Hudson River Valley Land Cover Map Accuracy Assessment

Final Report

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Table of Contents

EXECUTIVE SUMMARY

A land cover map of the Hudson River Valley (HRV) was produced to form the basis of vertebrate habitat modeling in support of biodiversity conservation in the region. Our objectives for this study were to: (1) assess the accuracy of the HRV land cover map produced at 30m spatial resolution; (2) conduct comparative analyses of HRV land cover maps produced at different taxonomic resolutions; and (3) recommend image processing and accuracy assessment procedures for future resource inventories and spatial modeling programs dedicated to biodiversity conservation.

For assessing the existing land cover map at 30m resolution, each sampled polygon was labeled in the field by a biologist as one of 38 land cover types corresponding to the modified NY-GAP classification scheme. Dominant canopy, sub-canopy, and ground layer vegetation were also recorded in the field to ensure consistency of land cover type interpretations between the field biologist and image analyst. Field data (observed land cover type) and image analysis data (predicted land cover type) were summarized in error matrices with statistics computed using conventional accuracy assessment protocols.

The dominant land cover at the Class/Subclass levels of the NVCS taxonomy is Forest/Woodland (66.6%) which includes coniferous forest types (1.1%), mixed forest and mixed woodland types (15.8%), and deciduous forest types (49.7%). Hemlock-northern hardwood forest is the dominant mixed forest type (8.2%), while oak-sugar maple forest is the dominant deciduous forest type (18%). Herbaceous land, primarily a mixture of old fields and cropland, is the next most common land cover type, encompassing 15.6% of the HRV. The remainder of land cover is mapped as Built Environment (13.1%), Water (2.8%), Shrub (1.6%), and Other (0.3%).

Overall accuracies of land cover types mapped at alliance, super-alliance, and subclass level were 51.6%, 60.1%, and 73.1%, respectively. Data summarized at Super-alliance and Subclass levels were aggregated from data in the Alliance error matrix. The land cover map at Alliance level is the least reliable given the nature and magnitude of classification errors. Land cover maps at Class and Subclass levels are reliable and most appropriate for regional scale analyses and applications. Applications at county-scale are questionable and not recommended. Applications at town- and parcel-scale are inappropriate given the nature of the remotely sensed data and image processing protocols used to create the map. The levels of accuracy obtained in this are similar to other studies using similar taxonomy and spectral data.

For future studies, we recommend using alternative analytical methods which could include the use of multi-temporal imagery, field-based knowledge in the cluster labeling process, and more robust image classification algorithms which exploit bio-physical data and local knowledge related to land cover patterns and processes. Only through collaborative relationships with resource management and assessment organizations, participatory inventory approaches with local communities and stakeholders, and analysis of remotely sensed data of higher spectral, spatial, temporal, and radiometric resolution can we expect to improve the quality and usefulness of such land cover maps.

INTRODUCTION

Background

A land cover map is of critical importance for biodiversity conservation and management because the map is the key element on which most other spatial data layers depend. A carefully assembled land cover map enhances the accuracy of the entire analytical process and improves the reliability and usefulness of both predictions and deductions. Current efforts at mapping natural land cover state-wide in New York requires a significant level of effort similar to the effort required to develop spatial data for animal species distribution, agency ownership patterns, or land management scenarios within the framework established by the National Gap Analysis Program.

A thematic, or choropleth, land cover map classifies landscape features using categories organized in a fixed, hierarchical framework based on local, national or international standards and designed to meet the objectives of map consumers. When the hierarchical framework is extensive and detailed, the map is said to be of high taxonomic resolution where many categories are used to describe landscape features. Creation and assessment of maps with high taxonomic resolution require the integration of field-based observations and various forms of remotely sensed data to characterize land cover conditions over large spatial scales.

Generally, the mapping of land cover is accomplished by developing a land cover classification scheme, delineating land areas of relative homogeneity for each category of the scheme using some form of remotely sensed data, then labeling these areas using the appropriate map unit symbol defined by the classification scheme. More detailed attributes of individual areas are added as more information becomes available, and a process of verifying polygon type, pattern, and label is applied for editing and revising the map. This process is conducted in an iterative fashion with results from one step informing subsequent steps. Finally, an assessment of the accuracy of the entire map and for individual categories is conducted. The final assessment of accuracy indicates where improvements should be made in the next inventory update.

Questions that need to be addressed by map producers include: How well does my map represent reality? How well do my map categories represent landscape features? How do I observe a representative area of my map for each map category to assess its quality? Do my observations adequately characterize the quality of my map? What are the nature, magnitude, frequency, and significance of errors associated with my map?

A land cover map of the Hudson River Valley (HRV), as defined by the Hudson River Estuary Program (HREP), was produced to form the basis of vertebrate habitat modeling in support of biodiversity conservation in the region. The map was created by extracting that portion of the HRV from the statewide land cover map originally produced by the New York Gap Analysis Project (NY-GAP) and performing separate statistical analysis and region-specific modeling (Smith et al. 2001).

Though this original map was produced at high spatial resolution (30m square pixels), map polygons of land cover were aggregated to a four-hectare (10-acre) minimum mapping unit to facilitate subsequent analyses and to comply with national Gap Analysis Program (GAP) specifications. Map accuracy for the four-hectare HRV land cover map was based on a subset of accuracy assessment plots used to evaluate the state-wide land cover map (Smith et al. 2001).

There was a need to assess the accuracy of the HRV land cover map we produced at high spatial resolution (30m) using a higher density of sampling observations than what we used for assessing the accuracy of the four-hectare HRV land cover map. Accuracy assessment provides a measure of overall reliability of a land cover map and identifies which land cover categories and regions of the map do not meet inventory objectives or accuracy goals.

Major challenges in this study were to: (1) develop an alternative sampling design for the 30m resolution HRV land cover map, (2) test the effectiveness of the design at assessing map accuracy at a regional scale, and (3) collect the requisite data to construct conventional error matrices to quantify the error associated with mapping individual land cover types.

By conducting this accuracy assessment, a more trustworthy land cover map and spatial database will be available for use in biological conservation programs in the HRV area, and we will gain a greater understanding of the advantages and limitations of using Landsat Thematic Mapper satellite data for future land cover inventories and habitat mapping projects in the region.

Objectives

Our objectives for this study were to: (1) assess the accuracy of the HRV land cover map produced at 30m spatial resolution using an alternative sampling design than that used for the four-hectare HRV land cover map; (2) conduct comparative analyses of HRV land cover maps produced at different spatial and taxonomic resolutions; and (3) recommend image processing and accuracy assessment procedures for future resource inventories and spatial modeling programs dedicated to biodiversity conservation.

Based on the anticipated outcomes of this study, we determined the degree of improvement in image processing and accuracy assessment methods used in the HRV land cover maps at both four-hectare and 30m spatial resolutions. We also plan to make recommendations on optimum image acquisition dates, image processing methods, and map accuracy assessment approaches for future resource inventories in the HRV.

METHODS AND MATERIALS

Study Area Description

The HRV study area is defined as the entire area of the 15 counties bordering the Hudson River from the Troy Dam south to the Verrazano Narrows, including the five boroughs of New York City (New York, Bronx, Queens, Kings, and Richmond). This biologically rich, but densely populated corridor encompasses an area of approximately 16,950 km^2, or 13.5% of the state of New York. According to NY-GAP, the dominant land cover types in the Hudson Valley are sugar maple-dominant and oak-dominant forests representing 31.7% and 29.5% of the total study area, respectively. Some of these land cover types are found predominantly or even exclusively in the HRV (Smith et al. 2001).

Land Cover Classification Scheme

The classification scheme used for this project was based on the classification scheme developed by the New York State Gap Analysis Project (NY-GAP). The NY-GAP classification is based on land cover types that include alliance and super-alliance level classifications of vegetated communities, as well as more generalized classes for water, built environments, and spectral obstructions (Table 1). Alliances are physiognomically distinct groups of plant associations that share dominant species. The classification scheme is consistent with a modified National Vegetation Classification System (NVCS) hierarchy (Grossman et al. 1998) and can be cross-referenced with Reschke (1990) community types. The NVCS is subject to peer review and periodic revision by a committee of the Ecological Society of America.

Due to the nature of spectral data, however, some alliances were combined or modified to form "super-alliances." As used in NY-GAP, a super-alliance is a combination of alliances with dominant species that either belong to the same genus or occur under similar environmental conditions. The final land cover map for the HRV consisted of 38 land cover types derived from the NY-GAP classification scheme (Smith et al. 2000).

Starting with the NY-GAP classification scheme, we added or subtracted land cover type classes because some classes in the statewide scheme were not found in the HRV, some unique HRV cover types were not represented in the statewide scheme (e.g. spruce-fir swamp), and cover types that were spectrally indistinguishable based on prior image processing experience were aggregated (e.g. all conifer plantation types aggregated to evergreen plantation).

