2011 Rainbow River Vegetation Evaluation

Prepared for: Southwest Florida Water Management District

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Plan Design Enable

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Executive Summary

The Rainbow River is a first magnitude spring run with exceptional ecological and aesthetic characteristics. The river attracts heavy recreational use and has been monitored and managed by several organizations. The objective of this project was to map submerged aquatic vegetation (SAV), emergent vegetation, and algae and to conduct a change analysis relative to previous mapping years (1996, 2000 and 2005). Shoreline, docks and springs were also mapped. Decreased water clarity, heavy algae coverage, and heavy recreational use on the river posed challenges to the 2011 field mapping.

Several analyses were used to characterize the river and changes in the river over time. SAV and algae were field mapped using three cover categories (high, medium and low) and the area of each is reported as an “actual” area. The “relative” area uses a weighted average of the three cover categories and represents the area that would be occupied if the algae or SAV species were it present at full coverage. Native SAV species were compared to the exotic nuisance hydrilla (*Hydrilla verticillata*). Algae and SAV areas were assessed river-wide and by zone. Changes within SAV beds were calculated by species and by tallying all species changes. A vegetation condition index was developed and vegetation relative to sediment type was analyzed.

Strap-leafed sagittaria (*Sagittaria kurziana*) has consistently been the dominant species since the 1950’s. Sagittaria remained the dominant SAV species in 2011 though it decreased 23% in relative area since 1996. Sagittaria showed slight decreases in 2000 and 2005 and a sharp decrease 2011. Hydrilla remained the second most dominant species in 2011. In spite of slight increases in 2000 and 2005 (when it peaked), the relative area of hydrilla has decreased 58% since 1996. The drop reflects a dramatic decline in hydrilla in the lower river in 2011 that is assumed to be from herbicide treatment. Hydrilla continued to increase in other parts of the river, particularly the middle 4 km of the river. It should be noted that while areas of high cover hydrilla have decreased, the low and medium cover category areas have increased. Eel grass (*Vallisneria americana*), the third most dominant species, increased in relative area 26% since 1996. Eel grass fluctuated, showing a slight decrease in 2000, a sharp increase in 2001 and a slight decrease in 2011. Southern naiad (*Najas guadalupensis*) was the fourth dominant species in 2011 as was the case in the prior four mapping events. These four most dominant species plus *Chara* sp. (muskgrass), and *Ceratophyllum demersum* (coontail) comprised 94% of the relative cover of SAV and were present throughout the river.

Though algae were mapped for the first time in 2011, increases in algae have been generally observed in recent years. 2011 algae cover was lowest in the upper river and increased on a fairly even gradient moving downstream. The lower river was dominated by benthic algal mats. Epiphytic algae cover averaged 27% and benthic algae cover averaged 60%. Vegetation index scores were best in the upper 4 km of the river. The middle 3 km had intermediate scores, and the lower 3 km the worst vegetation index scores.

A tally of changes within SAV beds (patches) for each of the mapping intervals showed that changes increased with time. Specifically, the area of patches with no changes decreased each time interval, and the area of patches with one or more changes increased each interval. The lower river (below Blue Cove) showed the least change, however those areas have been dominated by hydrilla monocultures. Mid-river SAV beds had the greatest change and changes have increased moving upriver with each time interval. Sagittaria was by far the most constant species on the river. Thirty-percent of its patch area did not change cover from 1996 to 2011. However, it was the only species with a greater portion of its patch area decreasing in cover than increasing in cover. Hydrilla was the second most stable species, though much less of its area (<2%) was unchanged. Hydrilla was also the most variable species, having the greatest area of patches that showed both increases in cover and decreases cover over time. Illinois pondweed (*Potamogeton illinoensis*) and bladderwort (*Utricularia* sp.), two species found only in the upper river, had the greatest portion of constant and/or increasing patch cover. Bladderwort had a smaller portion of decrease and/or constant cover than any other species mapped.

Considering patch changes for all SAV species, the mapping interval from 2000 to 2005 had the greatest cover gains and the smallest losses. The 2005 to 2011 interval had the greatest cover losses. Though the factors behind the conditions in 2005 are unclear, river flow in the months before 2005 was higher than in the months preceding the 1996, 2000, and 2011 events. Patch dynamics for the four most dominant species show that areas where the species was absent both times decreased each interval, indicating some degree of species expansion over time. The trend was most pronounced for hydrilla, the only species with a greater than 10% decrease in areas of species absence.

This report makes seven concluding recommendations:

1. Continue SAV mapping at minimum 5-year intervals. Hydrilla continues to expand in new areas. SAV changes are increasing. Increased algae, slower flow and recreational use can negatively impact SAV.

2. Create and maintain a digital database for hydrilla treatment. The response of hydrilla and other SAV species to control activities can be better understood and managed with specific treatment information.

3. Create digital maps of river flow velocity under different river stage/flow regimes. Flow velocity may be a significant component driving SAV and algae distribution. Velocity data would benefit interpreting SAV patterns and changes.

4. Continue emergent vegetation mapping in association with SAV mapping. The recent increase in the nuisance climbing hempvine (*Mikania scandens*) makes mapping particularly important.

5. Continue algae coverage and distribution mapping and monitoring. Increases in algae have been observed and should be monitored because of negative effects on SAV on other ecosystem components.

6. Study SAV/sediment relationships. Sediments change with river-cross-section and down-stream extent. Phosphate mining, dredging and other activities have altered sediments. The relationship between SAV and sediment on the Rainbow River can best be understood and managed with a suitably designed sampling program.

7. Conduct focused interim studies of SAV and algae coverage during very high and very low flow periods. Changes in response to flow and other factors that influence SAV and algae could be detected between five year intervals.

1. Introduction

1.1. Overview

This mapping and change analysis project was meant to assess trends in vegetation coverage since 1996 and to establish a baseline of algae coverage for future mapping and monitoring. This report describes variation in submerged aquatic vegetation (SAV) and algae coverage along the length of the river in order to identify areas and species with the greatest change. SAV species were also assessed to determine if certain species were more subject to change during particular mapping intervals or specific river segments. Similarly, a tally of SAV species changes was used to determine how much change occurred in each section of the river and during each mapping interval. Emergent wetland vegetation in the river was also mapped and assessed.

SAV species composition was compared to sediment characteristics from the 2005 Rainbow River Sediment Study (Gulf Coast Archeological Research Institute, 2007) to assess potential relationships between vegetation and sediment. Finally, an index of SAV and algae coverage was developed in order to consolidate and simplify the data. The final product will support the development and implementation of management approaches and projects to protect and manage aquatic and emergent vegetation in the river.

This project builds upon previous mapping efforts for the Rainbow River that occurred in 1991 (Water and Air Research, 1991), 1996 (FDEP, unpublished data), 2000 (PBS&J (now "Atkins," 2000), and 2005 (PBS&J, 2007). The primary objectives of this project were to produce a GIS format, geo-referenced map of emergent and submerged aquatic vegetation and algae for 2011 and analyze changes with the other mapping efforts since 1996. Accordingly, the 2011 vegetation coverage was mapped using methods consistent with the methods used in 1996, 2000, and 2005 to facilitate the detailed change analysis. Epiphytic and benthic algae were mapped for the first time in 2011. Shoreline features (hardening/seawalls), docks and spring vents were mapped in 2011 as they were in 2005. A new base map was established using 2010 imagery and the river shoreline was updated.

1.2. Project Area Description

The Rainbow River is one of Florida's largest spring runs and is located near Dunnellon, Florida in southwest Marion County. The Rainbow River flows 9.5 kilometers (6 miles) from its source at Rainbow Springs to its confluence with the Withlacoochee River (Figure 1.2.1). It is the fourth largest of the twenty-seven first magnitude springs in Florida, with average discharges of at least 100 ft^3/sec (Nordlie, 1990). The average discharge of the headsprings in 2011 was 500 ft^3/sec, the average since the last mapping event (2005 through 2011) was 597 ft^3/sec, and the average from 1965 through 2011 was 683 ft^3/sec. Water temperatures are relatively constant, averaging 74°F. Discharge varies seasonally with minimal lag time between changes in rainfall and the response of the spring discharge (Jones, 1996). The river has an average velocity of 0.5 miles/hour, and a hydrologic residence time of about half a day (Water and Air Research, 1991). Rainbow Springs are among the world's clearest natural waters (Durante and Canfield, 1990). The majority of the Rainbow River was designated the Rainbow Springs Aquatic Preserve in 1986 and an Outstanding Florida Waterway in 1987 due to its exceptional ecological and aesthetic characteristics.

The Rainbow River SAV community has been altered by the introduction and spread of the exotic plant, hydrilla (*Hydrilla verticillata*). Recreational use of the river is also thought to affect SAV cover and distribution (Mumma et al., 1996). In the late 1990's, increasing cover by the filamentous algae *Lyngbya* became a concern (Hoyer et al, 1997). *Lyngbya*, a nuisance algae, has been increasing in a number of Florida spring systems (Stevenson et al., 2007).

The upstream edge of the historical phosphate mine, Blue Cove, is 7.4 km downstream of the headspring. The 2007 Rainbow River sediment study (Gulf Coast Archeological Research Institute, 2007) identified the zones downstream of Blue Cove as an area that had been dredged around 1900 to allow barge and tug access to phosphate mines in Dunnellon.

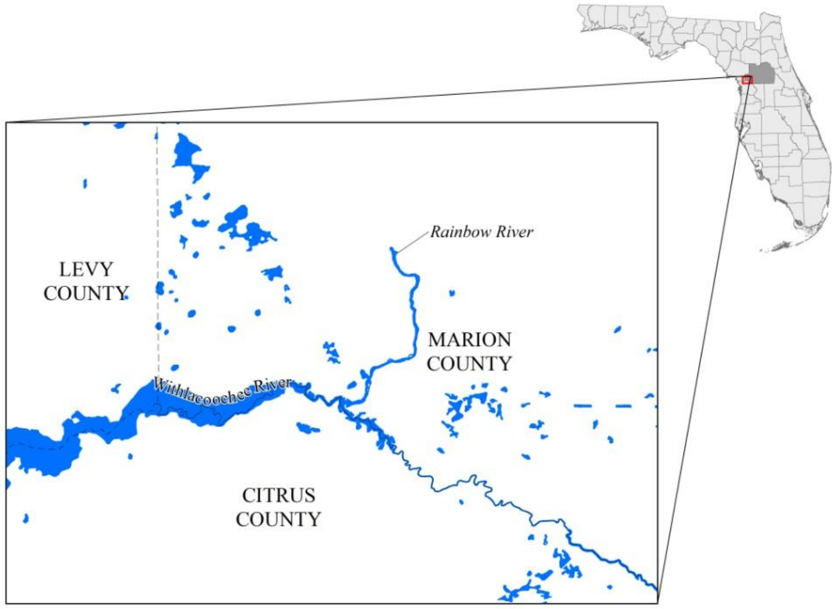

Figure 1.2.1. Rainbow River Study Area

1.3. Previous Vegetation Mapping Efforts

Florida Department of Environmental Protection (FDEP) Rainbow Springs Aquatic Preserve staff mapped submerged aquatic vegetation on the Rainbow River in 1996 and created detailed GIS maps and written mapping methods (FDEP, 1996). The mapping effort was repeated in 2000 using the same personnel as in 1996 by PBS&J (now "Atkins") under contract to and in conjunction with the Aquatic Preserve (PBS&J, 2000). Both efforts were funded by the SWFWMD SWIM Program. Primary team members from the 1996 and 2000 mapping effort mapped the river again in 2005 in a third SWFWMD funded effort also performed by Atkins (PBS&J, 2007).

There are several sources of historical data for vegetation on the Rainbow River prior to 1996. The consulting firm Henigar and Ray performed a detailed survey and developed maps of vegetation communities in 1991 for the Evaluation of Existing and Historical Vegetative Habitat task of the 1991 Rainbow River SWIM project Diagnostic Studies of the Rainbow River project (Water and Air Research, 1991). It was not possible to directly compare aerial coverage of all individual species between the mapping efforts prior to 1996 and the more recent (1996, 2000, 2005, and 2011) efforts. However, general comparisons of vegetation distribution were made and discussed in the 2005 mapping report (PBS&J, 2007).

Canfield and Hoyer (1988) briefly summarized vegetation data from the Rainbow River and several other spring-fed rivers in Central Florida. In 1986, an unpublished vegetation cover map of the River was developed for the Florida Game and Fresh Water Fish Commission (now Florida Fish and Wildlife Conservation Commission) by Hestand. Odum (1957) gave a brief overview of Rainbow River SAV in a paper discussing and comparing SAV communities. The Florida Department of Environmental Protection and Florida Fish and Wildlife Conservation Commission have regularly estimated hydrilla acreage since 1980 for the purpose of treating hydrilla though the data are not published.

1.4. Spring Flow during the 1996 through 2011 Period

Flow in the Rainbow River has not been consistent in the years leading up to each of the four SAV mapping events (1996, 2000, 2005, and 2011) (Figure 1.4.1). Changes in spring discharge or flow can potentially affect SAV and algae cover patterns in several ways. Spring discharge determines stream flow velocities and SAV distribution and cover are thought to be influenced by stream velocity (Hoyer et al, 2007). Changes in velocity may also be indicative of changing water quality characteristics which may in turn affect macroinvertebrate populations and algae growth and coverage (Heffernan et al, 2010). Figure 1.4.1 shows the Rainbow River daily flow from 1965 to 2011 the long-term, daily average flow for this period. Of particular note are the differences in flow during the periods leading up to the four mapping events.

The 1996 mapping event occurred during a period of slightly below average flow, following a relatively low flow period in the early 1990's. The 1996 to 2000 period consisted of generally average or above average flows with a few very high flow periods. The early 2000's were a low flow period. The period immediately preceding 2005 saw a return to normal or above average flows with some high flow events. Several hurricanes crossed the springshed in the summer of 2004. The 2005 to 2011 period consisted of generally below average flows. The entire period after 2000 represents a pattern of consistently below average flows moderated by a few high flow events around 2005.

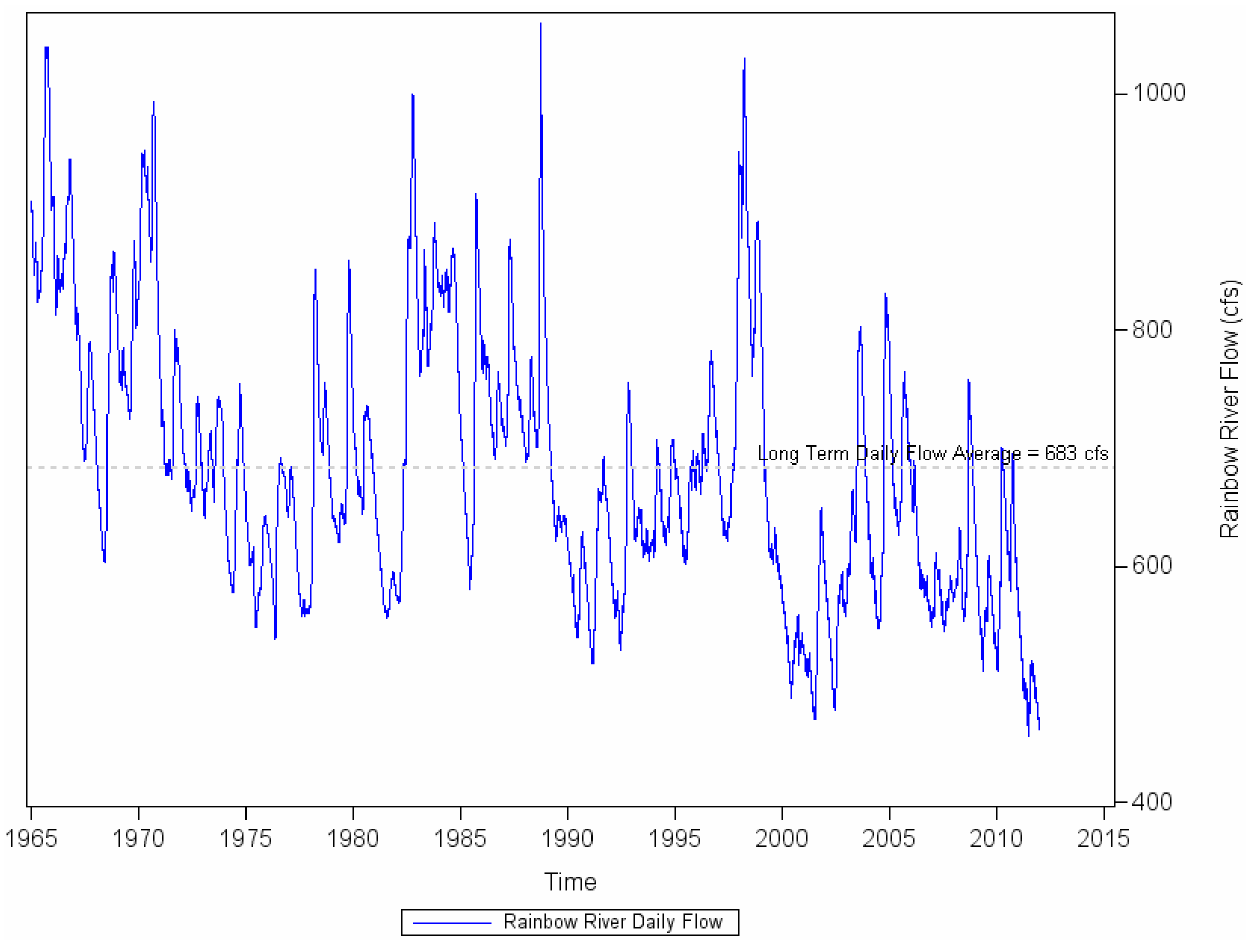

Figure 1.4.1. Daily Rainbow River flow from 1965 to 2011 (data source USGS)

2. Methods

2.1. Objective

The primary objective of this project was first to produce a 2011 submerged and emergent vegetation and algae map and secondly to conduct a change analysis relative to previous mapping efforts (1996 (FDEP, Unpublished Data), 2000, (PBS&J, 2000) and 2005 (PBS&J, 2000)). The 2011 mapping approach replicates the mapping protocol used in the past three mapping events. The mapping products enable a quantitative assessment of submerged aquatic vegetation (SAV) changes and analysis useful in evaluating trends and developing management strategies. Algae mapping (which was initiated in 2011) used an approach consistent with the vegetation mapping. Polygons were attributed with vegetation-species and algae coverage-classes in a geo-referenced GIS format.

Shoreline conditions, spring and dock locations were also mapped in 2005 and 2011. Sediment type relative to vegetation was analyzed in GIS using pre-existing data from a sediment study (Gulf Coast Archaeology Lab, 2007). An index was developed to synthesize detailed vegetation information. The hardware and software used, as well as the data delivered, followed industry standards that were compatible with those of SWFWMD. The main tasks of the project (described in greater detail below) were:

- Establish new base map
- Field mapping
- GIS mapping
- Vegetation and sediment analysis
- Index development
- Management considerations and reporting

2.2. Establish New Base Map

The basis of the 1996, 2000 and 2005 mapping projects were 1" = 200', rectified, geo-referenced 1972 SWFWMD topographic maps with aerial photography. It was the best available source when the river boundary and vegetation were mapped in 1996. In 1996, the river shoreline was carefully delineated using the 2’ elevation contours and features visible in the images, field observation and photographs from a 1995 over flight. The 1996 shoreline was also used as the river boundary for the 2000 and 2005 mapping. For the 2011 Rainbow River mapping, the 2010 digital orthophotos were adopted as the base map. While no significant positional discrepancies were observed while comparing the two base maps, there were some apparent differences in the shoreline.

Updates were made to the river shoreline to improve the appearance of GIS line work when viewed with the aerial photography, to incorporate any shoreline changes that had occurred, and to improve on the position of the shoreline using the most recent and best available digital imagery. Updates were also made to 1996, 2000, and 2005 SAV and emergent beds adjacent to modified shorelines. There was not a large quantitative difference in the areas of SAV or emergent polygons resulting from the shoreline changes, however the edits allowed for direct comparison of vegetation between years (a “change analysis”). Some shoreline differences were due to alterations (retaining wall, beach, heavy landscaping, etc.). Other differences may have resulted from gradual erosion or deposition. In a few cases, the shoreline was interpreted to be in a slightly different location using recent photography. True color aerial photographs from 1995 were useful for shoreline updates because different features were more clearly visible on those images than on the 2010 or 1972 photos (due to time of year, shadows, and camera angle, etc.). Though the 1972 black and white aerials had lower resolution and are less current, they were useful because the small size of trees sometimes made features in question more visible. Improvements were also made to mapped dock locations.

2.3. Field Mapping

Data were collected during ten separate mapping trips to the river in spring and summer of 2011. Field quality assurance verification was conducted in winter 2012. Data in all efforts were collected by a two-person team from a boat and while snorkeling. Consistency in field staff was maintained across the 1996, 2000, 2005 and 2011 events to reduce the potential methodological inconsistencies between the mapping efforts.

After updates to the shoreline were made using aerial photographs in GIS, shoreline features, docks, and emergent vegetation were field mapped. GIS data (aerial photographs and layers from prior mapping events) were loaded using ESRI ArcPad™ on a Trimble Yuma tablet computer with integrated GPS. The spatial accuracy of the GPS and GIS data was tested by checking the alignment of the GPS locations against known benchmarks such as docks, shoreline and bridges. GPS position and mapped features were referenced and considered during field mapping. All newly mapped features were drawn by hand onto hardcopy maps printed at 1"=100' scale with the 2010 orthophotos as well as vegetation, dock, shoreline and springs from 2005. A standardized notation system was used to record species and percent coverage categories.

Docks and hardened shoreline were mapped first and served as a reference for mapping of other features. Shoreline was considered to be hardened if wooden, concrete, rip-rap, or other rubble material acted as seawall, bulkhead, or a similar structure that functioned to retain the river banks. All other shoreline was considered not to be hardened, though it was not further characterized according to whether it was natural or had been modified. Dock locations were mapped as point features, with the point representing the location of the base of the dock along the shoreline.

Emergent vegetation was mapped next. It was classified as either herbaceous (marsh) or woody (trees and shrubs). To further characterize the emergent vegetation beds, plant species were later identified from the boat. Species were recorded as an attribute in the GIS layer with the most dominant species listed first.

After shoreline, docks and emergent vegetation were mapped SAV patches were identified and mapped. In order to be consistent with 1996, 2000 and 2005 SAV data, a minimum mapping unit of 225 square feet (15 by 15 feet), and a positional accuracy of less than 15 feet was implemented. Mapping was very detailed, with each species classified into one of four, modified, Braun-Blanquet cover categories: 0%; 1-10%; 10-50%; or 50- 100%. These cover categories were consistent with those used in 1996, 2000 and 2005. These four categories represent an aggregation of the standard eight categories in the Braun-Blanquet (1932) scale. The SAV species mapped are shown in Table 2.3.1. Emergent plant species mapped are given in Table 2.3.2.

A systematic reconnaissance of an area was performed to assess the species present, cover categories, and determine how each bed should be delineated. Percent coverage and aerial extent by SAV species was estimated visually. The visual estimation was made as if a 15 by 15 foot quadrat was present. SAV was observed from the boat (when wind, sunlight, and water clarity allowed) and while snorkeling. If no vegetation was present, bare substrate was categorized as sand, rock, or a mixture of sand and rock. SAV species identification was verified by the Rainbow Springs Aquatic Preserve Manager during field quality assurance reviews in winter 2012.

