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Statewide mapping and assessment of vernal pools: A New Jersey case study

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Abstract

In 2001, the New Jersey Department of Environmental Protection (NJDEP) adopted rules specifically protecting vernal pool habitat for the first time. Vernal pools are small isolated temporary bodies of water that provide critical breeding habitat for a number of amphibian species. To implement these rules and ultimately afford vernal pools protection, the NJDEP first needed to assemble a statewide database of vernal pool locations. In response, the Rutgers University Center for Remote Sensing and Spatial Analysis (CRSSA) was funded to develop a cost effective technique to map vernal pool locations statewide. The objective of CRSSA's mapping effort was to develop a complete potential vernal pool database to be able to identify individual isolated vernal pools as well as areas of high local density, or 'hotspots'. CRSSA used visual interpretation of leaf-off color infrared digital orthophotography in a computerized GIS environment to identify and map over 13,000 potential vernal pools. Using the 1 m scale imagery, we determined the minimum detectable pool size to be on the order of 0.02 ha in size. Subsequent field checking has revealed a 12% error of commission that was due to our inclination towards erring on the side of inclusion in mapping many water features as potential vernal pools. For a vernal pool to receive regulated protection, it must be 'certified' that it serves as habitat for obligate or facultative vernal pool amphibian species. To aid in these efforts, CRSSA developed an interactive internet mapping site to assist NJDEP and its citizen volunteer corps in locating and navigating to their survey areas and to facilitate the on-line submittal of survey observations.

Keywords: Mapping critical habitat; Wetlands; Amphibians; Internet mapping services

1. Introduction

Temporary ponds and pools serve as critical breeding sites for a number of amphibian species across a range of global ecosystems. In the northeastern United States, as these seasonally ephemeral ponds are present most commonly in spring time, they are known as vernal pools. While vernal pools can take many forms, they are usually confined wetland depressions, either natural or man-made, lacking a permanent outflow. During conditions of normal precipitation these vernal pools fill to capacity over the winter and into the spring and may retain water well into the summer months (Brooks and Hayashi, 2002). Due to their ephemeral nature, vernal pools are generally unsuitable as habitat for fish. Without the heavy predation pressure of fish, vernal pools serve as optimal breeding habitat for a number of species of amphibians (Gibbs, 1993; Kenney and Burne, 2003).

Though these amphibians spend the majority of their life cycle in adjacent uplands or wetlands, vernal pools can be critical to the maintenance of viable populations of amphibians across the broader landscape mosaic (Gibbs, 1993; Semlitsch and Bodie, 1998; Snodgrass et al., 2000; Preisser et al., 2000). Whereas state and federal regulations provide a modicum of protection to most wetlands, vernal pools, due to their small size and isolated nature, often do not meet the criteria for protection. Consequently, vernal pools are often filled or drained as the surrounding uplands are developed. Human development and land use practices, including road building, may degrade the pool's water quality or alter its physical characteristics as well as fragment and degrade the adjacent upland habitat (Semlitsch and Bodie, 2003). The outright loss or

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Table 1
List of New Jersey obligate and facultative vernal pool breeding amphibians and their Threatened and Endangered status

Common name	Latin name	NJ T&E status
Obligate species		
Easter tiger salamander	*Ambystoma t. tigrinum*	Endangered
Marbled salamander	*A. Opacum*	Special Concern
Spotted salamander	*A. maculatum*	
Jefferson salamander	*A. jeffersonianum*	Special Concern
Blue-spotted salamander	*A. laterale*	Endangered
Eastern spadefoot toad	*Acaphiopus holbrookii*	
Wood frog	*Rana sylvatica*	
Facultative species		
Green frog	*Rana clamitans melanota*	
Bullfrog	*R. catesbiana*	
Pickerel frog	*R. palustris*	
Southern leopard frog	*R. utricularia*	
Carpenter frog	*R. virgatipes*	Special Concern
Northern cricket frog	*Acris crepitans*	
Northern spring peeper	*Psuedacris crucifer*	
New Jersey chorus forg	*P. triseriata kalmii*	
Upland chorus frog	*P. triseriata ferarium*	
Northern gray treefrog	*Hyla versicolor*	
Southern gray treefrog	*H. chrysocelis*	Endangered
Pine Barrens treefrog	*H. andersonii*	Threatened
Four-toed salamander	*Hemidactylium scutatum*	
Long-tailed salamander	*Eurycea l. longicauda*	Threatened

As defined by New Jersey DEP regulations (NJDEP, 2002).

degradation of these habitats, as well as diminished habitat connectivity, has severely impacted populations of vernal pool breeders at a local scale as well as at broader regional scales (Gibbs, 1998; Preisser et al., 2000; Zedler, 2003). For example, several of the abystomatid (mole) salamanders that rely heavily on vernal pool habitats are listed as Threatened and Endangered in New Jersey (Table 1).