Map Development

Three Landsat-5 TM multi-spectral digital images (p14r30, p14r31, p13r32) were provided to NY-GAP project team by the Multi-Resolution Land Characteristics Interagency Consortium (MRLC). The date of imagery for path 14 (rows 30 and 31) was 9 May 1993, and the date of imagery for path 13 (row 32) was 13 April 1992 (Figure 1). The images were acquired as radiometrically and geometrically corrected data from the EROS Data Center. All images were virtually cloud-free.

Prior to image classification, the images were geo-referenced to the Universal Transverse Mercator (UTM) coordinate system and projection, North American Datum of 1983 (NAD83), Zone 18, and using a 30-meter square pixel based on a cubic convolution image re-sampling procedure. The average root-mean-squared error ($RMSE_{x,y}$) between the digital TM data and ground control points (GCP) was less than 1 pixel.

For each scene, spectral data from the visible, near-infrared, and short-wave infrared spectral bands (Bands 1-5, 7) were subjected to an unsupervised, multi-spectral data clustering procedure at the USGS-EROS Data Center using the Spectrum image classification program. This image classification approach generated a 240-cluster product.

Each scene was then stratified by the 15 minor ecozones that occur within the HRV study area, as defined by the NYSDEC ecozone map (Davis 1977, Dickinson 1979, Dickinson 1983, Will et al. 1982). Ecozones are defined as areas that share similar physiographic characteristics, such as geologic history, surficial geology, topography, soils, climate, vegetation, and land use.

Spectral clusters were labeled as one of 38 land cover types using training data derived from field sampling, aerial photo interpretation, New York Natural Heritage Program (NHP) element occurrence records, New York DEC wetland inventories, and additional spatial data representing hydrologic networks, urban areas, and transportation corridors. Spectral clusters were labeled independently within minor ecozones (or, strata) in an attempt to minimize errors due to spectral confusion. Spectral confusion results from different land cover types having similar spectral responses or, conversely, the same land cover type occurring in different locations of a study area having different spectral responses. This stratified labeling process not only eliminated some errors, but also proved essential for mapping rare land cover types that are only found in specific locations within the study area but tend to be spectrally confused with land cover types in other strata.

Prior to commencing this study, image analysts re-evaluated the quality of the HRV 240-cluster products for P14r30 and p14r31 images to gain a greater understanding of the multi-spectral response of, and spectral confusion among, land cover types. These two images were clipped to the HRV study area boundary and then subsets, based on minor ecozones, were created for additional field verification. Approximately 35 mixed and deciduous forest sites were located in areas that were difficult to map (e.g. urban areas, wetlands, Catskill Mountains). Some cluster labels were modified based on more intensive field survey and for those clusters of land cover types that were spectrally confused and found to be incorrectly labeled as part of the original NY-GAP project.

After independently labeling clusters by ecozone, all minor ecozones within the three Landsat scenes were merged. The final output land cover grid was edited to ensure a smooth transition between scenes, and map corrections were made using ancillary data to help map rare types that could not be identified using spectral data alone.

Accuracy Assessment

Map accuracy for the original HRV-GAP land cover map, where a four-hectare minimum mapping unit was used, was based on fifteen 1,600-ha plots whose locations corresponded to the starting points of 15 Breeding Bird Survey (BBS) routes in the study area. These BBS routes were randomly and spatially well-distributed throughout the HRV and located on publicly accessible transportation routes (Figure 2).

A higher density of sampling observations, however, was necessary to assess the accuracy of a land cover map at the higher 30m spatial resolution. An alternative sampling design was developed for this project and new field data were collected to construct conventional error matrices to quantify the errors associated with individual land cover types.

The final 30-m resolution land cover map was divided into individual grid-based maps for each land cover type and each grid map was converted into vector format. For each land cover type, a query was performed to select only those polygons greater than 1.44 ha (4 pixels x 4 pixels) and those that were within 30m of a transportation route. We assumed that only these polygons would be readily accessible to field crews, in addition to those which were sampled on public lands in the region.

Our goal was to select 50 polygons randomly per land cover type for field-based accuracy assessment procedure. A total of 970 polygons were selected and merged, and labeled using a unique numeric code. The polygons were unlabeled with respect to the predicted land cover type so as not to bias field observations.

Field data were collected by a field biologist during the summer and fall of 2002 for as many land cover type polygons that project resources would allow. Where possible, the field biologist recorded a GPS-based map coordinate within the polygon and characterized the land cover type at that point. Most polygons were observed from the road, however, due to private land access constraints. Some sample polygons occurred on public lands which facilitated access.

Ignoring the land cover conditions proximal to transportation routes, the field biologist, with the use of binoculars, a GPS unit, and the appropriate digital orthophoto quarter-quadrangles (DOQQ) for the site, created a sketch of the vegetative composition of the polygon. Using this information, the appropriate land cover type label was assigned to the unlabeled, sampled polygon corresponding to the dominate land area occupied by that land cover type within the polygon.

Using detailed land cover type descriptions, the field biologist labeled each polygon as one of the 38 land cover types corresponding to the modified NY-GAP classification scheme. The dominant canopy, sub-canopy, and ground layer vegetation types were also recorded in the field to ensure consistency of land cover type interpretations between the field biologist and image analyst. Field data (observed land cover type) and image analysis data (predicted land cover type) were summarized in error matrices with statistics computed using conventional accuracy assessment protocols (Congalton and Green 1999; Story and Congalton 1986).

Field data were checked for locational errors by plotting the field-recorded GPS coordinates on the appropriate digital orthophoto quarterquadrangle (DOQQ) and assessing the degree to which the field observation was made in or in close proximity to the land cover type polygon selected for sampling. In addition, the land cover type label affixed to each selected polygon was assessed for accuracy and logical placement within the modified NVCS hierarchy. Obvious errors in location and land cover type labeling were corrected in the laboratory once the data were returned to the project office.

Table 1. Classification scheme for 38 land cover types based on a modified NVCS hierarchy for the HRV study area.

Class	*Subclass* [n=9]	Group	Subgroup	Formation	*Super-Alliance* [n=22]	*Land Cover Types (Alliances)* [n=38]
Forest/Woodland	*Evergreen F/W*	Temp n-lvd	Nat/Sn	Upland	*Spruce-fir forest*	*Mountain spruce-fir forest*
				Wetland	*Evergreen wetland*	Evergreen wetland
						Spruce-fir swamp
						Black spruce-tamarack bog
			Cultiv	Plantation	*Evergreen plantation*	*Evergreen plantation*
	Mixed F/W	Evgr/decid	Nat/Sn	Upland	*Appalachian oak-pine forest*	*Appalachian oak-pine forest*
					Pitch pine-oak woodland	*Pitch pine-oak-heath rocky summit*
						Pitch pine-scrub oak barrens
					Evergreen-northern hardwood forest	*Pine-northern hardwood forest*
						Hemlock-northern hardwood forest
						Spruce-northern hardwood forest
						Red cedar rocky summit
					Mixed woodland	*Successional red cedar woodland*
				Wetland	*Mixed wetland*	Mixed wetland
						Atlantic white cedar swamp
						Red maple-tamarack swamp
	Deciduous F/W	Cold decid	Nat/Sn	Upland	*Oak forest*	*Oak forest*
						Oak-hickory forest
						Chestnut oak forest
						Oak-tulip tree forest
						Oak-sugar maple forest
					Sugar maple-mesic forest	*Sugar maple-mesic forest*
					Successional hardwood forest	*Successional hardwood forest*
				Wetland	*Deciduous wetland*	*Red maple-hardwood swamp*
						Floodplain forest
						Silver maple-ash swamp
Shrub	*Mixed Shrub*	Evgr/decid	Nat/Sn	Wetland	*Dwarf shrub bog*	*Dwarf shrub bog*
	Deciduous Shrub	Cold decid	Nat/Sn	Upland	*Successional shrub*	*Successional shrubland*
				Wetland	*Shrub swamp*	*Shrub swamp*
					Highbush blueberry bog	Highbush blueberry bog
Herbaceous	*Herb. Perennial*		Nat/Sn	Upland	*Old field/pasture*	*Old field/pasture*
			Nat/Sn	Wetland	*Emergent marsh/open fen/bog*	*Emergent marsh/open fen/bog*
	Herb. Annual		Cultiv	Agriculture	*Cropland*	*Row and field crops*
						Muck agriculture
Water	*Water*				*Water*	*Water*
Built Environment	*Built Environment*		Cultiv	Urban	*Urban*	*Urban*
					Suburban	*Suburban*
Spectral Obstructions						Spectral Obstructions

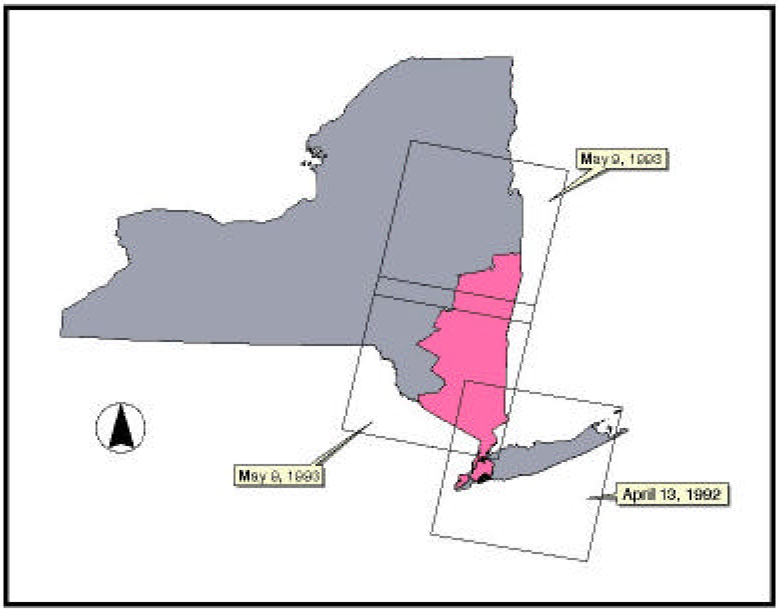

Figure 1. Landsat Thematic Mapper scene coverage for mapping land cover in the Hudson River Valley (HRV), New York.

