Mapping Threats to Florida Freshwater Habitats

FINAL REPORT
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Conserve Wildlife Tag Grant Program
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ABSTRACT

The Florida Fish and Wildlife Conservation Commission's Comprehensive Wildlife Conservation Strategy (CWCS) is an action plan for conserving the state's wildlife and natural areas. In 2005 the CWCS identified 27 threats to Florida's freshwater habitats. Creating a comprehensive database of threats is an essential step toward achieving the overall goals of improving strategic habitat conservation planning and addressing causes of low abundance and decline of species in aquatic habitats. This project assembled statewide geographic datasets representing 15 out the 27 threats. These data were used to determine the relative level of individual threats to each subwatershed (HUC 12 unit) within Florida. Ten uncorrelated data layers depicting unique threat categories were combined to create a composite Freshwater Threats Index. Based on the composite index map a distinct gradient of increasing threat level is evident progressing from Northwest Florida to the east and south. At a regional scale road density dominates as the most common reason for high threat values in northern Florida, while agriculture dominates in the west-central region and waterway modification dominates in east-central and southern Florida. This multi-scale assessment is effective at both highlighting local conditions which may instigate further investigations and illustrating regional trends.

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I. INTRODUCTION

Human-induced changes to flow regime and the subsequent impacts on water quality, food sources, habitat structure, and biotic interactions determine the ecological integrity of freshwater systems (Karr, 1991; Poff et al., 1997; Baron et al., 2002; Richter et al., 2006). In order to preserve or restore aquatic ecosystems an understanding of the impact of anthropogenic changes on these five components of ecological integrity is necessary (e.g. Freeman & Marcinek, 2006; Mattson & Angermeier, 2007). It is, therefore, the challenge of both public agencies and private organizations to first identify and then address deleterious activities affecting these ecosystems while satisfying the inevitable conflict between meeting societal needs and maintaining natural processes. Despite the difficulty in establishing causality between even one stressor and its effects on an aquatic ecosystem because of “synergistic and cumulative interactions” (Adams, 2003) due to incremental impacts, multiple source impacts and multiple stress impacts (Culp et al., 2000), O’Neill et al. (1999) note that for broad scale geographic analyses such as risk assessments the important point is to identify “large scale, synergistic stresses that *might* endanger the environment.” This knowledge may then instigate further investigation via additional research or direct action through policy changes or legal intervention (O’Neill et al., 1999).

The Florida Fish and Wildlife Conservation Commission’s (FWC) mission is “managing fish and wildlife resources for their long-term well-being and the benefit of people” (FWC 2008a). One opportunity available to the FWC to assist in this mission comes from the federal State Wildlife Grants program. Florida formulated a Comprehensive Wildlife Conservation Strategy (CWCS), a part of Florida’s Wildlife Legacy Initiative, to become eligible for this federal funding. This strategy, completed in 2005, is “an action plan for conserving all of the state’s wildlife and vital natural areas for future generations" (FWC 2008b). Two of the main goals of the CWCS are to focus on proactive conservation efforts to prevent decline of common species and to use a habitat-based approach to facilitate assessment of the basic requirements of the species sharing that habitat type. Overall 45 habitat types were identified for Florida with these grouped into 3 main categories: freshwater, terrestrial, and marine (Florida Fish and Wildlife Conservation Commission 2005).

A federal requirement of the CWCS includes identifying "problems which may adversely affect species…or their habitats" (Florida Fish and Wildlife Conservation Commission 2005). For assistance with this part the FWC employed The Nature Conservancy (TNC), an organization that has developed methods to pinpoint these problems. TNC uses its 5-S framework which operates under the premise that "abating the sources of stress should alleviate the stresses to the systems, resulting in greater viability of the conservation targets" (Low 2003). Through a step-by-step process the systems, or conservation targets, can be identified, and their corresponding stresses and sources of stress can be identified and ranked according to relative seriousness. For the TNC, stresses/sources refer only to those directly or indirectly attributable to humans. Natural processes which affect a habitat are not considered. A stress is defined as "the factor that destroys, degrades, or impairs habitats by impacting habitat size, condition, or configuration in the landscape" while a source represents "the proximate cause of the stress" (Gordon et al. 2005). Sources can cause more than one type of stress to a habitat and one type of stress can have more than one source. Stresses and their sources combined are viewed as "threats" to a system and these threats, ranked as Very High, High, Medium, or Low, are reported in the CWCS for the habitat types in Florida (see Gordon et al. 2005, for specific details). Rankings of threats, stresses, and sources occurred during workshops attended by numerous natural resources experts. This exercise resulted in a list of 27 threats to the 9 freshwater habitat types in Florida (Table 1). Although not expressly stated, each of these threats negatively impacts, in varying degrees, each of the five indicators of ecological integrity: flow regime, water quality, food sources, habitat structure, and biotic interactions.

The CWCS does incorporate indices of threats to habitats but these indices were used only to inform the workshop participants during the creation of the resulting table (Table 1) and neither do they represent this list explicitly (an impossibility considering the indices were created for the workshops to determine the list) nor do they consider threats at any other scale but statewide. Additionally, no composite or cumulative index of threats affecting freshwater habitats could be created due to incomplete geographic extents of the available data. Thus, an improved group of spatial threats indices based upon Table 1 is necessary. Once more comprehensive sets of spatial data exist focus on the ways in which each threat impacts ecological integrity can be examined in Ecological Risk Assessments for sensitive species and ultimately incorporated in Strategic Habitat Conservation Planning for Florida's freshwater habitats. Overall, this information will help to acquire desirable high-quality freshwater habitats and direct restoration efforts where threats are identified and habitat quality can be improved. Since the threats to ecological integrity have been identified, this project seeks to answer these questions at the most local scale permissible by available data:

1) For each threat category: where are threatened freshwater habitats?
2) Based on the composite index, which freshwater habitats are most/least threatened overall?
3) What are regional patterns, if any, of threats to freshwater habitats?

Table 1: The list of 27 threats to Florida's freshwater habitats found in the Comprehensive Wildlife Conservation Strategy (CWCS) (FWC 2005).

Table 3. Overall threat rank across freshwater habitat categories and collective threat status among freshwater habitat categories.

	Threat Category	Threat Rank By Habitat Category									Overall Threat Rank
		Aquatic Cave	Calcareous Stream	Coastal Tidal River or Stream	Large Alluvial Stream	Natural Lake	Reservoir/ Impoundment	Seepage/ Steephead Stream	Softwater Stream	Spring and Spring Run	All Habitat Categories
1	Invasive plants	-	High	Medium	-	High	High	-	Medium	Very High	Very High
2	Nutrient loads - urban	-	High	Medium	-	High	High	-	Medium	Very High	Very High
3	Surface water withdrawal	-	-	High	Medium	Medium	-	-	High	Medium	Very High
4	Invasive animals	-	Medium	Low	Medium	Medium	High	Medium	Medium	High	Very High
5	Nutrient loads - agriculture	-	High	Medium	-	Medium	Medium	-	High	High	Very High
6	Dam operations	-	-	High	High	High	-	-	Medium	-	Very High
7	Conversion to housing and urban development	-	Medium	High	-	High	-	Medium	High	-	Very High
8	Channel modification / shipping lanes	-	-	High	High	-	-	-	-	-	Very High
9	Roads	-	Medium	Medium	-	-	-	Medium	High	-	High
10	Chemicals and toxins	-	Medium	Medium	Low	Medium	Medium	-	Medium	-	High
11	Incompatible recreational activities	Medium	-	-	Low	Low	High	-	Low	Medium	High
12	Conversion to commercial and industrial development	-	-	Medium	-	Medium	-	Medium	Medium	Low	High
13	Management of nature - water control structures	-	-	-	High	-	-	Medium	-	-	High
14	Conversion to agriculture	-	-	-	-	Medium	-	-	High	-	High
15	Incompatible resource extraction: mining / drilling	Medium	Low	-	-	-	-	Medium	Medium	-	High
16	Shoreline hardening	-	-	High	-	-	-	-	-	-	High
17	Management of nature - veg clearing/snagging for water conveyance	-	-	Medium	-	-	-	-	-	-	Medium
18	Groundwater withdrawal	-	-	-	Low	Low	-	-	Low	Medium	Medium
19	Incompatible fire	-	-	-	-	-	-	Medium	-	-	Medium
20	Incompatible forestry practices	-	Low	-	Low	-	Low	Low	Low	Low	Medium
21	Incompatible agricultural practices	-	Low	-	-	Low	Medium	-	Low	-	Medium
22	Incompatible construction practices	-	-	-	-	-	Medium	-	-	-	Medium
23	Conversion to recreation areas	-	-	-	-	-	-	-	-	Low	Low
24	Management of nature - aquatic plant treatment	-	-	-	-	Low	-	-	-	-	Low
25	Sea level rise	-	-	Low	-	-	-	-	-	-	Low
26	Incompatible residential activities	-	-	-	-	Low	-	-	-	-	Low
27	Solid waste	Low	-	-	-	-	-	-	-	-	Low
	Habitat Category Threat Status	Medium	High	Very High	High	High	High	Medium	Very High	Very High	Very High

The two major objectives of this project are to assemble statewide data layers representing individual threats listed in Table 1 and to create a composite index of the threat data layers to determine relative condition of freshwater habitats within Florida.

II. DATA AND METHODS

A. Dataset development

Data for this project were collected based on the list of 27 threats to Florida's freshwater habitats found in the CWCS (Table 1). The 27 threats are ranked across all 9 habitat types as well as for each habitat type individually. For this project the 9 habitat types were considered collectively because knowledge of the spatial distribution and location of individual habitat types is incomplete. Priority focus was given to databases with both statewide coverage and existing spatial references, e.g. latitude/longitude coordinates. Databases were acquired from numerous sources (Table 2) and were in various stages of appropriate usability. Some were used without much further adaptation while others needed significant processing. The resulting data layers represent 15 out of 27 threats either by direct or proxy measurements (Table 3). Polygon data layers represent summarization of data at a subwatershed level which was necessary to allow comparisons across data layers whose base information exists at different scales and/or levels of accuracy. Subwatersheds are part of the hierarchically designed Hydrologic Unit Maps created by the U.S. Geological Survey (USGS) and continuously updated by both the USGS and the Florida Department of Environmental Protection (FL DEP). A subwatershed is identified by its Hydrologic Unit Code (HUC) and is also referred to as a "HUC 12 unit." There are 1,347 individual HUC 12 units at least partially within Florida (Figure 1). An important fact to consider about the data layers showing information summarized by HUC 12 unit is that

Table 2: Sources for the data layers created based on the 27 threats to freshwater habitats listed in Florida's Comprehensive Wildlife Conservation Strategy (CWCS).

Data Layer/ (Shapefile)	Data Sources	Data Source Locations
Invasive aquatic plants (catI_plants2007)	1. Florida Exotic Pest Plant Council (FLEPPC)	http://www.fleppc.org/EDDMapS/webservices/index.cfm
	2. FSU Herbarium	http://herbarium.bio.fsu.edu/projects.php
	3. FL DEP 2007 public waterbody survey	personal communication with Bill Caton and Rob Kipker at FL DEP
	4. USGS Nonindigenous Aquatic Species Program (NAS)	personal communication with Pam Fuller at USGS NAS
Waterway modification (channels_canals_sum)	1. Florida Stream Dataset (FSD)	FWC Center for Spatial Analysis [modified National Hydrography Dataset (NHD) Feb. 2007 version]
	2. Bureau of Transportation Statistics Navigable Waterways 2006	Florida Geographic Data Library at http://www.fgdl.org/
	3. South Florida WMD Canals	Florida Geographic Data Library at http://www.fgdl.org/
Petroleum contaminated sites (confacs_score_2008 & confacs_in_FL_P_scores)	1. FL DEP	http://www.dep.state.fl.us/waste/quick_topics/database_reports/pages/stcm/petro_reports.htm
Storage of federal dams (fed_dams_summary_2005)	1. 2001 & 2005 National Inventory of Dams, US Army Corps of Engineers (USACE)	Florida Geographic Data Library at http://www.fgdl.org/ & personal communication with Rebecca Ragon, USACE
	2. Northwest Florida Water Management District (WMD)	personal communication with Lance Laird, NWFWMD
Permitted average daily groundwater withdrawal rate (ground_HUCS2 & ground_ADR_final)	1. Northwest Florida WMD	personal communication with Fran Flores and Lauren Connell, NWFWMD
	2. Suwannee River WMD	personal communication with John Kruse, SRWMD
	3. St. Johns River WMD	http://webapub.sjrwmd.com/agws/sjrwmdpermit/ and personal communication with Jeri Parish, SJRWMD
	4. Southwest Florida WMD	http://www.swfwmd.state.fl.us/data/gis/layer_library/category/regulatory
	5. South Florida WMD	https://my.sfwmd.gov/portal/page?_pageid=734,1546097&_dad=portal&_schema=PORTAL; also personal communication with Donna Rickabus and Juan Tobar, SFWMD

Data Layer/ (Shapefile)	Data Sources	Data Source Locations
Land cover analysis (HUC12_landscape_2003)	1. FWC's Florida Vegetation and Land Cover 2004	FWC Center for Spatial Analysis, http://research.myfwc.com/features/category_sub.asp?id=7239
Invasive aquatic animals (invasive_animals_2007)	1. FWC Exotic Species Database	personal communication with Larry Connor
	2. FWC Freshwater Fisheries Sampling Database	FWC Fish & Wildlife Research Institute (FWRI) database via personal communication with Jim Estes
	3. Shafland et al. "Florida's Exotic Freshwater Fishes--2007 (unpublished manuscript)	personal communication with FWC biologist Paul Shafland
	4. FWC Freshwater Fisheries biologists	personal communication with FWC biologists: John Knight and Rich Cailteaux
	5. USGS NAS	personal communication with Pam Fuller at USGS NAS
Land use analysis (parcel_summary & selected_LU_2007)	1. Florida Department of Revenue (FDOR)	personal communication with James Diaz, FDOR
Riparian buffer zone analysis (riparian_landcov_2003)	1. FWC's Florida Vegetation and Land Cover 2004	FWC Center for Spatial Analysis, http://research.myfwc.com/features/category_sub.asp?id=7239
	2. Florida Stream Dataset (FSD)	FWC Center for Spatial Analysis [modified National Hydrography Dataset (NHD) Feb. 2007 version]
	3. National Hydrography Dataset (NHD) Waterbodies and Areas	FWC Center for Spatial Anaylsis
Road/stream crossings (roads_streams_2006)	1. TIGER roads 2006 version 2	http://www.census.gov/geo/www/tiger/tiger2006se/tgr2006se.html
	2. Florida Stream Dataset (FSD)	FWC Center for Spatial Analysis [modified National Hydrography Dataset (NHD) Feb. 2007 version]
Permitted average daily surface water withdrawal rate (surface_ADR_final & surface_HUCs2)	1. Northwest Florida WMD	personal communication with Fran Flores and Lauren Connell, NWFWMD
	2. Suwannee River WMD	personal communication with John Kruse, SRWMD
	3. St. Johns River WMD	http://webapub.sjrwmd.com/agws/sjrwmdpermit/ and personal communication with Jeri Parish, SJRWMD
	4. Southwest Florida WMD	http://www.swfwmd.state.fl.us/data/gis/layer_library/category/regulatory
	5. South Florida WMD	https://my.sfwmd.gov/portal/page?_pageid=734,1546097&_dad=portal&_schema=PORTAL; also personal communication with Donna Rickabus and Juan Tobar, SFWMD

Data Layer/ (Shapefile)	Data Sources	Data Source Locations
Impaired water quality (verified_impaired_2008)	1. FL DEP	Feb. 12, 2008, version downloaded from http://www.dep.state.fl.us/water/basin411/download.htm
Water control structures: non-federal (water_ctrl_stucs & WCS_summary_2007)	1. Northwest Florida WMD	personal communication with Lance Laird, NWFWMD
	2. Suwannee River WMD	personal communication with Berry Shafii and Tim Sagul, SRWMD
	3. St. Johns River WMD	personal communication with Kenneth John, SJRWMD
	4. Southwest Florida WMD	data CD received after online request to: gisdata@watermatters.org
	5. South Florida WMD	personal communication with Terri Bennett, SFWMD
Weighted road density (wtd_rd_dens)	1. TIGER roads 2006 version 2	http://www.census.gov/geo/www/tiger/tiger2006se/tgr2006se.html
	2. Florida Dept. of Transportation (FDOT)	http://www.dot.state.fl.us/planning/statistics/gis/default.htm#roads

Table 3: The relationship between data layers created and the Comprehensive Wildlife Conservation Strategy's list of 27 threats to Florida's freshwater habitats.

Shapefile	**Description**	**Corresponding Threat Category and Rank (from Table 1)**	**Geometry**
catI_plants2007	invasive aquatic plants	1. invasive plants	polygon
channels_canals_sum	river/stream modification due to channelization or canal	8. channel modification/shipping lanes	polygon
confacs_score_2008	petroleum contaminated sites	10. chemicals and toxins	polygon
fed_dams_summary_2005	average storage of federally controlled dams	6. dam operations	polygon
ground_HUCS2	summary of permitted average daily rate of groundwater withdrawal	18. groundwater withdrawal	polygon
ground_ADR_final	permitted average daily rate of groundwater withdrawal	18. groundwater withdrawal	point
HUC12_landscape_2003	summary of land cover classification analysis	7. conversion to housing and urban development; 12. conversion to commercial and industrial development; 14. conversion to agriculture	polygon
invasive_animals_2007	invasive aquatic animals	4. invasive animals	polygon
parcel_summary	summary of certain land use types	2. nutrient loads--urban; 5. nutrient loads--agriculture; 10. chemicals and toxins	polygon
riparian_landcov_2003	summary of land cover classification analysis within riparian buffer zones of different sizes	7. conversion to housing and urban development; 12. conversion to commercial and industrial development; 14. conversion to agriculture	polygon

Shapefile	**Description**	**Corresponding Threat Category and Rank (from Table 1)**	**Geometry**
roads_streams_2006	road and stream crossings	9. roads	polygon
selected_LU_2007	location of parcels of certain land use types	2. nutrient loads--urban; 5. nutrient loads--agriculture; 10. chemicals and toxins	polygon
surface_ADR_final	permitted average daily rate of surface water withdrawl	3. surface water withdrawal	point
surface_HUCs2	summary of permitted average daily rate of surface water withdrawal	3. surface water withdrawal	polygon
verified_impaired_2008	summary of waterbodies classified "impaired" by FL DEP	2. nutrient loads--urban; 5. nutrient loads--agriculture; 10. chemicals and toxins	polygon
water_ctrl_stucs	location of water control structures	13. management of nature--water control structures	point
WCS_summary_2007	summary of water control structures density	13. management of nature--water control structures	polygon
wtd_rd_dens	weighted road density	9. roads	polygon

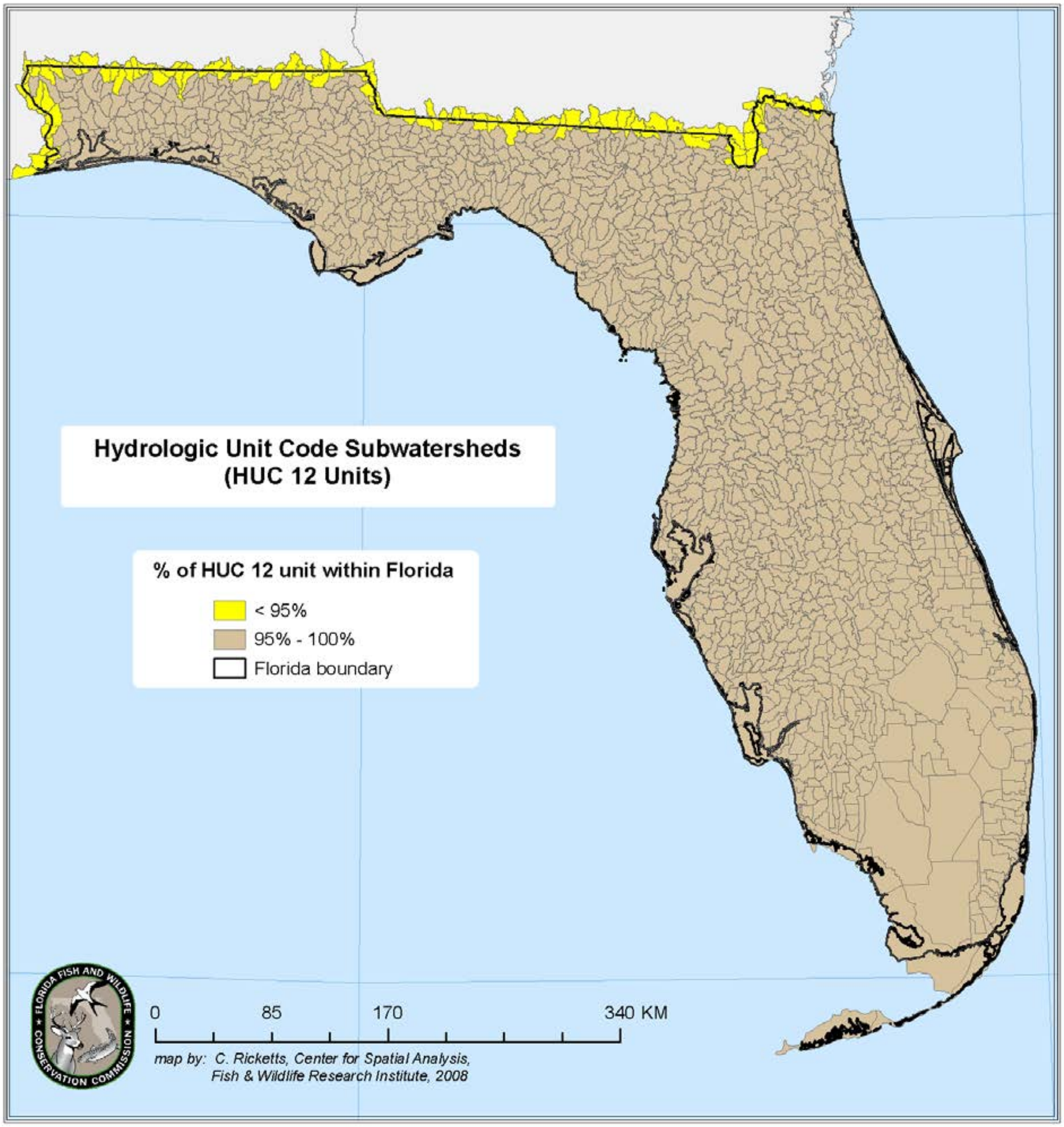

Figure 1: Subwatershed boundaries within, and partially within, Florida.

while some North Florida HUC 12 unit boundaries extend beyond the state line into Georgia or Alabama, *the data within them do not*. In each attribute table there exists a field (variously named, check metadata for specifics) which quantifies the percent of the HUC 12 that is within the state of Florida. For this project the North Florida HUC 12 units spanning the state line *are* included in the composite index/assessment since threat data for the Florida portion of the HUC 12 unit is available. Point data layers represent intermediate steps in the creation of some of the summarized layers. These point layers can provide more detailed locations of a particular threat. See Appendix A for a complete list of threat assessment metrics available within data layers.