Table 2.3.1. SAV species and other features mapped

Scientific Name/Category	Common Name/Description
Ceratophyllum demersum	Coontail
Chara sp.	Muskgrass
Hydrilla verticillata **	Hydrilla
Hydrocotyle umbellata	Marsh pennywort
Ludwigia repens	Red ludwigia
Myriophyllum sp.	Water milfoil
Najas guadalupensis	Southern naiad
Nasturtium sp.	Watercress
Potamogeton illinoensis	Illinois pondweed
Sagittaria kurziana	Strap-leaf sagittaria or Strap-leaf arrowhead
Utricularia sp.	Bladderwort
Vallisneria americana	Eelgrass or Tapegrass
Benthic mat algae	Mats of algae growing on substrate
Epiphytic algae	Algae and/or biofilms growing on plants
Bare substrate (rock, sand, mud)	No submerged or emergent vegetation
Herbaceous emergent vegetation	Emergent marsh plants
Woody emergent vegetation	Emergent trees and shrubs

Table 2.3.2. Emergent species mapped

Scientific name	Common name
*Alternanthera philoxeriodes***	Alligator weed
Cicuta mexicana	Water hemlock
Cladium jamaicense	Sawgrass
*Colocasia esculenta***	Wild taro
Crinum americanum	Swamp lily
*Cyperus papyrus***	Papyrus
Hydrocotyle spp.	Water pennywort
Hymenocallis spp.	Swamp lily
Mikania scandens	Climbing hempvine
Nuphar spp.	Spatterdock
Panicum spp.	Torpedo grass** and Maidencane
Paspalidium geminatum	Egyptian paspalidium
Paspalum spp.	Water paspalum or Knotgrass
*Pistia stratiotes***	Water lettuce
Polygonum spp.	Smartweed
Pontederia cordata	Pickerelweed
Rhyncospora spp.	St. Johnswort or Beakrush
Sagittaria lancifolia	Arrowhead
Sagittaria latifolia	Arrowhead
Schoenoplectus tabernaemontani	Soft-stem bullrush
Typha spp.	Cattail
Zizania aquatica	Wild rice

** Exotic species

Algae mapping was done at the same time as SAV mapping using the same approach. After several days of reconnaissance, it was decided that algae conditions on the river would be best captured using percent cover categories of 0 – 25%, 25 – 75% and 75 – 100%. Benthic mat algae (growing on substrate) and epiphytic algae (growing on plants) were individually mapped. In areas where mat algae obscured plant surfaces, epiphytic algae were mapped as 75-100%. Algae cover was far more homogenous than SAV cover. Though there were variations in algae cover, in general algae showed gradually changing gradients over large areas rather than abrupt cover changes like SAV. There were exceptions to this general condition of algae where more abrupt changes were seen on a small scale. Therefore the minimum mapping unit of 225 ft^2 was maintained. Algae mapping protocol was discussed on site and agreed upon by a SWFWMD biologist. Examples of algae cover categories are shown in Figures 2.3.1 to 2.3.6). Algae samples were collected at eleven locations and species identified (see section 2.7).

Locations of spring vents mapped in 2005 were field verified during the final stages of field data collection.

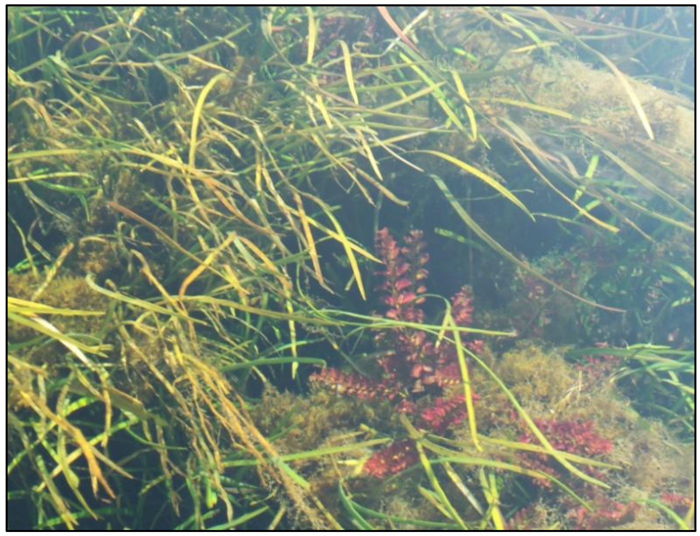

Figure 2.3.1 0% to 25% algae cover in the headsprings

Figure 2.3.2. 0% to 25% epiphytic and 25% to 75% benthic algae cover (excluding prop scar) just below K.P. Hole.

Figure 2.3.3. 50% to 100% epiphytic and 0% to 25% benthic algae cover near the confluence

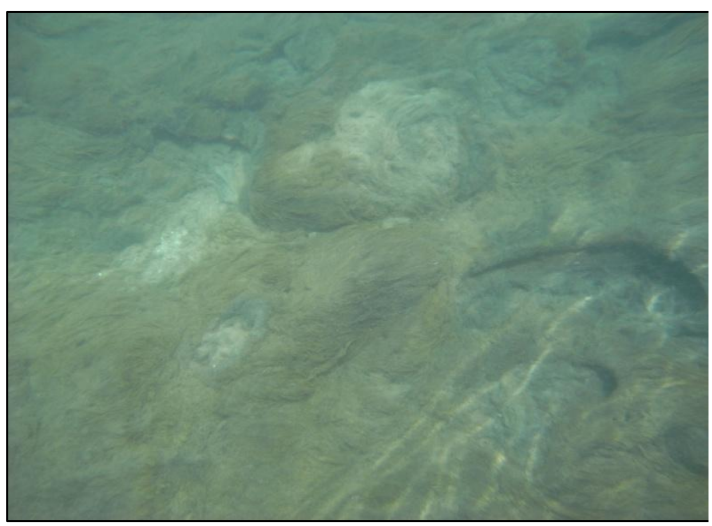

Figure 2.3.4. 75% to 25% epiphytic benthic algae cover and no SAV (downstream of Blue Cove)

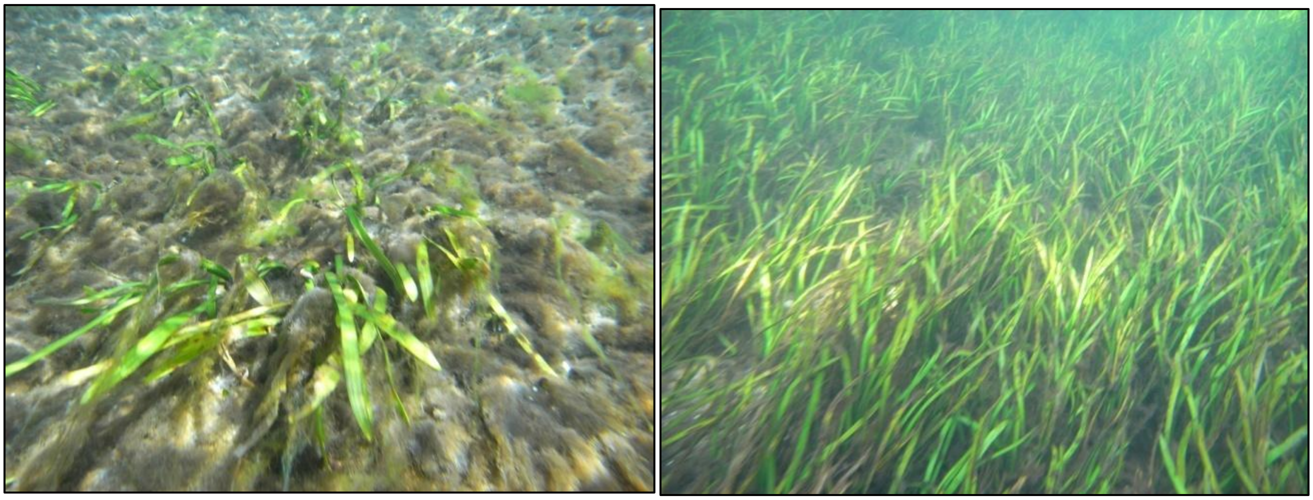

Figure 2.3.5. 0%-25% epiphytic and 75%-100% benthic algae (left, lower river) and 25%-75% epiphytic and 0%-25% benthic algae (right, mid river)

Figure 2.3.6. 25%-75% epiphytic (left, above Blue Cove, zone 73) and 0%-25% benthic algae (right, near the confluence)

2.4. GIS Mapping

After field mapping, the information was transferred and compiled into a geodatabase using ESRI ArcMap 10.0. Field delineations were digitized heads up (on screen), and attributed. The SAV database format from 2005 was replicated for the 2011 SAV map and generally adopted for the algae layer. All spatial data were documented in Florida Geographic Data Committee (FGDC) compliant metadata files created using ArcCatalog. These files are part of the digital deliverable associated with this project.

2.5. Quality Control

During preliminary digitizing and review of the GIS data (SAV, emergent vegetation, docks, shoreline, springs and algae), areas of uncertainty were identified and noted for follow up in the field. In addition, random areas of the completed GIS maps were field verified in order to calculate a rate of mapping error, and GIS data characteristics were further assessed to assure quality. Spot checking for field verification was done with the completed GIS maps downloaded onto the tablet computer with integrated GPS. This allowed for tracking and viewing one's location on the map while navigating the river. The map was verified at ninety-six locations. The points were selected randomly by an observer in the boat holding the tablet computer. The boat was navigated to the selected point using the GPS to identify the location of the boat relative to the map. SAV species or substrates observed beneath the boat were compared to the species and cover category indicated by the map. The map was considered to be accurate at that point if the substrate or species and cover category indicated by the map was the same as that observed at that location in the river.

Figure 2.5.1. Water clarity conditions downstream of Blue Cove

Overall accuracy was determined to 97% or greater, with three of the ninety-six assessed points changed after the field QC. Field verification identified one location in error where a poly line had been left off of the GIS map. The polygon had been correctly mapped on the original, paper, field map though. Two other locations were found to have a slightly different percent cover category than originally mapped (hydrilla cover 10-50% rather than1-10% and southern naiad 1-10% rather than 10-50%. Vegetation in those places (just above the bridge and in a phosphate pit near the confluence) may have been less visible at the initial time of mapping due to a higher mat algae cover and/or lower water clarity. Plant cover may also have changed since initial time of mapping. In addition to the 96 quality control points where information was recorded, species were observed and verified between quality control locations as logistics allowed.

All field data were thoroughly reviewed to ensure that information was correctly transferred to the final map. Every polygon was reviewed, and marked as checked. The GIS data were then assessed by a GIS analyst independent of the field data collection and mapping. Data were reviewed for un-labeled polygons, consistent attributes in all fields (for example, that a polygon with *Sagittaria kurziana* coverage of 50-100% did not have a bottom feature type of "bare") and for polygon slivers, gaps, and overlaps. All discrepancies were investigated and resolved.

2.6. Change Analysis

In order to compare SAV cover in 1996, 2000, 2005 and 2011, the Rainbow River was divided into 95 segments or zones. Each zone represented 100 meters of the river's length measured along the river's centerline. Contrary to typical river-centerline naming conventions where river kilometers (Rkm) are measured from the river's mouth, the Rainbow River centerline measurements began at the headspring and increased downstream. As such, zone 1 (Rkm 0.1) was located in the headspring and zone 95 (Rkm 9.5) was located at the Rainbow River's confluence with the Withlacoochee River (Figure 2.6.1). The zones were aggregated into 1-kilometer (10 zone) increments for certain analyses and index calculations. One area not shown on the map but discussed in the change analysis results is "The Narrows" which extends from approximately river zone 33 to river zone 53. Another important landmark in the discussion of the change analysis results is the upstream edge of Blue Cove at river zone 74. The 2007 Rainbow River sediment study (Gulf Coast Archeological Research Institute, 2007) identified the zones downstream of zone 74 as an area that had been dredged around 1900 to allow barge and tug access to phosphate mines in Dunnellon.

The "percent cover" and "relative area" of each SAV species was calculated by transforming the modified Braun-Blanquet cover categories to percentages using the midpoint of each cover category (5% for 1-10%; 30% for 10-50%; and 75% for 50-100%). Similar transformations are commonly used when performing quantitative analyses with Braun-Blanquet data. The same transformation was used to calculate SAV area in the SWIM plan (SWFWMD, 2004).

The relative area of a species was calculated by first determining the total area of each species in the three cover categories (1-10%; 10-50%; or 50- 100%). The cover category area was multiplied by the midpoint of the respective cover category (5%, 30%, and 75%). Finally, the products of cover category areas and midpoints were summed to generate relative areas for the species. The relative area for each species was calculated for the entire river and for 500-meter and 1-kilometer segments. The percent cover for an individual species was calculated by dividing the relative area of the species by the total area of the river or segment. The sum of percent covers does not equal 100% and the sum of relative areas does not equal total river area because the data were transformed using the midpoint (5%, 30%, 75%) rather than the maximum (10%, 50%, 100%) of the category. This is typical of Braun-Blanquet data transformed to relative areas or total percent covers.

The total area of the river occupied by various cover categories of different species was also calculated for each mapping year. This yielded total values by zone for 0%-10% covers, 10%-50% covers, and 50%-100% covers. Total area where a species occurred in any cover category was also calculated for the whole river and by zone. This measurement equates to the sum of the areas occupied by the 0%-10%, 10%-50%, and 50%-100% cover category for a species.

2.7. Comparison of Sediment and SAV Species

Logistic regression and principal components analysis were used to analyze the factors affecting the presence or absence of the dominant SAV species on the Rainbow River. Two groups of analyses were performed. In the first, sediment grain size categories were aggregated using principal components analysis and then analyzed with other factors relative to SAV species presence. Sediment size data were subjected to principal component analysis with the output set to produce one factor. The raw sediment size percent volume (as opposed to mass) data were subset, so that the surface layer (stratum) of each core was retained, provided that layer was at least one centimeter thick. If the surface later was less than one centimeter thick the second layer was retained. The percent volume of the various sediment size categories (pebble, granule, coarse sand, medium sand, fine sand, very fine sand, silt clay) were then entered into a principal component analysis. The eigenvalue greater than or equal to one criterion was used. There were three components which generated eigenvalues greater than 1 which cumulatively accounted for 76% of the variance in the sediment data. These components also occurred before a break in the scree plot, supporting the use of the eigenvalue equal to one criterion. Sediment size classes and corresponding factor pattern and communality estimates are presented in Table 2.7.1. The factor resulting from this analysis was used as a representative of the sediment data in regression analysis.

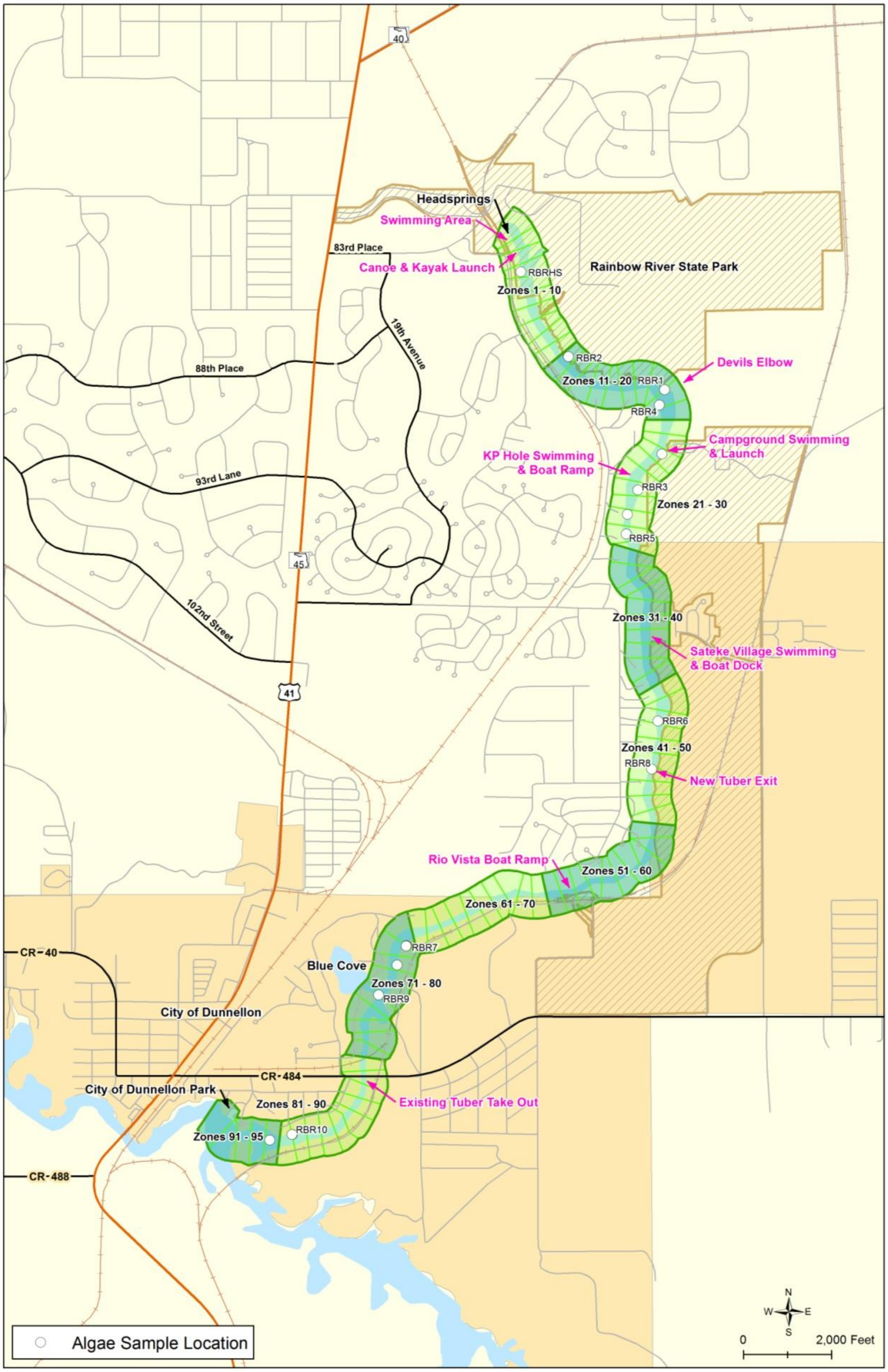

Figure 2.6.1. Rainbow River landmarks, 100-m analysis zones, and river kilometer locations

Table 2.7.1. Factor pattern and communality estimates from the sediment grain size PCA analysis

Grain Size Class	Factor Pattern	Communality Estimates
Pebble	0.53	0.28
Granule	0.71	0.5
Coarse Sand	0.62	0.39
Medium Sand	-0.79	0.62
Fine Sand	-0.87	0.75
Very Fine Sand	0.09	0.01
Silt Clay	0.23	0.05

The first regression predictor variables were river zone, water depth, depth to bedrock, and the sediment factor variable produced from the principal component analysis of the sediment grain size data. The response variable was presence or absence of a given SAV species. The specific regression used was stepwise logistic regression, with model entry at $p< 0.05$ and retention at $p<0.10$. There insufficient data to perform independent validation of the models. The four taxa occurring in more than six core samples, *Sagittaria kurziana, Hydrilla verticellata, Vallisneria americana,* and *Ceratophyllum demersum* were analyzed.

Logistic regression was also used to analyze the effect of individual sediment grain size categories on the presence or absence of the dominant SAV species on the Rainbow River. The predictor variables were all seven grain size categories (in order of descending size):

- pebble
- granule
- coarse sand
- medium sand
- fine sand
- very fine sand
- silt/clay

The response variable was presence or absence of a given SAV species. It is important to note that many of the sediment size classes have distributions that are not independent of location in the river. The specific regression utilized was stepwise logistic regression, with model entry at $p< 0.05$ and retention at $p<0.10$. There were insufficient data to perform independent validation of the models.

2.8. Analysis of Epiphyte and Benthic Mat Algae Species Composition

Algae samples were collected for qualitative examination of their epiphytic communities and benthic algal mats were collected for a qualitative examination of their algal species composition. Samples were collected on June 15, 2011 (samples RBR-1, RBR-2, RBR-3, and RBR-4), July 2 (samples RBR-5, RBR-6, and RBR-7), July 13 (RBR-8), July 20 (RBR-09 and RBR-10) and August 4, 2011 (RBR-HS). Samples were preserved in 4% buffered formalin, and shipped to Austin, Texas, for analysis by David Buzan of Atkins North America, Inc. Macrophytes were observed macroscopically to describe the periphytic communities relative to the size of the macrophytes. After macroscopic observations were made, randomly selected stems and/or leaves from each sample (if the sample contained macrophytes) were gently scraped and the scrapings composited into one 2.2 ml settling chamber. The base, middle, and near-top of each stem and/or leaf and in the case of *Vallisneria* leaves, from both sides of each leaf, were scraped.

The settling chamber was scanned at a magnification of 100X to identify large epiphytes and organisms. The settling chamber was then scanned at a magnification of 1000X (oil immersion) to identify small epiphytes. Microscopic analysis was conducted with a Nikon Eclipse TS100 inverted microscope. Taxonomic references used included: Edmondson (1959), Patrick and Reimer (1975), Prescott (1962), Round et al. (1990), Thorp, and Covich (2001), and Wehr, and Sheath (2003). Identifications were also verified using a variety of web pages, including AlgaeBase (http://www.algaebase.org/) and Diatoms of the United States (http://westerndiatoms.colorado.edu/).

2.9. Vegetation Condition Indices

Two versions of a vegetation condition index were calculated. One version did not include algae and was used to assess and compare 1996, 2000, 2005, and 2011 vegetation conditions. The other version included epiphytic and benthic algae data collected for the first time in 2011 and was used to represent 2011 vegetation conditions. Using basic principles of plant ecology, the indices assign value based on the coverage of native SAV species, exotic SAV species, and (for 2011) benthic and epiphytic algae. Higher values were assigned to higher native cover and value was incrementally detracted for both exotic species and benthic algae cover. Low epiphytic algae cover was considered beneficial and assigned a low positive value while high epiphytic algae was considered detrimental and assigned negative values.

To select the specific method that most meaningfully represented river conditions, several approaches to scoring vegetation and algae were examined and their limitations considered. The main issue in aggregating detailed SAV data into a simple, straightforward index lies in the range of cover categories used. Multiple cover categories (0%, 1-10%, 10-50% and 50-100%) can apply to one polygon because several species can be present. Two species with 10-50% cover could have a lower overall cover (15% + 15% = 30%) than one species with 50-100% (60%). Two species with 10-50% could also have a higher combined cover (40% + 40% = 80%) than one species with 50-100% cover (60%). Methods testing included assigning scores before and after area-weighting, summing of cover categories, using the high point of a cover category for area-weighting, and varying the range of index values used.

The approach chosen for this report represents the data in the most general way. The vegetation condition index for a zone is the sum of component scores that are area weighted averages based on cover categories (see scores in Table 2.9.1 and an example calculation in Table 2.9.2). For each zone, the native, exotic and algae components of the index were calculated separately, and then summed for a final score. SAV cover values were assigned to a polygon based on the highest cover category of any species present. The midpoint of the highest cover category was multiplied by the area of the polygon, and then the resulting values (area-weighted cover values) for all polygons in a zone were summed. This value was then divided by the area of suitable habitat in the zone. The resulting value was used to determine the component score according the scoring scheme in Table 2.9.1. The area of suitable habitat was established by eliminating areas of bare rocky substrate, assuming it is not suitable for SAV. Some rock areas may be human-caused and may have once been suitable substrate for SAV, however the data set does not distinguish between natural and human-caused areas of rock. Bare areas of sand or mixed sand and rock were included in the analysis as bare substrate considered suitable for SAV growth. Exotic (hydrilla) and algae cover values were calculated in the same way using the respective midpoints from the hydrilla and algae mapping classifications for individual polygons.