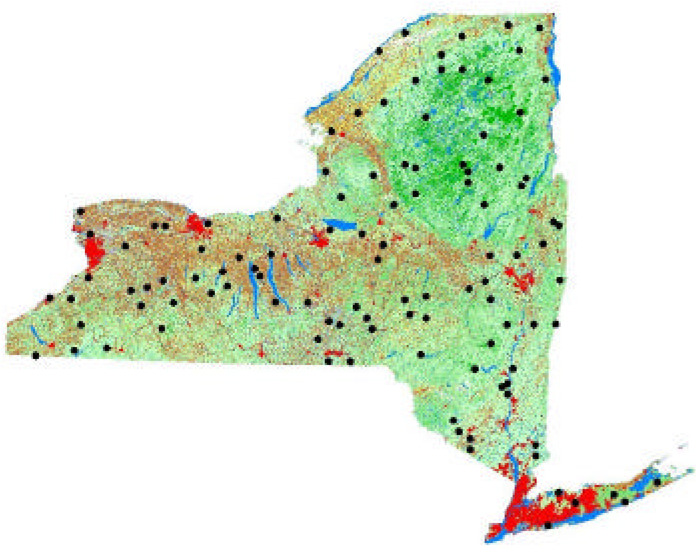

Figure 2. Location of 1600-ha accuracy assessment plots used for statewide NY-GAP project. A subset of plots occurring in the Hudson River Valley were used to assess the accuracy of the HRV-GAP land cover map (4-ha minimum mapping unit).

RESULTS AND DISCUSSION

Hudson River Valley Land Cover Map

Thirty-eight land cover types (Alliances), including spectral obstructions classified as "Other," were mapped at 30-meter spatial resolution (Figure 3). This map was aggregated taxonomically to yield a generalized land cover map at Subclass level having nine categories (Figure 4). Area and proportional extent of each land cover type (at Class, Subclass, and Alliance level) are summarized in Table 2. As expected, the dominant land cover at the Class/Subclass levels of the NVCS taxonomy is Forest/Woodland (66.6%), which includes coniferous forest types (1.1%), mixed forest and mixed woodland types (15.8%), and deciduous forest types (49.7%). Hemlock-northern hardwood forest is the dominant mixed forest type (8.2%), while oak-sugar maple forest is the dominant deciduous forest type (18%). Herbaceous land, primarily a mixture of old fields and cropland, is the next most common land cover type, encompassing 15.6% of the HRV. The remainder of land cover is mapped as Built Environment (13.1%), Water (2.8%), Shrub (1.6%), and Other (0.3%).

The absence of comparable studies in the HRV region prevents a quantitative assessment with respect to the diversity, proportional extent, and spatial pattern of land cover types as mapped in this study. A similar region-wide inventory (New York-New Jersey Region of USEPA), conducted by the Multi-Resolution Land Characteristics (MRLC) Consortium as part of a national land cover mapping program, predicted similar proportions of land cover types for New York State as did NY-GAP. We did not isolate the HRV region in the National Land Cover Data (NLCD) product to compare regional estimates of land cover type estimates as was done state-wide for the NY-GAP project (Smith et al. 2000). The differences in taxonomy at a similar level of taxonomic resolution prevent any meaningful comparison between the two land cover type inventories, except at a high level of the HRV land cover type taxonomy (Table 3)

In the state-level comparison, estimates at the Class and Subclass level land cover types are remarkably similar between NY-GAP and MRLC, respectively: Evergreen Forest (4% v. 6%), Deciduous Forest (40% v. 39%), Mixed Forest (17% v. 18%), Wetland (4% v. 3%), Herbaceous (24% v. 26%), and Built Environments (4% v. 5%). Other major classes included Shrub (1% v. n/a), Barren (0.2% v. 0.1%), Water (5% v. 3%), and Other (0.3% v. n/a). Major land cover types important to environmental management in the HRV included in the HRV-GAP map (at 30m resolution) were not included in the MRLC map so no valid comparison between the two inventories can be conducted. The MRLC did not map shrub communities nor was an "other" category included in their classification system for those land cover conditions that could not be characterized and mapped using more specific categories.

Accuracy Assessment

A total of 676 validation points representing polygons of predicted land cover types were collected by field biologists for assessing the accuracy of the land cover type map at 30m spatial resolution (Figure 5). These observations were used to create conventional error matrices at Alliance (31-class), Super-alliance (22 class), and Subclass (9-class) levels of classification. Of the 676 validation points, 564 were collected as part of this study and 112 were collected as part of a graduate student's thesis project (Braden 2002).

Due to access and time constraints, only 31 of 38 land cover types could be sampled in the field. In addition, the goal of sampling 50 polygons per land cover type was not achieved. The seven types not sampled included Evergreen wetland, Spruce-fir swamp, Black spruce-tamarack bog, Red cedar rocky summit, Mixed wetland, Highbush blueberry bog, and Spectral obstructions, all shown in non-italicized, yellow-highlighted font in Table 1.

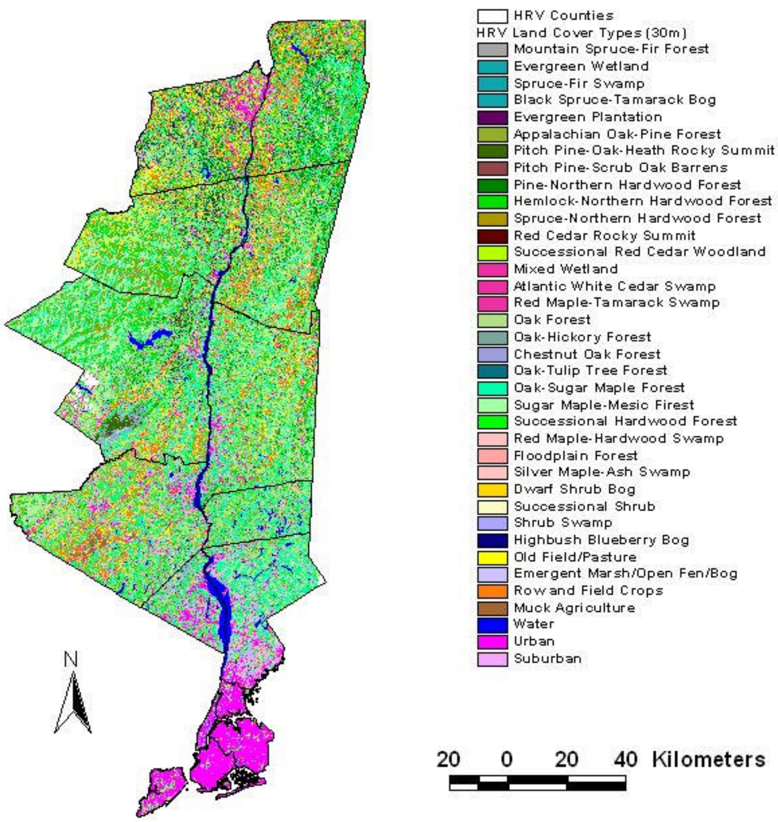

Figure 3. Thirty-eight land cover types of the HRV study area at Alliance level ("Other" not shown).

