Freshwater Snails of Lakes within Maine Public Lands

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The non-native Chinese Mystery Snail *Bellamya chinensis* by Animal Pictures Archive.

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Abstract

Sixteen lakes within Maine public lands were inventoried for freshwater snails in 2015. A total of 18 species of freshwater snails and an additional four amphibious-shoreline snail species were found at these lakes. A dense population of non-native Chinese Mystery Snails (CMS) *Bellamya chinensis* (J.E. Gray, 1834) was confirmed in Island Pond at Deboullie Public Reserved Lands in Aroostook County. All other lakes we checked were free of non-native snails. The absence of native freshwater snails at Island Pond - probably due to its ecological and physiographic characteristics - precluded an analysis of snail community effects of the invasion. Island Pond's small size and isolation may allow for containment of its CMS population, and perhaps its eradication. On public lands state-wide, preventing CMS from spreading can be promoted by leveraging existing policies and programs. These include improved informational signage, and expanded volunteer lake monitoring and boat inspections, in coordination with ongoing efforts to control other non-native aquatic species. Among native snails, the Bigmouth Pondsnail *Stagnicola mighelsi* (W.G. Binney, 1865), a Priority 1 Wildlife Action Plan species, was found at Scraggly Lake in Penobscot County. Broken shells of a *Stagnicola* species were also found at Duck Lake in Hancock County. Freshwater snail inventory data from this study and other work between 2010 and 2015 was compiled, and preliminarily analyzed. These data suggest that Bigmouth Pondsnails are more likely to be present in snail communities with few other species, and in lakes without dams.

Umsaskis lakeshore. DJM

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Underwater, non-native Chinese Mystery Snails (*Bellamya chinensis*; larger, darker) and native mystery snails (*Campeloma decisum*; smaller, paler) consume a fish carcass at Mousam Lake. Image by Dennis Roberge ©.

Introduction

Freshwater snails are a vital part of Maine's aquatic environments, in a state with approximately 92,000 square kilometers of lakes, rivers, and wetlands (Tiner, 2007). There are approximately 40 freshwater snail species in the state (Martin 1999), and at least two of these are non-native – Banded Mystery Snail (*Viviparous georgianus* [Lea, 1834]) and Chinese Mystery Snail (*Bellamya chinensis* [J.E. Gray, 1834]). These mollusks range from the size of a pinhead to 30+mm (e.g. Burch, 1982), and are a major component of lake ecosystems: they are mainly herbivores and detritivores; they serve as food for aquatic animals such as insects, fish, and a wide variety of water birds, including rails, loons, grebes, and various ducks, especially black ducks (e.g. *in* Martin et al., 1951); and they are a host to wildlife parasites including the trematode that causes “swimmer’s itch”. The abundance and species richness of freshwater snails can be a useful indicator of the water chemistry and health of lake ecosystems (e.g. Økland, 1983).

Freshwater snails can be affected by changes to water quality or quantity, introduced non-native species (including other snails), shoreline erosion, dredging or other substrate disturbances, and a variety of other impacts. Recent work by the Maine Volunteer Lake Monitoring Program shows that many lakes have been invaded by Chinese Mystery Snail (CMS).

The effects of CMS invasions upon other snails, other invertebrates, and aquatic ecosystems have not been thoroughly studied. In a multi-pond experiment, CMS reduced food availability (in the form of periphyton), which was suspected of causing a reduction in Lymnaeid snails (Johnson et al, 2009). Further, CMS in combination with non-native rusty crayfish (*Orconectes rusticus* [Girard, 1852]), extirpated one native snail and nearly extirpated a second. However, a look at 44 Wisconsin lakes did not show an increased loss in native snail species related to CMS (Solomon, 2010). Work in the Canadian Maritimes suggest that where CMS occurs it is at relatively low densities (e.g. at one site 3 CMS found in 90 minutes; McAlpine et al., 2016), while in a Nebraska reservoir CMS reached densities of 5.2 snails/m^2 (Chaine et al., 2012)

Climate change may have impacts upon several freshwater snail species in Maine, because some snails exhibit a rather narrow temperature range for optimal growth and reproduction (e.g. van der Schalie & Berry, 1973).

In Maine there has been scattered freshwater snail inventory, including early work by Edward S. Morse (1864) and work in northern Maine by naturalist Olof Nylander nearly 100 years ago (Nylander, 1900; 1921; 1936). The snails *Stagnicola mighelsi* (W.G. Binney, 1865) and *Stagnicola oronoensis* (F.C. Baker, 1904) are reported only from Maine. Both species have been the subject of recent work, with the former determined to be extant at six lakes and the latter at one lake and one river segment (Hotopp, 2012; 2015; unpublished data).

Chinese Mystery Snail (*B. chinensis*) emerging from its shell. Creative Commons

Study Animals

The Chinese Mystery Snail (*Bellamya* [previously *Cipangopaludina*] *chinensis* [J.E. Gray, 1834]) is a widespread Asian native, but introduced on other continents. It has a large (approximately 25 mm), dark gray-green to brown, rounded shell, often whitish within. The animal has an operculum or “trap door” that seals the aperture when the animal is inactive. They are primarily algae grazers on lake bottoms, but also consume carrion. In Asia they are one host of schistosomiasis, a serious parasitic disease caused by *Schistosoma* species flatworms affecting peoples’ urinary and digestive tracts. The disease does not occur in North America. Fecundity of CMS in a Nebraska reservoir was estimated at approximately 30 young per female per year (Stephen et al., 2013). Populations may rise and fall dramatically, though they are iteroparous, not semelparous (reproducing more than once, not once and then dying; *in* Dillon, 2016).

CMS were introduced into western North America in 1890, and into eastern North America – Muddy Creek, MA - prior to 1915 (*in* Jokinen, 1982). They now occur in eastern North America from Ontario, Quebec and Nova Scotia, south to at least the Mason-Dixon line, and west to the upper Midwest. CMS are quite tolerant of weather when removed from an aquatic environment. In a summertime experiment in Wisconsin, CMS at a natural forest site survived up to 63 days, and viable young were released after 54 days of exposure (Havel et al., 2014).

In Maine lakes where it occurs, this species is often the most commonly-observed snail. The Maine Volunteer Lake Monitoring Program has reports of Chinese Mystery Snail (CMS) in more than 60 lakes, and the actual number of invaded lakes could be much higher. Lakes with CMS are concentrated in a region to the south and west of approximately Skowhegan, in the watersheds of the Saco, Presumpscot, lower Androscoggin, Kennebec, and smaller coastal rivers. However, there are also reports from as far Downeast as Cherryfield in Hancock County, and as far north as Deboullie Public Reserved Lands in Aroostook County. CMS occurs in the lower St. John River watershed in New Brunswick (McAlpine et al., 2016), downstream of the St. John, Allagash, and Aroostook Rivers in Maine.

Chinese Mystery Snail view showing the operculum that seals the aperture when the animal is inactive. Image by Dave Britton

