Short Communication

Exploring malacological observations on iNaturalist: Citizen science as a tool for monitoring freshwater mussels

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Abstract

The aim of the present work was to determine the presence of freshwater mussels on the citizen science platform, iNaturalist, and present novel information on both threatened species and non-threatened species within the US. I assessed whether observations among these groups increased annually and states in which observations were high. Using this approach, I noted an increase for the amount of observations, and overall there were more observations for least concern species, with primarily Midwestern states having more observations, with the exception of Alabama and Texas, and South Dakota which had a large number of observations. Subsequently, this citizen science platform and online database may provide an avenue for future malacological monitoring across Unionidae mussels and serve as a companion to more traditional field surveys in aquatic ecosystems.

Keywords: Citizen science, Aquatic conservation, Unionida, Environmental management, Mussel assemblages, Freshwater science

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Introduction

Freshwater mussels, including those in the order Unionida, are among the most threatened aquatic species, with dramatic declines occurring throughout the United States (Anthony and Downing, 2001; Lopes-Lima *et al*., 2021). While many state natural resource agencies actively manage freshwater mussel populations (Bouska *et al*., 2018), there remain challenges coordinating surveying efforts, funding, etc., in documenting declines and future monitoring in aquatic conservation. Citizen science presents one method where monitoring aquatic resources can assist in collecting data on stream ecological patterns (Millar *et al*., 2023). Therefore, developing new methods for future monitoring which incorporate citizen science techniques are warranted for freshwater environments.

Among databases used for citizen science, iNaturalist (www.inaturalist.org), is emerging as a popular application utilized by the public in the field with cellphones. Previous studies have utilized this platform in aquatic ecosystems to conduct freshwater invertebrate surveys (Daniels *et al*,. 2022), and identify invasive freshwater mollusks (Tiemann *et al*., 2022). However, to date and the author's awareness, there is a dearth of published data on whether the number of observations on this citizen science platform include various threatened and non-threatened species and their distribution across the U.S. To this end, I assessed iNaturalist to document the total number of Unionida species presence, overall representation across states and region. Moreover, I quantified differences among freshwater mussels with and without special conservation status, if observations are increasing annually, and report on overall trends for freshwater mussels on iNaturalist within the U.S, as of 2023.

Methodology

The application iNaturalists was searched using the Explore tab using the following search parameters: "Order Unionida" (Freshwater Mussels), location = USA, with filters of "Verifiable" , "Research Grade", and "Wild". In order to compare the number of special conservation status species, an additional search was performed using "threatened". Species listed as threatened were assigned IUCN conservation status (i.e., EN for endangered, VU for vulnerable, etc.), with those not listed as threatened also assigned IUCN category (e.g., LC for least concern). The search was further constrained to include only observations up to December 31, 2023, using the "Date observed" filter, in order to compare annual observations for both threatened and non-threatened species. Observations were exported and downloaded on 02/14/2024.

Data was sorted in excel and primarily descriptive statistics are reported for major trends in observations and representative freshwater mussels across states in this short communication. I ran a Spearman's Rho correlation to assess the correlation between year and total number of

observations, beginning in 2008 to 2023, as 2008 is the year iNaturalist was introduced (Michonneau and Paulay, 2015). I compared the number of observations for listed species (Endangered, Near Threatened, Vulnerable, etc.) and not listed (LC) with a Man Whitney U test using a subset of species with a minimum of five observations. A heat map was generated for total observations of freshwater mussels across states to examine trends in species across regions of the U.S.

Results

In total, 32181 observations were assessed in this short communication, representing data from 228 species, 5,388 observers, and 1,217 identifiers. The number of observations increased annually, with the number of observations from 2008 to 2023 (Fig. 1), Spearman's Rho Correlation R=0.982, p=0.01.