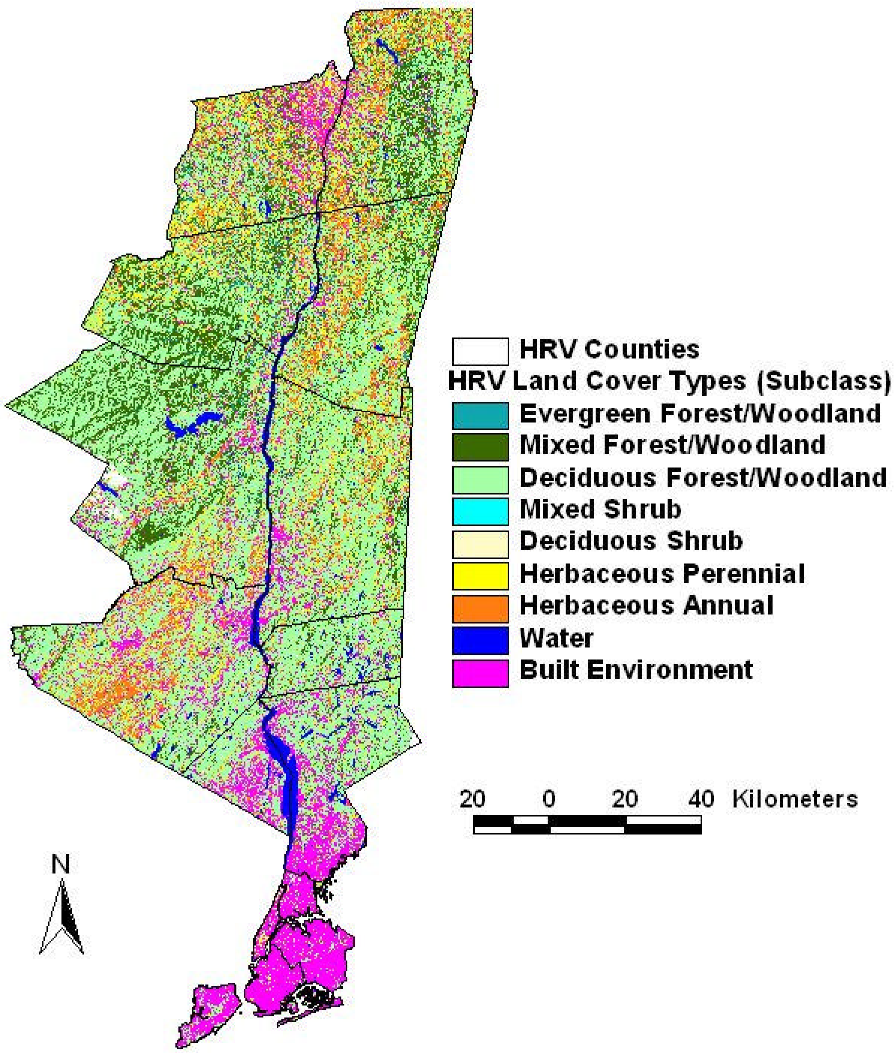

Figure 4. Nine land cover types for the HRV study area at Subclass level.

Table 2. Area (ha) and proportional extent (%) of land cover types in HRV study area at Class (bold font), Subclass (bold, italics font), and Alliance levels of classification.

Land Cover	Area, ha	%
Forest/Woodland	**1128667**	**66.6**
Evergreen Forest/Woodland	***18208***	***1.1***
Mountain spruce-fir forest	878	0.052
Evergreen wetland*	7	0.000
Spruce-fir swamp*	12	0.001
Black spruce-tamarack bog*	2	0.000
Evergreen plantation	17307	1.021
Mixed Forest/Woodland	***267811***	***15.8***
Appalachian oak-pine forest	14404	0.850
Pitch pine-oak-heath rocky summit	5253	0.310
Pitch pine-scrub oak barrens	126	0.007
Pine-northern hardwood forest	84636	4.994
Hemlock-northern hardwood forest	138926	8.197
Spruce-northern hardwood forest	24056	1.419
Red cedar rocky summit*	10	0.001
Successional red cedar woodland	105	0.006
Mixed wetland*	176	0.010
Atlantic white cedar swamp	80	0.005
Red maple-tamarack swamp	41	0.002
Deciduous Forest/Woodland	***842648***	***49.7***
Oak forest	237504	14.014
Oak-hickory forest	368	0.022
Chestnut oak forest	11775	0.695
Oak-tultip tree forest	2569	0.152
Oak-sugar maple forest	302751	17.864
Sugar maple-mesic forest	181411	10.704
Successional hardwood forest	89735	5.295
Red maple-hardwood swamp	16338	0.964
Floodplain forest	193	0.011
Silver maple-ash swamp	4	0.000
Shrub	**27682**	**1.6**
Mixed Shrub	***165***	***0.0***
Dwarf shrub bog	165	0.010
Deciduous Shrub	***27517***	***1.6***
Successional shrubland	15720	0.928
Shrub swamp	11757	0.694
Highbush blueberry bog*	40	0.002
Herbaceous	**264659**	**15.6**
Herbaceous Perennial	***116107***	***6.9***
Old field/pasture	109455	6.458
Emergent marsh/open fen/bog	6653	0.393
Herbaceous Annual	***148552***	***8.8***
Row and field crops	145391	8.579
Muck agriculture	3161	0.187
Water	**48157**	**2.8**
Built Environment	**221234**	**13.1**
Urban	136533	8.056
Suburban	84702	4.998
Spectral Obstructions*	**4368**	**0.3**
Total	**1694768**	**100.000**
*not sampled during accuracy assessment		

Table 3. Comparison of land cover types between HRV Accuracy Assessment (AA) and NLCD92 projects at similar levels of taxonomic resolution.

Type #	HRV AA (Super-Alliance)	Type #	NLCD 92
1	Spruce-fir forest	1.1	Open Water
2	Evergreen wetland	1.2	Perennial Ice/Snow
3	Evergreen plantation	2.1	Low Intensity Residential
4	Appalachian oak-pine forest	2.2	High Intensity Residential
5	Pitch pine-oak woodland	2.3	Commercial/Industrial/Transportation
6	Evergreen-n. hardwood forest	3.1	Bare Rock/Sand/Clay
7	Mixed woodland	3.2	Quarries/Strip Mines/Gravel Pits
8	Mixed wetland	3.3	Transitional
9	Oak forest	4.1	Deciduous Forest
10	Sugar maple-mesic forest	4.2	Evergreen Forest
11	Successional hardwood forest	4.3	Mixed Forest
12	Deciduous wetland	5.1	Shrubland
13	Dwarf shrub bog	6.1	Orchards/Vineyards/Other
14	Successional shrub	7.1	Grasslands/Herbaceous
15	Shrub swamp	8.1	Pasture/Hay
16	Highbush blueberry bog	8.2	Row Crops
17	Old field/pasture	8.3	Small Grains
18	Emergent marsh/open fen/bog	8.4	Fallow
19	Cropland	8.5	Urban/Recreational Grasses
20	Water	9.1	Wooded Wetlands
21	Urban	9.2	Emergent Herbaceous Wetlands
22	Suburban	n/a	

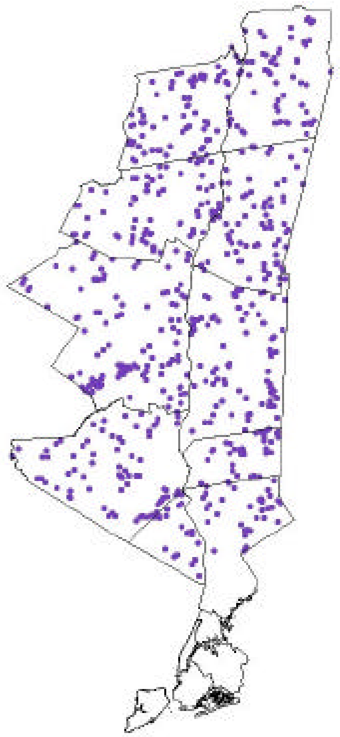

Figure 5. Location and distribution of 564 field sampling plots in HRV, augmented by 112 plots from Braden (2002).

We did not estimate the proportion of polygons that could not be sampled due to access constraints. Public lands were used whenever possible, but both public and private lands need to be included in the sample allocation procedure to ensure all land cover types can be sampled and to achieve a reasonably even distribution of sample plots throughout the study area. The number of observations we were able to achieve in this study for all land cover types was inadequate. Future accuracy assessment studies will need to ensure sufficient resources are available and sample sites accessible on both public and private lands to achieve a sufficiently larger sample size per land cover type.

An error matrix is a common and effective way to represent thematic map accuracy. The error matrix can also be used to compute useful accuracy statistics such as overall accuracy and user's accuracy, and producer's accuracy. Overall accuracies were computed by taking the sum of the correctly classified pixels (the major diagonal) and dividing this sum by the total sample size (n=676).

Overall accuracies of land cover types mapped at alliance, super-alliance, and subclass level were 51.6%, 60.1%, and 73.1%, respectively (Tables 4, 5, and 6, respectively). Data summarized at Super-alliance (Table 5) and Subclass (Table 6) levels were aggregated from data in the Alliance error matrix (Table 4). Data were not available for seven relatively rare land cover types:

Table 4. Error matrix for the HRV land cover map at Alliance level.