In 1987, Massachusetts became the first state in the nation to establish regulatory protection for vernal pool habitats. Based on the success of this earlier effort, the Endangered and Non-Game Species Program (ENSP) of the New Jersey Division of Fish and Wildlife initiated the Vernal Pools Project in 2000. The objective of this project was to map and inventory vernal pools across the state. Subsequently, in 2001, the New Jersey Department of Environmental Protection adopted a rule, strengthening the existing Freshwater Wetlands Protection Act, to protect vernal pools that met specific biological and physical criteria (NJDEP, 2002). The pool must also occur in a confined basin depression without a permanently flowing outlet and must maintain ponded water for at least two continuous months between March and September during a normal rainfall year. Further, it must be documented by on-the-ground surveys that the pool serves as vernal habitat for either a single obligate vernal pool breeder or several facultative breeders. An obligate vernal pool species is defined as one that is considered to have optimal breeding and recruitment success in fish-free vernal pool habitats (Table 1). A facultative species will use vernal pool habitats for breeding activities, but is also commonly found to use other types of habitats (Table 1).

Without a comprehensive collection of vernal pool locations, knowledge of the status of New Jersey's amphibian populations, including a number of threatened and endangered species, was tenuous. Thus, the initial objective in the vernal pool protection process was to assemble a statewide database of vernal pool locations. Prior to this survey, New Jersey's vernal pool database consisted of only a few hundred pools primarily located on state-owned land. There were likely thousands more un-documented pools scattered across the state's wetlands, meadows, and forests, on both public and private property. The ephemeral nature of these pools, as well as the broad spatial extent of the area of interest called for delineation techniques extending beyond conventional ground oriented surveys. The adoption of efficient remote sensing techniques was deemed necessary and highly desirable if the mapping and protection was to proceed in a time and cost effective manner.

Aerial photographic interpretation has been extensively used to map wetland habitats and formed the basis for the Unites States Fish and Wildlife Service National Wetland Inventory (Tiner, 1990, 1995). Starting in the 1990s, several New England researchers began experimenting with aerial photographic interpretation to identify and map vernal pools. Based on Stone's study (Stone, 1992) on the effectiveness of aerial photographic identification of vernal pools, the state of Massachusetts used leaf-off spring-time color infrared (CIR) aerial photography (scale 1:12,000) along with stereo viewing techniques to locate and map vernal pools (Burne, 2001). Stereo viewing has the advantage of providing a 3-dimensional view of the terrain, which helps in the detection of shallow depressions that may create vernal pool habitats. In 1995, Connecticut researchers used mirror stereoscopes to identify potential vernal pools on black and white aerial photographs (Pawlak, 1998). Maine researchers suggested that CIR aerial photography, though generally more expensive to acquire, is preferable to black and white (Calhoun et al., 2003). Aerial videography presents an alternative to the use of still photography especially in non-forested situations, as has been demonstrated in prairie pothole inventories (Strong and Cowardin, 1995).

In 2001, ENSP contacted the Rutgers University Center for Remote Sensing and Spatial Analysis (CRSSA) to investigate the feasibility of applying these or similar techniques in New Jersey. Due to a limited budget and tight timeline (approximately $60,000 was budgeted for the one year mapping project), a time and cost effective interpretation and mapping technique was critical. Based on a pilot project, on-screen visual interpretation and digitization from high resolution digital orthophotography was deemed a feasible alternative to identify and map vernal pools. While this approach lacked the advantages of a 3-dimensional stereo perspective, it had the advantages of much greater time efficiency and the ability to integrate other mapped data in a geographic information system (GIS) context. This paper discusses the techniques employed and issues of omission and commission error.

2. Study area

New Jersey, approximately 19,500 km^2 in size, is divided into five different physiographic regions; Ridge and Valley, Highlands, Piedmont, Inner Coastal Plain, and Outer Coastal Plain. Each physiographic region reflects the various geomorphic processes the area has undergone and accounts for the diversity of vernal pool types (Robichaud and Buell, 1983). The Ridge and Valley and the Highlands regions of northern New Jersey are bisected by the terminal moraine of the Wisconsinan Glaciation. The numerous kettle hole depressions are prime sites for vernal pools. In the Valley portion of the Ridge and Valley province, vernal ponds are typically associated with limestone sinkholes. The highly urbanized Piedmont is home to the former glacial lake, Lake Passaic, where the extensive Great Swamp harbors a dense array of vernal pool complexes. In the Inner and Outer Coastal Plain of southern New Jersey, vernal pools are associated with a variety of geomorphic features including periglacial depressions, locally known as spungs (French and Demitroff, 2001). Approximately 45% of New Jersey is forested with deciduous forests dominating in the Ridge and Valley, Highlands, and Piedmont regions (i.e. 84% of the forest is classed as deciduous upland or wetland forest type) and coniferous or mixed forests dominating in the Coastal Plain (i.e. 73% of the forest is classed coniferous or mixed coniferous/deciduous forest types).