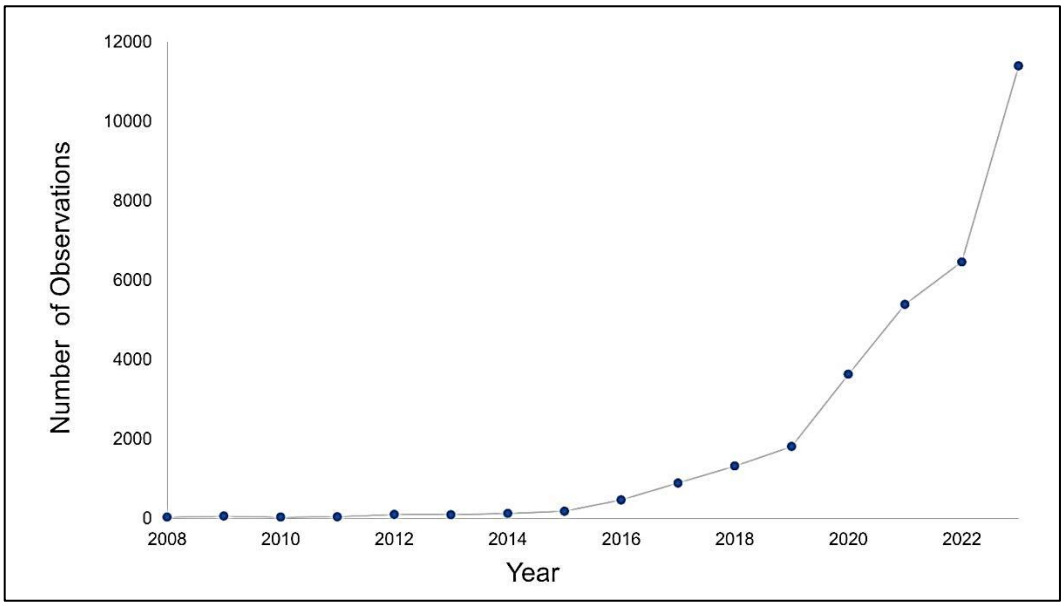

Figure 1: Number of freshwater mussel observations per year on iNaturalist showing annual increase up to 2023.

The month with the lowest percentage of observation occurred in January and December (2% for each), with 67.9% of observations occurring mostly during summer to fall months (range of 10.9% to 15.7%) across June to October. 27,856 observations and 4,018 observations, for non-listed and listed species, respectively, met the criteria for minimum of five observations per species (75 listed species, and 98 non-listed species). There was a significant difference between the number of observations for listed versus non-listed species, U=2144, p<0.001, median listed species=21, median non-listed species=76. States with the most number of observations include those within the Midwest and Southern U.S., Alabama (4,477), Wisconsin (3,715), South Dakota (3,191), Texas (3,172), Minnesota (1,928), Ohio (1,780), Illinois (1,693), Missouri (1,599), and Tennessee (1,152) (Fig. 2). Species with

the highest number of observations were primarily those listed as LC, with the Giant Floater, *Pyganodon grandis*, with 3168 observations, and NT, near threatened Western Pearlshell, *Margarififera falcata* having the highest number of observations for a listed species, with 611 observations (Table 1).

