Seeing the Pond for the Reeds: Biodiversity of Rural Ponds

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ABSTRACT

Ponds in rural ecosystems may provide valuable habitat for a variety of cosmopolitan species, including those that are either fully aquatic or pond associated species in riparian habitats of mixed agricultural/wooded areas. We assessed the diversity of three rural ponds on private property (Southern 8's Farm; Chesterfield, South Carolina), with different management histories using rapid species assessments. Surveys included aquatic dip-netting, sweep netting, acoustic surveys, camera trapping, and visual encounters. Identifications of organisms were performed using iNaturalist. In total, we compiled 240 unique taxonomic observations of different taxa across all ponds, representing 165 fully identified species (68.8% of observations). This consisted of 166 animal observations (largely arthropods, with some chordates), and 70 plant observations (mostly dicot flowering plants) and only 4 fungi observations. We found that iNaturalist provided a reliable method for identification of flora and fauna pond-associated species and should be considered for bioblitz surveys and rapid biological inventories to document species presence in riparian zones of agricultural ecosystems.

Introduction

Freshwater environments are facing numerous threats to local species diversity and habitat loss due to overexploitation, pollution, invasive species, and other variables (Dudgeon et al. 2006). Ponds are among the most biodiverse freshwater systems housing diverse communities of plants and animals (Janssen et al. 2018), yet are facing numerous threats to their long term stability or habitat degradation (Hill et al. 2016). In the southeastern US, ponds may provide direct habitat for a variety of plants and animals, acting as reservoirs of freshwater biodiversity. Rural ponds in largely agricultural ecosystems, along with their associated riparian habitats, (interface between aquatic wetland and land area) provide a potential valuable resource for many species, including insects (Walton et al. 2021), birds (Gonzalez et al. 2010), and amphibians (Knutson et al. 2004). In general, pond diversity has been quantified to a lesser extent than riverine systems (Wood et al. 2003), and sparingly on private lands. In addition, little is known regarding riparian zone biodiversity in habitats surrounding ponds with different land management on private land across the southeastern US, which can also house diverse organisms. However, many southeastern ponds are found in unprotected areas and with declining levels of native forest buffers (Evans et al. 2017). Therefore, investigating the most efficient techniques which result in rapid and reliable identification of species are needed to quantify biodiversity and foster monitoring by citizen scientists.

Several survey techniques have been developed for performing rapid biological inventories, many of which are performed increasingly using smartphone technology. This includes traditional acoustic surveys for frogs and birds (Acevedo and Villanuega-Rivera 2006), as well as performing visual encounter surveys using the application iNaturalist (www.inaturalist.org), which has been successful in identifying a number of organisms including plants, insects, and amphibians (Unger et al. 2020, Matheson 2014). Moreover, iNaturalist has allowed for the identification of introduced species (Agarwal 2017), documenting the presence of rare and threatened species (Wilson et al. 2020), and developing checklists of species present in many natural areas (Hewitt 2017). Rapid species assessments, often termed “bioblitzes” (defined as surveys of species found in a particular area over a short time period,) are typically conducted over a single day or weekend. While these bioblitzes are often limited in duration, they provide important scientific data to wildlife managers and biologist, and can even increase awareness of conservation issues and local biodiversity (Karns et al. 2006). Traditional methods for observing and identifying biodiversity of insects and other groups typically include some combination of published records, and increasingly, the presence of websites, citizen science, and other methods, which can increase the documentation of species presence (Kittelberger et al., 2021). iNaturalist has a great deal of potential to be a valuable tool for conducting rapid biological surveys in aquatic environments such as rural ponds.

We investigated the species diversity of three ponds with varying management regimes and surrounding forest cover type. We assessed diversity by conducting biological surveys including acoustics surveys, visual encounters, dip and sweep netting, and camera trapping. Identifications were performed by cataloging images and sounds, and uploading to iNaturalist (downloaded when identifications were “research grade”) and in some cases validated manually for sound files or trail cameras. We report on species presence, level of taxonomic diversity, and overall effectiveness of using iNaturalist in surveying ponds in agricultural ecosystems. This study contributes to our overall knowledge of species found in agricultural riparian ecosystems of agricultural pond in the southeast.