These indices were calculated for 100-m river zones and 1-km river zones and are discussed in the Results and Discussion section and shown on maps in Appendices A and B. An example of the scoring procedure is shown in Table 2.9.2.

Table 2.9.1. Vegetation condition index component scores for indices (a) with and (b) without algae

Component	Area weighted cover	(a) 1996, 2000, 2005 & 2011 Component Score	(b) 2011 Component Score
Native SAV	>74.9%	3	8
Native SAV	29.9%-74.9%	2	6
Native SAV	5%-29.9%	1	4
Native SAV	<5%	0	0
Exotic SAV	>74.9%	-3	-3
Exotic SAV	29.9%-74.9%	-2	-2
Exotic SAV	5%-29.9%	-1	-1
Exotic SAV	<5%	0	0
Epiphytic Algae	>87.5%	NA	-2
Epiphytic Algae	50%-87.49%	NA	-1
Epiphytic Algae	12.49%-49.9%	NA	0
Epiphytic Algae	<12.49	NA	1
Benthic Algae	>87.5%	NA	-3
Benthic Algae	50%-87.49%	NA	-2
Benthic Algae	12.49%-49.9%	NA	-1
Benthic Algae	<12.49-	NA	0

Table 2.9.2. Example SAV component score calculation for a hypothetical zone with three polygons

					Native SAV			Exotic SAV		
Polygon number	**Sagittaria**	**Vallisneria**	**Hydrilla**	**Polygon area**	**Midpoint of highest cover category**	**Area weighted cover for polygon**		**Midpoint of highest cover category**	**Area weighted cover for polygon**	
1	50-100%	0%	0%	100	75%	75				
2	0-10%	10-50%	50-100%	10	30%	3		75%	7.5	
3	0%	0%	0%	50	0%	0				
Totals				**160**		78			**7.5**	**<--Zone sum**
					Area weighted cover for zone:	**48.8**			**9.6**	**<--Zone sum/zone area**
					Zone component score:	**2**			**-1**	**<--Zone component score**
					Overall zone score:	**1**				

3. Results and Discussion

This section provides quantitative comparisons of SAV, emergent vegetation, and other features mapped for the four most recent mapping years (1996, 2000, 2005, and 2011). It also includes the 2011 algae mapping and an analysis of SAV relative to sediment type. Several analyses were used to characterize the river by zone as well as changes in the river over time. In addition to summing the areas of SAV species river-wide and by zone, this 2011 analysis assessed changes in SAV patches using intersected GIS data from all four time periods. The following is an overview of the results reported in this section.

- **Patch specific SAV changes**
  - **Cover change tally (1996-2000, 2000-2005, 2005-2011 and 1996-2011)**
    Individual polygons were queried for changes in cover category and the number of changes tallied (summed) for each polygon. The tally includes all six species that are found river-wide. The three intervals between the four mapping events were tallied separately. The 1996 to 2011 span was also tallied for all three intervals. Maps show 'hot-spots' of change throughout the river and graphs sum changes by zone
  - **Cover change trend (1996-2011)**
    Individual polygons were queried to identify where species cover categories were consistently absent, stable, increasing or decreasing, as well as where they were variable. The eight most prominent species are graphed for the river as a whole and the four most prominent species are graphed by zone
  - **Presence/absence change (1996-2000, 2000-2005, 2005-2011)**
    Individual polygons were queried to identify where species changed between present and absent, remained present or remained absent. The four most prominent species are graphed for each time interval for the river as a whole
- **SAV area and changes in area**
  - **Native and exotic species**
    The summed relative area of native species is compared with the relative area of hydrilla for each time period by river zone. Maps show areas with natives, exotics and a mix of native and exotics for each time period
  - **SAV species**
    - *The relative area and change in relative area for all fourteen SAV species for all four time periods in table format for the river as a whole*
    - *The actual area of each cover category in table format for all 14 SAV species for all four time periods and graphed by zone for five prominent species*
- **Benthic and Epiphytic Algae**
  2011 benthic and epiphytic algae graphed by cover and zone and mapped by cover category
- **Emergent vegetation, hardened shoreline, docks, springs**
  Changes in the area of emergent beds for each time period and the species growing in them are characterized. The length of hardened shoreline and number of springs and docks are also described
- **Statistical analysis of native and exotic species**
- **Comparison of sediment and SAV species**
- **Vegetation condition index**
  Scores for river zones reflect the amount of native and exotic vegetation present and (for 2011) the amount of detrimental and beneficial algae

The 1996, 2000, 2005, and 2011 vegetation mapping efforts used a Braun-Blanquet (1932) vegetation cover classification for SAV described in Section 2.6. SAV was mapped as being present in 1 to 10%, 10 to 50%, and 50 to 100% cover. These percent covers were transformed to "relative areas" to enable aggregated comparisons of aerial coverage. The method for calculating relative areas is described in Section 2.6. There is an important caveat when using these relative area data. Both changes in cover categories, as well as changes in the aerial extent of SAV beds, cause SAV relative areas to change. For example, a 1-acre

Sagittaria bed with a 10-50% cover has a 0.3-acre relative area of Sagittaria. If the percent cover of Sagittaria in this bed decreased to 1-10%, the relative area of Sagittaria would decrease to 0.05 acres. This same 0.25-acre decrease in relative area could also occur if the area of the 10-50% Sagittaria bed had decreased from 1 acre to about 0.17 acres. Each 100-m segment has a different area because the river width varies. Calculations of percent cover reported here normalize the relative areas of a given segment.

3.1. Patch Specific SAV Changes

Submerged aquatic vegetation mapping polygons from all four years (1996, 2000, 2005, and 2011) were intersected to examine patterns of year to year changes in individual SAV species cover. Comparisons elsewhere in this report address changes in species by summing species area river-wide and by zone. The two analyses in this section are spatially explicit in addressing which patches of vegetation have changed, how many individual SAV cover-category changes have occurred in each polygon (cover change tally), and whether the changes represented increases or decreases (cover change trend). Analyses were done to query for cover category changes (0, 0-10%, 10-50%, and 50 to 100%) as well as changes from present (>0%) and absent (0%) and to quantify the areas of changes.

3.1.1. Cover Change Tally

The number of SAV changes was tallied by polygon for the three mapping intervals between 1996 and 2011. The tally includes the six most common species found throughout the river (sagittaria, hydrilla, eelgrass, naiad, coon tail, and muskgrass) and counts each change in cover category. The remaining eight species were mapped only in the upper reach of the river and were not included in the tally. The change tally of the six species over three map intervals has a maximum of eighteen changes. Table 3.1.1 lists the area for each change tally. Only 9% of the river had no change in SAV cover category. Patches with one to four changes were about equal in area (13% or 14% each). The area of patches with five changes, six changes, seven changes, etc., decreased with each additional tally of change. Just over half (54%) of the river area had one to four cover category changes and a quarter had five to seven changes. Ten percent of the river had eight to ten changes. Only one percent of the river had eleven or more cover changes.

To determine if any time interval changed more than another, patch cover category changes were also tallied separately for each of the three intervals (1996 to 2000, 2000 to 2005, and 2005 and 2011). The maximum tally is 6 given one time interval and six species. Table 3.1.2 lists the area of cover category changes for each time interval. The area of patches without change decreased each time interval from 44% to 37% to 20%. The area of all change tallies increased each time interval. For example, the area of patches with one change increased from 15 ha to 17 ha. The increases are smaller between the first two intervals and greater in the third interval. The area of patches with four changes increased from 1.4 ha to 4.5 ha from 1996 to 2011. The entire river area is approximately 60 ha.

Graphs showing the change tally by zone (Figures 3.1.1 and 3.1.2) and maps showing change tally by patch (Figure 3.1.3) reflect the changes discussed above and also indicate the spatial distribution of changes are similar for all time periods. The largest, most stable portion of the river is upstream of zone 28. Between zone 28 and 81, there are several pulses in cover change with the change increasing somewhat with downstream distance. There are fewer changes below zone 81, which starts immediately above the County Road 484 bridge. However, the area is largely a monoculture of hydrilla, and the one species change during the latest time interval is likely the result of hydrilla treatment. Between 1996 and 2000, there was an increase in the number of cover changes in zones 21 and 22, which is where Indian Creek enters the river. Zones with 5 and 6 changes may correspond to the locations of historical phosphate pits or to the locations of springs. For instance, zone 31 contains a spring and possibly a phosphate pit. Zone 43 contains a spring and phosphate pit.

Table 3.1.1. Area of SAV Patches with each Cover Category Change Tally from 1996 – 2011. Tally includes six species over three mapping intervals.

Number of Cover Category Changes	Area (ha)	Percent of Total Area
0	5.4	9%
1	8.2	14%
2	7.9	13%
3	7.8	13%
4	8.2	14%
5	5.7	10%
6	5.0	8%
7	4.2	7%
8	2.6	4%
9	2.3	4%
10	1.3	2%
11	0.7	1%
12	0.3	0%
13	0.3	0%
14	0.1	0.2%
15	0.004	0.01%
16	0.0001	0.0002%

Table 3.1.2. Area of SAV Patches with each Cover Category Change Tally for 1996-2000, 2000-2005, and 2005-2011. Tally includes six species and one time interval.

	1996-2000		2000-2005		2005-2011	
Number of Cover Category Changes	Area (ha)	% Total Area	Area (ha)	% Total Area	Area (ha)	% Total Area
0	26.68	44.5%	21.96	36.6%	11.95	19.9%
1	14.65	24.4%	15.82	26.4%	17.17	28.6%
2	11.37	19.0%	11.68	19.5%	15.28	25.5%
3	5.73	9.6%	6.61	11.0%	9.48	15.8%
4	1.38	2.3%	3.11	5.2%	4.50	7.5%
5	0.21	0.4%	0.74	1.2%	1.34	2.2%
6	0	0%	0.11	0.2%	0.31	0.5%

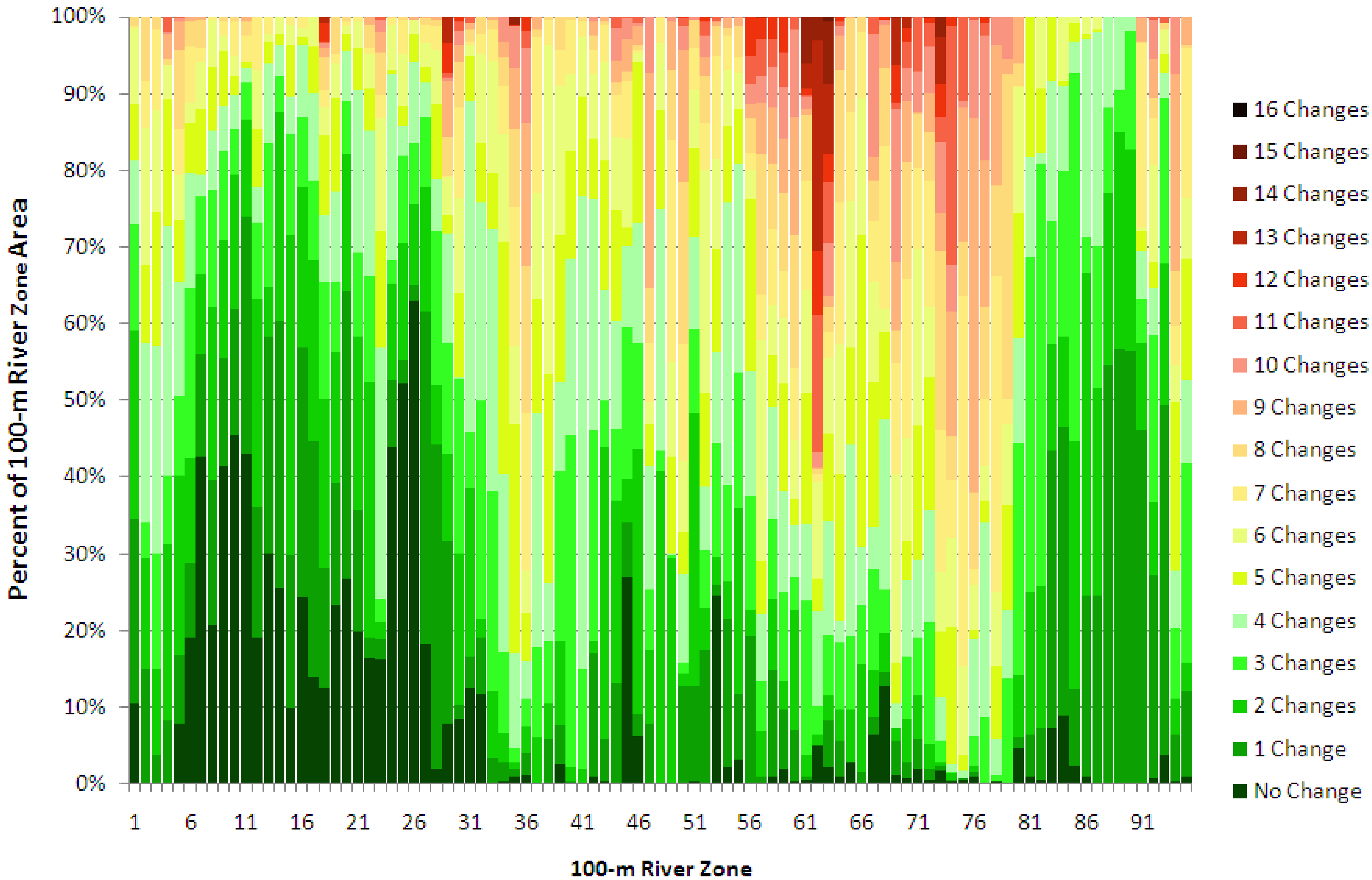

Figure 3.1.1. SAV Patch coverage category change tally for the three intervals from 1996-2011 summarized by 100-m river zone

New Landscape Page

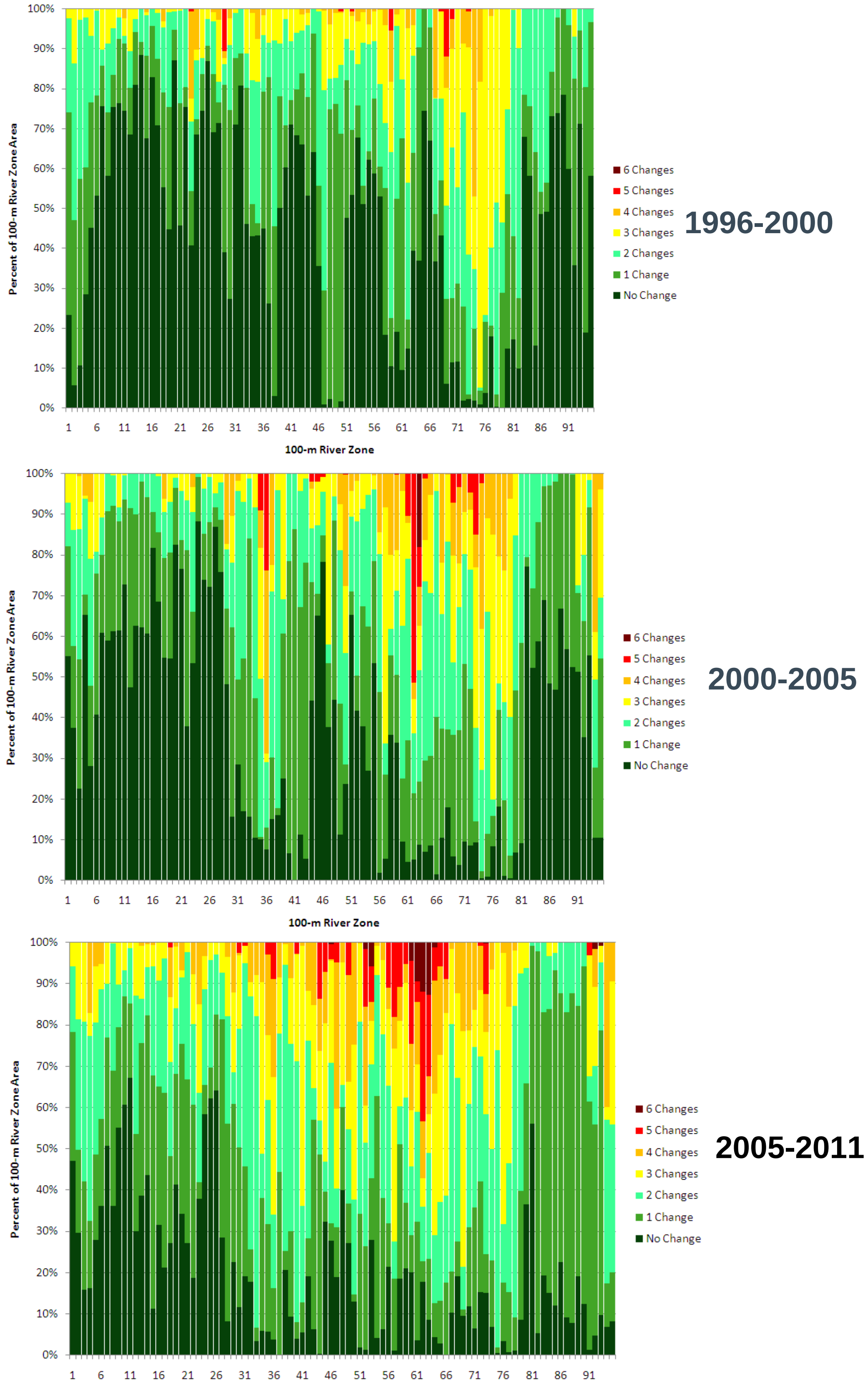

Figure 3.1.2. SAV patch cover category change tally

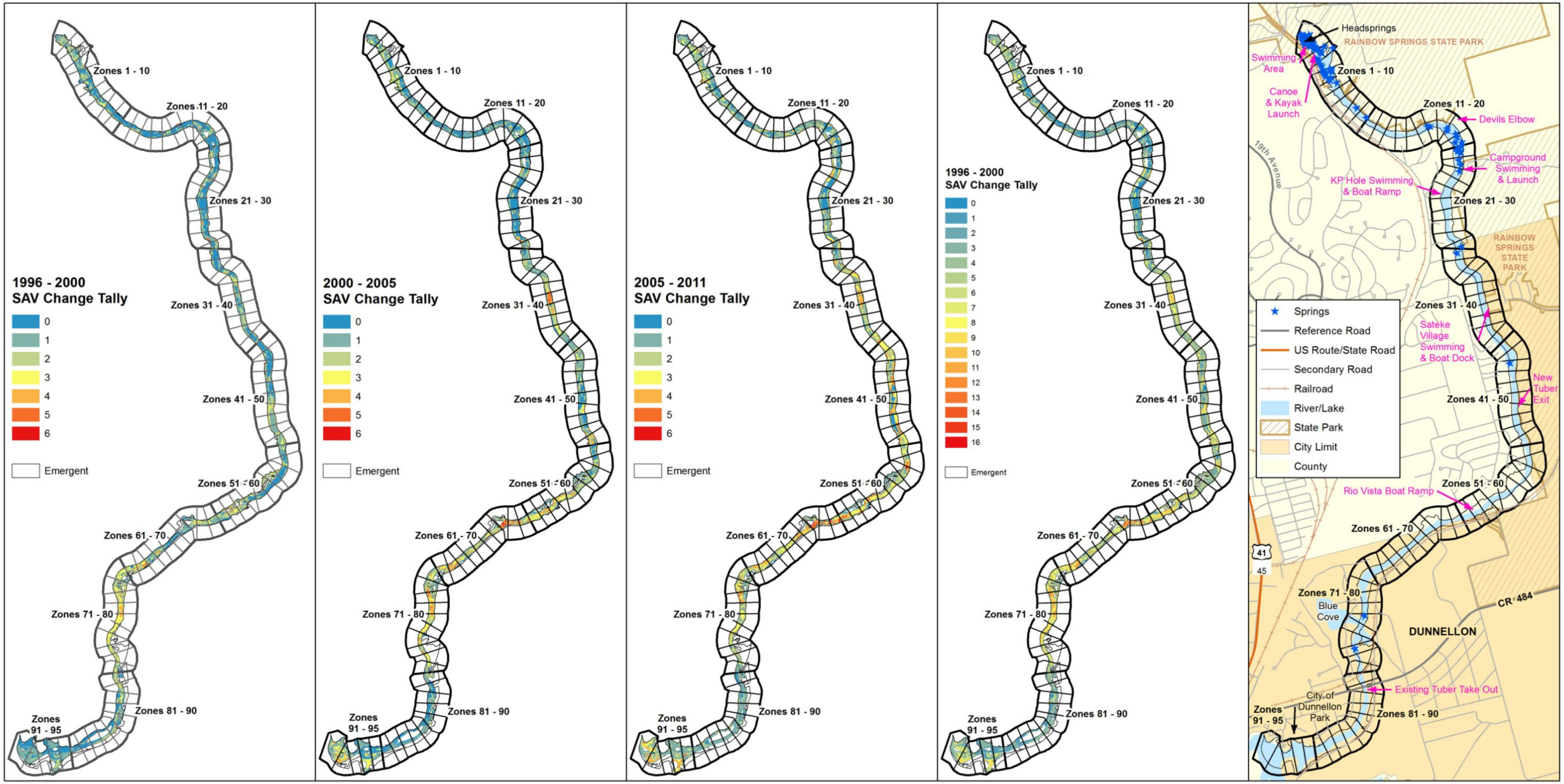

Figure 3.1.3. SAV cover category change tally through each of four mapping events in 1996, 2000, 2005, and 2011, and for the entire period from 1996 through 2011.

3.1.2. Cover Change Trend

SAV data were queried to identify species change conditions by polygon (patch) for the three periods between mapping events (1996-2000, 2000-2005, and 2005-2011). Given the GIS data format, polygon cover category changes could include the following for a given species:

- Increase some years and decrease others
- Increase every year or increase some years and no change others
- No change in any year
- Decrease in all years or decrease in some years and no change others
- Never present

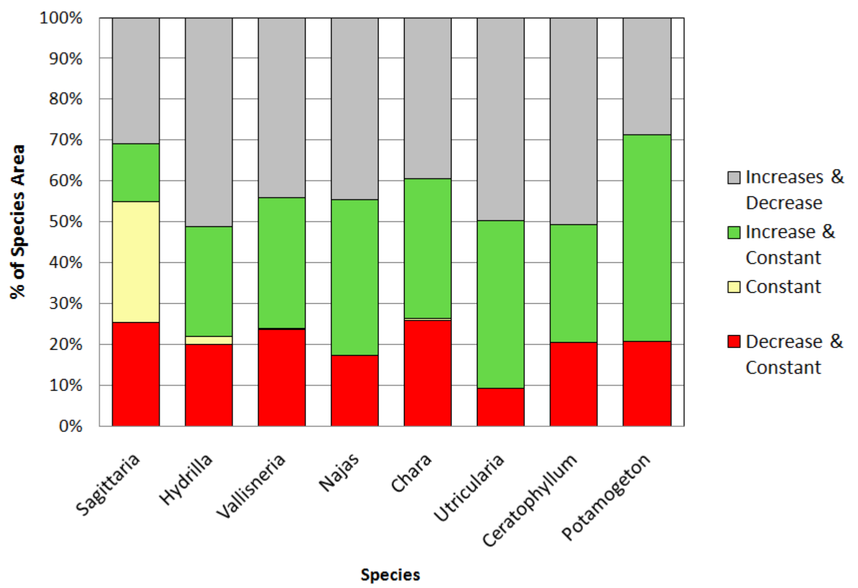

Figure 3.1.4. Cover category change trend from 1996 to 2011 as percent of area occupied by species

Because the patch area where a species increased each year was so small, it was combined here with the category where species cover either increased or remained the same. Likewise, the area of patches where cover decreased all years was combined with the category where species cover either decreased or remained the same.