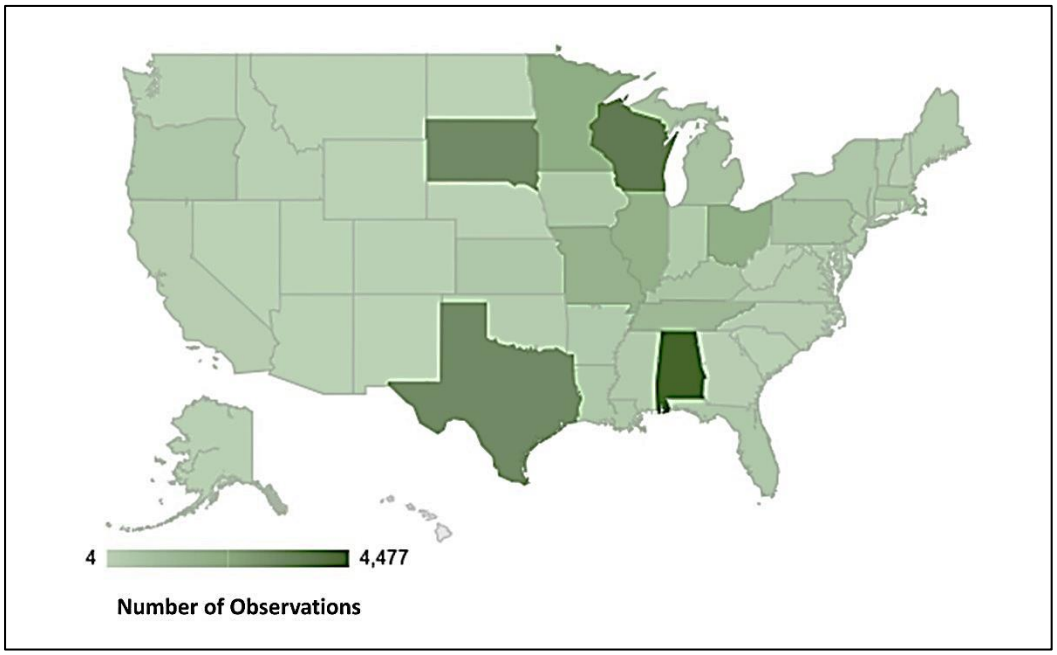

Figure 2: Heat map of observations of freshwater mussels across U.S. states on iNaturalist illustrating Midwestern and Southern states with highest number of observations.

Table 1: Scientific name, common name, number of observations, and conservation status of freshwater mussels in USA on iNaturalist (up to 12/31/2023) organized according to highest number of observations.

Scientific Name	Common Name	Number of Observations	Conservation Status
Pyganodon grandis	Giant Floater	3168	LC
Elliptio complanata	Eastern Elliptio	1727	LC
Lampsilis siliquoidea	Fatmucket	1657	LC
Amblema plicata	Three-ridge Mussel	1654	LC
Lampsilis cardium	Plain Pocketbook	1638	LC
Quadrula	Mapleleaf	1285	LC
Potamilus fragilis	Fragle Papershell	1138	LC
Utterbackia imecillis	Paper Pondshell	1137	LC
Lampsilis teres	Yellow Sandshell	1015	LC
Cyclonaias pustolosa	Pimpleback	882	LC
Fusconaia flava	Wabash Pigtoe	809	LC
Potamilus alatus	Pink Heelsplitter	795	LC
Lasmigona complanata	White Heelsplitter	675	LC
Eurynia dilatata	Spike	641	LC
Obliquaria reflexa	Three-horn Wartyback	632	LC
Margaritifera falcata	Western Pearlshell	611	NT
Pyganondon cataracta	Eastern Floater	560	LC
Truncila truncata	Deertoe Mussel	514	LC

Table 1(continued):