Methods

Description of Sample Sites:

Sites (ponds and surrounding riparian zones of ponds) were chosen for this study to allow for consistent sampling access, overall similar size and area, and to include a variety of land management types on private property located near Chesterfield, South Carolina; Chesterfield County. This biodiversity survey was part of an undergraduate summer research internship program between Wingate University and Southern 8’s Farm. We chose three ponds with, BJ’s pond (BJP), Firework’s Pond (FWP), and Otter Pond (OTP). Habitat types surrounding ponds varied, with BJP consists of successional upland mixed hardwoods, bottomland hardwood and pines, FWP consists of open field vegetation and grassland (warm season planted native grasses and fescue pastures) with OTP nestled in a planted loblolly pine (~25 years old stand) and bottomland hardwoods. Both BJP and OTP had significantly more forested cover than FWP (Figure 1). Ponds were similar in size and area with BJP being 505 m perimeter (~10,306 m2 area), FWP being 466 m perimeter (~8,922 m2 area) and OTP having a perimeter of 449m (~6,954 m2), measured on Google Earth. Samples sites were surveyed for biodiversity using a variety of methods detailed below.

Trail Camera Deployment:

Two Bushnell™ E3 Trophy trail cameras, baited with a combination of corn and sardines, were placed at each of the three ponds near the southeastern edges near pond dams and monitored from 6/21/21 to 8/17/21 within 5 meters of the pond’s edge. Both cameras were angled to capture a common field of view of the baited area to account for potential error of one camera. Trail cameras were checked periodically, baited every two weeks to increase animal detection and image capture probability, and SD cards were removed and images analyzed. To supplement the baited riparian trail cameras, one Reconyx® Hyper 2-time lapse camera was deployed at each pond overlooking wetland area to potentially detect aquatic basking turtles or wetland birds in flight.

Dip-Net and Sweep Net Sampling:

Dip-net sampling for aquatic insects occurred from 6/21/21 through 8/4/21. Samples were collected on the southern end (most accessible section) of the pond emergent vegetation area, and various specimens were preserved in tubes of 95% ethanol for storage until later identification. Insect nets (both canvas/cloth fabric nets and mesh aerial nets) were used to collect insects from terrestrial riparian zone vegetation surrounding each pond (within ~ 15 meters) on 7/12/21 and 7/14/21. The "figure 8" sweeping technique was used at various points around the pond with the canvas nets within approximately a 3-meter section of vegetation (Figure 2). Two sweeps were performed at each point near emergent aquatic vegetation and in the open water habitat. Photos were taken of most non-repeat organisms and a variety of individuals were placed in kill jars preloaded with ethyl acetate and transferred to plastic bags, which then were placed in a -80°C in the Wingate entomology lab as voucher specimens.

Auditory Surveys:

As short-term surveys or bioblitzes may underestimate amphibians such as frogs normally detected during call surveys (Foster et al. 2013), we deployed newly available affordable sounds detectors. At each pond, a Wildlife Acoustics song meter micro was placed at the Southwest portion from 7/5/21 through 7/12/21. Sound meters were deployed at the pond's edge, secured to a tree at a height of ~ 2m above the ground. The sound meters were placed in an open area to maximize acoustic detections (Figure 2). Settings for the sound meters included recording one hour at sunset and sunrise. Smartphones were used to program settings on sound meters. One sunrise and one sunset recording for each pond was selected to analyze frog and bird calls. Additionally, to augment sound meter recordings recorded by deployed sound meters, sound recordings were taken of various bird calls heard at all three ponds opportunistically while conducting other surveys during pond visits using an iPhone XR smartphone. Sound recording calls were initially identified using the smartphone app BirdNet (birdnet.cornell.edu; Kahl et al., 2021). Sound recordings of various anuran or bird species were also uploaded to iNaturalist and or compared to other identified recordings online to identify the species heard in the recordings and to compare the effective use of BirdNet to iNaturalist. While the BirdNet app made best suggestions for identifying the species heard in each call, the authors listened to audio recordings from the song meter micro to identification and validate all reported bird and frog calls uploaded to iNaturalist.

Visual Encounter Surveys:

From 6/26/21 to 8/4/21, the perimeter of each pond was periodically walked in either morning, mid or late afternoons and a photo was taken for each new encounter (a putative new potential species or taxonomic observation) with an iPhone XR smartphone and uploaded to iNaturalist. Care was taken to record any previously unobserved taxa potentially active during the day or in the case of plants in and around pond edge habitat and within ~10-15 meters of pond's edge (our defined riparian zone). All plants and fungi were observed using this survey method. Several insects and other arthropods were noted either directly on vegetation or actively moving on understory vegetation or trees. In some cases, this survey method was combined with sweep netting, which was often conducted following visual encounter of an arthropod, i.e., spider or insect.