3. Methods

3.1. Mapping

As outlined above, on-screen visual interpretation of digital orthophotography formed the basis for the New Jersey Vernal Pools Mapping Project. Orthophotos combine the image characteristics of a photograph with the geometric qualities of a map. We used standard digital orthophoto quarter quad (DOQQ) imagery produced by the US Geological Survey (USGS, 2004). A DOQQ is a 1 m ground resolution, quarter-quadrangle (3.75-min of latitude and 3.75-min of longitude) image cast on the Universal Transverse Mercator Projection (UTM) in the North American Datum of 1983 (NAD83). The majority of the continental United States is covered by the 1 m DOQQs in either black and white or color infrared (CIR) and are available from the USGS or USDA (USGS, 2004; USDA, 2004). The two central benefits of DOQQs are:

1. the spatial resolution—1 m ground resolution cell (GRC) provides the potential for detailed ground interpretation; and
2. the orthorectified imagery is planimetrically correct with differences in terrain elevation removed, allowing the direct digitization of vernal pool locations into a GIS.

The National Digital Orthophoto Program plans to update the existing DOQQ coverage with new and often higher resolution imagery (NDOP, 2004). As the DOQQs are in the public domain, they can be acquired at a comparatively low cost and in many cases are available for free download via the Internet through state level data clearinghouses. The DOQQs for the New Jersey project costs $15.00 each with a nominal base charge for a total of approximately $2500. Individual DOQQs require approximately 135 Mb of data storage per DOQQ in the original uncompressed Geotiff format or 5–10 Mb in a compressed format.

The CIR versions are preferable to black and white as standing water is more easily discriminated and the haze effect is minimized allowing for clear viewing of the terrain. Originally derived from aerial photographs acquired through the USGS National Aerial Photography Program, most DOQQs consist of leaf-off imagery acquired during the spring months. The New Jersey DOQQ coverages were derived from aerial photography acquired in mid-March, in 1995 and early April 1997. This spring imagery was advantageous for the Vernal Pool Project because:

1. the leaf-off conditions provide a clearer view of the ground, especially, where deciduous forest vegetation dominates; and,
2. there was a higher likelihood that pools will be flooded with standing water.

The existing statewide 1995/1997 digital orthophotographic imagery along with other physical environmental data (e.g. digital elevation, surficial and bedrock geology and freshwater wetland maps) were compiled in a GIS to support the visual interpretation. Using ESRI ArcGIS software, the DOQQs covering the New Jersey study area were visually examined on a typical color computer display screen at a map scale of 1:5000. A map scale of 1:5000 was chosen as a compromise between a high level of visible detail and the spatial extent displayed for any single image frame. MrSid compressed imagery was used to speed image display times and mapping throughout, though there was some sacrifice of image quality and interpretability. Pools were visually identified based on size, shape, color, texture and site cues. The pool centroid point location was digitized on-screen directly into a GIS thematic coverage. A single interpreter was employed to provide consistency in interpretation across the statewide region. Several field investigations of known pool sites were undertaken to aid in the training process.

3.2. Accuracy assessment

Subsequent to the mapping, we undertook an accuracy assessment to ascertain the validity of the resulting map. As in any remote sensing accuracy assessment, we wanted to quantify both errors of omission (i.e. pools observed in the field but not mapped; also know as false negatives) and errors of commission (i.e. pools mapped from the aerial photography that were not pools; also known as false positives). The errors of commission can come in two forms: (1) features that were bodies of water but that did not meet the physical definition of a vernal pool, and (2) features that were neither bodies of water nor vernal pools. In particular, we were interested in assessing the effectiveness of the mapping techniques in forested areas, as well as in ascertaining a minimum identifiable pool size. Three different methods were used to assess accuracy: (1) volunteer monitor field visits; (2) field confirmation of a sub-sample of mapped pools; and (3) systematic field plot surveys.

As of 2003, 3877 potential pools (approximately 30% of the 13,000+pools originally mapped) have been field surveyed by a combination of NJDF&W biologists, CRSSA staff and trained field survey volunteers. Each pool was assessed as to (1) whether it met the physical characteristics to qualify as a vernal pool; and (2) whether it could be certified as vernal habitat with documented occurrences of obligate or facultative species. A simple percent accuracy was calculated based on the number of pools documented to qualify as having the necessary physical characteristics. These data provided information on errors of commission.