Predicted Data

Alliance		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total	User's
Mountain spruce-fir forest	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0.0
Evergreen plantation	2	0	23	0	0	0	4	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29	79.3
Appalachian oak-pine forest	3	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	5	20.0
Pitch pine-oak-heath rocky summit	4	0	1	1	10	0	0	4	0	0	0	0	0	0	3	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	21	47.6
Pitch pine-scrub oak barrens	5	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	100.0
Pine-n. hardwood forest	6	0	0	0	0	0	14	8	1	0	0	0	1	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	30	46.7
Hemlock-n. hardwood forest	7	0	0	1	0	0	4	22	0	1	0	0	2	0	0	0	2	3	6	2	0	0	0	0	0	0	0	0	0	0	0	0	43	51.2
Spruce-n. hardwood forest	8	0	0	0	0	0	1	6	2	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	16.7
Successional red cedar woodland	9	0	1	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	5	60.0
Atlantic white cedar swamp	10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	100.0
Red maple-tamarack swamp	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0.0
Oak forest	12	0	0	1	0	0	0	0	0	0	0	0	18	2	2	0	5	2	15	2	0	0	0	0	0	0	0	0	0	0	0	1	48	37.5
Oak-hickory forest	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0.0
Chestnut oak forest	14	0	0	0	1	0	0	0	0	0	0	0	4	0	9	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	56.3
Oak-tulip tree forest	15	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	50.0
Oak-sugar maple forest	16	0	0	0	0	0	0	0	0	0	0	0	12	0	4	3	22	12	8	0	0	0	0	0	0	0	0	0	0	0	0	0	61	36.1
Sugar maple-mesic forest	17	0	0	0	0	0	0	0	0	0	0	0	4	4	1	0	2	18	10	0	0	0	0	1	1	2	0	0	0	0	0	0	43	41.9
Successional hardwood forest	18	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	3	3	9	0	0	0	0	0	0	12	0	2	0	0	0	2	34	26.5
Red maple-hardwood swamp	19	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	13	2	0	0	1	1	1	8	0	0	3	1	0	32	40.6
Floodplain forest	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0	0	0	0	5	80.0
Silver maple-ash swamp	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	100.0
Dwarf shrub bog	22	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.0
Successional shrub	23	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	4	1	11	0	3	0	0	0	1	22	18.2
Shrub swamp	24	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	2	1	0	0	0	0	4	0	8	2	1	1	0	0	20	20.0
Old field/pasture	25	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	4	0	0	0	0	0	0	47	0	5	0	0	0	1	60	78.3
Emergent marsh/open fen/bog	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	11	0	0	7	6	0	25	44.0
Row and field crops	27	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	22	0	18	0	0	1	0	43	41.9
Muck agriculture	28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	6	100.0
Water	29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26	0	0	26	100.0
Urban	30	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	4	3	0	0	0	26	7	42	61.9
Suburban	31	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	32	34	94.1
Total		0	26	4	11	4	24	42	3	6	1	0	50	6	21	4	37	47	63	21	7	1	0	6	7	100	31	30	7	37	36	44	676	
Producer's Accuracy		0.0	88.5	25.0	90.9	100.0	58.3	52.4	66.7	50.0	100.0	0.0	36.0	0.0	42.9	25.0	59.5	38.3	14.3	61.9	57.1	100.0	0.0	66.7	57.1	47.0	35.5	60.0	85.7	70.3	72.2	72.7		

Overall Accuracy = 51.6%

Table 5. Error matrix the HRV land cover map at Super-alliance level.

			Observed Data																						
	Super-alliance		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**Total**	**User's**
Predicted Data	Spruce-fir forest	**1**	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	3	**0.0**
	Evergreen wetland	**2**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**n/a**
	Evergreen plantation	**3**	0	0	23	0	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29	**79.3**
	Appalachian oak-pine forest	**4**	0	0	1	1	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	0	0	5	**20.0**
	Pitch pine-oak woodland	**5**	0	0	1	1	14	4	0	0	4	0	0	0	0	0	0	0	0	1	0	0	0	0	25	**56.0**
	Evergreen-n. hardwood forest	**6**	0	0	0	1	0	58	1	0	5	6	12	2	0	0	0	0	0	0	0	0	0	0	85	**68.2**
	Mixed woodland	**7**	0	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	5	**60.0**
	Mixed wetland	**8**	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	**50.0**
	Oak forest	**9**	0	0	0	1	1	0	0	0	84	15	23	2	0	0	0	0	1	0	0	0	0	1	128	**65.6**
	Sugar maple-mesic forest	**10**	0	0	0	0	0	0	0	0	11	18	10	0	0	1	1	0	2	0	0	0	0	0	43	**41.9**
	Successional hardwood forest	**11**	0	0	0	0	0	0	0	0	6	3	9	0	0	0	0	0	12	0	2	0	0	2	34	**26.5**
	Deciduous wetland	**12**	0	0	0	0	0	0	0	0	1	0	1	21	0	1	1	0	1	8	0	3	1	0	38	**55.3**
	Dwarf shrub bog	**13**	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**0.0**
	Successional shrub	**14**	0	0	0	0	0	0	0	0	1	0	1	0	0	4	1	0	11	0	3	0	0	1	22	**18.2**
	Shrub swamp	**15**	0	0	0	0	0	0	1	0	0	0	2	1	0	0	4	0	0	8	3	1	0	0	20	**20.0**
	Highbush blueberry bog	**16**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**n/a**
	Old field/pasture	**17**	0	0	0	0	0	0	0	0	2	1	4	0	0	0	0	0	47	0	5	0	0	1	60	**78.3**
	Emergent marsh/open fen/bog	**18**	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	11	0	7	6	0	25	**44.0**
	Cropland	**19**	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	22	0	24	0	1	0	49	**49.0**
	Water	**20**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26	0	0	26	**100.0**
	Urban	**21**	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	4	3	0	0	26	7	42	**61.9**
	Suburban	**22**	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	32	34	**94.1**
	Total		0	0	26	4	15	69	6	1	118	47	63	29	0	6	7	0	100	31	37	37	36	44	**676**	
	Producer's Accuracy		**0.0**	**n/a**	**88.5**	**25.0**	**93.3**	**84.1**	**50.0**	**100.0**	**71.2**	**38.3**	**14.3**	**72.4**	**0.0**	**66.7**	**57.1**	**n/a**	**47.0**	**35.5**	**64.9**	**70.3**	**72.2**	**72.7**		

Overall Accuracy = 60.1%

Table 6. Accuracy assessment for the HRV land cover map at Subclass level.

	Observed Data												
	Subclass		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Total**	**User's**
Predicted Data	Evergreen Forest/Woodland	**1**	**23**	7	2	0	0	0	0	0	0	32	**71.9**
	Mixed Forest/Woodland	**2**	3	**84**	33	0	0	1	0	0	1	122	**68.9**
	Deciduous Forest/Woodland	**3**	0	2	**204**	0	4	24	2	3	4	243	**84.0**
	Mixed Shrub	**4**	0	0	1	**0**	0	0	0	0	0	1	**0.0**
	Deciduous Shrub	**5**	0	1	5	0	**9**	19	6	1	1	42	**21.4**
	Herbaceous Perennial	**6**	0	0	8	0	0	**58**	5	7	7	85	**68.2**
	Herbaceous Annual	**7**	0	0	2	0	0	22	**24**	0	1	49	**49.0**
	Water	**8**	0	0	0	0	0	0	0	**26**	0	26	**100.0**
	Built Environment	**9**	0	1	2	0	0	7	0	0	**66**	76	**86.8**
	Total		26	95	257	0	13	131	37	37	80	**676**	
	Producer's Accuracy		**88.5**	**88.4**	**79.4**	**0.0**	**69.2**	**44.3**	**64.9**	**70.3**	**82.5**		

Overall Accuracy = 73.1%

Evergreen wetland, Spruce-fir swamp, Black spruce-tamarack bog, Mixed wetland, Red cedar rocky summit, and Highbush blueberry bog. Spectral obstructions, primarily cloud and cloud shadows, could not be sampled due to the ephemeral nature of this category. Therefore, these seven types are not included in the error matrix at the Alliance level of classification (Table 4) nor included in the error matrix at the Super-alliance level for Evergreen wetland or Highbush blueberry bog types (Table 5) which occur at the Super-alliance as well as the Alliance level of classification.

The overall accuracies achieved in this accuracy assessment are similar to other assessments at each level of taxonomic resolution or their equivalents at Subclass, Super-alliance, Alliance, Gap Type levels of classification (Braden 2002; Laba et al. 2002; Yang et al. 2001; Zhu et al. 2000). Using a detailed land cover type classification scheme results in more errors associated with spectral confusion; mixed pixels (multiple land cover types occurring within the ground surface area represented by a single pixel); image analyst and field observer errors; and lack of temporal agreement between phenological growth stages of vegetation or surface energy balance, multi-spectral response, image acquisition periods, and field observations.

Producer's and user's accuracy statistics are used to describe individual class accuracies. Producer's accuracy, an indication of how well the map maker represented land cover types, is calculated by dividing the total number of correct sample points within a column (observed land cover types) by the total number of sample points for that land cover type. User's accuracy, an indication of how likely a map user is to encounter the correctly mapped land cover type in the field, is calculated by dividing the total number of correct sample points within a row (predicted land cover type) by the total number of sample points within that row (Story and Congalton 1986). Producer's and user's accuracies for land cover types at alliance level are presented in Table 7.