Identifications:

Images or sound files obtained from all survey categories were uploaded to iNaturalist for potential identification (Figure 3). We manually confirmed identifications in most cases, i.e., especially with trail cameras, sound meters, etc., in addition to uploading for validation on iNaturalist. Insect voucher specimens were observed under a dissecting scope and photographed through the lens in the Wingate entomology lab, then uploaded to iNaturalist to aid in identification. Often multiple photos of an insect specimen were taken and uploaded, for example a dorsal and a ventral view, a side-view or a wing close-up. We recorded identifications to the lowest taxonomic level, including to Phylum, Class, Order, Family, Genus, and species for all identifications using an iNaturalist following current standard Linnaean taxonomy according to iNaturalist.

Data Analysis:

We enumerated identifications to each of the lowest taxonomic level, including to Phylum, Class, Order, Family, Genus, and species for all observations. We include descriptive statistics for sites (ponds) sampled. We performed a Chi Square analysis of major taxonomic groups across sites and also to compare the distribution of Class down to Order between plants and animals. All statistical analyses were performed using 0.05 as significance level.

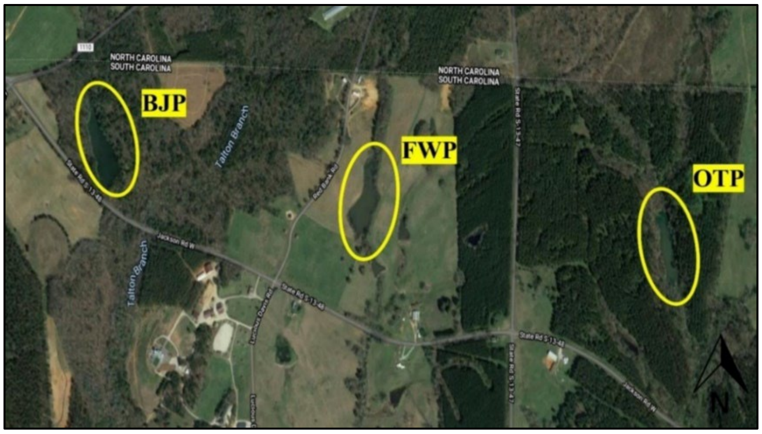

Figure 1. Map of Three Ponds surveyed as part of this study. Sites from west to east include BJ pond (BJP), Fireworks Pond (FWP), and Otter Pond (OTP) circled and labeled. Map created using Google Map imagery, Maxar Technologies, USDA Farm Service Agency, map data 2022.

Figure 2. Example of survey methods used in this study including trail camera, sound meter, net sampling, and visual encounter surveying. Arrow indicates spider sampled inside sweep net, with left panel showing Wildlife Acoustics Sound Meter Mini (*circled*), middle panel showing dip-netting pond, and right panel showing trail camera secured to tree (*circled*) along pond edge.

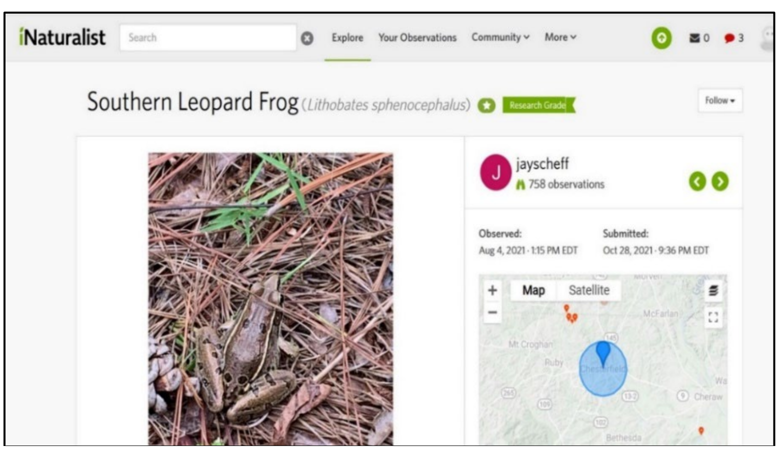

Figure 3. Example of iNaturalist identification method screenshot, showing Research Grade identification of Southern leopard frog, *Lithobates sphenocephalus* sampled and photographed during visual encounter surveys.