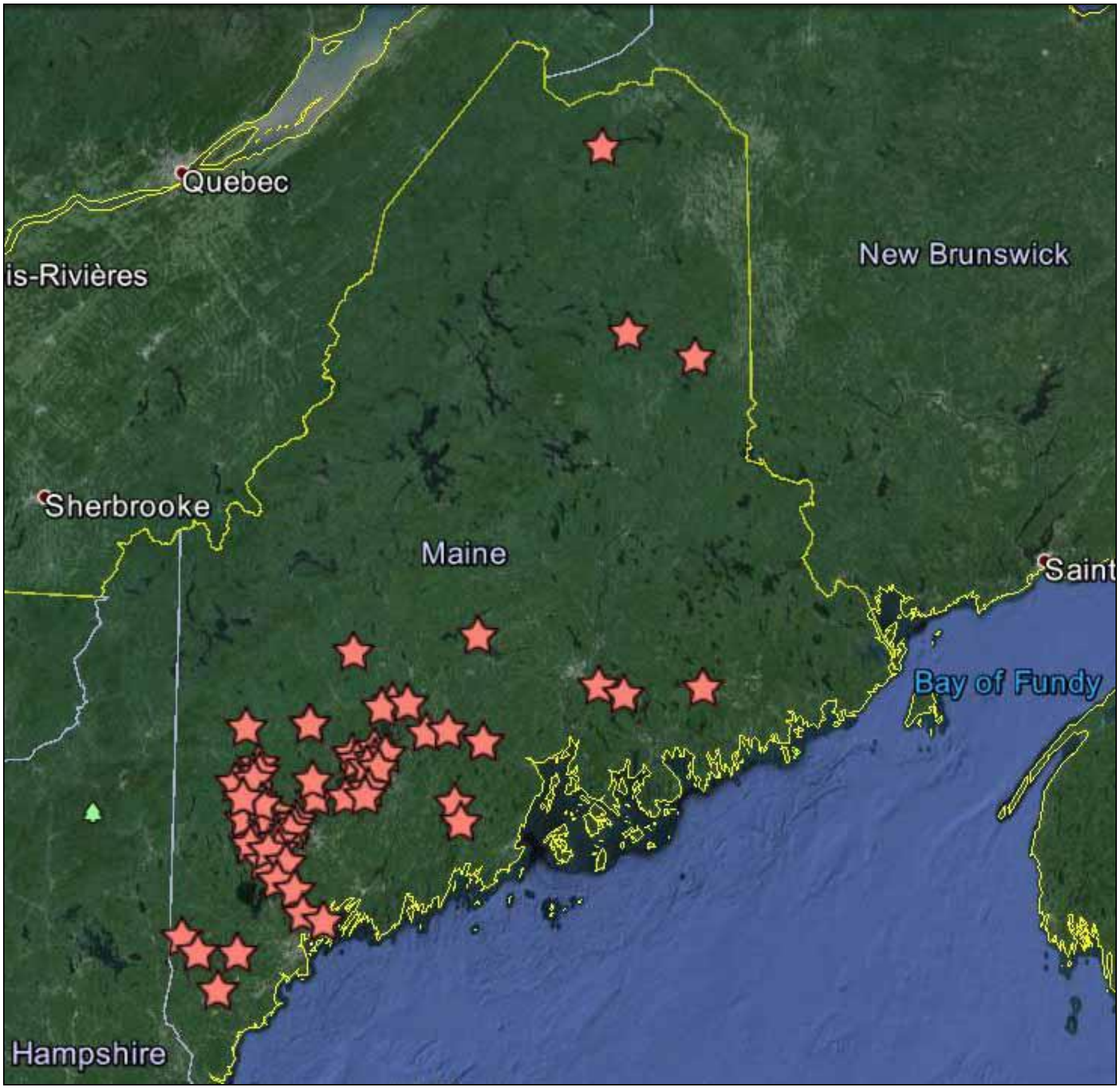
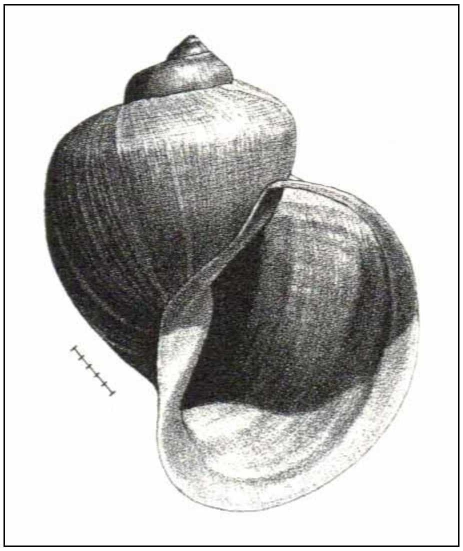


Figure 1. Chinese Mystery Snail (*B. chinensis*) sightings reported primarily by the Volunteer Lake Monitoring Program (Lakes of Maine, 2014). This does not include all lakes with CMS, but illustrates the concentration in southern Maine and outlier populations. The northernmost star is Island Pond at Deboullie Public Reserved Lands.

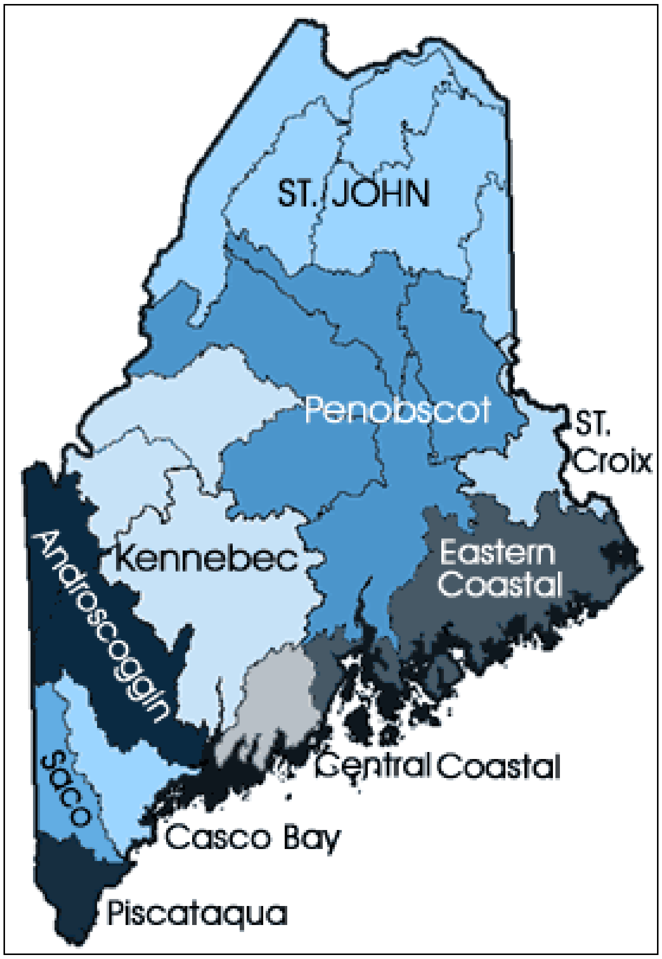


Stagnicola mighelsi from Burch & Tottenham, 1980. Scale line 5mm.

The Bigmouth Pondsnail *Stagnicola mighelsi* (W.G. Binney, 1865) has a reduced spire, and a final whorl that is “very large, flaring, and strongly shouldered” (Baker, 1911). The shell may have ridges at growth interruptions in the final whorl, and whitish or reddish radial streaks. Its internal anatomy is like that of *S. emarginata*.

This native snail occurs in northern Maine, and there are unconfirmed reports in nearby southeastern Canada. The Bigmouth Pondsnail was first discovered in the summer of 1842 by surveyor Alexander Longfellow, brother of the famous poet (*in* Martin, 1999). It was originally described by Mighels as *Lymnea ampla*, and published as part of his catalogue of Maine's marine, freshwater, and terrestrial shells (Mighels, 1843). The type specimens at the Portland Society of Natural History were destroyed by a large fire in 1854, but Aroostook County naturalist Olof Nylander was able to relocate the type locality in 1894 (Nylander, 1921).

This animal has been treated as a subspecies, race, or form, by some authors (Baker, 1911; Nylander, 1942; Hubendick, 1951), as a full species by others (Mighels, 1843; Burch, 1988; Turgeon et al., 1998; Martin 1999; NatureServe, 2016), and is not addressed by Clarke (1981). This snail’s NatureServe global rank is G1G3 (NatureServe 2016), and it is a Tier 1 animal in Maine’s Wildlife Action Plan, the highest conservation priority (Maine Dept. of Inland Fisheries & Wildlife, 2015).



Major watersheds of Maine (Maine Rivers, 2016).

Project Area

This freshwater snail inventory was conducted in four major watersheds – the Androscoggin, Kennebec, Penobscot, and St. John Rivers – which drain the vast majority of Maine. There are more than 92,000 square kilometers of lakes, rivers, and wetlands in the state (Tiner, 2007). Bedrock geology of western-central-northern Maine spans a vast chronology from Carboniferous to Cambrian. Forests are primarily northern mixed woods or spruce-fir.

The climate at Farmington (near the southwestern part of the study area) is warmest in July with an average high of 26° C (78° F), and coldest in January with an average low of -16° C (4° F) (1981-2010 data; Your Weather Service, 2016). The wettest months in Farmington are October and November, and average annual precipitation is 122 cm (48"). Average annual snowfall is 224 cm (88"). Bangor (near the central part of our study area) is warmest in July with an average high temperature of 26° C (79° F) and coldest in January with an average low of -14° C (7° F). Average annual precipitation is 107 cm (42"), with the wettest months in the fall.

At Presque Isle (near the northern end of the study region) the average annual precipitation is 91 cm (36"), with the wettest months in October, August and July. The weather is warmest in July with an average high temperature of 26° C (78° F) and coldest in January with an average low of -17° C (2° F). Average annual precipitation at Presque Isle is 91 cm (36") and snowfall is 226 cm (89").

Freshwater planorbid snails were found among the emergent and floating aquatic plants on an inlet mudflat at Holeb Pond, Somerset Co. KPH

Derek J. Moore collecting at Deboullie Ponds.   KPH

Methods

We selected 16 lakes across Maine that are surrounded, or nearly so, by public lands managed by the Maine Bureau of Parks and Lands (Table 1). A variety of littoral zone habitats were sampled, including rocky shoreline, sand beaches, mudflats, stream inlets, and wetland lake edges. Primary techniques were visual searches of the substrate, turning over rocks and logs, and hand-picking and sieving of vegetation with strainers. Field searches were conducted by one or two people. Specimens were placed in polystyrene containers and live animals were preserved in 90% ethanol. To estimate Chinese Mystery Snail numbers at Island Pond we canoed a 30 meter transect while counting snails visible on the substrate below, looking through a plexiglass-bottomed 5-gallon bucket to reduce glare.