A.1. INDIVIDUAL DATA LAYERS/SHAPEFILES

Data layers, each representing a single threat to Florida's freshwater habitats, were created from the sources listed in Table 2. Not all, however, were subsequently included in the composite index. Each individual data layer provides information about what threatens the freshwater habitats within a HUC 12 unit, or, if the data is more precise, at a certain location (Table 3). Even at the more general HUC 12 scale, the individual data layer can highlight those areas which may deserve additional attention from researchers and managers.

A.1.1. DATA LAYERS/SHAPEFILES FOR COMPOSITE ASSESSMENT

The 10 individual data layers (a-j) in this section are also included in the composite index. Some of these data layers have associated intermediate point data layers.

a. Non-native/exotic invasive aquatic plants:

The Florida Exotic Pest Plant Council (FLEPPC) maintains a list of category I invasive aquatic plants, defined as invasive exotics that are "altering native plant communities by displacing native species, changing community structures or ecological functions, or hybridizing with natives. This definition does not rely on the economic severity or geographic range of the problem, but on the documented ecological damage caused." (FLEPPC 2007). This 2007 list was used to select only plants classified as category I from the following databases:

- FLEPPC invasive plants list
- FSU Herbarium georeferencing project, 2005-2007
- FL DEP public waterbody survey 2007
- USGS Nonindigenous Aquatic Species Program (NAS)

Data were included from the past 25 years (1982 through 2007) with the rationale that if the plant was listed as "established," while its current presence may be different from when originally listed in a database, the possibility of the plant species re-colonizing the same area exists. The data from the FLEPPC and the related FSU Herbarium georeferencing project are point data for locations of invasive plants. These records were edited to include only aquatic plant species. Plant records listed as "removed" under the original "comments" field were deleted from the databases. Since these two databases used the same underlying data, records were edited to eliminate duplicates. The data from the 2007 FL DEP public waterbody survey were recorded as presence/absence records based on the waterbody's name and county location. To incorporate these into a spatial database, the "waterbody name" and "county" fields were used to link the records to existing georeferenced shapefiles containing waterbody names/locations (e.g. canals, lakes, major rivers, National Hydrography Dataset (NHD) rivers, NHD waterbodies). The FL DEP data had 421 unique waterbodies and all but 5 were linked to georeferenced data. The NAS database was edited to include only those aquatic plant records listed as "established" and dating after 1981. Further editing limited the records used to those that had a description in the "locality" field. These localities were then linked to georeferenced data as the FL DEP data was linked. The NAS database listed 549 unique locations and all but

53 of these were linked to georeferenced data. Of the 53 locations, 29 were county and other general place names and so were not specific enough to link to a particular waterbody. The remaining 24 locations were similarly not descriptive enough or the waterbody could not be matched to a georeferenced source. Then all the edited databases were combined to create both a list of all species established between 1982-2007 in each HUC 12 unit and a count of the same (see Appendix B for a list of plants meeting the criteria).

b. Waterway modification

This data layer shows percent modification of the Florida Stream Dataset (FSD) waterways, a revised version of the Feb. 2007, USGS National Hydrography Dataset (NHD) waterways, based on FType comparison and the 2006 Bureau of Transportation Statistics (BTS) navigable waterways data which indicate shipping lanes. Percent modification is summarized at the FL DEP/USGS Hydrologic Unit Code (HUC) 12 level representing subwatershed units for the state of Florida. The FSD FTypes included in this comparison of waterways are as follows:

- connectors
- artificial paths (as they can represent the centerline of major rivers)
- stream/rivers
- canals

The percentage of canal length compared to total length (of the above-mentioned waterway FTypes) was calculated for each HUC 12 unit in Florida using an ArcView extension for landscape analysis, ATtiLA (US EPA 2004). The BTS 2006 navigable waterways data indicate those waterways maintained (i.e. dredged) for shipping purposes. If there was no length attributed to a FSD canal in a HUC 12 unit but there existed a navigable waterway length, that value was added to the “modified” total length (i.e. the numerator of the percentage calculation).

If there was overlap between a FSD canal and a navigable waterway, only one value was used to avoid double-counting. If there were non-overlapping FSD and navigable waterway lengths, both values were included in the "modified" total length. Additionally, some of the FSD waterways were incorrectly classified as non-canals. Another canal dataset from the South Florida Water Management District was used to reclassify as canals these incorrectly classified FSD waterways. Their lengths were also summed by HUC 12 unit and subsequently included in the percentage calculation. Finally, although the FSD layer does extend beyond Florida state boundaries, the stream layer was clipped to remain within state lines, thereby maintaining comparability across all other data layers whose data *do not* extend beyond the state line.

c. Federal dam location summary

This data layer presents the average normal storage capacity in acre-feet from the 2005 National Inventory of Dams (NID) for each HUC 12 unit within Florida. Normal storage is defined by the U.S. Army Corps of Engineers (USACE) as "the total storage space in a reservoir below the normal retention level, including dead and inactive storage and excluding any flood control or surcharge storage." (NID Data Dictionary 2005). The source data, 2005 NID, which lists the normal storage capacity for each structure was summarized by an ArcView extension for landscape analysis, ATtiLA (US EPA 2004), to find the average normal storage for all federal dams within a HUC 12 unit. Point data showing locations of the dams themselves is not available for public release.

d. Ground water withdrawal points and summary

The ground water withdrawal summary data layer (polygons) contains descriptive statistics for permitted ground water withdrawal for each HUC 12 unit in Florida for fall 2007/winter 2008 data. These statistics are based on the point data layer (ground_ADR_final.shp) created from

Consumptive Use Permit information obtained from Florida's 5 Water Management Districts: Northwest Florida, Suwannee River, St. Johns River, Southwest Florida, and South Florida. The point data layer shows locations recorded by each District for ground water withdrawal either as the centroid of a township, range, section block or as coordinate values of the well itself. Descriptive statistics for the "average daily rate" of withdrawal in million gallons per day (MGD) allocated to each permittee per HUC 12 unit were calculated from the point dataset (representing known or approximated locations of wells) using an ArcView extension for landscape analysis, ATtiLA (US EPA 2004). The descriptive statistic used for the composite assessment is the field "sum_adr_mgd" in which ATtiLA sums the ADR value for each point, (i.e. ,well), within a HUC 12. Since two of the districts, Northwest and Suwannee River, identify their ground water withdrawal locations by township, range and section (TRS) block rather than by x, y coordinates for each well like the other three districts do, a summation by each HUC 12 unit allows comparisons across the entire state.

Depending on the District, the permitted allocation may be separated into two allocated amounts: one for surface and one for ground water withdrawal. In some Districts the permitted amount reflects an overall total volume allocated with no distinction made between the amounts allocated for surface vs. ground water. One permit is issued per permittee regardless of the number of wells and/or pumps (i.e. ground and/or surface water, respectively) that will be used by the permittee. The Districts do not require flow monitoring of all wells and/or pumps (only for larger allocation amounts) and just because the amount is allocated does not mean the entire allocation is used by the permittee, thus the true withdrawal from each device is generally unknown. Therefore, for these data layers, the allocated amounts were equally divided among all wells and/or pumps listed for each "active" permit (as identified in each District's database records) if no distinction is made between ground and surface water withdrawal. If there are separate ground and surface water allocations under one permit, then the ground water allocation was divided equally among wells and the surface water allocation was divided equally among pumps. The allocated amount was calculated as an average daily rate (ADR) in million gallons per day (MGD). Finally, the Suwannee River and Northwest Florida Water Management Districts identify their surface and ground water withdrawal permits by township, range, and section rather than by x, y coordinates for each well and/or pump like the other three Districts. For these cases the well/pump locations were assigned to the centroid of the township, range and section (TRS) it was assigned in the original permit. In some cases the TRS value given did not match any documented TRS value in the existing georeferenced, digital TRS maps of Florida. Some of these records were corrected by searching through the particular county's online property records, parcel maps, and associated data. If an online search did not clarify or conclusively resolve the location of the permit in question, then the record was deleted from the final database. Duplicate records were eliminated.

e. Non-native/exotic invasive aquatic animals

This data layer represents a summarization of the number of non-native/exotic invasive aquatic animal species in each HUC 12 unit of Florida. Data were included from the past 25 years (1982 through 2007) with the rationale that if the animal was listed as "established," while its current presence may be different from when originally listed in a database, the possibility of the animal species re-colonizing the same area exists. Two methods to determine the locations of the non-native/exotic invasive animal species in this data layer were used:

- data linked by waterbody name/county --

- species records where waterbodies/counties are named in the USGS NAS database "locality" field for all years after 1981 and where the status is described as "established,"
- species named in the manuscript "Florida's Exotic Freshwater Fishes—2007" (Shafland et al. unpublished manuscript)

These records were linked to existing digital maps of shapefiles containing waterbody names/locations (e.g. canals, lakes, major rivers, NHD rivers, NHD waterbodies), county, and HUC 12 unit number.

- data with x, y coordinates-- three other databases where non-native/exotic invasive animal species locations contain latitude/longitude values
  - data from John Knight for Panhandle species (2005-2007)
  - FWC's Freshwater Fisheries Sampling 2007 data of lakes in Florida
  - FWC's Exotic Species Database (where either "First Year Observed" or "First Observed Year" is after 1981 and NOT "unknown" or "null"; and "status" is NOT "extirpated" or "eradicated"; and "GIS precision" is NOT "county)

Information from these three databases was then linked to a HUC 12 unit. Only fish categorized as "Reproducing Fishes" (established, possibly established, or localized) (Shafland et al. unpublished manuscript) were included. Then all 5 edited databases were combined to create both a list of all species established in each HUC 12 unit and a count of the same. Generally, this dataset represents a conservative picture of non-native/exotic invasive animal species presence in the state and should be viewed as an underestimate due to the following reasons:

- Not all the “locality” field descriptions in the USGS NAS database could be linked to specific waterbodies in the existing digital maps. Some field descriptions mentioned a general place (e.g. Dade county, Everglades National Park, or roadside ditch by Hwy 27) and not a specific waterbody. These data were excluded. Out of 870 records from this database 424 were matched to a specific waterbody. These numbers do not reflect unique locations as some species were noted as established in the same area for multiple years. Some species could not be linked at all: coqui, saber crab, common caiman; and for others a majority of the records were not linked: Burmese python, cane toad, Cuban treefrog, greenhouse frog, Nile monitor, pond slider.
- The data from “Florida’s Exotic Freshwater Fishes—2007” (Shafland et al. unpublished manuscript) while at times was specific about a waterbody in which a fish was found, for multiple species accounts the description was too vague to link to specific waterbodies (e.g. “Blackchin Tilapia generally exists in areas with direct access to saltwater”).
- The FWC’s Exotic Species Database is not complete (personal communication with Larry Connor) and is skewed toward snail data.

See Appendix C for a list of animal species meeting the criteria.

f. Riparian/freshwater buffer zone landcover analysis—subwatershed (HUC 12) level

This data layer represents a HUC 12 level assessment of land cover within several sizes of buffer zones of riparian areas and freshwater bodies (i.e. lakes, ponds, reservoirs) based on the FWC Florida Vegetation and Land Cover 2003 classification (Stys et al. 2004). For each HUC 12 unit 13 categories of land cover aggregated from the 2003 data (see Appendix D for recoded values) are summarized within the following distances from freshwater sources:

- 0 meters (adjacent)
- 30 meters
- 90 meters

Percent values of each land cover class represent the percent of the total land within the particular buffer zone distance *not* the percent of the total land within the entire HUC 12 unit. Freshwater sources included in this analysis are from NHD high-resolution data of polygons (lakes, ponds, reservoirs and areal extents of large rivers) and the line features representing rivers, streams, etc., from the Florida Stream Dataset (FSD). These two datasets were used to provide a more accurate spatial representation of the physical presence of freshwater locations, particularly large rivers, for the riparian landscape analysis performed by ATtiLA (US EPA 2004). If the FSD, (i.e. center lines of waterways), was the only source used then a problem would occur during the analysis of riparian/freshwater land cover within selected buffer zones. The land cover surrounding a center line of a large river will be classified as "water" in the land cover raster and could easily extend from that center line past the width of the largest buffer zone size, 90 meters, meaning that the actual land cover 90 meters from the banks of the large river will not be accurately assessed. Therefore, using both areal extents (polygons) and line features of waterways successfully addresses this issue. The following steps were used to refine the NHD high-resolution data of these freshwater polygons before riparian landscape analysis occurred:

- Certain subtypes were excluded in the final NHD waterbodies/areas layer used with FSD layer to determine the extent of the riparian buffer zone. The subtypes *not included* are as follows:
    - from NHD Areas: hazard zone, foreshore, special use zone (unless outside a lake/pond, reservoir boundary), sea ocean

    - from NHD Waterbodies: ice mass, playa, swamp/marsh
    - The remaining subtypes are included; however, not all other subtypes are present in Florida.
- Duplicate features within the selected subset of NHD Waterbodies data were dissolved by FType prior to analysis.
- The edited polygons were then buffered at 30 meters (on each side) and 90 meters, or left as is (for the adjacent/0 meter analysis)

The FSD layer was also buffered at 30 meters and 90 meters resulting in 3 groups of shapefiles for the riparian/freshwater buffer zone land cover analysis: FSD flowlines/NHD waterbodies-areas not buffered, FSD flowlines/NHD waterbodies-areas with 30 m buffer, and FSD flowlines/NHD waterbodies-areas with 90 m buffer.

Although the entire state is represented by the underlying land cover data, some of the individual HUC 12 units extend beyond the state boundary into Georgia/Alabama and hence beyond the land cover dataset. Characterization of the riparian buffer zone was still performed on these types of HUC 12 units so it is recommended that before use of this data the RO_0, RO_30, or RO_90 (depending on the buffer zone of interest) field's attributes are checked. If the value is less than 95 (i.e. overlap between the land cover data and the HUC 12 unit is less than 95%), the user should consider whether to include these HUC 12 units.

Numerous riparian/freshwater buffer zone metrics were calculated (Appendix A) but for the composite index/assessment only the field showing the percent of landcover classified as “all agricultural uses within 90 meters of a freshwater source” was included.

g. Surface water withdrawal points and summary

The surface water withdrawal summary data layer (polygons) contains descriptive statistics for permitted surface water withdrawal for each HUC 12 unit in Florida for fall 2007/winter 2008 data. These statistics are based on the point data layer (surface_ADR_final.shp) created from Consumptive Use Permit information obtained from Florida's 5 Water Management Districts: Northwest Florida, Suwannee River, St. Johns River, Southwest Florida, and South Florida. The point data layer shows locations recorded by each District for surface water withdrawal either as the centroid of a township, range, section block or as coordinate values of the pump itself. Descriptive statistics for the "average daily rate" of withdrawal in million gallons per day (MGD) allocated to each permittee per HUC 12 unit were calculated from the point data layer (representing known or approximated locations of pumps) using a landscape analysis extension for ArcView, ATtiLA (US EPA 2004). The descriptive statistic used for composite assessment is the field "sum_adr_mgd" in which ATtiLA sums the ADR value for each point, i.e. pump, within a HUC 12 unit. Since two of the districts, Northwest and Suwannee River, identify their surface water withdrawal locations by township, range and section (TRS) block rather than by x, y coordinates for each pump like the other three districts do, a summation by each HUC 12 unit allows comparisons across the entire state.

Please see the "*Ground water withdrawal points and summary*" section above for further description as the methods for assembling these data layers are the same.

h. Verified impaired waters

The Florida Department of Environmental Protection (FL DEP) is mandated to compile a list of water bodies that do not meet water quality standards as set forth in the US EPA's Clean Water Act (CWA) of 1972. This list is referred to as the 303(d) list of verified impaired waters and is required by section 305(b) of the CWA to be reported biennially to the EPA. Therefore, every two years the FL DEP submits the "Integrated Water Quality Assessment for Florida," which presents the current 305(b) report and the 303(d) list update. The FL DEP also produces a corresponding shapefile of the Water Body ID polygons (hereafter, WBID) which are part of the 303(d) list. The attributes provide various data about the WBIDs including the reason for impairment. The WBIDs do not necessarily correspond to a HUC 12 unit; in some cases there are multiple WBIDs per HUC 12 unit (personal communication with David Anderson, FL DEP). Additionally, if a WBID is impaired by more than one factor an additional record with that WBID number is included in the attribute table for the shapefile. Thus to account for all possible impairments to a WBID, the duplicate values must be separated into multiple tables/shapefiles based on the parameter of impairment. For this project the parameters of impairment were aggregated into 9 groups based, in part, on the "Integrated Water Quality Assessment for Florida: 2006 305(b) Report and 303(d) List Update" (FL DEP 2006). If there was not a clear group in which to place a parameter then it was left separate (Table 4). For each of the 9 groups a "percent impairment" value for each HUC 12 unit was calculated based on the total area of the HUC 12 unit and the area of the impaired WBID(s) within it. To account for multiple parameters of impairment of WBIDs within a HUC 12 unit a "total impairment" value (range 0-900, i.e. no WBID within a HUC 12 having any impairment to a HUC 12 whose area is completely overlapped by WBID(s) that is/are impaired by all 9 groups) was calculated by summing all percent impairment values for each HUC 12. This value was then scaled to fall between 0 and 100.

Table 4: Nine groups created using the "parameter" field from the attribute table of the FL DEP verified impaired waters shapefile from Feb. 12, 2008; *The "biology" parameter was divided, based on comments from the attribute table, between the BOD/DO and nutrient categories.

