THE NORTH ATLANTIC VERNAL POOL DATA COOPERATIVE

Final Report Submitted to the North Atlantic Landscape Conservation Cooperative

July 2016 Revision

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Cover photo – Vernal pool, Norwich, VT, by Steven D. Faccio

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High Branch Conservation Services

North Atlantic Landscape Conservation Cooperative

Table of Contents

Revision History iii
List of Tables iv
List of Figures iv
Introduction vi
Chapter 1 – Compiling Vernal Pool Data for Conservation 1
Workshops and Outreach 1
Defining "Vernal Pool" 2
Data Access Levels 2
Database Structure 3
Data Submission Requests 7
The North Atlantic Vernal Pool Data Cooperative 10
Metadata Library 13
Coordinated Vernal Pool Mapping Projects in the North Atlantic Region 33
Delaware 36
Maine 36
Maryland 37
Massachusetts 39
New Hampshire 40
New Jersey 40
New York 41
Pennsylvania 41
Vermont 42
Virginia 43
Nova Scotia 43
Quebec 44
Data Gaps and Recommendations for Future Mapping 44
United States 44
Canada 46
Summary of Future Mapping Recommendations 46

References – Chapter 1 47
Appendix 1-A. North Atlantic Vernal Pool Cooperator Survey 48
Chapter 2 – Remote Sensing Based Identification of Vernal Pools Using LiDAR and Object-based Image Analysis 50
Introduction 50
Methods 52
Study Areas 52
Preliminary Data Processing 52
Automated Feature Extraction 57
Output and Assessment 69
Results 70
Automated Feature Extraction 70
Accuracy Assessment 71
Discussion 76
Recommendations for Remote Sensing Based Identification of Vernal Pools 80
Acknowledgments 82
References – Chapter 2 82
Appendix 2-A. LiDAR availability in eastern U.S. states 85
Appendix 2-B. LiDAR availability in eastern Canadian provinces 86

Revision History

Revision History Log

Version #	Date	Revised by	Changes
1.0	December 2015		Original final report
2.0	July 2016	Steven Faccio	Added details about pool data received from DE and PA in March and July of 2016, respectively. This included updating Figures 1-3 and 1-5, Tables 1-6 and 1-7, and the metadata library.

List of Tables

Table 1-1. Data fields and their description for the Access VPDC metadata table. 4
Table 1-2. Data fields and their description for the Access VPDC Min_data table. 5
Table 1-3. Data fields for the State_Province table. 5
Table 1-4. Data fields and their description for the Access VPDC Supplemental table. 6
Table 1-5. Individuals and their affiliations from whom vernal pool data were requested. 7
Table 1-6. List of data sets included in the VPDC and page number where metadata are archived in the Metadata Library. . 13
Table 1-7. Matrix of coordinated vernal pool mapping projects in the NALCC region. 34
Table 2-1. Input datasets for vernal pool modeling for Addison County, Vermont. 55
Table 2-2. Input datasets for vernal pools modeling for Cumberland County, New Jersey. 56
Table 2-3. Outlier analysis to remove candidate depressions that are unlikely to support vernal pools, Addison County, Vermont and Cumberland County, New Jersey. . 63
Table 2-4. Classification criteria for PVPs identified by automated feature extraction, Addison County, Vermont. . 66
Table 2-5. Classification criteria for PVPs identified by automated feature extraction, Cumberland Co., New Jersey. . 67
Table 2-6. Summary of final PVP classifications for Addison County, Vermont and Cumberland County, New Jersey. 71
Table 2-7. Two-part accuracy assessment for modeled potential pools in Addison County, Vermont. 73
Table 2-8. Two-part accuracy assessment for modeled potential pools in Cumberland County, New Jersey. 75

List of Figures

Figure 1-1. Map illustrating the NALCC region. vii
Figure 1-2. Relationships of the four tables included in the MS Access VPDC database 3
Figure 1-3. Regional map of vernal pool locations included in the North Atlantic Vernal Pool Data Cooperative. 10
Figure 1-4. Map of the northern portion of the NALCC region depicting field-verified and "potential" vernal pool locations submitted to the North Atlantic Vernal Pool Data Cooperative. 11
Figure 1-5. Map of the southern portion of the NALCC region depicting field-verified and "potential" vernal pool locations submitted to the North Atlantic Vernal Pool Data Cooperative. 12
Figure 2-1. Modeling flow for identification of potential vernal pools using object-based image analysis and high-resolution remote-sensing data. . 53
Figure 2-2. Landscape depression modeling for a suspected vernal-pool location in Addison County, Vermont. 61
Figure 2-3. Classification of a PVP in Cumberland County, New Jersey. . 68

Figure 2-4. Final PVP classifications for selected areas in Addison County, Vermont (a) and Cumberland County, New Jersey (b), superimposed on available orthoimagery. 72

Figure 2-5. Manual evaluation of PVPs in the Vermont Vernal Pools Database that were omitted by automated modeling. 777

Figure 2-6. Manual evaluation of PVPs in the New Jersey Vernal Pools Database that were omitted by automated modeling. 788

Introduction

The primary goal of this project was to advance vernal pool conservation by improving, a) knowledge of vernal pool distribution within the North Atlantic Region (Figure 1-1), and b) capacity to map vernal pool locations using remote-sensing technology. This was achieved by:

- compiling a spatially explicit database (the Vernal Pool Data Cooperative) of vernal pool locations in the NALCC region, including potential and field-verified pools;
- identifying and describing the coordinated mapping efforts within the region; and,
- developing a remote-sensing methodology to identify potential vernal pools using Light Detection and Ranging (LiDAR) technology and object-based image analysis.

Chapter 1 of this report details the process of developing the Vernal Pool Data Cooperative (VPDC) framework, describes the structure of the database and the data fields, and includes a metadata library which catalogues the data submitted to and included in the VPDC. There is also a section that identifies and describes the coordinated vernal pool mapping efforts across the NALCC region.

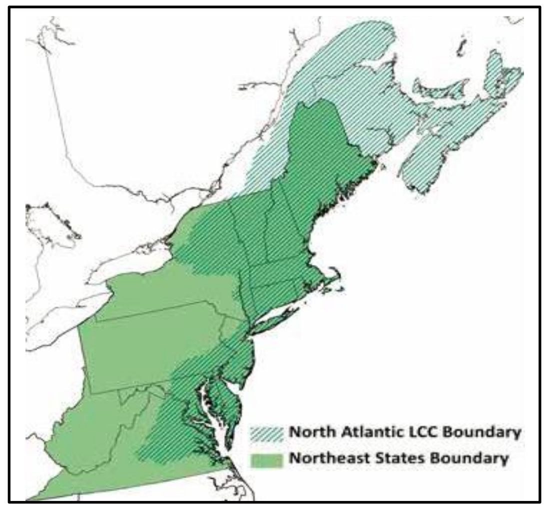

Figure 1-1. Map illustrating the NALCC region.

Chapter 2 describes the methodology used in developing model rule sets to identify potential vernal pools using Light Detection and Ranging (LiDAR) technology, multi-spectral imagery, and object-based image analysis. Results of the technique are presented for two pilot study areas located in northern New England (Addison County, Vermont) and the mid-Atlantic coastal plain (Cumberland County, New Jersey).

This project was funded by a Priority Science Grant from the North Atlantic Landscape Conservation Cooperative, and benefitted from the guidance and advice of a steering committee that consisted of the following members:

Rob Baldwin – Clemson University
Aram Calhoun – University of Maine
John Heilferty – New Jersey Division of Fish and Wildlife
Mary-Beth Kolozsvary – Siena College
David Patrick – The Nature Conservancy
Scott Schwenk – North Atlantic Landscape Conservation Cooperative
Scott Smith – Maryland Department of Natural Resources
Lesley Sneddon – Nature Serve

Chapter 1 – Compiling Vernal Pool Data for Conservation

Workshops and Outreach

The project was initiated in January 2014. In order to introduce the VPDC to potential cooperators and provide a forum for their participation in its development, a Vernal Pool Mapping and Conservation Workshop was hosted in April 2014 in conjunction with the Northeast Natural History Conference in Springfield, MA. About 30 members of state and federal agencies, NGOs, academia, and private consulting firms representing seven states across the Northeast and Mid-Atlantic regions participated in the workshop and completed a questionnaire that provided basic information about existing vernal pool datasets (see Appendix 1-A). Facilitated by Dan Lambert of High Branch Conservation Services, the half-day workshop featured presentations, directed discussions, and a working breakout session organized around four themes: 1) Data and Metadata Standards, 2) Data Access and Visualization, 3) Defining "Vernal Pool", and 4) Developing a Remote Sensing Vernal Pool Model.

A second workshop was hosted in Smyrna, DE in October 2014, in order to reach out to additional cooperators from the mid-Atlantic region. This full-day meeting drew 24 participants from six Mid-Atlantic states, plus Washington, DC, who provided rich input on data management, framework development, and model refinement. As in the previous workshop, we found a great deal of interest in adopting/customizing the spatial modeling rule set for areas outside of the pilot regions and for sustaining the VPDC beyond the project period to accommodate vernal pool mapping initiatives that are in their early stages. A two-hour field trip provided valuable insight regarding coastal plain intermittent ponds/Delmarva Bays. The outing proved valuable in refining modeling rule-sets for mapping potential vernal pools in coastal areas of the New Jersey pilot region.

In addition to the workshops, several oral presentations about the VPDC were presented, including one at the 2014 Northeast Fish and Wildlife Conference in Portland, ME, and another at the 2014 Annual Meeting of the Northeast Partners in Amphibian and Reptile Conservation.

Sean MacFaden also presented a webinar to present preliminary results from remote sensing modeling work that uses high-resolution LiDAR and multispectral imagery in conjunction with object-based imagery analysis to identify the location of potential vernal pools. Approximately 15 people attended the webinar, including steering committee members, ecologists, and GIS professionals from academia and various state and federal agencies. Several attendees participated in a discussion following the webinar, providing valuable feedback on model refinement and validation.

Defining "Vernal Pool"

Utilizing input from cooperators at workshop breakout discussions, the following definition for "vernal pool" was adopted for use in this project. It was modified from the definition provided by Calhoun and deMaynadier (2007), in order to be sufficiently broad to encompass most, if not all of the ephemeral wetland types that serve similar ecological functions for pool-breeding amphibians and invertebrates within the NALCC region. This definition is intended for use in screening records submitted to the Vernal Pool Data Cooperative. It is not intended for regulatory applications.

Definition of "Vernal Pool"

Vernal pools are temporary to semi-permanent pools occurring in shallow depressions that typically fill during the spring or fall and dry during summer or in drought years. Vernal pools provide important breeding habitat for amphibians, such as wood frogs and *Ambystomid* salamanders, as well as numerous invertebrate taxa adapted to temporary waters. Vernal pools may also support rare plant communities comprised of wetland and aquatic species. Although they may have intermittent inlets and outlets, vernal pools otherwise lack surface-water connections to permanent bodies of water and are usually free of predatory fish. Vernal pools occur in natural or excavated depressions in a diversity of landscape settings, including uplands, floodplains, coastal plains (including coastal plain ponds, Delmarva bays and Carolina bays), as part of headwater streams and seepage systems (as pools "strung" like pearls on an intermittent chain), or embedded in larger wetland complexes (e.g., shrub and forested swamps, peatland bogs).

–*modified from*, Calhoun, A.J.K. and P.G. deMaynadier. 2007. Science and Conservation of Vernal Pools in Northeastern North America. CRC Press, Boca Raton, FL. 363pp.

Data Access Levels

Data submitted to the VPDC are subject to any of three data restriction categories established by the original data source. These categories were decided upon after incorporating feedback from workshop breakout discussions, as well as from the project steering committee.

The data restriction categories are as follows:

Level 1: Unrestricted – Available for visualization and download through the NALCC Conservation Planning Atlas;
Level 2: Visualization only – Available for visualization in the Conservation Planning Atlas; download requires permission from data source;

Level 3: Restricted – Not available for visualization or download; access requires permission from data source.

Cooperators submitting data could choose to select a single restriction category for their entire data set, or vary the restriction level by each line of data. For example, while a cooperator may want the majority of their data set listed at Level 1, they may want a higher restriction category (Level 2 or 3) for individual pools that support rare or state-listed species. Alternatively, they could decide to exclude species-level information for those pools that support sensitive species, thereby maintaining a lower restriction category without revealing locations of rare fauna.

Database Structure

The VPDC database was built in Microsoft Access and consists of four tables, each described below. The relationships of these tables are illustrated in Figure 1-2.

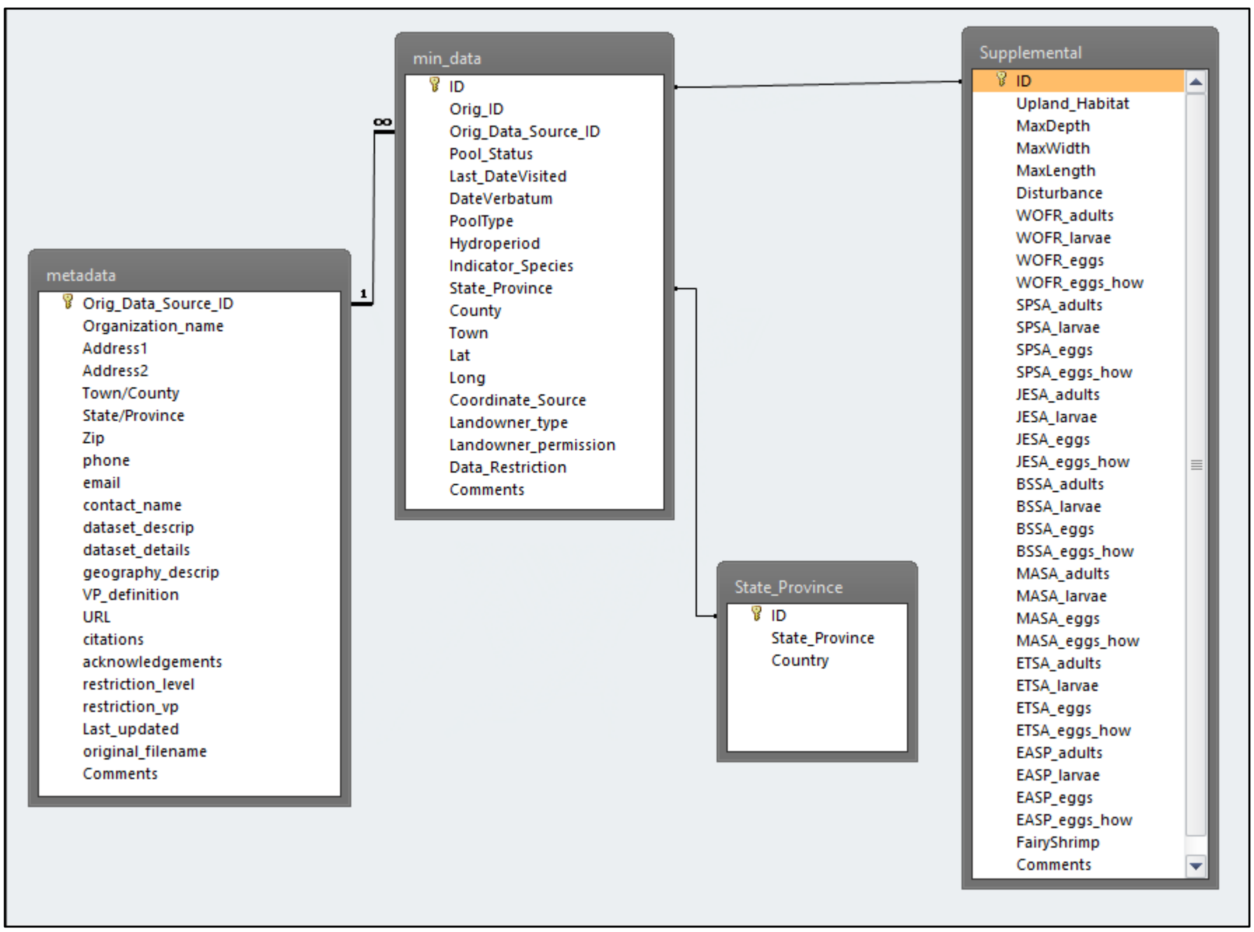

Figure 1-2. Relationships of the four tables included in the MS Access VPDC database.

Metadata Table **–** This table holds the metadata (provided by the original data source) for each dataset submitted to the VPDC (Table 1-1). Details for each dataset can be found in the Metadata Library beginning on page 13 of this report.

Table 1-1. Data fields and their description for the Access VPDC metadata table.

Field Name	**Data Type**	**Description**
Orig_Data_Source_ID	Text	Descriptive name of project or data set submitted (e.g. Vermont Vernal Pool Mapping Project, or ABC Preserve Vernal Pools); linked to Min_Table.
Organization_name	Text	Name of agency/organization submitting data
Address 1	Text	
Address 2	Text	
Town/County	Text	
State/Province	Text	
Zip Code	Text	
Phone	Text	
Email	Text	
Contact_Name	Text	Person to contact about this dataset
Dataset_descrip	Memo	Description of what the data set consists of, including details about field and/or remote sensing methodologies, etc.
Dataset_details	Memo	Check Box- Data set contains, □ field-verified locations; □ "potential" vernal pool locations; □ is part of an ongoing project actively being added to
geography_descrip	Text	Describe the geographic distribution of the dataset
VP_definition	Memo	Describe how "vernal pool" was defined for this dataset
URL	Text	Relevant URL for this dataset
Citations	Memo	Provide a citation for this dataset (e.g. paper, report, dataset, etc)
Acknowledgements	Memo	Provide how you would like this dataset acknowledged.
restriction_level	Text	Highest restriction level
restriction_vp	Text	Are all vernal pools in dataset restricted or just some?
Last_Updated	Date/Time	Date of last update to dataset; MM/DD/YYYY
Original_Filename	Text	Name of original file submitted by data owner/manager.
Comments	Memo	

Min_Data Table **–** This table holds the minimum data for submission to the VPDC, including geospatial coordinates, unique ID, and data restriction category (some fields may be left blank) (Table 1-2). It is linked to the other three tables by the "ID", "Orig_Data_Source_ID" and "State_Province" data fields.

Table 1-2. Data fields and their description for the Access VPDC Min_data table.

Field Name	Data Type	Description
ID	Text	Unique Pool ID, "State-IDnumber" (e.g. VT-999); Auto-number added post-submission; linked to Supplemental table
Orig_ID	Text	Unique Pool ID from original data source
Orig_Data_Source_ID	Text	Descriptive name of project or data set; linked to Metadata table
Pool_Status	Text	Field-verified or potential (remotely sensed, more data required, etc)
Last_DateVisited	Date/Time	MM/DD/YYYY
DateVerbatum	Text	Date that is not compatable with mm/dd/yyyy (e.g. Jan 1988, 2001, July, etc.)
PoolType	Text	Isolated VP, Carolina Bay/Delmarva Bay/Coastal Plain Pond, embedded in larger wetland, human-altered, other, unknown
Hydroperiod	Text	ephemeral, semi-permanent, permanent, unknown
Indicator_Species	Text	Yes, no, unknown
State_Province	Number	2-letter abbreviation; linked to State_Province table
County	Text	County of pool location
Town	Text	Town of pool location
Lat	Number	Decimal degrees (WGS84)
Long	Number	Decimal degrees (WGS84)
Coordinate_source	Text	Source of coordinates (GPS, Google Earth, topographic map, other, unknown)
Landowner_type	Text	Public, private, unknown
Landowner_permission	Text	Yes, no, or not known
Data_Restriction	Text	**Level 1**: Unrestricted - Available for visualization and download through Data Basin. **Level 2**: Visualization only – download requires permission from data source. **Level 3**: Restricted – Not available for visualization or download; access requires permission from data source.
Comments	Text	

State_Province Table **–** This table is linked to the Min_data table and provides the 2-letter code for the 16 states and provinces included within the NALCC region (Table 1-3, Fig. 1-1).

Table 1-3. Data fields for the State_Province table.

ID	Code	State_Province	Country
1	NB	New Brunswick	Canada
2	NS	Nova Scotia	Canada
3	QC	Quebec	Canada
4	CT	Connecticut	United States
5	DC	Washington D.C.	United States
6	DE	Delaware	United States
7	MA	Massachusetts	United States
8	MD	Maryland	United States
9	ME	Maine	United States
10	NH	New Hampshire	United States
11	NJ	New Jersey	United States
12	NY	New York	United States
13	PA	Pennsylvania	United States
14	RI	Rhode Island	United States
15	VA	Virginia	United States

Supplemental Table – This table is linked to the Min_data table by the "ID" field, and contains supplemental data regarding physical and/or biological characteristics of pools submitted to the VPDC (Table 1-4). These data fields are not "required" but provide additional data that add value to the data set.

Table 1-4. Data fields and their description for the Access VPDC Supplemental table.

Field Name	Data Type	Description
ID	Text	State-IDnumber (VT-999); linked to min_data table
Upland_Habitat	Text	Deciduous forest, conifer forest, mixed forest, shrub/scrub, field, ag land, developed, other
MaxDepth	Number	Estimated depth of pool at deepest point (in meters)
MaxWidth	Number	Estimated maximum width of pool (in meters)
MaxLength	Number	Estimated maximum length of pool (in meters)
Disturbance	Text	Dumping, logging, machinery, ditching, other
WOFR_adults	Text	Yes/No (were wood frog adults present?)
WOFR_larvae	Text	Yes/No (were wood frog larvae present?)
WOFR_eggs	Number	Number of wood frog egg masses present
WOFR_eggs_how	Text	Counted or Estimated (were the number of wood frog egg masses counted or estimated?)
SPSA_adults	Text	Yes/No (were spotted salamander adults present?)
SPSA_larvae	Text	Yes/No (were spotted salamander larvae present?)
SPSA_eggs	Number	Number of spotted salamander egg masses present
SPSA_eggs_how	Text	Counted or Estimated (were the number of egg masses counted or estimated?)
JESA_adults	Text	Yes/No (were Jefferson salamander adults present? Include morphologically similar hybrids)
JESA_larvae	Text	Yes/No (were Jefferson salamander larvae present?)
JESA_eggs	Number	Number of Jefferson salamander egg masses present
JESA_eggs_how	Text	Counted or Estimated (were the number of egg masses counted or estimated?)
BSSA_adults	Text	Yes/No (were blue-spotted salamander adults present? Include morphologically similar hybrids)
BSSA_larvae	Text	Yes/No (were blue-spotted salamander larvae present?)
BSSA_eggs	Number	Number of blue-spotted salamander egg masses present
BSSA_eggs_how	Text	Counted or Estimated (were the number of egg masses counted or estimated?)
MASA_adults	Text	Yes/No (were marbled salamander adults present?)
MASA_larvae	Text	Yes/No (were marbled salamander larvae present?)
MASA_eggs	Number	Number of marbled salamander egg masses present
MASA_eggs_how	Text	Counted or Estimated (were the number of egg masses counted or estimated?)
ETSA_adults	Text	Yes/No (were E. tiger salamander adults present?)
ETSA_larvae	Text	Yes/No (were E. tiger salamander larvae present?)
ETSA_eggs	Number	Number of E. tiger salamander egg masses present
ETSA_eggs_how	Text	Counted or Estimated (were the number of egg masses counted or estimated?)
EASP_adults	Text	Yes/No (were E. spadefoot toad adults present?)
EASP_larvae	Text	Yes/No (were E. spadefoot toad larvae present?)
EASP_eggs	Number	Number of E. spadefoot toad egg masses present
EASP_eggs_how	Text	Counted or Estimated (were the number of egg masses counted or estimated?)
FairyShrimp	Text	Yes/No (were fairy shrimp in the order Anostraca present?)
Comments	Text	

Data Submission Requests

Requests for vernal pool data were sent to 84 individuals representing a variety of state and federal agencies, NGOs, consultants, and academia from throughout the NALCC region (Table 1-5).

Table 1-5. Individuals and their affiliations from whom vernal pool data were requested. Listed in alphabetical order by State/Province.

Name	State/ Province	Affiliation
Alex Barrett	CT	Yale School of Forestry and Environmental Studies
Bob Gilmore	CT	CT Department of Energy and Environmental Protection
Hank Gruner	CT	Connecticut Science Center
Edward Pawlak	CT	Connecticut Ecosystems LLC
David Skelly	CT	Yale School of Forestry and Environmental Studies
Tracy Rittenhouse	CT	University of Connecticut
Darcy Winther	CT	CT Department of Energy and Environmental Protection
Mark Biddle	DE	Delaware Department of Natural Resources and Environmental Control
Kevin Kalasz	DE	Delaware Department of Natural Resources and Environmental Control
Bill McAvoy	DE	Delaware Department of Natural Resources and Environmental Control
Holly Niederriter	DE	Delaware Division of Fish and Wildlife
Matt Burne	MA	Walden Woods Project and Vernal Pool Association
Elizabeth Colburn	MA	Harvard Forest
Brad Compton	MA	University of Massachusetts
Evan Grant	MA	USGS Patuxent Wildlife Research Center
Sarah Haggerty	MA	Massachusetts Division of Fisheries & Wildlife
Scott Jackson	MA	University of Massachusetts Extension Service
Leo Kenney	MA	Vernal Pool Association
Jacob Kubel	MA	Massachusetts Division of Fisheries & Wildlife
Kevin McGarigal	MA	University of Massachusetts
Ethan Plunkett	MA	University of Massachusetts
Jon Regosin	MA	Massachusetts Division of Fisheries & Wildlife
Erica Sachs	MA	U.S. EPA - Boston
Lesley Sneddon	MA	Nature Serve
Bruce Spencer	MA	Forestry Works
Brad Timm	MA	University of Massachusetts
Tom Tyning	MA	Berkshire Community College
Bryan Windmiller	MA	Grassroots Wildlife Conservation
Jim Cummins	MD	Maryland Water Monitoring Council
Lynn Davidson	MD	Maryland Department of Natural Resources
Patricia Delgado	MD	Jug Bay Wetlands Sanctuary
Ron Klauda	MD	Maryland Water Monitoring Council

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Name	State/ Province	Affiliation
Dana Limpert	MD	Maryland Department of Natural Resources
Scott Smith	MD	Maryland Department of Natural Resources
Aram Calhoun	ME	University of Maine
Jason Czapiga	ME	Maine Department of Inland Fisheries and Wildlife
Phillip deMaynadier	ME	Maine Department of Inland Fisheries and Wildlife
Fred DiBello	ME	Stantec
Shane Duigan	ME	Maine Forest Service
Steve Pelletier	ME	Stantec
Trevor Persons	ME	Contract herpetologist
Mark Ward	ME	Ecological Consultant
Peter Bowman	NH	New Hampshire Natural Heritage Bureau
Laura Deming	NH	New Hampshire Audubon
Mike Marchand	NH	New Hampshire Fish and Game Department
Brett Amy Thelen	NH	Harris Center for Conservation Education
Will Staats	NH	New Hampshire Fish and Game Department
John Heilferty	NJ	New Jersey Division of Fish and Wildlife
Brian Zarate	NJ	New Jersey Division of Fish and Wildlife
Al Breisch	NY	New York State Department of Environmental Conservation (retired)
Andrea Chaloux	NY	New York State Department of Environmental Conservation
Jeff Corser	NY	New York State Department of Environmental Conservation
Jim Curatolo	NY/PA	Upper Susquehanna Coalition
Nate Nardi-Cyrus	NY	Scenic Hudson
James Gibbs	NY	SUNY-Syracuse
Laura Heady	NY	New York State Department of Environmental Conservation
Marnie Miller-Keas	NY	West Point Natural Resources Branch
Michael Klemens	NY/CT/NJ	Wildlife Conservation Society
Mary Beth Kolozsvary	NY	Siena College
Erik Kriviat	NY	Hudsonia, Ltd.
Jeff Luoma	NY	Forest Guild State Coordinator
Stacy McNulty	NY	SUNY - Adirondack Ecological Center
Dave Patrick	NY	The Nature Conservancy/Paul Smiths College
Mark Rooks	NY	Adirondack Park Agency
Gretchen Stevens	NY	Hudsonia, Ltd.
Jay Westerveld	NY	NY Natural History Council
Melissa Yearick	NY/PA	Upper Susquehanna Coalition
Holly Zdrodowski	NY	Columbia University
Kathy Gipe	PA	Pennsylvania Natural Heritage Program
Susan Klugman	PA	Pennsylvania Natural Heritage Program
Betsy Leppo	PA	Pennsylvania Natural Heritage Program
Tim Maret	PA	Shippensburg University

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Name	State/ Province	Affiliation
John Brazner	PNS	Nova Scotia Department of Natural Resources
Krista Hilchey	PNS	Nova Scotia Department of Natural Resources
Walter Bertacchi	PQC	Quebec Ministry of Natural Resources and Wildlife
Yohann Dubois	PQC	Quebec Ministry of Natural Resources and Wildlife
Antoine Richard	PQC	Quebec Ministry of Natural Resources and Wildlife
Nancy Karraker	RI	University of Rhode Island
Peter Paton	RI	University of Rhode Island
Chris Raithel	RI	Rhode Island Division of Fish and Wildlife
Christopher Riely	RI	Providence Water / Forest Guild State Coordinator
Rob Baldwin	SC	Clemson University
Gary Fleming	VA	Virginia Natural Heritage Program
Michael Hayslett	VA	Virginia Vernal Pools LLC
Mark Johnson	VA	NPS Mid-Atlantic Inventory & Monitoring Program
Justin Roberson	VA	Fairfax County Park Authority
Susan Watson	VA	Virginia Department of Game and Inland Fisheries
Anne Wright	VA	Virginia Commonwealth University
Mark Ferguson	VT	Vermont Fish and Wildlife Department

The North Atlantic Vernal Pool Data Cooperative

The Vernal Pool Data Cooperative consists of 61,331 records of vernal pools submitted by 13 cooperators (Fig. 1-3). Of these, 12,808 (20.9%) are locations of field-verified vernal pools and 48,523 (79.1%) are of "potential" vernal pools that were either remotely-sensed or require additional field work to confirm biological, hydrological, and/or physical characteristics (Figures 1-4 and 1-5). These data are found in the Min_Data Table of the Access Database (see Table 1-2). Thirty-three percent of the field-verified records (n=4,197) include supporting data which provide additional details about the physical and/or biological characteristics of pools in MD, ME, NH, NY, PA, VA, VT, and Quebec. These data are found in the Supplemental Table of the Access Database (see Table 1-4).