Scientific Name	Common Name	Number of Observations	Conservation Status
Ortmanniana ligamentina	Mucket	497	LC
Lasmigona costata	Flutedshell	445	LC
Tritogonia verrucosa	Pistolgrip	445	LC
Potamilus ohiensis	Pink Papershell	419	LC
Ligumia recta	Black sandshell	410	NT
Alasmidonta marginata	Elktoe	299	LC
Potamilus purpuratus	Bleufer	285	LC
Strophitus undulatus	Creeper	271	LC
Ellipsaria lineolata	Butterfly Mussel	257	NT
Cyclonaias tuberculata	Purple Wartyback	257	NT
Uniomerus tetralasmus	Pondhorn	252	LC
Toxolasma parvum	Lilliput	251	LC
Megalonaias nervosa	Washboard	247	LC
Elliptio jayensis	Florida Spike	238	LC
Reginaia ebenus	Ebonyshell	234	LC
Cyclonaias kieneriana	Alabama Orb	221	NT
Utterbackiana suborbiculata	Flat Floater	201	LC
Lampsilis fasciola	Wavyrayed Lampmussel	199	LC
Elliptio crassidens	Elephant Ear	196	LC
Truncilla donaciformes	Fawnsfoot	191	LC
Venustaconcha ellipsiformes	Ellipse	189	LC
Sagitunio subrostratus	Pondmussel	170	LC
Lampsilis radiata	Eastern Lampmussel	167	NT
Toxoplasma texasiense	Texas Lilliput	166	LC
Plectomerus dombeyanus	BankClimber	161	LC
Ptychobranchus fasciolaris	Kidneyshell	157	NT
Lampsilis ornata	Southern Pocketbook	154	LC
Pleurobema sintoxia	Round Pigtoe	153	LC
Cambarunio iris	Rainbow Mussel	148	LC
Theliderma cylindrica	Rabbitsfoot	141	NT
Cambarunio taeniatus	Painted Creekshell	130	LC
Sagittunio nasutus	Eastern Pondmussel	128	VU
Anodontoides ferussacianus	Cylinjdrical Papershell	123	LC
Lampsilis ovata	Pocketbook	116	LC
Utterbackiana implicata	Alewife Floater	107	LC
Margaritifera	Freshwater Pearl Mussel	104	EN
Atlantichoncha ochracea	Tidewater Mucket	102	NT
Leaunio lienosus	Little Spectaclecase	99	LC
Arcidens confragosus	Rock-Pocketbook	98	LC
Epioblasma triquetra	Snuffbox	97	EN
Obovaria subrotunda	Round Hickorynut	87	EN
Lampsilis hydiana	Louisiana Fatmucket	84	LC
Obovaria olivaria	Hickorynut	80	LC
Leaunio vanuxemensis	Mountain Creekshell	77	LC
Fusconaia cerina	Gulf Pigtoe	75	LC
Uniomerus declivis	Tapered Pondhorn	73	LC
Tritogonia nobilis	Gulf Mapleleaf	68	LC
Theliderma metanevra	Monkeyface Mussel	68	LC
Epidoblasma brevidens	Cumberlandian Combshell	64	CR
Lampsilis higginsii	Higgins' Eye Pearly Mussel	58	EN
Pleuronaia dolabelloides	Slabside Pearlymussel	56	EN
Toxolasma lividum	Purple Liliput	56	LC
Villosa vibex	Southern Rainbow	55	LC
Lasmigona compressa	Creek Healsplitter	54	LC

Table 1(continued):