Results

In total, we successfully identified 240 unique taxonomic observations across all three ponds during our study representing 304 total observations (i.e. some species, taxonomic observations were found at more than one location; FWP = 119, OTP = 102 and BJP = 84). We did not find a significant difference between sites for major taxonomic categories (Insects, Birds, Mammals, Reptiles, and Amphibians), $X^2 = (8, N = 186) = 6.21$, $p = 0.624$. Similarly, we observed comparable numbers of Animalia and Plantae groups (Figure 4) at FWP (animals = 83, plants = 36), BJP (59 animals, 24 plants), and OTP (animals = 79, plants = 20), with 166 unique animal and 70 unique plant observations, respectively. Within the Kingdom Animalia, 66.9% of our unique observations were in the phylum Arthropoda, followed by 31.3% Chordata, and 1.2% Mollusca and 0.6% Annelida. Major taxonomic groups observed across sites included a total of 89 insects, 29 birds, 7 mammals, 5 reptiles, and 6 amphibians. Within the Kingdom Plantae, and Phylum Tracheophyta, 74.3% of unique taxonomic observations were in the Class Magnoliopsida , followed by 18.5 % from Liliopsida, 4.3% from Polypodiopsida, and 2.9% Pinopsida. We also identified 4 total fungi (1 in phylum Ascomycota and 2 in phylum Basidiomycota at OTP and 1 Ascomycota at BJP, with none identified at FWP. At least fifty-eight taxonomic observations (presumed species) were seen more than once, at least at either 2 or 3 sample locations or using multiple survey techniques. The number of species identified at only one specific site (unique to only one pond/site) across sample locations were 18 at BJP, 51 at FWP, and 47 at OTP.

A total of 165 taxonomic observations were identified down to species level, or 68.8% of unique observations across all sites, with 40 observations identified down to genus or 16.7%. Most unique observations included the taxonomic family, with only 5 observations identified only down to order as the lowest taxonomic level or 2.1%, with one plant observation only identified down to class or 0.4%. We observed the highest number of species level observations identified at OTP with 69 species followed by 68 species at FWP, and 28 species at BJP. We did not find significant differences between the number of taxonomic groupings between Plants and Animals (excluding Fungi due to low identifications), X^2 $(4, N = 546) = 2.788$, $p = 0.594$. Overall, animals were more diverse at the family, genus, and species level than plants (Table 1, Figure 5).

Table 1. Number of taxonomic observations for Kingdoms Animalia, Plantae, and Fungi identified in this study.

	Phylum	Class	Order	Family	Genus	Species
Animalia	4	13	37	96	117	106
Plantae	1	4	24	40	54	55
Fungi	2	4	4	4	4	4

Figure 4. Examples of trail camera images captured in this study showing nocturnal mammals, including Gray fox and Common raccoon from BJP (*upper left and right*), and White-tailed deer from FWP (*lower left*) and Bobcat (*lower right*), from OTP.

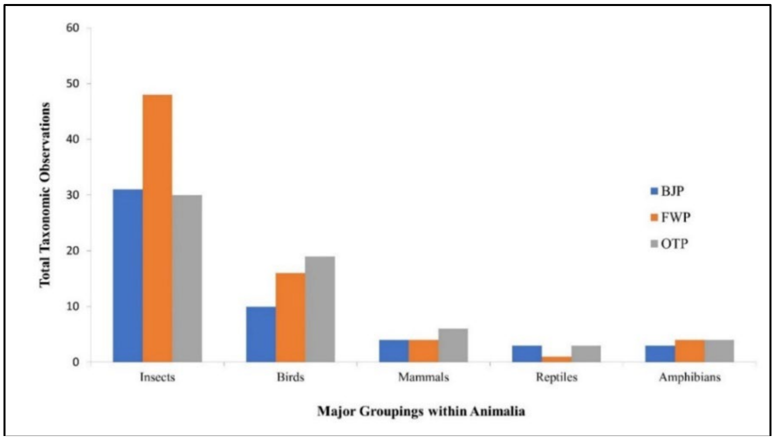

Figure 5. Unique identifications across taxonomic major groupings within Animalia across sample locations. Major groupings include Insects, Birds, Mammals, Reptiles, and Amphibians. BJP = BJ's Pond, FWP = Fireworks Pond, and OTP = Otter Pond.