Data submitted to the VPDC are not a comprehensive representation of all vernal pools on the landscape. Many data gaps exist, including in states that have conducted statewide mapping using remote-sensing methods (MA, NJ, and VT), in which errors of commission and errors of omission are inherent. In addition, other sources of vernal pool data exist that were not submitted to the VPDC, many of which are summarized in the section entitled, *Coordinated Vernal Pool Mapping Projects in the North Atlantic Region*, while others are summarized in the section entitled, *Data Gaps and Recommendations for Future Mapping*.

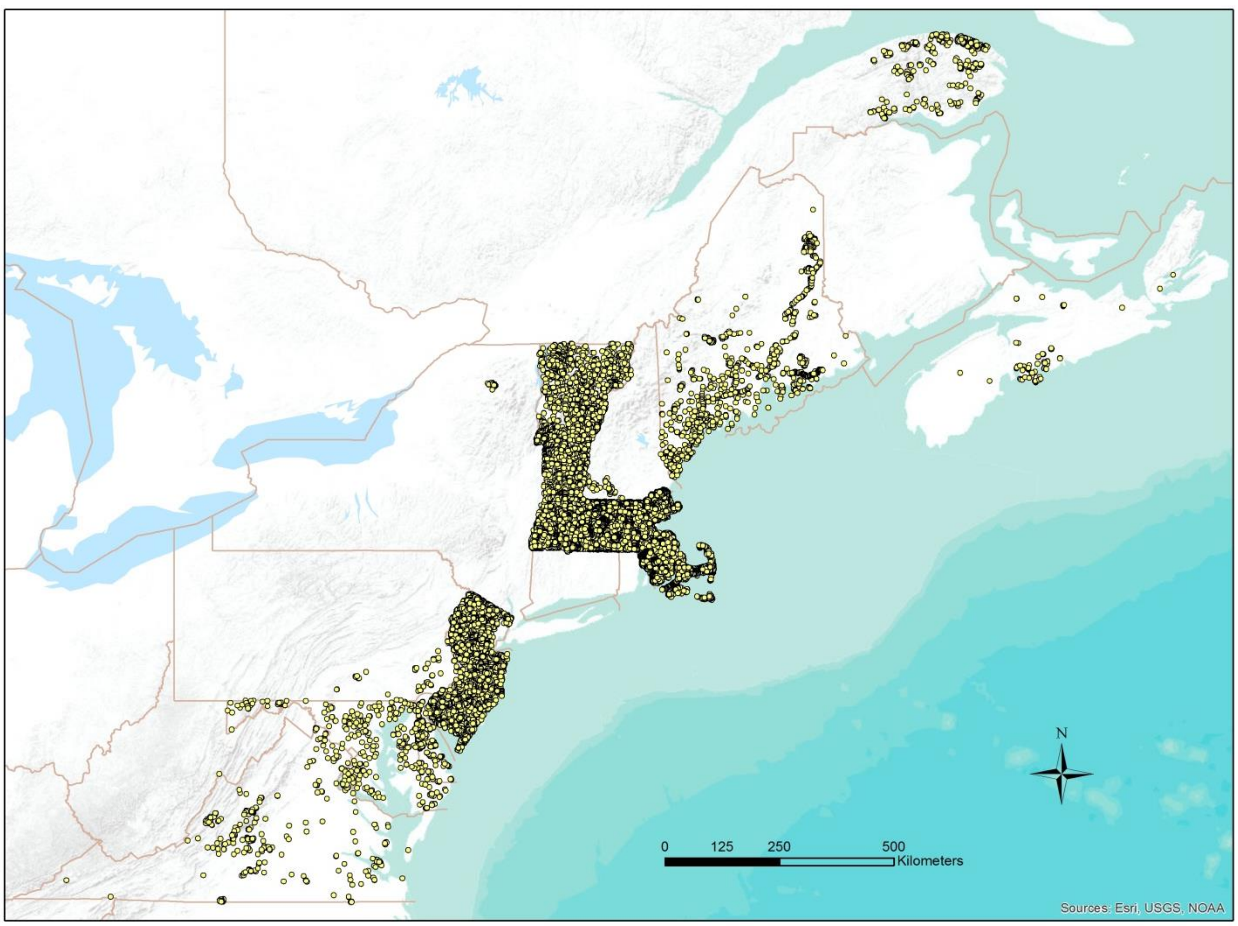

Figure 1-3. Regional map of vernal pool locations included in the North Atlantic Vernal Pool Data Cooperative. Data set includes both "potential" and field-verified vernal pools.

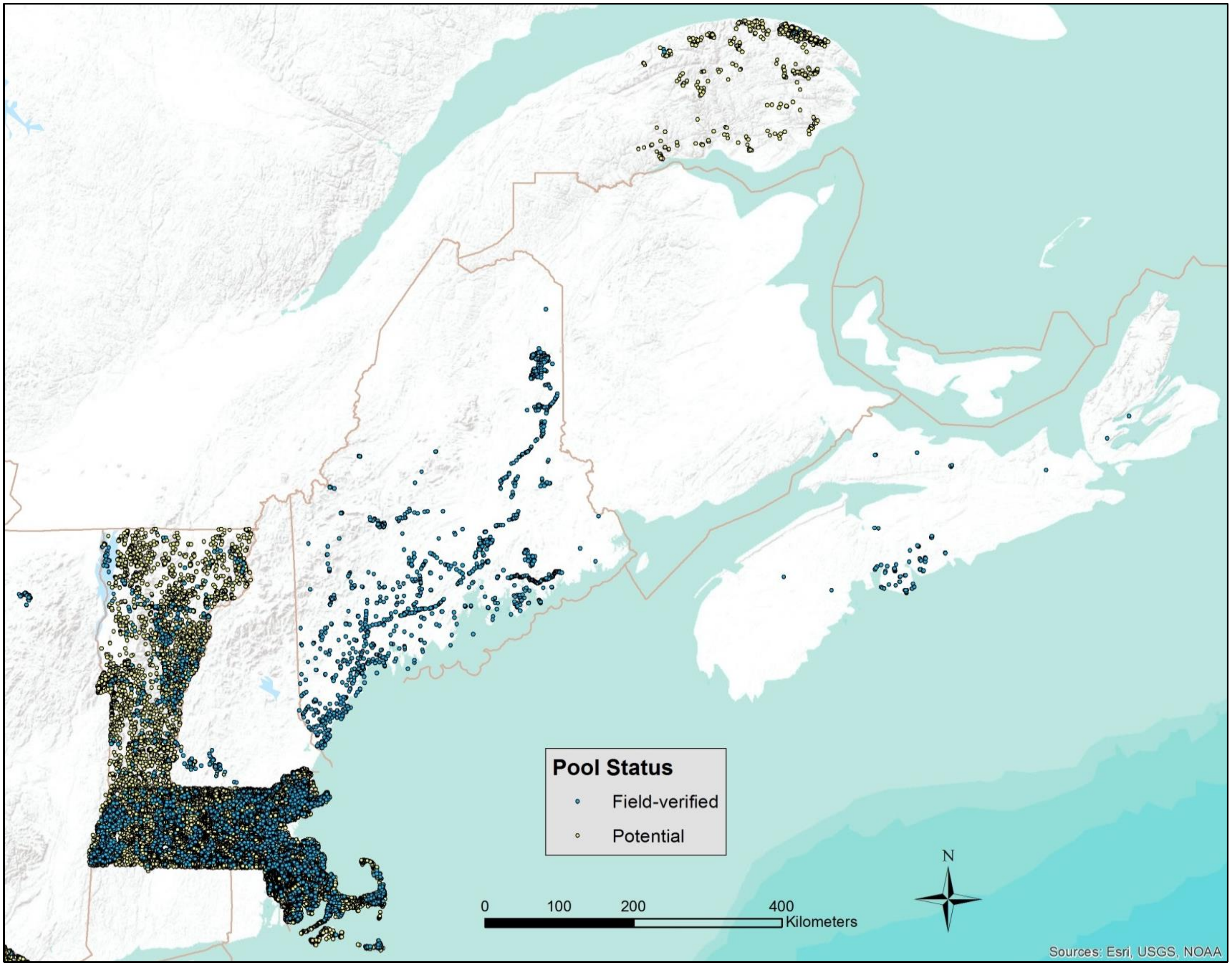

Figure 1-4. Map of the northern portion of the NALCC region depicting field-verified and "potential" vernal pool locations submitted to the North Atlantic Vernal Pool Data Cooperative.

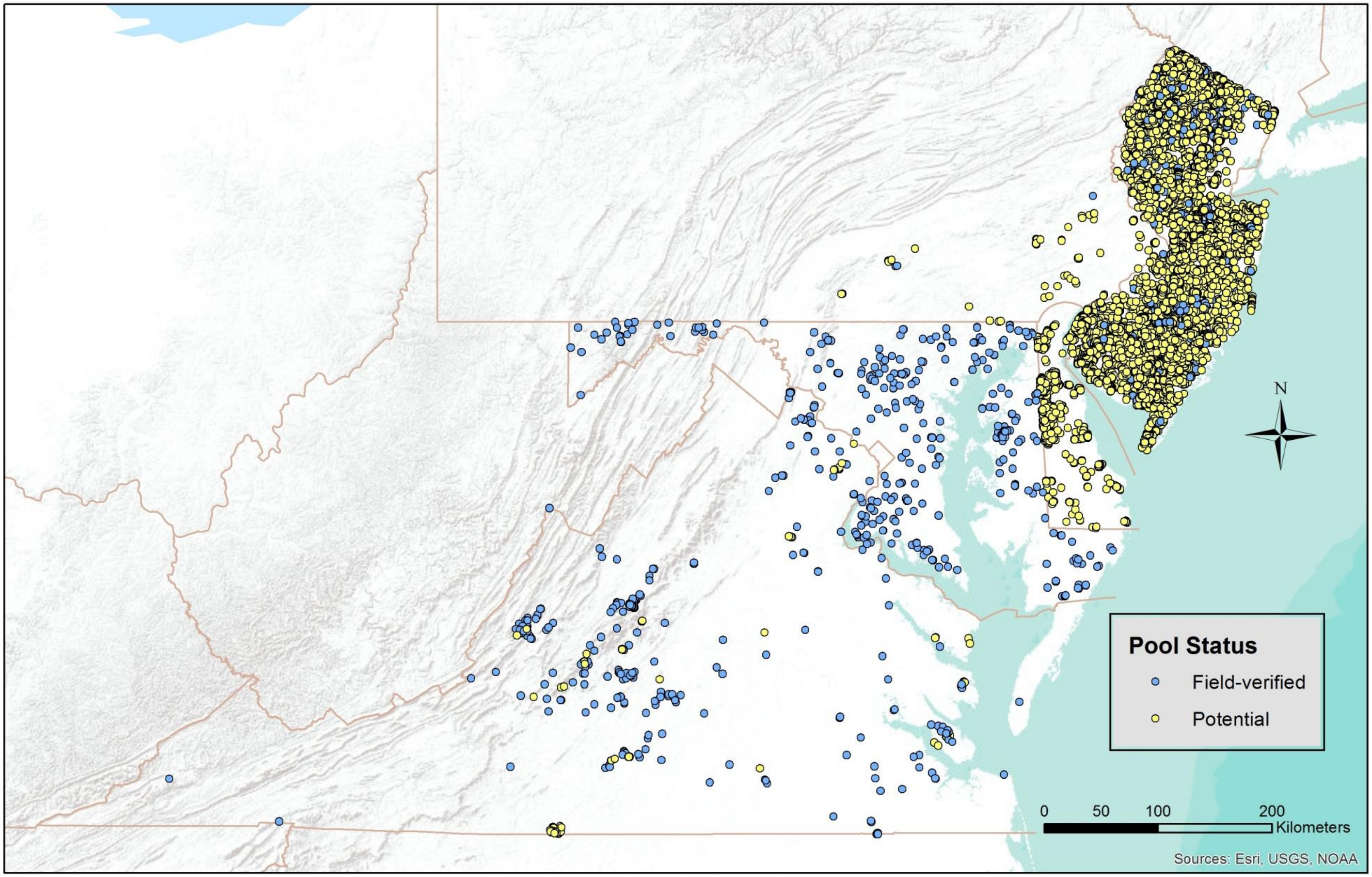

Figure 1-5. Map of the southern portion of the NALCC region depicting field-verified and "potential" vernal pool locations submitted to the North Atlantic Vernal Pool Data Cooperative.

Metadata Library

The metadata provided in this section are for all datasets submitted to the North Atlantic Vernal Pool Data Cooperative by 13 cooperators. Metadata were assembled through a Google Forms questionnaire completed by the owner/manager of each original data source. Metadata are listed in order of their date of submission. Refer to Table 1-6 for a complete list of submitted datasets and the page number where metadata can be found.

Table 1-6. List of data sets included in the VPDC and page number where metadata are archived in the Metadata Library. Listed in alphabetical order by State/Province.

State/Province	Name of Data Set	Region Covered	Page
Delaware	DNRC SWMP2007	Delaware statewide	28
Maine	State of Maine Vernal Pools	Maine statewide	27
Maryland	MD DNR-MBSS Vernal Pools 2007-14	Maryland statewide	26
Massachusetts	MA NHESP Certified Vernal Pools.	Massachusetts statewide	17
Massachusetts	MA Potential Vernal Pools.	Massachusetts statewide	19
New Hampshire	Vernal Pool Project (SW NH)	Cheshire and Hillsborough Counties in southwestern New Hampshire	20
New Jersey	NJDEP vernal habitat locations	New Jersey statewide	22
New York	D. Patrick_Egg Mass Monitoring	Area around Paul Smiths, Franklin County, New York	21
Nova Scotia	Nova Scotia Vernal Pool Mapping and Monitoring Project	Anywhere within Nova Scotia	24
Pennsylvania	Pennsylvania Natural Heritage Program Vernal Pool Datasets	NALCC region in PA (portions of Adams, Berks, Bucks, Chester, Delaware, Lancaster, Montgomery, Philadelphia and York Counties).	29
Quebec	Vernal Pool mapping in the Gaspesie Region of Quebec	A random sample within the Gaspesie Region of Quebec.	25
Vermont	Vermont Vernal Pool Mapping Project	Vermont statewide	14
Virginia	Element Occurrence Data for *Ambystoma tigrinum* and Coastal Plain Depression Wetlands Natural Communities	Virginia statewide	15
Virginia	VA Vernal Pools LLC.	Virginia statewide	16

Name of Data Set	**Vermont Vernal Pool Mapping Project**
Name of Agency/Organization submitting data	Vermont Fish & Wildlife Department, 1 National Life Dr., Davis 2, Montpelier, VT 05620.
Contact Person	Mark Ferguson, 802-828-1000, mark.ferguson@vermont.gov
Description of Data Set	Data consists of both remote-sensed "potential" pools and field-verified pools. From 2009 thru 2012, 1:40,000 color infrared (CIR) aerial photo interpretation was used to map the location of "potential" vernal pools statewide. A combination of field biologists and trained volunteers conducted field-verification of a proportion of mapped potential pools. In addition, information on vernal pool occurrence from other sources was incorporated into the project database. Project was coordinated by S. Faccio (Vermont Center for Ecostudies) and M. Lew-Smith and Aaron Worthley (Arrowwood Environmental), and funded in-part through the Vermont State Wildlife Grants Program.
Data Set Details	Data set contains field-verified vernal pool location data (n=644); Data set contains "potential" vernal pool locations mapped remotely (n=4214); Data set is part of an ongoing project and is actively being added to.
Geographic Distribution of Data Set	Vermont statewide.
Definition of "vernal pool"	A site was considered a vernal pool if it occurred in a forested context, had an ephemeral (seasonal) hydrology, was hydrologically isolated from permanent water sources, and had the presence of at least one of six indicator species (wood frog (*Lithobates sylvatica*), spotted salamander (*Ambystoma macultum*), Jefferson salamander (*Ambystoma jeffersonianum*), blue-spotted salamander (*Ambystoma laterale*), fairy shrimp (*Eubranchipus spp*.), fingernail clams).
URL of data set	http://vtecostudies.org/projects/forests/vernal-pool-conservation/vermont-vernal-pool-mapping-project/
Citation	Faccio, S.D., M. Lew-Smith, and A. Worthley. 2013. Vermont Vernal Pool Mapping Project, 2009-2012: Final Report to the Natural Heritage Information Project of the Vermont Department of Fish and Wildlife. Unpublished Report, Vermont Center for Ecostudies, Norwich, VT and Arrowwood Environmental, Huntington, VT.
Acknowledgements	Vermont Vernal Pool Mapping Project, Vermont Fish and Wildlife Department/Vermont Center for Ecostudies/Arrowwood Environmental.
Data Restriction Levels applied to this data set	Level 1: No restrictions - All data are unrestricted and can be visualized and downloaded in DataBasin.

Comments	
Timestamp of Data Submission	21 January, 2015; 16:25

Name of Data Set	**Element Occurrence Data for *Ambystoma tigrinum* and Coastal Plain Depression Wetlands Natural Communities.**
Name of Agency/Organization submitting data	Virginia Department of Conservation and Recreation, Natural Heritage Program, 600 E. Main St., 24th Floor, Richmond, VA 23219.
Contact Person	David Boyd, 804-786-6124, david.boyd@dcr.virginia.gov
Description of Data Set	Data consists of element occurrence records for 52 Coastal Plain Depression Wetlands and seven EO for *Ambystoma tigrinum* in Virginia.
Data Set Details	All locations have been field-verified.
Geographic Distribution of Data Set	Virginia statewide.
Definition of "vernal pool"	Coastal plain depression wetlands are a diverse group of poorly-drained basin wetlands characteristic of flat Coastal Plain terraces with fluctuating, seasonally perched water tables. Most of these wetlands are seasonally flooded and are believed to be sinkhole features that formed through dissolution of underlying carbonate-rich, shell marl deposits.
URL of data set	
Citation	Virginia Department of Conservation and Recreation, Natural Heritage Program, January 2016.
Acknowledgements	
Data Restriction Levels applied to this data set	Level 2: Visualization only – Available for visualization in the NALCC Conservation Planning Atlas; download requires permission from data source. License agreement with VA DCR-DNH through 1-Apr. 2017.
Comments	
Timestamp of Data Submission	12 April, 2015; 13:56; Updated 6 January, 2016.

Name of Data Set	**VA Vernal Pools LLC.**
Name of Agency/Organization submitting data	Virginia Vernal Pools, LLC, P.O. Box 410, Clifton Forge, Virginia 24422.
Contact Person	Michael Hayslett, 434-238-0223, vavernalpools@gmail.com
Description of Data Set	Data set consists of vernal pool and functional alternative wetlands plus the obligate fauna associated with these sites from around Virginia. These data were obtained over 25+ years through the field research efforts of Michael S. Hayslett, M.S. and his many associates. Sites were located through a combination of remote sensing via USGS 7.5 min. topo quads, aerial photos, and satellite imagery; personal communication with land owners/managers and other parties, and keen observation during extensive travels around the state over many years. Routine data obtained per site includes dimensional metrics, precision location, photo-documentation of site conditions and obligate faunal evidence, as well as ecological and conservation assessment of each site. Data have been maintained in an extensive archive of hard files, project reports, field journals, computer files, print/slide/digital photographs and Google Earth point files.
Data Set Details	Data set contains field-verified vernal pool location data (n=402); Data set contains "potential" vernal pool locations mapped remotely (n=147); Data set includes records of 75 pools lacking geospatial coordinates. Data set is part of an ongoing project and is actively being added to.
Geographic Distribution of Data Set	Virginia statewide.
Definition of "vernal pool"	Vernal pools in this VA data set are generally defined as isolated, ephemeral, forested wetlands in upland or floodplain settings that support the reproduction of obligate fauna. Virginia has ca. 12 obligate species (6 *Ambystoma*, 3 anurans, and several Fairy Shrimp species). The variability of environmental parameters in basin dynamics, hydrology and cover types across Virginia landscapes necessitates latitude in defining a vernal pool wetland, and it presents many gray areas to the definition process. Thus, the obligate fauna method has been employed as the common denominator for inventory of these environments across Virginia. "Functional" vernal pools are alternative wetlands that may depart more or less from the physical parameters above (e.g., pool basins and hydrologies that interface with other surface or groundwater systems but otherwise meet definition) but still support the reproduction of the obligate fauna. These functional alternatives include pools embedded in other, often larger wetland systems. "Created" sites are intentionally designed and constructed wetlands to serve the role and function of natural vernal pools in a given landscape.