Scientific Name	**Common Name**	**Number of Observations**	**Conservation Status**
Gonidea angulata	Western Ridged Mussel	53	VU
Lemiox rimosus	Birdwing Pearlymussel	51	CR
Pleuronaia barnesiana	Tennessee Pigtoe	51	LC
Alasmidonta viridis	Slippershell Mussel	50	LC
Lampsilis straminea	Rough Fatmucket	49	NT
Epidoblasma rangiana	Northern Riffleshell	45	CR
Toxolasma cylindrellum	Pale Lilliput	43	CR
Lampsilis cariosa	Yellow Lampmussel	42	VU
Lampsilis virescens	Alabama Lamp Naiad	39	CR
Elliptio fisheriana	Northern Lance	39	LC
Beringiana	Yukon Floater	38	LC
Elliptio pullata	Gulf Spike	37	LC
Pyganodon lacustris	Lake Floater	37	LC
Pleurobema clava	Clubshell Pearly Mussel	36	CR
Pleurobema decisum	Southern Clubshell	34	EN
Cyclonaias nodulata	Wartyback	34	LC
Potamilus amphichaenus	Texas Heelsplitter	32	EN
Lampsilis satura	Sandbank Pocketbook	32	NT
Cyprogenia aberti	Western Fanshell	32	LC
Ptychobranchus occidentalis	Ouachita Kidneyshell	31	NT
Anodonta nuttalliana	Winged Floater	31	VU
Plethobasus cyphyus	Sheepnose	30	EN
Lasmigona alabamensis	Alabama Heelsplitter	30	NT
Cyprogenia stegaria	Fanshell	29	CR
Glebula rotundata	Round Peaerlshell	28	LC
Lampsilis bracteata	Texas Fatmuckeet	26	NT
Alasmidonta undulata	Triangle Floater	26	LC
Epioblasma ahlstedti	Duck River Dartersnapper	25	CR
Truncilla macrodon	Texas Fawnsfoot	25	CR
Cumberlandia monodonta	Spectaclecase	24	EN
Lampsilis reeveiana	Arkansas Brokenray	24	LC
Fusconaia chunii	Texas Pigtoe	23	LC
Medionidus conradicus	Cumberland Moccasinshell	21	NT
Pleurobema oviforme	Tennessee Clubshell	21	VU
Cyclonaias necki	Guadalupe Orb	21	LC
Lampsilis abrupta	Pink Mucket	20	VU
Theliderma johnsoni	Southern Monkeyface	20	LC
Cyrtonaias tampicoensis	Tampico Pearly Mussel	19	EN
Margaritifera marrianea	Alabama Pearlshell	18	EN
Lampsilis floridensis	Florida Sandshell	18	LC
Ptychobranchus subtentus	Fluted Kidneyshell	17	EN
Uniomerus carolinianus	Eastern Pondhorn	17	LC
Villosa amygdalum	Florida Rainbow	17	LC
Fusconaia escambia	Narrow Pigtoe	16	EN
Cyclonaias petrina	Texas Pimpleback	16	EX
Potamilus streckersoni	Brazos Heelsplitter	16	LC
Cyclonaias succissa	Purple Pigtoe	15	LC
Lampsilis sietmani	Canary Kingshell	13	LC
Elliptio arctata	Delicate Spike	13	LC
Margaritifera hembeli	Louisiana Pearlshell	12	CR
Fuscinaia cor	Shiny Pigtoe	12	CR
Hamiota altilis	Finelined Pocketbook	12	EN
Epioblasma penita	Penitent Mussel	11	CR
Pleurobema perovatum	Ovate Clubshell	11	EX

Table 1(continued):

Scientific Name	Common Name	Number of Observations	Conservation Status
Cambarunio nebulosus	Alabama Rainbow	11	LC
Elliptio arca	Alabama Spike	11	LC
Amblema elliotti	Coosa Fiverridge	11	LC
Leaunio ortmanni	Kentucky Creekshell	11	LC
Anodonta kennerlyi	Western Floater	11	LC
Cambarunio hesperus	Western Rainbow	11	LC
Popenaias popeii	Texas Hornshell	10	CR
Anodonta californiensis	California Floater	10	LC
Pleurobema athearni	Canoe Creek Clubshell	10	LC
Lampsilis bergmanni	Guadalupe Fatmucket	10	LC
Fusconaia ozarkensis	Ozark Pigtoe	10	LC
Theliderma intermedia	Cumberland Monkeyface	9	EN
Lampsilis rafinesqueana	Neosho Mucket	9	EN
Pleurobema cordatum	Ohio Pigtoe	9	NT
Fusconaia subrotunda	Long Solid Mussel	9	VU
Leaunio umbrans	Coosa Creekshell	9	LC
Quadrula fragosa	Winged Mapleleaf	8	CR
Venustaconcha trabalis	Tennesee Bean	8	CR
Potamilus inflatus	Inflated Heelsplitter	8	EN
Pleurobema riddellii	Louisiana Pigtoe	8	NT
Pleurobema rubrum	Pyramid Pigtoe	8	NT
Pleruobema strodeanum	Fuzzy Pigtoe	8	VU
Obovaria arkansasensis	Southern Hickorynut	8	VU
Utterbackiana couperiana	Barrel Floater	8	LC
Utterbackiana hartfieldorum	Cypress Floater	8	LC
Villosa delumbis	Eastern Creekshell	8	LC
Elliptio occulta	Mystical Freshwater Mussel	8	LC
Medionidus acutissimus	Alabama Moccasinshell	7	EN
Paetulunio fabalis	Rayed Bean	7	EN
Obocaria unicolor	Alabama Hickorynut	7	NT
Alasmidonta varicosa	Brook Floater	7	VU
Simpsonaias ambigua	Salamander Mussel	7	VU
Cyclonaias infucata	Sculptured Pigtoe	7	VU
Lasmigona etowaensis	Etowah Heelsplitter	7	LC
Anodonta oregensis	Oregon Floater	7	LC
Strophitus radiatus	Rayed Creekshell	7	LC
Ptychobranchus foremanianus	Rayed Kidneyshell	7	LC
Epioblasma capsaeformis	Oyster Mussel	6	EN
Ellip[tio congaraea	Carolina Slabshell	6	NT
Ortmanniana pectorosa	Pheasantshell	6	NT
Lampsilis brittsi	Northern Brokenray	6	VU
Hamiota subangulata	Shiny-rayed Pocketbook	6	LC
Fusconaia mitchelli	False Spike	5	CR
Hamiota perovalis	Orangenacre Mucket	5	NT
Pleurobema rubellum	Warrior Pigtoe	5	NT
Pseudodontoideus connasaugaensis	Alabama Creekmussel	5	VU
Potamilus metnecktayi	Salina Mucket	5	LC