Table 1. Maine waterbodies sampled in 2015. Partially sourced from Maine Volunteer Lake Monitoring Program (2016).

waterbody	watershed	BPL	county	size (ha)	MIDAS#
Gardner Pd	Fish River/St John	Deboullie	Aroostook	115	1528
Deboullie Pd	Fish River/St John	Deboullie	Aroostook	112	1512
Pushineer Pd	Fish River/St John	Deboullie	Aroostook	26	1514
Island Pd	Fish River/St John	Deboullie	Aroostook	14	1516
Black Pd	Fish River/St John	Deboullie	Aroostook	59	1506
Togue Pd	Fish River/St John	Deboullie	Aroostook	138	1530
Round Pd	Allagash/St John	Round Pd	Aroostook	301	1470
Umsaskis L	Allagash/St John	Allagash	Aroostook	527	1896
Telos L	Allagash/St John	Allagash	Piscataquis	940	2710
Scraggly L	Penobscot	Scraggly	Penobscot	338	4264
Duck L	Penobscot	Duck L	Hancock	467	4746
Gassabias L	Penobscot	Duck L	Hancock	380	4782
Flagstaff L	Kennebec	Bigelow	Franklin	7,033	0038
Holeb Pd	Kennebec	Attean	Somerset	444	2652
Mooselook. L	Androscoggin	Rangeley	Oxford, Franklin	6,620	3302
Richardson L	Androscoggin	Rangeley	Oxford	3,137	3308

*MIDAS = Maine Information Display & Analysis System

In the laboratory, snail shells were sorted and identified with the aid of a dissecting microscope. Snails were identified using Burch and Tottenham (1980), Jokinen (1992), and others, then labeled and stored in glassware. Specimens will be deposited in the mollusk collection of the Carnegie Museum of Natural History in Pittsburgh, PA.

Freshwater snail inventory results and lake characteristics from this project and previous work back to 2010 were compiled and analyzed primarily in Microsoft Excel (2016). Lake characteristics used for analyses included values that we measured such as species richness, and species richness divided by search time. They also included physical characteristics of the lakes such as shoreline distance and lake area that we obtained from Lakes of Maine website (Maine Volunteer Lake Monitoring Program, 2016a). We estimated the number of lakeshore houses within 100 m of the shore using Google Earth Pro aerial photographs. Water chemistry values were also obtained from Lakes of Maine. We employed measures of calcium linked to mollusk species richness and abundance, such as alkalinity and pH (e.g. various authors *in* Dillon, 2000; Evans and Ray, 2010). We also used phosphorus, which can be important to certain snail species (e.g. Tibbetts, et al., 2010), and dissolved oxygen, an indicator of lake eutrophication and vital to aquatic animals (e.g. Tran-Ngoc et al., 2016).

For correlation analyses all measured data were converted to ranks. For relating binary characteristics (presence-absence) to measured data, a Mann-Whitney U Test available online (Lowry, 2016) was employed, and for the measured data correlations a Spearman Rank Correlation in Excel was used.

Above, at Duck Lake in Hancock Co. broken *Stagnicola* species shells were found along this tiny tributary with touch-me-nots, behind a sandy beach. At Deboullie Ponds in Aroostook Co., freshwater snails were scarce in many habitats. Below, this sedge stand at Pushineer Pond had only the amphibious shoreline species *Zonitoides nitidus* at the upland edge. KPH

Results

Sixteen lakes comprising 32 collection sites within public lands managed by the Bureau of Parks & Lands were inventoried for freshwater snails during July and August 2015 (Tables 1, 2, Figure 2). Lakes were located in four major watersheds – Androscoggin, Kennebec, Penobscot, and St. John – and varied in size from 14 ha to more than 7,000 ha.

A total of 18 species of freshwater snails and an additional four amphibious-shoreline species were found at these sites (Table 3). Between 0 and 103 snails were collected at individual sites (including the amphibious-shoreline species). Site collections averaged 13.9 snails, noting that many observable snails were not collected at snail-rich sites. Including amphibious-shoreline species, sites ranged from 0 to 7 snail species (average 2.1 species). The most frequently-encountered snail was *Helisoma anceps* (Menke, 1830), found at 10 lakes. *Amnicola limosa* (Say, 1817) was at six lakes, and *Campeloma decisum* (Say, 1817) and *Ferrissia* cf *rivularis* (Say, 1817) were each at five lakes.

A dense population of CMS was confirmed in Island Pond at Deboullie Public Reserved Lands in Aroostook County. All other lakes we checked were free of non-native snails. At Island Pond, three canoe transects yielded counts of 19, 20, and 32 live CMS, for an average count of 24 CMS. The transect length was 31 m long, and our view of the bottom (at a depth of 2-3 m) was approximately 2 m wide, giving us a transect area of approximately 62 m^2. Dividing the number of CMS by transect area, the density of CMS in this end of the lake was approximately $0.4/m^2$. The end of the lake with CMS and suitable CMS habitat, as indicated by algae and shoreline emergent aquatic vegetation, was approximately 1 ha, giving us a CMS population estimate of 4,000 CMS at Island Pond (because of the difficulty in seeing small CMS, estimating suitable CMS habitat area, and standardizing transect variables, discussed later, this measure might be more useful as an index to population size rather than as a population estimate).

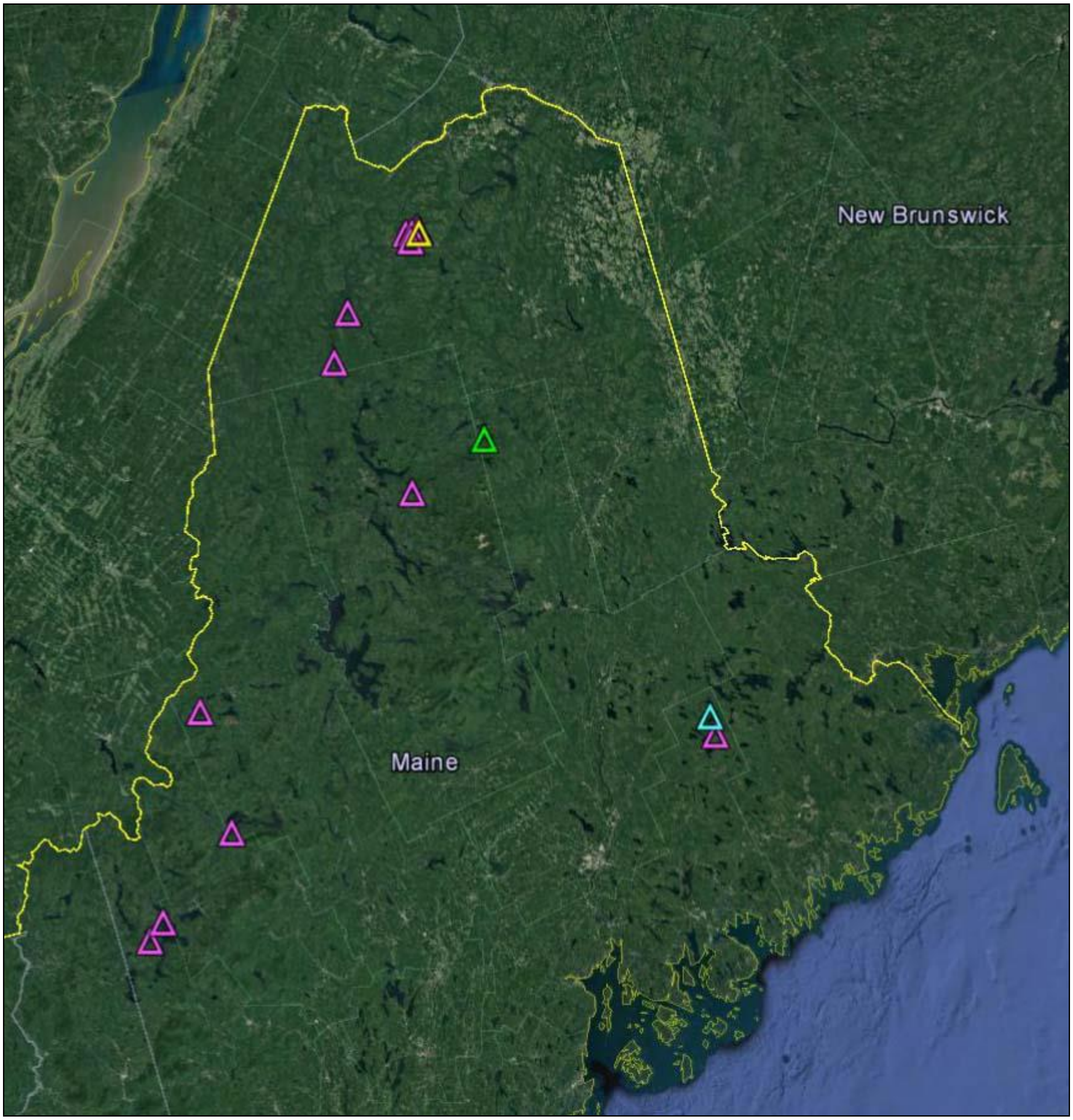


Figure 2. Locations of Maine lakes searched for freshwater snails in 2015. The yellow triangle marks Island Pond with non-native Chinese Mystery Snail, the green triangle marks Scraggly Lake with native Bigmouth Pondsnail, the blue triangle marks Duck Lake with a *Stagnicola* species to be determined, and the purple triangles are all other searched lakes. Mapped in Google Earth Pro.