Group ID	Group Name	Parameters Included
21	nutrients	nutrients, nutrients (algal mats), nutrients (chla and historic chla), nutrients (chla and other information), nutrients (chla), nutrients (histchla), nutrients (other information), nutrients (TP), nutrients (TSI), biology*
12	conductivity	conductivity
33	turbidity	turbidity
1430	pesticides/dioxin	dioxin, pesiticides (in fish tissue)
34	un-ionized NH_3	un-ionized NH_3
3	bacteria	bacteria, bacteria (in shellfish), beach closure advisory for bacteria
Me	metals	arsenic, cadmium, copper, iron, lead, nickel, mercury (in fish tissue), selenium, silver
01	BOD/DO	BOD, DO, biology*
9	coliforms	coliform (fecal coliform), coliform (shellfish harvesting classification), coliforms (beach advisory), fecal coliforms

i. Water control structures points and summary

Florida's 5 Water Management Districts (Northwest Florida, Suwannee River, St. Johns River, Southwest Florida, and South Florida) are responsible for regulating surface water management. This data layer represents the most current data available (late 2007 to early 2008) for permitted water control structures from each Water Management District (WMD). Locations are shown either as the centroid of a township, range, section block or as coordinate values of the water control structure itself. These data do NOT include federal dams. Some data were excluded from the Suwannee River's original database of water control structures based on permit status. If the permit status was listed as "expired" or "no permit issued" these points were excluded. Records listed as "ponds" were also excluded. Duplicate records were eliminated. Some data were also excluded from Northwest Florida's original database of water control structures. If the status was listed as “withdrawn,” “revoked,” “incomplete,” “expired,” “denied,” or “no permit required” then these were excluded. Again, duplicate records were eliminated. The Suwannee River and Northwest Florida Water Management Districts identify their water control structures by township, range, and section rather than by x, y coordinates for each structure like the other three Districts do. For these cases the structure locations are assigned to the centroid of the township, range and section (TRS) it was assigned in the original permit. In some cases the TRS value given did not match any documented TRS value in the existing georeferenced, digital TRS maps of Florida. Some of these records were corrected by searching through the particular county’s online property records, parcel maps, and associated data. If an online search did not clarify or conclusively resolve the location of the permit in question, then the record was deleted from the final database. Personnel at both of these Districts noted that their databases of water control structures are incomplete and not current, but represent the best available information. All 5 databases were then combined to obtain a both a count of water control structures per HUC 12 unit and a density value. Density was calculated as the number of structures per kilometer of stream length within each HUC 12 unit. Stream length values were calculated for each HUC 12 unit from the FHD using the landscape analysis ArcView extension, ATtiLA (US EPA 2004).

j. Weighted road density

This data layer depicts road density per HUC 12 unit for Florida using TIGER Roads 2006 Second Edition data, Florida Department of Transportation (FDOT) “surface width” data and “number of lanes” data from Jan. 2008. A landscape analysis extension for ArcView, ATtiLA (US EPA 2004), calculated a standard road density measurement of kilometers of road per square kilometer of area for each HUC 12 unit. The FDOT data enhance the original TIGER data by accounting for width of major road surfaces in a weighted calculation of road length. Multiplying the length of the roadway by a weighted width factor captured the larger footprint created by multi-lane roads. The following method was used to calculate weighted road density values:

1. Ran ATtiLA with only TIGER roads data to calculate total road length for each HUC 12 unit
2. Joined the FDOT number of lanes with FDOT surface width to attach a width to each roadway's number of lanes
3. Found average width for each number of lanes: e.g. 1 lane road averaged 12 feet wide, 2 lane road averaged 23 feet wide, etc.
4. After determining the average width for 1 lane road, 2 lane road, 3 lane road etc. a weighting scheme for roads of each width was developed. A road of width 12 feet (which corresponds to the average width of a 1 lane road) received a weighting factor of one. Roads of width 8-11 feet also received a weighting factor of one. The 2 lane road averaged 23 feet wide. So roads from 13 to 22 feet wide received incremental weighting factors between 1 and 2. The 3 lane road averaged 35 feet wide so roads from 24 to 34 feet wide received incremental weighting factors between 2 and 3. This process was repeated until reaching the upper limit of road width (98 feet) and number of lanes (8).
5. For this density analysis, all other road segments not accounted for in the FDOT data were given a weighting factor of one (in other words, assuming they are all 1 lane roads).
6. Used ATtiLA to calculate road length by surface width class (i.e. what is the total length per HUC 12 for roads of 8 ft, 9 ft, 10 ft, 11 ft, 12 ft, 13 ft, etc.) for the FDOT roads for each HUC 12 unit. This step also gives the (unweighted) total road length for each HUC

12. This results in the calculation of length of each class of FDOT roadway in each HUC 12. These values were multiplied by the corresponding weighting factors calculated above and summed across all classes to get a weighted total road length for each HUC 12 unit.

7. From the initial TIGER roads ATtiLA HUC 12 summary of road length (step 1) subtract the unweighted FDOT roads ATtiLA HUC 12 summary of road length. Then add the WEIGHTED FDOT road length to the difference of the above resulting in TIGER road length plus weighted FDOT road length.
8. Then the weighted road density is calculated: weighted road length/area of HUC 12 unit.

A.1.2. OTHER DATA LAYERS/SHAPEFILES AVAILABLE (NOT INCLUDED IN COMPOSITE)

Data layers (a-d) in this section were not included in the composite index of threats to Florida’s freshwater habitats but are available.

a. Petroleum contaminated sites

The Florida Administrative Code (FAC) stipulates a Petroleum Contamination Site Priority Ranking rule in Chapter 62-771. This scoring system provides a way to prioritize for eligibility to various programs assisting in the cleanup of petroleum spills (Florida Department of State 2008a). A high score equals a high priority and a low score equals a low priority. These scores are based on points awarded for fire/explosion hazard, threat to uncontaminated drinking water supplies, migration potential (e.g. to wells), and environmental setting (e.g. within 0.5 miles of Outstanding Florida Water or in high recharge/permeability geological area). This data layer summarizes the scores by HUC 12 unit from the March 4, 2008, FL DEP database. While it is not possible to separate the scores based on water-related contamination only, the higher the score the more likely a contamination potential for water exists. The original FL DEP database contained 14,411 records of petroleum contamination. Upon importing this data into ArcGIS it was discovered that 666 records had latitude/longitude values that placed the point outside the state boundary of Florida. These records were deleted. Of the remaining 13,745 records, 299 were found to have a null value for the score. These records were also deleted leaving a final total of 13,446 records for which the summary analysis by HUC 12 was completed using ATtiLA (US EPA 2004). The resulting "average score" and "point density" fields were used to calculate a density weighted average score.

b. Road & stream crossings

This data layer represents a HUC 12 unit based assessment of metrics related to road/stream crossings for Florida. Since a major component of this data layer is derived from the TIGER Roads 2006 Second Edition data, users should be aware of the inherent errors in horizontal positional accuracy of TIGER files. The linear FSD layer is the other component of this data layer. ATtiLA calculates road/stream crossings metrics using only linear themes for both water and roads. Thus no other types of waterbodies are included (e.g. lakes, ponds, reservoirs).

c. Parcels of selected land use, summary and polygons

This data layer summarizes the land use of selected parcels obtained from the Florida Department of Revenue (FDOR) tax roll data from 2007 by HUC 12 unit. FDOR receives information about the parcels within each county including a land use classification code. The code is assigned by the property appraiser should reflect the highest and best use of the property (Florida Department of State 2008b). FDOR is subsequently supposed to verify that the code assigned by the property appraiser does reflect this use. There are 99 land use classification codes. Here a selected subset of parcels includes only 5 of these codes: (68) dairies/feedlots, (91) utility, electricity, gas, telephone and telegraph, locally assessed railroads, water and sewer service, pipelines, canals, and radio and television communication, (92) mining lands, petroleum lands, or gas lands, (93) subsurface rights, and (96) sewage disposal, solid waste, borrow pits, drainage reservoirs, wastelands, marsh, sand dunes, swamps, etc. An intermediate data layer of these selected parcel polygons was assembled and then using a polygon-in-polygon analysis via Hawth's Tools ver. 3.27, the HUC 12 summary layer was created showing the percent of the HUC 12 unit designated as one of the selected land uses.

d. Landscape analysis—subwatershed (HUC12) level

Studies have examined the ability of riparian buffer zones to effectively protect water quality when proportions of human-based landcover types outside the buffer zone cross certain thresholds (Goetz et al., 2003; Jones et al., 2006; Roy et al., 2007). This data layer represents a HUC 12 unit based assessment of land cover utilizing FWC's Florida Vegetation and Land Cover 2003 classification (Stys et al. 2004). The percentages and total area of aggregated land cover types from the 2003 data (see Appendix D) are calculated along with two index values: U_INDEX and N_INDEX which represent a summation of all human-based land cover types and natural land cover types, respectively. These calculations consider only terrestrial land cover, i.e. land cover classified as "water" is excluded, and therefore percentages of land cover calculations exclude water from total area. Three different assessments are contained in this shapefile (Appendix A). The first set of metrics characterizes the entire HUC 12 unit (excluding water as stated above). The second set characterizes the land cover of the HUC 12 unit excluding not only the water but also a 90 meter buffer zone around the waterbodies/streams. The third set characterizes the land cover of the HUC 12 unit excluding not only the water but also a 30 meter buffer zone around the waterbodies/streams.

To perform this landscape analysis using ATtiLA (US EPA 2004), the original raster land cover dataset was modified to exclude the 30 and 90 meter buffer zone areas using the existing 30 m and 90 m buffered NHD waterbodies/areas polygons and the 30 m and 90 m buffered FSD flowlines previously created for the riparian landcover analysis (see section A.1.1.f above). The modified raster was created using the following steps (listed for 30 meters, but same process for 90 m):

1. 30 meter buffer NHD waterbody/area polygons and corresponding FSD layer were merged
2. merged file used to extract from the original land cover map the pixels within the 30 meter buffer zone
3. recoded this extracted raster into a binary raster where the buffer zone pixels equal 100 and all other pixels equal 0
4. added this binary raster to original raster land cover so all buffer zone pixel values are >100 and the rest of the land cover is classified as before
5. the pixels with values >100 can then be classified as “no data” in the ATtiLA program and would not be included in the landscape analysis

The same process for the entire HUC 12 unit (i.e. non-buffered freshwater) was used except the FSD layer was not used since extracting every 30 meter pixel through which an unbuffered stream passes would tend to exaggerate the amount of water present in a HUC 12 unit.

Although the entire state is represented by the underlying land cover data, some of the individual HUC 12 units extend beyond the state boundary into Georgia/Alabama and hence beyond the land cover dataset. Characterization of the riparian buffer zone was still performed on these types of HUC 12 units so it is recommended that before use of this data the

LC_OVERLAP, LC_OVERL_1, or LC_OVERL_2, (depending on the buffer zone of interest) field's attributes are checked. If the value is less than 95 (i.e. overlap between the land cover data and the HUC 12 unit is less than 95%) the user should consider whether to include these HUC 12 units. Numerous landscape metrics were calculated (Appendix A) but none were included in the composite assessment/index.

B. Individual assessments

The individual data layers from sections A.1.1 and A.1.2 were categorized into 5 classes using the Jenks natural breaks method available in ArcGIS 9.2. A sixth class representing both the absence of the threat (i.e. a true zero value) and "undetermined" threats (i.e. is the threat truly absent or is it present and undocumented) was included *after* the initial classification to prevent these types of HUC 12 units from skewing the natural breaks of those HUC 12 units with known/non-zero threat values.

A search of relevant literature revealed evidence for threshold values for certain threats beyond which there are empirically supported declines in freshwater habitat quality. However, this support was strongest for only one type of threat, urban landcover/impervious surface, and much weaker for road density. Therefore, the classifications were not modified from the original natural breaks results.

C. Composite assessment/Freshwater Threats Index

Freshwater ecosystems are often negatively impacted by more than one factor. Despite the difficulty in accurately determining the synergistic effects of multiple threats to freshwater ecosystems, a basic assessment of relative overall threat level can be derived from a composite of the individual data layer metrics created. First, these metrics were analyzed for significant correlations to prevent the inclusion of metrics representing essentially the same threat. If the

Spearman correlation coefficient was greater than 0.6 (or less than -0.6) the metrics were considered to have significant correlation and both were not included in the composite Freshwater Threats Index. The uncorrelated metrics' values for each HUC 12 unit were recoded to range between 1 and 6 based on the natural breaks classification performed in section B, above, with 1 representing an absence of the threat/"undetermined" threat and 6 representing the highest level of the threat. Using these index values the following composite assessments were derived:

- Maximum index value across all uncorrelated metrics for a HUC 12 unit
- Cumulative index value (sum of all index values) for a HUC 12 unit
- Count of index values 4 and higher (i.e. 4, 5, or 6) within each HUC 12 unit
- Overall index value (3 digit number where the first digit represents the maximum index value and the second two digits represent the cumulative index value)

Finally, a regional assessment at a HUC 8 level was performed to investigate potential patterns of threats within different regions of the state. HUC 8 units are two tiers up in the hierarchically designed Hydrologic Unit Maps from the USGS compared to HUC 12 units (Figure 2). In Florida, there are 54 HUC 8 units and 1,347 HUC 12 units at least partially within Florida. For all HUC 12 units within a particular HUC 8 the metric (or metrics) responsible for the highest index value of that HUC 12 was determined. Then the metric (or metrics) with the greatest frequency of highest value in a HUC 8 was considered the most common reason for a region's overall threat level. The second most common reason for a region's overall threat level was also calculated.

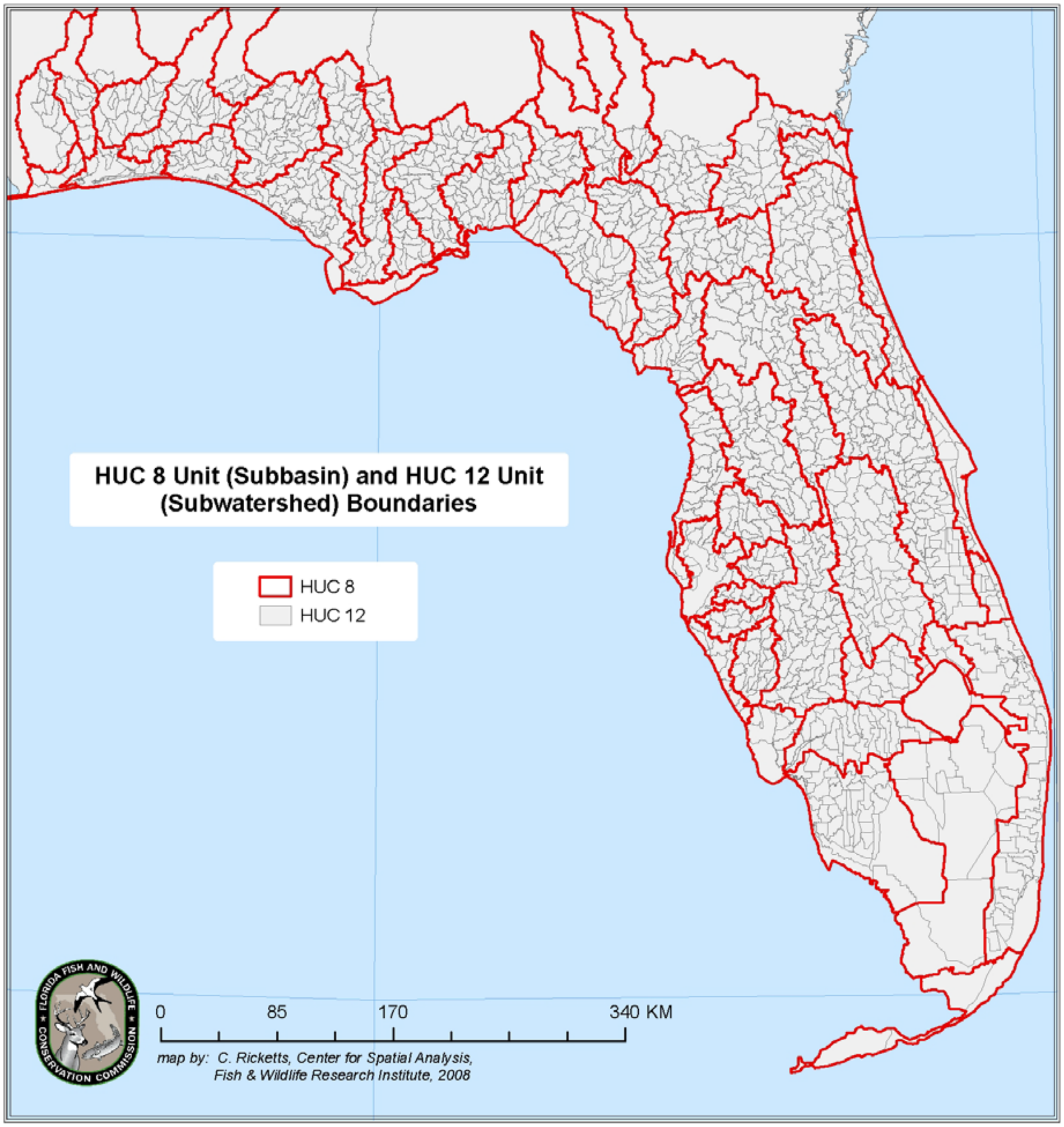

Figure 2: Tiered HUC 8 subbasins and HUC 12 subwatersheds.

III. RESULTS

A. Individual Assessments

Only those data layers which were ultimately included in the composite assessment/Freshwater Threats Index are described in detail. For each layer data was summarized at a HUC 12 unit level which provides a perspective on local conditions that could instigate more targeted investigations. Additionally, FWC's Regions are employed as a standardized way to refer to regions within the state when describing larger-scale patterns (Figure 3).

A.1. NON-NATIVE/EXOTIC INVASIVE AQUATIC PLANTS

Although every major river basin in Northwest Florida contains invasive aquatic plant species, diversity is greatest in the North Central Region south to Lake Okeechobee. Across the Southern Region of Florida including the Gulf and Atlantic coastlines as well as the Everglades and Big Cypress Swamp, invasive aquatic plant diversity is low compared to the rest of the state (Figure 4). Two plant species, water-hyacinth (*Eichhornia crassipes*) and torpedo grass (*Panicum repens*), are considered established in 31% of Florida's HUC 12 units (Table 5).

A.2. WATERWAY MODIFICATION

Most of the modification in Northwest Florida consists of both canals and channelized waterways along coastal areas with the major exception being the Apalachicola River along its entire length in Florida. The hotspots in Madison/Taylor counties (C, Figure 5) and Leon/Jefferson/Wakulla counties (B, Figure 5) reflect low overall waterway length within each HUC 12 unit. These areas also contain industrial pinelands through which some