	"Artificial" sites are those rare occasions where human-created features unintentionally support obligate species' reproduction (or at least their attempts at such).
URL of data set	www.virginiavernalpools.org
Citation	Vernal pools, related wetlands and their associated obligate fauna as distributed across Virginia: Results of field research by Michael S. Hayslett, M.S. from circa 1987 to 2015.
Acknowledgements	Personal research dataset of Michael S. Hayslett, M.S. of Virginia. Data preparation for and provision to the NAVPDC provided by Mike Hayslett and Seth Dorman under contract to VCE in June 2015.
Data Restriction Levels applied to this data set	Level 2: Visualization Only - Data can be used for visualization in DataBasin, but download requires permission from data owner.
Comments	M. Hayslett is grateful to the Vermont Center for Ecostudies for the provision of funding that has allowed an opportunity to organize and submit a portion of these data from the author's extensive data archive for the first time, after decades of research and amassing information. The team of Hayslett & Dorman, during 120 man-hours over three weeks' time, assembled over 500 sites from 40 Virginia counties for the NAVPDC template. This product may represent only half of the existing vernal pool data available through the author's Virginia dataset. The author desires to share more of this Virginia vernal pools dataset with the NAVPDC and requests consideration for additional funding to continue this effort.
Timestamp of Data Submission	10 June, 2015; 21:23

Name of Data Set	**MA NHESP Certified Vernal Pools.**
Name of Agency/Organization submitting data	Massachusetts Division of Fisheries & Wildlife / Natural Heritage and Endangered Species Program, 1 Rabbit Hill Rd., Westborough, MA 01473.
Contact Person	Sarah Haggerty, 508-389-6360, sarah.haggerty@state.ma.us
Description of Data Set	This data set contains points for all vernal pools that have been certified by the Natural Heritage and Endangered Species Program (NHESP) as of May 2015. Certified Vernal Pools (CVPs) with a Unique ID of #6000 or greater were certified according to the 2009 Guidelines for the Certification of Vernal Pool Habitat (MA Division of Fisheries & Wildlife, 2009). Somewhat different criteria were used in the original establishment of CVPs with a Unique ID of #1 – 5621; the 2001 Guidelines for the Certification of Vernal Pool Habitat (MA Division of Fisheries & Wildlife, 2001) are generally

	applicable to those certifications (but please note that many of those CVPs have been and continue to be updated opportunistically with new biological data that meet the 2009 guidelines). Please visit www.mass.gov/nhesp to view the 2009 Guidelines for the Certification of Vernal Pool Habitat and contact MA NHESP to request to the 2001 Guidelines for the Certification of Vernal Pool Habitat. Before 2004, Certified Vernal Pools were mapped on 1: 24,000 or 1: 25,000 USGS topographic quadrangle maps. The datalayer was created by NHESP by generating an Arc/Info coverage from a database of latitude and longitude points read from the USGS quads. Currently though, CVPs are heads-up digitized onscreen at approximately 1: 25,000 scale, using MassGIS' 2012 Digital Orthophotos as a basemap and based on the submitted locus documentation of a particular (CVP).
Data Set Details	Data set contains field-verified vernal pool location data (n=7,111); Data set is part of an ongoing project and is actively being added to.
Geographic Distribution of Data Set	Massachusetts statewide.
Definition of "vernal pool"	Confined basin depressions which, at least in most years, hold water for a minimum of two continuous months during the spring and/or summer, and which are free of adult fish populations, as well as the area within 100 feet of the mean annual boundaries of such depressions, to the extent that such habitat is within an Area Subject to Protection Under M.G.L. c. 131, § 40 as specified in 310 CMR 10.02(1). These areas are essential breeding habitat, and provide other extremely important wildlife habitat functions during non-breeding season as well, for a variety of amphibian species such as wood frog (*Lithobates sylvatica*) and spotted salamander (*Ambystoma macultum*), and are important habitat for other wildlife species. [Vernal Pool Habitat, per the Massachusetts Wetlands Protection Act regulations (310 CMR 10.00)].
URL of data set	http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/cvp.html
Citation	
Acknowledgements	MA NHESP Database, May 2015.
Data Restriction Levels applied to this data set	Level 1: No restrictions - All data are unrestricted and can be visualized and downloaded in DataBasin.
Comments	
Timestamp of Data Submission	22 May, 2015; 10:18

Name of Data Set	**MA Potential Vernal Pools.**
Name of Agency/Organization submitting data	Massachusetts Division of Fisheries & Wildlife / Natural Heritage and Endangered Species Program, 1 Rabbit Hill Rd., Westborough, MA 01473.
Contact Person	Sarah Haggerty, 508-389-6360, sarah.haggerty@state.ma.us
Description of Data Set	Data set consists of remotely-sensed "potential" vernal pools (n= 29,723) identified using aerial photo interpretation of 1: 12,000 color infra-red aerial photos for the entire state of Massachusetts. Photo interpretation was conducted during 1999-2000, using CIR photo imagery acquired in 1993, 1999, and 2000, depending on region.
Data Set Details	Since development of this Potential Vernal Pool layer in 2001, a portion of these pools may have received official certification; however, the Potential Vernal Pool data layer is a static layer and is not being updated. Potential vernal pools identified in this survey that have not been certified, do not receive protection under the Massachusetts Wetlands Protection Act Regulations (310 CMR 10.00), or under any other state or federal wetlands protection laws.
Geographic Distribution of Data Set	Massachusetts statewide.
Definition of "vernal pool"	Confined basin depressions which, at least in most years, hold water for a minimum of two continuous months during the spring and/or summer, and which are free of adult fish populations, as well as the area within 100 feet of the mean annual boundaries of such depressions, to the extent that such habitat is within an Area Subject to Protection Under M.G.L. c. 131, § 40 as specified in 310 CMR 10.02(1). These areas are essential breeding habitat, and provide other extremely important wildlife habitat functions during non-breeding season as well, for a variety of amphibian species such as wood frog (*Lithobates sylvatica*) and spotted salamander (*Ambystoma macultum*), and are important habitat for other wildlife species." [Vernal Pool Habitat, per the Massachusetts Wetlands Protection Act regulations (310 CMR 10.00)].
URL of data set	http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/layerlist.html
Citation	Burne, M.R. 2001. Massachusetts Aerial Photo Survey of Potential Vernal Pools. Natural Heritage & Endangered Species Program Massachusetts Division of Fisheries & Wildlife.

	http://www.mass.gov/eea/docs/dfg/nhesp/vernal-pools/ma-aerial-survey-pvp.pdf.
Acknowledgements	
Data Restriction Levels applied to this data set	Level 1: No restrictions - All data are unrestricted and can be visualized and downloaded in DataBasin.
Comments	
Timestamp of Data Submission	14 July, 2015; 10:10

Name of Data Set	**Vernal Pool Project (SW NH).**
Name of Agency/Organization submitting data	Harris Center for Conservation Education, 83 King's Highway, Hancock, NH 03449.
Contact Person	Brett Amy Thelen, (603) 358-2065, thelen@harriscenter.org
Description of Data Set	This data set consists of field-verified vernal pools and potential vernal pools (sites that resembled vernal pools in the field, but for which no evidence of breeding by obligate species was found), for a subset of public and conserved lands in the Monadnock Region of southwestern New Hampshire. Some of the GPS coordinates were originally generated via remote sensing, but all of the locations in this data set have been visited at least once by trained citizen science volunteers.
Data Set Details	Data set contains field-verified vernal pool location data, "potential" vernal pool locations mapped remotely, and is part of an ongoing project that is actively being added to.
Geographic Distribution of Data Set	Cheshire and Hillsborough Counties in southwestern New Hampshire.
Definition of "vernal pool"	For this data set, "vernal pool" was defined as an ephemeral water body in which one or more of the following species is breeding: spotted salamander, wood frog, Jefferson/blue-spotted salamander complex, and fairy shrimp. Very few of the sites in this data set were visited outside of the spring field season, so we relied heavily on evidence of breeding by obligate species, and only rarely assessed hydroperiod.
URL of data set	http://www.aveo.org/citizen-science/vernal-pools/
Citation	Unpublished data set

Acknowledgements	Data set courtesy of Ashuelot Valley Environmental Observatory (AVEO), the citizen science arm of the Harris Center for Conservation Education.
Data Restriction Levels applied to this data set	Level 1: No restrictions - (data are unrestricted and can be visualized and downloaded in DataBasin), and Level 2 - Visualization Only - (Data can be used for visualization in DataBasin, but download requires permission from data owner).
Comments	We have been training volunteers to document vernal pools since 2007. Over the years, we have refined our documentation process to make it more accessible for our volunteers, to improve the usefulness of the data, and to keep pace with changing vernal pool documentation procedures at the statewide level in New Hampshire. Our 2015 methods are outlined in our volunteer handbook at: www.aveo.org/wp-content/uploads/2012/08/vernal_pool_volunteer_handbook_2015.pdf. Our 2015 field data form is available at: www.aveo.org/wp-content/uploads/2015/05/Vernal_Pool_Project_data_form_2015.pdf. Because we have added a number of fields to the data form over the years, many of our older records contain blank fields. Whenever we did not have a definitive response to a given VPDC field, we left that field blank.
Timestamp of Data Submission	31 August, 2015; 17:35

Name of Data Set	**D. Patrick_Egg Mass Monitoring.**
Name of Agency/Organization submitting data	
Contact Person	David Patrick, 603-224-5853, david.patrick@tnc.org
Description of Data Set	Data set developed during monitoring of amphibian egg mass counts at pools/wetlands around Paul Smiths College, NY.
Data Set Details	Data set contains field-verified pools visited in the field, often multiple times over several years.
Geographic Distribution of Data Set	Area around Paul Smiths, Franklin County, New York.
Definition of “vernal	In general, “vernal pool” was defined as an isolated wetland with an

pool"	ephemeral or semi-permanent hydroperiod lacking connection to a permanent surface water source.
URL of data set	
Citation	D. Patrick, unpublished data set.
Acknowledgements	
Data Restriction Levels applied to this data set	Level 2: Visualization Only - (Data can be used for visualization in DataBasin, but download requires permission from data owner).
Comments	
Timestamp of Data Submission	9 September, 2015; 13:51

Name of Data Set	**NJDEP vernal habitat locations**
Name of Agency/Organization submitting data	New Jersey Department of Environmental Protection (NJDEP), Division of Fish Wildlife, Endangered Nongame Species Program (ENSP), PO Box 400, Trenton, NJ 08625-0400.
Contact Person	Peter Winkler, 609-292-1231, Peter.Winkler@dep.state.nj.us
Description of Data Set	In 2001 ENSP partnered with Rutgers University Center for Remote Sensing and Spatial Analysis (CRSSA) to develop a method for mapping potential vernal pools throughout New Jersey. Through an on-screen visual interpretation of digital orthophotography, CRSSA identified over 13,000 potential pools throughout the state. Standard 1995/1997 digital orthophoto quarter quad (DOQQ) imagery was used for the interpretation at a scale of 1:5000. Pools were identified based on visual characteristics as well as other physical environmental data. The pool centroid was then digitized and recorded. A subset of these pools was field verified and confirmed, with an 88% accuracy rate (Lathrop et al. 2005), to meet the physical characteristics to qualify as a vernal pool. In accordance with N.J.A.C. 7:7A-1.4, the term "vernal habitat" includes a vernal pool - or the area of ponding - plus any freshwater wetlands adjacent to the vernal pool. The Department here includes mapping of vernal habitat locations that relies upon data developed by the Department and Rutgers University Center for Remote Sensing and Spatial Analysis (CRSSA) to identify sites that should be field checked for possible identification as vernal habitats areas. DEP staff is in the process of field-verifying these pools. The Department also maps vernal habitat areas based upon on-the-ground assessment of sites not captured by the CRSSA mapping.
Data Set Details	These vernal habitat locations, all of the CRSAA-identified sites, as well as

	sites identified by on-the-ground reconnaissance, are categorized as either "potential" vernal habitat location or "field-verified" vernal habitat location as defined below: "Potential" vernal habitat location - These are areas identified by CRSSA as possibly containing a vernal pool that meets the criteria of a "vernal habitat" pursuant to N.J.A.C. 7:7A-1.4. These sites include sites that have been field inspected and have been found to meet the physical characteristics of a vernal habitat, but for which biological criteria have not yet been measured, as well as sites that have not been checked by DEP staff. "Field-verified" vernal habitat location - These are areas that contain pools that have been field-verified by the Department and have been determined to meet both the physical and biological characteristics of a vernal habitat in accordance with N.J.A.C. 7:7A-1.4.
Geographic Distribution of Data Set	New Jersey statewide
Definition of "vernal pool"	A vernal pool is a confined depression without a permanently flowing outlet, provides documented habitat for obligate or facultative vernal habitat species (these species are identified in N.J.A.C. 7:7A, Appendix 1), maintains ponded water for at least two continuous months between March and September of a normal rainfall year, and is free of fish populations throughout the year, or dries up at some time during a normal rainfall year.
URL of data set	
Citation	Lathrop R.G, Montesanoa P., Tesauro J., Zarate B., 2005. Statewide mapping and assessment of vernal pools: A New Jersey case study. Journal of Environmental Management 76: 230-238.
Acknowledgements	
Data Restriction Levels applied to this data set	Level 1: No restrictions - (data are unrestricted and can be visualized and downloaded in DataBasin).
Comments	Terms of Agreement 1. Digital data received from the NJDEP are to be used solely for internal purposes in the conduct of daily affairs. 2. The data are provided, as is, without warranty of any kind and the user is responsible for understanding the accuracy limitations of all digital data layers provided herein, as documented in the accompanying cross-reference files (see Section 1.14 CROSS-REFERENCE). Any reproduction or

	manipulation of the above data must ensure that the coordinate reference system remains intact. 3. Digital data received from the NJDEP may not be reproduced or redistributed for use by anyone without first obtaining written permission from the NJDEP. This clause is not intended to restrict distribution of printed mapped information produced from the digital data. 4. Any maps, publications, reports, or other documents produced as a result of this project that utilize NJDEP digital data will credit the NJDEP's Geographic Information System (GIS) and Site Remediation Program as the source of the data with the following credit/disclaimer: "This (map/publication/report) was developed using New Jersey Department of Environmental Protection Geographic Information System digital data, but this secondary product has not been verified by NJDEP and is not state-authorized." 5. Users shall require any independent contractor, hired to undertake work that will utilize digital data obtained from the NJDEP, to agree not to use, reproduce, or redistribute NJDEP GIS data for any purpose other than the specified contractual work. All copies of NJDEP GIS data utilized by an independent contractor will be required to be returned to the original user at the close of such contractual work. Users hereby agree to abide by the use and reproduction conditions specified above and agree to hold any independent contractor to the same terms. By using data provided herein, the user acknowledges that terms and conditions have been read and that the user is bound by these criteria.
Timestamp of Data Submission	21 September 2015; 13:24

Name of Data Set	**Nova Scotia Vernal Pool Mapping and Monitoring Project**
Name of Agency/Organization submitting data	Nova Scotia Dept. of Natural Resources, Provincial Bldg. 3rd Floor, 136 Exhibition St., Kentville, Nova Scotia B0P 1V0
Contact Person	John Brazner, 902-679-6247, braznejc@gov.ns.ca
Description of Data Set	Our dataset is all field-based. Each pool has been observed by someone in the field and logged as a GPS waypoint. The Anna Bishop points are part of a systematic search that she did in several ecoregion close to Halifax but all other points are simply those encountered when other fieldwork was being done and pools were noticed. Some remote-sensed potential pools have been identified in student projects for parts of Nova Scotia but these have not yet been submitted as part of our dataset.

Data Set Details	Data set contains field-verified vernal pool location data. Data set is part of an ongoing project and is actively being added to.
Geographic Distribution of Data Set	Anywhere within the province of Nova Scotia.
Definition of "vernal pool"	Our definition is based on Elizabeth Colburn's in her 2004 book, Vernal Pools: Natural History and Conservation. Dr. Colburn's is a five-part definition based on woodland context, isolation, size, hydrology and the biological community that is present. A summarized and simplified version of her definition is that vernal pools: ■ have a short hydro-period (the number of days per year the pool is filled with water); vernal pools fill, dry and sometimes refill seasonally; they dry out completely at least every few years; ■ occur next to forests and wooded areas; ■do not have permanent streams flowing in or out of them; ■ are usually small (< 0.5 ha) and shallow (<1m deep); ■ are usually deepest in the spring and sometimes again in late fall; ■ lack fish and are occupied by animals adapted to vernal conditions (ie. wood frogs, spotted salamanders, fairy shrimp).
URL of data set	http://www.novascotia.ca/nse/wetland/vernal.pool.mapping.project.asp
Citation	There is no formal report yet for this data set. Our project is described on the website linked above and should officially be cited as "Government of Nova Scotia. Vernal Pool Mapping and Monitoring Project."
Acknowledgements	"Government of Nova Scotia. Vernal Pool Mapping and Monitoring Project."
Data Restriction Levels applied to this data set	Level 2 - Visualization Only - Data can be used for visualization in DataBasin, but download requires permission from data owner.
Comments	Data submitted in three separate spreadsheets corresponding to person who conducted fieldwork: Anna Bishop, Rich LaPaix, and Rob Cameron. Data combined into one submission covered by this metadata.
Timestamp of Data Submission	28 September, 2015; 12:19.

Name of Data Set	**Vernal Pool mapping in the Gaspesie Region of Quebec**
Name of Agency/Organization submitting data	Quebec Ministry of Forests, Wildlife, and Parks, 195 blv. Perron Ouest, Caplan, Québec G0C 1H0

Contact Person	Antoine Richard, 418-388-2125, antoine.richard@mffp.gouv.qc.ca
Description of Data Set	Data set consists of vernal pools mapped by aerial photographic (30 cm resolution) interpretation. A subset of the mapped potential pools were field-verified.
Data Set Details	Data set contains field-verified vernal pool location data. Data set contains "potential" vernal pool locations mapped remotely. Data set is part of an ongoing project and is actively being added to.
Geographic Distribution of Data Set	A random sample within the Gaspesie Region of Quebec.
Definition of "vernal pool"	Four criteria had to be met for an element to be identified as a vernal pool: 1) presence of water, 2) area smaller than 2 ha, 3) unconnected to mapped permanent stream, and 4) not being already mapped as another type of wetland (e.g. pond, lake, etc.).
URL of data set	http://mffp.gouv.qc.ca/publications/forets/etangs-vernaux-gaspesie.pdf
Citation	Richard, A. and J. Ouellet. 2015. Acquisition de connaissances sur l'abondance et la répartition des étangs vernaux sur le territoire forestier gaspésien. Direction de la gestion des forêts de la Gaspésie-Îles-de-la-Madeleine, Ministère des Forêts, de la Faune et des Parcs. Caplan, Qc. 23 p.
Acknowledgements	Direction de la gestion des forêts de la Gaspésie-Îles-de-la-Madeleine, Ministère des Forêts, de la Faune et des Parcs du Québec
Data Restriction Levels applied to this data set	Level 1 - No restrictions - All data are unrestricted and can be visualized and downloaded in DataBasin.
Comments	The main objective of this mapping project was to estimate distribution and abundance of vernal pools in Gaspésie. Considering aerial photographs availability and staff availability, the whole peninsula was not surveyed. Instead, a subset of the territory was randomly chosen. Please refer to cited reference for further information.
Timestamp of Data Submission	2 October, 2015; 12:16.

Name of Data Set	**MD DNR-MBSS Vernal Pools 2007-14**
Name of Agency/Organization submitting data	MD Dept. of Natural Resources, Resource Assessment Service, 580 Taylor Avenue, C-2, Annapolis, MD 21401
Contact Person	Scott Stranko, 410-260-8603, scott.stranko@maryland.gov

Description of Data Set	Consists of pools identified during the Maryland Biological Stream Survey. Excel data file with 2 worksheets: first with coordinates and supporting data, second with definitions of column headers found in the first worksheet. This dataset may contain locations of temporary water that does not conform to a specific definition of a vernal pool.
Data Set Details	Data set contains field-verified vernal pool location data; Data set is part of an ongoing project and is actively being added to.
Geographic Distribution of Data Set	Maryland statewide
Definition of "vernal pool"	Not Provided
URL of data set	
Citation	
Acknowledgements	
Data Restriction Levels applied to this data set	Level 2 - Visualization Only - Data can be used for visualization in DataBasin, but download requires permission from data owner.
Comments	This form was generated by Lynn Davidson, MD DNR, Wildlife and Heritage Service, Natural Heritage Program; lynn.davidson@maryland.gov; 410-260-8563.
Timestamp of Data Submission	19 October, 2015; 15:45

Name of Data Set	**State of Maine Vernal Pools**
Name of Agency/Organization submitting data	Maine Department of Inland Fisheries & Wildlife, 650 State Street, MDIFW Building, Bangor, ME 04401
Contact Person	Jason Czapiga, 207-561-5620, jason.czapiga@maine.gov
Description of Data Set	This dataset depicts vernal pools identified in the field by Maine Department of Environmental Protection (MDEP) staff, Maine Department of Inland Fisheries and Wildlife (MDIFW) biologists, and appropriately trained consultants.
Data Set Details	Data set contains field-verified vernal pool location data; Data set is part of an ongoing project and is actively being added to.

Geographic Distribution of Data Set	Maine statewide; Limited to project survey areas.
Definition of "vernal pool"	A vernal pool must have the following characteristics: natural origin, temporary to semi-permanent hydroperiod, lack permanently flowing inlet or outlet, and lack predatory fish. A vernal pool qualifies as significant if it meets either the abundance or rarity criteria established in rule. Abundance refers to any one or combination of the following species abundance levels, documented in any given year: Fairy Shrimp (presence), Blue-spotted salamander (10 or more egg masses), Spotted salamander (20 or more egg masses), Wood frog (40 or more egg masses). Rarity relates to a pool with documented use in any given year by state-listed rare, endangered or threatened species that commonly require a vernal pool to complete a critical portion of their life-history.
URL of data set	
Citation	Maine Department of Inland Fisheries & Wildlife. (2015). State of Maine Vernal Pools (ver. 11/06/2015). Available from: http://www.maine.gov/ifw/wildlife/environmental/mdifw/index.html
Acknowledgements	
Data Restriction Levels applied to this data set	Level 2 - Visualization Only - Data can be used for visualization in DataBasin, but download requires permission from data owner.
Comments	
Timestamp of Data Submission	06 November, 2015; 15:19

Name of Data Set	**DNRC SWMP 2007**
Name of Agency/Organization submitting data	Delaware Department of Natural Resources and Environmental Control, 820 Silver Lake Blvd., Suite 220, Dover, DE 19904
Contact Person	Mark Biddle, 302-739-9939, mark.biddle@state.de.us
Description of Data Set	This dataset depicts Coastal Plain Ponds extracted from the DNRC SWMP2007 wetlands layer, using a DE_Modifier code of "2" (Coastal Plain Seasonal Ponds). Photo interpreters identified the wetland targets at a scale of approximately to 1:10,000 with delineations completed at 1:5,000 and, occasionally, larger as necessary. Polygons were then attributed with a code corresponding to the existing NWI classification scheme (Cowardin et al. 1979) and Delaware specific modifiers, where applicable.

Data Set Details	Data set contains "potential" pools mapped remotely.
Geographic Distribution of Data Set	Delaware statewide.
Definition of "vernal pool"	Coastal plain ponds, also called Delmarva Bays, are isolated, small, shallow, seasonally-wet areas, often circular/elliptical in shape, fed by groundwater/ rainfall/snow melt in winter/spring and drying up in summer/fall. Often surrounded by woodlands, the inner (wetter) zones feature a variety of low shrubs (e.g. buttonbush) and non-woody plants. Despite their isolated, seasonal nature, coastal plain ponds provide critical habitat to many rare and threatened plants and animals, and are especially vital to frog and salamander breeding.
URL of data set	http://opendata.firstmap.delaware.gov/datasets/b2320cfb54be420f8abc6e1d12ddc386_0
Citation	Delaware Department of Natural Resources and Environmental Control, SWMP2007 Wetlands (2011).
Acknowledgements	
Data Restriction Levels applied to this data set	Level 1 - No restrictions - All data are unrestricted and can be visualized and downloaded in DataBasin.
Comments	Use of this information is for guidance purposes only and is subject to change or modification at any time. Use of this information by others is at the own risk and the DNREC in no way guarantees the accuracy of this information.
Timestamp of Data Submission	21 March, 2016; 13:12

Name of Data Set	**Pennsylvania Natural Heritage Program Vernal Pool Datasets**
Name of Agency/Organization submitting data	Pennsylvania Natural Heritage Program, Department of Conservation and Natural Resources, 400 Market Street, Harrisburg, PA 17105
Contact Person	Betsy Leppo, 717-705-2814, Bleppo@paconserve.org
Description of Data Set	The data provided were derived from 3 projects of the Pennsylvania Natural Heritage Program (PNHP): (1) **PNHP Biotics Database 2016**: The point locations from the Biotics geodatabase represent Biotics Source Features. Each Source Feature represents a discrete observation of a vernal pool. In Biotics, Source

	Features can be stored as points, lines or polygons. All of the vernal pools in this dataset were originally mapped in Biotics as either points or polygons. Coordinates for polygons are the centerpoint of the polygon. The data were exported from the PNHP Biotics database on 24 June 2016. (2) **PNHP Seasonal Pools Registry 2008**: A seasonal pool geodatabase of confirmed (extant) and unconfirmed (potential) vernal pool locations in Pennsylvania documented by volunteer/citizen scientist submissions to PNHP. Volunteer participants submitted information about the location of vernal pools in Pennsylvania. Funding for the Vernal Pool Registry was provided by the U.S. Fish and Wildlife Service through the State Wildlife Grants Program, administered through the Pennsylvania Game Commission and Pennsylvania Fish and Boat Commission. The database contains two types of vernal pools based on the degree of confidence we have that the vernal pool is truly vernal and not some other wetland type: confirmed and unconfirmed. Refer to the attribute field "Confirmed" to see if the pool has sufficient documentation to consider it a 'Confirmed' vernal pool: Confirmed (Extant) vernal pools: Pools that have been confirmed by a biologist qualified to recognize vernal pools; or documented by a registry volunteer with sufficient evidence to prove that it is a vernal pool community. Unconfirmed (Potential) vernal pools: Pools that do not currently have sufficient documenting evidence to prove that the pool is vernal. Examples: • records submitted as part of the registry by volunteers • pools mapped using aerial photography only with no field visit • potential habitats flagged by reports of indicator or facultative vernal pool species through the Pa Herp Atlas and other sources. If the Confirmed field is blank, it should be assumed to be Unconfirmed. (3) **PNHP WRCP – EPA Project 2009**: Pennsylvania Statewide Seasonal Pool Ecosystem Classification. This project, funded by the Wild Resource Conservation Program and the U.S. Environmental Protection Agency, involved the description, mapping and classification of confirmed seasonal pools, their associated communities, and the surrounding landscape.
Data Set Details	Data set contains field-verified vernal pool location data, Data set contains "potential" vernal pool locations mapped remotely. Data set is part of an ongoing project and is actively being added to.
Geographic Distribution of Data Set	NALCC region in Pennsylvania (portions of Adams, Berks, Bucks, Chester, Delaware, Lancaster, Montgomery, Philadelphia and York Counties).
Definition of "vernal pool"	**PNHP Biotics Database** Vernal Pool records were selected from the dataset by searching for the following Community Types:

- Bottomland Oak – hardwood palustrine forest
- Buttonbush Wetland
- Ephemeral/fluctuating Natural Pool
- Herbaceous Vernal Pond
- Red maple – Black-gum Palustrine Forest
- Rice Cutgrass – Bulrush Vernal Pool
- Sparsely Vegetated Vernal Pool Community
- Wool-grass – Mannagrass - Mixed Shrub Marsh

Vernal Pool Registry Definition
(see http://www.naturalheritage.state.pa.us/VernalPools.aspx)
Small, shallow wetlands that go through a drying phase most years (usually in the summer), have no fish, and are not permanently connected to another body of water, though they may be temporarily connected during flooding events. They may also be called seasonal pools, temporary pools, autumnal wetlands, or ephemeral wetlands.

Pennsylvania Seasonal Pool Classification Project
From the 2009 Report:
Names and definitions for seasonal pools are as variable as the habitat. Seasonal, temporary, ephemeral, vernal, and autumnal are all terms used to describe these wetlands. While "vernal" is a term commonly attached to these temporary wetlands, it is not always accurate. A vernal pool is technically a water body that experiences a dry phase in the fall and winter, and a wetted phase in the early spring and summer. In contrast, an autumnal pool fills in the fall and retains water through the winter and spring (Wiggins et al. 1980; Williams 1987; Batzer and Sion 1999). For the remainder of this report, the terms pool and pond will be used interchangeably, as will the terms vernal, temporary, seasonal, and ephemeral.

Seasonal pools occur along a gradient of flood duration and frequency. On one end of the spectrum are rain puddles that hold water for a few weeks. At the other end of the spectrum are pools with water levels that fluctuate seasonally, but only dry down completely during drought years. The definition of a vernal pool may vary based on geographic region and even upon the interest of the researcher or management agency. The U. S. Environmental Protection Agency uses four criteria to define a vernal pool: surficial hydrologic isolation, periodic drying, small size and shallow depth, and a distinctive biological community (Brown and Jung 2005). Colburn (2004) proposed five indicators for vernal pools in the glaciated northeastern United States: a forested landscape context, physical isolation, relatively small size, seasonally fluctuating water levels, and a distinctive, specialized fauna.

Vernal pools are relatively small, fishless, still-water environments found within forest depressions. They generally have an impermeable substrate

	such as hardpan or clay, and have a fluctuating hydroperiod characterized by an annual or semi-annual dry phase (Wiggins et al. 1980; Thompson and Sorenson 2000). Temporary pools within a region share a backdrop of climatic and geomorphologic conditions, and share the same potential assemblage of organisms adapted to withstanding those particular environmental conditions (Schneider and Frost 1996). Processes such as habitat duration or habitat disturbance largely determine invertebrate community structure (Schneider and Frost 1996). In a temporary pool, the habitat is disturbed by the seasonal, cyclic pattern of flooding and drying. The physical stress exerted by a fluctuating hydroperiod and the adaptations of the temporary pool organisms to this stressful environment are therefore dominant factors in determining the insect community composition (Sharitz and Batzer 1999, Zimmer et al. 2000). While a temporary hydroperiod is a significant obstacle for an aquatic organism to overcome, there is a good evolutionary reason to do so. Fish are major predators of invertebrate fauna, but are typically unable to tolerate temporary aquatic environments. When fish are present in an aquatic habitat, they become one of the most significant variables affecting the composition and abundance of the insect community (Zimmer et al. 2000). Temporary pools provide a place for immature animals to develop without the threat of predation from fish.
URL of data set	
Citation	Pennsylvania Natural Heritage Program, 2016. Pennsylvania Natural Heritage Program Biotics Database, Harrisburg, PA. Pennsylvania Natural Heritage Program Vernal Pools Registry, 2008. Pennsylvania Natural Heritage Program, Harrisburg, PA. Leppo, B., Zimmerman, E., Ray, S., Podniesinski, G., and Furedi, M. 2009. Pennsylvania Statewide Seasonal Pool Ecosystem Classification: Description, mapping, and classification of seasonal pools, their associated plant and animal communities, and the surrounding landscape. Pennsylvania Natural Heritage Program, Western Pennsylvania Conservancy, Pittsburgh, PA.
Acknowledgements	Pennsylvania Natural Heritage Program, Department of Conservation and Natural Resources, Harrisburg, PA, 2016.
Data Restriction Levels applied to this data set	Level 2 - Visualization Only - Data can be used for visualization in DataBasin, but download requires permission from data owner.
Comments	Please refer to the signed Pennsylvania Natural Heritage Program Data Sharing Agreement for Data Use restrictions and guidelines.
Timestamp of Data Submission	19 July, 2016; 14:59

Coordinated Vernal Pool Mapping Projects in the North Atlantic Region

Fifteen projects were identified in the NALCC region that used remote-sensing and/or field methods to systematically map vernal pools within a specified geographic region (usually a state or province, but occasionally a smaller more focused area). Table 1-7 briefly summarizes these projects in a matrix, while a more detailed description of each project is found below, listed alphabetically by state and province.