Figure 3.1.4 gives a river-wide summary of polygon-specific change for the eight most prominent species as a percent of total species area. Figure 3.1.5 shows these same relationships but as a percent of total river area. Sagittaria was the only species with a sizable portion of stable patches, yet had the smallest portion of increasing and constant patches. Approximately 20% of the river area has sagittaria patches that showed no cover change in any of the reported mapping years. Hydrilla had the greatest proportion and area of patch variability. In terms of portion of the species area, *Utricularia* and *Potamogeton* had the greatest portion stable

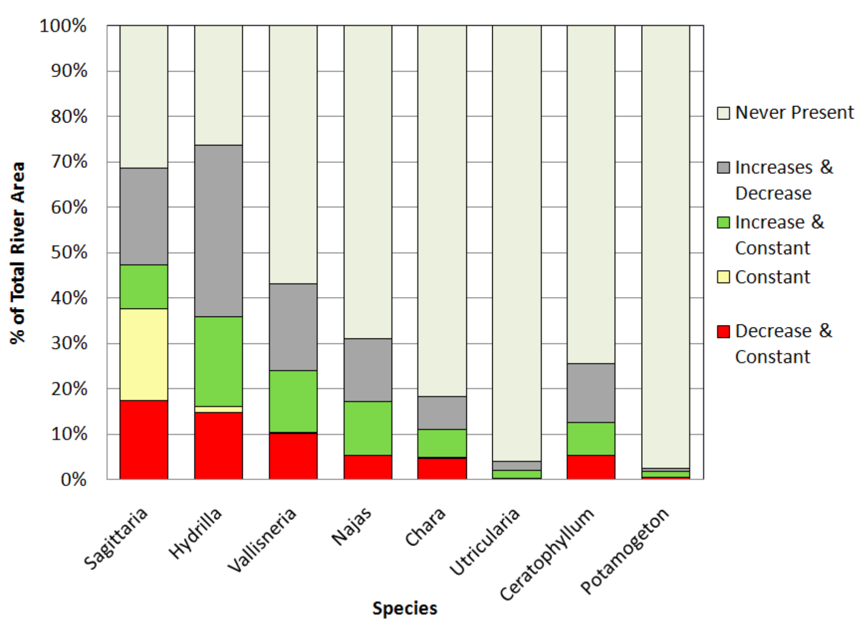

Figure 3.1.5. Cover category change trend from 1996 to 2011 as percent of total river area

or increasing patches, and *Utricularia* smallest portion of stable or decreasing patches. Otherwise, the species had somewhat similar change conditions.

Figures 3.1.6 through 3.1.8 show change conditions by river zone. Most of the stable sagittaria areas were above zone 50. Sagittaria showed the largest portion of patches that were constant or decreasing in zones 51-60 and was the most variable in zones 61-80. Sagittaria was not mapped in zones 81-90 during any period (Figure 3.1.6). Hydrilla showed the greatest area of patches with both increase and decrease in cover (by both percent of individual species cover and percent of total river area) (Figures 3.1.4 and 3.1.5). All zones showed at least 20% increase/decrease in hydrilla, though zones 60 to 80 showed the greatest portion of increase and decrease (near 80%) (Figure 3.1.7). Zones 10 to 60 had a greater portion of increasing and constant hydrilla than any other species.

Vallisneria had patches of increase and constant in all zones except 81 through 90 (Figure 3.1.8). Zones 71 – 90 showed greater loss and constant values for *Vallisneria* than other zones. Southern naiad had patches with some increase and constant in all zones except 61-70 (Figure 3.1.9). Naiad was the only species to show increase and constant patches in zone 81-90, where the greatest decrease and constant hydrilla patches were. Sagittaria, *Vallisneria* and naiad had patches of increased and constant cover in zone 91-95, where there were also large hydrilla decreases.

In addition to assessing species changes as a change in cover category, polygon specific changes were also assessed as species changes from present (by combining all cover categories greater than 0%) and absent (0% cover category). Possible change conditions for a species for the three individual time intervals (1996 to 2000, 2000 to 2005 and 2005 to 2011) were:

- Species is absent both time periods in the polygon
- Species changes from absent to present in the polygon
- Species is present both time periods in the polygon
- Species changes from present to absent in the polygon

Figure 3.1.10 shows that (for the four species reported) the area of patches where each species was absent both time periods decreased, at least slightly, with each time interval. Hydrilla had the greatest decrease in area of patches were the species was absent both time periods (over 10% overall). Relatively speaking, all species had their largest gains and the smallest losses during the second interval (2000 to 2005). Losses appear to be greatest for all species during the most recent interval (2005 to 2011) and gains smallest during first interval (1996 to 2000). Hydrilla was subject to pesticide treatment as noted earlier. *Vallisneria* loss shows relatively less of an increase than other species from 1996 to 2000. *Vallisneria* gains were essentially equal to losses during that interval. *Vallisneria* was the most constant (present to present) during the middle interval and was almost as constant during the last interval. The 2005-2011 interval saw equal areas increase (absent to present) as it did constant during the last interval and an area about 2/3 that size that decreased from present to absent. The greatest present to absent change for eelgrass was 1996-2000. Naiad had the greatest constant area in the middle interval, the greatest decreased area in the first interval, and the greatest increase area in the latest time interval.

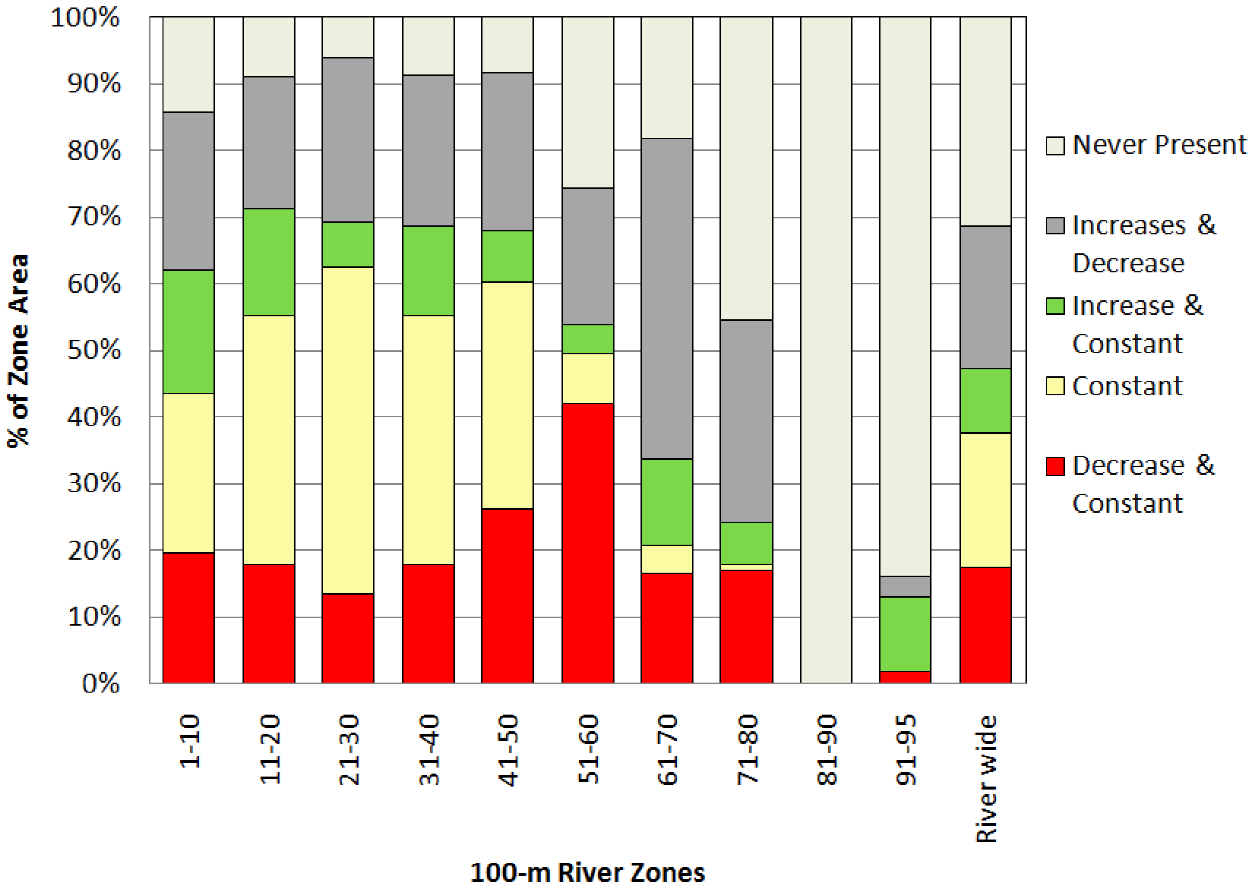

Figure 3.1.6. Cover category change trend in *Sagittaria kurziana* from 1996 to 2011 by 1-km river zone (from the headspring)

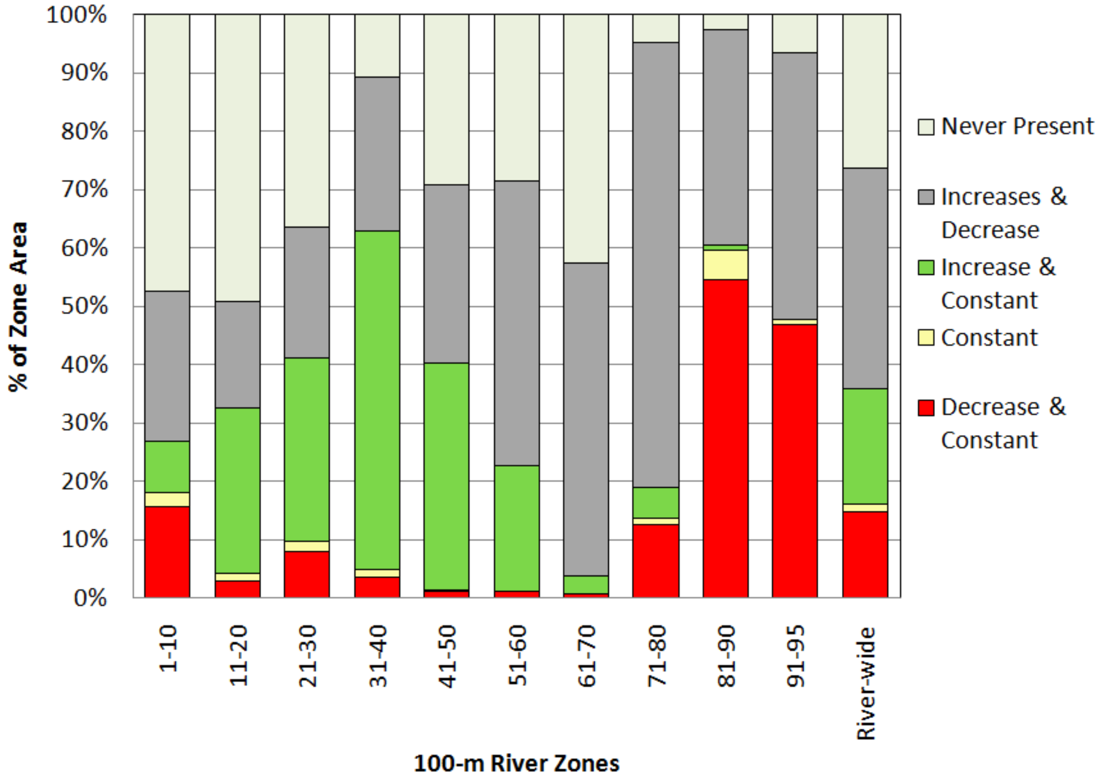

Figure 3.1.7. Cover category change trend in *Hydrilla verticillata* from 1996 to 2011 by 1-km river zone

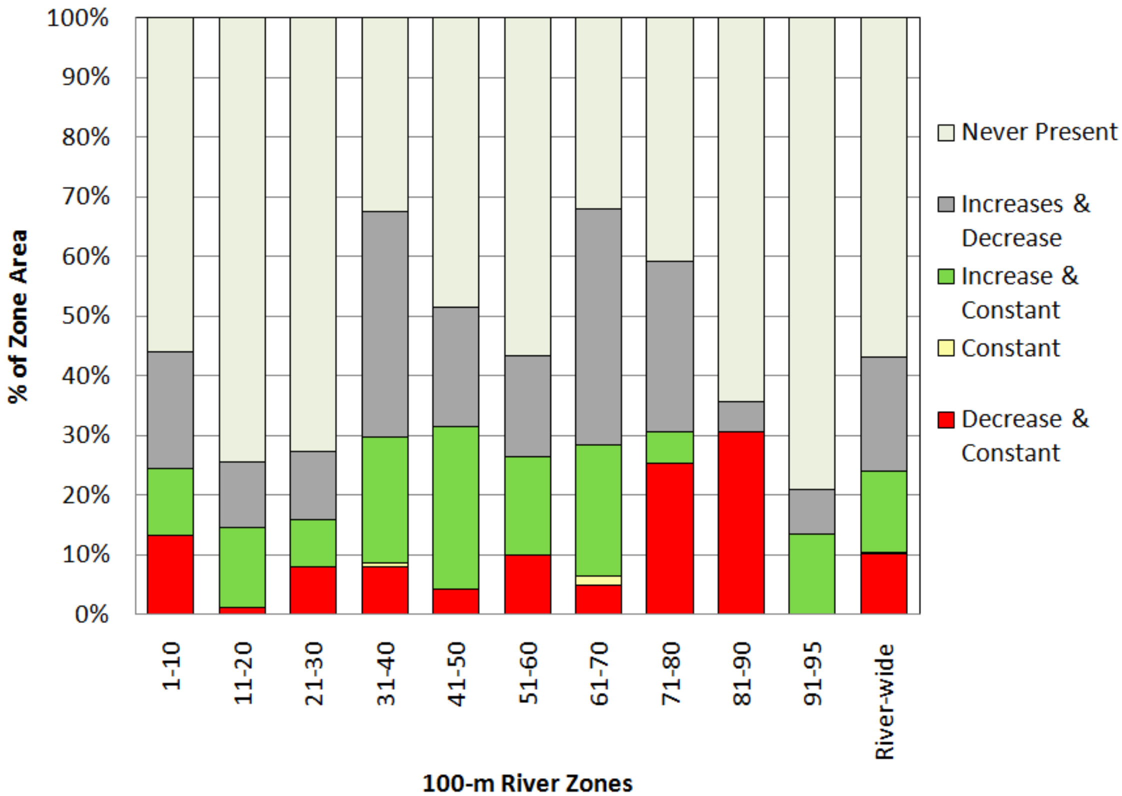

Figure 3.1.8. Cover category change trend in *Vallisneria americana* from 1996 to 2011 by 1-km river zone

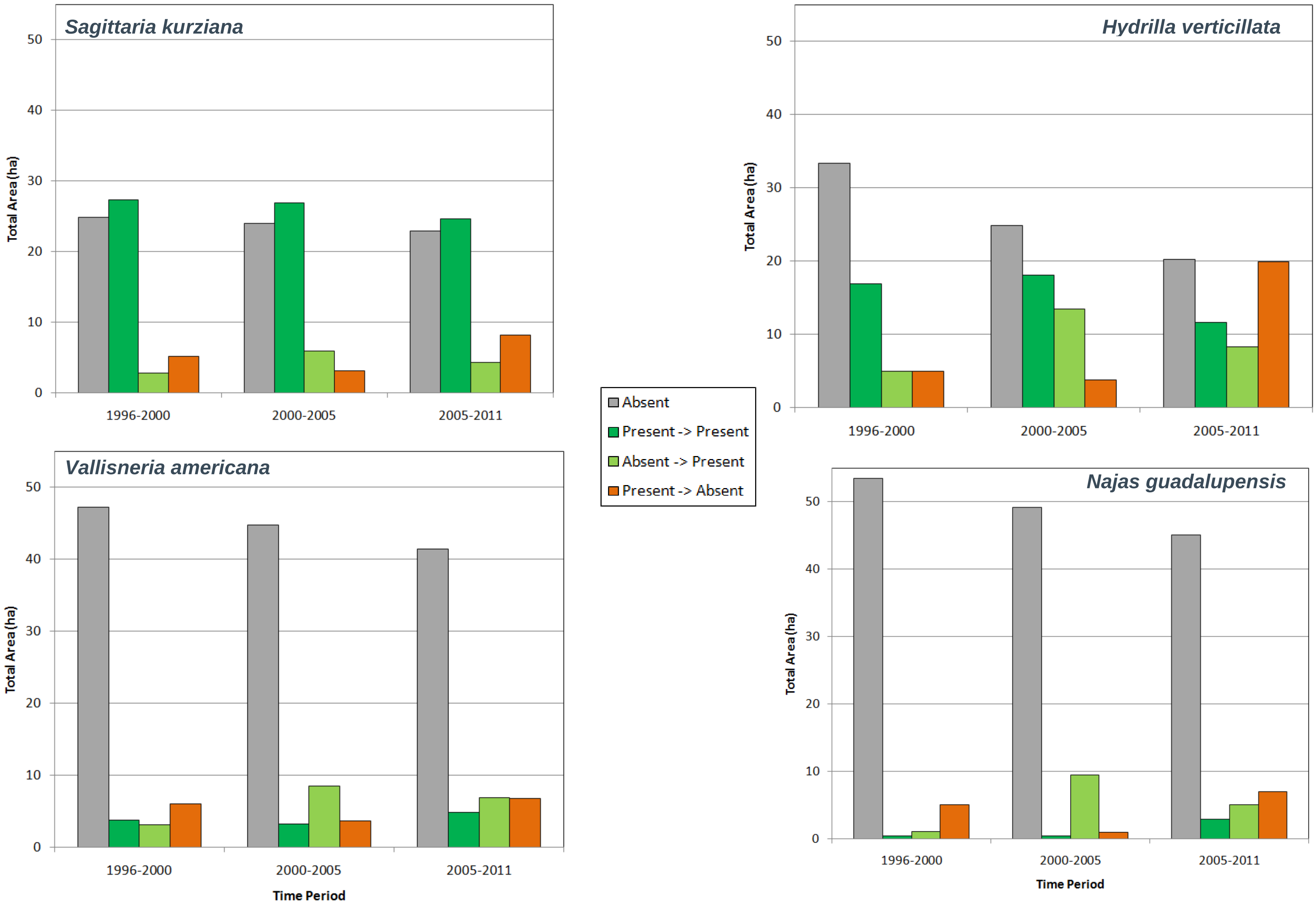

Figure 3.1.9. Presence/absence changes for four SAV species from 1996-2000, 2000-2005, and 2005-2011

3.2. SAV Area and Changes in Area

Maps of native and exotic SAV on the rainbow river in 2011, 2005, 2000, and 1996 are in Appendix A. The relative area of each species in each of the four mapping periods is shown in hectares (Table 3.2.1). These values are shown in acres in Appendix D

3.2.1. Native and Exotic Species

The relative area of all SAV species in the Rainbow River in 2011 was 28.80 ha which is considerably lower than the 35 ha and 38 ha values from previous years (Table 3.2.1). Native SAV species comprised 24.75 of the 28.80 ha. Native species have fluctuated from 26 ha in 1996 to 24 ha and 27 ha in 2000 and 2005 respectively. The relative area of the exotic SAV species hydrilla in 2011 was 4.05 ha, notably less than the 9 to 11 ha totals observed in previous years. Figure 3.2.1 shows relative area of native and exotic SAV species by 100-m river zone in 1996, 2000, 2005 and 2011. While there are some differences between the first three years, 2011 stands out as being distinctly different. Most of this difference is a result of changes in hydrilla cover and it is discussed further in later sections. The actual areas of the river where different cover categories of individual SAV species were present are shown in hectares in Table 3.2.2. SAV occupied 41.48 actual hectares in 2011 or 69% of the open-water river area. The area of bare substrate increased a large amount in the 2005 to 2011 period. This was by far the largest increase in the 1996-2011 time spans.

3.2.2. Strap-leafed sagittaria (*Sagittaria kurziana*)

The 2011 relative area for native SAV species *Sagittaria kurziana* was approximately 15.6 ha. This was by far the largest relative area of any species as was the case in past years. It accounted for approximately 54% of the SAV relative area in the Rainbow River in 2011. The relative area of sagittaria decreased in 2000, 2005 and 2011. The largest relative area decrease was 20% in 2011 and the overall decrease was 23%. However, sagittaria comprised approximately 54% of the SAV relative area in 2011, which was slightly larger than the 2005 52% value, but smaller than the 57% value in 2000 and 1996. Sagittaria had greater changes in the lower percent cover categories and lesser changes in the higher percent cover categories (Table 3.2.2).

The pattern of sagittaria presence from the headspring to the river mouth is shown by 100-m segments for all four mapping years in Figure 3.2.2. Sagittaria has consistently occupied over 50% of the river area upstream of river zone 55. The decrease in the upper-most zone (zone 1) after 1996 represents construction of the state park swimming area. Sagittaria presence decreased below river zone 55 in the 1996 to 2000 period. It increased in the same zones from 2000 to 2005, and then decreased again from 2005 to 2011. Below zone 91 however, sagittaria has consistently increased since 1996. This increase was most pronounced in the 2005 to 2011 period, when hydrilla had a pronounced decrease in those zones.

Sagittaria is unique among all the Rainbow River SAV species in that large areas of sagittaria maintained the same cover categories from 1996 to 2011. Almost all of these beds were located upstream of zone 50. The stability of sagittaria cover in the top 50 zones (5 km) of the river is the driving factor behind the relative small number of changes in the upper river’s SAV cover identified in section 3.1.

3.2.3. Hydrilla (*Hydrilla verticillata*)

Hydrilla verticillata was the second-most prevalent SAV species in the Rainbow River during the 1996 to 2011 period. Maps showing hydrilla percent cover in 1996, 2000, and 2005 are in Appendix A where hydrilla is represented by the “exotic” category. After increasing slightly between the first and second mapping intervals, hydrilla relative area decreased substantially from 10.90 ha to 4.05 ha in the 2005 to 2011 interval (Table 3.2.1). This represents a 63% decline from 2005 to 2011 and a 58% net decline in the 1996 to 2011 period. Hydrilla coverage by 100-m zone from 1996 to 2011 is shown in Figure 3.2.3.