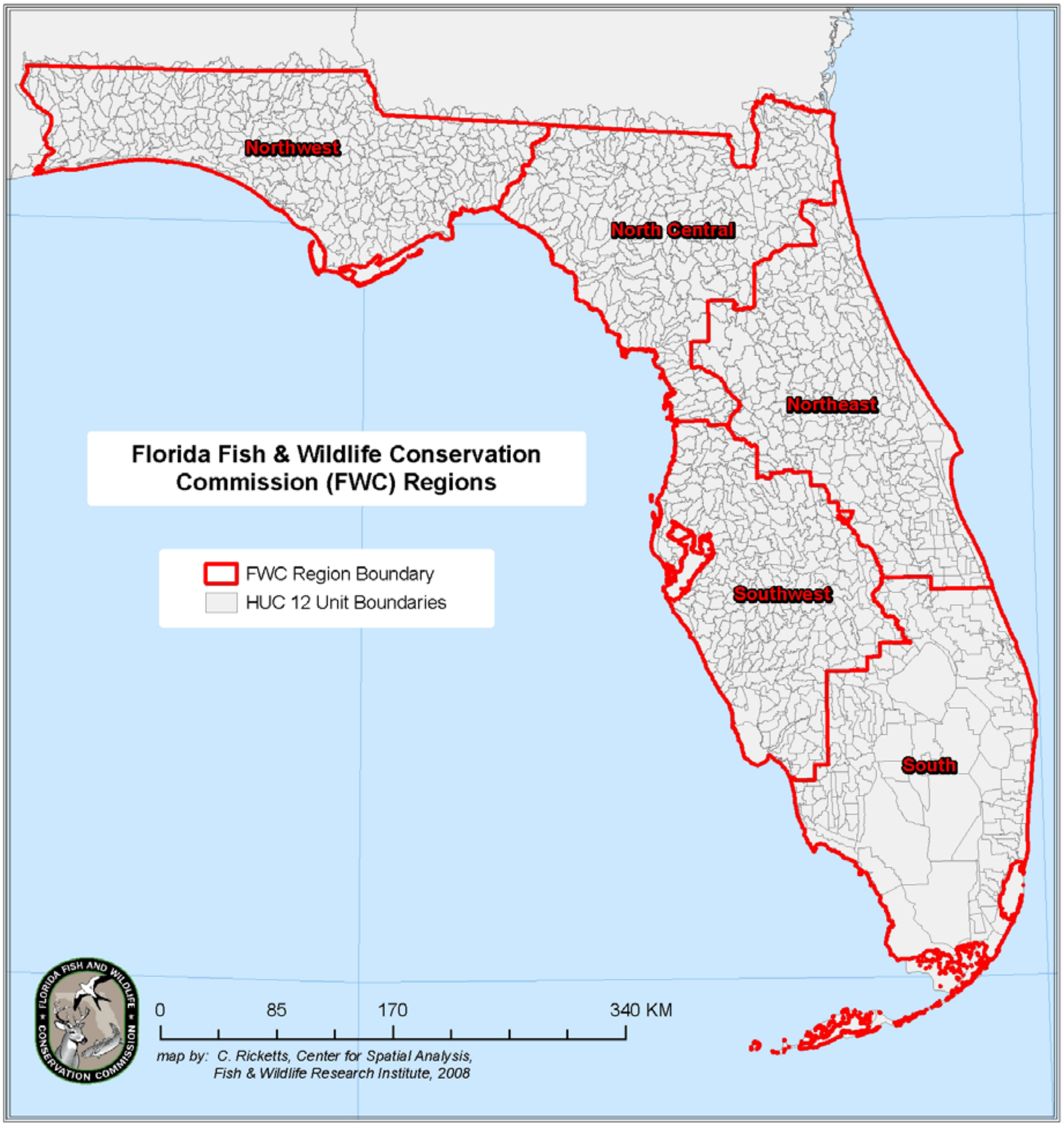

Figure 3: Florida Fish and Wildlife Conservation Commission's Region boundaries

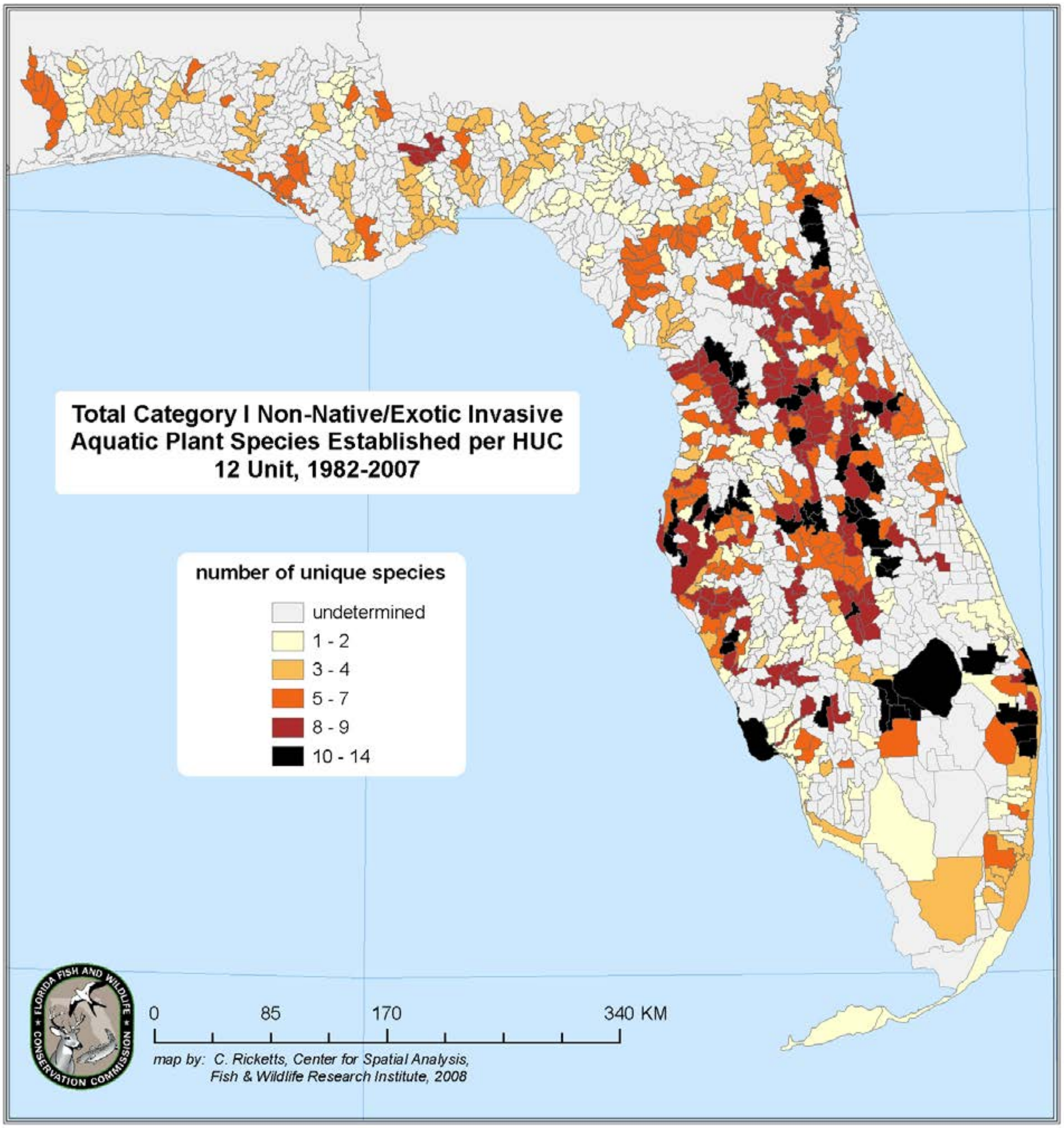

Figure 4: Jenks natural breaks method automatically calculated the classes for values 1-14. The "undetermined" class represents HUC 12 units where either no invasive plant species was recorded or where no effort to detect invasive plants was made and was not included in the natural breaks classification.

Table 5: The number of HUC 12 units in which each invasive aquatic plant species was recorded as established for 1982-2007.

SPECIES	# of HUC 12 units
Eichhornia crassipes	428
Panicum repens	428
Hydrilla verticillata	367
Colocasia esculenta	340
Ludwigia octovalvis/peruviana	292
Pistia stratiotes	285
Brachiaria mutica	274
Sapium sebiferum	153
Melaleuca quinquenervia	111
Schinus terebinthifolius	103
Hygrophila polysperma	97
Hymenachne amplexicaulis	75
Pennisetum spp.	58
Casuarina equisetifolia	50
Solanum tampicense	19
Lygodium microphyllum	17
Ipomoea aquatica	14
Casuarina glauca	10
Pennisetum purpureum	10
Lygodium japonicum	2

(Madison/Taylor) or all (Leon/Jefferson/Wakulla) of the waterways classified as canals pass. The hotspot in Liberty/Franklin counties (A, Figure 5) is within Tate's Hell State Forest and the modified waterways appear to follow the forest road network. The remaining north Florida waterways are relatively free from modification. South of a line stretching from the mouth of the St. John's River along the Oklawaha River to the northern edge of Citrus county (roughly the border between FWC's North Central and Northeast Regions) increasing modification is the trend. A total of 175 HUC 12 units fall within the highest category (81.16%-100%) and all of these except the aforementioned hotspots (A, B, and C in Figure 5) occur south of the St. John's River-Citrus county diagonal line shown in Figure 5. The HUC 12 units with lower percent waterway modification along the extreme southwest coast and the southern tip of Florida

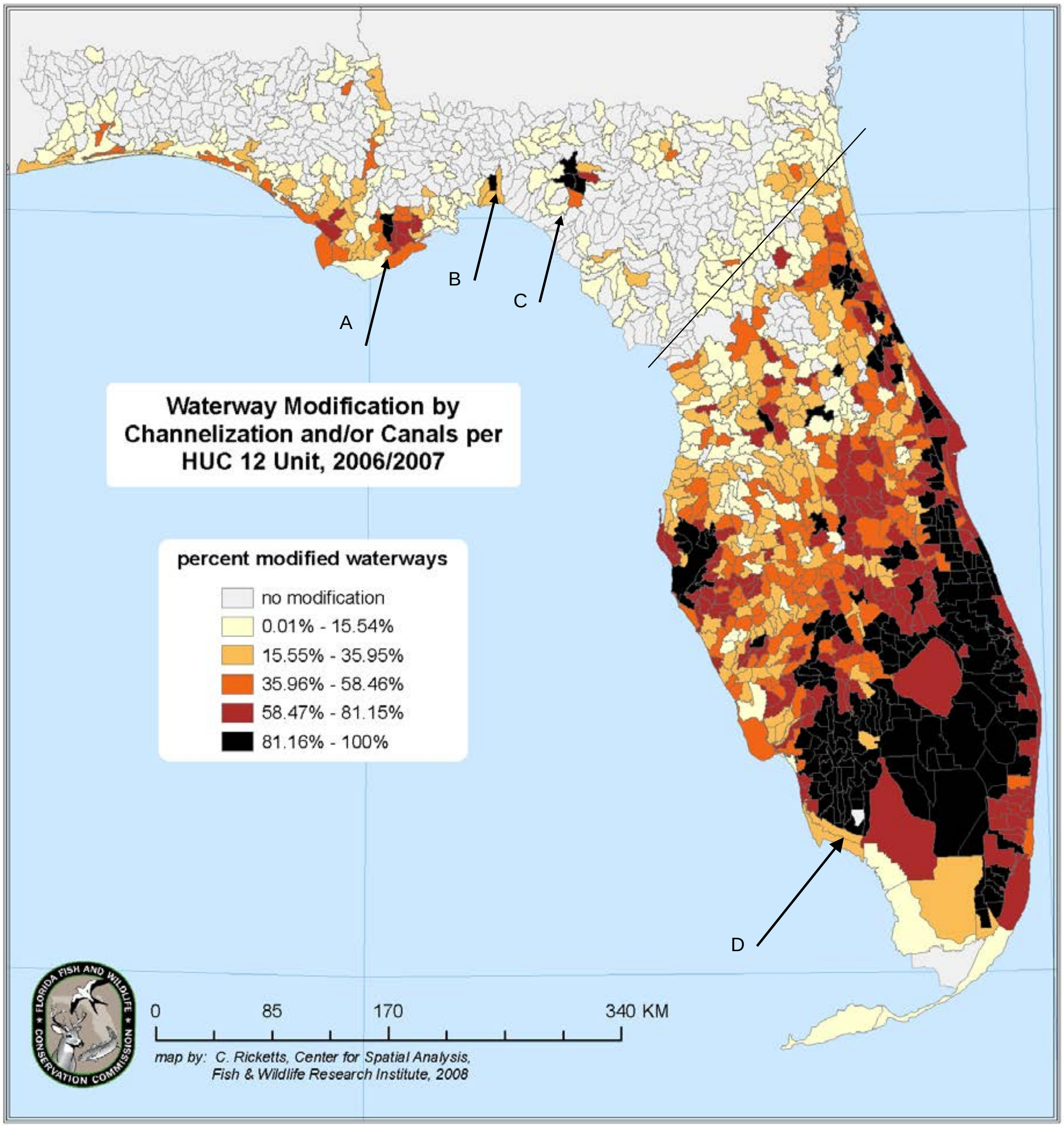

Figure 5: Jenks natural breaks method automatically calculated the classes for non-zero percent values. The "no modification" class represents true zero values where no modification exists and was not included the natural breaks classification. "A" =Liberty/Franklin, "B" =Leon/Jefferson/Wakulla, "C"= Madison/Taylor, "D" = no linear waterways.

(excluding the Keys) contain Everglades National Park and Ten Thousand Islands National Wildlife Refuge, while those HUC 12 units containing the Keys have limited linear water features (Figure 5). The HUC 12 unit in the Southwest Region which has no modification (D, Figure 5) actually contains no linear waterways.

A.3. FEDERAL DAM STORAGE

A total of 287 HUC 12 units contain federal dam structure(s). The greatest average storage capacity per HUC 12 unit occurs from Lake Okeechobee southward (Figure 6). The majority of structures within these units, along with those in the two HUC 12 units north of Lake Okeechobee with higher storage, are for flood control and storm water management. In the Northwest Region storage capacity is low overall and the two main primary purposes of structures here are (1) recreation and (2) fish/wildlife ponds. Storage is also low overall in the North Central Region but the primary purposes shift to (1) tailings and (2) other. The “other” category often refers to structures owned by various industries. East of Tampa-St. Pete the cluster of relatively low storage capacity HUC 12 units contain structures owned by mining and other industrial companies and are used primarily for (1) other and (2) tailings.

A.4. GROUNDWATER WITHDRAWAL

The permitted total average daily rate of groundwater withdrawal in Northwest Florida is greatest in 5 HUC 12 units (Figure 7). For the three westernmost HUC 12 units with the highest rates, the dominant permittee is Gulf Power (A, Figure 7). For the two near Tallahassee, the dominant permittees are Florida State University, Florida A&M University, and the City of Tallahassee (B, Figure 7). Moving east from the Northwest Region toward the North Central Region the trend is toward both more widespread and greater average rate of permitted withdrawals. In those HUC 12 units with the highest permitted withdrawal rates for this region,

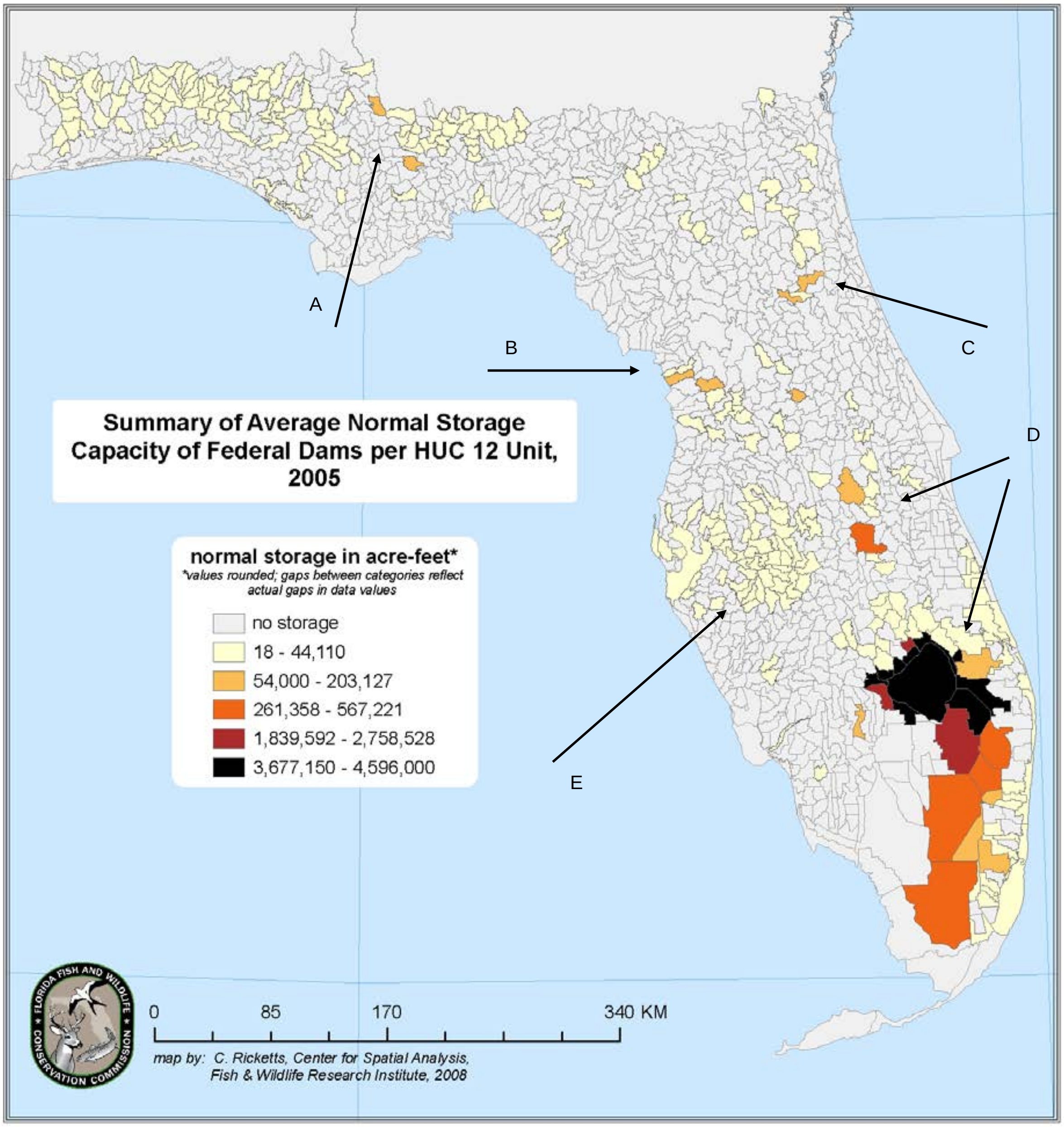

Figure 6: Jenks natural breaks method automatically calculated the classes for non-zero storage values. The "no storage" class represents true zero values where no storage (i.e. no federal dam structure) exists and was not included the natural breaks classification. "A" = Jim Woodruff and Lake Talquin dams, "B" = Inglis Spillway and Hernando Outfall, "C" = Buckman Lock and Rodman dam, "D" = Kissimmee-St. Cloud-Okeechobee-Everglades, "E" = many structures owned by industry/mining.

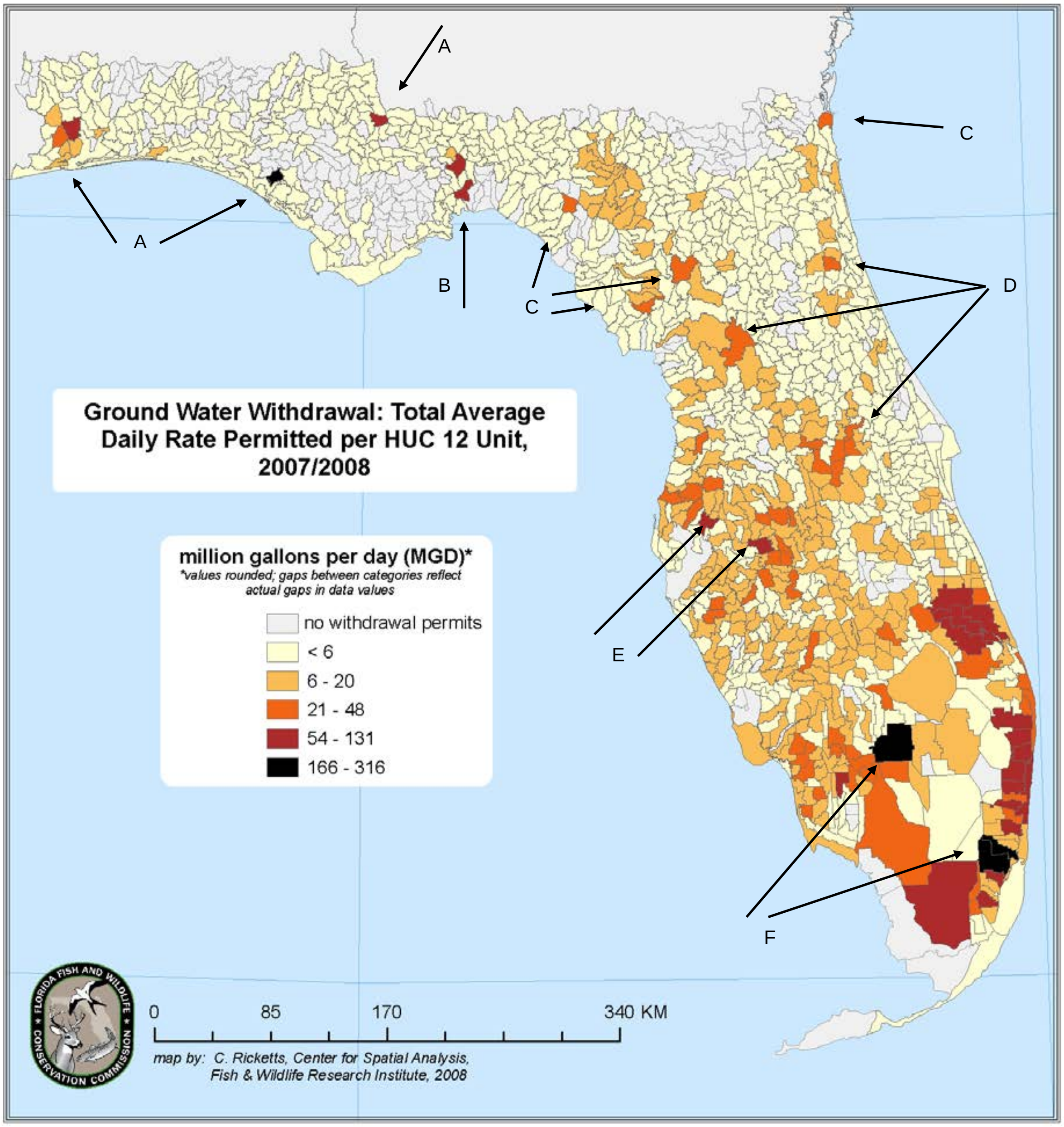

Figure 7: Jenks natural breaks method automatically calculated the classes for non-zero permitted withdrawal values. The "no withdrawal permits" class represents true zero values where no permits have been issued and was not included the natural breaks classification. "A" = Gulf Power dominates, "B" = Tallahassee hotspot, "C" = farms/nurseries, industry, "D" = utilities, communities, golf courses, "E" = Tampa utilities, Mosaic Co., "F" = ranches/citrus, golf courses, quarries, utilities, Miami Int'l Airport.

dominant permittees are nurseries, farms, some mining and Buckeye Technologies. Hotspots in the Northeast Region are attributed to utilities, communities, and golf courses, while those in the Southwest Region are due to Tampa Bay Water, City of Tampa, and Mosaic Company (E, Figure 7). The South Florida hotspots include agricultural interests (farms/ranches, citrus), along with quarries, golf courses, utilities and the Miami International Airport as high volume permittees (F, Figure 7).