Table 1-7. Matrix of coordinated vernal pool mapping projects in the NALCC region.

Project	Geographic Region	Year Started	Status	Remote-sensing Methods	Field-verification?	Contact Agency/Organization	Included in VPDC?
United States							
DNRC SWMP 2007	Delaware statewide	Unknown	Completed in 2011	Updated 2007 imagery was used at a scale of 1:10,000 to delineate wetlands, including Coastal Plain Seasonal Ponds	No	Mark Biddle, Environmental Scientist, mark.biddle@state.de.us	Yes
Maine Vernal Pools Database	Maine statewide	1998; "Significant vernal pools" protected in 2007	Ongoing	None	Yes, by ME DEP, F&W staff, and trained consultants.	Phillip deMaynadier, Maine Dept. of Inland Fisheries and Wildlife, Phillip.deMaynadier@maine.gov	Yes
Maine Vernal Pool Municipal Mapping and Assessment Project	Primarily southern, coastal Maine	2007	Completed in 2014	Hi-resolution digital CIR aerial photo interpretation, usually by Stantec Consulting.	Yes, by staff and trained volunteers.	Aram Calhoun University of Maine Orono, calhoun@maine.edu	Yes, if field-verified and included in MVPD, above
Maryland Wildlife Diversity Conservation Plan	Maryland state-owned lands statewide	Approx. 2003	Completed 2005	Identified potential pools in GIS using all palustrine wetlands with NWI water regime modifiers of temporarily flooded, seasonally flooded, seasonally flooded/saturated, saturated, and semi-permanently flooded.	None	Maryland Dept. of Natural Resources.	No
Maryland Biological Stream Survey	Maryland statewide	2007	ongoing	None	Yes, DNR staff identify pools encountered during stream surveys.	Scott Stranko, Maryland Dept. of Natural Resources scott.stranko@maryland.gov	Yes
Massachusetts Aerial Photo Survey of Potential Vernal Pools	Massachusetts statewide	2000	Completed, 2001	Potential vernal pools were identified from 1:12,000 scale, color infra-red (CIR), leaf-off aerial photographs.	No coordinated effort, but see *Massachusetts Certified Vernal Pools*, below.	Sarah Haggerty Massachusetts Division of Fisheries & Wildlife, sarah.haggerty@state.ma.us	Yes
Massachusetts Certified Vernal Pools	Massachusetts statewide	2001	Ongoing	See above	Yes, primarily by volunteers; MA F&W staff review for official "certification."	Jacob Kubel Massachusetts Division of Fisheries & Wildlife, jacob.kubel@state.ma.us	Yes
Ashuelot Valley Environmental Observatory Vernal Pool Project	Public and Conserved lands in SW New Hampshire	2013	Ongoing	None	Yes, primarily by trained volunteers.	Brett Amy Thelon Harris Center for Conservation Education, thelen@harriscenter.org	Yes

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Project	Geographic Region	Year Started	Status	Remote-sensing Methods	Field-verification?	Contact Agency/Organization	Included in VPDC?
New Hampshire Vernal Pool Documentation	New Hampshire statewide	Approx. 2013	Ongoing	None	Yes, primarily by volunteers submitted to the NH Wildlife Sightings website.	Mike Marchand New Hampshire Fish and Game, Michael.Marchand@wildlife.nh.gov	No
NJ DEP Vernal Habitat Locations	New Jersey statewide	2001	Ongoing	1:5000 digital orthophoto quarter quad imagery interpretation	Yes, by DEP staff and volunteers.	Brian Zarate New Jersey Endangered Nongame Species Program, Brian.Zarate@dep.nj.gov	Yes
The Upper Susquehanna Coalition Vernal Pool Project	South-central New York and Northeast Pennsylvania	Unknown	Ongoing	None	Yes, primarily by volunteers.	Melissa Yearick Upper Susquehanna Coalition, melissa@u-s-c.org	No
Pennsylvania Vernal Pool Registry	Pennsylvania statewide	Unknown	Ongoing	None	Yes, primarily by volunteers.	Betsy Leppo, Pennsylvania Natural Heritage Program, Bleppo@paconserve.org	Yes; pools within NALCC region of PA
Pennsylvania Biotics Database	Pennsylvania statewide	Unknown	Ongoing	Unknown	Unknown	Besty Leppo, Pennsylvania Natural Heritage Program, Bleppo@paconserve.org	Yes; pools within NALCC region of PA
Pennsylvania Statewide Seasonal Pool Ecosystem Classification	Pennsylvania statewide	2007	Completed in 2009	Orthophoto interpretation was used in some areas but did not prove useful in detecting pools.	Yes, by PNHP staff	Besty Leppo, Pennsylvania Natural Heritage Program, Bleppo@paconserve.org	Yes; pools within NALCC region of PA
Vermont Vernal Pool Mapping Project	Vermont statewide	2009	Ongoing	1:40,000 stereo-paired color-infrared aerial photograph interpretation	Yes, primarily by staff and trained volunteers.	Steve Faccio Vermont Center for Ecostudies, sfaccio@vtecostudies.org Mark Ferguson, VT Fish and Wildlife mark.ferguson@vermont.gov	Yes
Vernal Pool Cooperative of Virginia	Virginia statewide	2013	Ongoing	None	Yes, primarily by volunteers and trained naturalists.	Anne Wright Virginia Commonwealth Univ., abwright@vcu.edu	No
Canada							
Nova Scotia Vernal Pool Mapping and Monitoring Project	Nova Scotia province-wide	2011	Ongoing	None	Yes, primarily NS DNR staff.	John Brazner Nova Scotia Department of Natural Resources, John.Brazner@novascotia.ca	Yes
Vernal Pool Distribution and Abundance in the Gaspesie Region of Quebec	Gaspe Peninsula area of Quebec	2013	Completed, 2015, but ongoing as time allows	True-color leaf-off orthophotos (30 cm resolution) were compared to late-summer orthophotos to confirm pool drying.	Yes, by Quebec MNRW staff, but limited effort.	Antoine Richard Quebec Ministry of Natural Resources and Wildlife, antoine.richard@mffp.gouv.qc.ca	Yes

United States

Delaware

1) DNRC SWMP 2007

Summary: The USFWS and the State of Delaware contracted with the Conservation Management Institute to complete an updated and enhanced version of the existing NWI and SWMP for Kent, New Castle and Sussex Counties in Delaware. Photo interpreters identified the wetland targets at a scale of approximately to 1:10,000 with delineations completed at 1:5,000 and, occasionally, larger as necessary. Polygons were then attributed with a code corresponding to the existing NWI classification scheme (Cowardin et al. 1979) and Delaware specific modifiers, where applicable. Wetlands listed in the "DE_Modifier" column are those polygons where a special Delaware modifier(s) has been added to reference unique ecological communities that may harbor rare, threatened or endangered (RTE) plants and animals, including Coastal Plain Seasonal Ponds.

Status: Completed 2011

For more information:

http://opendata.firstmap.delaware.gov/datasets/b2320cfb54be420f8abc6e1d12ddc386_0

http://www.nav.dnrec.delaware.gov/dnreceis/downloads/swmpcodes.pdf

Maine

1) Maine Vernal Pools Database

Summary: The Maine Division of Inland Fisheries and Wildlife maintains a spatially explicit database of field-verified vernal pools, which includes biological and physical data. Since 2007, "Significant Vernal Pools" are protected by law under Maine's Natural Resources Protection Act (NRPA). Vernal pool significance must be determined and documented by an individual who has experience and training in either wetland ecology or wildlife ecology, and therefore has qualifications sufficient to identify and document a significant vernal pool.

Criteria for significance include:

- Abundance of indicator species. Any one of or combination of the following species abundance levels, documented in any given year, determine the significance of a vernal pool.

Species	Abundance Criteria
Fairy shrimp	Presence in any life stage
Blue-spotted Salamander	Presence of 10 or more egg masses
Spotted Salamander	Presence of 20 or more egg masses
Wood Frog	Presence of 40 or more egg masses

- A pool that has documented use in any given year by state-listed rare, endangered or threatened species that commonly require a vernal pool to complete a critical portion of their life-history is a significant vernal pool. Examples of vernal pool dependent state-listed endangered or threatened species include, but are not limited to, Blanding's Turtle, Spotted Turtle, and Bog Haunter Dragonfly.

Status: Ongoing.

For more information:

http://www.maine.gov/ifw/pdfs/IFWInsidervernalpoolfeb2011medium.pdf

http://www.maine.gov/dep/land/nrpa/vernalpools/

http://www.maine.gov/dep/gis/datamaps/index.html

2) Maine Vernal Pool Municipal Mapping and Assessment Project

Summary: A project of the University of Maine that worked with interested municipalities to educate them about vernal pool ecology and assist them with the process of using citizen scientists to proactively map and survey vernal pool resources, with special attention to identifying pools that meet the biological criteria for "Significant Vernal Pools." Initiated in 2007, the project worked with about 12 municipalities, primarily in southern coastal Maine, and often used remote methods (CIR aerial photo interpretation) to map locations of potential vernal pools and trained citizen scientists for field-verification. Mapping data from concentrated efforts were archived in the Maine Division of Inland Fisheries and Wildlife Significant Vernal Pools database (see above).

Status: Completed in 2014.

For more information:

http://www.vernalpools.me/pools-and-municipalities/

Calhoun, A.J.K. and P. Reilly. 2008. Conserving vernal pool habitat through community based conservation. In: Calhoun, A.J.K. and P.G. deMaynadier (eds). Science and conservation of vernal pools in northeastern North America. CRC Press.

Morgan, D.E., and A.J.K. Calhoun. 2011. The Maine Municipal Guide to Mapping and Conserving Vernal Pools. University of Maine, Sustainability Solutions Initiative, Orono, ME.

Oscarson, D., and A.J.K. Calhoun. 2007. Developing vernal pool conservation plans at the local level using citizen scientists. Wetlands 27:80-95.

MARYLAND

1) Maryland Wildlife Diversity Conservation Plan

Summary: A potential vernal pool mapping exercise was conducted in GIS for state lands during preparation of the 2005 Maryland Wildlife Diversity Conservation Plan (MD DNR 2005). All palustrine wetlands (emergent, scrub-shrub, and forested) with NWI water regime modifiers of temporarily flooded, seasonally flooded, seasonally flooded/saturated, saturated, and semi-permanently flooded (beaver) were included. The resulting GIS layer could possibly serve as a starting point for identifying significant vernal pools, however the map was never ground-truthed and NWI maps often overlook smaller wetlands. Thus a concerted effort is still needed to ground-truth the existing map and to survey for significant vernal pools that have been missed.

In addition, through an ongoing inventory of natural communities by the MD Natural Heritage Program, approximately 175 acres of coastal plain ponds (also called Delmarva Bays) have been documented in Maryland. Restricted to the Lower Coastal Plain and considered an extremely rare habitat type in Maryland, approximately 25% of Delmarva Bays are owned by the state, 25% are owned by conservation organizations (primarily The Nature Conservancy), and 50% are in private ownership.

Status: Completed, but the vernal pool map was never ground-truthed and was limited to state-owned land. Vernal pools and Delmarva Bays are identified as "Key Wildlife Habitat" in the Maryland Wildlife Action Plan and several DNR staff opportunistically track their locations, but to date, no coordinated statewide mapping effort has been done.

For more information:

2005 Maryland Wildlife Diversity Conservation Plan, Chapter 4: Key Wildlife Habitats and Their Conservation, Part 2: Wetland Habitats, pp 13-20.
http://dnr.maryland.gov/wildlife/plants_wildlife/wldp/pdfs/wcdp_chapter4_part2_20050926.pdf

Sustainable Forest Management Plan for Potomac-Garrett State Forest, Maryland DNR, April 22, 2015.
http://dnr2.maryland.gov/forests/Documents/potomac/PGSF_SFMP_2015.pdf

2) Maryland Biological Stream Survey

Summary: The Maryland Biological Stream Survey (MBSS), led by the Maryland DNR, began collecting geo-referenced information on vernal pools located in the riparian zone adjacent to freshwater stream sampling sites in 2007, and also on pools encountered by field crews enroute to stream sampling sites. Since the MBSS focuses on 1st- through 4th-order streams, few data are collected on vernal pools located in upland areas outside the riparian zone. Vernal pools included must be <1 acre in area and not directly connected to a flowing stream.

Status: Ongoing. The MBSS uses randomly-selected sample sites to provide a statistically rigorous representation of Maryland's stream conditions. The current round, initiated in 2014, involves re-sampling over five years, a subset of randomly-selected sites that were sampled between 2000 and 2004. Following that, sites that were sampled in 1995, 1996, and 1997 will be re-sampled 20 years later (in 2015, 2016, and 2017).

For more information:

http://dnr2.maryland.gov/streams/Pages/mbss.aspx

MASSACHUSETTS

1) Massachusetts Aerial Photo Survey of Potential Vernal Pools

Summary: Comprehensive, state-wide remote-mapping project completed in 2001 by the Massachusetts Division of Fisheries and Wildlife, Natural Heritage and Endangered Species Program (NHESP), to develop and provide a GIS layer of potential vernal pools (PVPs). Potential vernal pools were identified from 1:12,000 scale, color infra-red (CIR), leaf-off aerial photographs flown between late-March and early-May of 1993, 1999, or 2000 (depending on region). Aerial photo interpretation was done using a mirror stereoscope and paired CIR photos, resulting in 29,723 potential vernal pools identified statewide.

Status: Completed. Since development of this Potential Vernal Pool layer in 2001, a portion of these pools may have received official certification; however, the Potential Vernal Pool data layer is a static layer and is not updated.

The project did not include a coordinated field-verification effort, but helped encourage citizens and professionals to submit documentation of vernal pools for possible "certification" by NHESP (see MA Certified Vernal Pools below). Potential vernal pools identified in this survey do not receive protection under the Massachusetts Wetlands Protection Act Regulations or under any other state or federal wetlands protection laws; only Certified Vernal Pools receive such protections.

For more information:

http://www.mass.gov/eea/agencies/dfg/dfw/natural-heritage/vernal-pools/

http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/pvp.html

Burne, M.R. 2001. Massachusetts Aerial Photo Survey of Potential Vernal Pools. Natural Heritage & Endangered Species Program Massachusetts Division of Fisheries & Wildlife. http://www.mass.gov/eea/docs/dfg/nhesp/vernal-pools/ma-aerial-survey-pvp.pdf.

2) Massachusetts Certified Vernal Pools

Summary: This data layer contains points for all vernal pools that have been Certified by the Natural Heritage and Endangered Species Program (NHESP) according to the Guidelines for the Certification of Vernal Pool Habitat (MA Division of Fisheries & Wildlife, 2009). The Vernal Pool Certification Program relies largely on volunteers to survey potential vernal pools and to submit documentation of certain biological and physical evidence of vernal pool habitat. The NHESP then reviews the documentation and makes a determination whether the wetland basin in question meets the biological and physical criteria necessary for status as a "Certified Vernal Pool".

Status: Ongoing. In Massachusetts, only Certified Vernal Pools may receive protection under several state and federal laws, including the Massachusetts Wetlands Protection Act, Title 5 of the Massachusetts Environmental Code, Section 401 of the Federal Clean Water Act, the Massachusetts Surface Water Quality Standards (which relate to Section 401), and the Massachusetts Forest Cutting Practices Act.

For more information:

http://www.mass.gov/eea/agencies/dfg/dfw/natural-heritage/vernal-pools/vernal-pool-certification.html

http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/cvp.html

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NEW HAMPSHIRE

1) Ashuelot Valley Environmental Observatory Vernal Pool Project

Summary: This citizen science effort coordinated by the Harris Center's Ashuelot Valley Environmental Observatory was initiated in 2013 to document vernal pools in southwest New Hampshire, focusing on public and conserved lands throughout the towns of Peterborough, Hancock, and Keene. Following the 2015 season, more than 160 vernal pools had been documented in the region. Spring training sessions are offered to train local volunteers how to field-verify pools and document use by indicator species.

Status: Ongoing.

For more information:

http://www.aveo.org/citizen-science/vernal-pools/

2) New Hampshire Vernal Pool Documentation

Summary: The Nongame and Endangered Wildlife Program of New Hampshire Fish and Game encourages citizens to document the locations of vernal pools using a downloadable form and/or through their NH Wildlife Sightings website, a web tool for reporting wildlife observations throughout the state.

Status: Ongoing

For more information:

http://www.wildlife.state.nh.us/nongame/documents/vernal-pool-manual.pdf

http://nhwildlifesightings.unh.edu/vp_entry.shtml

NEW JERSEY

1) NJDEP Vernal Habitat Locations

Summary: In 2001 the New Jersey DEP Endangered Nongame Species Program partnered with Rutgers University Center for Remote Sensing and Spatial Analysis (CRSSA) to develop a method for mapping potential vernal pools throughout New Jersey. Through an on-screen visual interpretation of digital orthophotography, CRSSA identified over 13,000 potential pools throughout the state. Standard 1995/1997 digital orthophoto quarter quad (DOQQ) imagery was used for the interpretation at a scale of 1:5000. Pools were identified based on visual characteristics as well as other physical environmental data. The pool centroid was then digitized and recorded. A subset of these pools was field verified and confirmed, with an 88% accuracy rate (Lathrop et al. 2005), to meet the physical characteristics to qualify as a vernal pool. In accordance with N.J.A.C. 7:7A-1.4, the term "vernal habitat" includes a vernal pool - or the area of ponding - plus any freshwater wetlands adjacent to the vernal pool.

Status: As of 2007, 1,340 vernal habitats have been field-confirmed. NJDEP staff is in the process of field-verifying additional pools. The Department also maps vernal habitat areas based upon on-the-ground assessment of sites not captured by the CRSSA mapping.

For more information:

http://www.state.nj.us/dep/fgw/ensp/vernalpool.htm

Lathrop R.G, Montesanoa P., Tesauro J., Zarate B., 2005. Statewide mapping and assessment of vernal pools: A New Jersey case study. Journal of Environmental Management 76: 230-238.

NEW YORK

1) The Upper Susquehanna Coalition Vernal Pool Project

Summary: The USC Vernal Pool Project relies on citizens to report locations of vernal pools and areas where vernal pool species breed. Data can be submitted using an online form or by mail and will be archived in a database with landowner permission.

Status: Ongoing

For more information:

http://www.u-s-c.org/html/vernalpoolpage.htm

PENNSYLVANIA

1) Pennsylvania Vernal Pool Registry

Summary: A project of the Pennsylvania Natural Heritage Program, the Pennsylvania Vernal Pool Registry is a citizen-based program to document locations of vernal pools. The program relies on volunteer participants to submit information about the location of vernal pools and the animals that are using them. The information collected for this project will be used to create a database of vernal pools in Pennsylvania, which will be incorporated into the Statewide County Natural Heritage interactive map. The data will also be available to researchers who study seasonal pools in the state and to landowners and agencies that manage these often-overlooked wetlands.

Status: Ongoing. As of 2014, the database consisted of approximately 1,500 confirmed and unconfirmed vernal pools, with the best coverage in the Ridge and Valley Bioregion.

For more information:

http://www.naturalheritage.state.pa.us/VernalPools.aspx

2) Pennsylvania Biotics Database

Summary: A project of the Pennsylvania Natural Heritage Program, the Pennsylvania Biotics Geodatabase tracks the occurrence and location of native plant, animal, natural community and geologic resources, with a focus on rare and endangered species.

Status: Ongoing.

For more information:

http://www.naturalheritage.state.pa.us

3) Pennsylvania Statewide Seasonal Pool Ecosystem Classification

Summary: This study was the first state-wide effort focused on documenting and classifying the plant, amphibian, and invertebrate communities of upland seasonal pool wetlands across multiple ecoregions in Pennsylvania. Eighty-nine seasonal pools spread across forty-three sites were selected for this study and were sampled in 2007 and 2008 for water chemistry, aquatic macroinvertebrates, amphibians, and vegetation, along with describing their associated communities, and the surrounding landscape.

Status: Completed in 2009.

For more information:

Leppo, B., Zimmerman, E., Ray, S., Podniesinski, G., and Furedi, M. 2009. Pennsylvania Statewide Seasonal Pool Ecosystem Classification: Description, mapping, and classification of seasonal pools, their associated plant and animal communities, and the surrounding landscape. Pennsylvania Natural Heritage Program, Western Pennsylvania Conservancy, Pittsburgh, PA.
http://www.apps.dcnr.state.pa.us/conservationscience/grantreports/GrantReports/WRCP-06187/WRCP-06187_report.pdf

4) The Upper Susquehanna Coalition Vernal Pool Project

Summary: See listing under New York

VERMONT

1) Vermont Vernal Pool Mapping Project

Summary: Largely funded through the State Wildlife Grants Program of the Vermont Fish and Wildlife Department, and coordinated by the Vermont Center for Ecostudies and Arrowwood Environmental, the Vermont Vernal Pool Mapping Project used stereo-paired color-infrared aerial photographs flown in the spring (April and May) of 1992-1993 at a scale of 1:40,000 to identify more than 4,000 potential vernal pools statewide. The project also offered public workshops to train volunteers to help field-verify a proportion of mapped pools. In addition, information on vernal pool occurrence from other data sources was incorporated into the project database.

Status: Ongoing. Aerial photo interpretation and focused field-verification work occurred between 2009 and 2012. Since then, field-verification has been sporadic and more opportunistic. As of August 2015, over 1,000 pools have been field-visited, with more than 700 confirmed as vernal pools.

For more information:

http://vtecostudies.org/projects/forests/vernal-pool-conservation/vermont-vernal-pool-mapping-project/

http://aevt.maps.arcgis.com/apps/OnePane/basicviewer/index.html?appid=339654cc6cea47398344e9beed7874df

Faccio, S.D., M. Lew-Smith, and A. Worthley. 2013. Vermont Vernal Pool Mapping Project, 2009-2012: Final Report to the Natural Heritage Information Project of the Vermont Department of Fish and Wildlife. Unpublished Report, Vermont Center for Ecostudies, Norwich, VT and Arrowwood Environmental, Huntington, VT. http://vtecostudies.org/wp-content/uploads/2014/08/vce-vernal-pool-mapping-final-report.pdf

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VIRGINIA

1) Vernal Pool Cooperative of Virginia

Summary: A joint project of the Virginia Master Naturalist Program, Virginia Department of Game and Inland Fisheries, and Virginia Commonwealth University's Rice Rivers Center, the Vernal Pool Cooperative of Virginia is a project to document and monitor vernal pools on public lands and on private lands with landowner permission. Project was initiated in 2013 and data are archived at CitSci.org.

Status: Ongoing.

For more information:

http://www.citsci.org/cwis438/Browse/Project/Project_Info.php?ProjectID=453

https://www.facebook.com/VernalPoolsVA?fref=ts

Canada

NOVA SCOTIA

1) Nova Scotia Vernal Pool Mapping and Monitoring Project

Summary: Nova Scotia Environment launched the Vernal Pool Mapping and Monitoring Project in the spring of 2011, with the goal of developing a database of vernal pools around the province to improve the conservation and understanding of these fragile and important habitats. The dataset is all field-based, although some student projects have used remote-sensing technology to identify potential pools for parts of Nova Scotia. Data have not been acquired systematically, but rather opportunistically when agency staff encountered a pool while conducting other fieldwork.

Status: Ongoing.

For more information:

http://www.novascotia.ca/nse/wetland/vernal.pool.mapping.project.asp

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QUEBEC

1) Vernal Pool Distribution and Abundance in the Gaspesie Region of Quebec

Summary: The Quebec Ministry of Forests, Wildlife, and Parks used aerial photo interpretation (30cm resolution) to map potential vernal pools on 82,400 ha of public forest on the Gaspé Peninsula. True-color orthophotos taken in spring 2013 were used to locate water-filled pools and then compared to late-summer orthophotos from previous years to confirm pool drying. A total of 490 potential vernal pools were identified, with the highest concentration in the northeast of the peninsula. Thirty-four pools were field-visited in spring 2014, of which 30 were confirmed to be vernal pools. The total number of vernal pools on Gaspé forest land was estimated to be between 6,944 and 21,802.

Status: Initial project completed 2015; field-verification ongoing opportunistically. Future vernal pool mapping of entire peninsula using the methodology tested is possible.

For more information:

Richard A. and J. Ouellet. 2015. The abundance and distribution of vernal pools on Gaspé Peninsula forest land. Direction of the forest management of the Gaspésie-Îles-de-la-Madeleine, Department of Forestry, Wildlife and Parks. Caplan, QC. 23 p. (in French). http://mffp.gouv.qc.ca/publications/forets/etangs-vernaux-gaspesie.pdf

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Data Gaps and Recommendations for Future Mapping

In this section we summarize by state/province, what is known about obvious data gaps visible in Figures 1-3, 1-4, and 1-5, and make recommendations for future mapping efforts.

UNITED STATES

Connecticut

To the best of our knowledge, no statewide coordinated mapping efforts have been undertaken or are currently in progress in CT, although the CT Association of Wetland Scientists has assembled some information about vernal pool locations in the state (Ed Pawlak, personal communication). In addition, a project by a graduate student at Central

Connecticut State University used GIS to map potential vernal pools in a CT state park (Dentamaro 2009).

Outside of its most-developed areas, Connecticut may still support a relatively high density of vernal pools. This, combined with both its high population density (ranked 4th in the U.S.) and high development pressure (United States Census Bureau 2013), suggests that mapping vernal pools statewide should be a high conservation priority for the region.

District of Columbia

Brown and Jung (2005) cited two efforts to locate and map vernal pools in D.C. The Amphibian Research and Monitoring Initiative has mapped vernal pools in Rock Creek Park, a 1,755-acre National Park, and The Nature Conservancy has mapped vernal pools in the Potomac Gorge area of the Chesapeake and Ohio Canal National Historic Park that traverses D.C. and Maryland.

New Hampshire

The Nongame and Endangered Wildlife Program of New Hampshire Fish and Game has a Vernal Pool Documentation Program (see *Coordinated Vernal Pool Mapping Projects in the North Atlantic Region*, above). Adding these data to the VPDC should be a high priority for future updates to the database.

New York

Other than a small regional project in the Upper Susquehanna River area of south-central NY (see *Coordinated Vernal Pool Mapping Projects in the North Atlantic Region*, above), we are unaware of any other coordinated mapping efforts that have been undertaken or are currently in progress in NY. However, NY Natural Heritage Program (Matt Schlesinger) and SUNY ESF (James Gibbs and Stacy McNulty) were recently awarded an EPA grant to "determine the importance of vernal pools across geophysical and urbanization gradients in order to inform regulation, conservation, and management in New York." Although this project is not likely to include new field work or mapping, it will facilitate the compilation of current knowledge about NY vernal pools, and determine how to categorize and prioritize small, ephemeral wetlands statewide (S. McNulty, personal communication).

