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Registered Office: 3A2 Varadarajulu Nagar, FCI Road, Ganapathy, Coimbatore, Tamil Nadu 641006, India
Ph: +91 9385339863 | www.threatenedtaxa.org
Email: sanjay@threatenedtaxa.org

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continued on the back inside cover

Cover: Life and death in one night - wolf hunting the hare. Mixed media—gouache, acrylics, pen & colour pencils. © Dupati Poojitha.

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COMMUNICATION

Citizen science conservation: a case study using two threatened large aquatic American salamanders (Amphibia: Urodela), the Common Mudpuppy *Necturus maculosus* (Proteidae) and the Eastern Hellbender *Cryptobranchus alleganiensis* (Cryptobranchidae) observations on iNaturalist

Shem Unger

Biology Department, Wingate University, Wingate, North Carolina 28174, USA.
s.unger@wingate.edu

Abstract: Amphibians are facing threats globally which can present challenges to managers seeking to document declines. Citizen science platforms are emerging as an effective tool to document presence of species worldwide. However, little is known regarding the ability to characterize trends of large, fully aquatic easily identifiable salamander presence on these platforms within North American freshwater habitats, as a proxy for monitoring threatened species. This manuscript provides a baseline for the use of iNaturalist observations to characterize life history and anthropogenic factors associated with two amphibian species in decline, the Eastern Hellbender *Cryptobranchus alleganiensis* and Common mudpuppy *Necturus maculosus* salamanders. I report on predatory behavior, percent alive versus dead, and potential impacts of fishing on these salamanders. Conservation approaches such as those presented in this communication can provide a method for monitoring species using the power of citizen science in areas where researchers are managing threatened populations of amphibians.

Keywords: Amphibian declines, aquatic conservation, biodiversity, community science, herpetology.

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Author details: Dr. Shem Unger is an associate professor of Biology at Wingate University. He researches amphibian and reptile conservation and conducts research on the Eastern Hellbender Salamander.

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INTRODUCTION

Threats to freshwater biodiversity can include decreased water quality, habitat degradation, and microplastic pollution (Ahmed et al. 2022). Moreover, worldwide amphibians are facing numerous threats, including habitat destruction, fragmentation, emerging infectious diseases, and synergistic impacts (Green et al. 2020). Salamanders found in streams may be especially susceptible to environmental changes brought on by climate change (Lowe 2012). Two large fully aquatic salamanders which have a wide geographic range and are readily identified, are the Eastern Hellbender, *Cryptobranchus alleganiensis* (Daudin, 1803), and the Common Mudpuppy *Necturus maculosus* (Rafinesque, 1818). While information is lacking, mudpuppies may be experiencing declines (Lannoo et al. 1994; Hoffman et al. 2014), as they are often found in similar habitats with hellbenders (Nickerson et al. 2002). Purported reasons for mudpuppy declines include chemical pollution from lampricide and siltation alongside degraded habitat (Bonin et al. 1995; Matson 2005) and exploitation by biological supply companies (Holman 2012). Mudpuppies are regularly captured as bycatch during ice fishing, as they are active during the winter (Lennox et al. 2018). Eastern Hellbender declines are characterized by a lack of recruitment, with populations primarily comprised of older adults across their historical geographic range (Wheeler et al. 2003, Keitzer et al. 2013). Therefore, methods are needed which allow for temporal monitoring of these populations using effective, low costs non-invasive solutions. One potential solution to this issue is citizen science monitoring.

Citizen science monitoring via natural history databases has allowed for rare, threatened species to be documented and shared with the scientific community (Wilson et al. 2020). Among the many citizen science platforms, iNaturalist (www.inaturalist.org) is rapidly emerging as a powerful tool to document species presence, as a popular smartphone application where users upload images which are later identified by experts (Nugent 2018). Data obtained from citizen science participants on this platform can provide valuable freely accessible data, in many cases accurate to the species level (Wittmann et al. 2019). While this application has been used to assess injury rates of turtles (Seburn et al. 2023) and document invasive reptiles (Mo & Mo 2022), further work needs to consider how this citizen science data can contribute to monitoring rare species, their interactions with recreationalists, and potentially document mortality and even ecological connections with other species.