Two major limitations to this study included (1) difficulty in mapping selected land cover types, primarily grassland and shrubland types, and (2) limited sample size to assess adequately the accuracy of land cover maps produced at variable spatial and taxonomic resolutions and for land cover types that occur over limited spatial extents throughout the study area. Visual examination of the resulting maps indicates close association of particular land cover types where they are likely to occur on the landscape. Prediction errors are logical for many extensive land cover types which are similar in nature (e.g. pine-oak v. evergreen-n. hardwood, oak v. successional hardwood v. sugar maple-mesic, and old field/pasture v. cropland). Illogical errors, in many cases resulting from spectral confusion primarily caused by image acquisition dates (leaf off) and interpreter error, occurred between old field/pasture v. successional hardwood v. successional shrub.

Table 7. Producer's and user's accuracies by land cover type.

#	Land Cover Types (Alliances)	Producer's	User's
1	Mountain spruce-fir forest	0.0	0.0
2	Evergreen plantation	88.5	79.3
3	Appalachian oak-pine forest	25.0	20.0
4	Pitch pine-oak-heath rocky summit	90.9	47.6
5	Pitch pine-scrub oak barrens	100.0	100.0
6	Pine-northern hardwood forest	58.3	46.7
7	Hemlock-northern hardwood forest	52.4	51.2
8	Spruce-northern hardwood forest	66.7	16.7
9	Successional red cedar woodland	50.0	60.0
10	Atlantic white cedar swamp	100.0	100.0
11	Red maple-tamarack swamp	0.0	0.0
12	Oak forest	36.0	37.5
13	Oak-hickory forest	0.0	0.0
14	Chestnut oak forest	42.9	56.3
15	Oak-tulip tree forest	25.0	50.0
16	Oak-sugar maple forest	59.5	36.1
17	Sugar maple-mesic forest	38.3	41.9
18	Successional hardwood forest	14.3	26.5
19	Red maple-hardwood swamp	61.9	40.6
20	Floodplain forest	57.1	80.0
21	Silver maple-ash swamp	100.0	100.0
22	Dwarf shrub bog	0.0	0.0
23	Successional shrub	66.7	18.2
24	Shrub swamp	57.1	20.0
25	Old field/pasture	47.0	78.3
26	Emergent marsh/open fen/bog	35.5	44.0
27	Row and field crops	60.0	41.9
28	Muck agriculture	85.7	100.0
29	Water	70.3	100.0
30	Urban	72.2	61.9
31	Suburban	72.7	94.1

Difficulty in locating and correctly identifying accuracy assessment polygons calls for more extensive efforts at making field observations, using exiting field plot data of collaborating organizations, and using local field biologists skilled at navigation and plant community identification both in the field and with geo-referenced spatial databases, global positioning system, and digital orthophotographs.

With respect to the MRLC land cover map for the region, similar accuracies were obtained for similar land cover types (Table 8) at similar levels of taxonomic resolution (Laba et al. 2002; Yang et al. 2001; Zhu et al. 2000). Difficulties and inconsistencies in accurately mapping several major land cover types in both NY-GAP and MRLC (e.g. Herbaceous perennial, Herbaceous annual) have inhibited robust analysis of regional land cover change and the impact of that change on wildlife habitat evaluation, management, and planning, especially for grassland associated species (Thogmartin et al. 2004). Though quantitative comparisons between the two inventories are limited, the HRV land cover type inventory at 30m spatial resolution can form the baseline against which future inventories can be assessed.

Table 8. Comparison of producer's accuracies for NY-GAP, MRLC, and HRV-GAP for selected land cover types common to both inventories (Adapted from Laba et al. 2002).

Land Cover Type (NY-GAP)	NY-GAP	HRV-GAP (30m)	MRLC*	Class (MRLC)
Evergreen Forest/Woodland	43.1	88.5	38.6	Conifer forest
Deciduous Forest/Woodland	73.7	79.4	79.9	Deciduous forest
Mixed Forest/Woodland	61.5	88.4	72.3	Mixed forest
Cropland (Herbaceous Annual)	51.5	64.9	51.4	Row crop
Old field/pasture (Herb. Perennial)	32.7	44.3	45.3	Hay-pasture

* From Table 3, Zhu et al. (2000).

CONCLUSIONS AND RECOMMENDATIONS

For future studies, we recommend using alternative analytical methods which could include the use of multi-temporal imagery, field-based knowledge in the cluster labeling process, and more robust image classification algorithms which exploit bio-physical data and local knowledge related to land cover patterns and processes (Braden 2002).

Application of different accuracy assessment methods will be useful for understanding better the strengths and weaknesses of the classification scheme, appropriateness of surveyed field plots, and limitations of using single-date spectral analysis for mapping land cover conditions at high taxonomic resolution. Increasing the number and broadening the pattern of field observations for each land cover type will improve our knowledge of landscape level distribution patterns leading to improved mapping and classification accuracies.

Certainly more field observations and use of existing field plot records and observations of skilled staff in collaborating organizations will advance our abilities to map accurately critical land cover types and land cover type change that are important for management of biodiversity in the region. Taking advantage of public lands and seeking authorization to measure plots on private land will help in allocating sample locations and increasing sample size for more robust estimates of overall accuracy, producer's accuracy, and user's accuracy. Field observations of adequate sample size for conducting a reliable accuracy assessment are time-consuming and costly, but essential for work of this type. Use of remotely sensed imagery can extent and generalize observations from specific sites to larger regional scales in a cost-effective manner, though not without additional cost.

The land cover map at Alliance level (highest taxonomic resolution) is the least reliable given the nature and magnitude of errors of omission and commission. The land cover map at Class and Subclass levels are reliable and most appropriate for regional scale analyses and applications. Given the coarse resolution of spectral data used to create this inventory of land cover types in the HRV, use of the map is appropriate for regional scale environmental applications. Applications at county-scale are questionable and not recommended. Applications at town- and parcel-scale are inappropriate given the remotely sensed data used (Landsat Thematic Mapper at 30m resolution), mapping criteria adopted, and accuracy assessment protocol implemented.

The levels of accuracy obtained in this assessment of the high spatial resolution (30m) land cover map are similar to other studies using similar taxonomy and spectral data. All such studies encounter similar challenges with respect to image acquisition, image processing and analysis, and field validation. Only through cooperative and collaborative relationships with resource management and assessment organizations, use of participatory inventory approaches with local communities and stakeholders (Sydenstricker-Neto, et al. 2004), and analysis of remotely sensed data of higher spectral, spatial, temporal, and radiometric resolution can we expect to improve the quality and usefulness of such land cover maps. Such approaches are, of necessity, expensive to implement. However, the expense can be justified by the long-term utility of such studies to assess changes in patterns of land use at appropriate spatial and temporal scales.

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Appendix 1: Hudson River Valley land cover type descriptions

Forest/Woodland

Forests are defined as upland communities with tree crowns overlapping for 60-100% canopy cover. Woodlands include communities with an open canopy of stunted or dwarf trees (< 16 ft.), often occurring on shallow soils over bedrock with numerous rock outcroppings. Canopy cover may be as low as 30%.

Evergreen Forest[1]

Evergreen tree species typically comprise > 75% of the total tree cover.

Mountain spruce-fir forest[2]
Dominant species: red spruce, balsam fir
Associated species: yellow birch, mountain paper birch, mountain ash
Site factors: usually found between 3000-4000 ft (900-1200m) elevation, often above spruce-northern hardwood forests
Distribution: Catskill Mountains

Evergreen wetland
Dominant species: pitch pine, northern white cedar, red spruce, black spruce, balsam fir
Similar communities: any evergreen forest wetland that cannot be classified as Spruce-fir swamp or Black spruce-tamarack bog, including but not limited to Pitch pine-blueberry peat swamp, Northern white cedar swamp or Atlantic white cedar swamp.
Distribution: throughout the HRV

Spruce-fir swamp
Dominant species: red spruce, balsam fir, or both co-dominant
Associated species: green alder, mountain ash, and wild raisin
Site factors: occurs on gentle slopes of islands or along margins of drainage basins where there is some nutrient groundwater discharge; canopy usually dense (80-90% cover)
Distribution: Appalachian Plateau

Black spruce-tamarack bog
Dominant species: black spruce, tamarack, or both co-dominant
Associated species: leatherleaf, bog laurel, highbush blueberry, Labrador tea, mountain holly, sphagnum, pitcher plant, and small cranberry
Site factors: occurs on acidic peatlands in cool, poorly drained depressions; canopy cover variable
Distribution: throughout the HRV

Evergreen plantation
Dominant species: spruce, fir, pine, or other conifer
Associated species: red maple, white ash, yellow birch, paper birch (among others)
Site factors: planted for cultivation, harvest, landscaping, or to provide wildlife habitat; often monocultures with at least 90% of the canopy consisting of one species; ground layer is sparse
Distribution: throughout the HRV

Mixed Forest/Woodland

Evergreen and deciduous tree species each comprise 25-75% of the total tree cover; includes both upland and wetland communities.