Rhode Island

We are unaware of any coordinated mapping efforts that have been undertaken or are currently in progress in RI. However, Nancy Karraker, graduate students, and colleagues at the University of RI recently began compiling all known records of vernal pools in the state. A field protocol was developed that uses physical and biological criteria to confirm if a wetland is a vernal pool, and two graduate students have been working to confirm locations and status of vernal pools throughout the state as part of their Master's projects. This work is ongoing and will be for several years (N. Karraker, personal communication). The addition of these data to the VPDC should be a high priority for future updates to the database.

Virginia

The Vernal Pool Cooperative of Virginia was recently initiated to map vernal pools on public lands statewide (see *Coordinated Vernal Pool Mapping Projects in the North Atlantic Region*, above). In addition, herpetologist Michael Hayslett (VA Vernal Pools LLC) submitted more than 500 vernal pool records to the VPDC gleaned from his personal field notes (see *Metadata Library*, above). These data represent approximately half of Hayslett's Virginia vernal pool data, which he desires to share with the VPDC if additional funding is available. Adding both of these VA data sets to the VPDC should be a high priority for future updates.

CANADA

New Brunswick

To the best of our knowledge, no coordinated mapping efforts have been undertaken or are currently in progress in New Brunswick. Any information on vernal pool occurrence in this province would be a valuable addition to the VPDC.

Prince Edward Island

To the best of our knowledge, no coordinated mapping efforts have been undertaken or are currently in progress on PEI. Any information on vernal pool occurrence in this province would be a valuable addition to the VPDC.

Quebec

Other than limited mapping on the Gaspe Peninsula (see *Coordinated Vernal Pool Mapping Projects in the North Atlantic Region*, above), we are unaware of any coordinated mapping efforts elsewhere in Quebec. However, the Quebec Ministry of Natural Resources and Wildlife has expressed an interest in mapping vernal pools in the future (Y. Dubois, personal communication). If this occurs, especially south of the St. Lawrence River, adding these data to the VPDC would be highly valuable.

Summary of Future Mapping Recommendations

Any efforts to fill the data gaps outlined above will help advance regional vernal pool conservation. There are a variety of successful mapping initiatives that can serve as templates for future efforts, depending on goals, scale, funding availability, and other considerations. Below are six key steps to consider.

1. Conduct an inventory of potential vernal pools using color infrared aerial photo interpretation, object-based image analysis, or other remote-sensing method. GIS users and geospatial analysts should refer to, *Recommendations for Remote Sensing Based Identification of Vernal Pools*, on page 74 of this report for more information.
2. Field-verify potential pools during the appropriate season on lands where access is unrestricted or special permission is granted.
3. Collect data in accordance with VPDC standards.
4. When selecting supplementary data fields, pursue alignment with other data sets collected in the same ecoregion.
5. Train and deploy volunteers to help carry out field surveys.
6. Share data through VPDC/NALCC Conservation Planning Atlas.

References – Chapter 1

Brown, L.J. and R.E. Jung. 2005. An Introduction to Mid-Atlantic Seasonal Pools, EPA/903/B-05/001. U.S. Environmental Protection Agency, Mid-Atlantic Integrated Assessment, Ft. Meade, Maryland.

Calhoun, A.J.K. and P.G. deMaynadier. 2007. Science and Conservation of Vernal Pools in Northeastern North America. CRC Press, Boca Raton, FL. 363pp.

Dentamaro, N. 2009. Using GIS to Identify, Map, and Assess Potential Vernal Pool Habitats in Connecticut: A Case Study of Scantic River State Park, East Windsor and Enfield, Connecticut. A Special Project Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science In Geography, Central Connecticut State University, New Britain, CT.

United States Census Bureau. 2013. Annual Estimates of the Population for the United States, Regions, States, and Puerto Rico: April 1, 2010 to July 1, 2013. United States Census Bureau, Population Division. December 2013.

Appendix 1-A. North Atlantic Vernal Pool Cooperator Survey

1. Are you interested in contributing location records and methodological information to the Vernal Pool Data Cooperative? (check all that apply)
   __ yes
   __ maybe
   __ no (please skip to item 20)
   __ only if VPDC can help organize my data
   __ only if data access and security measures meet my needs
   __ other: ____

2. Project name (if applicable) ____

3. Data were collected during: (check all that apply)
   __ wetland, forest, or wildlife inventory   __ research or monitoring project
   __ environmental impact assessment   __ other: ____________________

4. Name: ____

5. Organization: ____

6. Address: ____

7. Telephone: ________________________ 8. Email: ____________________________________

9. Are the data privately held or in the public domain?   __ private   __ public

10. If the data are available through an online resource, please provide access instructions.

____

11. In what formats do the data exist? (check all that apply)

    __ hand-written data sheets   __ GIS database
    __ photographs   __ point file
    __ spreadsheet   __ shape file
    __ relational database (e.g., Access)

12. Do metadata exist to describe the data fields? __ yes   __ no

13. Is there a written description of methods used to identify/locate the pools? __ yes __ no

14. How were the vernal pool locations identified? (check all that apply)

    __ field observation   __ GIS model
    __ color infrared aerial photo   __ other

15. What scale best describes the geographic extent of the data?

__ small property
__ neighborhood or large property
__ town
__ watershed or county
__ state
__ multi-state region

16. What is the approximate number of vernal pool locations in this dataset? _______________

17. When were the first records in the dataset collected? _________________

18. When were the last records collected? ____________________

19. What is the status of the vernal pool mapping effort? __ active __ sporadic __ completed

20. Where do gaps in the knowledge of vernal pool locations exist in your area?

Area: ________ Gaps:____

____

21. Where have vernal pools been well documented in your area?

____

22. Here are the proposed, *owner-assigned* data access levels. Please identify the level you might choose if you participate in the VPDC and suggest modifications to meet your needs.

___ Level 1: Unrestricted - Vernal pool data are unrestricted and can be made available for visualization and download through Data Basin.
___ Level 2: Visualization only – Vernal pool data can be used for visualization in Data Basin. Anyone wishing to download and use the data must contact the original data source.
___ Level 3: Restricted – Vernal pool data cannot be used for visualization in Data Basin. Anyone wishing to obtain the data must contact the original data source.

23. Please provide information on other vernal pool mapping projects with which you're familiar, as well as the contact information of project leaders.

Project name:_________________________________ Organization:___________________________

Contact information: ____

Please return survey to: Steve Faccio
Vermont Center for Ecostudies
PO Box 420
Norwich, VT 05055

Chapter 2 – Remote Sensing Based Identification of Vernal Pools Using LiDAR and Object-based Image Analysis

Introduction

Vernal pools provide essential habitat for amphibians, freshwater invertebrates, and aquatic plants in many different landscapes, occupying a near global distribution (Keeley and Zedler 1998). This diversity is well represented in the North Atlantic region, where pools occur in wooded upland environments, riverine floodplains, open agricultural zones, and coastal piedmonts. These pools exhibit a wide range of physical characteristics, from large and deep to small and shallow, and they may also be dependent on different hydrological inputs (surface flows, groundwater, or a combination of the two), hydroperiods (annual duration of inundation), and vegetation composition (Calhoun et al. 2003) . They may differ even further in their spatial patterning, with some pools highly isolated from other hydrological features while others are clumped with multiple pools or occur in close proximity to connected wetland complexes.

Given the well-known ecological importance of vernal pools, as well as their high sensitivity to disturbance, there has been much interest in mapping vernal pools at landscape scales. Many possible mapping approaches exist, from time-tested methods of manual interpretation using stereo imagery to modeling techniques that incorporate LiDAR and other remote-sensing datasets. Manual photo-interpretation methods have proven effective for statewide identification of potential vernal pools (Burne and Lathrop 2005), including projects in New Jersey (Lathrop et al. 2005), Vermont (Faccio et al. 2013), and Massachusetts (Burne 2001). Predictive statistical analysis has also proven useful, identifying large-scale habitat features that influence the location of pools in Massachusetts (e.g., topographic slope, surficial geology, and the proportion of developed landscape features) (Grant 2005).

The increasing availability of high-resolution remote-sensing data has prompted development of new and innovative modeling approaches to depression identification and characterization. LiDAR is central to these newer methods, offering the ability to map topography and hydrological flows at much higher spatial resolutions than commonly-available digital elevation models (DEMs). Lichvar et al. (2006) mapped vernal pools on a California military installation using a combination of satellite-acquired multispectral imagery (IKONOS) and LiDAR-based depression mapping, increasing the area of potential pools by 169% compared to field-based methods. Varin et al. (2014) used LiDAR to first map depressions in a Quebec study area and then to evaluate them according to size, distance to hydrological networks (i.e., an indication of isolation), depth, and flow potential (i.e., flow accumulation and direction). Wu et al. (2014) also used LiDAR to map depressions in two Massachusetts towns and classified them with a normalized difference water index (NDWI), achieving rates of omission and commission less than 10% when compared to a database of certified and potential vernal pools.

In addition to these depression-mapping methods, Julian et al. (2009) used LiDAR intensity (i.e., the strength of the return signal) to strengthen predictive modeling of amphibian breeding ponds by incorporating the spatial variability of intensity values. LiDAR collected with a near-infrared sensor was strongly absorbed by water, providing a sharp contrast with pond edges. This approach was particularly effective in reducing classification errors attributable to confusion between in-pond vegetation and vegetation on the pond edges.

Efficiency remains an issue with these methods, however. Manual interpretation can be very laborious while most modeling efforts tend to focus on relatively small areas or rely on coarse-resolution input datasets, reducing their suitability for broad-area identification of vernal pools. Ideally, a hybrid approach is needed, one that maximizes the expert knowledge necessary for manual mapping, capitalizes on the increasing availability of high-resolution LiDAR and other remote-sensing datasets, and expedites mapping across large study areas with automated modeling.

Object-based image analysis (OBIA) is an approach that bridges the gap between cognitive methods such as manual interpretation and automated techniques that offer economies of scale. Unlike traditional pixel-based analyses, OBIA focuses on groups of pixels that represent meaningful landscape objects, making it possible to evaluate not only the specific characteristics of individual objects but also the relationship between objects and its neighbors, both immediate and distant (Benz et al. 2004). This capacity for contextual analysis mimics how humans perceive landscapes, synthesizing contrast, shadow, and other traditional elements of image interpretation (O'Neil-Dunne et al. 2011). The object-based approach also tends to produce output with greater realism and coherence, making it an increasingly popular option for mapping spatially-explicit landscape features from remote-sensing data (Blaschke 2010). Frohn et al. (2009) have already demonstrated the utility of OBIA to coarse-scale mapping of large, isolated wetlands using 15-m resolution Landsat-7 imagery, and in combination of high-resolution imagery OBIA should also provide an effective approach for finer-scale features such as vernal pools.

Additional benefits of OBIA include data fusion and enterprise processing (O'Neil-Dunne et al. 2013). Data fusion permits simultaneous analysis of multiple input datasets, including data types as diverse as LiDAR point clouds, LiDAR-derived surface models (e.g., Digital Elevation Models, or DEMs), multispectral imagery (e.g., 4-band aerial orthoimagery), and thematic GIS layers (e.g., roads, buildings). This combined approach extracts usable information from multiple inputs, maximizing their collective value while minimizing their individual limitations. And when input datasets are divided into sets of small tiles, enterprise processing expedites mapping by distributing modeling of these tiles across multiple processing cores. Both features facilitate rapid processing of huge volumes of data, and indeed OBIA has been use to map fine-scale land-cover features at statewide scales (O'Neil-Dunne et al. 2014).

In this project, part of an effort by the North Atlantic Landscape Conservation Cooperative (NALCC) to understand and conserve the regional distribution of vernal pools, the sensitivity and processing power of OBIA were considered essential to effective mapping of pools across large geographic areas. With a focus area stretching from Virginia to the

Canadian Maritimes, NALCC seeks to synthesize existing vernal pools datasets and to develop new vernal pools maps for areas currently lacking them. However, a single mapping approach across the immense distances and high landscape diversity of the North Atlantic is impractical, even with OBIA enterprise processing; pools vary too widely in physical characteristics and landscape position, and available remote-sensing datasets vary in content, extent, and quality. This project thus focused on development of flexible, robust mapping protocols that could be modified for use in different sections of the North Atlantic region.

This project also focused on pools isolated from connected wetland complexes. As noted by Zedler (2003), definitions of connectedness vary by region and scale, making it difficult to sharply demarcate vernal pools from other ephemeral wetlands. Furthermore, functional vernal pools may occur within a matrix of large wetland complexes, complicating discrimination of these features from adjacent wetlands that form a network of direct hydrological connections. However, pools tightly interspersed with wetlands were not considered a priority in this project, given that wetlands already receive regulatory protection that true vernal pools lack in many states. Pools in active agricultural fields were also excluded because in many cases they have already been heavily modified and their presence may vary from year to year depending on current agricultural practices. Pools that occur near or adjacent to wetlands were part of the analysis, however, as were pools adjacent to developed features. It was also acknowledged *a priori* that pools identified using remote-sensing methods should be considered *potential* vernal pools (PVPs); true functionality as breeding habitat for amphibians and invertebrates can only be determined in the field.

Methods

STUDY AREAS

Two study sites encompassing very different landscapes in the North Atlantic region were selected: the majority of Addison County, Vermont (1,254 km^2, 485 mi^2) and the entirety of Cumberland County, New Jersey (1,300 km^2, 502 mi^2). Addison County includes a mix of land-cover types, extending from the largely agricultural Lake Champlain Valley to the forested slopes of the Green Mountains and interspersed with pockets of suburban land uses. Its topography is similarly varied, with elevations ranging 28-1,166 m (92-3,826 ft). Most of the pools in upland sites are fed by surface flows, although isolated pools in wetland complexes or riverine areas may be fed by groundwater. In contrast, Cumberland County is located in the southern New Jersey coastal plain that empties into the Delaware River; its elevation ranges 0-50 m (0-164 ft). Agriculture is the primary land use in the northwestern portion of the county, forest covers much of the eastern third, and extensive salt marshes occur along the southern boundary. Concentrations of urban and suburban features also occur in the county, especially along tributaries of the Delaware River. With so little topographic relief, most pools are likely fed from groundwater.

PRELIMINARY DATA PROCESSING

The modeling approach was divided into 3 primary sections: preliminary data acquisition and preparation, automated feature extraction, and output generation and assessment (Figure 2-1).

Data Acquisition

In the United States, LiDAR is often acquired at the county level, making it a good unit for mapping land-cover at broad scales. In addition to their varied landscapes, the two study counties were chosen for the availability of high-resolution LiDAR with post spacings equal to or less than 2 m. LiDAR datasets for both counties were acquired at no cost from GIS data clearinghouses in their respective states (Tables 2-1 and 2-2). Orthoimagery and pertinent thematic GIS data layers (e.g., hydrography, road centerlines, land-cover data) were similarly acquired at no cost from publicly-available sources. Leaf-off data layers collected during spring conditions were required for the input LiDAR and orthoimagery datasets, although leaf-on orthoimagery (National Agricultural Imagery Program) was also obtained for reference. All orthoimagery was 4-band multispectral data containing the visible bands (Red, Green, Blue) and a Near Infrared (NIR) band. Temporally-similar datasets (i.e., collected in the same year) were selected when possible but temporal consistency was not essential to the mapping protocol; it was assumed that functional vernal pools in the two study areas contain water in most years.

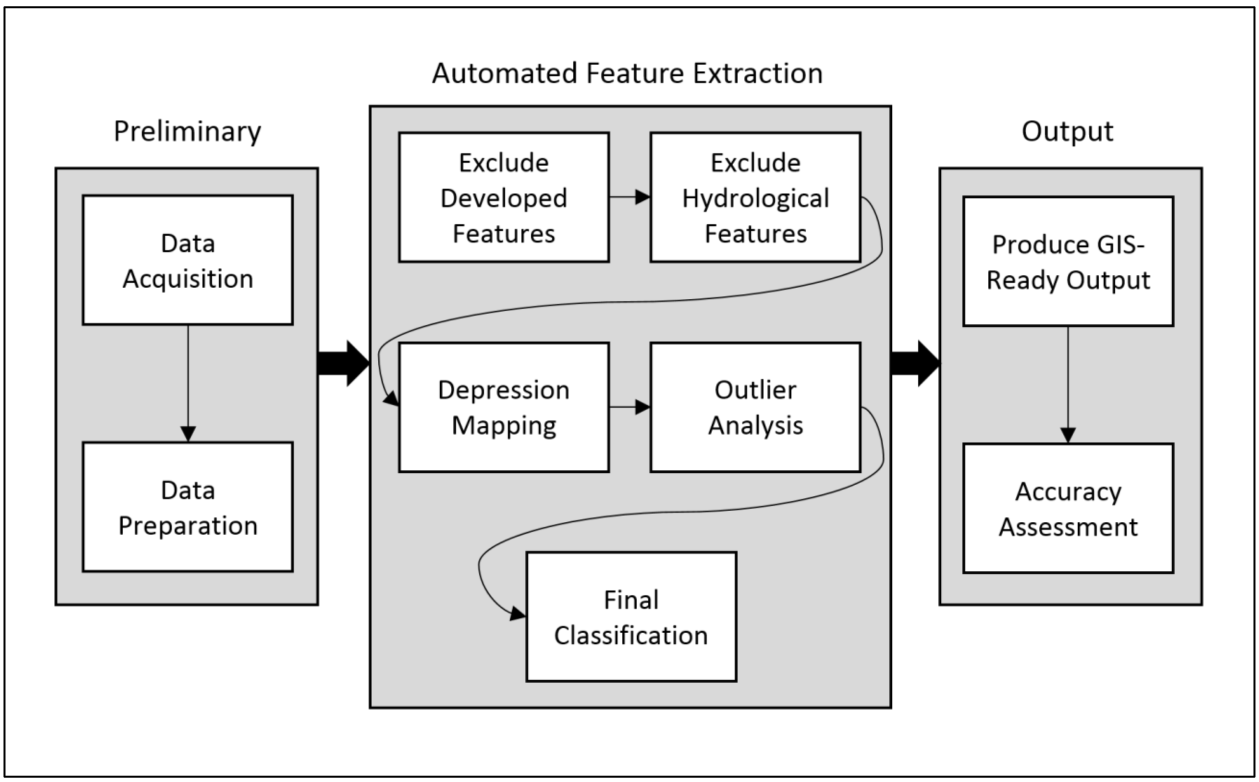

Figure 2-1. Modeling flow for identification of potential vernal pools using object-based image analysis and high-resolution remote-sensing data. After initial acquisition and preparation of input datasets, automated feature extraction focused on mapping landscape depressions and classifying them. Classified output was exported to a GIS data layer and evaluated.

Data Preparation

Many different software packages exist for processing GIS data and LiDAR, and most can be used interchangeably. Little or no processing was required for thematic GIS layers. Orthoimagery (i.e., multispectral imagery orthorectified to accommodate relief displacement) was obtained in tiles, requiring only mosaicking into seamless county-wide layers in the MosaicPro module (Version 2013) of ERDAS IMAGINE (Hexagon, Stockholm, Sweden). Existing LiDAR-derived surface rasters were used where possible, but other useful derivatives required manipulation and processing of the original LiDAR point-cloud datasets.

Digital Elevation Model (DEM). Commonly-used tools for exploiting LiDAR point clouds are Quick Terrain Modeler (Applied Imagery, Chevy Chase, Maryland, USA), SCALGO (Scalable Algorithmics, Aarhus, Denmark), and LAS Tools (rapidlasso GmbH, Gilching, Germany). For Addison County, Quick Terrain Modeler (Version 8.0.4.1) was used to filter *all* LiDAR returns classified as ASPRS Class 2 (Ground) (ASPRS 2014). The gridding options were *Mean Z* and *Adaptive Triangulation* with no smoothing filter, and the output cell size was equal to the nominal post spacing of the original point cloud (1.6 m). The output tiles were mosaicked into a seamless DEM using MosaicPro. For Cumberland County, the Raster Construction module in SCALGO Model (Version 1.4) was used to filter all LiDAR returns classified as ASPRS Class 2 (Ground) and then to create a topographic model using *TIN Interpolation* as the processing mode. The output cell size was similarly equal to the post spacing of the original LiDAR (1 m)

Normalized Digital Surface Model (nDSM). These layers show the height of aboveground features such as buildings and trees and are thus very useful for discriminating developed land cover types from forests and other features most likely to support vernal pools. An existing 1.6-m nDSM was used for Addison County without modification. For Cumberland County, SCALGO Raster Construction (Mode, *TIN Interpolation*; output cell size, 1 m) was used to filter *first* LiDAR returns for ASPRS Classes 0-12, creating a Digital Surface Model (DSM) that contained the height of aboveground features relative to sea level. To normalize the height relative to ground surfaces, the DEM was subtracted from the DSM using the Two Image Functions\Subtraction in ERDAS IMAGINE.

LiDAR Intensity. The intensity values associated with each LiDAR return are useful for identifying water because this surface type strongly absorbs the Near Infrared range typically used by LiDAR sensors. A 1.6-m intensity layer was created for Addison County in Quick Terrain Modeler using all *last* returns, regardless of classification. The gridding options were *Max Z* and *Adaptive Triangulation*, performed with a smoothing filter (*Radius*, 1.00 Bins; *Z Tolerance*, 3 m). A 1-m intensity layer for Cumberland County was created in SCALGO Raster Construction by specifying *last* returns for classes ASPRS Classes 0-11 (Mode, *TIN Interpolation*).

Flow Accumulation. Flow accumulation raster datasets show the watershed area that drains into an individual point and thus help predict where surface water may collect. For both study areas, flow accumulation layers were created in SCALGO Hydrology (Version 1.4). First, the direction of likely flows across sloped terrain was calculated in the Flow Directions module using the previously-created DEMs (Routing Model, *Steepest Downslope Neighbors*; Flat Routine Module, *Geodesic*; NoData Cells, *All Low*). The flow direction rasters were then converted into flow accumulation layers using the Flow Accumulation module. The output cells sizes matched those for the input DEMs (1.6m for Addison County; 1m for Cumberland County).

Table 2-1. Input datasets for vernal pool modeling for Addison County, Vermont.

Input Dataset	**Type**	**Source**	**Processing**
Digital Elevation Model (DEM)	LiDAR derivative, 1.6-m ground sample distance (GSD)	Original LiDAR data (LAS format) from U.S. Geological Survey (2013)	Filtered ground returns and exported to surface (Quick Terrain Modeler)
Normalized Digital Surface Model (nDSM)	LiDAR derivative, 1.6-m GSD	Vermont Center for Geographic Information (derived from original LiDAR data, U.S. Geological Survey 2013)	None
LiDAR Intensity	LiDAR derivative, 1.6-m GSD	Original LiDAR data (LAS format) from U.S. Geological Survey (2013)	Filtered last returns and exported to surface (Quick Terrain Modeler)
Flow Accumulation	LiDAR derivative, 1.6-m GSD	Original LiDAR data (LAS format) from U.S. Geological Survey (2013)	Flow directions modeled from DEM (SCALGO Hydrology – Flow Directions) and in turn used to model flow accumulation (SCALGO Hydrology – Flow Accumulation)
Compound Topographic Index (CTI)	LiDAR derivative, 3-m GSD	Original LiDAR data (LAS format) from U.S. Geological Survey (2013)	Gradients calculated from DEM (SCALGO) and then used with flow accumulation to calculate index (ERDAS IMAGINE)
Orthoimagery	Multispectral imagery (4-bands: Red, Green, Blue, Near Infrared), leaf off, 0.5-m GSD	Vermont Center for Geographic Information (2012)	Mosaic tiles (ERDAS IMAGINE)
National Agricultural Imagery Program (NAIP)	Multispectral imagery (4-band), leaf on, 1-m GSD	USDA Farm Service Agency (2011)	Mosaic tiles (ERDAS IMAGINE)
Study Area Boundary, Based on LiDAR Index (Index_LAS_2013_Addison County.shp)	Thematic GIS layer (polygons)	U.S. Geological Survey (2013)	None
County Boundary (BoundaryOther_BND HASH)	Thematic GIS layer (polygons)	Vermont Center for Geographic Information (2010)	None
Road Centerlines (Emergency_RDS)	Thematic GIS layer (lines)	Vermont E911 Board (2012)	None
Building Locations (Emergency_ESITE)	Thematic GIS layer (points)	Vermont E911 Board (2012)	None
Vermont Hydrography Dataset – Lakes and Ponds	Thematic GIS layer (polygons)	U.S. Geological Survey (2010)	None
Vermont Hydrography Dataset - Streams	Thematic GIS layer (lines)	U.S. Geological Survey (2010)	None
Impervious Surfaces (roads, buildings, other pavement)	Thematic GIS layer (polygons)	University of Vermont Spatial Analysis Laboratory (2011)	None
Vermont Vernal Pools Database[a]	Thematic GIS layer (points)	Vermont Center for Ecostudies (2013)	None

[a]Reference dataset only; not used in modeling.

Table 2-2. Input datasets for vernal pools modeling for Cumberland County, New Jersey.

Input Dataset	Type	Source	Processing
Digital Elevation Model (DEM)	LiDAR derivative, 1-m ground sample distance (GSD)	Original LiDAR data (LAS format) from U.S. Geological Survey (2008)	Filtered ground returns and exported to surface (SCALGO Raster Construction)
Normalized Digital Surface Model (nDSM)	LiDAR derivative, 1.0-m GSD	Original LiDAR data (LAS format) from U.S. Geological Survey (2008)	Filtered first returns and exported to surface (SCALGO Raster Construction), then normalized values by subtracting DEM
LiDAR Intensity	LiDAR derivative, 1-m GSD	Original LiDAR data (LAS format) from U.S. Geological Survey (2008)	Filtered last returns and exported to surface (SCALGO Raster Construction)
Flow Accumulation	LiDAR derivative, 1-m GSD	Original LiDAR data (LAS format) from U.S. Geological Survey (2008)	Flow directions modeled from DEM (SCALGO Hydrology – Flow Directions) and in turn used to model flow accumulation (SCALGO Hydrology – Flow Accumulation)
Compound Topographic Index (CTI)	LiDAR derivative, 3-m GSD	Original LiDAR data (LAS format) from U.S. Geological Survey (2008)	Gradients calculated from DEM (SCALGO) and then used with flow accumulation to calculate index (ERDAS IMAGINE)
Orthoimagery	Multispectral Imagery (4-bands: Red, Green, Blue, Near Infrared), leaf off, 0.3-m GSD	New Jersey Geographic Information Network (2007)	Mosaic tiles (ERDAS IMAGINE)
National Agricultural Imagery Program (NAIP)	Multispectral Imagery (4-band) leaf on, 1-m GSD	USDA Farm Service Agency (2013)	Mosaic tiles (ERDAS IMAGINE)
Study Area Boundary, Based on County Polygon (Counties of New Jersey)	Thematic GIS layer (polygons)	New Jersey Office of Information Technology (2013)	None
County Boundary (Counties of New Jersey)	Thematic GIS layer (polygons)	New Jersey Office of Information Technology (2013)	None
Road Centerlines (New Jersey Roadway Network)	Thematic GIS layer (lines)	New Jersey Department of Transportation (2005)	None
National Hydrography Dataset – Lakes and Ponds	Thematic GIS layer (polygons)	U.S. Geological Survey (2002)	None
National Hydrography Dataset - Streams	Thematic GIS layer (lines)	U.S. Geological Survey (2002)	None
Land Use/Land Cover	Thematic GIS layer (polygons)	New Jersey Department of Environmental Protection (2007)	None
New Jersey Vernal Pools Database[a]	Thematic GIS layer (points)	New Jersey Department of Environmental Protection (2005)	None

[a]Reference dataset only; not used in modeling.