A.5. NON-NATIVE/EXOTIC INVASIVE AQUATIC ANIMALS

Based on available data, diversity of invasive aquatic animal species is highest in South Florida. The major river basins of Northwest Florida all contain at least one species while the North Central Region is relatively sparse in within HUC 12 level diversity of invasive aquatic animal species. Within the Northeast Region, the HUC 12 units containing the St. John's River have greater numbers of species as do those upstream of Lake Kissimmee. The Southwest Region has a distinct hotspot of elevated species numbers in HUC 12 units containing the Manatee, Myakka, and Peace Rivers in addition to those around Tampa-St. Pete (Figure 8). The muscovy duck and the brown hoplo are found in 21% and 9% of HUC 12 units, respectively (Table 6).

A.6. RIPARIAN/FRESHWATER BUFFER ZONE AGRICULTURAL LAND COVER ANALYSIS

Agricultural land concentration within 90 meters of riparian/freshwater buffer zones per HUC 12 unit follows two trends (Figure 9). First, from the coasts inland, the percent of agricultural land within a HUC 12 unit's buffer zone generally increases. Second, along a north-south gradient (except coastal areas), the agricultural land within the buffer zone within a HUC 12 unit also increases. The hotspot in the North Central Region does not contain linear hydrology, but rather individual waterbodies not superficially connected according to FSD

Table 6: Based on available information, the number of HUC 12 units in which each invasive animal species was recorded as "established" for 1982-2007 (top 15 out of 77 are listed).

SPECIES	# of HUC 12 units
muscovy duck	286
brown hoplo	119
island applesnail	105
flathead catfish	91
blue tilapia	73
asian clam	66
vermiculated sailfin catfish	53
blue catfish	47
asian swamp eel	40
oriental weatherfish	37
walking catfish	36
common carp	36
African jewelfish	31
Mozambique tilapia	27
Orinoco sailfin catfish	21
spotted tilapia	20
purple swamphen	17
Nile tilapia	16
suckermouth catfish	16
jaguar guapote	15

information (A, Figure 9). The HUC 12 unit just to the north of Lake Apopka (B, Figure 9), those east of Lake Winder and Lake Washington, and those near Blue Cypress Lake (C, Figure 9) are hotspots in the Northeast Region. Other than two near Tampa Bay (D, Figure 9), the majority of HUC 12 units with high agricultural land percentages in Southwest and South Florida are centered around Lake Okeechobee, and 53 out of the 65 HUC 12 units with the highest percentages in the state occur in these regions near the lake.

A.7. SURFACE WATER WITHDRAWAL

Total average permitted surface water withdrawal is essentially divided among two major groups within the state: energy and agriculture. Those HUC 12 units north of "A" in Figure 10

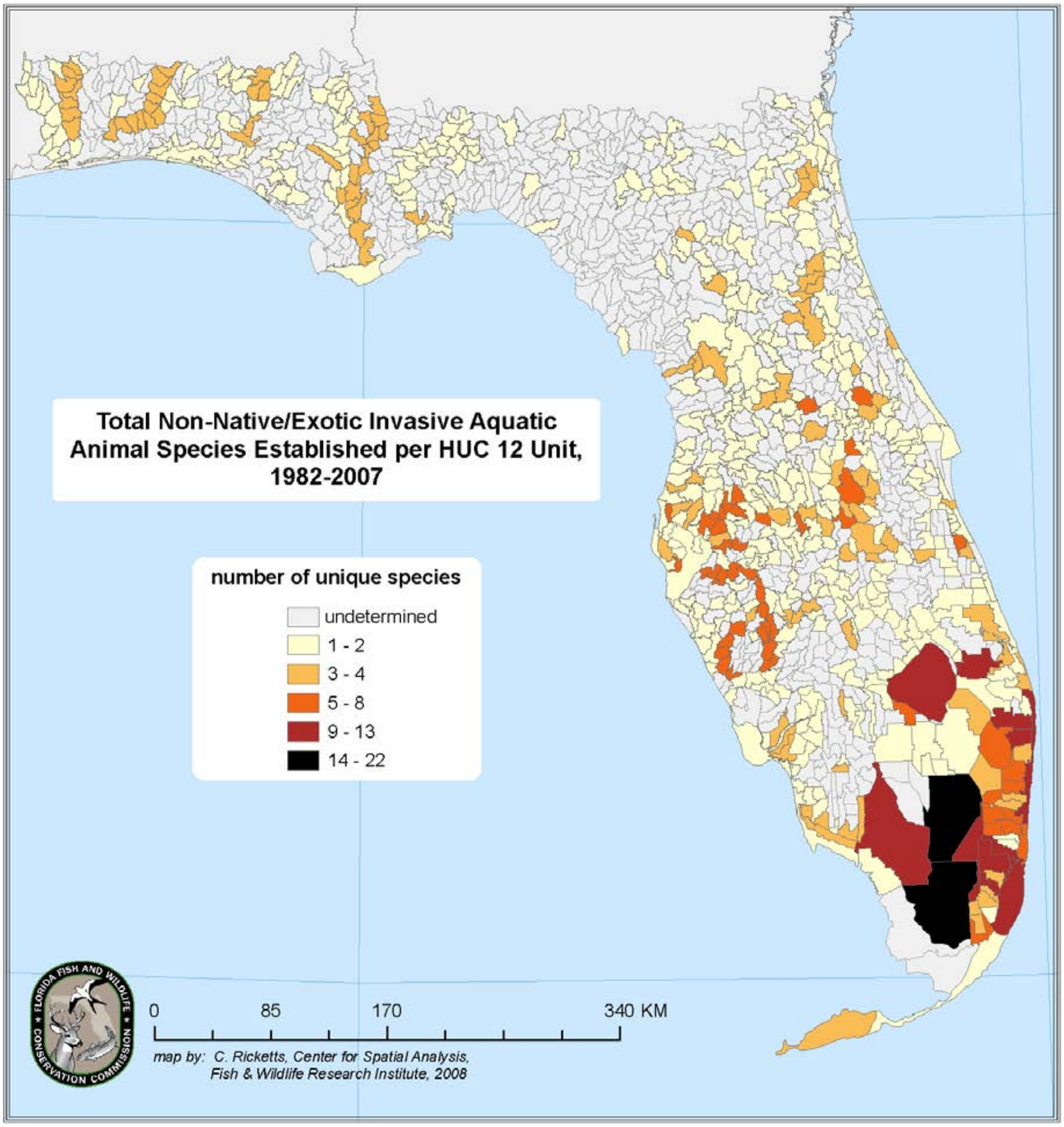

Figure 8: Jenks natural breaks method automatically calculated the classes for values 1-22. The "undetermined" class represents HUC 12 units where either no invasive animal species was recorded or where no effort to detect invasive animals was made and was not included in the natural breaks classification.

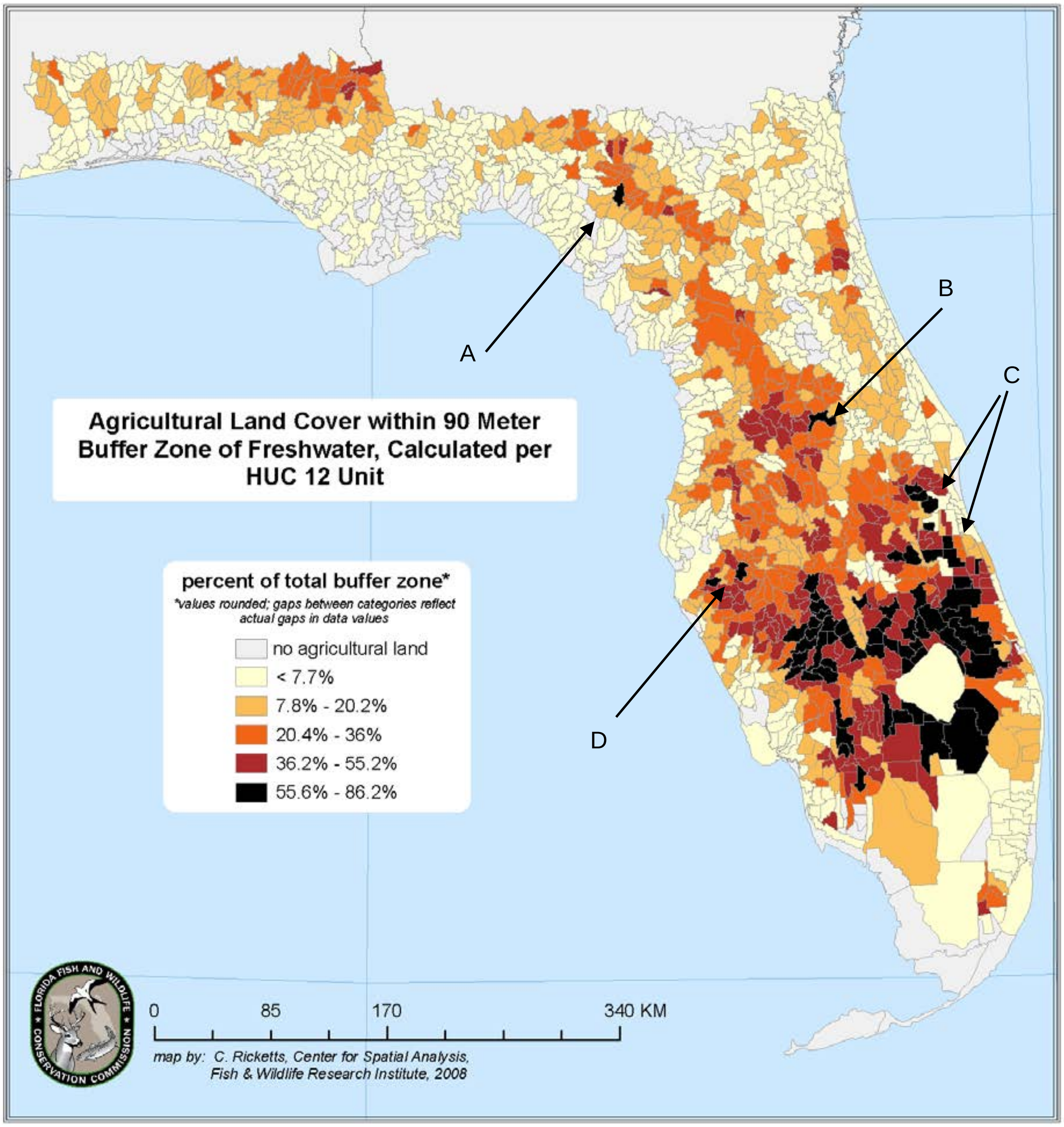

Figure 9: Jenks natural breaks method automatically calculated the classes for non-zero agricultural land cover values. The "no agricultural land" class represents true zero values where no land cover classified as agricultural within a 90 meter buffer zone around freshwater exists and was not included in the natural breaks classification. "A" = non-linear water features, "B" = north of Lake Apopka, "C" = Lakes Winder, Washington and Blue Cypress, "D" = near Tampa Bay.

with high rates of permitted withdrawal are dominated by energy companies including Gulf Power, St. John's River Power Park, and Florida Power & Light. Near Tallahassee and Tampa (B and A, respectively, Figure 10) the City of Tallahassee and Tampa Bay Water also have high rates of permitted withdrawal. In South Florida major permitted surface water withdrawal amounts are allocated to citrus, sugar, and other agricultural interests (D, Figure 10). Minor players in these high permitted withdrawal in southern Florida HUC 12 units include some mining companies (C, Figure 10) as well as golf courses and private communities.

A.8. VERIFIED IMPAIRED WATERS

The scaled values of impairment for each HUC 12 unit account for the percent area of each unit that is impaired by up to 9 different factors. Seventy-six percent of the HUC 12 units (44 out of 58) with the highest scaled impairment values are found from Tampa southward (Figure 11). Northwest Florida has a single HUC 12 unit in the highest category of impairment and it contains 11 Mile Creek, a tributary of the Perdido River (A, Figure 11). Reasons for impairment of this subwatershed include coliforms, Biochemical Oxygen Demand (BOD)/Dissolved Oxygen (DO), and un-ionized NH_3. The North Central Region also has a single highly impaired HUC 12 unit. This subwatershed is near Perry, contains a portion of the Fenholloway River and is impaired by conductivity, BOD, and un-ionized NH_3 (B, Figure 11). The cluster of highly impaired HUC 12 units along the Brevard county coast are almost uniformly impaired by nutrients, metals, and BOD/DO (C, Figure 11). One out the 8 is also affected by coliforms. Further south at the Indian River County coast, coliforms, BOD/DO, nutrients and metals are the reasons for impairment of the HUC 12 units in the highest scaled impairment category (D, Figure 11). All 8 of the most highly impaired subwatersheds east of Lake Okeechobee are impaired by BOD/DO. Six are also impaired by nutrients and metals, with fewer by turbidity, coliforms,

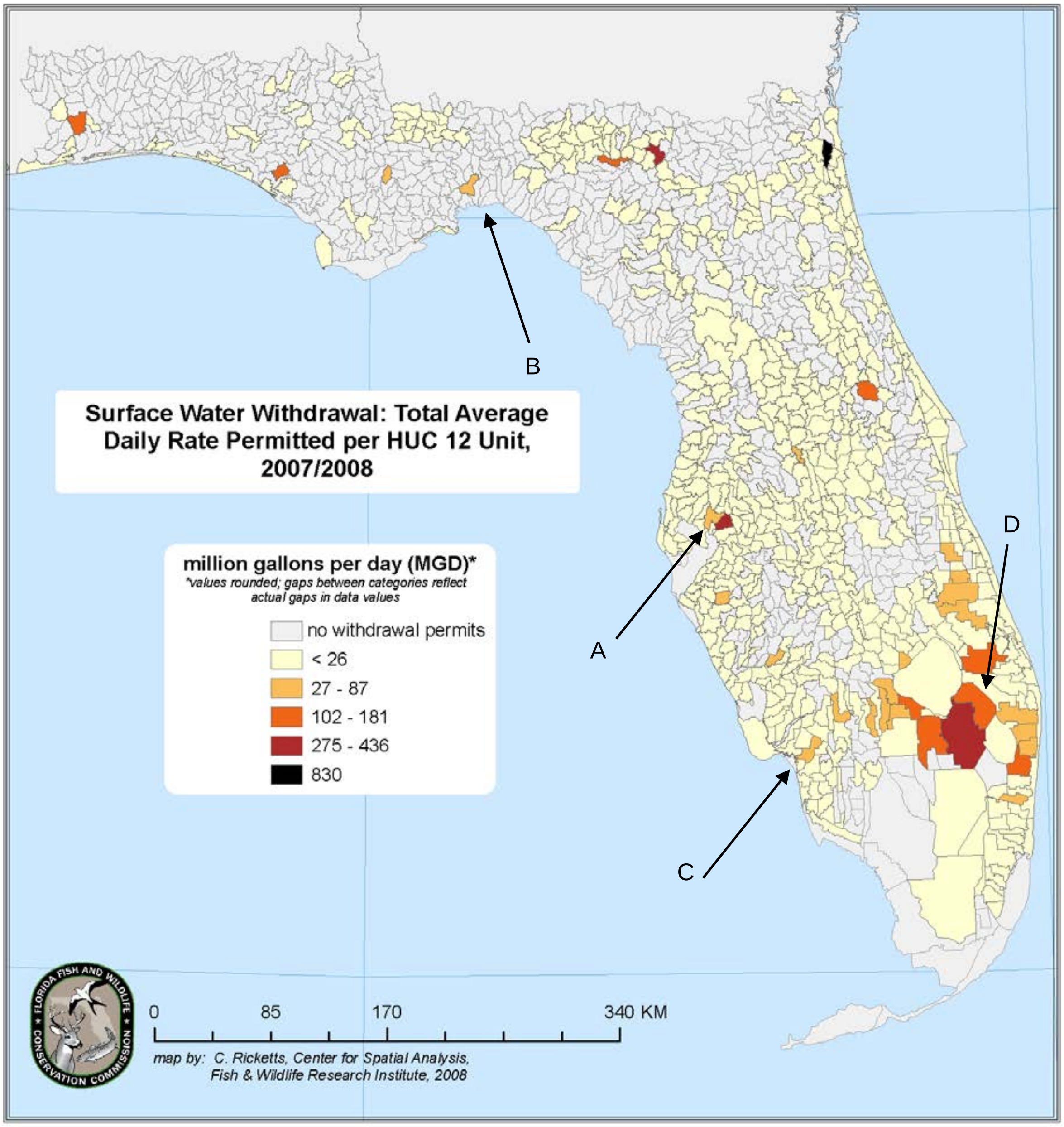

Figure 10: Jenks natural breaks method automatically calculated the classes for non-zero permitted withdrawal values. The "no withdrawal permits" class represents true zero values where no permits have been issued and was not included in the natural breaks classification. "A" = Tampa Bay Water, "B" = Tallahassee hotspot, "C" = mining, communities, golf courses "D" = citrus, sugar, other agriculture.

conductivity, and/or bacteria. This grouping is impaired by the greatest variety of parameters—7 out of 9—of any of the subwatershed clusters described here (E, Figure 11). The 15 most highly impaired subwatersheds west of Lake Okeechobee are all impaired by nutrients and BOD/DO while 12 are also impaired by metals but only one by coliforms (G, Figure 11). Finally, the cluster of 9 subwatersheds near to and surrounding the Caloosahatchee River are all impaired by nutrients and BOD/DO, while 6 are also impaired by coliforms and metals and 1 by conductivity (F, Figure 11).

A.9. WATER CONTROL STRUCTURE (NON-FEDERAL) DENSITY

The datasets obtained from both the Northwest Florida and Suwannee River Water Management Districts were described as "incomplete" by WMD personnel. The hotspots in both the Northwest (A, Figure 12) and North Central Regions (B and C, Figure 12) are due to low total waterway length as opposed to numerous water control structures. No HUC 12 unit in the remainder of Florida falls within the 2 highest categories for water control structure density. In South Florida the widespread nature of HUC 12 units with at least some density of structures is due, of course, to the prevalence of canals for agriculture, flood management, and water flow control. In this region the HUC 12 units south of the Lake Okeechobee subwatershed unit have the highest densities. The one anomalous HUC 12 unit (D, Figure 12) actually has the greatest number of water control structures (96) but also has the greatest waterway length (2,610 km) resulting in its low density value.

A.10. WEIGHTED ROAD DENSITY

The weighted road density assessment at the HUC 12 level essentially highlights the urban areas of Florida. These values were significantly correlated with urban land cover metrics;

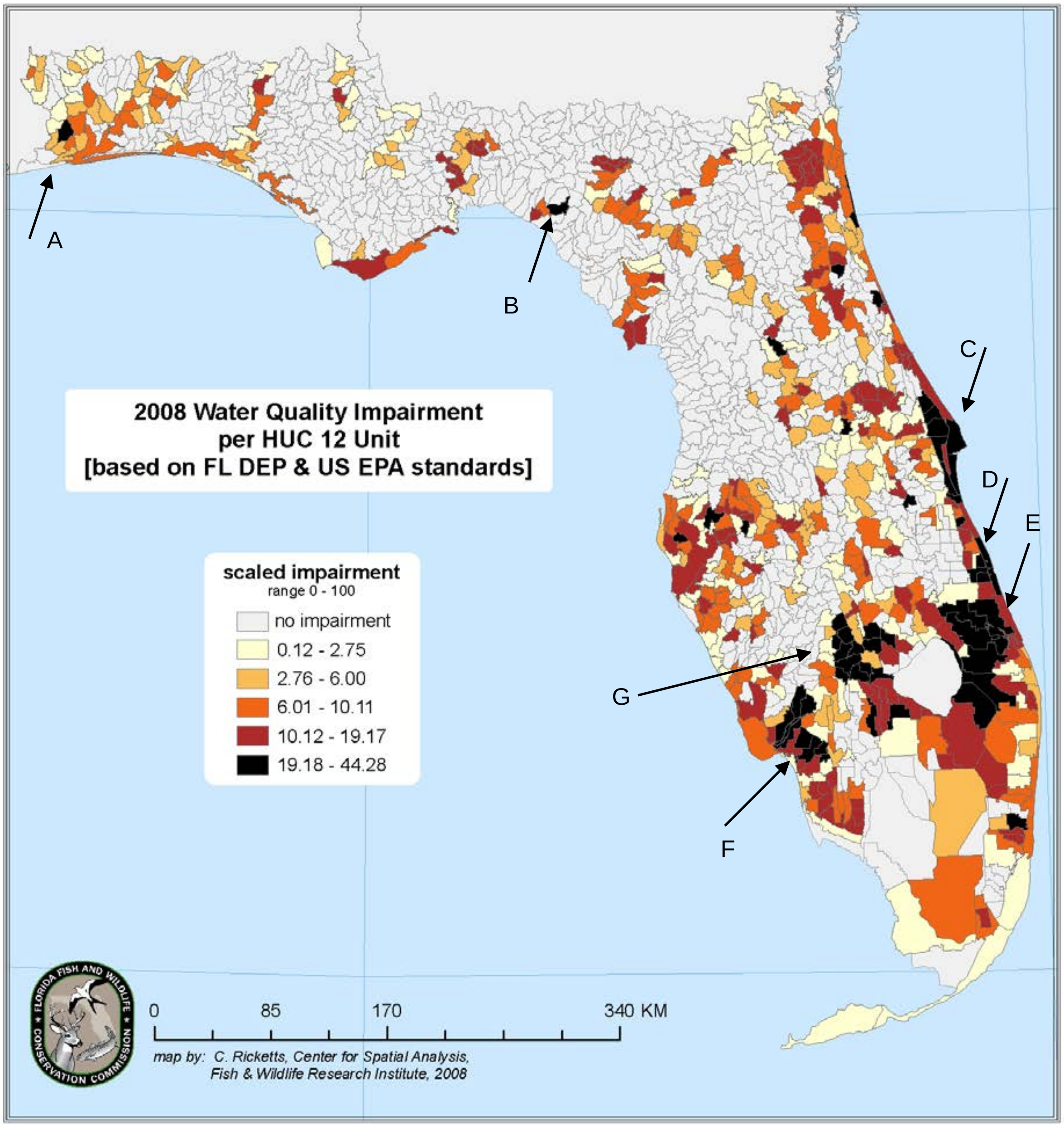

Figure 11: Jenks natural breaks method automatically calculated the classes for non-zero impairment values. The "no impairment" class represents true zero values where no impairments have been verified by FL DEP and was not included in the natural breaks classification. "A" = 11 Mile Creek subwatershed, "B" = contains portion of Fenholloway, "C" = Brevard coast, "D" = Indian River coast, "E" = 7 out of 9 impairment parameters represented, "F" = near Caloosahatchee River, "G" = west of Lake Okeechobee.

