosts is different. In Egypt, the change in water flow and ecology of the Nile River not only improved the breeding habitat of host snails but also the decreased current velocity in the lower Nile facilitated the infection of host snails and humans by both miracidia or cercaria (Malek, 1975; Barakat, 2013). However, flooding decreased calcium levels and silting downstream to the NT2 dam, reducing the numbers of *N. aperta* to undetectable levels. A similar finding for Pak Mun Dam, Thailand, was also noted in a study by Attwood and Upatham (2013) where there was no significant increase in the *N. aperta* population after the damming operation.

In addition to schistosomiasis, Ziegler *et al* (2013) cautioned the damming of Mekong tributaries could trigger more cases of opisthorchiasis. *Bithynia (D.) s. goniomphalos* is the intermediate host for *O. viverrini*, the human liver fluke, and an important food-borne pathogen in the Lao PDR (Upatham and Viyanant, 2003; Kiatsopit *et al*, 2012). *O. viverrini* infection can induced human cholangiocarcinoma and is considered a Group I carcinogen (Sripa *et al*, 2007). There are three *Bithynia* species in the Mekong region but, in Lao PDR, only *Bithynia (D.) s. goniomphalos* has been found (Petney *et al*, 2012). Kiatsopit *et al* (2012) reported the prevalence of *O. viverrini* in *B. s. goniomphalos* collected from Vientiane and Suvannakhet Provinces ranged from 0.73% to 8.37%. In our study, these snails were found in moderate numbers in a variety of habitats, including lentic waters, such as ponds, swamps, paddy fields, irrigation canals and reservoirs. Petney *et al* (2012) found *B. s. goniomphalos* in Lao PDR is more common in paddy fields and reservoirs. Our study is further confirmation of the habitat ecology and distribution of *B. s. goniomphalos* and the rates of infection with *O. viverrini* in Lao PDR. It is not possible to draw any conclusions regarding the impact of the NT2 damming operation on the transmission of *O. viverrini*; however, Sittithaworn *et al* (2012) concluded that dam construction, road building and artisanal aquaculture can all contribute to increased transmission of the human liver fluke (*O. viverrini*).

The golden apple snail, *Pomacea canaliculata,* is the intermediate host for *Angiostrongylus (Parastrongylus) cantonensis* (Wang *et al*, 2012) and a serious rice crop pest (Halwart, 1994; Sin, 2003). In both surveys, and especially in the November 2011 survey, it was found to be widely distributed. If this species continues to increase, it may become a serious pest in rice fields close to the NT2 project, destroying native aquatic vegetation leading to serious habitat modification, and competitively interacting with native aquatic fauna, such as snails.

In conclusion, the results of this study demonstrate seasonal variation in the snail population in terms of abundance and diversity after the NT2 hydroelectric dam project became fully operational. Ongoing studies of the fauna of snails and the possible transmission of parasitic diseases are necessary to monitor the long-term impact of the NT2 project.

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REFERENCES

Abdel-Wahab MF, El-Sahly A, Zakaria S, Strickland GT, El-Kady N, Ahmed L. Changing pattern of schistosomiasis in Egypt 1935-79. *Lancet* 1979; 314(8136): 242-4.

Attwood SW. Genetic variation in *Neotricula aperta*, the snail intermediate host of *Schistosoma mekongi* in the lower Mekong Basin. *J Zool* 1999; 249: 153-64.

Attwood SW. Public health: use snail ecology to assess dam impact. *Nature* 2012; 482(7384): 162.

Attwood SW, Upatham ES. A new strain of *Neotricula aperta* found in Khammouane Province, central Laos, and its compatibility with *Schistosoma mekongi*. *J Mollusc Stud* 1999; 65: 371-74.

Attwood SW, Upatham ES. Observations on *Neotricula aperta* (Gastropoda: Pomatiopsidae) population densities in Thailand and central Laos: Implications for the spread of Mekong schistosomiasis. *Parasit Vectors* 2012 Jun 21; 5: 126.

Attwood SW, Upatham ES. A population growth trend analysis for *Neotricula aperta*, the snail intermediate host of *Schistosoma mekongi*, after construction of the Pak-Mun Dam. *PLoS Negl Trop Dis* 2013; 7: e2539.

Attwood SW, Campbell I, Upatham ES, Rollinson D. Schistosomes in the Xe Kong river of Cambodia: the detection of *Schistosoma mekongi* in a natural population of snails and observations on the intermediate host's distribution. *Ann Trop Med Parasitol* 2004; 98: 221-30.

Babko R, Kuzmina T. Effect of dams on hydrological parameters and the structure of benthic molluscs: case study in Dnieper river Basin. *Ecohydrol Hydrobiol* 2009; 9: 159-64.

Barakat RMR. Epidemiology of schistosomiasis in Egypt: travel through time: review. *J Adv Res* 2013; 4: 425-32.