Compound Topographic Index (CTI). A recent study in Minnesota (Rampi et al. 2014) demonstrated the utility of topographic indices combining slope and flow potential to automated feature extraction of wetlands. To examine their value to identification of potential vernal pools, a compound topographic index (CTI) layer was created for each of the study-area counties using the same method as Rampi et al. (2014):

$$CTI = \ln [\alpha/\tan(\beta)]$$

In this formula, α is the local upslope area draining each cell ([Flow Accumulation + 1]*[Area of each cell in DEM]) and β is the local slope gradient ([Slope Gradients*1.570796]/90). Rampi et al. (2014) found that a 3-meter resolution CTI best distinguished wetlands from adjacent uplands, so 3-meter DEMs were first created in SCALGO Model\Raster Construction using the above methods. Flow accumulation layers were then created with this cell size using the Flow Directions (Routing Model, *All Downslope Neighbors*) and Flow Accumulation functions in SCALGO Hydrology. During derivation of the flow directions layers, slope gradients were also generated. Finally, the actual CTI calculations were performed in ERDAS IMAGINE using a Model Maker model that connected the separate processing steps in the CTI formula into a single work flow.

AUTOMATED FEATURE EXTRACTION

At two regional meetings hosting biologists, land managers, mapping specialists, and others interested in vernal pools identification and conservation (April 7, 2014, Springfield, Massachusetts; October 24, 2014, Smyrna, Delaware), stakeholders expressed the need for maps that maximize both the quantity and quality of information describing potential habitat. Most participants agreed that true functionality can only be confirmed in the field by the presence of breeding amphibians and invertebrates, meaning that remote-sensing approaches must necessarily be confined to identifying *potential* pools. A related conclusion was that it is better to limit errors of omission (false negatives) than commission (false positives); it is generally easier to examine and discount false positives than find depressions missed by either manual interpretation or modeling. Based on these conclusions, the operating premise for automated feature extraction was that the most useful output would be produced by models that are biased toward over-prediction, ensuring capture of all legitimate candidate pools while also showing the distribution of lesser-quality pools.

The OBIA software eCognition (Version 9.1.2, Trimble Navigation Limited, Westminster, Colorado, USA) was used for all automated feature-extraction steps. This software is an expert system-based approach that relies on sequences of image segmentation and classification rules to model land-cover features of interest. Rule-set development usually requires iterative design and testing until a desired balance of processing efficiency, detail, and accuracy is achieved. Rule sets can then be copied and modified as necessary for other study areas, input datasets, or modeling criteria.

To facilitate efficient modeling in eCognition, rule-set testing and subsequent map production were performed on individual tiles, or small subsets of each study area. For

Addison County, the tiling scheme was based on 364 original LiDAR point cloud tiles (1,758 x 2,000 pixels, or 351.6 ha), which were imported into eCognition to create a separate project for each tile. For New Jersey, the orthoimagery for the full study area was imported into eCognition and then divided into 597 2,000 x 2,000-pixel (400-ha) tiles using the *Create Scene Tiles* algorithm. All other input datasets for both study areas were then imported and clipped according to the dimensions of each tile using the *Create\Modify Project* algorithm. The modeling resolution for both study areas was 1 m, which represented a compromise between the post spacing of the available LiDAR datasets and the even higher-resolution orthoimagery. This pixel size also represented a reasonable balance between resolution and processing efficiency.

For mapping potential vernal pools, rule-set development focused on producing a modeling flow that could be easily adapted for disparate sections of the North Atlantic region. Accordingly, the rule sets for the two study sites shared the same overall structure (Figure 2-1) but were tailored to the specific characteristics of their respective landscapes. Existing vernal pools databases (Tables 2-1 and 2-2) for Vermont (Faccio et al. 2013) and New Jersey (Lathrop et al. 2005) were used as reference data during rule-set development, aiding identification of depression characteristics that could be incorporated into specific classification routines. However, these databases were not used in actual modeling.

Exclude Developed Features

Impervious Surfaces. The first step in feature extraction was exclusion of developed features where vernal pools are unlikely to occur; elimination of these features would not only focus modeling on the most favorable landscapes but also reduce subsequent time. Wherever possible, existing GIS datasets representing roads, buildings, impervious surfaces, and other land-cover features were included in this preliminary step. For Addison County, a native processing filter in eCognition (*Convolution Filter*; Type, *Gauss Blur*; 2D Kernel Size, 41; Number of Slices, 1) was used to produce a density layer from thematic road centerlines, driveways and building points (Table 2-1). The density layer was in turn segmented (*Multi-threshold Segmentation*; Threshold <0.015) to identify the highest concentrations of developed features, which were then assigned to the land-cover class *Non Habitat*. A convolution filter was similarly applied to Cumberland County road centerlines and developed land-use/land-cover features (Table 2-2) and then segmented (*Multi-threshold Segmentation*; Threshold <0.25) to produce the *Non Habitat* class.

Agriculture. Although agricultural land uses can support vernal pools in some regions, variable year-to-year management may limit pool functionality and complicate reliable remote sensing-based identification. These areas were thus removed from consideration by mapping large tree-less areas using LiDAR-derived normalized digital surface models (nDSM). For Addison County, the available nDSM was segmented (*Multi-threshold Segmentation*; Threshold <=0.61 m) to identify areas with short land-cover features and then smoothed and filled with *Pixel-based Object Resizing* routines. A similar process (*Multi-threshold Segmentation*; Threshold <=0.2 m) was used for Cumberland County. Additional agricultural features in Cumberland County were classified using an available land-use/land-cover map (Table 2-2). For both study areas, these features were assigned to the *Non Habitat* class. Large emergent wetlands were occasionally captured by the vegetation-height modeling but no further attempt was made to discriminate these features from *Non Habitat* because they were also considered unacceptable as vernal-pool habitat.

Exclude Hydrological Features

Water Bodies. For both study areas, all features in the available hydrology polygon layers labeled as rivers and streams (FType = 460) were assigned to *Large Water Bodies*, as were all lakes and ponds (FType = 390) exceeding a size threshold (Area >0.04 km2).

Connected Wetlands. To exclude wetlands connected to other hydrological features by flowing water, one option would have been to incorporate existing thematic wetlands layers such as the National Wetlands Inventory (NWI) into the draft classification. However, previous experience with NWI and similar layers suggested that some versions may have errors of omission and commission that limit their utility in high-resolution mapping. They also occasionally capture isolated features such as vernal pools. Instead, a modeling routine was developed in eCognition that identified low-slope areas adjacent to thematic hydrology. This routine first used eCognition's native processing capabilities to produce a slope layer from the available DEM for each study area (*Surface Calculation*; Algorithm, *Slope*; Gradient Unit, *Degree*; Unit of Pixel Values, 1). For Addison County, a *Multi-Threshold Segmentation* (Threshold <13 degrees) identified flat areas and then a *Multiresolution Segmentation* on the slope layer (Image Weight, 1; Scale, 25; Shape, 0.1; Compactness, 0.7) divided these areas into smaller objects. After identifying objects that overlapped with hydrological lines, these objects were "grown" into adjacent flat objects that had similar elevation values (Mean Difference in DEM <0.15). Although eCognition has a variety of object-growing algorithms, the actual process in this case simply used the *Assign Class* algorithm to add adjacent objects to the same temporary wetlands class. This process was repeated for 2 additional iterations. The mapped features were then expanded with a second growing operation with a more stringent elevation threshold (Mean Difference in DEM <0.1), performed for 10 iterations. The final set of mapped objects were assigned to the class *Connected Wetlands*.

The modeling flow was similar for Cumberland County but used different parameters. The second-stage Multiresolution Segmentation used a larger scale parameter (50) and the first growing operation used a larger elevation threshold (0.7).

Large Wetlands. Wetlands mapping for Addison County was augmented by a second routine that relied on the textural properties of the CTI layer; CTI values for wetlands tend to be very heterogeneous while values for upland areas appear much smoother. The *Edge Extraction Lee Sigma* algorithm (Sigma, 5; Edge Extraction Mode, *Bright*) was first applied to the CTI layer to produce a separate layer that highlighted wetland\upland transitions. After a segmentation based on the leaf-off orthoimagery (*Multiresolution Segmentation*; Image Weight for Red band, 1; Green, 1; Blue, 1; NIR, 2; Scale, 30; Shape, 0.3; Compactness, 0.5), the initial objects were merged using a *Multiple Object Difference Conditions-based Fusion* algorithm incorporating both the Lee Sigma CTI derivative and the orthoimagery (Common Border, 0.2; Difference in Lee Sigma CTI, 0.02; Difference in NIR, 25; Difference in Red, 25; Difference in Green, 25; Difference in Blue, 25).

To classify these objects, a set of fuzzy classifiers was used. Fuzzy classifiers are very useful in object-based mapping applications, often providing better sensitivity to real-world variability than simple parameter thresholds by combining multiple variables defined by individual membership functions (Benz et al. 2004). For wetlands mapping, one fuzzy classifier combined mean Lee Sigma CTI (Membership Function, *Positive Curvilinear*; Range, 0-0.15), mean NIR from the leaf-off orthoimagery (Membership Function, *Full Range*; Range, 0-150), and skewness in the CTI layer (Membership Function, *Positive Curvilinear*; Range, 0-1.5). Objects that satisfied a combined classification threshold for this classifier (>0.7) were identified and "grown" (*Assign Class*) into objects (5 iterations) that shared a long common border (Relative Border >0.4) and had high mean Lee Sigma CTI values (>0.125). The second classifier combined Lee Sigma CTI and mean NIR but with different value ranges (0-0.2 and 0-50, respectively). It expanded the preliminary wetland areas when adjacent objects (Relative Border >0.1) had a high combined classification threshold (>0.8), with 5 iterations. A third 5-iteration growing routine further expanded mapped wetlands when adjacent objects with a long common border (Relative Border >0.5) had even higher Lee Sigma CTI values (>0.15). All identified features were assigned to the *Connected Wetlands* class after they were smoothed and filled to improve their appearance.

Note that CTI-based wetlands mapping was not used for Cumberland County. The CTI layer was less diagnostic for this study area because much of the county is flat; transitions between wetlands and adjacent uplands are blurred and more gradual. This routine often captured PVPs in initial testing so it was dropped from the final Cumberland rule set.

Depression Modeling

Landscape concavities can be mapped with many GIS and image analysis software packages, including a separate module in SCALGO for depression mapping (SCALGO Topology – Depression Mapping, Version 1.4). This module was considered for possible use with Addison County, but initial testing indicated that it tended to overestimate the size of potential vernal pools in hilly terrain where pools are likely to be small. Use of this module also would have required an additional data-preparation step. To ensure a self-contained modeling flow and to help limit the volume of data preparation, a simple depression-mapping routine was developed in eCognition (Figure 2-2). For Addison County, the DEM-derived slope layer previously created for connected wetlands (Figure 2-2b) was segmented with a *Multi-threshold Segmentation* (Threshold <0.75 degrees) to identify low-slope areas that would serve as "seeds" for subsequent growing operations (Figure 2-2c). To better approximate actual depressions, seeds were iteratively grown into adjacent areas (*Pixel-based Object Resizing*; Mode, *Coating*) until steeper slopes were reached (Slope of Adjacent Objects <1.5 degrees) (Figure 2-2d). Very small depressions (Area <18 m^2) and small depressions with little evidence of water in the NIR band of the available leaf-off orthoimagery (Area <55 m^2 and Mean NIR >100) were removed before a second growing operation (Slope of Adjacent Objects <4 degrees) further enlarged the remaining candidate depressions (Figure 2-2e). After again removing very small (<85 m^2) and small objects with little evidence of water (Area <125 m^2 and Mean NIR >95; Area <300 m^2 and Mean LiDAR Intensity >80), the final set of candidate depressions were smoothed and filled with additional *Pixel-based Object Resizing* routines (Figure 2-2f).

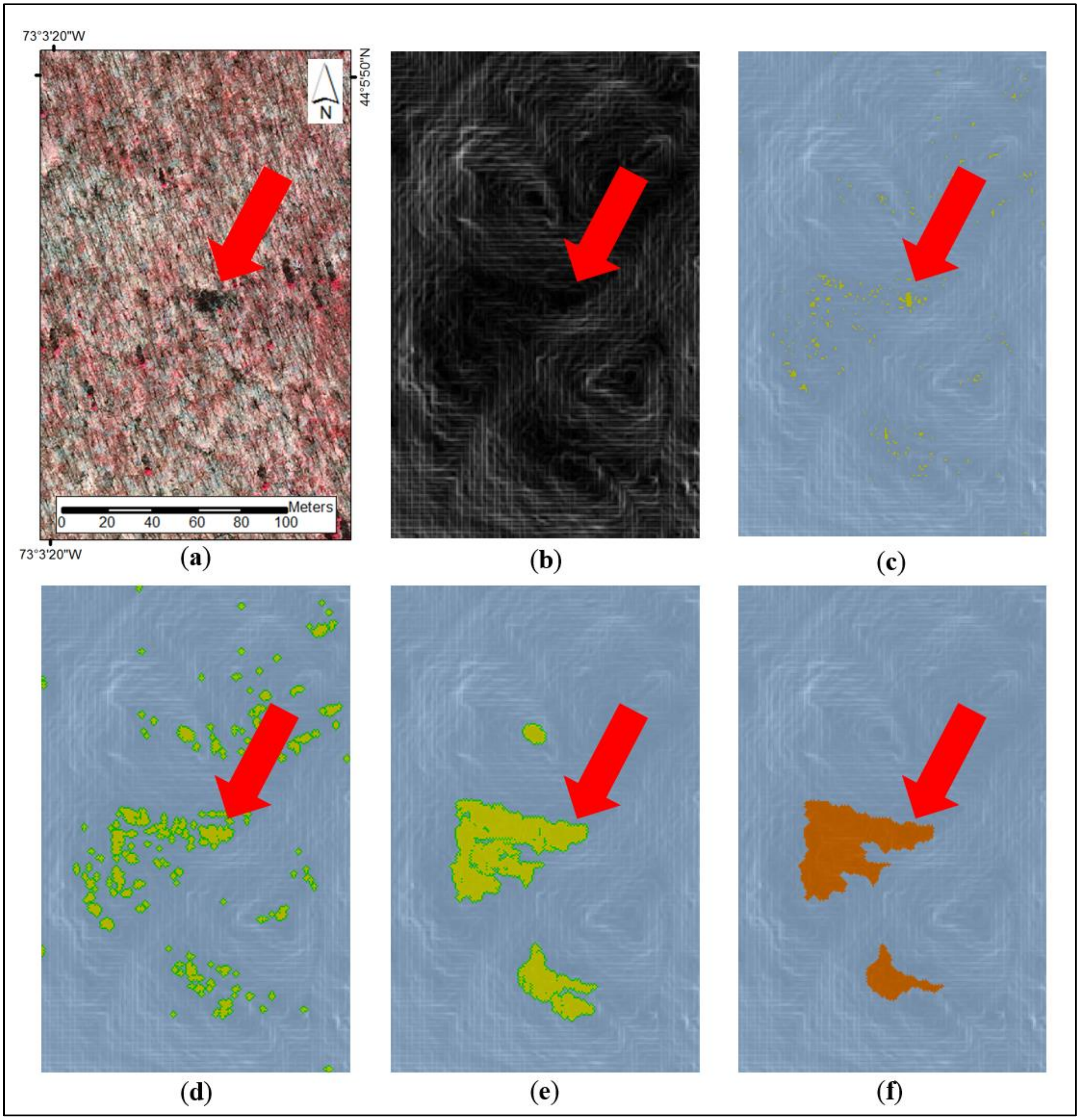

Figure 2-2. Landscape depression modeling for a suspected vernal-pool location in Addison County, Vermont. The potential site is visible in both leaf-off, 0.5-m GSD orthoimagery (a) and a slope layer derived from a 1.6-meter Digital Elevation Model (b). The modeling routine first identified areas of low slope (c) and then built out from them until steeper slopes were reached (d). After eliminating very small depressions, a second growing routine enlarged candidate depressions (e). Additional small depressions were then removed and remaining features were filled and smoothed to improve appearance (f).

For Cumberland County, the same set of algorithms was used; the only differences were the resizing thresholds and the size and spectral criteria used to eliminate unlikely depressions. Given the flat topography of this coastal plain area, larger slope thresholds were needed to adequately capture depressions in both seed-growing operations (first operation, Slope of Adjacent Objects <3 degrees; second operation, Slope of Adjacent

Objects <5 degrees). The removal criteria for small depressions were similarly adjusted to accommodate the specific range of spectral variability in the available orthoimagery (first operation, Area <25 m^2 and Mean NIR >7,500, Area <55 m^2 and Mean NIR >20,000; second operation, Area <50 m^2, Area <125 m^2 and Mean NIR > 32,000, Area <300 m^2 and Mean LiDAR Intensity >85 and Mean NIR <15,000).

Outlier Analysis

Before producing a final classification, the initial set of candidate pools was refined by examining both the individual characteristics of mapped depressions and their relationship to adjacent features. This step was termed an outlier analysis because only depressions with extreme values, high or low, were removed from further consideration. The goal was to reduce the incidence of false positives while retaining legitimate candidate pools.

Adjacent to Connected Wetlands. Candidate pools sharing a long common border with hydrological features mapped as *Connected Wetlands* were assumed to be part of those flows, except when such features were compact, exhibited strong evidence of water in leaf-off orthoimagery (low NIR values) and LiDAR Intensity (low values), and were distant from known water bodies (Table 2-3). Distance from water was estimated by using the *Distance Map* algorithm in conjunction with available thematic GIS hydrology layers (Tables 2-1 and 2-2).

Thematic Hydrology-Lines. Any depressions in Cumberland County that coincided with thematic GIS hydrology layers representing streams and rivers were removed. A slightly-less stringent criterion was used for Addison County; pools occasionally occurred near, but were not connected to, streams in the more variable terrain of this landscape.

Thematic Hydrology-Polygons. For Addison County, any depressions that coincided with thematic GIS hydrology layers representing small (<0.04 km^2) streams, rivers, and open water bodies were removed from the set of candidate pools. Depressions adjacent to larger water polygons of any type were also removed if they shared a long common border. For Cumberland County, only depressions that shared a common border with rivers and streams were removed; depressions coinciding with small (<0.04 km^2) open-water polygons were retained for further evaluation because review of the hydrology layer indicated that some of its minor lakes and ponds captured potential vernal pools.

Flow Accumulation. For Addison County, depressions with a low potential for surface water were evaluated using a set of flow-based criteria. The first eliminated depressions with low mean flow accumulation (<4 m^2) and the second considered mean flow accumulation per pool area (<15). A third outlier routine examined specific flows on the periphery of mapped depressions, eliminating occurrences that appeared to have outflows indicative of running water (mean difference in elevation between depression and adjacent flow <-1.5m). None of these flow criteria were used for Cumberland County because the PVPs in this study area were assumed to be fed primarily by groundwater.

Table 2-3. Outlier analysis to remove candidate depressions that are unlikely to support vernal pools, Addison County, Vermont and Cumberland County, New Jersey. All references to low NIR pertain to leaf-off orthoimagery.

	Addison County, VT	**Cumberland County, NJ**
Variable	*Removal Criteria*	*Removal Criteria*
Adjacent to *Connected Wetlands*	Long common border (Relative Border >60%) but excluding: 1) round depressions (Border Index <2) with very low NIR (<55); 2) large (750 m^2) round depressions (Border Index <4) with low NIR (<100) and low LiDAR Intensity (<65); 3) small depressions (1,500 m^2) with moderate NIR (<115), moderate LiDAR Intensity (<105), and distant from water (>50 m).	Not used
Thematic Hydrology - Lines	Common border (Relative Border >10%)	Common border (Relative Border >0%)
Thematic Hydrology - Polygons	Common border (Relative Border >0%) with all small (<0.04 km^2) hydrology polygons; or long common border (Relative Border >30%) with large (>0.04 km^2) polygons	Common border (Relative Border >0%) with all hydrology polygons representing rivers and streams (FType = 460)
Flow Accumulation	Low Flow Accumulation (<4 m^2); or low Flow Accumulation per depression area (<15); or small difference in Elevation between depression and adjacent Flow Accumulation (<-1.5 m)	Not used
Size - Large	Large (>7,250 m^2) and high LiDAR Intensity (>90)	Not used
Size - Small	Small (<110 m^2) and close to water (<20 m); or small (<300 m^2) and high LiDAR Intensity (>80)	Small (<300 m2) and high LiDAR Intensity (>80) and high NIR (>16,000)
CTI Texture	Very high GLCM Homogeneity (>0.98); or low Lee Sigma Edge Extraction (<0.125); or small difference in Lee Sigma Edge Extraction between depression and adjacent buffer (<0.05)	Low Lee Sigma Edge Extraction (<0.17) and large area (>1,000 m2); or low Lee Sigma Edge Extraction (<0.18) and large area (>3,000 m2); both excluding depressions with: 1) low NIR (<,20,000); 2) low NIR (<25,500) and low LiDAR Intensity (<65); 3) low NIR (<26,500) and low LiDAR Intensity (<30)
Pool Depth	Very low depth (<0.035 m)	Very low depth (<0.03 m)
Adjacent to *Non Habitat*	Common border (Relative Border >20%); or common border (>0%) and high Visible Brightness in NAIP (>400); or common border (Relative Border >0%) and low NIR (<50); or close to water (<20 m) and short vegetation (nDSM <1 m)	Common border (Relative Border >20%); or common border (>0%) and high Visible Brightness in NAIP (>400); or common border (Relative Border >50%) and small (<200 m2) but excluding: 1) low NIR (<25,500) and low LiDAR Intensity (<65); 2) low NIR (<26,000) and low LiDAR Intensity (<30)
Developed Features	Low difference in NDVI between leaf-off Orthoimagery and leaf-on NAIP (<0) and low NDVI for NAIP (<0); or Visible Brightness in NAIP (>350)	Low difference in NDVI between leaf-off Orthoimagery and leaf-on NAIP (<0) and low NDVI for NAIP (<0); or Visible Brightness in NAIP (>400)
High Slope	Not Used	High mean slope (Mean Slope >24 degrees)

Size – Large. Most of the vernal pools in the rolling topography of Addison County are relatively small, so its depressions were considered outliers if they were large (>7,250 m^2) and had high LiDAR Intensity values (>90). These criteria were not used for Cumberland County because the pools in its coastal plain landscape tend to be larger than those in variable upland terrain.

Size – Small. Very small depressions unlikely to serve as functional vernal pools were eliminated from both study areas. For Addison County, the removal criteria combined small size (<110 m^2) and close proximity to water (<20 m) in one routine and size (<300 m^2) and high LiDAR Intensity (>80) in a second. The Cumberland County routine included size (<300 m^2), high LiDAR Intensity (>80), and high NIR (>16,000) values in the leaf-off orthoimagery.

Compound Topographic Index (CTI). The Lee Sigma Edge Extraction derivative produced from each study area's CTI layer was used to exclude depressions that apparently had no sharp transitions in topography or flow between individual candidates and adjacent features. For Addison County, depressions with only a small difference in Lee Sigma CTI (<0.05) were excluded, as were candidates that had a low overall Lee Sigma CTI value (<0.125). A third routine for this study area removed depressions with a very high GLCM Homogeneity value (>0.98), a textural parameter that can be calculated for each object in eCognition. For Cumberland County, depressions with low Lee Sigma CTI and large area were removed with two routines (Lee Sigma CTI <0.17 and area >1,000 m^2; Lee Sigma CTI <0.18 and area >3,000 m^2). However, depressions with low NIR (<20,000) in the leaf-off orthoimagery, low NIR (<25,500) and low LiDAR Intensity (<65), or low NIR (<26,000) and low LiDAR Intensity (<30) were excluded because they exhibited strong evidence of water.

Pool Depth. Vernal pools may vary widely by depth, but very shallow depressions unlikely to support functional pools were removed from the classification for both study areas (<0.035 m for Addison County, <0.03 m for Cumberland County).

Adjacent to Non Habitat. In both study areas, depressions occurring immediately adjacent to features previously mapped as *Non Habitat* were considered unlikely to be PVPs when they shared a relatively long common border (>20%). A second routine removed depressions with any common border with Non Habitat (>0%) when they also possessed high visible brightness (sum of Red, Green, and Blue bands) in the leaf-on NAIP imagery (>400). Additional routines for Addison County removed candidates with a common border (>0%) and low NIR values in the leaf-off orthoimagery (<50) or candidates close to water (<20 m) with short vegetation (nDSM <1 m). Another routine for Cumberland County removed small depressions (<200 m^2) with a long common border with Non Habitat (>50%) but excluded candidates with strong evidence of water (low NIR and/or LiDAR Intensity).

Developed Features. Isolated developed features that had not been excluded by initial *Non Habitat* mapping (e.g., bare soil and impervious surfaces) sometimes coincided with candidate depressions, necessitating an outlier routine that examined multispectral characteristics of the available orthoimagery. The Normalized Difference Vegetation Index

(NDVI), a commonly-used index calculated from the NIR and Red bands of multispectral imagery, was the primary variable for both study areas. For each depression, NDVI values calculated from the leaf-off orthoimagery were compared to NDVI calculated from the leaf-on NAIP imagery, and a small difference (<0) between them suggested the presence of a feature that was unaffected by seasonal vegetation growth. These depressions were removed when a small NDVI difference was combined with low NDVI values in the NAIP imagery (<0), which ensured that only developed features were eliminated. An additional routine removed depressions with high visible brightness (sum of the Red, Green, and Blue bands) in the NAIP (>350 for Addison County, >400 for Cumberland County).

High Slope. Given the generally flat topography of Cumberland County, depressions with high mean slope values (>24 degrees) were eliminated because they tended to occur on or near the banks of major rivers and streams. This criterion was not used for Addison County because PVPs in the more variable terrain of this study area were more likely to capture the adjacent slopes that helped form each candidate depression.

Final Classification

Classification of the final set of mapped depressions was structured to approximate how manual-interpretation methods identify vernal pools, by isolating the presence of water. To aid this effort, the existing vernal pools databases for Vermont and New Jersey were used as references during development of classification rules. The existing databases were not used as statistical training sites, as they would be with pixel-based classifiers; rather, the characteristics of the database pools were queried during iterative testing and incorporated into classification rules that captured as many known PVPs as possible while limiting the number of false positives.

The primary inputs indicating the presence of water were the NIR band in the leaf-off orthoimagery and the LiDAR Intensity layer. To maximize the information content of the final product, these inputs were incorporated into a set of classes that ranked the weight of available evidence using a combination of fuzzy classifiers and simple thresholds (Tables 2-4 and 2-5). For Addison County, the class with the highest level of confidence (*PVP – High Classification Value*) was based on a fuzzy classifier (Rule 1) that required evidence of water in both the NIR band and LiDAR Intensity. The specific parameters were calculated as the proportion of each depression's area that was occupied by low NIR (<57) or Intensity (<50) values. Using positive linear membership functions, the contribution of these parameters to the final classification value increased with increasing areal proportions. The overall size of the depression was also incorporated into this classifier, with larger depressions contributing more than smaller ones. Depressions that exceeded a combined fuzzy value (>0.4) were assigned to the highest-confidence class. A secondary rule (Rule 2) was also used with this class, focusing on a relatively high proportionate area of low Intensity values in a simple threshold (>0.10). This and other secondary rules were useful in capturing PVPs that did not meet the combined criteria but still showed strong evidence of water. The highest-confidence class was similarly structured for Cumberland County (Figure 2-3); besides a different threshold for low NIR values (<13,000), the only divergence was a secondary rule (Rule 2) that incorporated a fuzzy classifier combining a high proportion of LiDAR Intensity and total depression area.