In order to test the potential for iNaturalist as a monitoring tool for threatened amphibian taxa, I quantified observations for two readily identifiable aquatic salamanders, the Eastern Hellbender and the Common Mudpuppy in the United States across their geographic range. The aim of this study is to determine: i) the overall presence of observations for each species, ii) any trends for annual increased use of the application using yearly observations as a proxy alongside seasonal observation trends, and iii) discuss how this approach can be incorporated into other conservation studies of threatened taxa by examining life history, ecological traits, and anthropogenic impacts in observations on this citizen science platform.

MATERIALS AND METHODS

Obtaining observation data

To compile data, observations were searched within iNaturalist, using the "explore" tab for both "Hellbender *Cryptobranchus alleganiensis*" and "Common Mudpuppy *Necturus maculosus*" in the United States, then further constrained to only those for wild, verified, research grade quality (confirmed by at least two agreeing naturalist). Research grade observations entail finer taxonomic resolution and reliable identification (Campbell et al. 2023). I also constrained search to only include observations up to 31 December 2023 so as not to bias annual observations. Observations were then exported for collection of state data, annual increase, monthly observations, and notes on individual specimens. All observations were downloaded on 20 January 2024. Moreover, each observation image was visually examined by author between 20 January 2024 and 31 January 2024, and manually processed for number of live versus dead, documentation of any behaviors, and life history stage (adult versus juvenile). Observation images were further assessed for species accuracy, as these two species are readily identifiable with adult hellbenders possessing dorsally flattened bodies, overall large size and reduced eyes, while adult mudpuppies possessing large feathery external gills, small limbs, and flattened tail (Petranka 1998). Moreover, larval hellbenders are robust with similar morphologies, while mudpuppy larvae often possess distinct dorsal dark lines bordered by yellow stripes (Conant & Collins 1998). Observations that included information on fishing were also noted. For quantification of juvenile, overall body size was assessed in image and if larvae or eggs

were present, the observation was counted as 'juvenile'. Data from downloaded observation was sorted in excel and primarily descriptive statistics are reported.

RESULTS

In total I documented 260 total observations for Eastern Hellbenders and 457 for Common Mudpuppy which met search requirements on the iNaturalist platform. All post included images that were readily identifiable to species level for both hellbenders and mudpuppies. Observations for hellbenders were from ten total states, while observations for mudpuppies were across 20 states, all within their historical geographic range. The top three states with observations for mudpuppies were Pennsylvania, New York, and Michigan, whereas for hellbenders was North Carolina, Pennsylvania, and Tennessee. The percentage of alive and dead individuals was similar for both species, 87.7% & 12.3% and 97.7% & 2.3%, respectively for mudpuppies and hellbenders (Table 1). All mortalities ('dead') observations for hellbenders were of adults, whereas for mudpuppies only one juvenile was characterized as 'dead' with all remaining mortalities comprised of adults. Moreover, the percentage of adult versus juvenile was 79.4% & 20.6% and 90.4% & 9.6%, for mudpuppies and hellbenders, respectively. All observations of hellbenders included only one individual in image, whereas for common mudpuppy, there were 444 observations with one individual, 10 observations with two individuals, and one each for three, four, and nine individuals in an observation image.

Several instances of observations including text mention of individuals being captured by fisherman were included with representative examples as "*Hooked this hellbender in the tail while fly fishing*", "*hooked by fisherman*", and "*caught on rod and reel*" "*caught on hook*" ,"*angler caught on nightcrawler*", "*a fisherman had caught and killed this poor mudpuppy while powerlining*", and "*killed by fisherman*". In at least one observation for mudpuppies, there was mention of "*found while netting for minnows, released unharmed*" and for one with hellbender as "*it was caught in a fishing line, it survived*" which implied release of individual following observer encounter. Instances of predation on mudpuppy included several observations of mink predations (4), seagulls (2), and a water snake (1) predating on live adults (Image 1). In addition, there was one incidence of an observation of a dead mudpuppy regurgitated from a water snake. There were no observations for predation on hellbenders. The number of images including eggs was six for both mudpuppies and hellbenders. Four observations of mudpuppies and three for hellbenders included only the skeletal remains (Image 2), yet was readily identifiable as species based on unique morphology.

Table 1. Observation data from iNaturalist for the Common Mudpuppy, *Necturus maculosus* and the Eastern Hellbender, *Cryptobranchus alleganiensis*. Ad—adult | Juv—Juvenile | A—alive | D—dead.