To assess and document the minimum discernable pool size with our mapping techniques, a subset of 43 potential vernal pools that approached the lower bound of mappable size (as mapped through the normal on-screen interpretation process) were selected for spot checking. These pools were approximately equally allocated across the five physiographic regions. The UTM coordinates of the pool were used to navigate to the location in the field. If a pool was present, the perimeter of the depression (and not just the ponded water) was measured. The pool perimeter was measured rather than some other shape or area metric as the perimeter was easier and faster to measure in the field by a single observer. In addition, the immediate area surrounding these pools was also surveyed to determine if there were any omitted pools. The 1995 New Jersey Level 3 Land Cover classification data set was used to determine the land cover composition of the area immediately surrounding the above vernal pools (http://www.crssa.rutgers.edu/projects/lc/data/njtm95l3lc.htm). In particular, we were interested in examining whether vernal pools located in the conifer or mixed conifer/deciduous forests were obscured and had a higher likelihood of omission.

To better understand the errors related to the omission of pools, we undertook a systematic field checking of 1 ha plots that were selected through a stratified random sampling design. Four study areas were selected representing conditions encountered across New Jersey: 1 site in the Highlands; 2 sites in the Inner Coastal Plain; and 1 site in the Outer Coastal Plain. The four study areas were dominated by a deciduous to mixed coniferous/deciduous forested matrix. A vernal pool density GIS grid file was generated from the mapped potential vernal pools to stratify areas into high, medium and low vernal pool density. Five 1 ha plots were selected within each density class based on ease of access for three of the four study areas. Fifteen high density 1 ha plots were selected for one of the Inner Coastal Plain study areas to perform a more intensive survey of an area most likely to contain small vernal pools. A total of 60 ha plots were field surveyed. A GPS-enabled handheld PC with color display screen (Trimble GeoXT) was used to display the GIS layer of mapped vernal pools and CIR orthophotography. Each 1 ha plot was surveyed by systematically walking a series of transects traversing the plot. Mapped pools were confirmed while additional un-mapped pools were identified, geo-located and their perimeters measured with a tape-measure. Area and diameter estimates were calculated for each perimeter based on the area of a circle, as a majority of these small pools approximated a circular shape. Land cover composition of the 1 ha plots was determined using the 1995 New Jersey Level 3 Land Cover classification data set.

Once created, the vernal pools GIS database was then used to generate a vernal pool density map which was generated in ESRI's ArcView GIS software. The map is based on a 5 km search radius, has a 100 m grid cell resolution, and shows the number of potential vernal pools per square mile across the state.

4. Results

Over 13,000 potential vernal pools were mapped. While vernal pools were distributed broadly across the state occurring in all physiographic regions (Fig. 1a) there were some 'hotspots' with high concentrations of potential vernal pools (Fig. 1b). Of the 3877 potential pools field surveyed as of 2003, 3425 were documented as having the physical characteristics to qualify as vernal pools. This resulted in an accuracy of 88% (i.e. 3425/3738). The 12% error of commission was due to our inclination to mark many water features as potential vernal pools in the interpretation and mapping process, even if they did not fit all the necessary criteria. We decided that it was better to err on the side of inclusion (i.e. commission error) so as to decrease the likelihood of overlooking possibly certifiable vernal pools. Of the 3425 documented vernal pools, 739 (or approximately 22%) of these were certified as serving as habitat for either a single obligate or multiple facultative vernal pool species.

To help determine the minimum discernable pool size with our mapping techniques, field measured perimeter and area measurements were characterized for 43 small pools selected from the potential vernal pools database (Table 2). These 43 small pools were first confirmed during subsequent field surveys as satisfying the physical criteria to be considered vernal pools. An additional eight nearby pools were located while surveying in the field. This set of eight pools was not initially digitized on the orthophotography because they were either inadvertently missed in