Table 2-4. Classification criteria for PVPs identified by automated feature extraction, Addison County, Vermont. The criteria include both fuzzy classifiers combining multiple variables (as noted by membership functions) and simple thresholds.

PVP Class	Criteria	Membership Function	Range	Weight	Threshold
High Classification Value (Rule 1)	% Area of Pools with Low Mean NIR (<57)	Positive Linear	0-0.1	2	>0.4
	% Area of Pools with Low LiDAR Intensity (<50)	Positive Linear	0-1	1	
	Area (m^2)	Positive Linear	0-1,000 m^2	1	
High Classification Value (Rule 2)	% Area of Pools with Low LiDAR Intensity (<50)	None	None	None	>0.1
Moderate Classification Value (Rule 1)	% Area of Pools with Low Mean NIR (<57)	Positive Linear	0-0.1	2	>0.2
	% Area of Pools with Low LiDAR Intensity (<50)	Positive Linear	0-1	1	
	Area (m^2)	Positive Linear	0-1,000 m^2	1	
	% Area of Pools with Low LiDAR Intensity (<50)	None	None	None	0.02
Moderate Classification Value (Rule 2)	% Area of Pools with Low LiDAR Intensity (<50)	Positive Linear	0-1	1	>0.16
	Area (m^2)	Positive Linear	0-2,000 m^2	1	
Moderate Classification Value (Rule 3)	% Area of Pools with Low Mean NIR (<57)	Positive Linear	0-1	1	>0.16
	Area (m^2)	Positive Linear	0-2,000 m^2	1	
Low Classification Value (Rule 1)	Same as High Classification Value (Rule 1) but with different threshold				>0
Low Classification Value (Rule 2)	Same as Moderate Classification Value (Rule 2) but with different threshold				>0.1
Low Classification Value (Rule 3)	Mean NIR	Negative Linear	100-150	1	>0.5
	Pool Depth	Positive Curvilinear	0-1 m	1	
	Mean Distance to Other Pools	Negative Linear	0-250 m	1	
Low Classification Value (Rule 4)	Mean NIR	Negative Linear	100-150	1	>0.29
	Pool Depth	Positive Curvilinear	0-1 m	1	
	Mean Distance to Other Pools	Negative Linear	0-250 m	1	
	% Area of Pools with Low Mean NIR (<57)	None	None	None	>0.1
Low Classification Value (Rule 5)	Same as Low Classification Value (Rule 4) but with different thresholds				>0.05 >0.75
Obscured by Conifers	Mean Difference in NDVI, Leaf-off Orthoimagery and Leaf-on NAIP	Negative Linear	0-0.2	2	>0.8
	Mean NIR	Positive Boolean	0-160	1	
	Mean Distance to Other Pools	Negative Linear	0-1,000 m	1	
	Pool Depth	Positive Curvilinear	0-1 m	1	
	Mean nDSM	Positive Boolean	0-5 m	1	

Table 2-5. Classification criteria for PVPs identified by automated feature extraction, Cumberland Co., New Jersey. The criteria include both fuzzy classifiers combining multiple variables (as noted by membership functions) and simple thresholds.

PVP Class	Criteria	Membership Function	Range	Weight	Threshold
High Classification Value (Rule 1)	% Area of Pools with Low Mean NIR (<13,000)	Positive Linear	0-0.1	2	>0.5
	% Area of Pools with Low LiDAR Intensity (<50)	Positive Linear	0-1	1	
	Area (m^2)	Positive Linear	0-1,000 m^2	1	
High Classification Value (Rule 2)	% Area of Pools with Low LiDAR Intensity (<50)	Positive Linear	0-1	1	>0.8
	Area (m^2)	Positive Linear	0-2,000 m^2	1	
Moderate Classification Value (Rule 1)	Same as High Classification Value (Rule 1) but with different threshold				>0
Moderate Classification Value (Rule 2)	% Area of Pools with Low LiDAR Intensity (<50)	None	None	None	>0.9
Moderate Classification Value (Rule 3)	Same as High Classification Value (Rule 2) but with different threshold				>0.5
Moderate Classification Value (Rule 4)	% Area of Pools with Low LiDAR Intensity (<50)	Positive Linear	0-1	1	>0.2
	Area (m^2)	Positive Linear	0-2,000 m^2	1	
	% Area of Pools with Low LiDAR Intensity (<50)	None	None	None	>0.5
Moderate Classification Value (Rule 5)	% Area of Pools with Low Mean NIR (<13,000)	Positive Linear	0-1	1	>0.5
	Area (m^2)	Positive Linear	0-2,000 m^2	1	
Moderate Classification Value (Rule 6)	% Area of Pools with Low Mean NIR (<13,000)	Positive Linear	0-1	1	>0.2
	Area (m^2)	Positive Linear	0-2,000 m^2	1	
	% Area of Pools with Low Mean NIR (<13,000)	None	None	None	>0.5
Low Classification Value (Rule 1)	Mean NIR	Negative Linear	25,000-35,000	1	>0.7
	Pool Depth	Positive Curvilinear	0-1 m	1	
	Mean Distance to Other Pools	Negative Linear	0-250 m	1	
Low Classification Value (Rule 2)	Mean NIR	Negative Linear	25,000-35,000	1	>0.6
	Pool Depth	Positive Curvilinear	0-1 m	1	
	Mean Distance to Other Pools	Negative Linear	0-250 m	1	
	% Area of Pools with Low Mean NIR (<13,000)	None	None	None	>0
Obscured by Conifers	Mean Difference in NDVI, Leaf-off Orthoimagery and Leaf-on NAIP	Negative Linear	0-0.3	2	>0.7
	Mean NIR	Positive Boolean	0-6,000	1	
	Mean Distance to Other Pools	Negative Linear	0-1,000 m	1	
	Pool Depth	Positive Curvilinear	0-1	1	

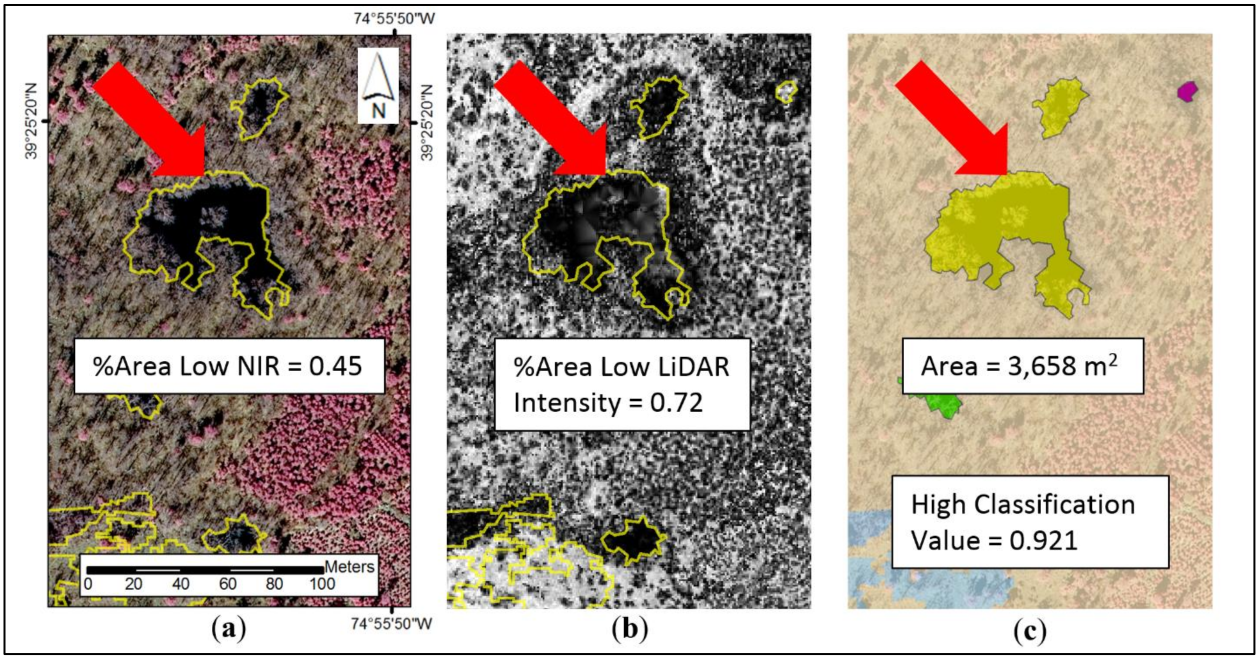

Figure 2-3. Classification of a PVP in Cumberland County, New Jersey. A fuzzy classifier combining the percent area of each depression occupied by low NIR values in leaf-off, 0.3-m GSD orthoimagery (a), the percent area with low LiDAR intensity values (b), and overall pool area (c) assigned this candidate depression to PVP – High Classification Value (c) when it exceeded a threshold (0.5) established through iterative testing.

A second PVP class (*PVP – Moderate Classification Value*) was similarly structured with primary and secondary rules that required less evidence of water. The primary rules were fuzzy classifiers incorporating the same parameters as the highest-confidence class but using lower thresholds (<0.2 for Addison County, >0 for Cumberland County) or classifiers further constrained by the addition of a simple threshold (>0.02 proportionate area of low LiDAR Intensity for Addison County). Multiple secondary rules incorporated relatively strong evidence of water in either the NIR band of the leaf-off orthoimagery or LiDAR Intensity but not both simultaneously. Overall depression area again contributed to these moderate-confidence classifiers, weighting selection in favor of larger PVPs.

Selection criteria for a third class (*PVP – Low Classification Value*) diverged more between the two study areas. For Addison County, the same primary classifiers established for the highest- and moderate- confidence PVP classes were used with lower thresholds, which helped capture depressions with limited evidence of water. Additional secondary rules then incorporated mean NIR for entire depressions rather than the proportionate area of low NIR pockets, using a negative linear membership function to weight pools with low NIR values. These rules also included estimated pool depth to avoid shallow depressions that may be partly or wholly shadowed by adjacent trees and the mean distance to other pools to favor depressions occurring in clumped spatial patterns. For Cumberland County, both the primary and secondary classifiers combined mean NIR, pool depth, and mean distance to other pools. In addition to different thresholds, the secondary rule included a simple low threshold for the proportionate area of low mean NIR pockets.

A final class (*PVP – Obscured by Conifers*) reflected a technical limitation of LiDAR in coniferous or mixed forests: fewer LiDAR pulses reach the ground through dense coniferous canopy cover, limiting the ability to detect underlying water. As with manual interpretation of leaf-off aerial imagery, it thus can be difficult or impossible to reliably identify PVPs partly or wholly obscured by conifers. However, the ability to map depressions in such landscapes provides information that is still useful if not diagnostic. To identify the likely presence of conifers, a negative linear membership function compared NDVI between the leaf-off orthoimagery and the leaf-on NAIP available for each study area. NDVI is typically high for trees with photosynthetic foliage, meaning that deciduous trees will have low NDVI in leaf-off imagery and high NDVI in growing-season imagery. In contrast, coniferous trees will have similar NDVI regardless of imagery acquisition date. For Addison County, the fuzzy classifier combined this NDVI comparison with mean NIR, distance to other pools, pool depth, and vegetation height as indicated by the mean nDSM (only features >5m). The classifier for Cumberland County was similarly structured but did not include vegetation height because the tree cover in this coastal plain environment tended to be shorter than forests in Addison County.

Depressions that did not satisfy any of the PVP classifiers were assigned to a new class, *Other Potential Habitat*, as were all remaining unclassified objects. This class indicated the landscape areas that were evaluated for PVPs but ultimately deemed unsuitable or marginal habitat. The previously-mapped classes *Non Habitat*, *Large Water Bodies*, and *Connected Wetlands* were also included in the final map, showing the distribution of PVPs relative to the zones considered unlikely to support functional vernal pools.

OUTPUT AND ASSESSMENT

GIS-ready Output

To produce output for the two study areas, the final rule set for each was applied to all tiles using eCognition Server. This module permitted enterprise processing (simultaneous processing) of multiple tiles, and 20 processing cores were used for both study areas. Final classifications were exported from eCognition as vector shapefiles and then mosaicked and dissolved into seamless layers using ArcGIS (Version 10.3, ESRI, Redlands, California, USA).

Accuracy Assessment

The customary approach for assessing remotely-sensed land-cover maps is to establish a random set of points and then compare them against reference data that identify the actual on-the-ground features (Congalton 1991). As a rule-of-thumb, at least 50 points are needed for pixel-based accuracy assessment. This approach was impractical for assessing PVPs, however, because the features of interest are comparatively small and constitute a tiny fraction of the overall study areas. Obtaining an adequate sample for each PVP class while maintaining a manageable number of total points would have been difficult, potentially requiring review of thousands of additional points. This method also would have ignored the value of the existing vernal pools databases. Accordingly, a hybrid method was developed that capitalized on the existing databases and also examined the entire set of mapped PVPs to gauge the incidence of false positives.

The first part of the assessment was a direct comparison between the Vermont and New Jersey vernal pools databases and the modeled output for each study area. The Vermont database contained 85 occurrences that coincided with Addison County, 9 of which were considered confirmed; all others had not been visited in the field and were labeled as potential pools. The New Jersey database contained 920 points for Cumberland County, only two of which had been confirmed. Given that the databases consisted of points whose locations were approximate, each was buffered by 15 m in ArcGIS to permit better comparison with modeled PVPs. Some of the New Jersey points occurred within close proximity and likely represented the same pools, so the buffered point locations were dissolved to eliminate overlapping polygons. This step reduced the number of New Jersey pools to 815. After intersecting the buffered pools with the modeled output, each site was examined relative to the leaf-off orthoimagery and LiDAR Intensity layers to assess the weight of evidence in the available reference datasets. Modeled PVPs with strong evidence of water in either the orthoimagery or LiDAR Intensity were labeled as such (*Potential Pool – Strong Evidence*); pools with less convincing evidence that could not be entirely discounted as possible vernal pools were also labeled (*Potential Pool – Limited Evidence*). PVPs that were incorrectly classified relative to reference imagery were labeled according to actual land cover (*Not Pool – Agriculture*, *Not Pool – Developed*, *Not Pool – Upland*, *Not Pool – Water Body*, *Not Pool – Wetland*). The available thematic hydrology layers and the LiDAR-derived DEMs were also examined during labeling of PVPs misclassified as wetlands.

In the second part, all pools not coinciding with the existing vernal pools databases were examined against the leaf-off orthoimagery and LiDAR Intensity. Each was classified according to the weight of available evidence using the same set of reference labels. Both assessments were then summarized in error matrices detailing sources of omission and commission.

Results

AUTOMATED FEATURE EXTRACTION

OBIA modeling for Addison County's 364 tiles required about 6.5 hours using 20 processing cores. Cumberland County's 597 tiles required about 5.25 hours. Most of the processing time for individual tiles was attributable to the depression-mapping routine and its pixel-based growing approach. The longer total processing time for Addison County's fewer tiles was attributable to the more numerous outlier routines used for this study area.

The Addison County routine identified 2,435 PVPs constituting 235.7 ha (Table 2-6a), or about 0.2% of the study area. The *PVP – High Classification Value* class captured 13% of these potential pools, followed by the moderate (27%) and low-confidence (44%) classes. The *Obscured by Conifers* class captured the remaining 16% of the mapped pools. The highest-confidence PVPs were generally the smallest pools identified, with an average pool size of 0.07 ha; average pool sizes for the moderate and low-confidence PVPs matched the combined size (0.10 ha).

In the coastal plain of Cumberland County, OBIA modeling predictably captured a much larger number of PVPs: 10,161 pools constituting 7,238.8 ha, or about 5.5% of the study area (Table 2-6b). These pools were also much larger than the PVPs in Addison County, with an average size of 0.71 ha. In particular, the highest-confidence PVPs were more than

3 times (2.45 ha) the average size of all pools and more than 35 times the size of Addison County PVPs. Another divergence between the study areas was the pattern of average pool sizes among the classified PVPs, which declined to 0.84 ha for the moderate-confidence class in Cumberland County and to 0.35 ha for the low-confidence class. However, the distribution of pools in the highest-, moderate-, and low-confidence classes were similar between the study sites, with the number of captured PVPs inversely proportionate to confidence.

The classified maps for both study areas showed not only the location and spatial patterning of PVPs but also illustrated their relationship to features excluded from consideration in initial land-cover modeling (*Large Water Bodies*, *Connected Wetlands*, *Non Habitat*) and to areas actively examined for pools but later deemed unsuitable in the final classification (*Other Potential Habitat*). In Addison County, many of the PVPs occurred in hilly upland sites in deciduous forest where pools were small and irregular (Figure 2-4a). In Cumberland County, the more numerous and larger PVPs were usually more symmetrical, contained more open water, and occurred near connected wetlands (Figure 2-4b). In both landscapes, PVPs often occurred in clumped distributions; this was partly by design (the *PVP – Low Classification Value* class contained a criterion for distance to other pools), but it also suggested that favorable topographies and water-source conditions occurred non-randomly in the study areas.

Table 2-6. Summary of final PVP classifications for Addison County, Vermont and Cumberland County, New Jersey.

A. Addison County, Vermont			
PVP Class	*Number*	*Area (ha)*	*Mean Area/PVP (ha)*
High Classification Value	316 (13%)	20.6	0.07
Moderate Classification Value	659 (27%)	62.9	0.10
Low Classification Value	1,077 (44%)	106.7	0.10
Obscured by Conifers	383 (16%)	45.5	0.12
Total	2,435 (100%)	235.7	0.10
B. Cumberland County, New Jersey			
PVP Class	*Number*	*Area (ha)*	*Mean Area/PVP (ha)*
High Classification Value	978 (10%)	2,394.2	2.45
Moderate Classification Value	2,085 (21%)	1,755.5	0.84
Low Classification Value	6,257 (61%)	2,123.8	0.34
Obscured by Conifers	841 (8%)	965.3	1.15
Total	10,161 (100%)	7,238.8	0.71

ACCURACY ASSESSMENT

For Addison County, comparison of the final classified map to the existing Vermont vernal pools database showed that 52 of 85 (61%) represented pools were captured by modeled PVPs (Table 2-7a). Most of the captured pools were assigned to the highest-confidence class (22%), but similar proportions were noted for the moderate- and low-confidence classes. Only 2 PVPs were assigned to the *Obscured by Conifers* category. However, review of the reference orthoimagery and LiDAR Intensity suggested that only 5 of the 33 missing occurrences were true omissions; no evidence of water was detected for the other omissions, which were manually interpreted as upland sites (24%) or water bodies (8%). When the false omissions were excluded, the classification rate for modeled PVPs relative to the Vermont database was 91%.Review of the remaining modeled PVPs showed that 33% of the mapped sites contained some evidence of water in orthoimagery and LiDAR Intensity, with most of these occurring in the reference class *Potential Pool – Limited Evidence* (Table 2-7b). The classification increased to 40% when the *Low Classification Value* and *Obscured by Conifers* were excluded. The largest sources of confusion were

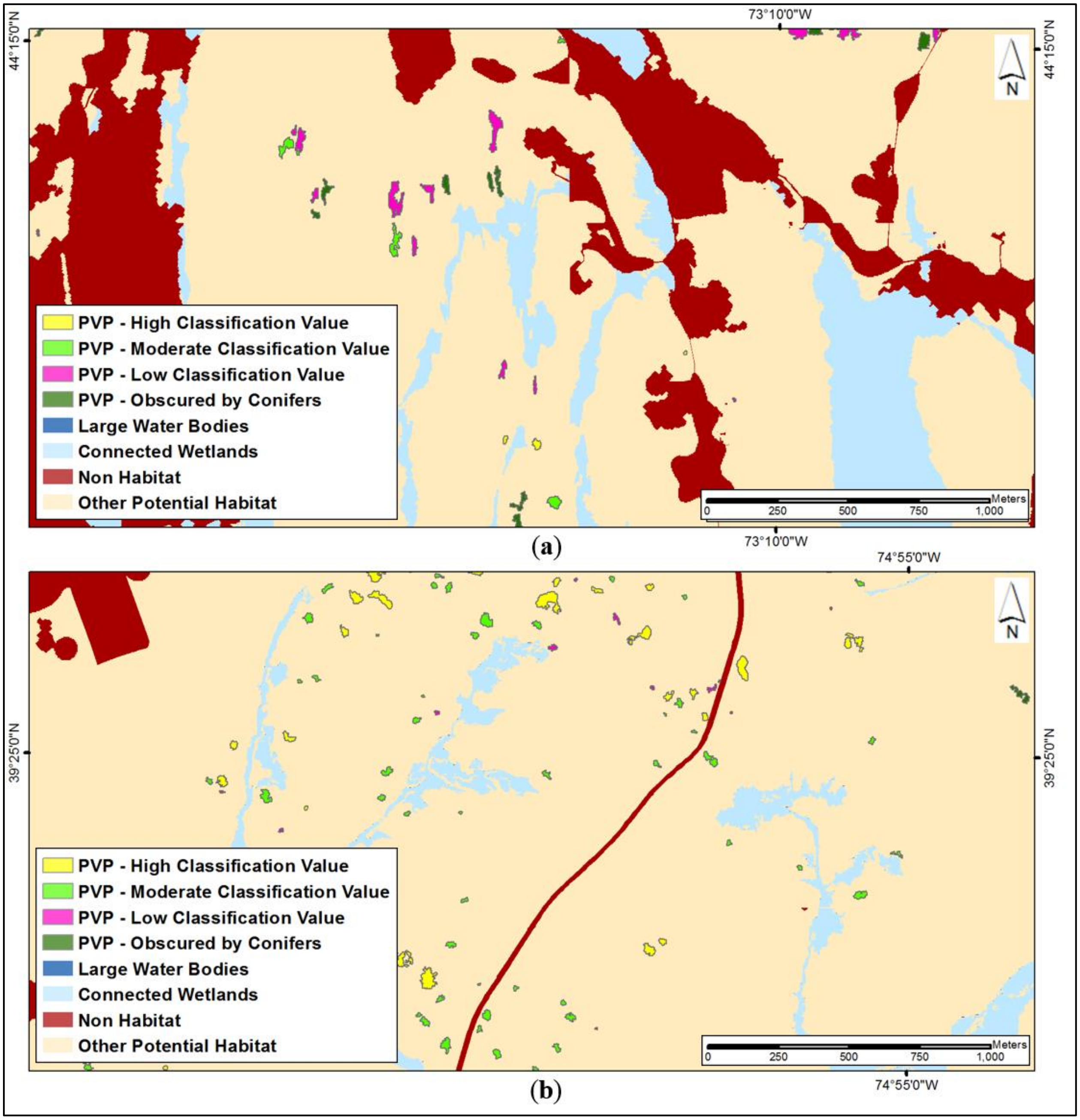

Figure 2-4. Final PVP classifications for selected areas in Addison County, Vermont (a) and Cumberland County, New Jersey (b), superimposed on available orthoimagery. Each classification shows not only PVPs but also areas initially excluded from consideration (Large Water Bodies, Connected Wetland, Non Habitat) and areas where pools were not identified (Other Potential Habitat).

Table 2-7. Two-part accuracy assessment for modeled potential pools in Addison County, Vermont. The first part compared modeled output to the existing vernal pools database for Vermont and also relative to the available leaf-off, 0.5-m GSD orthoimagery and LiDAR intensity. The second evaluated the remaining modeled pools relative to leaf-off orthoimagery and LiDAR intensity.

A. Modeled Potential Pools Relative to Existing Vernal Pools Database, Orthoimagery, and LiDAR Intensity

	Modeled PVPs					
Reference	High Classification Value	Moderate Classification Value	Low Classification Value	Obscured by Conifers	Omitted	Totals
Potential Pool – Strong Evidence	19	13	7	0	3	42 (49%)
Potential Pool – Limited Evidence	0	3	8	2	2	15 (18%)
Not Pool - Agriculture	0	0	0	0	0	0
Not Pool - Developed	0	0	0	0	0	0
Not Pool - Upland	0	0	0	0	20	20 (24%)
Not Pool – Water Body	0	0	0	0	8	8 (9%)
Not Pool - Wetland	0	0	0	0	0	0
Totals	19 (22%)	16 (19%)	15 (18%)	2 (2%)	33 (39%)	85 (100%)

B. All Remaining Modeled Potential Pools Relative to Orthoimagery and LiDAR Intensity

	Modeled PVPs				
Reference	High Classification Value	Moderate Classification Value	Low Classification Value	Obscured by Conifers	Totals
Potential Pool – Strong Evidence	31	32	33	4	100 (4%)
Potential Pool – Limited Evidence	61	248	313	71	693 (29%)
Not Pool – Agriculture	0	2	1	1	4 (<1%)
Not Pool - Developed	23	40	26	4	93 (4%)
Not Pool - Upland	55	213	596	277	1,141 (48%)
Not Pool – Water Body	81	27	2	0	110 (5%)
Not Pool - Wetland	46	81	91	24	242 (10%)
Totals	297 (12%)	643 (27%)	1,062 (45%)	381 (16%)	2,383 (100%)

upland sites (48%) and wetlands (10%). The errors of commission for uplands included depressions that were shadowed by adjacent trees, but others were likely seeps that contained insufficient depth and hydroperiod to serve as functional vernal pools. Indeed, limited field examination of a subset of draft PVPs (June 2015) suggested that most false positives were seeps that satisfied NIR criteria for leaf-off orthoimagery but otherwise did not have diagnostic evidence of open water. The commission errors interpreted as wetlands were usually sites that appeared to be hydrologically connected to larger wetland complexes but were not mapped as *Connected Wetlands* in initial modeling. Although PVPs misclassified as water bodies were only 5% of the total number of mapped pools, they constituted the largest source of error with the *PVP – High Classification Value* class. Most of these errors were small ponds not excluded by the *Large Water Bodies* class or short stream reaches near, but not traversed, by hydrology GIS layers.

For Cumberland County, 431 of 815 (53%) pools represented in the New Jersey vernal pools database were captured by modeled PVPs (Table 2-8a). The largest proportion of pools was assigned to the PVP – High Classification Value category (28%), followed by the moderate- and low-confidence classes (17% and 8%, respectively). Only 5 pools (<1%) were captured by *Obscured by Conifers*. As with Addison County, however, review of the omissions relative to remote-sensing imagery indicated that most could not be classified as PVPs, with only 66 pools (8%) classified as true omissions. Most of the false omissions were interpreted as wetlands (15%), uplands (15%), and developed industrial sites (5%). The classification rate relative to the vernal pools database was 87% when false omissions were removed. For modeled PVPs not represented by the vernal pools database, 27% exhibited evidence of water in the orthoimagery and LiDAR Intensity layers (Table 2-8b); this rate improved to 41% when the *Low Classification Value* and *Obscured by Conifers* categories were removed. The largest sources of confusion were again upland sites (42%) shadowed by adjacent trees or sites with shallow depressions that were damp but not wet. Wetlands (28%) were also confused in the classification, especially in large complexes with hummocky terrain; the *Connected Wetlands* routine likely did not approximate the full extent of wetlands with this topography, meaning that pockets on the edge of large complexes were mapped as PVPs. The large total number of mapped PVPs (10,161) was also partly attributable to the difficulty in mapping vernal pools in hummocky terrain; vernal pools that would be represented by a single point with manual-interpretation methods sometimes contained multiple small hummocks that were mapped separately by the depression-modeling routine. Similarly, wetlands misclassified as PVPs often contained multiple objects that would have been drawn as a single polygon with analog methods.