Table 2. Freshwater snail collection site characteristics (UTM zone 19T, base datum NAD83). Sites are ordered chronologically.

locale/site	coord's	habitat
Gardner Pond 7/22/15 #1	0507269 5201265	sand, gravel, mud inlet delta wi aquatic emergent and alders
Gardner Pond 7/22/15 #2	0507962 5201094	sand and gravel shoreline only sparsely vegetated, near lean-to site
Deboullie Pond 7/22/15 #3	0509542 5200968	sand and gravel at inlet mouth wi emergent sedges/rushes, at carry
Deboullie Pond 7/22/15 #4	0511795 5201036	very rocky shoreline wi shrubs
Pushineer Pond 7/22/15 #5	0511968 5201058	rocky and muddy substrate wi dense emergent rushes and shrubs, more, pH 7.0
Island Pond 7/22/15 #6	- -	rock and mud substrate
Black Pond 7/23/15 #2	0511876 5202165	rocky shrub shoreline near trail
Island Pond 7/23/15 #4	- -	scout entire shoreline, mostly rocky wi shrubs and some emergents
Togue Pond 7/23/15 #5	0508276 5198213	sand and mud inlet
Mooselookmeguntic 8/6/15 #1 Griffin I	0355872 4978245	rocky shore and sand/mud beach, circumnavigate island
Richardson N Arm 8/8/16 #1	- -	several coves, rocky or sand/mud beach
Flagstaff Lake 8/20/15 #1	0387156 5001061	sandy beach and bluff, eroding
Flagstaff Lake 8/20/15 #2	0387325 5001369	sandy beach and sedge wetland
Flagstaff Lake 8/20/15 #3	0389239 5004057	extensive mudflat, sedge/shrub wetland
Flagstaff Lake 8/20/15 #4	0387873 5004114	mud/bog/sandy beach, eroding
Round Pond 8/25/15 #1	0479056 5178797	aquatic floating and emergents, mud bottom, pH 7.1, end search 0479134, 5178461
Round Pond 8/25/15 #2	0479240 5178287	mud and dark sand, wi rushes
Round Pond 8/25/15 #3	0480412 5177719	sand and gravel beach wi rocks above, wood hip debris
Umsaskis 8/25/15 #4	0469776 5161973	sand and gravel beach underlain by clay, emergent and shrub marsh behind
Umsaskis 8/25/15 #5	0469934 5160038	sedge and rush shoreline
Telos 8/26/15 #1	0485601 5108270	mostly rocky shoreline, with rush/shrub behind

Telos 8/26/15 #2	0485030 5108333	more than half rock wi mud, also checked opposite 0485015, 5108449 (spikerush stand held all snails)
Scraggly Lake 8/26/15 #3	- -	sandy shallows off public campsite
Scraggly Lake 8/27/15 #1	0516334 5120753	lean-to beach, nearby stream mouth (#1A), and nearby gravel point (#1B)
Scraggly Lake 8/27/15 #2	0516545 5120539	rocky outcrop, mussel shell midden
Scraggly Lake 8/27/15 #3	0517713 5120314	mud/bog edge wi aquatic emergent/shrubs
Scraggly Lake 8/27/15 #4	0517264 5120847	shallow cove wi emergent horsetails and sedge behind small rocky spit
Duck Lake 8/28/15 #1	0571230 5001260	sand beach wi spikerush near camps, pH 6.7
Duck Lake 8/28/15 #2	0570870 5001106	sand beach and sandbar wi spikerush and algae at small stream mouth, emergent wetland behind
Gassabias Lake 8/28/15 #3	0571439 4994199	sand and mud shoreline at small cove at woods edge
Gassabias Lake 8/28/15 #4	0571468 4994812	stream mouth with aquatic floating and emergents
Gassabias Lake 8/28/15 #5	0572163 4994977	mostly rocky shoreline with shrubs and sedges

Table 3. Freshwater and amphibious snails collected in 2015.

Viviparidae
Bellamya chinensis (J.E. Gray, 1834); 1 lake
Campeloma decisum (Say, 1817); 5 lakes
Hydrobiidae
Lyogyra possible *granum* (Say, 1822); 1 lake
Amnicola cf *limosa* (Say, 1817); 6 lakes
Lymnaeidae
Fossaria cf *obrussa* (Say, 1825); 1 lake
Pseudosuccinea columella (Say, 1817); 2 lakes
Stagnicola sp.; 1 lake
Stagnicola mighelsi (W.G. Binney, 1865); 1 lake
Physidae
Physa acuta Draparnaud, 1805; 1 lake
Physa ancillaria (Say, 1825); 1 lake
Physa gyrina (Say, 1821); 2 lakes
Planorbidae
Gyraulus deflectus (Say, 1824); 3 lakes
Gyraulus parvus (Say, 1821); 2 lakes
Helisoma anceps (Menke, 1830); 10 lakes
Planorbella campanulata (Say, 1821); 4 lakes
Planorbella trivolvis (Say, 1817); 3 lakes
Planorbula armigera (Say, 1821); 1 lake
Ancylidae
Ferrissia cf *rivularis* (Rowell, 1863); 5 lakes
Gastrodontidae
Zonitoides nitidus (Müller, 1774) (amphibious); 2 lakes
Succineidae
Catinella vermeta (Say, 1829) (amphibious); 1 lake
Oxyloma retusa (I. Lea, 1834) (amphibious); 1 lake
Limacidae
Deroceras laeve (Müller, 1774) (amphibious); 1 lake

Among native snails, the Bigmouth Pondsnail *Stagnicola mighelsi* (W.G. Binney, 1865), a Priority 1 Wildlife Action Plan species, was found at Scraggly Lake in Penobscot County. Broken shells of a *Stagnicola* species were also found at Duck Lake. To examine *S. mighelsi* ecology, freshwater snail inventory data from this study and other work between 2010 and 2015 were compiled (N = 37; Appendix 2), and preliminarily analyzed. These data show that Bigmouth Pondsnail presence is negatively correlated with snail community species richness, and positively correlated with undammed lakes (Table 4).

Key to lake characteristics:
SPPR = species richness (N = 43 waterbodies)
TST = total search time (N = 27)
SPP/T = species/time (N = 27)
LA = lake area (N = 42, Lakes of Maine website data)
LMD = lake mean depth (N = 41, LOM)
LMAXD = lake maximum depth (N = 41, LOM)
LH = lakeshore houses (N = 42, estimated from Google Earth Pro)
SD = shoreline distance (N = 42, LOM)
LHD = lake housing density (N = 42)
PH = pH (N = 30, LOM)
ALK = alkalinity (most recent, N = 36, LOM)
DO = dissolved O^2 (most recent @ I m depth, N = 39, LOM)
DA = dammed lake
PB = phosphorous (most recent bottom grab, N = 26, LOM)
PREC = phosphorus (most recent epilimnetic core, N = 39, LOM).

Table 4. Mann-Whitney U tests comparing ranked characteristics of lakes with *S. mighelsi* to those without (two-tailed test). Lakes sampled 2010-2015. Gold highlights rows with significant correlations (P > 0.1). Several autocorrelated characteristics were left out of this analysis.

variable	n_a	n_b	U_a	z	$P_{(2)}$
SPPR	6	37	193	-2.86	0.0042
LA	6	36	150	-1.49	0.1362
LMD	6	35	122	-0.49	0.6241
LHD	6	36	108	0.02	0.984
ALK	6	31	112	-0.76	0.4473
DO	6	33	111	-0.45	0.6527
DA	6	36	236	-4.58	<0.0001
PB	6	33	97	0.06	0.9522

n_a = N for lakes with *S. mighelsi*; n_b = N for lakes without *S. mighelsi*

Table 5. Spearman rank correlation coefficients for metrics from 42 lakes and one river segment sampled 2010-2015. Gold highlights critical values of P_2 = 0.10 or less (note that critical values vary with N, reported in the key to lake characteristics).