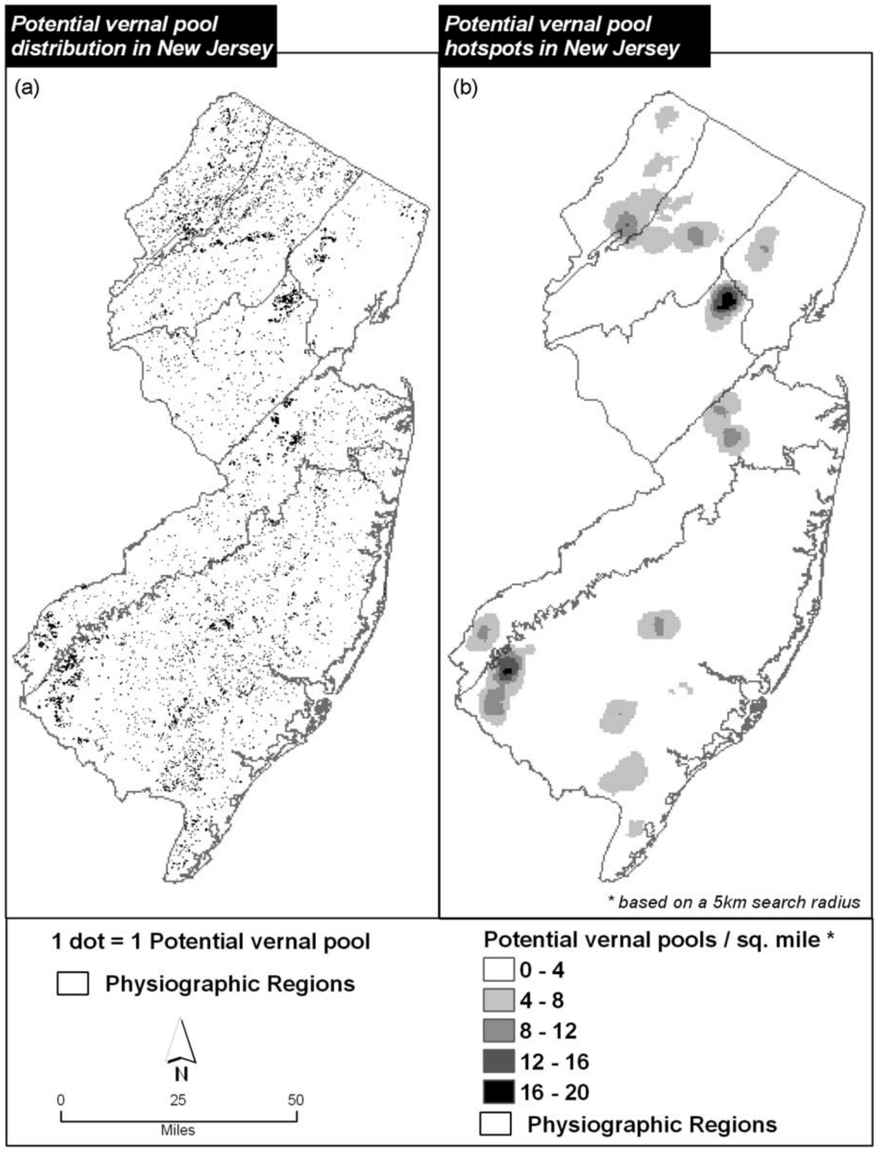

Fig. 1. Maps of potential vernal pool distribution and vernal pool 'hotspots' across New Jersey.

the photo-interpretation process or were too small and indistinct to make a positive identification. The field-measured perimeters for the eight omitted pools ranged from 15 to 37 m with a median of 28 m (Table 2). Examination of the surrounding land cover composition for the omitted pools did not reveal any discernable pattern with respect to higher omission errors in mixed or conifer dominated forests. Of the original 43 pools, 35 were located in deciduous forest and eight were located in mixed or conifer forest. Of the eight omitted pools, six were found in a deciduous forest matrix and two in a mixed or coniferous dominated matrix for an omission error of approximately 15% (i.e. 6 out of 41) and 20% (i.e. 2 out of 10), respectively.

Systematic field checking of the sixty 1 ha plots selected, via stratified random selection process, showed that these plots contained a total of 22 potential pools as mapped through the original photo-interpretation process. The vast majority of the low to medium density plots did not contain any mapped potential vernal pools. Subsequent field surveys confirmed the 22 mapped potential pools as satisfying the physical criteria to be considered vernal pools. Approximately 1/3 of the plots contained additional vernal pools that had been omitted from the original mapping, for a total of nine new un-mapped pools or an omission error of approximately 30%. These omitted pools had perimeters ranging from 15 to 39 m with a median of 28 m (Table 2). This range in perimeter (assuming a standard circular shape) equates to a range in area of 18–121 m^2 in size (Table 2). These perimeters were consistent with the range of the sizes of those pools discovered in the field during the spot surveys (see above). Examination of the surrounding land cover composition for the omitted pools did not reveal any discernable pattern with respect to higher omission errors in

Table 2
Statistics for pools at the small size limit of detection from the spot-checked field surveys and from pools omitted from the original mapping effort but that were located during the spot-checked field surveys and sixty 1 ha systematically checked plots

	# of pools	Perimeter min (m)	Perimeter max (m)	Perimeter median (m)	Diameter median (m)	Area min (m^2)	Area max (m^2)	Area median (m^2)
Spot-checked pools	43	26	50	37	12	54	199	109
Omitted pools								
Spot checked	8	15	37	28	9	18	109	62
1 ha plots	9	15	39	28	9	18	121	62

mixed or conifer dominated forests. Of the original 60 plots, 42 were located in deciduous forest, eight in mixed forest, nine in conifer forest and one in non-forest. Of the nine omitted pools, eight were found in deciduous forest and one in conifer dominated forest for an omission error of approximately 15% (i.e. 8 out of 42 deciduous forest plots) and 6% (i.e. 1 out of 17 mixed or conifer forest plots), respectively.