Appalachian oak-pine forest

Dominant species: oak and pine co-dominant; oaks can include red oak, black oak, white oak, chestnut oak; pines are either white pine or pitch pine
Associated species: red maple, eastern hemlock, American beech, black cherry
Site factors: generally on well-drained soils, often rocky or sandy
Distribution: Central Hudson Valley and Taconic Highlands

Pitch pine-oak-heath rocky summit

Dominant species: pitch pine, chestnut oak, scrub oak, common juniper
Associated species: low heath shrubs such as blueberry, black huckleberry, sweet-fern
Site factors: rocky ridgetops, often with numerous rock outcrops; vegetation may be sparse or patchy
Distribution: primarily in the Shawangunk Mountains

Pitch pine-scrub oak barrens

Dominant species: pitch pine, percent cover ranging from 20%-60%
Associated species: scrub oak, often in dense thickets; groundlayer of sweet-fern, blueberry, and black huckleberry
Site factors: well-drained sandy soils
Distribution: Central Hudson Valley

Pine-northern hardwood forest

Dominant species: white pine, red pine, red maple, paper birch, quaking aspen, bigtooth aspen
Associated species: yellow birch, balsam fir, red spruce
Site factors: gentle slopes and flats; often overgrown plantations that have a large component of hardwood trees
Distribution: throughout HRV

Hemlock-northern hardwood forest

Dominant species: eastern hemlock, American beech, red maple, yellow birch, sugar maple
Associated species: black cherry, white pine, red oak, black birch, striped maple
Site factors: middle to lower slopes of ravines and well-drained sites on the margins of lakes and swamps
Distribution: throughout the HRV

Spruce-northern hardwood forest

Dominant species: red spruce, sugar maple, American beech, yellow birch red maple
Associated species: balsam fir, mountain maple, striped maple, hobblebush
Site factors: lower mountain slopes and flats, below mountain spruce-fir forests
Distribution: Catskill Mountains

Red cedar rocky summit
Dominant species: eastern red cedar, shagbark hickory, hop hornbeam, serviceberry
Site factors: rocky ridgetops and summits with calcareous soils; vegetation may be sparse and patchy with numerous rock outcrops
Distribution: throughout the HRV

Successional red cedar woodland
Dominant species: eastern red cedar
Associated species: gray birch, hawthorn, buckthorn, and other early successionals
Site factors: occurs on abandoned agricultural fields and pastures, usually at elevation < 1000 ft.
Distribution: throughout the HRV

Mixed wetland
Dominant species: eastern hemlock, northern white cedar, pitch pine
Similar communities: any mixed forest wetland that cannot be classified as Atlantic white cedar swamp or Red maple-tamarack swamp, including but not limited to Hemlock-hardwood swamp or Northern white cedar swamp
Distribution: throughout the HRV

Atlantic white cedar swamp
Dominant species: Atlantic white cedar; ranges from pure stands to as little as 30% canopy cover
Associated species: red maple, eastern hemlock
Site factors: on organic soils in poorly drained depressions
Distribution: Hudson Highlands

Red maple-tamarack swamp
Dominant species: red maple and tamarack with relatively open canopy
Associated species: poison sumac, red-osier dogwood, highbush blueberry, alders, buckthorn
Site factors: on organic soils (peat or muck) in poorly drained depressions; often associated with shrub or graminoid fens
Distribution: throughout the HRV

Deciduous

Deciduous tree species typically comprise > 75% of the total tree cover; includes both upland and wetland communities.

Oak forest
Dominant species: red oak, black oak, white oak
Associated species: red maple, black birch, hop hornbeam, white ash, witch hazel, big tooth aspen, flowering dogwood
Site factors: well-drained ridgetops and upper slopes, south-and west-facing slopes
Distribution: throughout the HRV

Oak–hickory forest
Dominant species: red oak, black oak, white oak, shagbark hickory, pignut hickory
Associated species: red maple, black birch, hop hornbeam, white ash, witch hazel, big tooth aspen, flowering dogwood
Site factors: well-drained ridgetops and upper slopes, south- and west-facing slopes; soils are usually loams or sandy loams
Distribution: throughout the HRV

Chestnut oak forest
Dominant species: chestnut oak, red oak
Associated species: white oak, black oak, red maple, American chestnut
Site factors: well-drained sites
Distribution: Hudson Highlands and Manhattan Hills

Oak-tulip tree forest
Dominant species: red oak, tulip tree, American beech, black birch, red maple, black oak, white oak
Associated species: flowering dogwood, witch hazel, sassafras, black cherry
Site factors: moist, well-drained sites
Distribution: Hudson Highlands, Manhattan Hills, and Triassic Lowlands

Oak-sugar maple forest
Dominant species: red oak, American beech, sugar maple, red maple, white ash), black cherry, cucumber tree, white oak
Associated species: tulip tree, basswood, bitternut hickory, hop hornbeam, striped maple, witch hazel
Site factors: well-drained low to mid slopes
Distribution: throughout the HRV

Sugar maple-mesic forest
Dominant species: sugar maple, American beech, basswood, white ash, yellow birch
Associated species: bitternut hickory, tulip tree, hop hornbeam, American elm
Site factors: middle to lower elevation concave slopes with north or east aspects
Distribution: throughout the HRV

Successional hardwood forest
Dominant species: quaking aspen, bigtooth aspen, red maple, pin cherry, white pine, paper birch, white ash, American elm, black locust, box elder, buckthorn
Site factors: cleared or disturbed sites that have reverted to woodland or forest cover; often lack of reproduction in the canopy species
Distribution: throughout the HRV

Red maple-hardwood swamp
Dominant species: red maple, black ash, American elm, swamp white oak, butternut, bitternut hickory

Associated species: red-osier dogwood, arrowwood, highbush blueberry
Site factors: poorly drained sites, usually on inorganic soils
Distribution: throughout the HRV

Floodplain forest
Dominant species: silver maple, red maple, American sycamore, cottonwood, butternut, black willow, bitternut hickory, swamp white oak, white ash, black ash, basswood
Associated species: white willow, Virginia creeper
Site factors: river floodplains and deltas; irregular flooding; broadly defined community and very diverse
Distribution: throughout the HRV

Silver maple-ash swamp
Dominant species: silver maple (as much as 70% cover)
Associated species: black ash, white ash, American elm
Site factors: poorly drained soils along rivers, lakeshores, and poorly drained depressions; usually uniformly wet conditions
Distribution: throughout the HRV

Shrub

Shrub refers to areas comprised of shrubs and small trees (< 16 ft.) covering at least 50% of the total area and includes successional shrubland, salt shrubland, maritime shrubland, shrub swamps, and dwarf shrub bogs.

Mixed Shrub

Evergreen and deciduous shrub species each comprise 25-75% of the total vegetative cover.

Dwarf shrub bog
Dominant species: leatherleaf (may have more than 50% cover)
Associated species: sheep laurel, bog laurel, huckleberry, highbush blueberry, small cranberry, sedge, black spruce, tamarack, red maple
Site factors: peatland dominated by low-growing evergreen, ericaceous shrubs, and peat mosses; water is nutrient-poor and acidic
Distribution: throughout HRV

Deciduous Shrub

Deciduous shrub species typically comprise > 75% of the total vegetative cover; includes both upland and wetland communities.

Successional shrubland
Dominant species: gray dogwood, eastern red cedar, raspberries, hawthorn, serviceberries, sumac, arrowwood, rose
Associated species: gray birch, buckthorn, white ash, red maple
Site factors: on sites that have been cleared or otherwise disturbed
Distribution: throughout HRV

Shrub swamp
Dominant species: alder or red-osier dogwood, silky dogwood, and willow
Associated species: meadow-sweet, gray dogwood, swamp azalea, highbush blueberry, buttonbush, arrowwood
Site factors: broadly defined type; occurs on shores of a lake or river, in wet depressions, or in transitions between wetland and upland; mineral soil or muck
Distribution: throughout HRV

Highbush blueberry bog
Dominant species: highbush blueberry, swamp azalea, mountain holly
Associated species: winterberry, black huckleberry, false Solomon's-seal, red maple
Site factors: peatland; water is usually nutrient-poor and acidic
Distribution: throughout HRV

Herbaceous

Herbaceous encompasses lands dominated by herbs, both natural and cultivated, and largely absent of woody plants (< 30% total area). This class includes cropland (including orchards and vineyards), pastures, old fields, parks, lawns, golf courses, tidal marshes, emergent marshes, salt marshes, fens, bogs, sedge meadows, and peatlands.