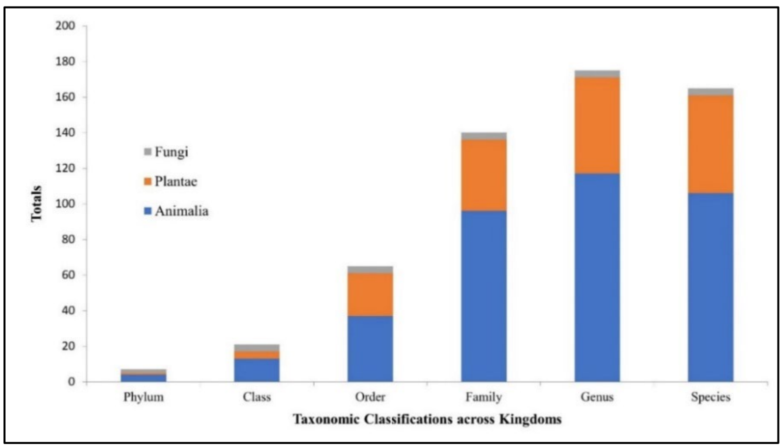

Figure 6. Totals of taxonomic classifications identified across plant, animal, and fungal kingdoms and groupings. Biological classifications numerated include Phylum, Class, Order, Family, Genus, and Species.

Figure 7. Examples of Class Insecta identifications during this study sampled during sweep netting and visual encounter surveys.

The majority of taxonomic identifications were provided by visual encounter survey methodology (walking in woods and taking cell phone images) and sweep netting (~82% visual encounter & sweep net survey methods combined, due to overlap in identification method for arthropods), with some small number of observations provided by other survey methods, i.e., trail cameras (~5%), sound recording (~8.5%), and dip-net sampling (~4.5%). All plants and fungi were observed during visual encounter surveys. For auditory surveys, only 38% of our smartphone recorded sound files analyzed in BirdNet were in the category "Almost Certain", "Highly Likely" or "Likely" with 62% of our smartphone sound recordings were in the category of "Uncertain" or "Only a Wild Guess". Therefore, we only report birds identified by authors using the Wildlife Acoustics song meter micro and validated on iNaturalist and by authors. For all taxonomic observations uploaded to iNaturalist in our study, 85.3% were "research grade" indicating that a minimum of two agreeing identifications by experts or knowledgeable naturalists confirmed and verified identification.

Mammals sampled with trail cameras included White-tailed deer, *Odocoileus virginianus*, Eastern gray squirrel, *Sciurus carolinensis*, Gray fox, *Urocyon cinereorgenteus*, bobcat, *Lynx rufus*, Common raccoon, *Procyon lotor,* Virginia opossum, *Didelphis virginiana*, and American beaver, *Castor canadensis*. We also captured several birds on trail cameras including the Eastern Meadowlark, *Sturnella magna*, the American Crow, *Corvus brachyrhynchos*, and the Turkey vulture, *Cathertes aura* all confirmed with sound files, and even one reptile, a snapping turtle, family Chelydridae on trail cameras consuming bait. Two arthropods sampled during visual encounter surveys were categorized as introduced (a Japanese beetle, *Popillia japonica* and Nosy Pill woodlouse, *Armadillium nasatum*) with six plants categorized as introduced including Brazilian Vervain, *Verbena brasiliensi*s, Japanese stiltgrass, *Microstegium vimineum*, Curly Dock, *Rumex crispus*, Vasey grass, *Paspalum urvillei*, Tall fescue, *Lolium arundinaceum*, and Japanese honeysuckle, *Lonicera japonica*. One invasive species, Chinese Privet, *Ligustrum sinense*, was also identified. Fish observed and identified during dip-net surveys included members of the family Centrarchidae, *Micropterus* spotted bass and *Lepomis* common sunfish. Reptiles encountered during visual surveys included the Green anole, *Anolis carolinensis*, and the Eastern box turtle, *Terrapene carolina*. Several amphibians were seen both during visual encounter surveys and confirmed on sound recordings, including the Green tree frog, *Dryphytes cinereus*, the Southern toad, *Anaxyrus terrestris*, and the Southern Leopard frog, *Lithobates sphenocephalus*. Several spiders were sampled during both visual encounter surveys and sweep netting, including Orchard Orbweaver, *Leucauge venusta*, Spinybacked orbweaver, *Gasteracantha cancriformis*, and the Arrow-shaped orbweaver, *Micrathena sagittata*. All butterflies and moths, in the insect order Lepidoptera, sampled primarily during visual encounter surveys, were able to be identified down to species (Figure 6), both as winged adults and as caterpillars, including common species such as the Black swallowtail, P*apilio polyxenes*, the Viceroy, *Limenitis archippus*, and White-marked tussock moth, *Orgyia leucostigma*. Further representations of insects and other organisms are included in the supplemental file.