5. Discussion

The ability to discern a potential vernal pool on digital orthophotography is dependent upon the size and shape of individual pools and the surrounding landscape context/contrast as well as the spatial resolution and radiometric characteristics of the imagery. The success of our vernal pool mapping project was highly dependent on the optimal weather and precipitation conditions prior to the image acquisition. In the spring-time leaf-off photography, vernal pools in a deciduous forest matrix were readily recognizable when flooded. Comparing orthophotography from 1995 to 2002 (Fig. 2) reveals that pools clearly visible as dark features in the 1995 CIR orthophotography are absent in 2002. The years prior to the collection of the 1995/1997 orthophotography had normal precipitation (http://climate.rutgers.edu/stateclim/data/njhistprecip.html) with water tables sufficient to flood most vernal pools across the state. The fall 2001 and winter 2002 period was a record drought and many pools did not fill until late in the spring (after the photography was acquired) (Robinson, 2003). In the 2002 imagery, the dry pool basins in the deciduous forest matrix are exceedingly difficult to distinguish because pools appear simply as breaks in the forest canopy and there

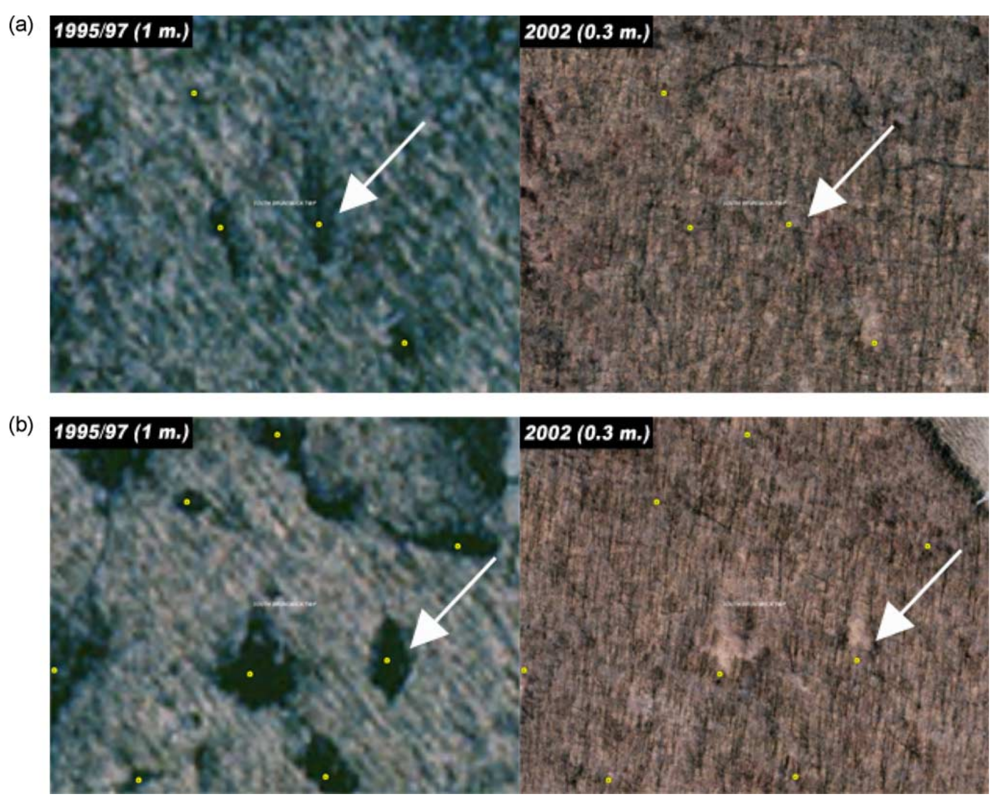

Fig. 2. (a and b) Examples of vernal pools in deciduous forest matrix, comparing 1995/1997 and 2002 orthophotography. The 1995/97 and 2002 orthophotography are displayed at the same scale though the original pixel size of is 1 and 0.3 m, respectively. The centroid of mapped vernal pools are denoted with a yellow dot (For interpretation of the reference to colour in this legend, the reader is referred to the web version of this article.).

is no difference in the reflectance of the pool bottom from the surrounding forest floor. Even the higher spatial resolution of the 2002 imagery (0.3 m as compared to the 1 m GRC for the 1995/1997 imagery) cannot compensate for the lack of ponded water.