Table 3.2.1. Change analysis of SAV, emergent and woody vegetation, and bare areas mapped in the Rainbow River 1996 to 2011. Relative areas calculated by transforming Braun-Blanquet categorical percent covers to hectares. River-wide species comprise 94% of total SAV coverage and are shown shaded in bold. Un-shaded species only occur in the headspring

RELATIVE AREAS												
	Hectares	Hectares	Hectares	Hectares	Hectares	Hectares	Hectares	Hectares	%	%	%	%
SAV Species	**1996 Relative Area**	**2000 Relative Area**	**2005 Relative Area**	**2011 Relative Area**	**96-'00 Change**	**00-'05 Change**	**05-'11 Change**	**96-'11 Change**	**96-'00 Change**	**00-'05 Change**	**05-'11 Change**	**96-'11 Change**
Sagittaria kurziana	**20.36**	**19.87**	**19.65**	**15.63**	**-0.48**	**-0.23**	**-4.02**	**-4.73**	**-2%**	**-1%**	**-20%**	**-23%**
Hydrilla verticillata	**9.67**	**10.43**	**10.90**	**4.05**	**0.76**	**0.47**	**-6.86**	**-5.63**	**8%**	**5%**	**-63%**	**-58%**
Vallisneria americana	**2.47**	**2.34**	**3.27**	**3.10**	**-0.13**	**0.93**	**-0.17**	**0.64**	**-5%**	**40%**	**-5%**	**26%**
Najas quadalupensis	**1.02**	**0.39**	**1.86**	**2.30**	**-0.63**	**1.47**	**0.45**	**1.29**	**-62%**	**376%**	**24%**	**126%**
Chara sp.	**0.57**	**0.84**	**0.39**	**1.22**	**0.27**	**-0.45**	**0.83**	**0.65**	**47%**	**-53%**	**213%**	**115%**
Ceratophyllum demersum	**1.06**	**0.63**	**1.09**	**0.73**	**-0.43**	**0.46**	**-0.36**	**-0.33**	**-40%**	**73%**	**-33%**	**-31%**
Utricularia sp.	0.40	0.06	0.51	0.87	-0.35	0.45	0.37	0.47	-86%	783%	73%	116%
Potamogeton illinoensis	0.23	0.29	0.27	0.60	0.06	-0.01	0.33	0.38	27%	-5%	120%	167%
Ludwigia repens	0.02	0.03	0.10	0.09	0.004	0.07	-0.01	0.07	16%	266%	-8%	291%
Fontinalis sp.	0.00	0.00	0.03	0.07	0.000	0.03	0.05	0.07			171%	
Myriophyllum sp.	0.00	0.01	0.00	0.05	0.005	0.00	0.05	0.05	125%	-51%	1228%	1365%
Zizania aquatica	0.00	0.00	0.01	0.04	0.000	0.01	0.03	0.04			267%	
Nasturitium sp.	0.001	0	0.003	0.01	-0.001	0.003	0.01	0.01	-100%	100%	399%	1207%
Hydrocotyle sp.	0.001	0	0.001	0	-0.001	0.001	-0.001	-0.001	-100%	100%	-100%	-100%
Total	**35.81**	**34.88**	**38.09**	**28.80**	**-0.92**	**3.21**	**-9.30**	**-7.01**	**-3%**	**9%**	**-24%**	**-20%**
Native Species	**26.13**	**24.45**	**27.19**	**24.75**	**-1.68**	**2.73**	**-2.44**	**-1.39**	**-6%**	**11%**	**-9%**	**-5%**
Exotic Species**	**9.67**	**10.43**	**10.90**	**4.05**	**0.76**	**0.47**	**-6.86**	**-5.63**	**8%**	**5%**	**-63%**	**-58%**
TOTAL AREAS												
	1996 Total Area	**2000 Total Area**	**2005 Total Area**	**2011 Total Area**	**96-'00 Change**	**00-'05 Change**	**05-'11 Change**	**96-'11 Change**	**96-'00 Change**	**00-'05 Change**	**05-'11 Change**	**96-'11 Change**
Total SAV Occupied Area	52.92	51.15	53.57	41.48	-1.76	2.42	-12.09	-11.43	-3%	5%	-23%	-22%
Bare	7.11	8.87	6.45	18.54	1.76	-2.42	12.09	11.43	25%	-27%	187%	161%
Emergent	9.97	10.15	11.56	12.72	0.18	1.40	1.16	2.75	2%	14%	10%	28%
Forested	10.84	10.55	10.64	10.53	-0.28	0.08	-0.11	-0.31	-3%	1%	-1%	-3%
Total River Area	**80.84**	**80.73**	**82.22**	**83.27**	**-0.10**	**1.49**	**1.05**	**2.44**	**0%**	**2%**	**1%**	**3%**

Notes: ** Hydrilla

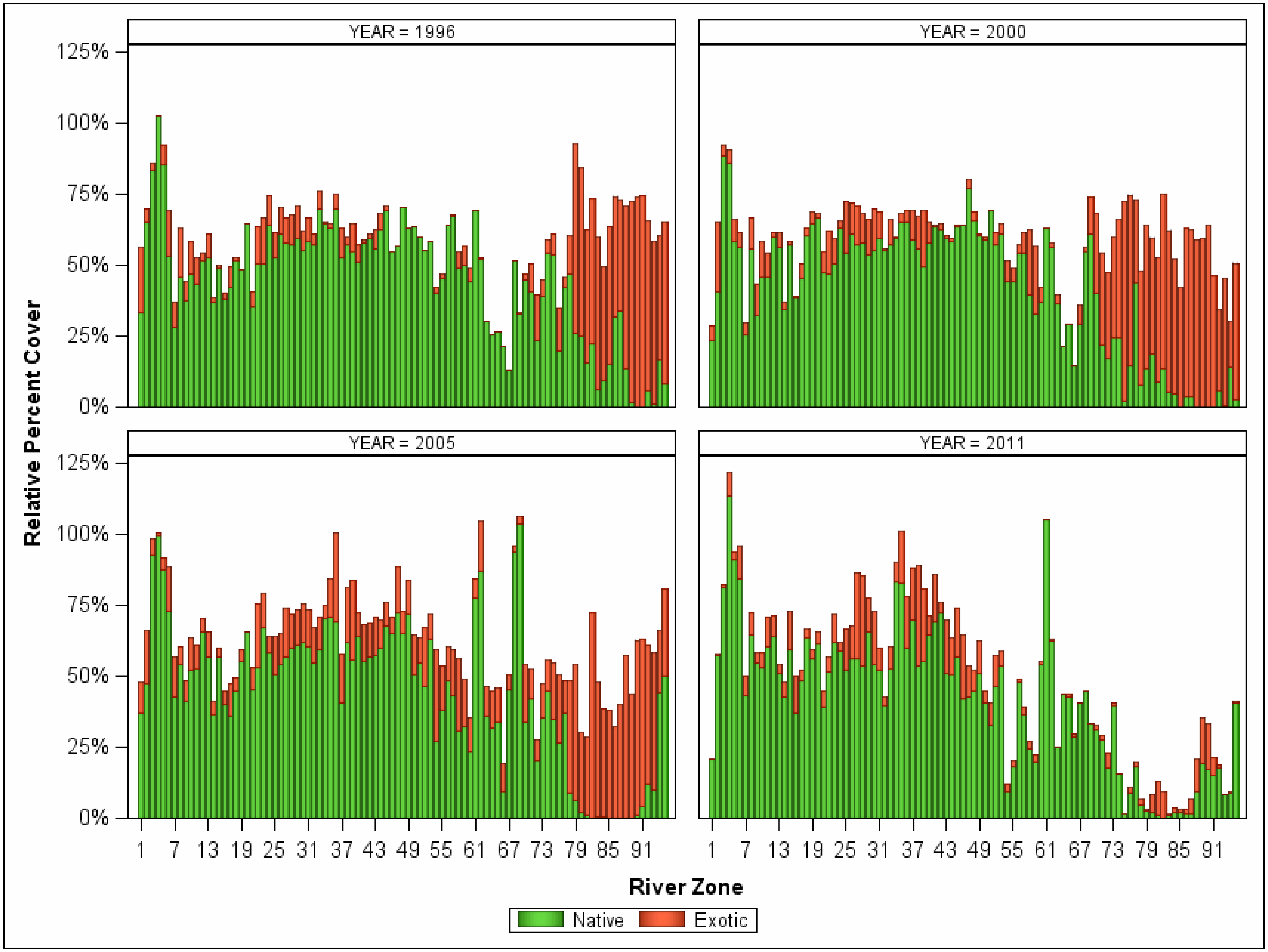

Figure 3.2.1. Relative area of native and exotic SAV species by 100-m river zone in 1996, 2000, 2005, and 2011

Table 3.2.2. Actual river area (ha) occupied by different cover categories of SAV species in 2011

Species	Year	0-10% Cover Area	10-50% Cover Area	50-100% Cover Area	Area of All Covers	0-10% Cover % of River	10-50% Cover % of River	50-100% Cover % of River	All Covers Total % of River
Sagittaria kurziana	1996	2.36	5.12	24.94	**32.42**	4%	9%	42%	**54%**
	2000	1.79	3.17	25.11	**30.07**	3%	5%	42%	**50%**
	2005	3.86	5.10	23.90	**32.86**	6%	9%	40%	**55%**
	2011	5.40	4.13	19.38	**28.90**	9%	7%	32%	**48%**
Hydrilla verticillata	1996	6.99	3.91	10.87	**21.77**	12%	7%	18%	**36%**
	2000	5.36	4.81	11.63	**21.79**	9%	8%	19%	**36%**
	2005	12.70	8.52	10.29	**31.51**	21%	14%	17%	**53%**
	2011	11.15	6.74	1.99	**19.88**	19%	11%	3%	**33%**
Vallisneria americana	1996	4.00	4.50	1.22	**9.73**	7%	8%	2%	**16%**
	2000	2.29	2.58	1.94	**6.81**	4%	4%	3%	**11%**
	2005	5.65	3.37	2.64	**11.66**	9%	6%	4%	**19%**
	2011	6.65	2.37	2.74	**11.77**	11%	4%	5%	**20%**
Najas quadalupensis	1996	3.89	0.79	0.78	**5.46**	6%	1%	1%	**9%**
	2000	0.79	0.36	0.33	**1.47**	1%	1%	1%	**2%**
	2005	6.73	1.89	1.27	**9.89**	11%	3%	2%	**16%**
	2011	3.37	2.97	1.66	**8.00**	6%	5%	3%	**13%**
Chara spp.	1996	3.08	1.38	-	**4.47**	5%	2%	0%	**7%**
	2000	0.52	0.88	0.73	**2.13**	1%	1%	1%	**4%**
	2005	2.32	0.81	0.04	**3.17**	4%	1%	0.1%	**5%**
	2011	2.58	2.00	0.66	**5.24**	4%	3%	1%	**9%**
Utricularia spp.	1996	0.21	0.82	0.20	**1.23**	0.3%	1%	0.3%	**2%**
	2000	0.13	0.17	-	**0.30**	0.2%	0.3%	0%	**0.5%**
	2005	0.14	0.26	0.56	**0.96**	0.2%	0.4%	1%	**2%**
	2011	0.45	0.40	0.98	**1.82**	1%	1%	2%	**3%**
Ceratophyllum demersum	1996	5.61	1.63	0.39	**7.63**	9%	3%	1%	**13%**
	2000	1.42	1.06	0.33	**2.81**	2%	2%	1%	**5%**
	2005	5.65	1.23	0.59	**7.47**	9%	2%	1%	**12%**
	2011	6.21	0.83	0.23	**7.27**	10%	1%	0%	**12%**
Potamogeton illinoensis	1996	-	0.38	0.15	**0.53**	0%	1%	0.3%	**1%**
	2000	0.03	0.14	0.33	**0.49**	0.05%	0.2%	1%	**1%**
	2005	0.19	0.10	0.31	**0.60**	0.3%	0.2%	1%	**1%**
	2011	0.07	0.06	0.78	**0.91**	0.1%	0.1%	1%	**2%**
Ludwigia repens	1996	0.21	0.05	-	**0.25**	0.3%	0.1%	0%	**0.4%**
	2000	0.04	0.09	-	**0.13**	0.1%	0.1%	0%	**0.2%**
	2005	0.20	0.30	0.004	**0.50**	0.3%	0.5%	0.01%	**1%**
	2011	0.89	0.17	-	**1.05**	1%	0.3%	0%	**2%**
Fontinalis spp.	1996	-	-	-	**-**	0%	0%	0%	**0%**
	2000	-	-	-	**-**	0%	0%	0%	**0%**
	2005	0.26	0.05	-	**0.31**	0.4%	0.1%	0%	**1%**
	2011	0.54	0.14	0.01	**0.68**	1%	0.2%	0.01%	**1%**
Myriophyllum spp.	1996	0.07	-	-	**0.07**	0.1%	0%	0%	**0.1%**
	2000	0.02	0.02	-	**0.05**	0.04%	0.04%	0%	**0.1%**
	2005	0.07	0.00	-	**0.07**	0.1%	0.005%	0%	**0.1%**
	2011	0.25	0.14	0.00	**0.39**	0.4%	0.2%	0.004%	**1%**
Nasturitium spp.	1996	0.02	-	-	**0.02**	0.04%	0%	0%	**0.04%**
	2000	-	-	-	**-**	0%	0%	0%	**0%**
	2005	0.02	0.01	-	**0.03**	0.04%	0.01%	0%	**0.05%**
	2011	-	-	0.02	**0.02**	0%	0%	0.03%	**0.03%**
Zizania aquatica	1996	-	-	-	**-**	0%	0%	0%	**0%**
	2000	-	-	-	**-**	0%	0%	0%	**0%**
	2005	0.24	-	-	**0.24**	0.4%	0%	0%	**0.4%**
	2011	0.32	0.09	-	**0.41**	1%	0.2%	0%	**1%**
Hydrocotyle spp.	1996	0.02	-	-	**0.02**	0%	0%	0%	**0%**
	2000	-	-	-	**-**	0%	0%	0%	**0%**
	2005	0.02	-	-	**0.02**	0.03%	0%	0%	**0.03%**
	2011	-	-	-	**-**	0%	0%	0%	**0%**

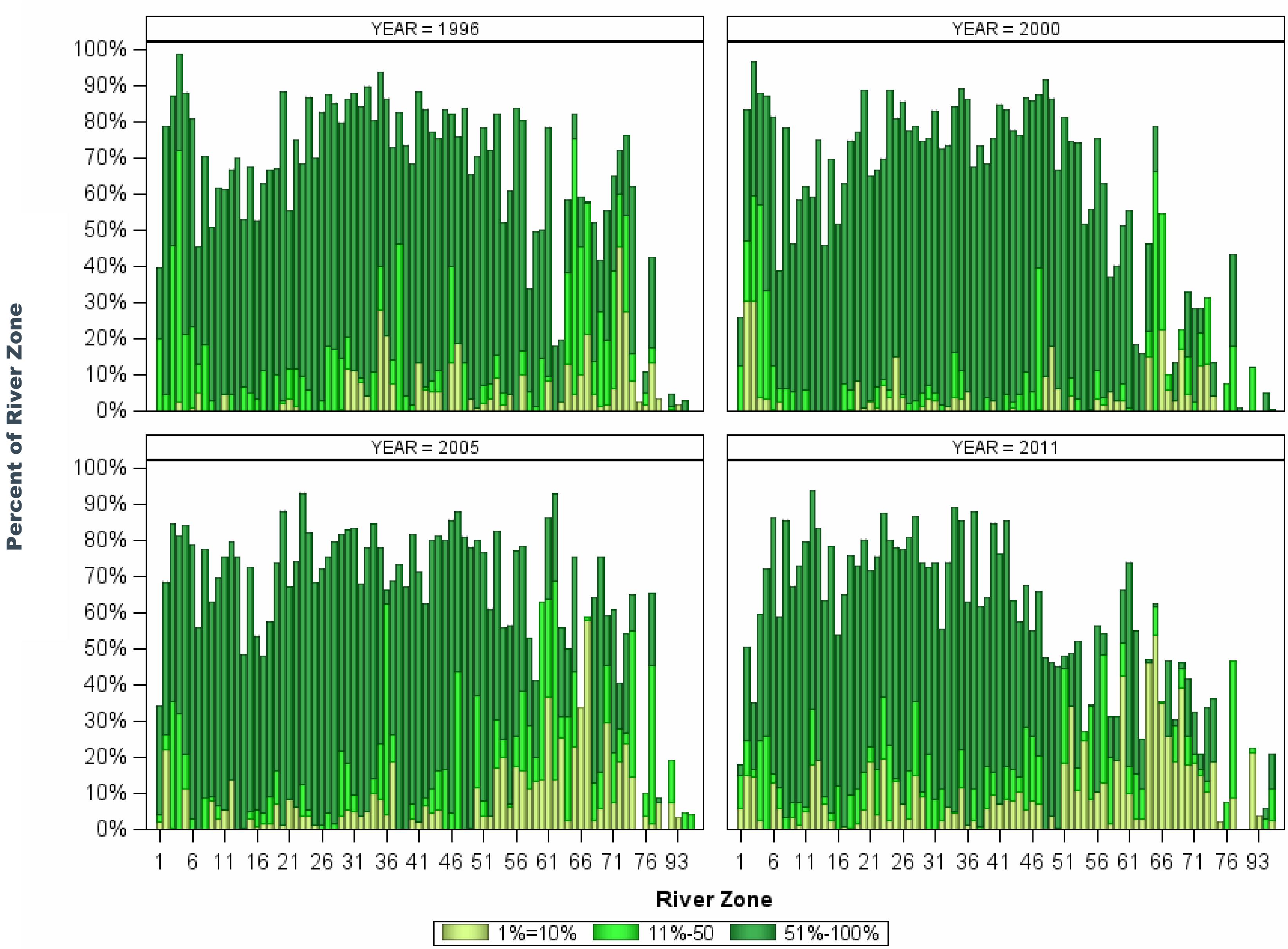

Figure 3.2.2. Percent of 100-m river zones with Sagittaria kurziana present in 1%-10%, 11%-50%, and 51%-100% cover (1996-2011)

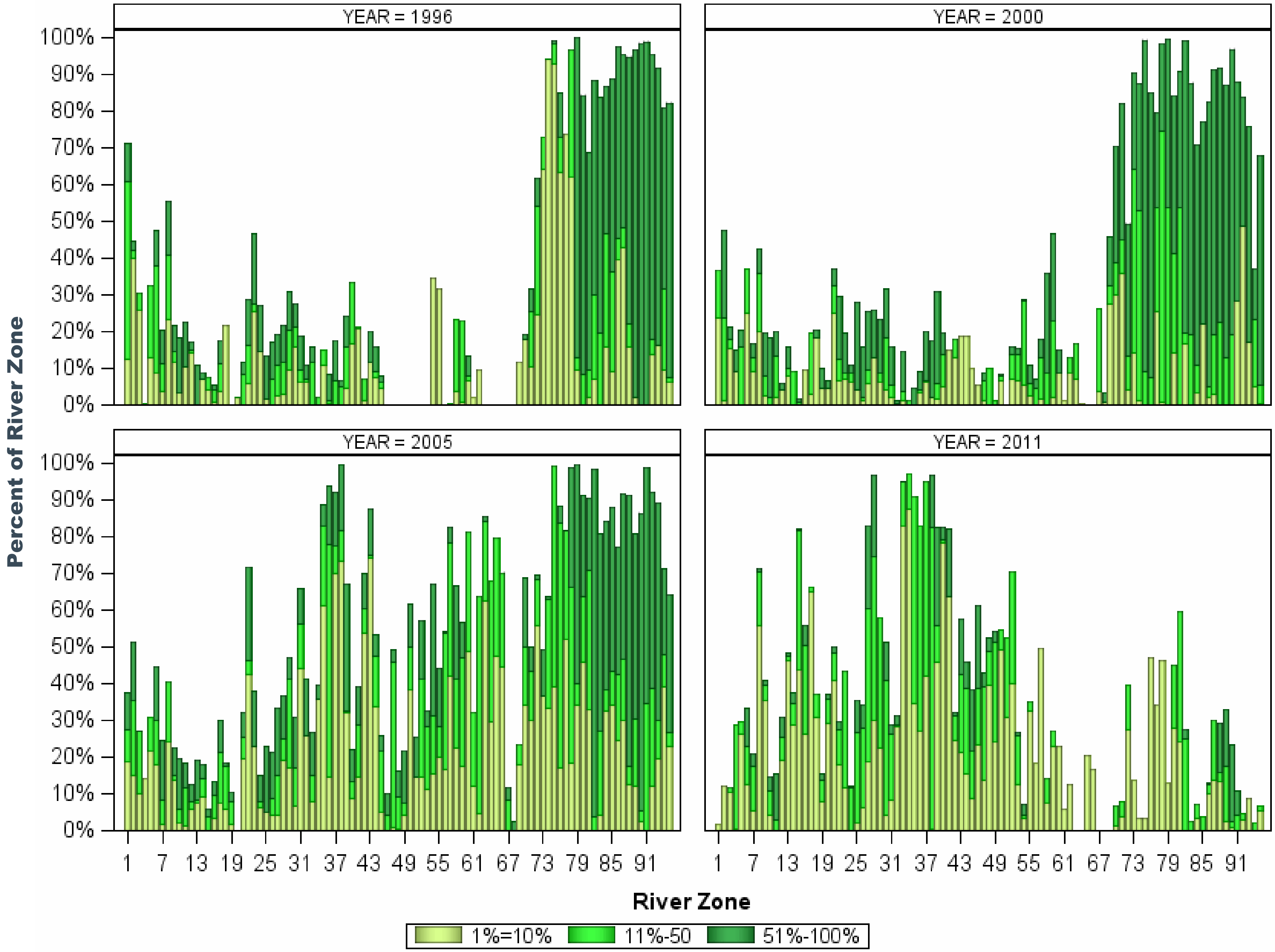

Figure 3.2.3. Percent of 100-m river zones with *Hydrilla verticillata* present in 1%-10%, 11%-50%, and 51%-100% cover (1996-2011)

Hydrilla distribution showed noteworthy changes. In 2000, hydrilla had increased between zone 40 and 67. In 2005 hydrilla increased in zones 20 – 67. There were mid-river increases between 2005 and 2011. More obvious though were the declines below zone 50. The 2005-2011 period decrease at the confluence was almost certainly the result of control and removal treatments. Other observed decreases may result from treatment as well. Hydrilla is the only species that showed continued expansion and percent cover increases in the upper river from 1996 to 2011. Other species showed both increases and decreases during this period.

Hydrilla relative cover remained fairly constant in the 2000 to 2005 period (Table 3.2.1), but the total area of the river with hydrilla present increased almost 50% (Table 3.2.2). This difference is driven by decreases in area of high-percent cover polygons of hydrilla. At the same time, hydrilla invaded new polygons, but did so at low cover levels. This pattern of high cover decrease and low cover increase appeared to continue in the 2005 to 2011 period. Hydrilla cover categories decreased in numerous zones resulting in major declines in both the relative area and the total area in 2011. The area occupied by hydrilla in the 50% to 100% cover category decreased by over 80% while the areas occupied by hydrilla in the 10% to 50% and 1 to 10% cover categories decreased by 21% and 10% respectively.

Hydrilla was largely confined to the river edges above zone 35 (see Appendix A maps) in all years. Between zone 34 and zone 60, some large beds extended across the river in all years. This is the area where the increase in lower cover categories (1-10% and 10-50%) described for the 2000-2005 and 2005-2011 periods manifests. Since the first mapping in 1996, hydrilla was present in the entire cross section of the river from river zone 73 to the confluence (as opposed to individual beds that extended across the river). By 2005, hydrilla was present in most of the river cross section from the confluence to zone 70. The greatest change in hydrilla relative area from 2005 to 2011 was seen downstream of river zone 50 (Figures 3.2.1 and 3.2.3). Between 2005 and 2011 the total area with hydrilla present below river zone 55 decreased dramatically, however the total area with hydrilla present increased somewhat between river zone 30 and 40 during this same period.