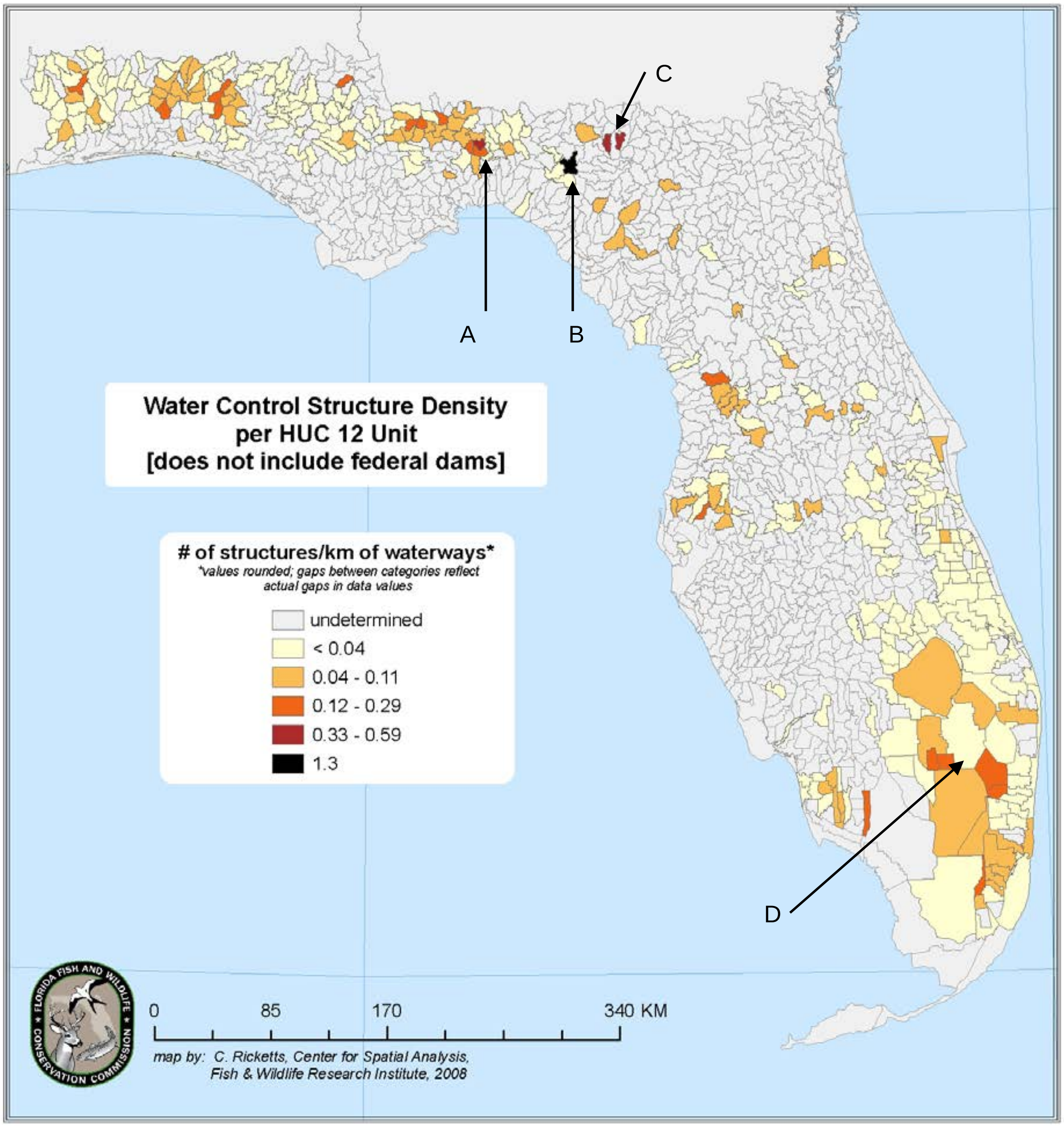

Figure 12: Jenks natural breaks method automatically calculated the classes for non-zero values. The "undetermined" class represents HUC 12 units where either no water control structure exists or where the database is incomplete and was not included in the natural breaks classification. "A", "B", and "C" = low total waterway length; "D" = low density despite greatest # of structures because of greatest waterway length.

however, unlike the urban land cover data, the weighted road density analysis captures more of the human presence in the Northwest and North Central Regions. There are fewer major urban areas in these regions but road density of these HUC 12 units does not generally fall within the lowest category. The Apalachicola National Forest (A, Figure 13) and the Osceola National Forest (B, Figure 13) are two areas in the Northwest and North Central Regions, respectively, with low road density. If an area is not highly urbanized, nor publicly owned/managed, it might be assumed that the area would likely be agricultural. Yet, those HUC 12 units with lower road densities that are not within managed/publicly owned lands do not necessarily have a high percentage of land cover classified as agriculture. These two metrics are not correlated (-0.093). Two areas with lower road density (C and E, Figure 13) have different levels of agricultural activity (Figure 9). HUC 12 units within area C have lower percentages of land cover classed as agricultural land than those in area E. Area D, (Figure 13) however, has HUC 12 units categorized at the same level for both agricultural land and road density.

B. Composite Assessments/Freshwater Threats Index

The compilation of the previously described 10 threat category data layers results in a Freshwater Threats Index which contains different metrics to describe the overall level of relative threat to freshwater habitats within HUC 12 units. The following series of figures shows both HUC 12 unit level evaluations as well as a more regional hydrologic evaluation at a HUC 8 level.

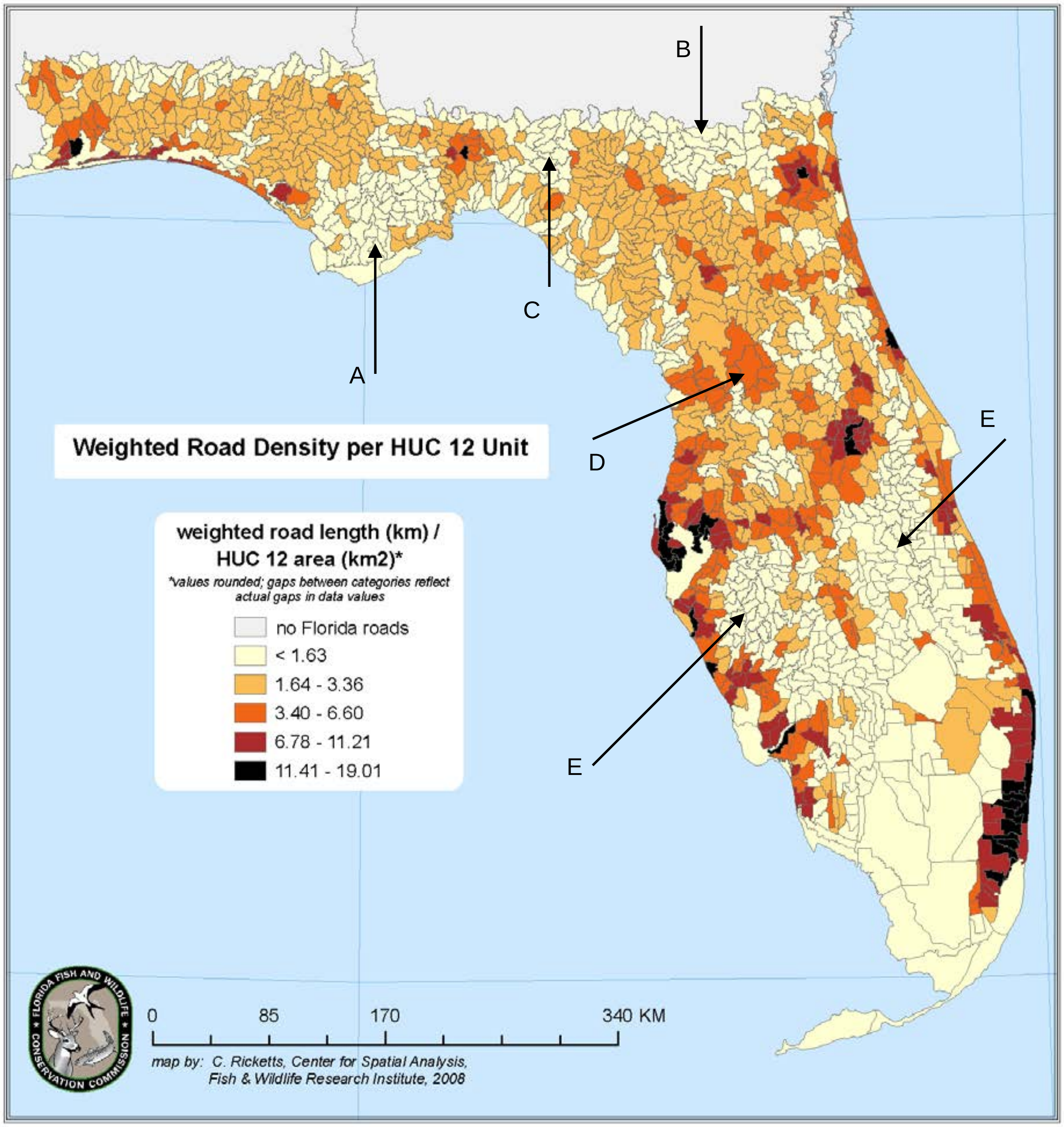

Figure 13: Jenks natural breaks method automatically calculated the classes for non-zero road density values. The "no Florida roads" class represents true zero values where no roads within that HUC 12 unit are within state lines and was not included in the natural breaks classification. "A" = Apalachicola National Forest, "B" = Osceola National Forest, "C" = relatively low agricultural land cover compared to "E" with very high agricultural land cover, "D" = similar levels of agricultural land cover and road density.

B.1. CUMULATIVE INDEX VALUE

Adding the index values across all 10 threat categories for an individual HUC 12 unit results in a cumulative assessment of the relative level of threat to freshwater habitats within that subwatershed. The range of possible values is 10 through 60 (Figure 14). There are two HUC 12 units that received a cumulative score of 10 meaning that all threat categories scored a 1 and all threats were absent or undetermined in that subwatershed. However, these two are located on the border with Georgia and both have less than 1% of their area within Florida. Thus, no subwatershed in Florida is truly free from threats to its freshwater habitats. Generally, the South Region contains the highest concentration of HUC 12 units with cumulative values in the highest category while the North Central and Northwest Regions contain the highest concentration of HUC 12 units with cumulative values in the lower categories (Table 7).

Table 7: Spatial distribution of HUC 12 units within the 6 cumulative value categories; *percents add up to >100 due to rounding.

cumulative value range	# of HUC 12 units	% of total HUC 12 units (1347)*	majority region(s)
10	2	1%	n/a--along GA border
11-16	360	27%	North Central, Northwest
17-21	416	31%	North Central, Northwest
22-26	322	24%	Northeast, Southwest
27-31	180	13%	Northeast, Southwest
32-44	67	5%	South

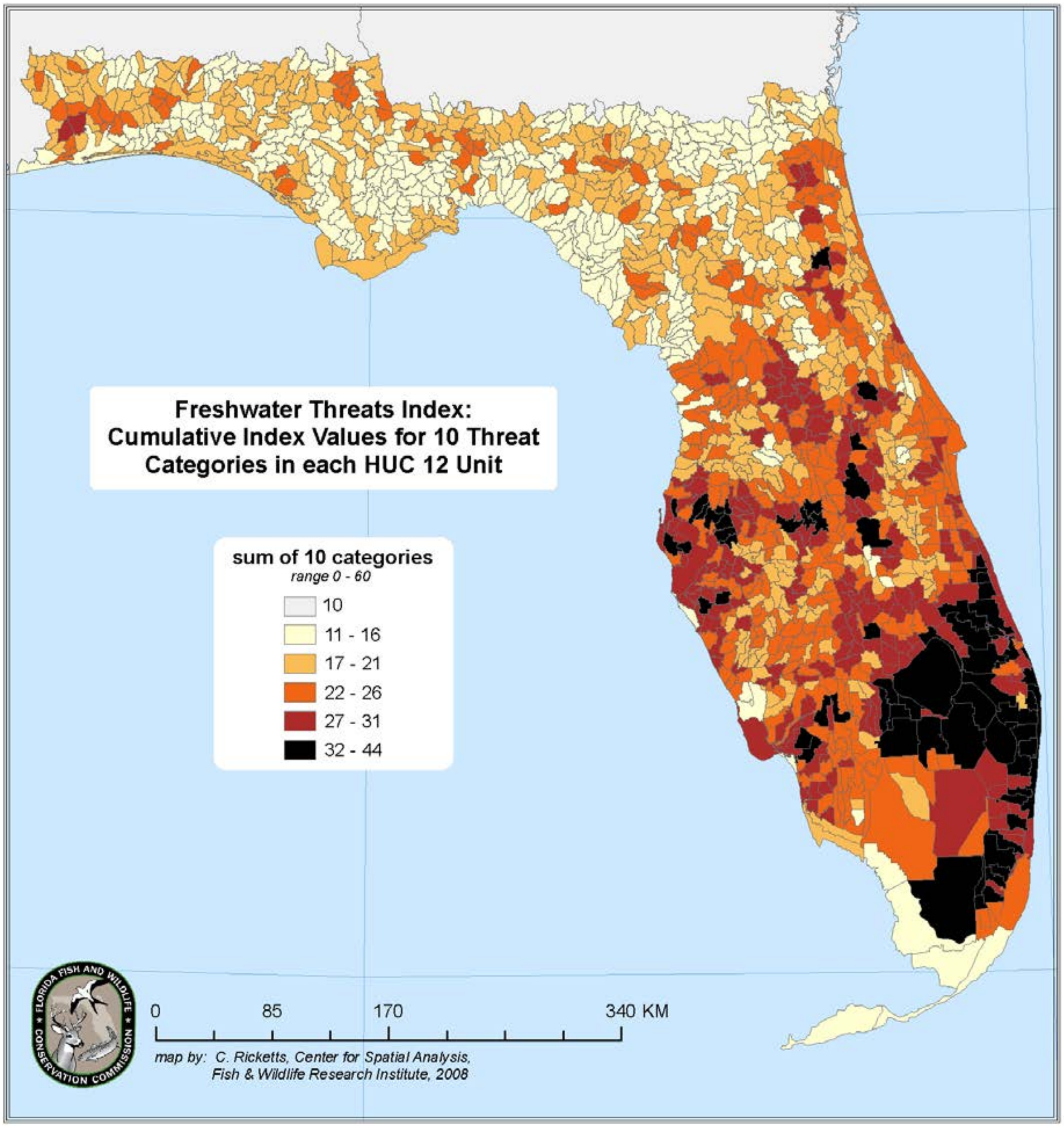

Figure 14: Jenks natural breaks method automatically calculated the classes for values 11-14. The lowest class, "10," represents both the true zero values and the "undetermined" zero values within that HUC 12 unit and was not included in the natural breaks classification.

B.2. Index value: 4, 5, or 6

While cumulative values illustrate the relative threat levels for a HUC 12 unit compared to others, they do not provide information about values within a particular HUC 12 unit. At the low end of the cumulative range, for instance, it is simple to deduce for a HUC 12 unit whose cumulative value is 11 that 9 threat categories have an index value of 1 and the 10th has an index value of 2. However, in the middle and upper end of the range there are numerous combinations of threat index values for the 10 categories which could result in the cumulative values. Therefore, a count of threat categories whose index value is 4, 5, or 6 per HUC 12 unit was performed (Figure 15) to identify which HUC 12 units are affected by many high index values. It is evident that the majority of the Northwest and North Central Regions have lower relative levels of threats overall compared to the remainder of Florida. The hotspots in north Florida are the three major urban areas of Pensacola, Tallahassee, and Jacksonville along with the HUC 12 units near Madison and Live Oak (A, Figure 15). The group of HUC 12 units between Lake Okeechobee and the Atlantic coast are also highlighted as not only being high in cumulative values (Figure 14), but also in high in individual index values across numerous threat categories (B, Figure 15). A similar scenario exists for HUC 12 units in central Florida (C, Figure 15).

B.3. Maximum index value

The maximum index value is the highest index value found across all 10 categories for a HUC 12 unit. The two HUC 12 units spanning the Georgia border that had the lowest cumulative value (11) represent the only 2 HUC 12 units that have a maximum value of 1 (i.e. no threat or undetermined). So, all other subwatersheds in Florida are affected by at least one threat and most have at least one threat whose maximum value is 3 or greater (Figure 16). The distribution of HUC 12 units across the 6 maximum value categories (Table 8) is more even than

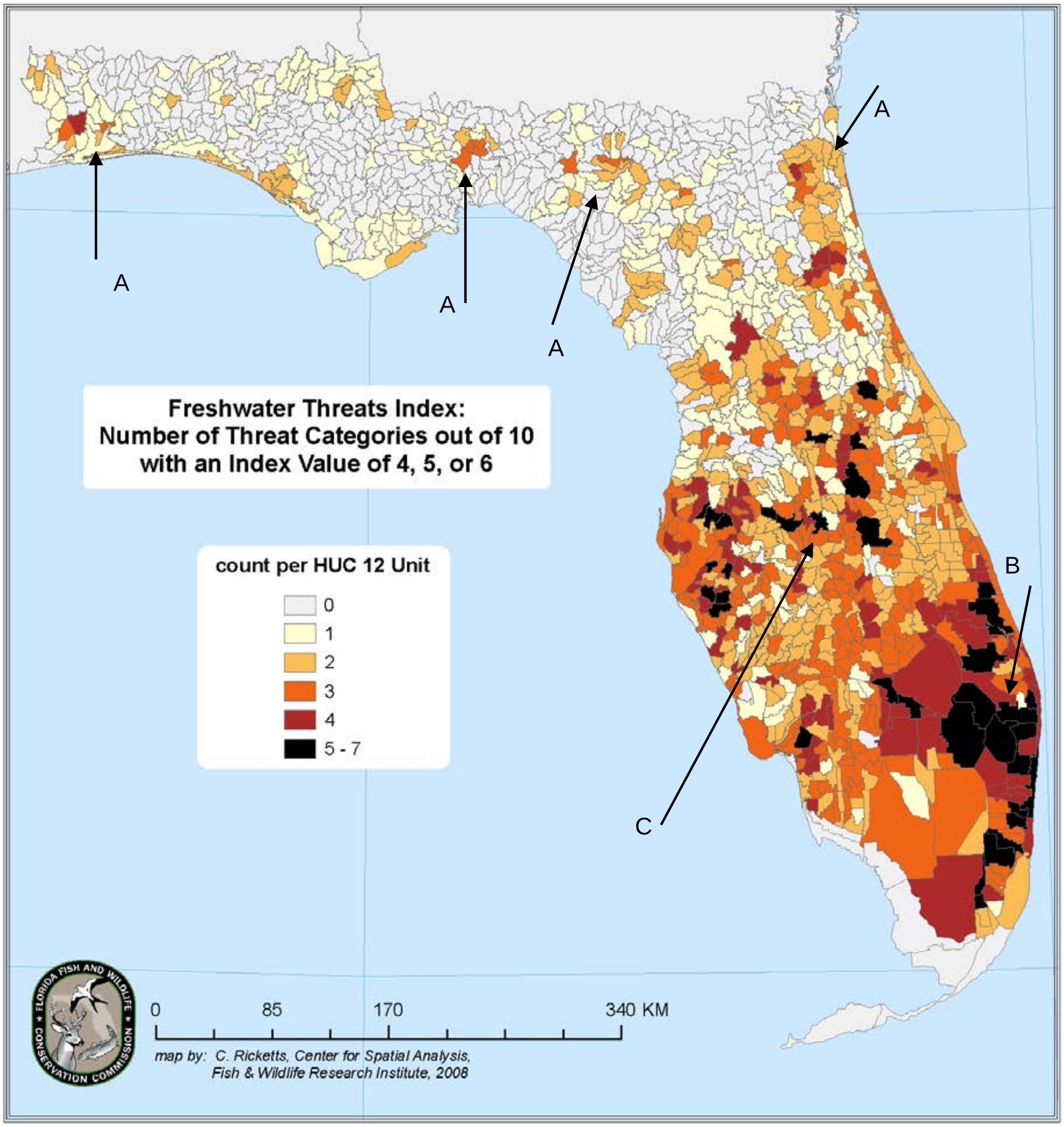

Figure 15: Jenks natural breaks method automatically calculated the classes for values 1-7. The lowest class, "0," represents true zero values within that HUC 12 unit and was not included in the natural breaks classification. "A" = north Florida hotspots, from west to east: Pensacola, Tallahassee, Madison/Live Oak, Jacksonville, "B" = between Lake Okeechobee and Atlantic coast, "C" = central Florida HUC 12 units.

in the cumulative index value evaluation (see Table 7). Still, the South Region experiences the greatest concentration of subwatersheds within the highest category (max. value =6) and they cover nearly the entire region, not just the eastern half as with the cumulative values.