As the main objective of this project was to identify and map pool locations, only the centroid point location was digitized. While it may have been desirable to collect more spatial information on the potential vernal pools, such as the individual pool area, this would have required digitizing the pool boundaries. The interpretation and digitizing of the pool boundaries would have been more time consuming, as well as subject to greater uncertainty, especially in the smaller size classes. While on the ground it is often feasible to discern and measure the general outline of the vernal pool depression even when not flooded, the digitization of pool boundaries from remotely sensed imagery is highly dependent on the water level at the time of imagery acquisition (as evidenced in the differences between the 1995 and 2002 imagery, Fig. 2).

The overlap of pool size ranges between the mapped and field confirmed set of pools shows that there is not always a consistent minimum detectable pool size (Table 2).

While the data does not reveal an absolute minimum detectable pool size, these two assessment data sets provide some idea of the threshold pool sizes that can be consistently identified and mapped using our data and methods. There is an apparent drop-off in the general ability to resolve vernal pools with perimeters less than from 40 m or corresponding areas of less than 120 m^2. Based on this assessment, we have a high degree of confidence in mapping pools with perimeters greater than approximately 50 m and areas greater than approximately 200 m^2 (0.02 ha) in size (assuming a roughly circular shape). Our area and diameter estimates for the minimum detectable pool size are based on the assumption of a circular shape and thus are conservative in that a circle represents the largest area for any shape of a given perimeter. Detecting and mapping pools smaller than this size is possible as our results show, however, the errors of commission (i.e. false positives) as well as omission (i.e. false negatives) are likely to increase. Our ability to identify and map long oblong pools with a narrow width (i.e. that approaches the ground resolution cell size of the imagery) is further limited.

Examination of the surrounding land cover composition in the validation surveys did not reveal any discernable pattern with respect to higher omission errors in mixed or conifer dominated forests. However, our validation surveys were limited in number and a larger sample size is needed to more conclusively examine this issue. In our experience, vernal pools in the conifer-dominated Pinelands of the outer coastal plain are often associated with particular geomorphological features (i.e. spungs) that are generally of sufficient size to break the forest canopy and thus be visible from the aerial imagery. Even under dry conditions, these pool depressions can be discriminated from the surrounding landscape as the bright soil substrate of the spungs contrasts well with the dominant coniferous forest vegetation (Fig. 3).

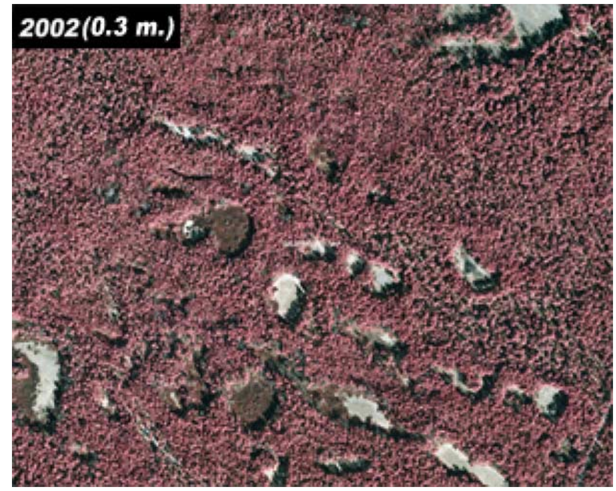

Fig. 3. Example of a vernal pool complex in the New Jersey Pinelands from the 2002 orthophotography (pixel size of approximately 1 foot or 0.3 m). Note that some pools have a bright substrate and others have a continuous mat of low-growing evergreen vegetation. These types of pools are locally known as spungs.

The spatial extent of the landscape area to be mapped is also a significant factor contributing to both errors of commission and omission. The photointerpretation process works by the photointerpreter developing a search image, if there are few such occurrences within a particular geographic area, an appropriate search image may be difficult to formulate. Consequently, during interpretation of vast stretches of upland, where vernal pools were comparatively rare, errors of omission of isolated individual pools may be more common. Our validation surveys were limited in number and a larger sample size is needed to more conclusively examine this issue. Conversely, in areas with consistently moderate vernal pool density, the interpreter can key in on a search image and more confidently identify individual vernal pools. However, uncertainties can arise in some high density complexes, where it is difficult to distinguish individual ponded depressions and small pools may be overlooked. Attempts were made to minimize this error by a second review of the orthophotography in regions densely populated with pools. Areas of high spatial heterogeneity of land cover types can also present problems as it can be difficult to discern a pool against the many spectral changes. Working at the statewide extent with a premium on time efficiency prevented the same level of thoroughness that might be expected for a smaller study area, even at the same map scale.