	SPPR	*TST*	*SPP/T*	*LA*	*LMD*	*LMAXD*	*LH*
SPPR	1						
TST	0.515709	1					
SPP/T	-0.06265	-0.44458	1				
LA	0.236579	0.296471	-0.31987	1			
LMD	-0.20135	-0.18464	-0.21765	0.306203	1		
LMAXD	-0.08652	-0.07532	-0.21528	0.431554	0.922605	1	
LH	0.285993	0.149844	-0.18	0.75986	0.260285	0.330103	1
SD	0.269085	0.419295	-0.23406	0.947654	0.214186	0.354272	0.740839
LHD	0.272041	-0.08119	-0.084	0.492547	0.177141	0.206594	0.91506
PH	0.210753	-0.16041	-0.19167	-0.27497	0.165967	0.164959	-0.23733
ALK	0.340222	0.203479	-0.30141	-0.18359	-0.07673	-0.2422	-0.04714
DO	0.322285	0.011593	0.23351	0.200354	0.120255	0.130499	0.241889
PB	-0.01224	-0.3401	0.320499	-0.2951	-0.60887	-0.65896	-0.18613
PREC	0.165646	0.007337	-0.11803	0.164923	-0.49097	-0.48179	0.208156

	SD	*LHD*	*PH*	*ALK*	*DO*	*PB*	*PREC*
SPPR							
TST							
SPP/T							
LA							
LMD							
LMAXD							
LH							
SD	1						
LHD	0.442902	1					
PH	-0.33372	-0.15694	1				
ALK	-0.20266	0.033206	0.554722	1			
DO	0.228257	0.22048	-0.17391	-0.07508	1		
PB	-0.21804	-0.03076	-0.00135	0.39862	0.063864	1	
PREC	0.193348	0.236685	-0.15945	0.323497	0.100798	0.828303	1

Bigmouth Pondsnail summer habitat at Scraggly Lake - sand and stone bottom with fine woody debris and sparse arrowhead and spikerush in about 0.5 m of water. DJM

To look at snail community metrics more broadly, freshwater snail species richness and lake characteristics were examined. A Spearman rank correlation test found that various lake characteristics are correlated (Table 5). Several of these are autocorrelated or confounded measures, such as lake mean depth and lake maximum depth. Species richness was correlated with many characteristics - search time, lakeshore houses, shoreline distance, lakeshore housing density, alkalinity, and dissolved oxygen. As discussed later, some of these may be spurious while others may suggest functional relationships.

Freshwater snails were lacking at large dam-controlled lakes with an impoverished littoral zone, such as this stony island beach on Mooselookmeguntic Lake in Oxford and Franklin Counties. KPH

A tributary inlet at Scraggly Lake was a productive freshwater snail habitat with abundant *Fossaria* cf *obrussa* and other species upon spatterdock and other floating aquatic plants. DJM

Discussion

This freshwater snail inventory work is based upon a brief visit or a few to each selected lake, targeting certain habitats that might have invasive or rare snails. As such, it is a rapid and extensive, but rather incomplete in its coverage of every lake's various habitats. Nor is the sampling designed to be tightly-standardized. Despite these limitations, it seems likely that more than half of the snail species present were found, at most lakes. To help with repeatability, aerial photographs were diagrammed with search areas (Appendix 1) and search time is reported (Appendix 2).

Several lakes in this project were large and oligotrophic, without an extremely rich snail fauna. Others were smaller but shallow, very rocky lakes in the relatively cold-climate region of Deboullie Ponds, also lacking in snail species richness. Adding to this, dam control at several lakes, such as Mooselookmeguntic and

Flagstaff Lake, have caused an obvious and dramatic reduction in aquatic life in littoral zones.

Snail searches have fortunately revealed that CMS are not widespread in lakes within Public Reserved Lands, which makes prevention efforts possible and timely. We did find CMS at Island Pond, where there is a dense population in one cove. The remainder of the lake had virtually no CMS – we only encountered one small specimen near the outlet – possibly because the water elsewhere is too shallow and nutrient-poor.

We attempted a rough count of CMS visible along a canoe transect in this cove, using a canoe and a plexiglass-bottomed bucket. Our estimated snail density at 0.4 snails/m^2 was extrapolated to a population size of very approximately 4,000 snails. However, it was only possible to see larger snails, and more were likely hidden among the substrate detritus. In addition, densities may vary around the cove, and there is no easy delimitation between the cove and larger lake. Because of difficulties in measuring and controlling these variables, this transect technique might be more useful as an index to population size, rather than as a population estimate *per se*.

CMS were first noted by Jen Brophy in 2001 in this cove on Island Pond, Deboullie Ponds. KPH

By comparison, a reservoir in Nebraska was estimated to have a density of 5.2 snails/m^2 throughout (eight times that of Island Pond), for a total population of 169,400 snails (Chaine et al., 2012). The study used a sophisticated and intensive mark-and-recapture technique. The size of the Nebraska reservoir was 6.5 ha and Island Pond is 14 ha.

The absence of native freshwater snails at Island Pond - probably due to its ecological and physiographic characteristics - precluded an analysis of snail community effects of the invasion. It is quite possible that no native freshwater snails existed in this lake prior to the introduction of CMS. Based upon observations in Midwestern pond “mesocosms” (Johnson et al., 2009) and natural lakes (Solomon et al., 2010) it seems very unlikely that CMS would have already extirpated all the native snails at Island Pond.

More generally, one concern raised by the mesocosm work is that in some ponds CMS extirpated a large native Lymnaeid snail (*Lymnaea stagnalis*), and Maine’s uncommon Bigmouth Pondsnail is a large Lymnaeid as well. If CMS were to invade Maine lakes with Bigmouth Pondsnail, population reductions or extirpation of the native might occur.

It may also be a concern that CMS have the potential to alter energy and nutrient flows in aquatic systems. In Northwest lakes whose native snails were lost to development, CMS provided a new food source to sustain native pumpkinseed sunfish (Twardochleb and Olden, 2016). However, where CMS populations reach high densities, as in the Nebraska reservoir discussed above, it seems that disruption effects must be dramatic.

Jen Brophy, the operator of Red River Camps on Island Pond said that she first noticed CMS in 2001. This suggests that CMS have been in the Deboullie area for at least 15 years, while our results show it has remained limited to Island Pond. Brophy also said that both black and mallard ducks are seen eating the snails, though they appear to have difficulty eating the largest snails.

Island Pond’s small size and isolation may allow for continued containment of the CMS population, provided people do not deliberately move snails to additional ponds. The relatively small size of this population may also make it a candidate for

CMS eradication. Because there are several thousand CMS, and immature snails are small, it seems unlikely that they could be eliminated by hand-picking, even if the lake were drawn down. Its large size, thick shell, and operculum are probably what make this species invulnerable to chemical treatments with rotenone or copper sulfate (Haak et al., 2014). There are no traps designed specifically catch CMS, however, developing a passive trap might be an avenue to explore. Island Pond might present an ideal test lake because there are no native snails that might also be trapped.

Signage encouraging vigilance against non-native plants and animals at lake access points was not checked during this project. Casual observation suggests it is not yet consistent or easily-seen, but a more systematic assessment is needed. Signs with bright colors, large type, graphics, and strategic placement can be effective in creating awareness for boaters and sportsmen.

Volunteers monitor invasive plants and lake water quality in many parts of Maine, often through local lake associations, and in coordination with the Maine Dept. of Environmental Protection and the nonprofit Maine Volunteer Lake Monitoring Program (VLMP). There are approximately 1,200 volunteers monitoring 500 lakes statewide (Maine Volunteer Lake Monitoring Program, 2016b). Training about invasive plants and animals, including CMS, is widely available in Maine each summer through VLMP workshops. Of the lakes inventoried in this study, only two currently have certified invasive plant volunteers - who would also have some training to identify CMS (Table 6). Eight of the lakes have never been screened for invasive plants by trained volunteers, DEP staff, or other experts. The only lake mentioned here that is receiving regular monitoring for invasive species is Mooselookmeguntic.

CMS are able to survive more than two months of exposure out of an aquatic environment (Havel et al., 2014), making them obvious candidates for accidental introduction via boats or gear travelling between lakes. Maine has a strong and growing Courtesy Boat Inspection Program coordinated by the Dept. of Environmental Protection and non-profit partners, especially the Lakes Environmental Association. In 2015, volunteer and paid boat inspectors worked at 150 boat launch sites at 117 lakes (Maine Dept. of Environmental Protection, 2016a). Information about CMS is already included in the guidelines for Courtesy Boat Inspections (Maine Dept. of Environmental Protection, 2016b). However, few if any of these boat inspections take place on interior lakes surrounded by Maine Public Reserved Lands, so there is an opportunity to expand this program onto public lands with regularly-used boat launches. Of course, some sites are too remote or infrequently used to make this practical for every boat launch on public lands.

Table 6. Monitoring of water quality and invasive species at waterbodies in this report. From Maine Volunteer Lake Monitoring Program (2016).