Table 8: spatial distribution of HUC 12 units within the 6 maximum value categories; *percents add up to >100 due to rounding.

maximum value	# of HUC 12 units	% of total HUC 12 units (1347)*	majority region(s)
1	2	1%	n/a--along GA border
2	113	8%	North Central, Northwest
3	317	24%	North Central, Northwest
4	317	24%	Northwest, North Central, Southwest
5	308	23%	Northeast, Southwest
6	290	22%	South

B.4. OVERALL INDEX VALUE

The following series of maps (Figures 17-21) combine both the cumulative index value and the maximum index value into an overall index value. Each map focuses on a single maximum value (e.g. 2, in Figure 17) and shows associated cumulative values for those HUC 12 units with that particular maximum value. Since only 2 HUC 12 units had a maximum value of 1, no overall map was created at this level.

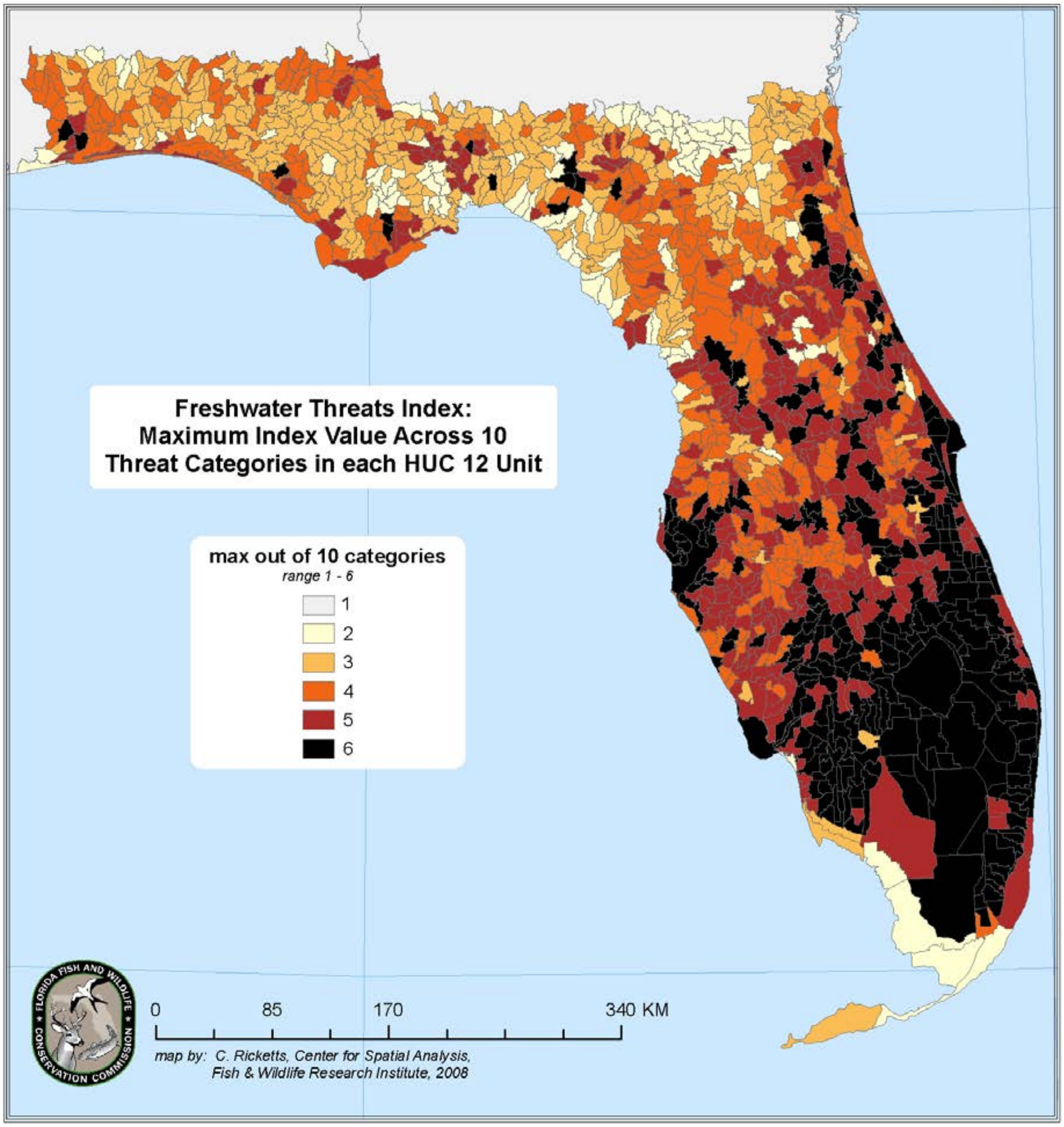

Figure 16: Northwest to southeast gradient of increasing maximum value within a HUC 12 unit.

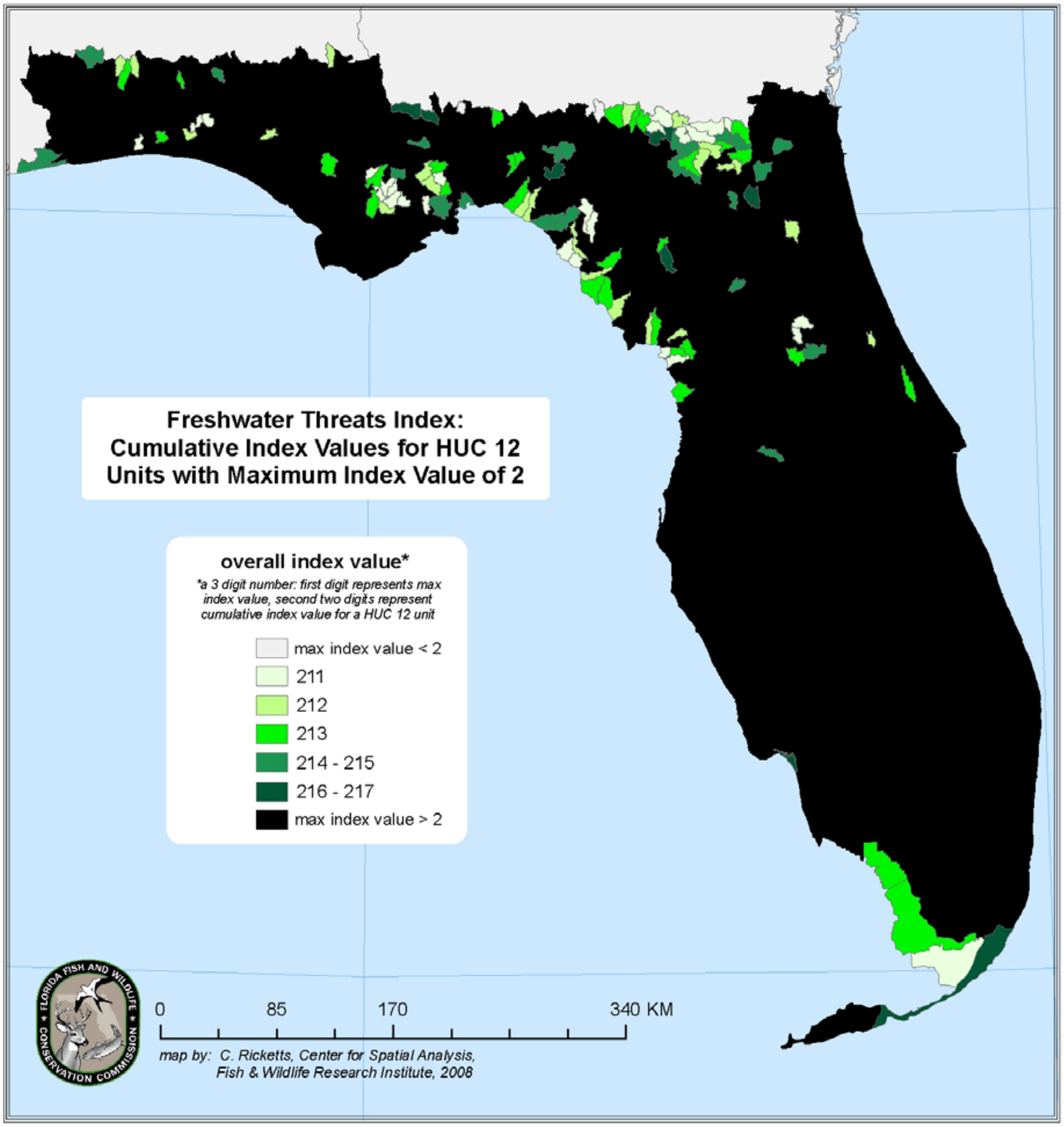

Figure 17: Jenks natural breaks method automatically calculated the classes for values 211-217. The class "max index value <2," represents the two HUC 12 units with a maximum index value = 1 and was not included in the natural breaks classification. The class "max index value >2" represents the HUC 12 units whose maximum index value is 3, 4, 5, or 6 and was not included in the natural breaks classification.

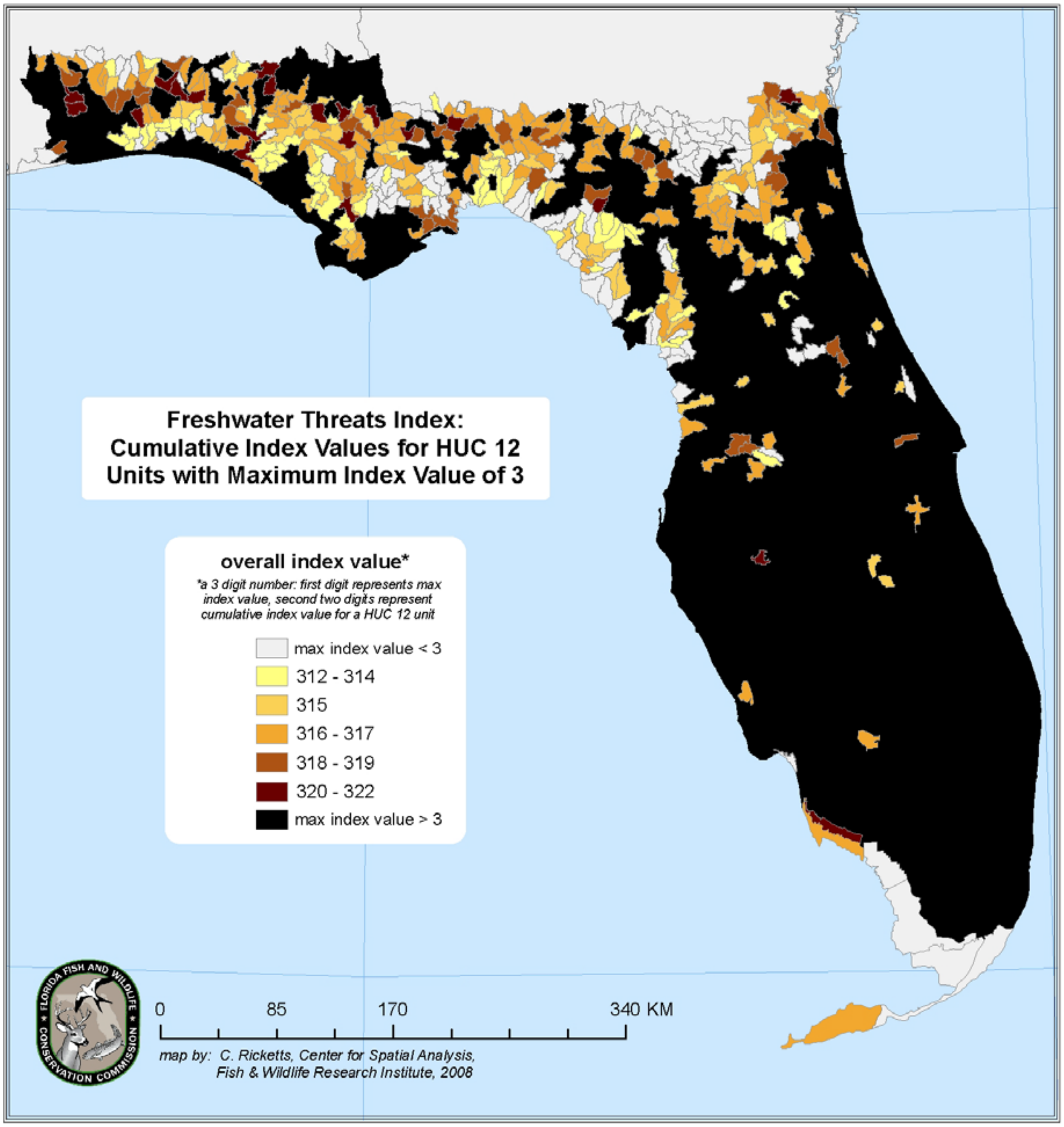

Figure 18: Jenks natural breaks method automatically calculated the classes for values 312-322. The class "max index value <3," represents the HUC 12 units with a maximum index value of 1or 2 and was not included in the natural breaks classification. The class "max index value >3" represents the HUC 12 units whose maximum index value is 4, 5, or 6 and was not included in the natural breaks classification.

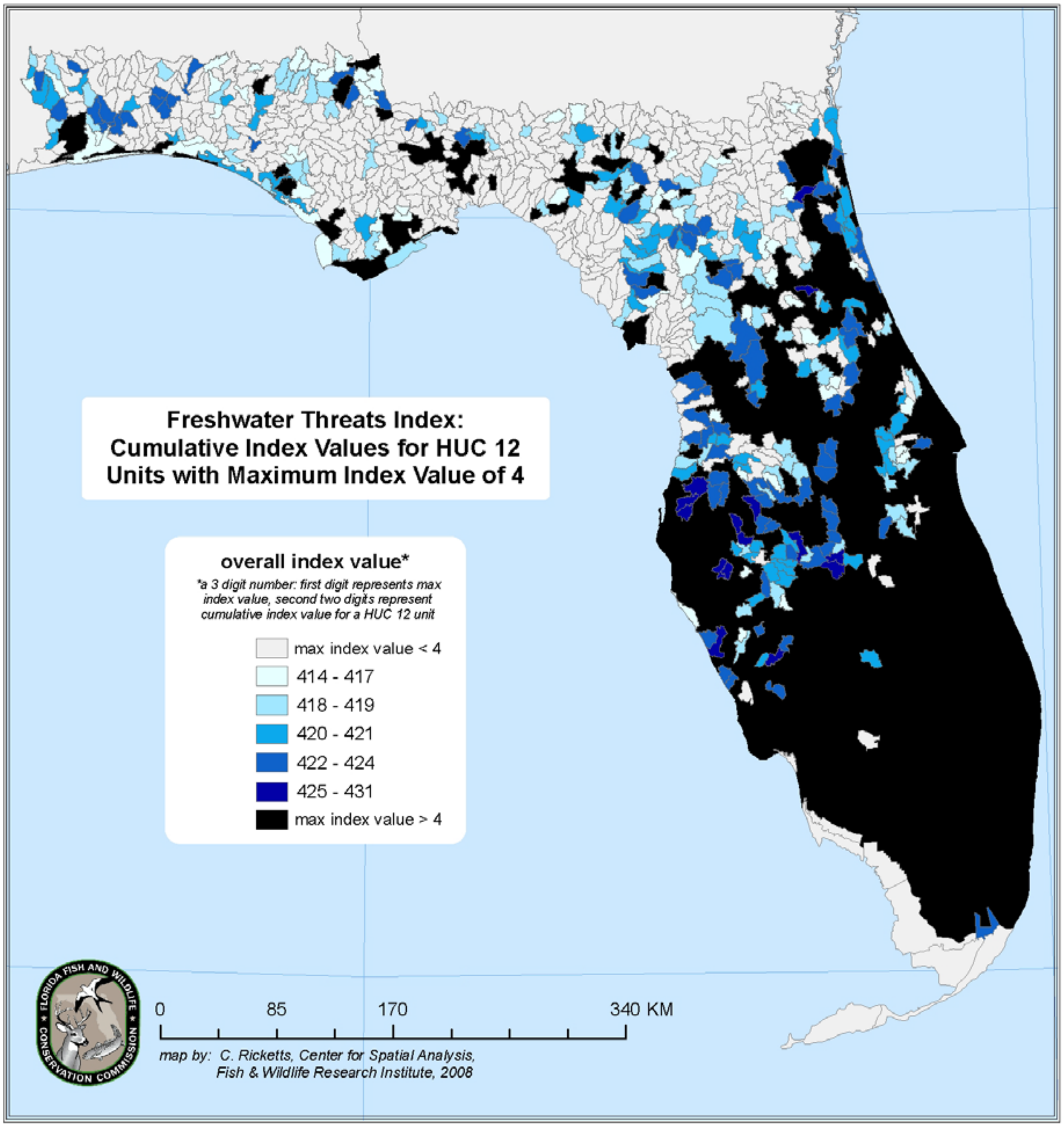

Figure 19: Jenks natural breaks method automatically calculated the classes for values 414-431. The class "max index value <4," represents the HUC 12 units with a maximum index value of 1, 2, or 3 and was not included in the natural breaks classification. The class "max index value >4" represents the HUC 12 units whose maximum index value is 5 or 6 and was not included in the natural breaks classification.

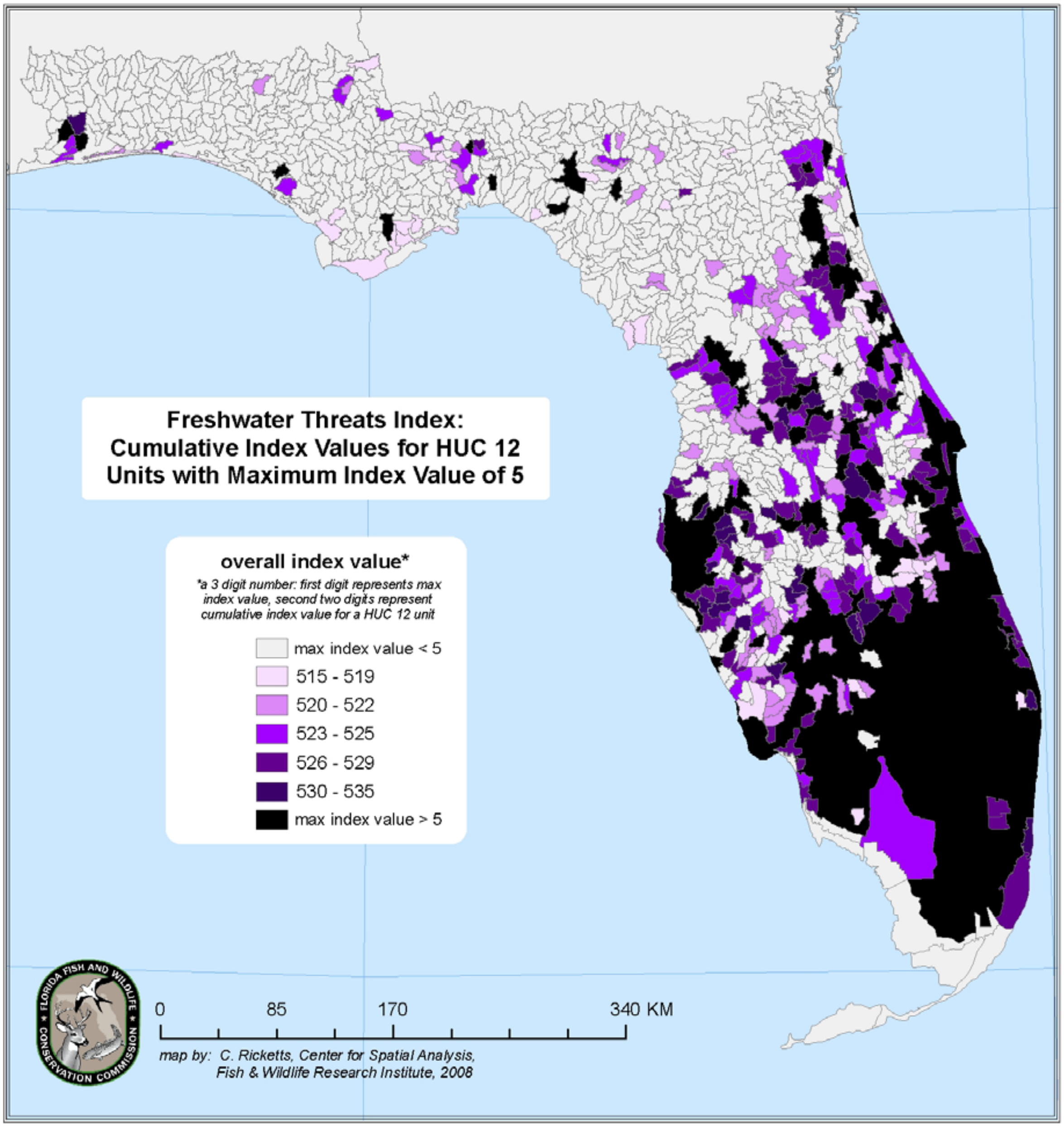

Figure 20: Jenks natural breaks method automatically calculated the classes for values 515-535. The class "max index value <5," represents the HUC 12 units with a maximum index value of 1, 2, 3, or 4 and was not included in the natural breaks classification. The class "max index value >5" represents the HUC 12 units whose maximum index value is 6 and was not included in the natural breaks classification.