	Common Mudpuppy	Eastern Hellbender
% Life Stage	Ad:79.4%, Juv: 20.6%	Ad: 90.4%, Juv: 9.6%
% Alive/Dead	A: 87.7%, D:12.3%	A: 97.%, D: 2.3%
Representative textual observations	*"angler caught on nightcrawler", " a fisherman had caught and killed this poor mudpuppy while powerlining", "regurgitated from a water snake", "being eaten by a water snake", "killed by fisherman", "caught on hook", "caught on rod and reel".*	*"it was caught in a fishing line, it survived", "nest with male guarding", "hooked by fisherman", "hooked this hellbender in the tail while fly fishing", "specimen was deceased. A rock crushed his shoulder and front leg. It was given to the NC Wildlife Resources Biologist".*

The number of annual observations for both mudpuppies and hellbenders generally increased over time (Figure 1). As the iNaturalist platform came into existence in 2008, there were still retrospective posts from 2000 till 2008, which include previous observations prior to the posting date for several observations. In addition, there was a distinct decrease in the number of annual observations for both species from 2020 to 2022, likely due to the Covid-19 lockdown. The months in which the greatest number of observations were documented was April (70), July (54), and March (53) for mudpuppies, and July (54), August (47), and September (45) for hellbenders. For hellbenders these three observation months account for 56.1% of all observations. Therefore, when these observations are combined, iNaturalist provided a successful tool to investigate natural history, presence, predation, mortality, and anthropogenic issues associated both species of large fully aquatic amphibians.

DISCUSSION

This communication provides evidence of utilizing the citizen scientists platform iNaturalist to document presence of declining salamanders species across their home range alongside observations which are of interest to conservation managers, including fishing

Image 1. Representative observations of the Common Mudpuppy showing adult caught on fishing line, predation by mink, predation by seagull, predation by water snake, and juvenile, and egg life stages. Image obtained from iNaturalist under Creative Commons, from the following users: tuckerc, teuclide, baker053, suepk, jcmon, and jayinmadtown.

and documentation of predation events involving these large fully aquatic salamanders. Interestingly, the use of iNaturalist observations to obtain data reveals that this platform may provide similar results for other declining herpetofauna, and other taxa (e.g., mammals, birds, fish) to detect potential exploitation or human-wildlife interactions. Historically, the Eastern Hellbender has been harvested and exploited in some cases large numbers killed (Nickerson & Briggler 2007), largely due to the false beliefs that it is either venomous or consumes all the fish. However, engaging trout anglers via outreach education programming has been found to increase reporting of observations to state agencies responsible for managing eastern hellbenders (Williams et al. 2019). While several observations included images which show either mudpuppy or hellbender in a fishing net, it is unclear for many observations which were mortalities what the exact cause of death was for a specific individual.

The months in which observations were highest for both species could be explained by times in which natural aquatic areas are frequented by recreationalists or anglers frequenting natural areas. Interestingly, the months with the greatest number of observations for hellbenders includes a portion of their breeding season, when individuals are known to be active (Nickerson & Mays 1973) and are likely readily visible in shallow clear streams. Interestingly, the number of observations increased annually over time for both species, indicating the potential for this method of monitoring to provide managers with data on locations as a complement to more traditional surveys or even more recent non-invasive techniques in aquatic environments, i.e., eDNA and underwater camera surveys. However, it is important to note that this increase in annual observations likely does not reflect an actual on ground population increase for these salamanders, but just a change in likely frequency of posts or usage of the iNaturalist application. Subsequently, further research in population estimation which incorporates mark-recapture studies should be more reflective of actual status and population trends of these two enigmatic aquatic salamanders.