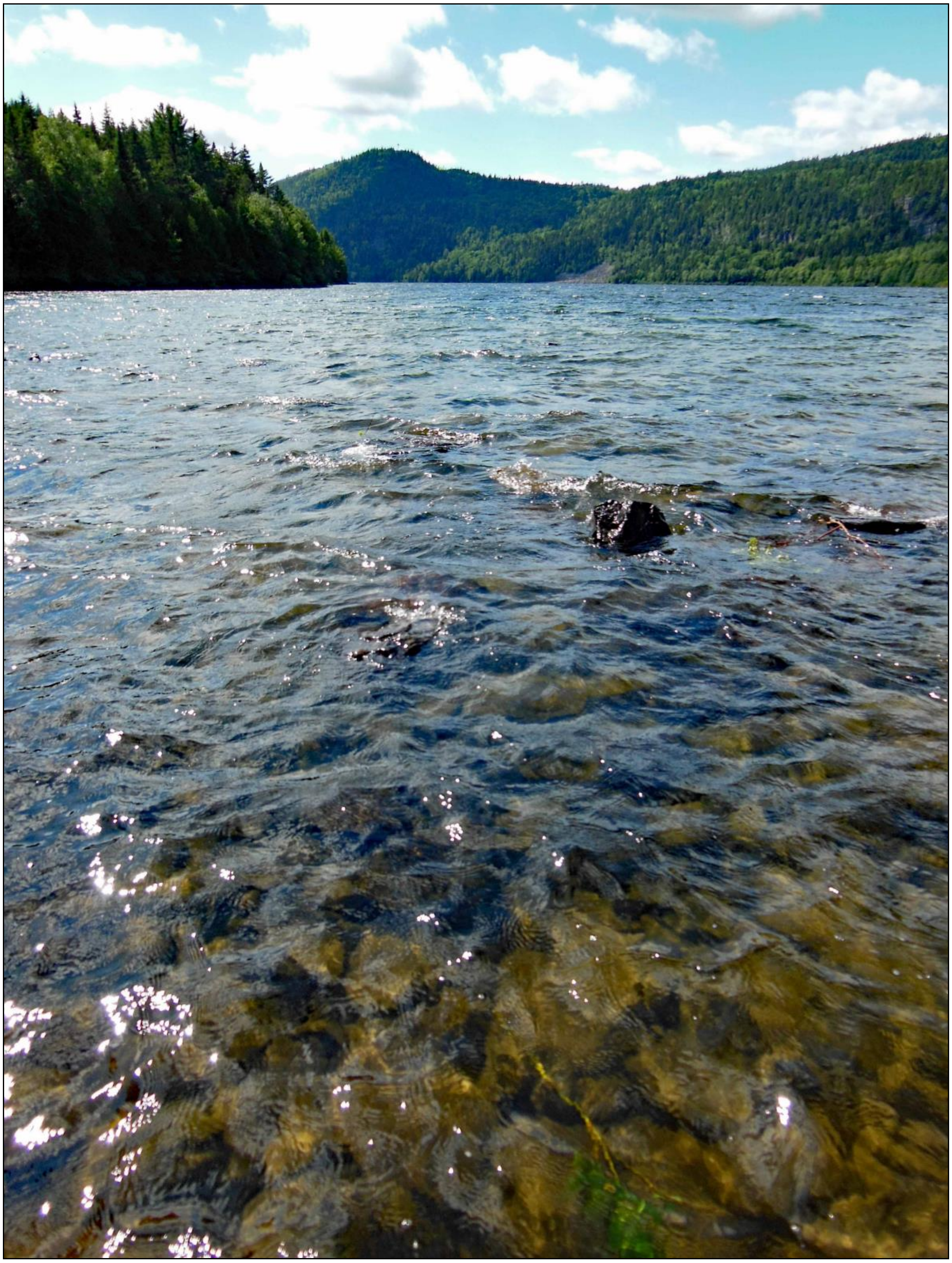
waterbody	MIDAS#	#water	#plant	invasive plant screening surveys
Gardner Pd	1528	0	0	2005 limited, agency staff
Deboullie Pd	1512	0	0	2005 limited, agency staff
Pushineer Pd	1514	0	0	0
Island Pd	1516	0	0	0
Black Pd	1506	0	0	2005 limited, agency staff
Togue Pd	1530	0	0	0
Round Pd	1470	0	0	0
Umsaskis L	1896	1	0	0
Telos L	2710	1	0	0
Scraggly L	4264	0	0	2007 limited, agency staff
Duck L	4746	0	0	2007 level 1, staff; 2014 level 1, professional
Gassabias L	4782	0	0	0
Flagstaff L	0038	0	1	2010 level 1, volunteers; 2012 level 2, vol's
Holeb Pond	2652	0	0	2004 limited, agency staff
Mooselook. L	3302	5	10	2003; 04; 06; 08; 10; 11; 12; 14 by various
Richardson L	3308	1	0	0

#water = number of certified water quality monitor volunteers
#plant = number of certified invasive plant monitor volunteers

As freshwater snail inventory of Maine lakes continues, cumulative data reveals more about these communities. While the analysis here suggests the Bigmouth Pondsnail appears to be associated with lakes lacking dams and with relatively species-poor snail communities, a better-controlled data set is needed for a conclusive result. The data complied so far should be interpreted with caution for several reasons. Most of the inventory work has been aimed at a preliminary assessment of species presence, and is not designed (or funded) for more intensive, quantitative work. The relative populations of species are not measured - shells found in wrack, for example, provide evidence of species presence, but not population size. In analysis, pseudoreplication is a problem, as data from different lakes collected in the same year are treated as independent samples. For example, annual variation in weather may impact the detection of species. And, as with any large dataset, some spurious correlations should be expected.

Rusty Crayfish (*Orconectes rusticus*) were not the subject of our current investigation. However, literature on this crayfish, a native to the U.S. Midwest, suggests the potential for dramatic effects upon freshwater ecosystems in Maine. In combination with CMS, this crayfish has the potential to reduce native freshwater snails (e.g. Johnson et al., 2009). The Rusty Crayfish is already present in Maine (Reid and Scott, 2006) and the VLMP has initiated volunteer sampling for this species (2016c). Research into non-native crayfish distribution and impacts may be helpful and timely.

Rusty Crayfish by Jeff Gunderson, from the VLMP website.



Deboullie Pond in Aroostook Co. KPH

The inlet to Round Pond on the Allagash Wilderness Waterway had abundant eelgrass and other floating aquatic vegetation that harbored freshwater snails. DJM

Recommendations

1) Inventory invasive animal and plant signage at water access points on public lands, and where needed, develop and/or deploy high-visibility signs to help prevent freshwater snail and other invasions.
2) Establish regular monitoring of lakes within public lands for invasive species outbreaks - including freshwater snails - by staff, certified volunteers, or professionals.
3) Expand Courtesy Boat Inspection Program voluntary inspections to access points on Maine public lands where practicable.
4) Develop a CMS trap for testing upon selected invasive snail populations.
5) Continue work to locate and conserve rare snail species and high-quality freshwater snail communities.
6) Expand research into Rusty Crayfish (*Orconectes rusticus*) distribution and impacts.

Derek J. Moore at Deboullie Pond KPH

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Sunset at Duck Lake, Hancock Co. KPH

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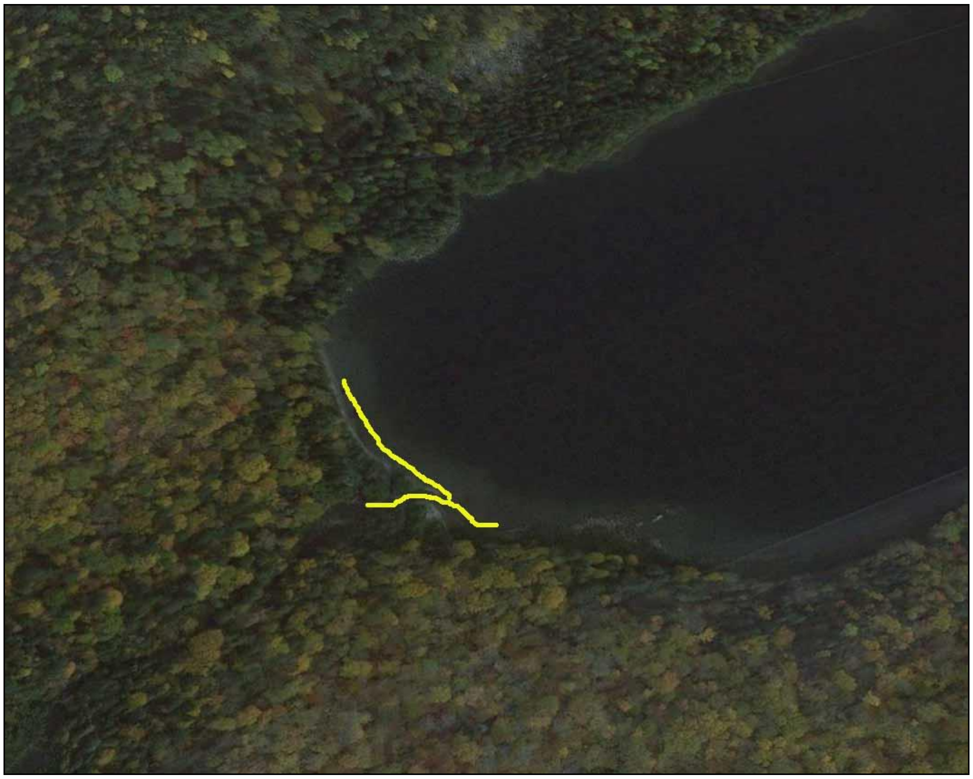
About the Investigator

Kenneth P. Hotopp is an environmental consultant specializing in land snails and still learning about freshwater snails. He is interested in various other invertebrate and plant taxa, old forest, and habitat restoration as well. Ken's company, Appalachian Conservation Biology, is active in eastern North America from Maine to Virginia. He is also a Research Associate of the Section of Mollusks, Carnegie Museum of Natural History. Ken has a BS in forest biology from SUNY College of Environmental Science and Forestry, and an MS in animal behavior from the State University of New York, Albany.