Brandt RAM. The non-marine aquatic Mollusca of Thailand. *Arch Moll* 1974; 105: 1-423.

Burch JB, Lohachit C. Snails of medical importance in Thailand. *Walkerana* 1983; 1: 395-8.

Burch JB, Upatham ES. Medically important mollusks of Thailand. *J Med Appl Malacol* 1989; 1: 1-9.

Chitramvong YP. The Bithyniidae (Gastropoda: Prosobranchia) of Thailand: comparative external morphology. *Malacol Rev* 1992; 25: 21-38.

Halwart M. The golden apple snail *Pomacea canaliculata* in Asian rice farming systems: present impact and future threat. *Int J Pest Manage* 1994; 40: 199-206.

Keawjam RS. Guide for the identification of freshwater snails of the family Pilidae in Thailand. *Walkerana* 1987; 2: 173-86.

Kiatsopit N, Sithithaworn P, Saijuntha W, *et al*. Exceptionally high prevalence of infection of *Bithynia siamensis goniomphalos* with *Opisthorchis viverrini* cercariae in different wetlands in Thailand and Lao PDR. *Am J Trop Med Hyg* 2012; 86: 464-9.

Lohachit C. Snail-mediated diseases of Nam Theun 2 Project in Khammouane and Bolikhamxai, Lao PDR. Bangkok: Department of Social and Environmental Medicine, Faculty of Tropical Medicine, Mahidol University and TEAM Consulting Engineers Co., Ltd. 1996: 37pp.

Malek EA. Effect of the Aswan High Dam on prevalence of schistosomiasis in Egypt. *Trop Geogr Med* 1975; 27: 359-64.

McManus DP, Gray DJ, Li Y, *et al*. Schistosomiasis in the People's Republic of China: the era of the Three Gorges Dam. *Clin Microbiol Rev* 2010; 23: 442-66.

Petney T, Sithithaworn P, Andrews R, *et al*. The ecology of the *Bithynia* first intermediate hosts of *Opisthorchis viverrini*. *Parasitol Int* 2012; 61: 38-45.

Sin TS. Damage potential of the golden apple snail *Pomacea canaliculata* (Lamarck) in irrigated rice and its control by cultural approaches. *Int J Pest Manage* 2003; 49: 49-55.

Sithithaworn P, Ziegler AD, Grundy-Warr C, Andrews RH, Petney TN. Changes to the life cycle of liver flukes: dams, roads, and ponds. *Lancet Infect Dis* 2012; 12: 588.

Sri-aroon P. Handbook of freshwater snails of medical importance in Thailand. Bangkok: Special publication on the 50th anniversary of the Faculty of Tropical Medicine, Mahidol University 2010: 22 pp.

Sri-aroon P, Butraporn P, Limsomboon J, Kerdpuch Y, Kaewpoolsri M, Kiatsiri S. Freshwater mollusks of medical important in Kalasin Province, Northeast Thailand. *Southeast Asian J Trop Med Public Health* 2005; 36: 653-57.

Sri-aroon P, Intapan P, Lohachit C, *et al*. Molecular evidence of *Opisthorchis viverrini* in infected bithynid snails in the Lao People's Democratic Republic by specific hybridization probes based real-time fluorescence resonance energy transfer PCR method. *Parasitol Res* 2011; 108: 973-8.

Sripa B, Kaewkes S, Sithithaworn P, *et al*. Liver fluke induces cholangiocarcinoma. *PLoS Med* 2007; 4: e201.

Temcharoen P. New aquatic molluscs from Laos. *Arch Moll Band* 1971; 101: 91-109.

Tropmed Technical Group. Snails of medical importance in Southeast Asia. Bangkok:

SEAMEO-TROPMED Technical Meeting, 1986; 17: 282-322.

Upatham ES, Viyanant V. *Opisthorchis viverrini* and opisthorchiasis: a historical review and future perspective. *Acta Trop* 2003; 88: 171-6.

Upatham ES, Sornmani S, Kittikoon V, Lohachit C, Burch JB. Identification key for fresh- and brackish-water snails of Thailand. *Malacol Rev* 1983; 16: 107-32.

Wang QP, Wu ZD, Wei J, Owen RL, Lun ZR. Human *Angiostrongylus cantonensis*: An update. *Eur J Clin Microbiol Infect Dis* 2012; 31: 389-95.

World Bank. Nam Theun Second Power Company Ltd, 2004. Laos-Nam Theun 2 Hydroelectric Project: summary environmental and social impact assessment. Washington DC: World Bank, 2004: 81 pp. [Cited 2015 Mar 7]. Available from: http://documents.worldbank.org/curated/en/2004/11/7317750/laos-second-nam-theun-power-project-second-nam-theun-social-environment-project

Ziegler AD, Petney TN, Grundy-Warr C, *et al*. Dams and disease triggers on the Lower Mekong River. *PLoS Negl Trop Dis* 2013; 7: e2166.