Closer examination of individual points highlighted some of the challenges inherent to depression classification. In Addison County, point #MLS718 in the Vermont vernal pools database was not mapped as a PVP in automated modeling even though a minor depression was observable in the LiDAR-derived slope layer (Figure 2-5a). Neither the leaf-off orthoimagery (Figure 2-5b) nor the LiDAR Intensity layer (Figure 2-5c) showed diagnostic evidence of water at this location, so the final classification routines excluded it. The intensity layer was also inconsistent near the depression, a problem with some LiDAR collections that can limit their utility in site-specific areas. Nonetheless, this point's designation as a false omission was appropriate; insufficient evidence existed to classify it

Table 2-8. Two-part accuracy assessment for modeled potential pools in Cumberland County, New Jersey. The first part compared modeled output to the existing vernal pools database for New Jersey and also relative to the available leaf-off, 0.3-m GSD orthoimagery and LiDAR intensity. The second evaluated the remaining modeled pools relative to leaf-off orthoimagery and LiDAR intensity.

A. Modeled Potential Pools Relative to Existing Vernal Pools Database, Orthoimagery, and LiDAR Intensity

	Modeled PVPs					
Reference	High Classification Value	Moderate Classification Value	Low Classification Value	Obscured by Conifers	Omitted	Totals
Potential Pool – Strong Evidence	226	131	58	2	41	458 (56%)
Potential Pool – Limited Evidence	0	5	6	3	25	39 (5%)
Not Pool - Agriculture	0	0	0	0	15	15 (2%)
Not Pool - Developed	0	0	0	0	42	42 (5%)
Not Pool - Upland	0	0	0	0	121	121 (15%)
Not Pool – Water Body	0	0	0	0	14	14 (2%)
Not Pool - Wetland	0	0	0	0	126	126 (15%)
Totals	226 (28%)	136 (17%)	64 (8%)	5 (<1%)	384 (47%)	815 (100%)

B. All Remaining Modeled Potential Pools Relative to Orthoimagery and LiDAR Intensity

	Modeled PVPs				
Reference	High Classification Value	Moderate Classification Value	Low Classification Value	Obscured by Conifers	Totals
Potential Pool – Strong Evidence	185	322	164	6	677 (7%)
Potential Pool – Limited Evidence	113	495	1,195	161	1,964 (20%)
Not Pool – Agriculture	1	1	15	2	19 (<1%)
Not Pool - Developed	86	48	52	8	194 (2%)
Not Pool - Upland	23	273	3,212	589	4,097 (42%)
Not Pool – Water Body	19	4	9	0	32 (<1%)
Not Pool - Wetland	325	806	1,546	70	2,747 (28%)
Totals	752 (8%)	1,949 (20%)	6,193 (64%)	836 (8%)	9,730 (100%)

as a PVP. Temporal changes between the 2012 orthoimagery used in this analysis and the earlier orthoimagery used with the Vermont vernal pools database (Faccio et al. 2013) undoubtedly played a role in this discrepancy, but a pool that appears only in certain years would likely be sub-optimal breeding habitat for amphibians.

Also in Addison County, point #MLS724 was similarly missed by automated feature extraction. The depression for this pool was more distinct (Figure 2-5d) and the orthoimagery (Figure 2-5e) showed a blurred but noticeable feature with moderately-low NIR values. The LiDAR Intensity layer was also more consistent in this area (Figure 2-5f) and showed weak evidence of water. However, the NIR and LiDAR Intensity classifiers were not sensitive enough to reach the same conclusion as the human interpreter who mapped it in the vernal pools database. Less stringent classification criteria perhaps would have captured this depression, but this gain would have been achieved at a cost: additional false positives that had similar spectral and intensity characteristics.

In Cumberland County, point #14436 from the New Jersey vernal pools database was a minor depression in hummocky terrain (Figure 2-6a) that contained no evidence of water in the available orthoimagery (Figure 2-6b). The LiDAR Intensity layer (Figure 2-6c) was finely textured at this location, suggesting the presence of vegetation rather than standing water. The weight of evidence thus indicated that the point was correctly mapped as *Other Potential Habitat* in the final automated classification. Point #14459 also coincided with a small depression in hummocky terrain (Figure 2-6d), but in this case evidence of water was observable in the orthoimagery (Figure 2-6e). However, LiDAR Intensity (Figure 2-6f) was again finely textured, indicating the presence of vegetation rather than water, and its small size and mixed evidence of water failed to meet any of the classification criteria. Many of the 66 true omissions relative to the New Jersey vernal pools database shared this profile of hummocky terrain with small pools interspersed with vegetation that is short and presumably emergent. With no confirmed vernal pools in the Cumberland study area, it was unclear whether these sites were functional breeding habitat for amphibians or a type of unmapped emergent wetland ultimately connected to other hydrological flows. It is also possible that such sites were something in between: shallow, vegetation-dominated depressions that provide sub-optimal yet still useful breeding or movement habitat.

Discussion

This project demonstrated that OBIA is an efficient and sensitive method for mapping PVPs in diverse landscapes. Automated feature extraction in eCognition effectively mapped high percentages of previously-identified sites by combining depression mapping and classification into rule sets that processed large geographic extents in a matter of hours. It also provided contextual information that is useful to both landscape-level characterization of PVP distribution and site-specific analysis of habitat quality: where pools are located relative to other land-cover features and how they compare to each other in probable value. As expert systems, the rule sets for Addison County, Vermont and Cumberland County, New Jersey can be easily adapted for other study areas with similar landscape characteristics and input datasets, and they can also be expanded and refined for dissimilar landscapes where vernal pools have different topographic and morphological profiles.

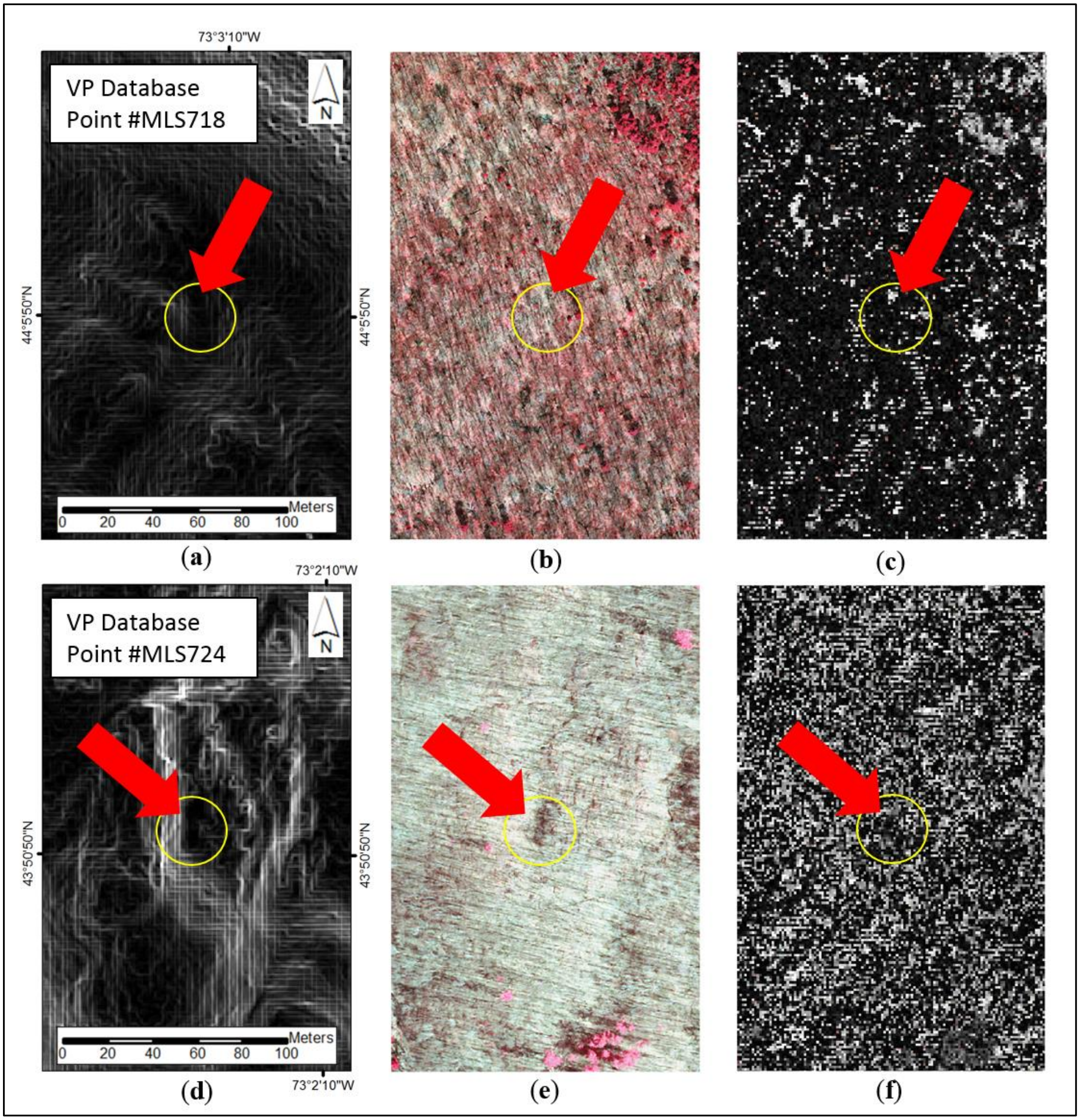

Figure 2-5. Manual evaluation of PVPs in the Vermont Vernal Pools Database that were omitted by automated modeling. For database point #MLS718, a slight but discernible depression was detected in the slope layer derived from the DEM (a), but no reliable evidence of water was detected in either the 0.5-m GSD leaf-off orthoimagery (b) or LiDAR Intensity (c). For point #MLS724, the observed depression was more distinct (d) but the available evidence was still limited in the orthoimagery (e) and LiDAR Intensity (f). In the accuracy assessment, the first point was considered an upland site but the latter was labeled as a PVP – Limited Evidence.

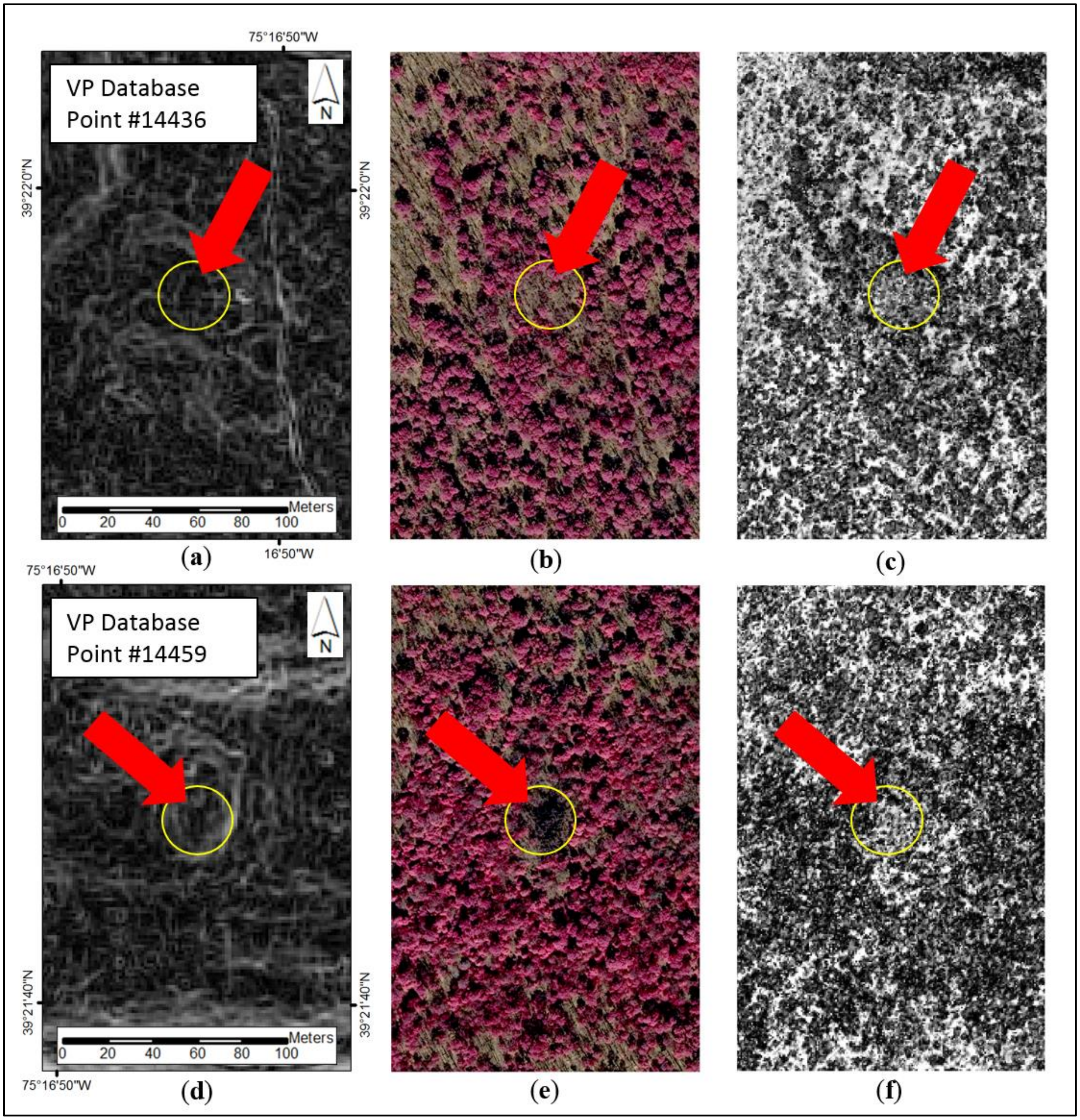

Figure 2-6. Manual evaluation of PVPs in the New Jersey Vernal Pools Database that were omitted by automated modeling. For database point #14436, a small depression was discernible in the slope layer derived from the DEM (a), but no reliable evidence of water was detected in either the 0.3-m GSD leaf-off orthoimagery (b) or LiDAR Intensity (c). For point #14459, the observed depression was relatively small because it included hummocky terrain (d). Although water was discernible in the orthoimagery near #14459 (e), LiDAR Intensity (f) indicated that the depression was instead filled with vegetation, further complicating classification. In the accuracy assessment, the first point was considered an upland site but the latter was labeled as a PVP – Limited Evidence.

Local knowledge that can be effectively incorporated into rule sets will maximize classification accuracy and ultimate value to biodiversity assessment at multiple scales.

This versatility will be needed when the rule sets are adapted for study areas with other constellations of available remote-sensing datasets and data-processing capabilities. The current rule sets are ideally suited for county-sized areas for which good LiDAR data and multispectral orthoimagery are available. The datasets need not date from the same year, but they must capture leaf-off conditions when vernal pools are visible on the landscape. Ancillary thematic GIS layers and leaf-on orthoimagery such as NAIP are useful but not essential. In areas where good leaf-off imagery is unavailable, the rule set can be adjusted to rely exclusively on LiDAR derivatives. Similarly, if LiDAR intensity data are unavailable, classification rules can be modified for exclusive dependence on orthoimagery. Individual routines can also be bypassed or superseded as needed or desired. For example, the depression-mapping section can be de-activated if a user prefers an outside processing utility such as SCALGO; a pre-existing depression map can be imported into eCognition and classified with pertinent contextual relationships and site characteristics. Another example is the CTI layer used in estimating connected wetlands and in the outlier analysis. If this layer cannot be developed with the available datasets and processing capabilities, thematic GIS layers can instead be used to exclude wetland complexes if good-quality versions exist for specific study areas. Whether developed directly from LiDAR point clouds or obtained pre-processed from other sources, however, a high-resolution DEM must be available for vernal-pools mapping; coarse-scale DEMs will not discriminate PVPs from other landscape features. Many U.S. states in the North Atlantic region are approaching near-complete LiDAR coverage (Appendix 2-A), which will facilitate development of the requisite high-resolution DEMs. Fewer LiDAR datasets are currently available for the Canadian provinces (Appendix 2-B), but interest in LiDAR products is similarly high in this part of the region and will likely encourage future data investments.

The rule sets over-predicted PVPs by design; the goal was to capture as many previously-identified candidates as possible by mimicking human cognition of vernal-pool morphology and landscape position. The rule sets not only met this goal, capturing most of the pools represented in the available databases, but also captured many additional depressions that show some evidence of water during spring conditions. From a practical perspective, however, fewer false positives would better facilitate field-based confirmation of pool status. The classification scheme was constructed to partly address this concern, prioritizing PVPs for subsequent examination. The *PVP – High Classification Value* category can be the starting point for further analysis, and the moderate- and low-confidence classes can be addressed as resources permit. This classification can also help focus manual review of the available remote-sensing datasets; PVPs that are obvious false positives can be eliminated from consideration while others with equivocal evidence can be set aside for more detailed examination. Manual review of automated mapping output is still a commonly-used and effective way to ensure overall map quality and aesthetic integrity (e.g., O'Neil-Dunne et al. 2013, O'Neil-Dunne et al. 2014).

Additional rule-set refinements could further reduce the incidence of false positives. Pool depth was included as a criterion in fuzzy classification of the *PVP – Low Classification*

Value category but not in the highest- and moderate-confidence classes. Initial analysis of pools in the available vernal pools databases confirmed a wide variability in physical characteristics, and pool depth would have eliminated PVPs with clear evidence of water in orthoimagery and LiDAR Intensity. However, model calibration based on potential pools rather than confirmed pools, as was the case with Addison and Cumberland Counties, will inevitably capture a proportion of erroneous or sub-optimal pools, and the accuracy assessment performed for this project indicated that many false positives were indeed included in the final product. Experience in Vermont has also indicated that about half the pools identified by manual photo-interpretation are ultimately categorized as false positives when examined in the field (S. Faccio, personal communication). Inclusion of a depth criterion in the highest- and moderate-confidence classes will likely reduce the number of false positives substantially, as will more stringent size criteria. These criteria will likely reduce the level of correspondence with the existing databases but will provide a more robust assessment of likely vernal pools.

The rule sets could also be fine-tuned by a calibrating their classification routines to confirmed vernal pools in other study areas. Wu et al. (2014) achieved their simultaneously-low rates of omission and commission using a non-OBIA method that was quite similar conceptually to the modeling flow in this project: depression modeling followed by identification of water using NDWI. However, the vernal pools database available for their Massachusetts study area contained a much higher proportion of field-certified vernal pools (21%), providing a better selection of confirmed sites for devising sensitive NDWI-based selection criteria. The size of their study area (147.9 km^2) was also about a tenth of the study areas in this project, further reducing the range of landscape variability that must be addressed in classification rules. Nonetheless, better delineation of the physical and spectral characteristics that define confirmed vernal pools in specific study landscapes will aid development of optimal selection criteria.

More detailed field examinations of pools in hummocky terrain could also benefit model refinement. Most of the omissions in Cumberland County were small, well-vegetated depressions that occur in close proximity to similar pockets, and it was unclear from remote-sensing data alone whether these features serve as functional vernal pools. If they are pools, one model refinement could be an adjusted depression-modeling routine that encompasses larger pools with variable microtopography. Another could be to incorporate indices of spatial variability in LiDAR intensity like the one Julian et al. (2009) used to isolate pool edges from in-pond vegetation. This refinement could also benefit identification of isolated pools that occur within a matrix of interconnected wetlands. Such pools were excluded from this analysis to focus on pools with little or no regulatory protection, but they constitute important habitat in their own right and merit further examination if they can be effectively discriminated from adjacent wetlands.

Recommendations for Remote Sensing Based Identification of Vernal Pools

This project adds to the growing body of research demonstrating that automated approaches can greatly facilitate identification of potential vernal pools. It confirms that OBIA makes it possible to analyze large areas sensitively and efficiently, combining elements of traditional image interpretation with sophisticated data-fusion capabilities. Its methods depend on high-resolution LiDAR and imagery, data types that are now increasingly available in the United States and Canada, often at minimal or no cost (see Appendices 2-A and 2-B). Where these datasets exist, there is little reason to use a fully manual approach to PVP mapping.

When end users have access to the OBIA software eCognition, the first option should be fully automated feature extraction. In addition to its processing power and ability to incorporate contextual analyses, eCognition is extremely versatile; the template rule sets developed for this project can be adapted for use in other regions, adding or subtracting routines as needed to accommodate the available input datasets and variability in pool origin, morphology, and landscape position. We recommend that users start simply, initially trying only the depression-identification routine in combination with a classification procedure that focuses on evidence of water. If the model selects too many candidates (i.e., high incidence of false positives), outlier routines can be added to remove unlikely pools before producing a final classification.

The template rule sets can also be tailored to suit end-user priorities. If the highest priority is capturing all potential pools, even marginal ones, the final classification can be configured with low-threshold selection criteria. The omission rate with criteria that capture marginal candidate pools will be low but the number of false positives will likely be high. If the goal is to limit the classification to high-probability candidates, the selection criteria can be more stringently constructed to capture only pools that exhibit strong evidence of water. It is also possible to create additional classes that distinguish groups of candidates with similar physical and contextual characteristics.

Hybrid approaches are also possible and may be especially useful with projects focusing on inclusive selection criteria. OBIA methods routinely achieve high classification rates in land-cover mapping projects, but no automated approach will perfectly replicate human perception of fine-scale landscape features. Manual review and correction of eCognition output can thus be an effective way to eliminate obvious errors and ensure consistent, reliable output. With vernal pools, this process would entail visual comparison of the draft map to the available input datasets (e.g., orthoimagery, LiDAR-derived DEM) and could be performed in any GIS program. This process could also help end users prioritize candidate pools for subsequent field verification, highlighting pools according to their accessibility, spatial patterning, and apparent physical characteristics (e.g., size).

If end users do not have access to eCognition, a similar conceptual approach could be used with commonly-available GIS tools: 1) identify landscape depressions; and 2) classify them according to the observable evidence of water. It is unclear how accurately or efficiently a pixel-based method works for large study areas, and it would lack the processing power and contextual analysis that OBIA provides, but it would similarly use high-resolution data to automate initial identification of potential pools. Further experimentation with this GIS-based variant will help show whether it is adaptable and appropriate for regional analyses encompassing diverse landscapes.

All automated methods depend on the availability of a high-resolution, LiDAR-derived DEM; coarse-scale elevation models cannot resolve the small landscape depressions that support vernal pools in many parts of the North Atlantic region. Where LiDAR is unavailable and no collections are planned, manual image interpretation will likely remain the best option for identifying potential pools. Although laborious, this method is undoubtedly effective and requires much less technical proficiency in geospatial analysis. Where LiDAR collections are planned, however, we recommend that end users wait until the resulting datasets and key derivatives are available for use in modeling; whether performed by OBIA, common GIS platforms, or a hybrid method, automated mapping provides a margin of speed and comprehensiveness that directly benefits vernal pools research and conservation.

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References – Chapter 2

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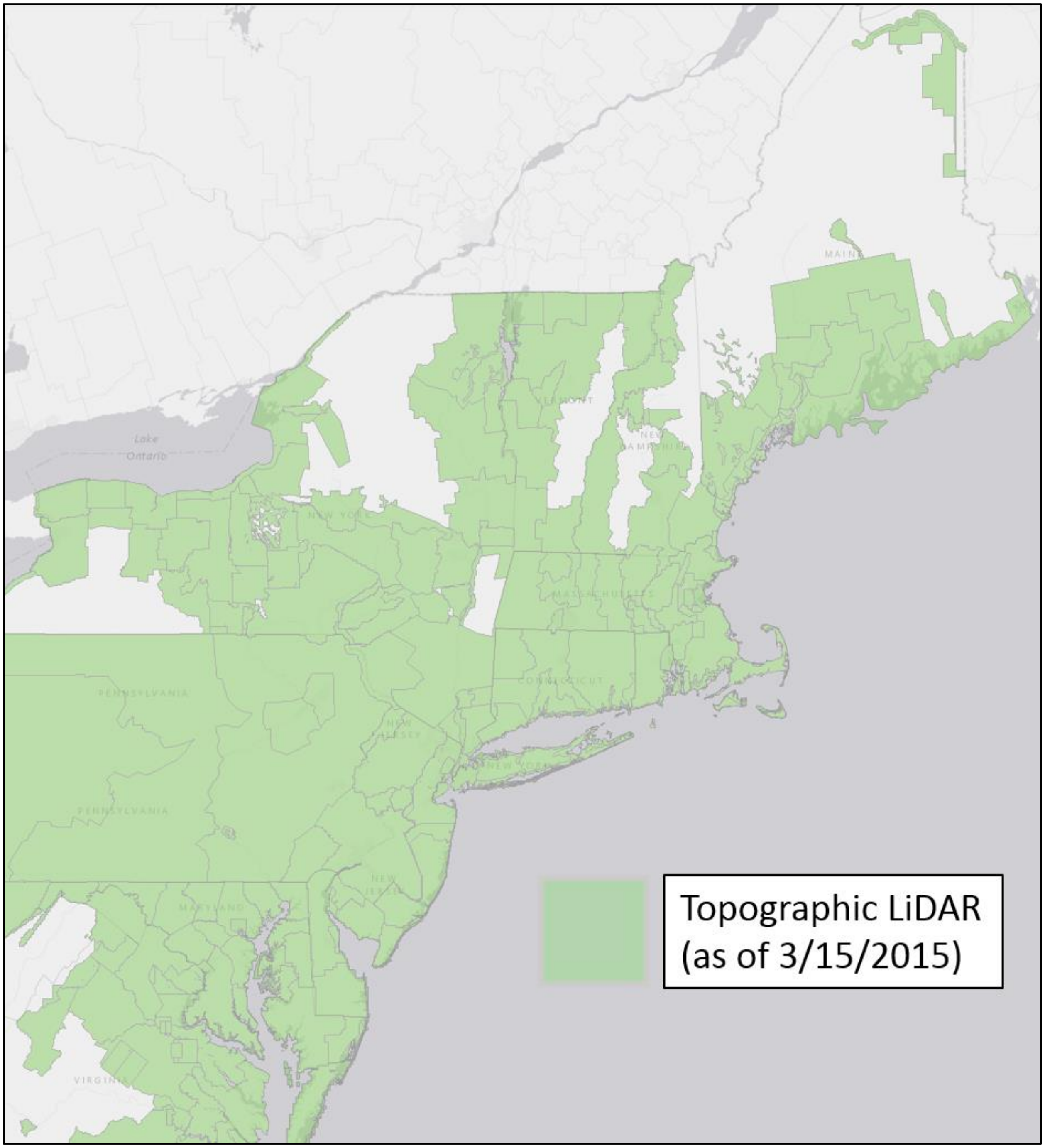
Appendix 2-A. LiDAR availability in eastern U.S. states, as compiled by the United States Interagency Elevation Inventory. The acquisition, resolution, collection parameters, and quality of individual LiDAR datasets can be interactively queried at this organization's website (**https://coast.noaa.gov/inventory/**).



Appendix 2-B. LiDAR availability in eastern Canadian provinces, as compiled by the Applied Geomatics Research Group. The acquisition date, resolution, and collection parameters of individual LiDAR datasets can be interactively queried at this organization's website (**http://agrg.cogs.nscc.ca/projects/LiDAR_Metadata/**).