Appendix 1. Google Earth aerial photographs of freshwater snail collection sites. Yellow lines indicate littoral zone and wetland areas searched.

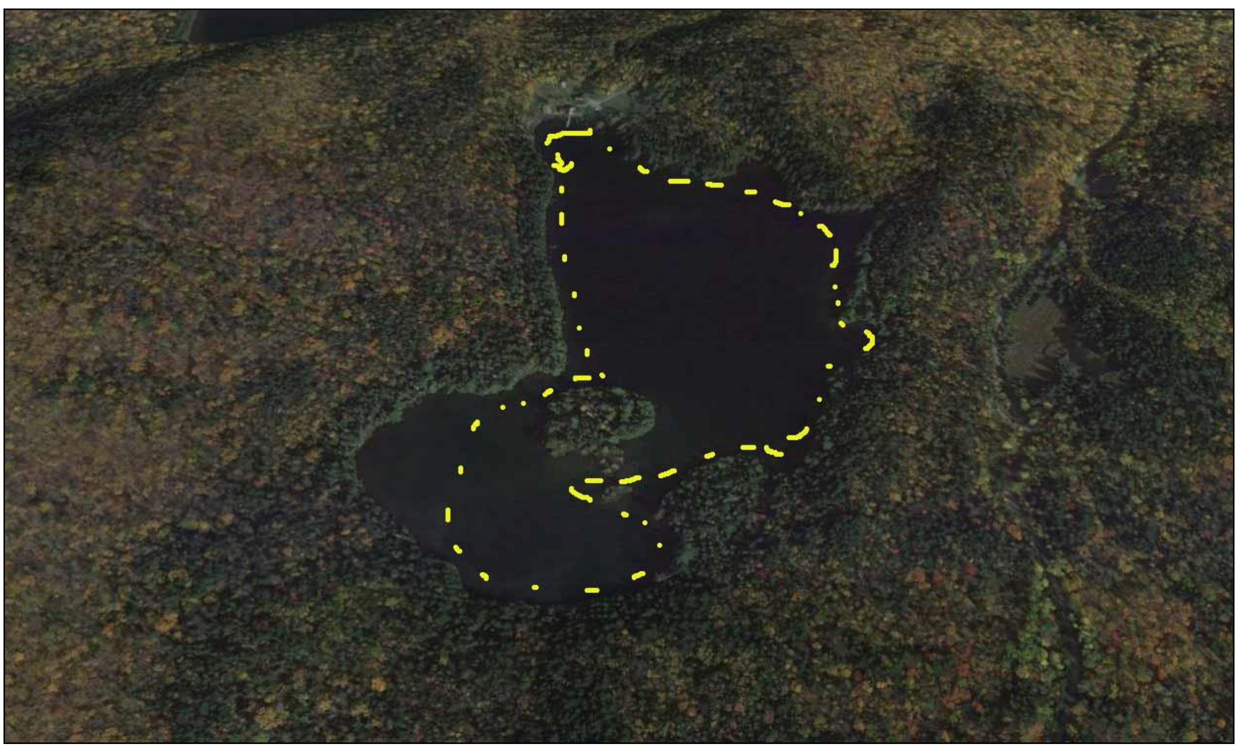
Gardner Pond at Deboullie Ponds PRL: 7/22/15 #1 (top) and #2 (bottom)



Deboullie Pond at Deboullie Ponds PRL: 7/22/15 #3 (above) and #4 (below)

Pushineer Pond at Deboullie Ponds PRL: 7/22/15 #5 (above)

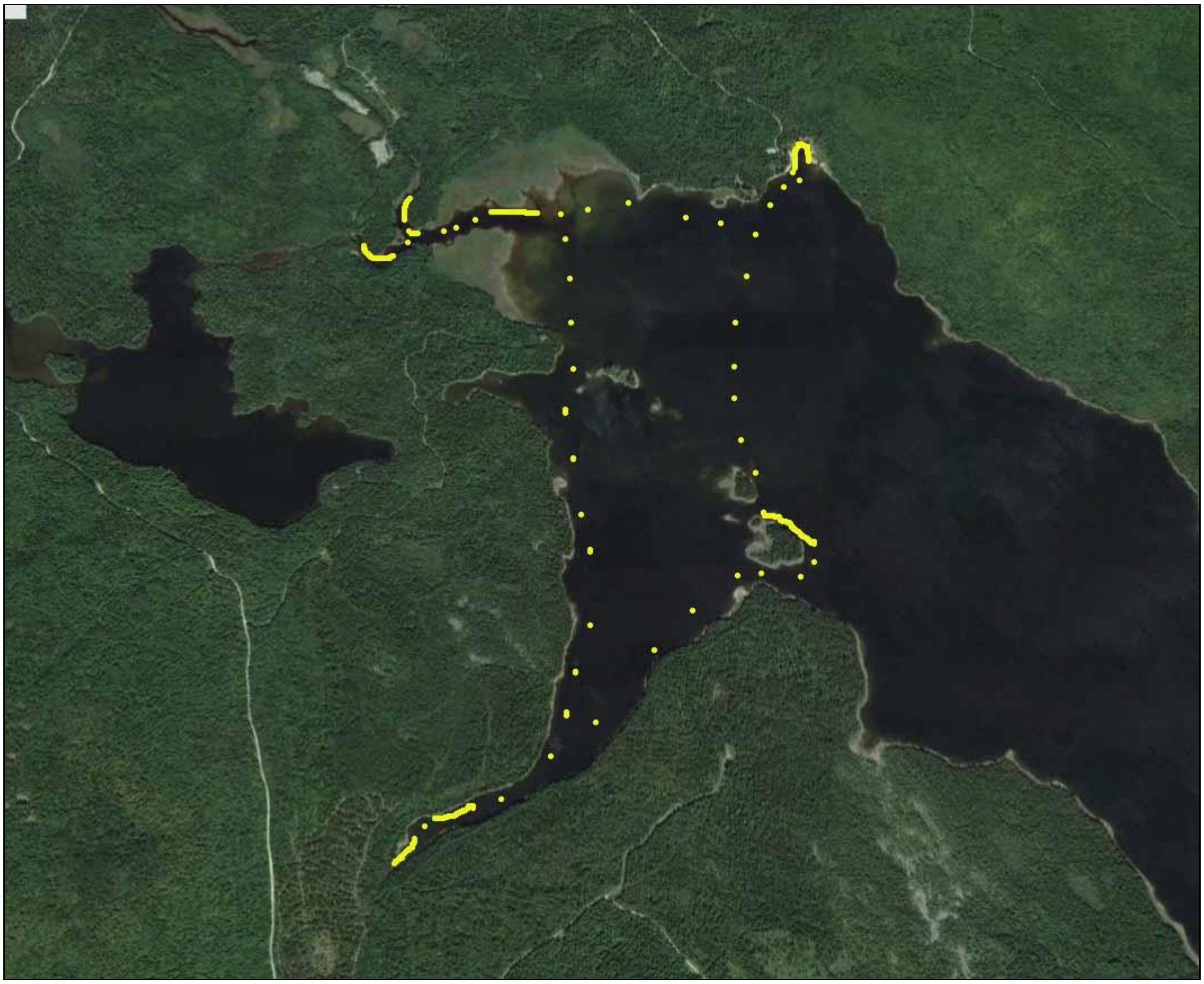
Black Pond at Deboullie Ponds PRL: 7/23/15 #2 (above)



Island Pond at Deboullie Ponds PRL: 7/23/15 #4 (above)

Togue Pond at Deboullie Ponds PRL: 7/23/15 #5 (above)