3.2.4. Eelgrass or Tapegrass (*Vallisneria americana*)

Vallisneria americana was the second-most common native SAV species in the Rainbow River and the third most common species overall. It accounted for approximately 11% of the SAV relative area in 2011, a decrease of 5% from 2005. Eelgrass also decreased slightly from 1996 to 2000 but increased 40% in relative area from 2000 to 2005 for an increase of 26% in relative area from 1996 -2011 (Table 3.2.1).

Eelgrass coverage by 100-m river zone is shown in Figure 3.2.4. Changes in eelgrass cover follow a somewhat similar distribution over the years, but with two marked changes in zones 75 to 85. In these zones, eelgrass was present in 1996 and 2000, disappeared by 2005, and remained absent in 2011. There was also a noticeable increase in 2005 and 2011 in the five zones nearest the confluence. This is the same area that showed an increase in sagittaria during the same period. Anecdotal observations suggest that eelgrass may be better able to establish or expand in areas that have undergone hydrilla treatment. This may be worthy of closer study.

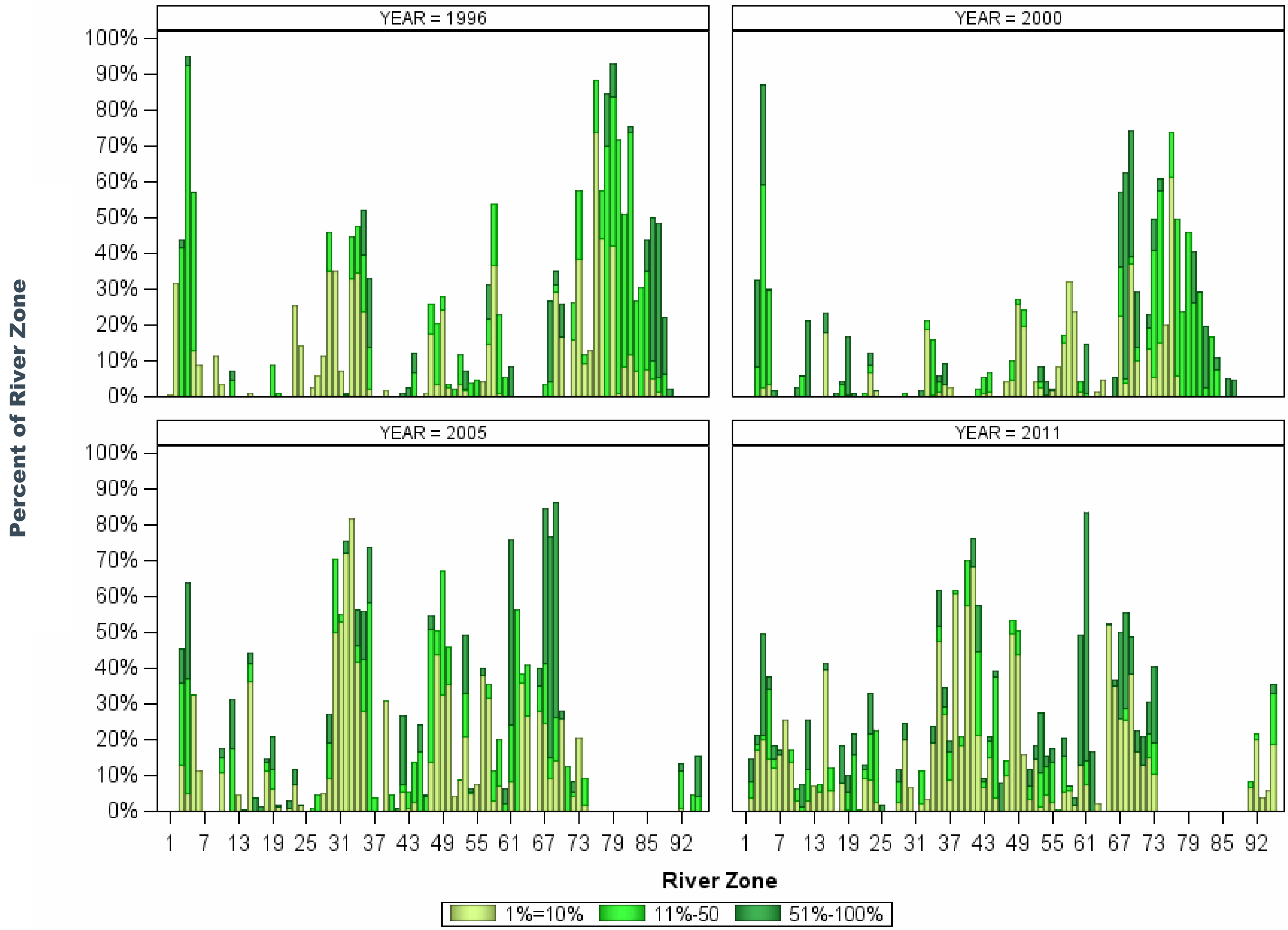

Figure 3.2.4. Percent of 100-m river zones with eelgrass (*Vallisneria americana*) present in 1%-10%, 11%-50%, and 51%-100% cover (1996-2011)

3.2.5. Southern naiad (*Najas guadalupensis*)

Southern naiad (*Najas guadalupensis*) was the fourth-most prevalent SAV species in the Rainbow River during the 1996 to 2011 period. It comprised 8% of the SAV species relative area in 2011. Southern naiad relative area has been variable during the 1996 to 2011 period (Table 3.2.1.) reaching a low of 0.39 ha in 2000 and a high of 2.3 ha in 2011. Relative area increased somewhat during the 2005-2011 period, but total area occupied by southern naiad decreased slightly (Table 3.2.2). There was a large decrease in the area occupied by southern naiad in the 1%-10% range, but increases in the areas occupied in the 10%-50% range and the 50%-100% range.

The percent of 100-m river zones occupied by southern naiad from 1996 to 2011 is shown in Figure 3.2.5. Naiad distribution in 2011 has some similarities to that in 2005. Southern naiad distribution in 2000 was very different than other years. There was a large southern naiad loss in the area of river zone 61 to 80 and around zone 30 in the 2005 to 2011 period.

3.2.6. Muskgrass (Chara spp.)

Muskgrass (*Chara* spp.) is a rooted macro algae, but was mapped with SAV species in the 2011 Rainbow River mapping effort in order to remain consistent with the methods used in 1996, 2000, and 2005. *Chara* was more prevalent in 2011 than 2005 ranking fifth in prevalence for SAV species. Muskgrass had a relative area of 0.5 ha in 1996 (Table 3.2.1). This increased to 0.84 ha in 2000 and decreased to 0.39 ha in 2005. Muskgrass relative area in 2011 was larger at 1.22 ha. The total river area occupied by muskgrass in 2011 was also larger than in previous years (Table 3.2.2). Muskgrass occupied 5.14 ha in 2011 as opposed to 3.15 in 2005. Areas occupied by *Chara* in the 50%-100% and 10%-50% cover categories increased, while the area in the 1%-10% category remained the same.

The changes described above were confined to the 4 kilometers of the middle and lower river occupied by muskgrass. The percent of 100-m river zones occupied by muskgrass from 1996 to 2011 is shown in Figure 3.2.6. Muskgrass was primarily located between river zones 30 and 70. Muskgrass occupied more of the 100-m zones in this range during 2011 accounting for increases in relative area and area occupied (absolute area of all cover categories combined).

3.2.7. Coontail (*Ceratophyllum demersum*)

Ceratophyllum demersum (coontail) was the seventh-most common species in the Rainbow River declining from the sixth-most common in 2005. Like many of the less common SAV species, Coontail relative area was relatively stable during the 1996 to 2005 period (Tables 3.2.1 and 3.2.2). It comprised approximately 3% of the relative SAV percent cover in the Rainbow River. The total area occupied by coontail of all cover categories was slightly more than 7 ha in 1996, 2005, and 2011. The 2000 event mapped much less coontail at less than 3 ha. The 2000 difference was primarily driven by a decrease in coontail of the 1%-10% cover category. The percent of 100-m river zones occupied by coontail from 1996 to 2011 is shown in Figure 3.1.7. Coontail presence shows a general pattern of increase from the headspring to the river mouth. Coontail occupied a slightly greater range of river zones in 2011 than in previous years. There was a decrease in coontail at the river mouth where hydrilla also decreased and sagittaria and eelgrass increased.

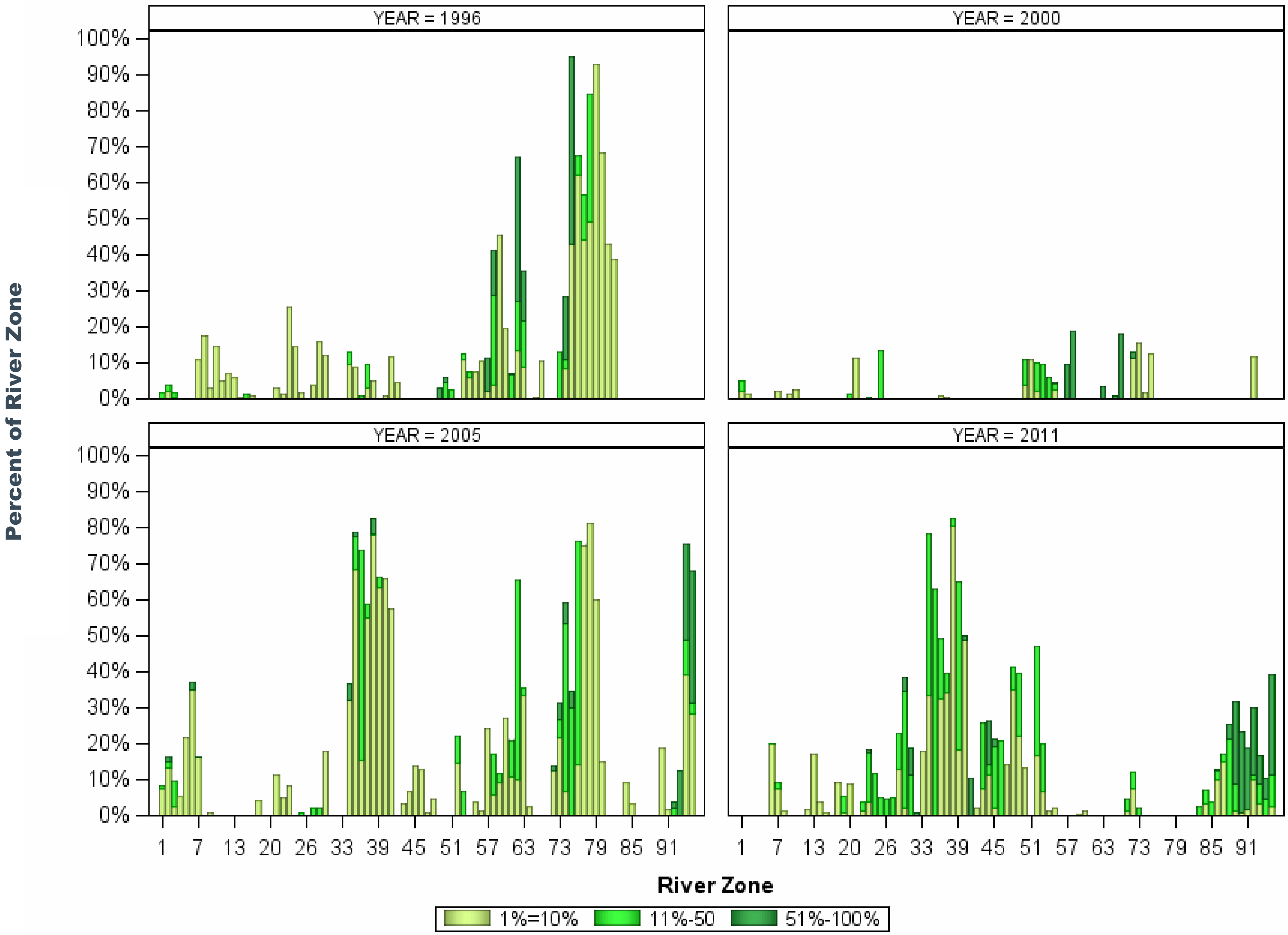

Figure 3.2.5. Percent of 100-m river zones with Southern naiad (*Najas guadalupensis*) present in 1%-10%, 11%-50%, and 51%-100% cover (1996-2011)

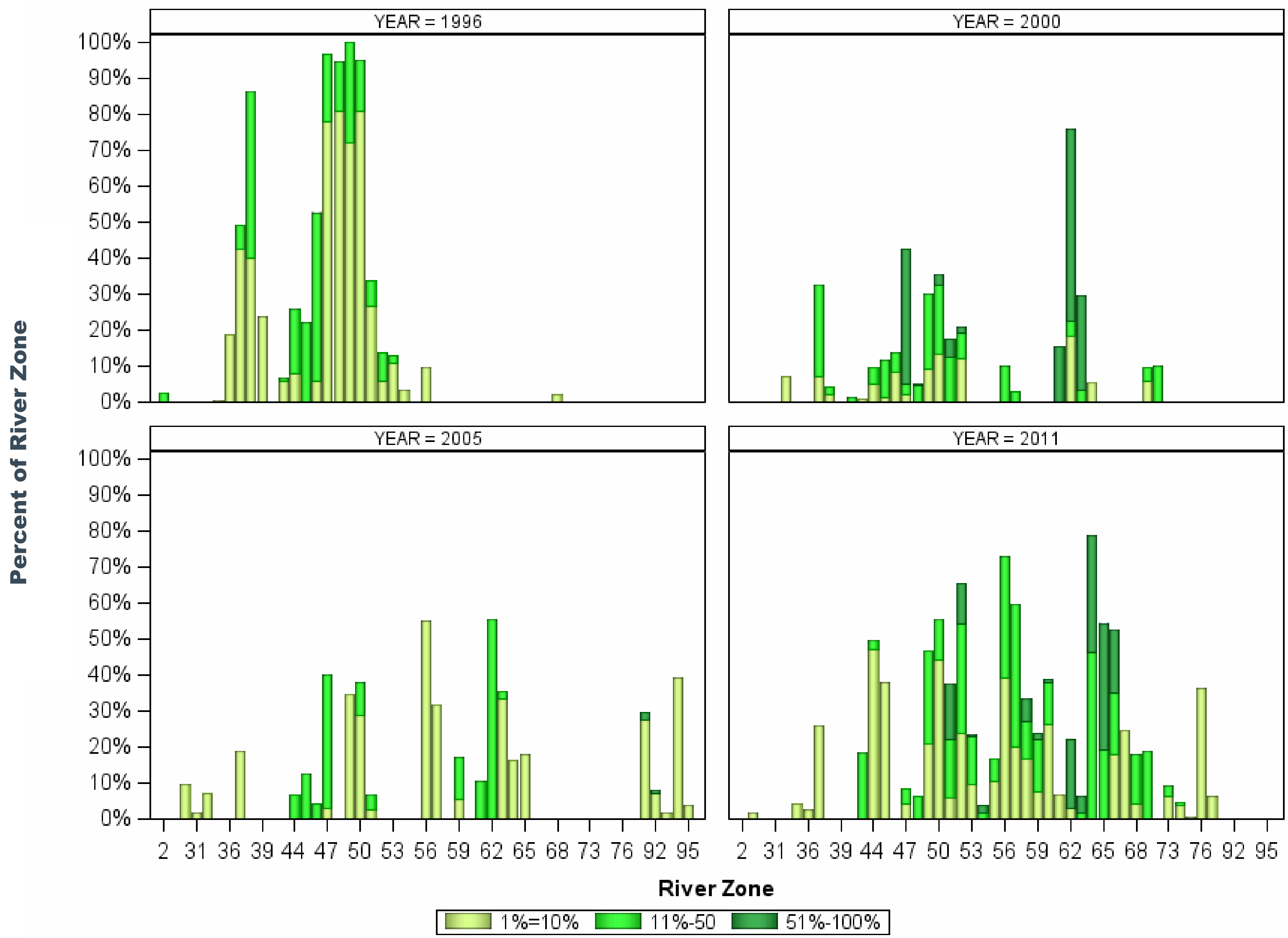

Figure 3.2.6. Percent of 100-m river zones with Muskgrass (*Chara* spp.) present in 1%-10%, 11%-50%, and 51%-100% cover (1996-2011)

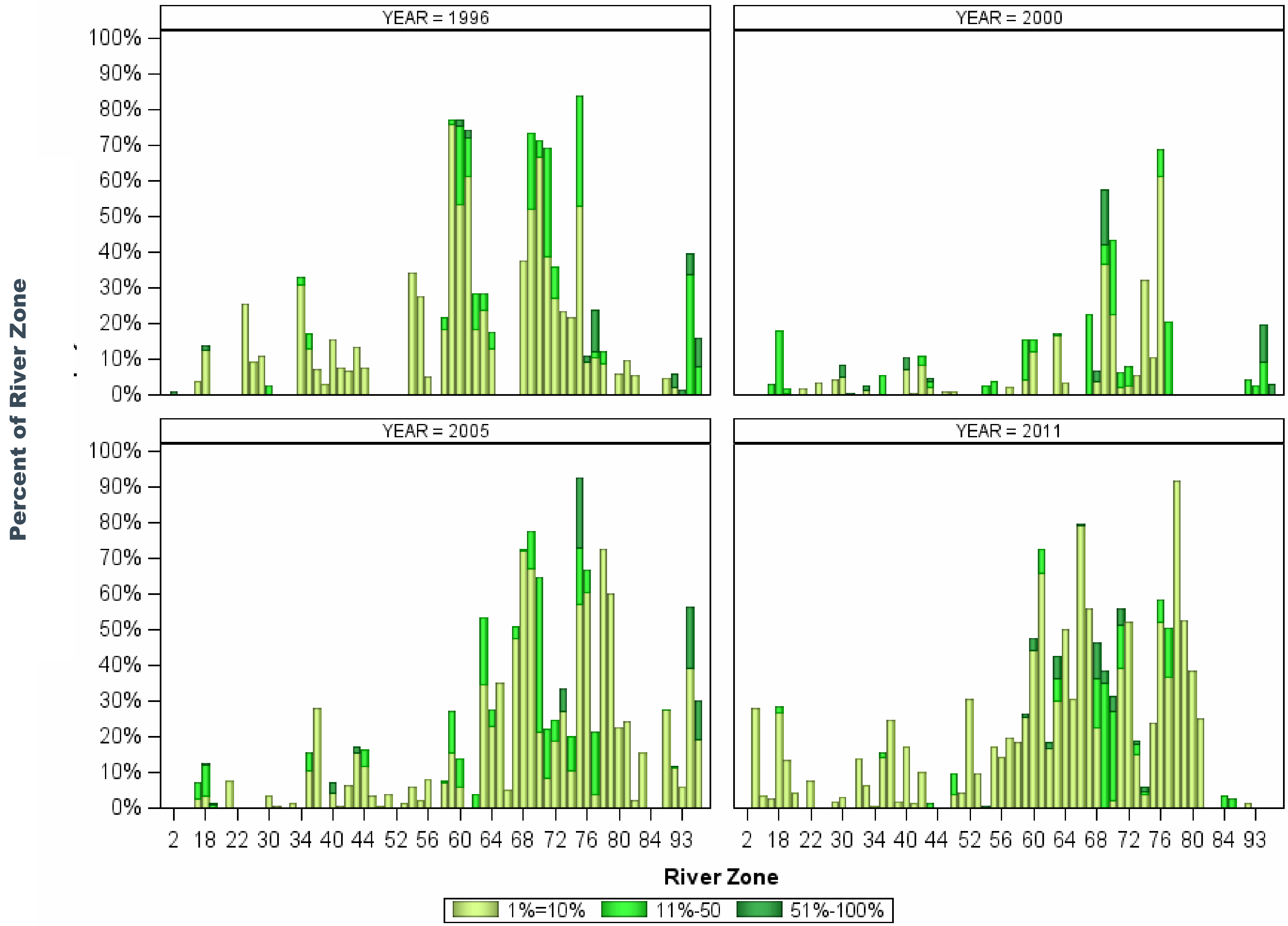

Figure 3.2.7. Percent of 100-m river zones with Coontail (*Ceratophyllum demersum.*) present in 1%-10%, 11%-50%, and 51%-100% cover (1996-2011)

3.3. 2011 Algae Mapping

Maps of benthic mat algae and epiphytic algae coverage on the Rainbow River in 2011 are given in Appendix B. The maps also show a vegetation condition index scored using algae and native/exotic SAV. Figures 3.3.1 and 3.3.2 graph the percent cover of benthic and epiphytic algae by 100-meter long zones beginning at the headspring (river zone 1) and moving downstream to the river mouth (river zone 95). Epiphytic algae coverage was calculated by multiplying the mid-point of the algae cover category for a given polygon by the relative percent cover of SAV in that polygon, and dividing by the total area of the polygon. Benthic algae percent cover was calculated using the midpoint of the cover category for each polygon and weighted for polygon area. The average epiphytic algae cover on the river was 27% and the average benthic algae coverage was 60%.

Figures 3.3.1 and 3.3.2 show two inflection points worth noting. First, the increase in benthic algae around river zone 46 (Figure 3.3.1) is the result in a change in mapping cover category rather than a dramatic increase in algae cover at that point. Algae was mapped in 0%-25%, 25%-75%, and 75%-100% cover categories. The shift around zone 46 represents a change from polygons with primarily the 25%-75% category to polygons with the 75%-100% category. This represents actual field conditions, but the algae cover increases on a fairly even gradient moving downstream from the headsprings not at an abrupt point. The second inflection point of note is the decrease in epiphytic algae coverage downstream of river zone 74 (3.3.2). This also represents actual field conditions, but it is indicative of a lack of attachment sites for epiphytic algae in an area dominated by benthic algal mats. Epiphytic algae would likely be present at high covers if the substrate was available.