Herbaceous Perennial

Old field/pasture
Dominant species: goldenrods, Kentucky bluegrass, compressed bluegrass, timothy grass, quackgrass, smooth brome, sweet vernal grass, orchard grass, common chickweed, old-field cinquefoil, wild strawberry, ragweed, calico aster, New England aster
Associated species: gray dogwood, silky dogwood, arrowwood, staghorn sumac; may have immature scattered trees such as red maple, white ash, and white pine
Site factors: on sites that have been cleared and plowed and then abandoned; succeeds to shrubland, woodland, or forest communities
Similar communities: this type also includes mowed lawns on residential, recreational, or commercial lands, such as golf courses, parks, and lawns
Distribution: throughout HRV

Emergent marsh/open fen/bog
Dominant species: bulrushes, cattails, bur-reed, reed canary grass, sedges, yellow pond lily, white water lily, sweetflag, rice cutgrass, cottongrass, common horsetail, marsh fen, cinnamon fern, skunk cabbage, marsh marigold
Associated species: red-osier dogwood, alder-leaf buckthorn, red maple
Site factors: wet areas, sometimes with peat and/or marl, flat or gently sloping
Similar communities: this is a broadly defined type that encompasses virtually all permanently or seasonally flooded herbaceous vegetation; includes but is not limited to emergent marshes, tidal marshes, lake shores, wet meadows, vernal pools, bogs, fens, peatlands, and salt marshes
Distribution: throughout HRV

Herbaceous Annual

Row and field crops
Dominant species: corn, alfalfa, beans, and other commonly planted (annual) crops
Associated species: various weeds
Site factors: land used for the production of food and fiber; often with distinctive geometric row and field patterns
Similar communities: this type includes other cultivated lands such as orchards, groves, and vineyards
Distribution: throughout HRV

Muck agriculture
Dominant species: onions, celery, potatoes, turf
Associated species: various weeds
Site factors: soils with high levels of organic matter, plowed and planted with annual crops
Distribution: Central Hudson Valley

Water
Water is defined as permanently flooded (fresh or salt water) areas with little or no vegetation and includes streams, canals, lakes, reservoirs, bays, and estuaries.

Built Environment
Built Environment refers to areas created and maintained for human use with much of the land covered by structures and includes cities, towns, villages, strip developments, roads, highways, and transportation, power, and communications facilities, as well as mines, quarries, gravel pits, beaches, and other sandy or rocky areas with little or no vegetation.

Urban
Site factors: high-density residential, commercial, and industrial areas
Similar communities: this type includes barren lands such as mines, quarries, gravel pits.
Distribution: throughout HRV

Suburban
Site factors: low- to mid-density residential, often interspersed with trees and small yards; sparse residential land use (structures comprise an area less than one mapping unit), such as farmsteads, should be included into most closely related type
Distribution: throughout HRV

Spectral Obstructions (land areas obscured by clouds and cloud shadows).

[1] **italicized, bold font indicates NVCS Subclass designation for aggregated HRV Land Cover Types (n=9).**
[2] **bold, underlined font indicates modified NVCS Alliances, or HRV Land Cover Types (n=38)**

Appendix 2: Hudson River Valley Accuracy Assessment Field Sheet

County ________________ Polygon# _______ Date: _______ Time _______

Observers ____

Land Cover Type ____

Alternate Type (if applicable) ____

Location: *UTM ZONE18, NAD83*

GPS waypoint #________ X (easting)_______________ Y (northing)_____________

Species Composition:

	Dominant	Associated
Canopy		
Subcanopy		
Shrubs/herbs		

Comments: ____

____

____

Appendix 3: Hudson River Valley Land Cover Map (30m) Metadata

Attribute Tables:	Items (or Fields) in the Grid Attribute Table
Contact:	Leslie Zucker Hudson River Estuary Program
Documentation Date:	
Usage Notes:	
Geographic Data Set:	Hudson River Valley Gap Analysis 30m Land Cover Map
Development Status:	Complete
Distribution Constraints:	None
Description:	30 meter land cover map resulting from the Hudson River Valley Gap Analysis.
Available:	DEC Regions 3 & 4 plus offices with statewide data.
Location:	Use the Master Habitat Data Bank's Data Selector, OR **For PC Users:** $DATAHOME/ xxx/xxxx/xx **For Central Office Unix Users:** /nysdec/gis/prod/gis -serv/decmhdb/reg0/reg0data/ xxx/xxx/xxx
Completion or Most Recent Revision Date:	March 2001
Type of Data:	ESRI Grid
Source of Information:	The Hudson River Valley GAP Analysis Project (HRV-GAP) uses the New York State GAP Analysis Project (NY-GAP) database to perform analyses and answer research questions directly related to the Hudson River Valley (HRV). Landsat-5 TM multi-spectral digital imagery provided to NY-GAP by the Multi- Resolution Land Characteristics Interagency Consortium (MRLC) was the primary source of spectral data for mapping the distribution of land cover types in the HRV. Parts of the three TM scenes were required to provide coverage of the HRV. Pre -processing of the digital imagery was conducted at the EROS Data Center under the auspices of the MRLC agreement (http://www.epa.gov/mrlc). Each scene was geo-referenced to the Universal Transverse Mercator (UTM) coordinate system, extended Zone 18 (New York Transverse Mercator, NYTM), North American Datum of 1983 (NAD83), and resampled to a 30 meter square pixel using a cubic convolution resampling algorithm. The root mean square error (RMSEx,y) resulting from the resampling process was less than 30 meters in both x and y dimensions. (Smith, C.R., S.D. DeGloria, M.E. Richmond, S.K. Gregory, M. Laba, S.D. Smith, J.L. Braden, W.P. Brown, E.A. Hill. 2001. An Application of Gap Analysis Procedures to Facilitate Planning for Biodiversity Conservation in the Hudson River Valley, Final Report, Part 1: Gap Analysis of the Hudson River Valley and Part 2: Atlas of Predicted Ranges for Terrestrial Vertebrates in the Hudson River Valley. New York Cooperative Fish and Wildlife Research Unit, Department of Natural Resources, Cornell University, Ithaca, NY.)
Projection and Map Units:	NYTM in meters, NAD83 Horizontal Datum

1. For the complete accuracy assesment report, refer to DeGloria, S.D., M. Laba, and J. Braden. 2005. Hudson Valley Land Cover Map Accuracy Assessment. NY Cooperative Fish and Wildlife Research Unit, Department of Natural Resources, Cornell University, Ithaca, NY.

2. The 30 meter minimum mapping unit (mmu) land cover map for the HRV consists of 38 land cover types. The classification scheme is consistent with a modified NVCS hierarchy (Grossman et al. 1998) and can be cross-referenced with Reschke (1990) community types. It was developed for the New York State and the Hudson River Valley Gap Analysis Projects (NY-GAP, HRV-GAP). The classification scheme is based on land cover types that include alliance and super-alliance level classifications of vegetated communities, as well as more generalized classes for water, built environments, and spectral obstructions. Alliances are a physiognomically distinct group of plant associations that share dominant species. However, due to the nature of spectral data, some alliances were combined or modified to form super-alliances. As used in NY-GAP, a super-alliance is a combination of alliances with dominant species that either belong to the same genus or occur under similar environmental conditions.

3. Expert opinion from the New York Natural Heritage Program staff, literature reviews, and field surveys were used to enhance and adapt the NY-GAP classification scheme for use in the HRV. Alliances and super-alliances were added or subtracted based on presence or absence in the HRV, spectral distinguishability, and importance to natural resource managers.

Attribute Tables

Items (or Fields) in the Grid Attribute Table

Value: Pixel value:

10011: Mountain Spruce-Fir
10030: Evergreen Wetland
10031: Spruce-Fir Swamp
10032: Black Spruce-Tamarack Bog
10040: Evergreen Plantation
10050: Sugar Maple-Mesic
10060: Oak
10061: Oak-Hickory
10063: Chestnut Oak
10064: Oak-Tultiptree
10065: Oak-Sugar Maple
10070: Successional Hardwood
10081: Red Maple-Hardwood Swamp
10082: Silver Maple-Ash Swamp
10083: Floodplain Forest
10111: Appalachian Oak-Pine
10115: Pitch Pine-Oak-Heath Rocky Summit
10116: Pitch Pine-Scrub Oak Barrens
10121: Pine-Northern Hardwood
10122: Hemlock-Northern Hardwood
10123: Spruce-Northern Hardwood
10130: Mixed Wetland
10131: Atlantic White Cedar Swamp
10133: Red Maple-Tamarack Swamp
10151: Red Cedar Rocky Summit
10152: Successional Red Cedar Wetland
10200: Successional Shrubland

	10220: Shrub Swamp 10230: Highbush Blueberry Bog 10250: Dwarf Shrub Bog 10300: Old Field/Pasture 10310: Emergent Marsh 10371: Row and Field Crops 10372: Muck Agriculture 10501: Water 10610: Urban 10620: Suburban/Residential 10700: Spectral Obstructions
Count:	Pixel count of land cover type.
Area:	Total area of land cover type.
Percent:	Percentage of land cover type.
Land_cover:	Land cover type. See pixel values above for complete list.

Back to Attribute Tables