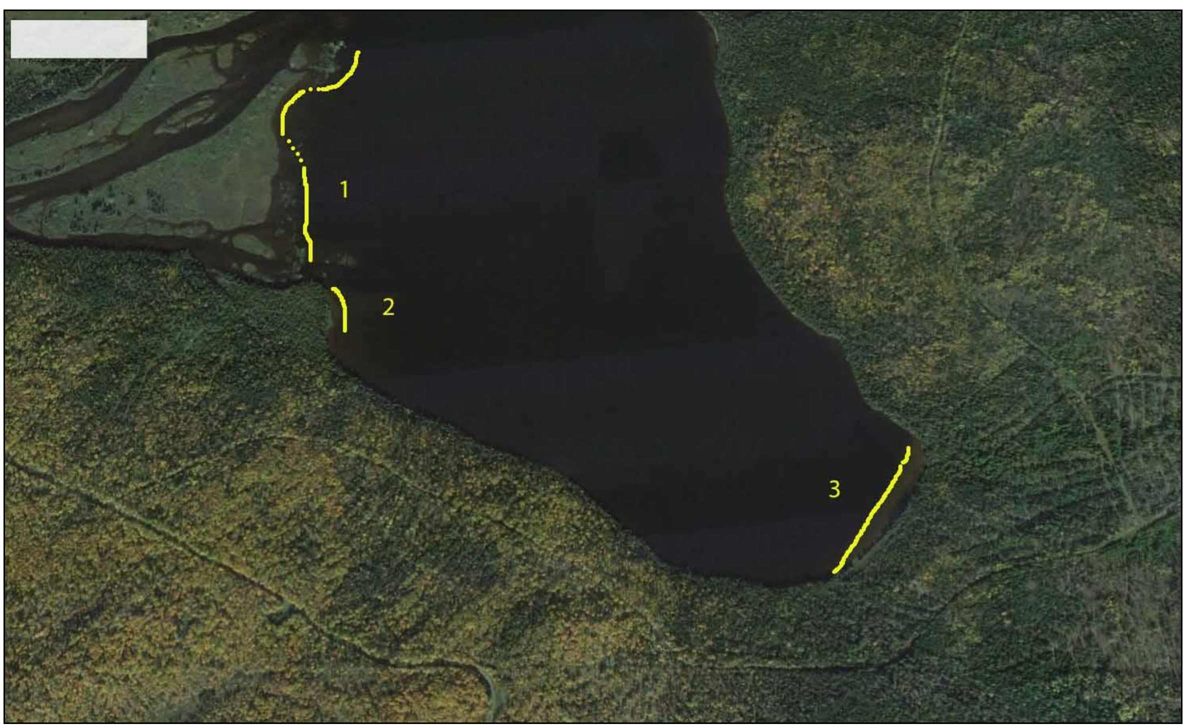
Little Mud Pond (upper center-right): 8/5/15; Mooselookmeguntic Lake, Griffin Is.: 8/6/15 #1



North Arm Richardson Lake: 8/8/15 #1

Flagstaff Lake: 8/20/15 #1 and #2 (top); 8/20/15 #3 (above)

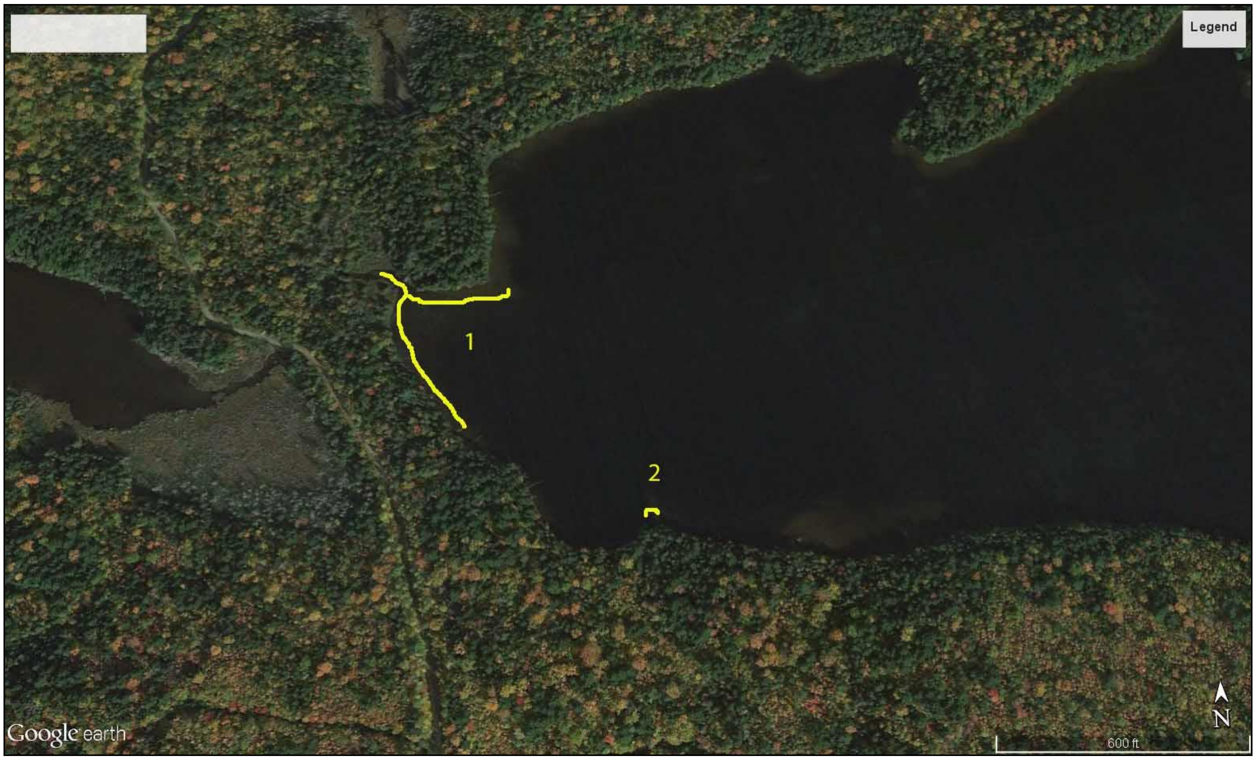
Flagstaff Lake: 8/20/15 #4



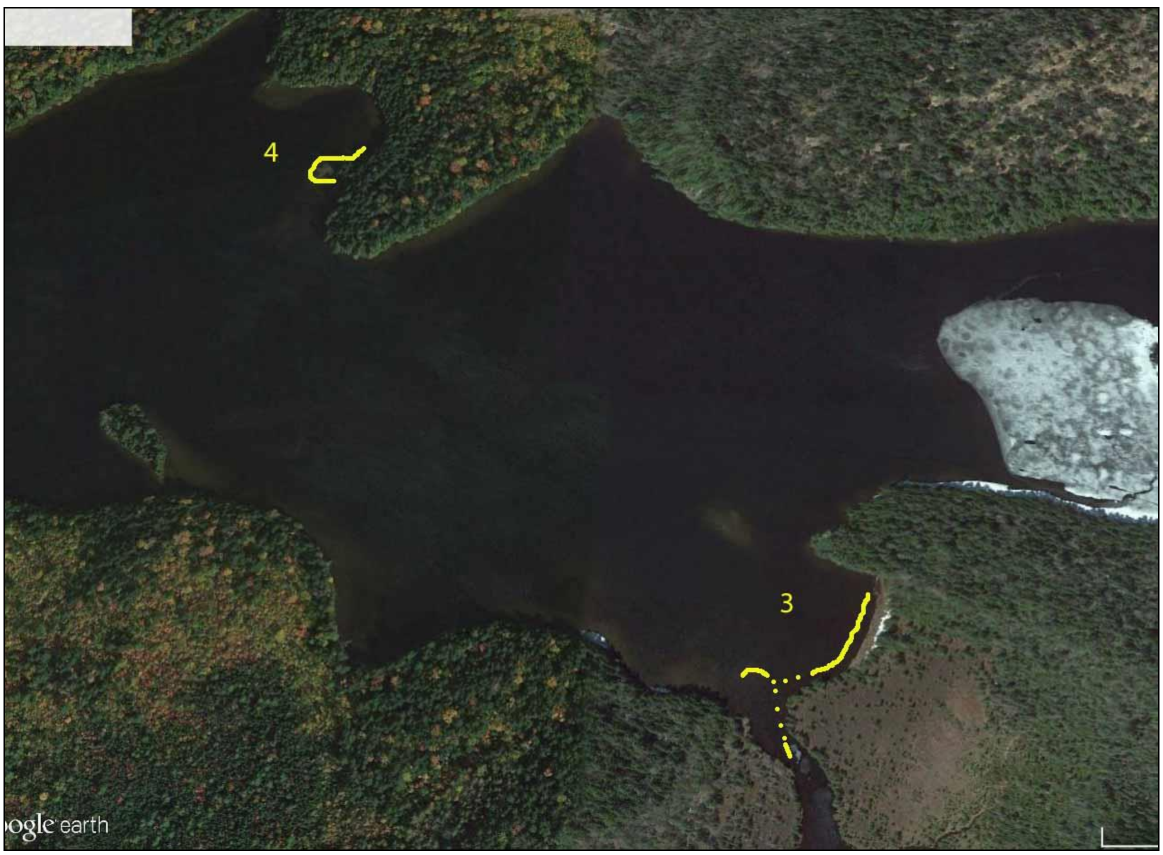
Round Pond, Allagash Wilderness Waterway: 8/25/15 #1, #2, and #3

Umsaskis Lake, Allagash Wilderness Waterway: 8/25/15 #4 and #5

Telos Lake, Allagash Wilderness Waterway: 8/26/15 #1 and #2



Scraggly Lake: 8/27/15 #1 and #2 (above): 8/27/15 #3 and #4 (below: white is ice)



Duck Lake: 8/28/15 #1 and #2 (above); Gassabias Lake 8/28/15 #3, #4, and #5 (below)

Appendix 2. Freshwater snail inventory summary data 2010-2015. Digital file Excel spreadsheet.