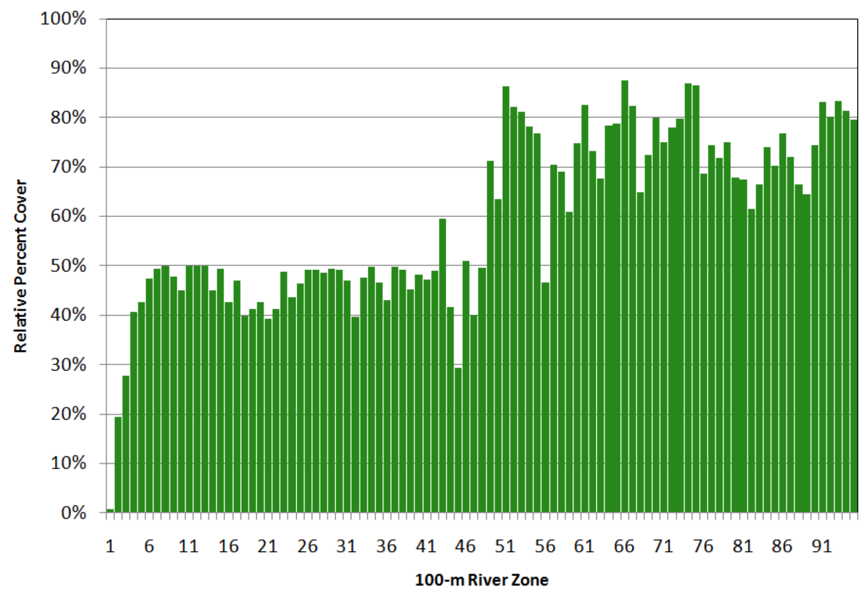

Figure 3.3.1. Relative percent cover of benthic algae by 100-m river zones in 2011

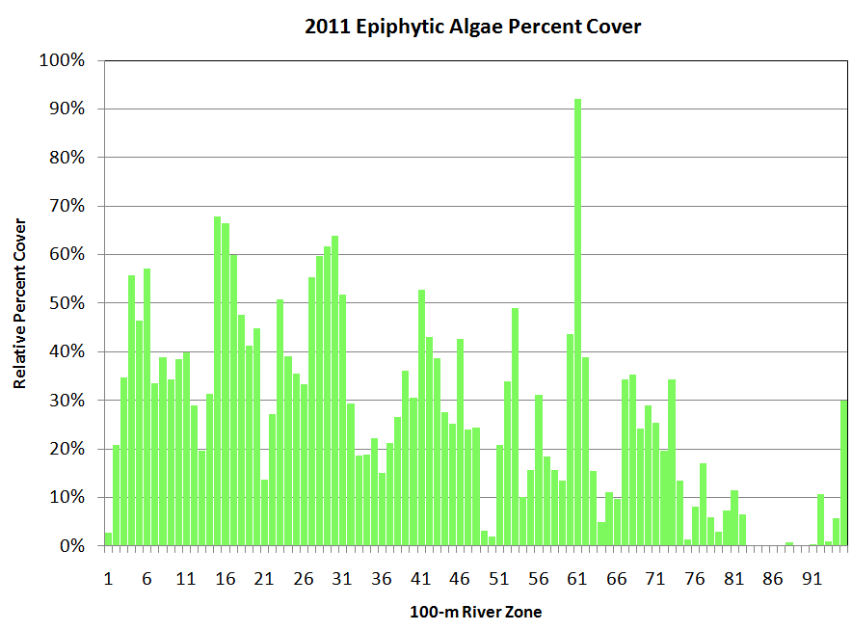

Figure 3.3.2. Relative percent cover of epiphytic algae by 100-m river zones in 2011

3.4. 2011, 2005, 2000, and 1996 Emergent Vegetation, Docks, and Springs Comparison

The overall area of herbaceous emergent vegetation increased by 22% since 1996. Between 1996 and 2000 the area decreased by 1%, between 2000 and 2005 the area increased by 13%, and it increased 10% during the most recent mapping interval (2005 to 2011). Forested or 'woody' emergent vegetation was generally unchanged within the mapping boundary. However, lower water levels and the resulting slight shift in shoreline location appeared to have produced slight alterations in the species observed beyond the river boundaries (upland of the river shoreline). The area and number of polygons in which individual species are dominant and non-dominant and the total area and number of polygons where they are present are given in Table 3.4.1.

The most drastic change in emergent plants was the increase of the vine, climbing hempweed or climbing hempvine (*Mikania scandens*). An example of a *Mikania* dominant bed is shown in Figure 3.4.1. In 2005 *Mikania* was present in 60 emergent beds totalling 7.4 ha. In 2011 *Mikania* was present in 49 beds (2.6 ha) and became dominant in 122 (9.1 ha) totalling 11.7 ha. Conversely, the most prominent emergent plant on the river, paspallum, decreased both in dominant area (9.6 to 8.3 ha) and the number of polygons (195 to 157) where it is dominant. The area of beds with paspallum increased in area overall however (from 103 to 126 ha of dominant and present polygons combined) due to an increase in area and number of polygons where it is present but not dominant (7 to 42 ha and 17 to 70 beds). Another prominent emergent plant, paspalidium, decreased both in the area dominant and present (2.6 to 2.4 ha combined) yet increased in number of polygons from 49 to 70 (number dominant polygons increased only from 39 to 41, present from 49 to 70). Note that in some cases, an increase in the number of polygons could be due to one polygon being divided into two. Also, when a species is mapped as being present in a polygon, it is not necessarily present throughout the entire polygon.

Mikania scandens (Figure 3.4.1) has always been present on the river. It has been a nuisance species during the entire mapping period (since 1996). Another *Mikania* species, *Mikania micrantha*, is listed as one of the 100-most noxious weeds in the world and has recently been indentified in south Florida (Sellers and Langeland, 2010). There is no indication that *M. micrantha* is on the Rainbow River though.

Figure 3.4.1. Emergent beds with heavy *Mikania* cover (left, zone 89) and no *Mikania* cover (right, mid to lower river

Table 3.4.1. Emergent vegetation areas and polygon presence in 2005 and 2011

	2005 Emergents						2011 Emergents						2005 to 2011 Change					
Species	Area of Polygons with Species (ha)	Polygons with Species (#)	Area Dominant (ha)	Polygons Dominant	Area Present Not Dominant (ha)	Polygons Present Not-Dominant	Area of Polygons with Species (ha)	Polygons with Species (#)	Area Dominant (ha)	Polygons Dominant	Area Present Not Dominant (ha)	Polygons Present Not-Dominant	Area of Polygons with Species (ha)	Polygons with Species (#)	Area Dominant (ha)	Polygons Dominant	Area Present Not Dominant (ha)	Polygons Present Not-Dominant
Paspalum spp.	**10.28**	**212**	9.62	195	0.65	17	**12.55**	**227**	8.35	157	4.20	70	**2.27**	**15**	-1.28	-38	3.55	53
Hydrocotyle umbellata	**8.85**	**94**	0.27	9	8.58	85	**8.51**	**107**	0.18	11	8.33	96	**-0.34**	**13**	-0.08	2	-0.26	11
Mikania scandens	**7.40**	**60**	0	0	7.40	60	**11.74**	**171**	2.61	49	9.13	122	**4.34**	**111**	2.61	49	1.73	62
Typha spp.	**5.11**	**27**	1.45	7	3.66	20	**6.01**	**36**	0.19	9	5.81	27	**0.90**	**9**	-1.26	2	2.16	7
Schoenoplectus tabernaemontani	**4.75**	**28**	0	0	4.75	28	**5.04**	**36**	0.36	6	4.69	30	**0.29**	**8**	0.36	6	-0.06	2
Pistia stratiotes	**4.36**	**53**	0.01	1	4.36	52	**1.98**	**26**	0.00	0	1.98	26	**-2.39**	**-27**	-0.01	-1	-2.38	-26
Cicuta mexicana	**3.72**	**15**	0	0	3.72	15	**0.89**	**20**	0	0	0.89	20	**-2.83**	**5**	0	0	-2.83	5
Sagittaria latifolia	**2.78**	**26**	0	1	2.78	25	**2.80**	**15**	1.51	4	1.30	11	**0.02**	**-11**	1.50	3	-1.48	-14
Paspalidium geminatum	**2.64**	**49**	1.11	39	1.53	10	**2.43**	**70**	1.05	41	1.38	29	**-0.21**	**21**	-0.06	2	-0.15	19
Hymenocallis crassifolia	**2.34**	**26**	0	0	2.34	26	**0.28**	**12**	0	0	0.28	12	**-2.07**	**-14**	0	0	-2.07	-14
Rhynchospora spp.	**2.30**	**13**	0.02	2	2.29	11	**2.69**	**29**	0.01	4	2.68	25	**0.39**	**16**	-0.002	2	0.39	14
Cladium jamaicense	**1.90**	**14**	0.01	2	1.89	12	**1.96**	**26**	0.18	5	1.77	21	**0.06**	**12**	0.17	3	-0.12	9
Nuphar luteum	**1.78**	**7**	0.23	1	1.55	6	**1.83**	**8**	0.23	1	1.60	7	**0.05**	**1**	<<0.001	0	0.05	1
Pontederia cordata	**1.35**	**5**	0.01	2	1.33	3	**0.83**	**5**	0.71	4	0.12	1	**-0.52**	**0**	0.69	2	-1.21	-2
Zizania aquatica	**1.29**	**5**	0.01	2	1.28	3	**0.99**	**12**	0.02	4	0.97	8	**-0.30**	**7**	0.01	2	-0.31	5
Colocasia esculenta	**1.16**	**32**	0.10	7	1.06	25	**1.56**	**19**	0	1	1.56	18	**0.40**	**-13**	-0.10	-6	0.50	-7
Polygonum spp.	**0.88**	**3**	0	0	0.88	3	**0.03**	**3**	0	0	0.03	3	**-0.86**	**0**	0.00	0	-0.86	0
Sagittaria lancifolia	**0.69**	**4**	0	0	0.69	4	**1.73**	**18**	0.10	2	1.63	16	**1.04**	**14**	0.10	2	0.94	12
Panicum spp.	**0.59**	**10**	0.01	2	0.58	8	**1.08**	**29**	0.04	9	1.04	20	**0.49**	**19**	0.03	7	0.46	12
Cyperus spp.	**0.19**	**4**	0.005	2	0.18	2	**-**	**-**	0	0	0	0	**-0.19**	**-4**	-0.005	-2	-0.18	-2
Alternanthera philoxeroides	**0.12**	**2**	0	0	0.12	2	**0.004**	**2**	0	0	0	2	**-0.12**	**0**	0	0	-0.12	0
Crinum americanum	**0.02**	**4**	0	0	0.02	4	**0.01**	**1**	0	0	0.01	1	**-0.01**	**-3**	0	0	-0.01	-3

The overall number of docks increased from two hundred forty-one in 2005 to two hundred fifty-one in 2011. Six docks were added in a planned residential development (Figure 3.4.2). A large dock with three boat slips was added at KP Hole County park and a tuber-exit dock added mid-river. Two other residential docks were added and two removed. The 2005 dock map was edited to include five locations where a boat was present during the 2005 and 2011 period though no dock was mapped in 2005. One site included the restaurant on the north side of the bridge and two are boat houses. The five docks were also included in the 2011 map.

There are 57,836 meters of natural shoreline and 13,601 meters of hardened shoreline. A slight change in shoreline is shown between 2000 and 2005 were the State Park added a canoe/kayak rental adjacent to the location where the State Park boat is docked as well as the campground. Between 2005 and 2011 the shoreline at the KP Hole County Park was modified. As described in Section 2.2 (development of new base map), the placement of docks and shoreline were updated using recent imagery. No changes in the number or location of springs were observed.

Figure 3.4.2. New docks since 2005 mapping, zone 67 and 68

3.5. Submerged Aquatic Vegetation and Emergent Vegetation Change Analysis

Figure 3.5.1 shows a comparison of median percent cover and other summary statistics for native and exotic SAV in individual 100-m river zones from 1996 to 2011. Changes in the area occupied by specific cover categories of individual species are given in Table 3.5.1. Figures 3.5.2 and 3.5.3 show the cumulative distribution of native and exotic SAV relative cover in 100-m river zones by year (1996, 2000, 2005, and 2011).

The median relative coverage of exotic vegetation within individual 100-m river zones was less in 2011 than in previous years (Figure 3.5.1). Native vegetation coverage was more variable in 2011, but it was not different as a whole from previous years. Specifically, there were more zones with lower native SAV coverage than in previous years even though the median coverage value was not notably different.

Most of the inter-annual variation in native SAV coverage by zone occurs in the zones with low relative cover (Figure 3.5.2). While slightly more than 20% of the zones had 30% or less relative cover by native vegetation in 1996, nearly 40% of the zones fell in this category in 2011. The years 2000, 2005, and 2011 were most similar in terms of cumulative distribution of zones with less than 15% relative cover by native SAV. Years 2005 and 1996 were very similar in cumulative distribution of zones with greater than 25% cover by native SAV. The current mapping year, 2011, was notably different than previous years in its cumulative distribution of zones with relative native SAV cover between 15% and 55%.

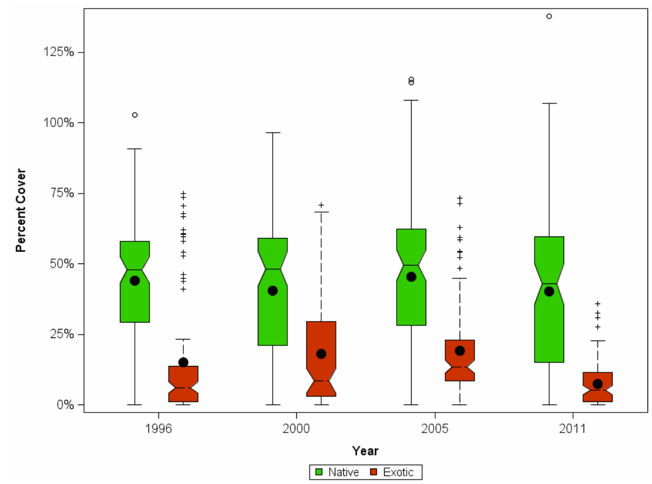

Figure 3.5.1. Comparison of median percent cover and related summary statistics of native (desirable) and exotic SAV in 100-meter river segments from 1996-2011

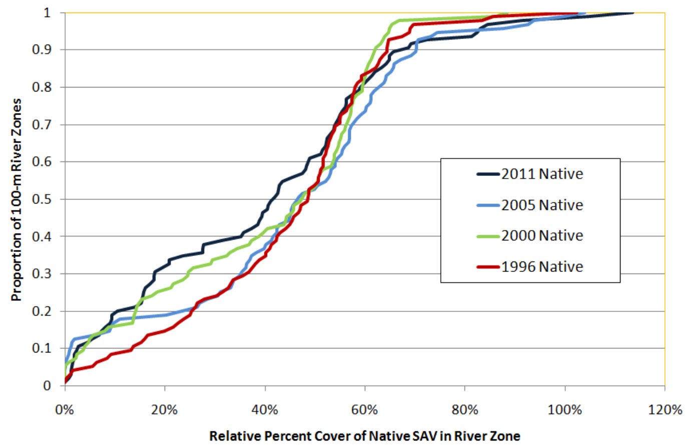

Figure 3.5.2. Cumulative distribution of native SAV relative percent cover in all 100-m river zones 1996 – 2011

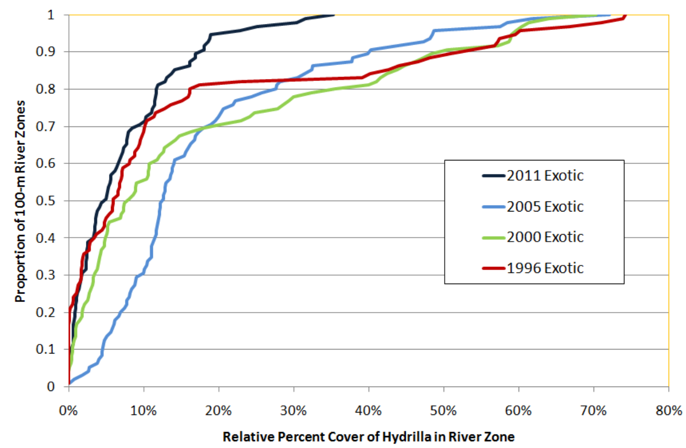

Figure 3.5.3. Cumulative distribution of hydrilla relative percent cover in all 100-m river zones 1996 - 2011

Table 3.5.1. Change in actual river area (ha) occupied by different cover categories of SAV species in 1996-2000, 200-2005, and 2005-2011

Species	Period of Change	0-10% Cover Change (ha)	10-50% Cover Change (ha)	50-100% Cover Change (ha)	All Covers Change (ha)	0-10% Cover Change %	10-50% Cover Change %	50-100% Cover Change %	All Covers Change %
Sagittaria kurziana	1996-2000	(0.57)	(1.95)	0.17	(2.35)	-24%	-38%	1%	-7%
	2000-2005	2.07	1.94	(1.21)	2.79	115%	61%	-5%	9%
	2005-2011	1.54	(0.98)	(4.52)	(3.96)	40%	-19%	-19%	-12%
Hydrilla verticillata	1996-2000	(1.63)	0.89	0.76	0.02	-23%	23%	7%	0%
	2000-2005	7.35	3.71	(1.34)	9.72	137%	77%	-12%	45%
	2005-2011	(1.56)	(1.78)	(8.30)	(11.63)	-12%	-21%	-81%	-37%
Vallisneria americana	1996-2000	(1.71)	(1.92)	0.71	(2.92)	-43%	-43%	58%	-30%
	2000-2005	3.35	0.79	0.70	4.85	146%	31%	36%	71%
	2005-2011	1.00	(1.00)	0.11	0.11	18%	-30%	4%	1%
Najas quadalupensis	1996-2000	(3.11)	(0.43)	(0.46)	(3.99)	-80%	-55%	-58%	-73%
	2000-2005	5.95	1.53	0.94	8.42	756%	432%	290%	574%
	2005-2011	(3.36)	1.08	0.39	(1.90)	-50%	57%	30%	-19%
Chara spp.	1996-2000	(2.56)	(0.51)	0.73	(2.33)	-83%	-37%	100%	-52%
	2000-2005	1.79	(0.07)	(0.69)	1.04	343%	-8%	-94%	49%
	2005-2011	0.26	1.19	0.62	2.07	11%	146%	1504%	65%
Utricularia spp.	1996-2000	(0.08)	(0.65)	(0.20)	(0.93)	-40%	-79%	-100%	-76%
	2000-2005	0.01	0.09	0.56	0.66	10%	51%	100%	224%
	2005-2011	0.31	0.14	0.41	0.86	224%	54%	73%	90%
Ceratophyllum demersum	1996-2000	(4.19)	(0.57)	(0.07)	(4.82)	-75%	-35%	-17%	-63%
	2000-2005	4.23	0.17	0.27	4.66	297%	16%	82%	166%
	2005-2011	0.55	(0.40)	(0.36)	(0.20)	10%	-32%	-61%	-3%
Potamogeton illinoensis	1996-2000	0.03	(0.24)	0.18	(0.04)	100%	-64%	117%	-7%
	2000-2005	0.17	(0.04)	(0.01)	0.11	591%	-29%	-4%	22%
	2005-2011	(0.12)	(0.04)	0.46	0.31	-61%	-39%	148%	51%
Ludwigia repens	1996-2000	(0.17)	0.04	-	(0.13)	-80%	90%		-50%
	2000-2005	0.16	0.21	0.004	0.38	376%	245%	100%	292%
	2005-2011	0.69	(0.13)	(0.004)	0.55	336%	-44%	-100%	109%
Fontinalis spp.	1996-2000	-	-	-	-				
	2000-2005	0.26	0.05	-	0.31	100%	100%		100%
	2005-2011	0.28	0.09	0.01	0.38	106%	203%	100%	122%
Myriophyllum spp.	1996-2000	(0.05)	0.02	-	(0.03)	-68%	100%		-36%
	2000-2005	0.04	(0.02)	-	0.02	177%	-88%		43%
	2005-2011	0.18	0.13	0.00	0.32	280%	4730%	100%	465%
Nasturitium spp.	1996-2000	(0.02)	-	-	(0.02)	-100%			-100%
	2000-2005	0.02	0.01	-	0.03	100%	100%		100%
	2005-2011	(0.02)	(0.01)	0.02	(0.01)	-100%	-100%	100%	-33%
Zizania aquatica	1996-2000	-	-	-	-				
	2000-2005	0.24	-	-	0.24	100%			100%
	2005-2011	0.08	0.09	-	0.18	36%	100%		74%
Hydrocotyle spp.	1996-2000	(0.02)	-	-	(0.02)	-100%			-100%
	2000-2005	0.02	-	-	0.02	100%			100%
	2005-2011	(0.02)	-	-	(0.02)	-100%			-100%

Cumulative distribution of zones with hydrilla coverage under 15% was notably different in 2005 relative to the other three years (Figure 3.5.3). Likewise, the cumulative distribution of zones with hydrilla coverage over 15% in 2011 appeared different than other years. In 2005, approximately 50% of the zones had hydrilla relative coverages of 15% or less. In contrast, zones with 15% or less coverage accounted for 65% to 85% of the zones in 2000 and 2011 respectively. Zones with more than 25% relative cover by hydrilla accounted for less than 5% of total zones in 2011 while the comprised 20% to 30% of the zones in 1996, 2000, and 2005.

3.6. Comparison of Sediment and SAV Species

It has been suggested that the Rainbow River sediment composition is important both as a substrate for vegetation and as a sink for nutrients (SWFWMD, 2008). A sediment study completed in 2007 produced baseline data on the nature and extent of the sediments within the Rainbow River (Gulf Coast Archeological Research Institute, 2007). The project collected one hundred thirty sediment cores along the river from the headspring to the river mouth. Sediment grain size distribution was determined for each sediment horizon or vertical stratum within the sediment cores. The study also recorded water depth and depth to bedrock at each core sample location. The sediment study was designed to produce baseline data on the nature and extent of the sediments within the Rainbow River as well as assess sediment deposition and re-deposition, sediment depth, and constituency. The study characterized the river sediment regime as dominated by medium to fine sand mixed with coarse, very fine, silt and clay, and organic debris/detritus.

The grain size data could provide the opportunity to compare sediment grain size composition to SAV occurrence in the Rainbow River. However, the core sample locations were not randomly selected. The study used river bathymetry, SAV cover, geomorphology, and other data to create a series of 180 potential sample areas with the highest probability of providing sediment suitable for coring. Only 130 of these locations were found to have at least 10 inches of sediment and subsequently sampled. This sampling method was appropriate for the objectives of the sediment study. However, it likely precludes the use of the sediment data in SAV analyses because the 2005 SAV mapping data were used as one of the indicators to determine suitable core sample locations.

The relationships between SAV and the core sample data were tested using a series of analyses with the goals of examining the use of the sediment data in SAV analyses. Principle components analysis and logistic regression were used to analyze the factors affecting the presence or absence of the dominant SAV species on the Rainbow River. The results are given in Appendix E. Only four taxa occurred in enough of the sediment core samples to justify analyses: sagittaria; hydrilla; eelgrass; and coontail. Patterns of sediment grain size distribution from the headspring to the river mouth were also qualitatively reviewed.

All four of the species showed relationships with sediment grain size, but all the species also have distinct longitudinal gradients of increasing or decreasing presence in the river which may not be related to sediment characteristics. Only the surface layer or stratum sediment grain sizes were used in this analysis. Numerous methods to combine sediment grain size from lower strata with the surface layer were considered. These options were not perused because the underlying bias in sample site selection relative to both SAV presence and sediment thickness was believed to overwhelm the potential of lower sediment layers to explain variation in SAV occurrence.

3.7. Qualitative Description of Epiphytic and Benthic Mat Algae Species Composition

The epiphytic algae community in each of the SAV samples was dominated, both in species richness and biomass, by diatoms. However, filamentous algae contributed a substantial portion of the epiphyte biomass with the blue-green algae *Lyngbya* and *Oscillatoria* present in all samples. The filamentous green algae, *Cladophora, Spirogyra, and Rhizoclonium* were present in some samples. Very few types of epiphytes other than diatoms and these filamentous algae were observed in any of the samples. The benthic algae mat samples were dominated by *Lyngbya* with *Oscillatoria and Pseudoanabaena* abundant but secondary to *Lyngbya*. A number of diatom taxa were also very abundant in the benthic algae mats. A table of the algae sample taxa and their relative abundances is given in Appendix C.

Observations were made of non-algal organisms and other biogenic material scraped off the leaves and stems. Dipteran larvae were observed in some samples and appeared to have constructed tubes in which they could be observed in some cases. When present, these tubes could make up a substantial proportion of the biogenic matter scraped off each leaf. Protozoa, water mites, nematodes, and tardigrades were observed in some of the samples. The majority of biogenic material collected from the macrophytes in decreasing order of biomass were diatoms, filamentous blue-green algae, *Lyngbya*, and fly larvae and their tubes and pupae. A photo of an algae sample is shown in Figure 3.7.1.