Additional sources of error include those that are not necessarily related to size but rather to other physical attributes related to the definition of a vernal pool. As the goal of this mapping project was to identify as many potential vernal pools as possible, an explicit decision was made to err on the side of including features that possibly did not fit all the vernal pool criteria (i.e. ponds, catchment basins). Pools that are connected to permanent outflows, or are permanent bodies of water that support fish, are often identified as vernal pools on the orthophotography. As shown in the overall certification survey results, approximately 12% of these mapped potential pools were revealed to not have the physical environmental characteristics to qualify as vernal pools.

Ultimately, for a vernal pool to receive protection, it must be 'certified' that it serves as habitat for obligate or facultative vernal pool amphibian species. To aid in this effort, the ENSP has enlisted the help of a cadre of trained volunteers to conduct surveys of vernal pools throughout the state. CRSSA developed an interactive internet mapping website to aid the citizen volunteer corps in locating potential vernal pool sites in the field and recording their observations. The web site can be found at http://www.dbcrssa.rutgers.edu/ims/vernal. The website begins with some background information regarding vernal pools and basic instructions on how to use the interactive map. The web map enables database querying, panning and zooming to various scales and exhibits a number of geographic layers, including aerial photography, so as to provide volunteers with the opportunity to envision the complexities of the landscape in which they are performing the field surveys. Volunteers can visually locate pools they would like to survey and query the map to get the pool's unique ID code number and UTM coordinate. The pool's ID number is directly linked to a survey form that can either be downloaded and printed or filled out and submitted online.

While there is high confidence in the classification of certified pools due to the documented presence of obligate or facultative species, there is lower confidence in the classification of the non-certified pools because of the uncertainty over the absence of species. Usage of pools as breeding habitat may be variable from year to year due to low water levels, local amphibian population swings, etc. Due to the vagaries of chance, a single field survey may be inconclusive. Multi-year surveys at multiple intervals over the breeding season are needed to conclusively rule out pools as not serving as viable breeding habitat. As additional certification surveys are undertaken over the span of several years and the database of certified vs. non-certified pools becomes more complete, we should be able to mine this data set to provide a better understanding of how changing land use patterns and habitat fragmentation may be impacting vernal pool habitats and amphibian populations.

6. Conclusions

On-screen visual interpretation and digitization of CIR DOQQ imagery was used to identify and map over 13,000 vernal pools across the state of New Jersey. While this approach lacked the advantages of a 3-D stereo perspective, it had the advantages of much greater time efficiency and the ready ability to integrate other mapped data in a GIS context. With the increasing availability of CIR DOQQ imagery and desk-top GIS mapping software, our mapping technique can easily be adopted to meet the information needs of individual towns to entire states. Spring leaf-off imagery was crucial as broad-leaf deciduous trees are the dominant forest type across much of the state and the lack of a leafed-out forest canopy provides a clearer view of the ground. Spring imagery and a normal rainfall year also provide the highest likelihood that pools will be flooded with standing water. Our accuracy assessment based on field surveys suggested that there were both errors of omission (false negatives) and commission (false positives). Using the 1 m GRC scale imagery, we determined the minimum detectable pool size to be on the order of 0.02 ha in size. Pools less than this size were more likely to be omitted. The accuracy assessment also suggested that we over-estimated the number of pools above this minimum mapping unit size by approximately 12%. In some respects this overestimation was by design due to our inclination towards erring on the side of inclusion in mapping many water features as potential vernal pools even though they did not specifically satisfy all the defined criteria.

The New Jersey Vernal Pools Mapping Project is an example of synthesizing computer-mapping tools with basic air photo interpretation techniques to meet a critical information need. For these vernal pool habitats to receive protection under the state of New Jersey's regulations, these often small landscape features have to be first be identified and field checked. Given New Jersey's rapidly developing landscape, with over 4000 ha of the state's forests and wetlands converted to development annually (Lathrop, 2004), we do not have the luxury of time. The entire New Jersey Vernal Pools Mapping Project took under one person year to complete with an overall budget of $60,000. The field certification will take longer, but using citizen volunteers and web-based tools, the certification process has been streamlined. While the initial comprehensive mapping phase is completed, the potential vernal pools database is not static and will be updated periodically. We fully expect to include new pool locations to the database based on increased volunteer activity and more intensive field mapping efforts. As the certification process continues, this database will become increasingly valuable in enhancing our understanding of the status of New Jersey's vernal pool dependent amphibian populations. The ultimate conservation potential for the completed data set is enormous as it is being incorporated into New Jersey's Endangered and Non-Game Species Program larger landscape level wildlife protection efforts as well as other state and local land use planning and management activities.

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