Discussion

The three ponds and their surrounding riparian habitats in this study represent important components of the southeastern-managed agricultural ecological landscape, as they harbored unique biodiversity when taken together. Moreover, we found a great deal of both plants and animals with some fungi associated with pond areas using multiple sample methods. We were able to quickly document a large number of insects utilizing pond habitat and surrounding riparian zones using primarily visual encounter surveys and sweep netting, which resulted in every plant and fungi identification and almost all terrestrial arthropod identifications. While visual encounter surveys provided the majority of observations, other survey methods were complimentary to overall documenting biodiversity around ponds. Trail cameras provided an affordable method to survey for several mammals active nocturnally (i.e., Virginia opossum, Gray fox), which we may have missed if only conducting visual encounter surveys during the day. Surprisingly, we detected bobcat at 2 ponds on trail cameras, likely using pond areas as a corridor. We also found among several mammals, beaver at OTP, which their presence has been linked to the importance of forested lands surrounding ponds to preserve biodiversity for mammals (Nelner and Hood 2011). Lastly, the use of Wildlife Acoustics sound recorders allowed for detection and subsequent identification of common bird and amphibian species.

Our findings and number of species detected in this short-term summer biodiversity study is comparable with other studies performing bioblitzes with various survey methodologies (Matassa and Hitchcock 2021) and bioblitzes using iNaturalist as an identification tool (Gass et al. 2021). Additional methods for sampling organisms, such as live-trapping turtles or netting deeper water for fish, may increase our future ability to identify species and record presence. However, this study was focused on using short-term, predominantly non-invasive survey methods, as trapping vertebrates requires permitting by state agencies. Therefore, we recommend future projects coordinate with biological survey experts and follow state laws for sampling organisms. However, as the majority of our observations were from visual surveys, iNaturalist proved to be an invaluable resource and interactive tool for identifications, both if samples were collected or to identify a variety of encountered animals and plants. Individuals and/or citizen scientists with an iNaturalist account are able to post photos or sounds of their findings and receive comments and suggested identifications from other iNaturalist users, some of which are experienced naturalists who specialist in specific taxa. This allows for taxonomic expert feedback on identifications of which are "research grade" and not just generated by the application initial identifications.

While we observed similar taxonomic groupings across sites, we did observe the most plants at FWP. It is possible the more vegetation and open canopy around FWP may have resulted in the most diversity, specifically potentially insect communities which were found on a variety of plants, with the most insects detected at FWP. Several important pollinators in the insect order Lepidoptera were all identified down to species, indicating the potential for researchers to utilize iNaturalist identifications to further study pollinator-plant interactions and even potential food items for native birds. As there are many environmental variables which could have affected the number of plant and animal species we observed during this study, future research could focus on observations across the year and taken at different seasons or even time of day, as we suspect activity patterns and temperature effects could have resulted in varying numbers of identifications. However, we suspect this trend is minimized as we conducted surveys over the same general time frame, or summer season. Alternatively, we expect weather along with fluctuations in rain can always impact some species present, especially those reliant on aquatic habitats. Therefore, we recommend projects which sample across seasons incorporate analysis of varying species count by taxonomic group when possible, as our study period was confined to summer.

The number of site unique species (only identified at one sample location), was low overall. The lowest number of site unique species identified was at BJP, possibly due to its proximity to a nearby road on one side or other factors, with FWP having less canopy and possibly more unique species due to open vegetation and habit, with OTP characterized by a greater amount of contiguous forest cover. While we detected little difference across ponds, previous studies have shown intermediate sized ponds can harbor greater levels of diversity for amphibians, as small ponds dry out, and larger ponds may contain more fish predators (Semlitsch et al. 2015). Therefore, future research and monitoring should be conducted across various pond sizes and pond types to further sample salamanders and frogs as well as aquatic reptiles (turtles). Moreover, further work could be conducted on bird surveys using smartphones and the application BirdNET, as it is likely that recordings made on the smartphone were not of sufficient quality to discern bird calls reliably, or were not long enough sound files, or there may have been multiple birds calling at the time of recordings (i.e. interference), making it difficult to properly identify. Interestingly, more work should be conducted on birds associated with pond riparian zones as proper management of agricultural ponds can lead to increased ecosystem connectivity as emerging aquatic insects provide important seasonal food sources for many bird species (Lewis-Phillips et al. 2020).