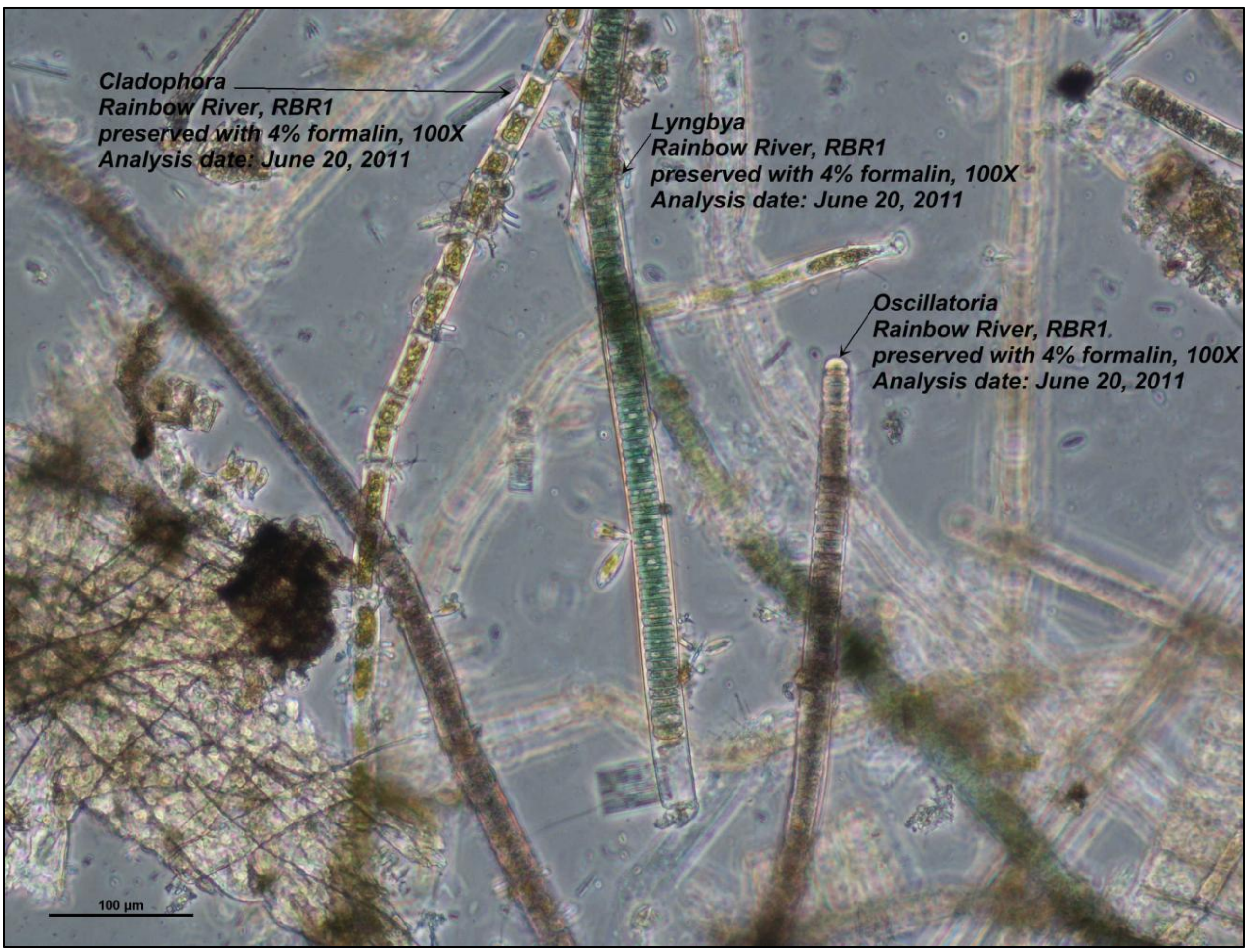

Figure 3.7.1. Algae in a sample collected from the Rainbow River

3.7.1.1. Vegetation Condition Indices

Two versions of a vegetation condition index were calculated using the SAV and algae mapping data. These indices were calculated for 100-m river zones and 1-km river zones. The methods of calculating are described in the Methods section and results are shown on maps in Appendices A and B. The first index was calculated for native SAV, exotic SAV (hydrilla), and benthic and epiphytic algae, and therefore only used for 2011.

The 2011 results that include algae are graphed in Figure 3.8.1 and shown on maps in Appendix B. The best condition zone in 2011 had a score of "5." The worst condition zone had a score of "-4" and the median score was "1." The highest scoring zones were zone 4 (just below the headspring), zones 12 to 14 (just above Devils' Elbow), zone 22 (just below Devils' Elbow), and zones 33 and 34 (just above the narrows). All but five of the zones upstream of zone 42 had scores of "3" or better. In contrast, only two of zones downstream of zone 42 were above a "2" and they were located just downstream of the Rio Vista boat ramp. Between zones 43 and 73 (the upper reaches of the Narrows to Blue Cove) most zones had scores of "1." Below zone 73, two-thirds of the zones were "-2" or worse.

The second version of the index was calculated for each of the four mapping years using only native SAV and exotic SAV (hydrilla). Algae data were not available prior to 2011. These data are shown in Figure 3.8.2 and in maps in Appendix B and Figure 3.8.3. With the possible exception of 2005, the scoring regime does not show worse conditions below zone 43 as the first index did. Scores generally range between "1" and "2" between zones 1 and 73 for the first two time periods. There are fewer "2's" in those zones in the latter two time periods and 2005 has the most "0"s. All four years show a marked decrease in conditions below zone 70, which is consistent with the first index for 2011. An improvement in the condition of the downstream-most 8 zones of the river for 2011 is illustrated with both indices.

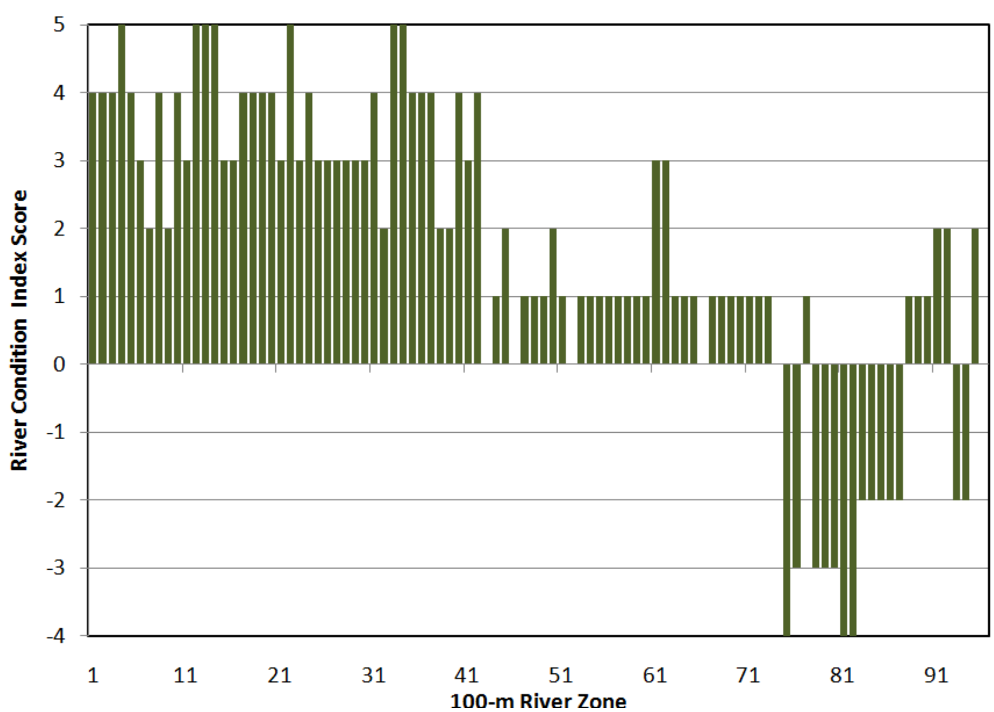

Figure 3.8.1. 2011 Vegetation Condition Index calculated for 100-m river zones using native SAV, exotic SAV, and epiphytic and benthic algae.

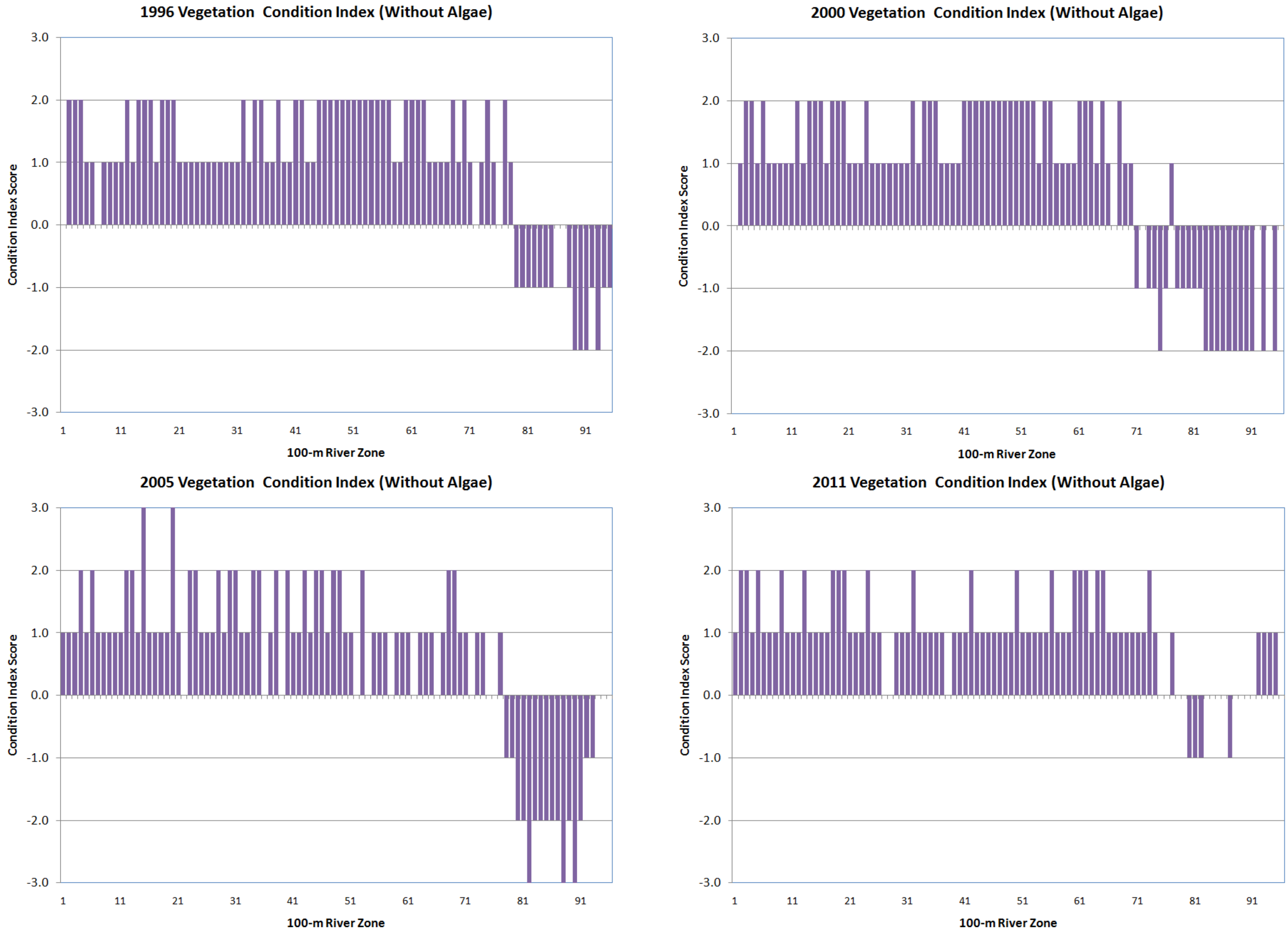

Figure 3.8.2. Native/Exotic Vegetation Condition Indices calculated for 100-m river zones in 1996, 2000, 2005, and 2011

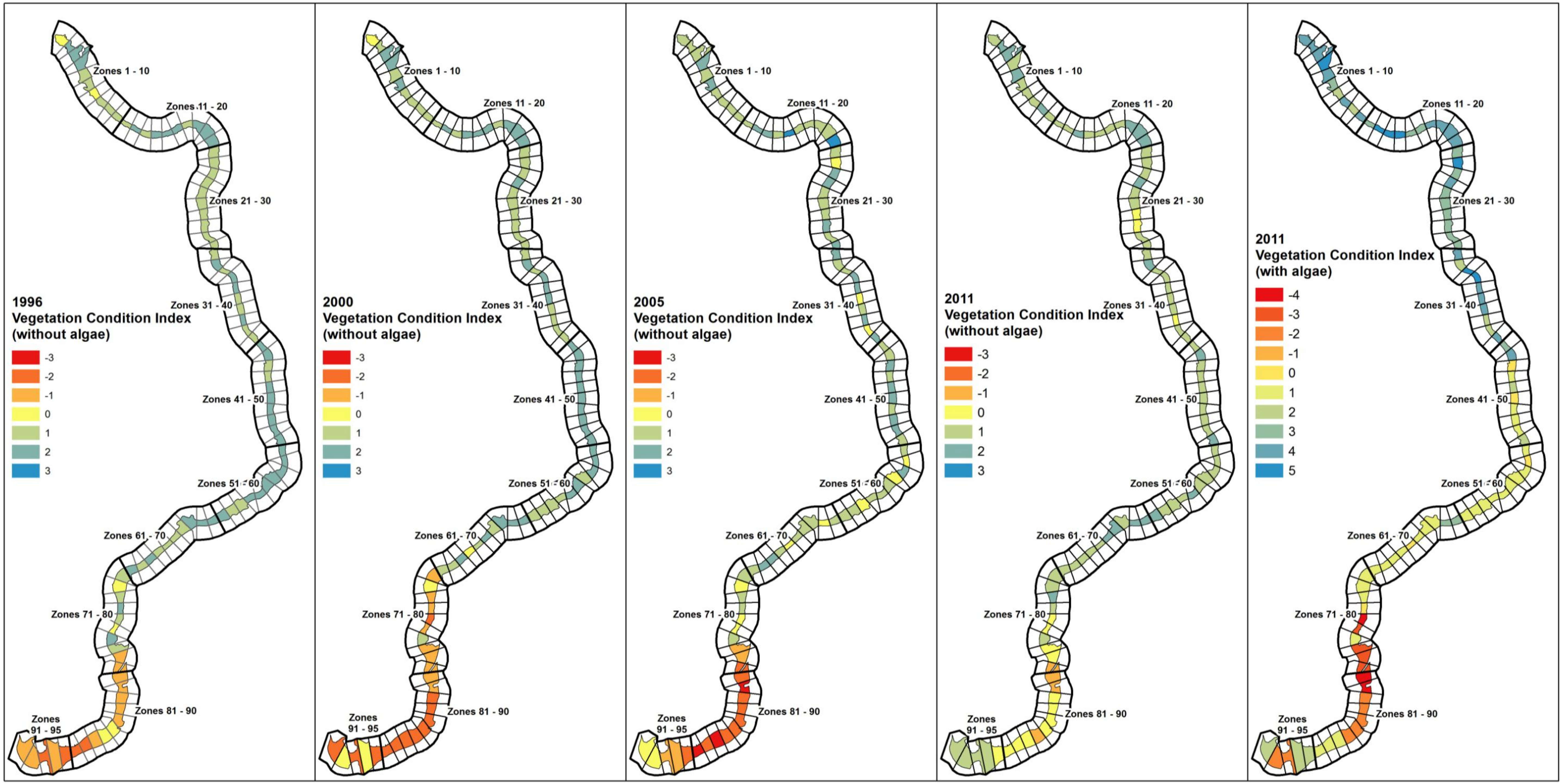

Figure 3.8.3. Maps of vegetation condition indices for 1996, 2000, 2005, and 2011

3.8. Field Observations

In comparison to prior mapping episodes, the river level (and river velocity) appeared to be noticeably lower in 2011. Some of the shallower SAV beds were topped-out and collected drift (Figure 3.9.1). There were more rafts of uprooted vegetation and other drift atop rooted SAV, against docks and other fixed objects. Rafts were not mapped however because they are too temporary in nature and are intentionally dislodged by people. Some beds were observed for the first time to be a mix of sparse emergent and SAV species. Species in emergent beds may be changing due to lower water levels, with species seen above the water line shifting down the river bank.

Figure 3.9.1. Collected rafts of uprooted SAV in shallow river margin of zone 46 or 47, near new tuber exit

There was clearly more algae in the river and water clarity seemed to be decreased as well. In the past, heavy benthic algae cover was generally limited to the river margins at few locations of the mid and lower river, and crossed the width of the river only near the confluence. During previous mapping events, epiphytic algae were not as noticeable in the upper river, were moderate in the lower river and only seemed particularly heavy in what may be disturbed areas of low velocity. Increased algae and decreased water clarity made mapping more difficult. Unfortunately the accuracy of the 2011 map may be decreased because of algae obscuring SAV species (Figure 3.9.2). Spot-checking was done by fanning away algae to identify hard to see species and increase confidence. Epiphytic algae sometimes appeared to be heavier on whorled species and less on strap-leaf plants. The age of growth (newer blades having less algae) and flow were also obvious factors.

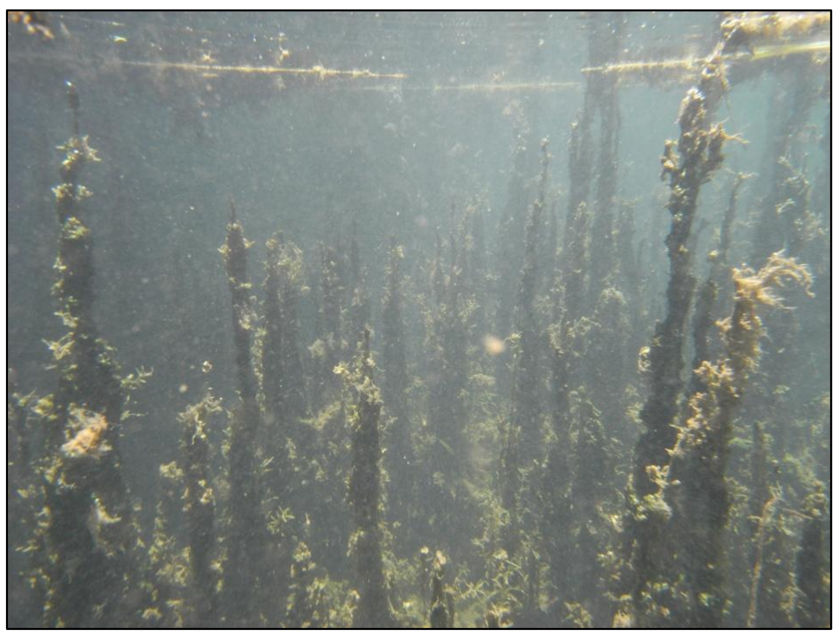

Figure 3.9.2. High epiphytic algae cover in low flow area of mining impacted area of zone 72

Some areas previously dominated by hydrilla appeared to have other species present in 2011. More otters and ducks were observed. The river appeared to be in more of a transition and have more variability than in past, particularly mid-river. Field mapping was more difficult and time-consuming due to a higher degree of variability in SAV species cover categories.

There was much more recreational use observed for the spring and summer weekdays spent field mapping than seen in the past (Figure 3.9.3). Not only were there more tubers, but more people fishing or cruising in small motor boats and other paddle craft. The increased number of users created logistical challenges for mapping and may also have increased turbidity. Lower water levels and the new tuber take-out appear to have created more opportunities for standing in the river, and accompanying activities that disturb SAV and sediments (mud fights and rock-throwing) and resultant bare areas (Figure 3.9.4).

Figure 3.9.3. Recreational use, zone 39

Figure 3.9.4. Bare areas and over-turned rocks resulting from recreational use mid river

4. Recommendations

The results of the 2011 and previous mapping efforts suggest several initiatives and courses of action that would aid resource managers in improving vegetation conditions of the Rainbow River. These are provided here as recommendations:

SAV Mapping

Continued mapping of SAV at minimum 5-year intervals is also recommended. While hydrilla area was much reduced in 2011, it continues to invade new areas of the river. Low river levels also appear to be allowing additional recreational and boating impacts to vegetation. Thirdly, if the rapid increase in algae coverage between 2005 and 2011 continues, the SAV community may be further affected.

Hydrilla Treatment Records

The areas where hydrilla can be effectively treated on the Rainbow River are limited to lower flow velocity locations. The locations of these potential treatment areas are generally known. Specific records regarding the locations, dates, and types of hydrilla and other vegetation control would make vegetation assessment more meaningful. Important changes and patterns in SAV distribution may be driven by hydrilla control activities, but without specific data that can be incorporated into the analyses, the conclusions remain anecdotal.

Information from past and future activities could be incorporated into a GIS database to facilitate spatial analysis. If resources are not available to develop and maintain a GIS database, information could be recorded on paper maps (printed directly from this report if needed) and saved by Aquatic Preserve and/or SWFWMD staff for incorporation into a digital database at a later time. Chemical treatment by government agencies, manual removal by property owners and other methods could be included. Delineating the spatial extent of activities on the same base maps used for this project would maximize spatial accuracy with minimum effort. An analysis of changes in hydrilla and other species in response to control measures is the next logical step in determining effective, beneficial vegetation management recommendations.

Digital Maps of River Flow Velocity

River flow velocity data would benefit interpreting SAV patterns and changes. It appears from both spatial observations and inter-annual comparisons between high and low flow periods, that flow velocity may be a significant component driving SAV and algae distribution and coverage. Studies on other rivers have also highlighted the significance of flow velocity (Hoyer et al., 2007). The ideal map would express velocity under different flow conditions and use the same base maps as this vegetation assessment project. There may be a product from the river’s minimum flows analyses that would meet this need. If necessary a new map could be created during SAV mapping or as a separate study.

The mapping product should be coupled with monitoring stations where velocity cross sections of the river are measured at different river stage/flow regimes. The stations should be sufficient in number and locations for the cross section data to be used to create several digital velocity maps of the entire river under different river stages/flow regimes.

Emergent Vegetation Mapping

Continued mapping of emergent vegetation is recommended in association with SAV mapping. This continued monitoring is particularly important given the recent higher coverage by the nuisance species climbing hempweed and changes in other emergent species observed.

Continue Algae Coverage and Distribution Mapping and Monitoring

Though the observations are qualitative, it appears epiphytic and benthic algae coverage increased between the 2005 and 2011 mapping events. It is recommended that algae coverage mapping be continued at minimum 5-year intervals. Given the rapid increase in algae between 2005 and 2011, an interim monitoring event is probably warranted before 2016. This event may not require whole-river mapping, but it should be sufficient to characterize change.

SAV Sediment Relationships

The 2007 sediment study provides a good framework for designing a directed sampling regime to control for other variables related to distance down river while testing the effect of sediment characteristics on SAV presence and species composition. The ideal sampling program would obtain a representative number of samples for each river length location/river cross sectional location/flow velocity combination.

Focused Interim Studies during Very High and Very Low Flow Periods

As suggested in the 2005 report, the 5-year duration between the three mapping efforts, might obscure short-term or small-scale patterns or dynamics that probably exist in the Rainbow River vegetation assemblages. More frequent vegetation mapping and detailed change analysis focused on selected sections of the river following very high or very low flow events would help identify these small-scale, short-term patterns. This sort of directed study would also help elucidate the influence of river flow velocity on SAV.

5. References and Relevant Literature

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