Future biodiversity studies should investigate threatened taxa across conservation status and taxonomic groupings in other geographic regions using this citizen science platform. This study demonstrates the potential of iNaturalist to provide a monitoring tool for threatened species and should be applied to other threatened taxa. Species which are readily identifiable based on morphology should be further studied for their presence on this citizen science platform, as it is vital for citizen science collected data to be accurately

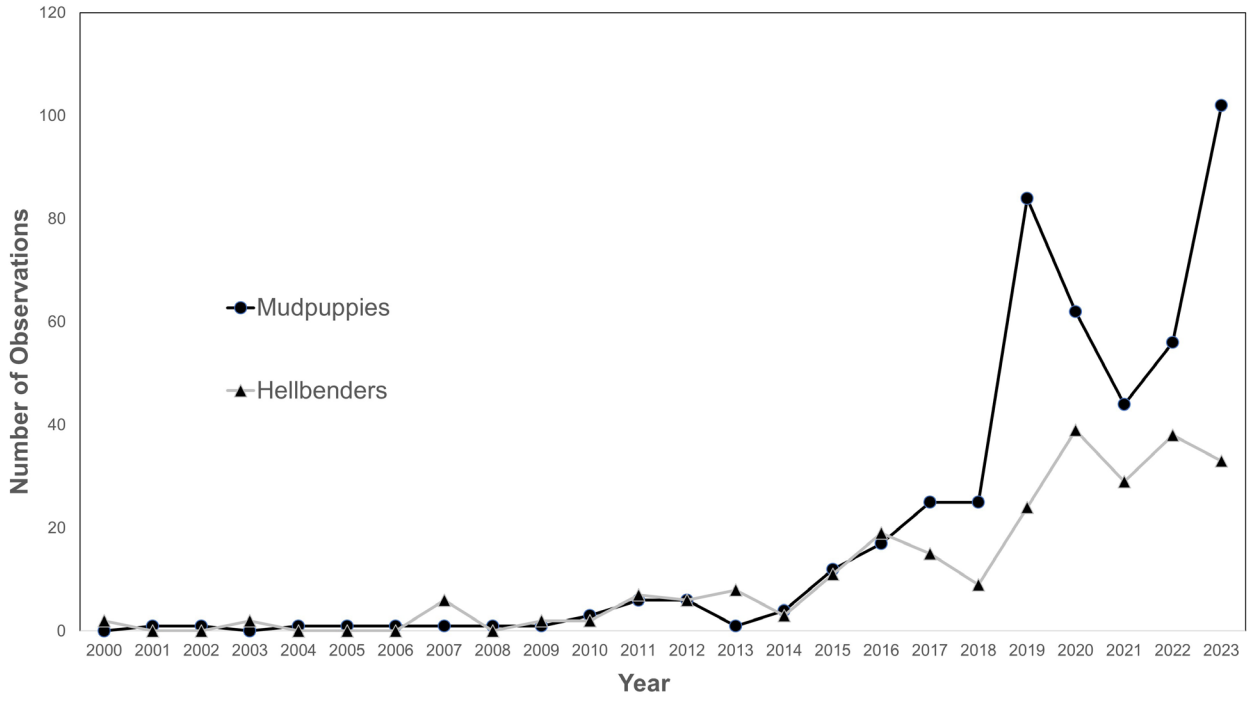

Figure 1. Annual number of observations for mudpuppies and hellbenders on iNaturalist.

Image 2. Representative observations of the Eastern Hellbender showing adult caught on fishing line, mortality, skeletal remains, larvae in hand, juvenile, and eggs. Image obtained from iNaturalist under Creative Commons, from the following users: sjhnny, acmills, hikeleader, hydrophilus, jsexton22, and mcw162.

verified if it to be used for research. Subsequently, it is important for researchers to only include species that are research grade or species for which morphology can be utilized for reliable identification. It is also important to only use images where animals are clearly visible and identification is further validated by researchers or

taxonomic experts. Given the large number of threats facing freshwater fauna, obtaining data using this method can provide a metric for threatened species presence while identifying conservation priorities. For example, while some rare species found in other areas of the world present challenges for surveying, researchers should consider scanning iNaturalist observations for their species and geographic region of choice. As I noted both species being captured by anglers, future outreach should incorporate the impact of fishing on these large fully aquatic salamanders in decline. Moreover, iNaturalist observations are concentrated in North America, with fewer observations in Africa, central America, and southeastern Asia (Di Cecco et al. 2021). Subsequently, it is possible that in some geographic areas, this application may not have as many observations as others, outreach science programs where researchers encourage local communities to record observations on their phones can add value to rare species surveys. I anticipate the use of this smartphone application will continue to increase in its use, it may indeed provide a tool for future monitoring of threatened taxa.

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ravi@threatenedtaxa.org & ravi@zooreach.org

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