In addition, we did not identify many fungi. However, this is likely due to their overall lack of presence near the pond's riparian area or inability to detect fungi or lack of identification based on image or the weather pattern. Further work using other microbiology survey methods and collection centered on fungi and even bacteria could be carried out. Surveys could even potentially culture fungi and bacteria and upload images of growth morphologies on agar plates for identification to larger taxonomic groupings. Alternatively, further studies could increase sampling of protists and other smaller aquatic organisms (phytoplankton and zooplankton) by directly sampling the water's surface as well as log-rolling to potentially increase several lesser represented groupings of organisms.

We found that iNaturalist worked exceptionally well across arthropods, including butterflies and moths down to species, as well as for crayfish down to genus. Interestingly, iNaturalist was helpful as a resource for identification of footprints for raccoons, and also for identification of images of animals taken with trail cameras to confirm identifications. Indeed, iNaturalist holds much promise as a smartphone application and tool for identifying organisms, as it has even been used to involve citizen scientists in bioblitzes (rapid assessment of the species living in a particular area) or field-based events where identifications are a part of cataloging biodiversity (Aristeidou et al. 2021). Where short term bioblitzes similar to our study, previously involved the combined efforts of many scientists and naturalists with different levels of expertise across taxonomic groups (Cantonwine et al., 2019; Karns et al., 2006), similar levels of important scientific information on species presence or absence and even relative abundance can now be obtained using iNaturalist. Moreover, iNaturalist can be useful to study future interactions between insects, aquatic plants, and trees around ponds, as previous research has found that many images of insects (i.e., bees, butterflies, etc.), also included flowers (Gazdic and Groom 2019). In addition, short term surveys on insects, when repeated annually, can produce a clearer picture of insect presence and can be a source for monitoring insect communities (Chandler et al. 2012); even potentially detecting any fluctuations in common species or future declines if taxonomic groups are monitored accordingly. However, we encourage researchers to work closely and coordinate with land managers to involve local citizen scientists as well as biology students, faculty, and state agency personnel in bioblitzes occurring in natural areas such as ponds or other habitats, as it provides important avenues for outreach education to include community members in active and engaging science education (Roger and Klistorner 2016; Baker et al. 2014).

We found that using iNaturalist as an identification application provided an additional avenue for communication with experts in taxonomy (top identifiers on the application), who were able to provide feedback on further helpful tips on identification. Therefore, use of iNaturalist can be beneficial for less experienced biology students or naturalists to both start a dialogue with experts across various disciplines (e.g., botany, entomology, etc.). Moreover, within the iNaturalist application, users are able to navigate to additional tabs which allow comparison identifications based on life history stages. For example, for plants user can select "plant phenology" and examine images of "flowering", "fruiting", or "no evidence of flowering" selections, or for animals, users can investigate terrestrial insects as "adult" or "larva" and aquatic insects with additional life stages of "egg" and "nymph". In addition to identification, this application may be helpful as a teaching tool for instructors to teach about various organismal life history stages.

In this bioblitz study, iNaturalist provided a critical tool for identification across taxonomical groupings of plant and animals observations. Making natural history data available can help state agencies monitor species in both public and in private, largely agricultural land where our study occurred. Having this level of biodiversity readily available on iNaturalist can also help monitor the spread of invasive, non-native species, an emerging issue in environmental conservation (Simpson et al. 2009). Several of our identifications in this study were labeled as introduced species and one invasive species, highlighting the potential for this application to serve as a database for tracking biological invasions across regions. However, we also caution that inclusion of identification of specific taxa be validated by experts for more challenging species or those that require closer inspection or multiple images of either leaf, body morphologies, and other identifying structures. Lastly, we recommend students conducting biodiversity surveys sample across different seasons and times of day to adequately detect species with different activity patterns. Indeed, we envision iNaturalist increasingly being utilized not only to serve as a connection for identification and validation of taxa encountered during biological surveys, but as a tool to foster connections between students, faculty, biologists, land managers, land owners, and citizen scientists in the future.

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