*Note: IUCN listing included (LC=Least Concern, NT=Near Threatened, VU=Vulnerable, EN=Endangered, CR=Critically Endangered, EX=Extinct).

Discussion

These results indicate that iNaturalist may indeed function as a tool allowing for monitoring of Unionida mussels as an exemplar for species inhabiting aquatic ecosystems. Particular of

interest, the state with the most observations, Alabama, is known to house roughly 60% of mussel fauna (Grabarkiewicz and Davis, 2008; Williams *et al*., 2008). Moreover, there was representation of species across states, with trends for less observations for conservation status (listed) species. Qualitatively, when assessing images in iNaturalist, many images included both live and dead Unionida individuals held in hand by observers, with clear morphological identifying features for identification. In some cases, observations included one shell with complete dorsal and ventral margins visible or both, complete shells present. Follow up research using iNaturalist could determine local areas where conservation efforts and surveys could occur. Moreover, as growth annulus were visible for well preserved or live shells in observations, age and date could be further evaluated within species to determine trends for age estimates of adults across states.

One caveat of this short communication regards the accuracy of species identification on iNaturalist. While I only used research grade observations, there is the possibility that some species may be misidentified, particularly those that may require expert evaluation. However, in many observations mussels were held in hand with clear morphological features present, which may indicate that most species are identified properly on the application and validated by expert naturalists. Future research could examine the percentage of properly identified freshwater mussels. In addition, future studies could access iNaturalist observations, state records, alongside scientific datasets for freshwater mussels and assess trends in geographic distribution, as management may benefit from utilizing multiple widely available data sources (Hopper *et al*., 2023).

As citizen science is increasing globally (Peters *et al*., 2019), future monitoring aquatic environments which incorporates communities, stream recreationists, fishermen, etc. may be one avenue for long term approaches to encourage the participation of non-researchers as a resource for data collection in aquatic ecosystems. Citizen science projects have previously been utilized to monitor invasive quagga mussels using recreational divers (Brümmer *et al*., 2021) and a similar approach may be beneficial for recreational divers, kayakers, and recreationalist within local regions using this emerging application and online database. In addition, this database could be used to check for rare species observations and conduct follow up surveys in streams where potentially rare species are encountered by observers, as freshwater mussel surveys should be targeted to ensure high probability of detecting species presence (Smith, 2006). iNaturalist could, for example, be utilized to search for locations of *Simpsonaias ambigua*, Salamander Mussel, for which there were 7 observations. Moreover, as the highest number of observations occurred during June to October, citizen science

programs and surveys could target these time frames. Subsequently, having citizen science volunteers acquire data on existing citizen science platforms in aquatic environments can aid in sustainable management strategies, enabling a "many eyes on the water" approach for freshwater mussels (Tricarico, 2022). Therefore, iNaturalist may provide a tool for current and future monitoring and conservation of both listed and non-listed freshwater mussel distributions across aquatic ecosystems.

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