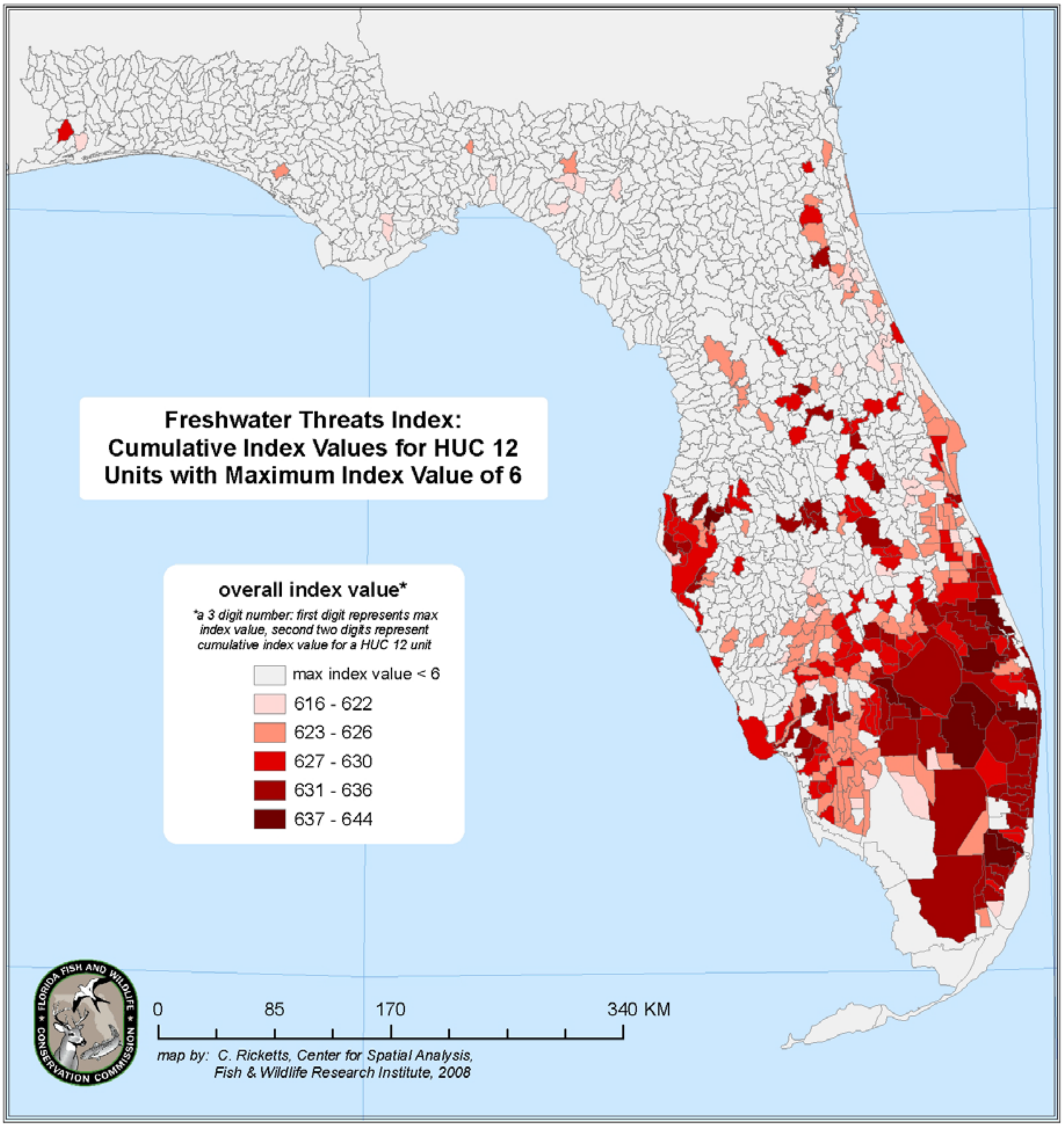

Figure 21: Jenks natural breaks method automatically calculated the classes for values 616-644. The class "max index value <6," represents the HUC 12 units with a maximum index value of 1, 2, 3, 4, or 5 and was not included in the natural breaks classification.

B.5. REGIONAL HYDROLOGIC ASSESSMENT

Throughout the descriptions of results for each individual layer reference is made to certain areas of Florida based on the FWC's regional designations (Figure 3) as a way to identify and compare HUC 12 unit level threat data within different parts of the state. Using the composite index data a hydrologically based regional assessment is shown in Figure 22. Here it is evident that 3 threat categories out of 9 dominate the most common reason for the highest index values within a HUC 8 unit (Table 9). Additionally, there is a distinct spatial distribution of the HUC 8 units affected by each of these threat categories. HUC 8 units whose most common reason for high index values is the weighted road density category are found mostly in north Florida and along the Gulf coast from the Big Bend south to the Sarasota area. Those HUC 8 units with highest index values mostly attributed to agricultural land cover within 90 meters of freshwater are found in two pockets in northern Florida (portions of Washington, Holmes, and Walton counties; portions of Jefferson and Madison counties) and in west-central Florida from Sumter county south to Charlotte county. HUC 8 units in the waterway modification category are located in south Florida and along the Atlantic coast. Since the 3 threat categories in Table 6 have the most comprehensive spatial coverage in the underlying datasets (for instance, roads and streams are present in nearly every HUC 12 unit while other threats are not as continuous in

Table 9: Three threat categories out of 9 dominate the most common reason for the highest index values within a HUC 8 unit. From a total of 54 HUC 8 units, 44 are represented by 3 threat categories.

threat category	# of HUC 8 units	% of total HUC 8 units (54)
weighted road density	20	37%
agricultural land cover within 90m buffer zone	14	26%
waterway modification	10	20%

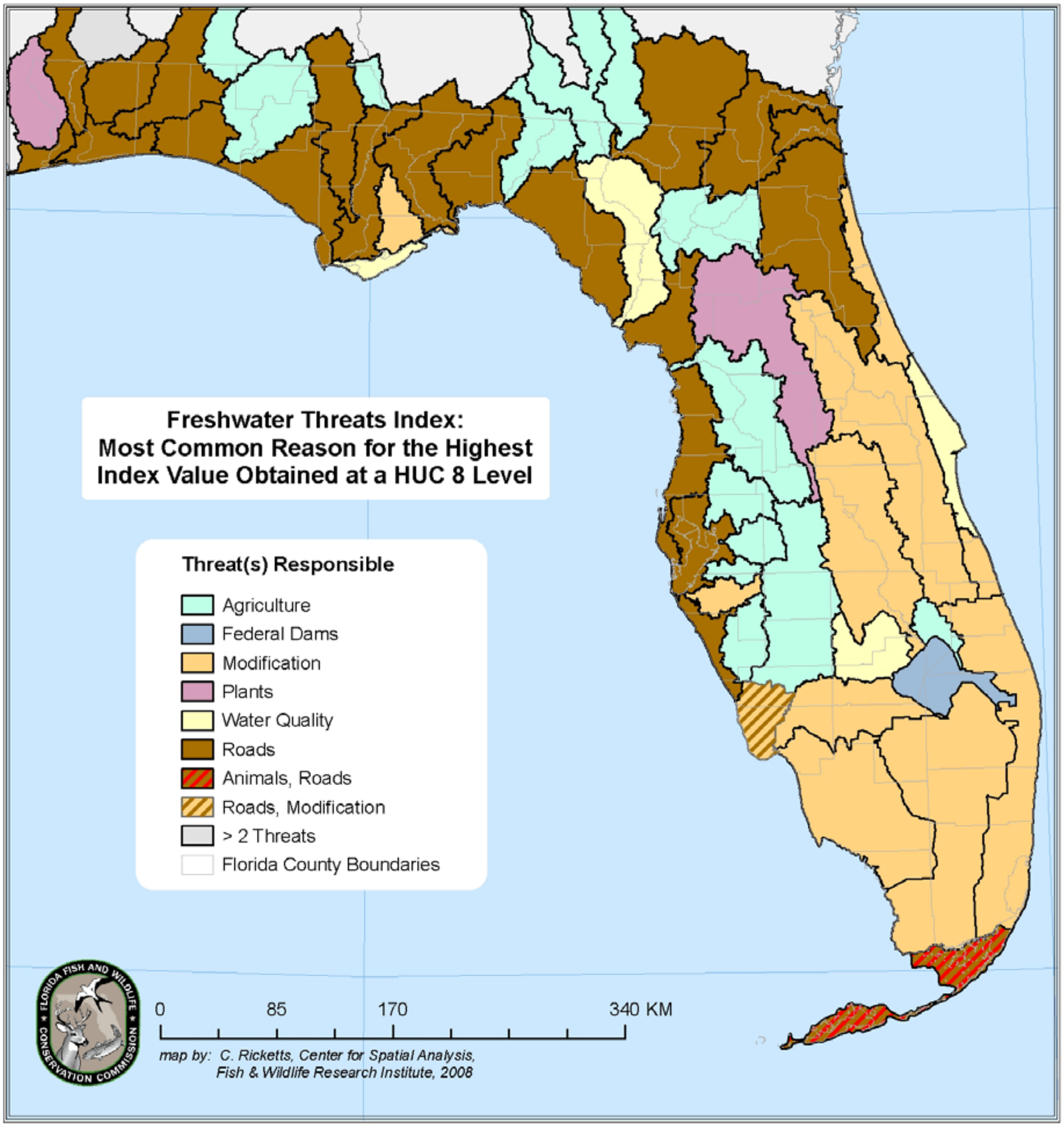

Figure 22: Spatial distribution of most common reason for highest index value at HUC 8 level shows the domination by weighted road density, waterway modification and agricultural land cover within 90 meters of freshwater.

distribution) other threats which may be prevalent in a HUC 8 unit and responsible for high index values within a number of HUC 12 units contained in that particular HUC 8 unit, may be masked by the 3 spatially-dominating categories. Therefore an additional map of the *second* most common reason for high index values within a HUC 8 unit was created (Figure 23). This regional view reveals more variation in causes for high index values across HUC 8 units. Agricultural land cover and waterway modification are the second most common reason for the highest index values in 10 HUC 8 units each, while invasive plants which was the most common reason for 2 HUC 8 units, is the second most common reason for 9 other HUC 8 units. Additionally, there are more HUC 8 units which show multiple factors contributing to high index values. The spatial distribution of these threat categories is similar to that of Figure 22. HUC 8 units in the agricultural land cover category are still found in north and central Florida, although somewhat more concentrated in north-central Florida. The area south of Lake Okeechobee also is highlighted as affected by agricultural land cover. In Figure 22 the two invasive plant HUC 8 units are found in extreme western Florida and in central Florida, but as the second most common reason invasive plants affect 6 HUC 8 units in central Florida and are more dominant in north Florida as well. As might be expected in southeast Florida along the Atlantic coast, if a HUC 8 is not dominated by high index values for waterway modification, then it is by weighted road density, while southwest Florida is more impacted by high index values for water quality once waterway modification is removed. North Florida HUC 8 units show the most variety in terms of threat categories as the second most common reason for high index values once the most common reason (i.e. weighted road density) is removed.

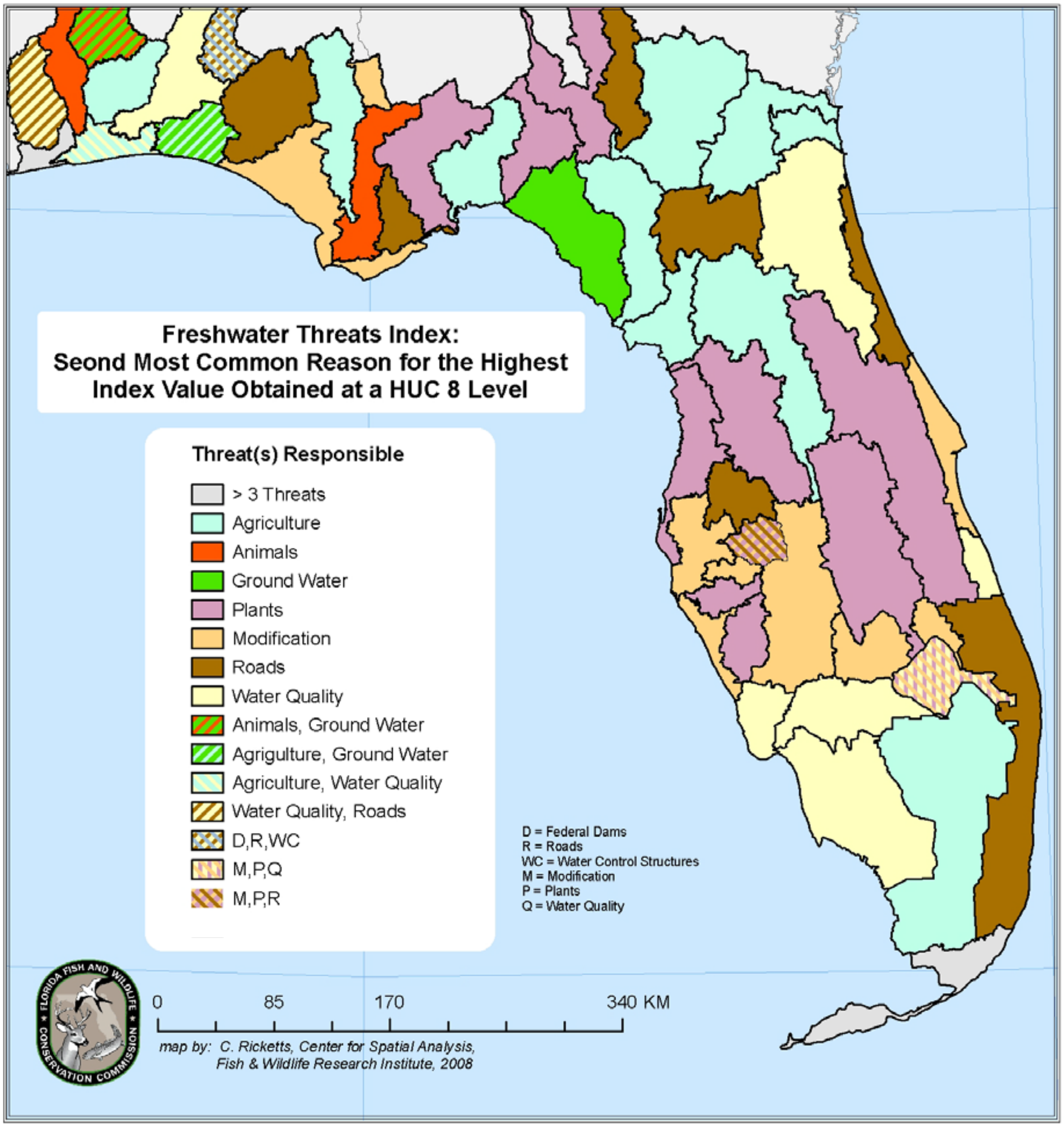

Figure 23: Spatial distribution of the second most common reason for highest index value at HUC 8 level shows increased influence by invasive plants in central and north Florida, more concentration of HUC 8 units affected by agricultural land cover in north-central Florida and more variety of threat categories overall.

IV. DISCUSSION AND CONCLUSIONS

Threats assessments have been developed for study areas of differing sizes from a single wildlife sanctuary (Barve et al., 2005) to a specific river basin (Mattson & Angermeier, 2007) to regions encompassing aquatic systems across multiple states (Bryce et al., 1999; Sowa et al., 2005; Danz et al., 2007). The creation of a cumulative/composite index of threats is common within the above studies and in two the cumulative index was expressly compared with field data and found to be correlated with various metrics of biological indicators showing that the index provided a useful way to identify potentially impacted areas (Barve et al., 2005; Danz et al., 2007). Many different methods can be employed to develop the cumulative index each having different strengths and weaknesses stemming from their capacity to address four key data integration issues: discontinuity, imbalance, skewness, and interdependency (Table 10) (Smith et al., 2003; Locantore et al., 2004).

Table 10: Data integration issues, from Smith et al., 2003.

DATA ISSUE	DESCRIPTION
discontinuity	raw variable form is discrete rather than continuous
imbalance	too many variables of a particular type
skewness	many statistical methods valid for only symmetrical data
interdependency	highly correlated variables

In this project the index values developed from the individual layers are summed to describe overall threats to freshwater habitats. Summation is one of the simplest methods and is sensitive to imbalance and interdependency but insensitive to discontinuity and skewness (Smith et al. 2003). Imbalance of data was not a factor in this project as only one data layer was used to represent each threat and these data layers were subject to a correlation analysis to eliminate duplicate information in the composite index. The simple sum index is an important first step to gain insight into an area's relative environmental condition (particularly with respect to outliers) and can be enhanced by incorporating more complicated analyses such as Principal Component Analysis (PCA) or cluster analysis (Smith et al., 2003).

The results of this project highlight what is likely an existing debate: the differences in available habitat between North and South Florida and what makes a habitat more "threatened." South Florida contains most of the subwatersheds in the highest cumulative index value category, has most of the subwatersheds with a maximum index value of 6, and has the most subwatersheds with the highest count of index values >3 across all 10 categories. These numbers would indicate South Florida subwatersheds are more threatened than those in North Florida (i.e. Pensacola to Jacksonville). Yet, this part of Florida has an extreme degree of hydrologic modification. Essentially all subwatersheds except those within protected lands have at *least* 58% of their waterways classified as canals or modified by channelization and many have over 81% (see Figure 5). Many of these waterways did not exist in a natural state but were created for the express purposes of urban flood control or agricultural irrigation. North Florida subwatersheds with their lower overall relative threat levels are perhaps actually *more* threatened due to their current condition.

One topic not addressed in this project is the idea of permanence or irreversibility of a threat. Two of the dominant threats described at the HUC 8 level, the numerous canals of South Florida and the roads of North Florida, are not likely to be reduced or eliminated. These threats to freshwater habitats will always be present in the subwatersheds in which they currently exist. Other threats such as invasive animal and plant species represent areas where education and continued management can reduce the impact to aquatic ecosystems. Water quality issues (nutrients, bacteria, metals) should be a threat that is completely reversible with strict enforcement of regulations and improving technology.

The data layers and resulting composite indices show information across the entire state but are summarized at a subwatershed level. Therefore, it is possible to discover regional patterns and also identify conditions at a more local level. Managers and researchers can use this threat data along with consideration of the both the permanence of the threat and its impact on the 5 indicators of ecological integrity to initiate further study into the issues affecting a particular freshwater ecosystem.

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VII. APPENDICES

APPENDIX A

This table contains a list of the metrics included in the composite threat assessments as well as additional metrics that could (1) identify threats at a more precise level, e.g. the point datasets, or (2) identify different threats not included in the composite assessment. These metrics are distilled from the attribute tables of the data layers and do not represent a comprehensive list of fields from those tables. As of July, 2008, all these layers are available with associated metadata from the Center for Spatial Analysis, FWRI, FWC, in Tallahassee, Florida.

DATA LAYER	THREAT ASSESSMENT METRIC
used for composite index/assessment	
catI_plants_2007	number of species per HUC 12 unit
channels_canals_sum	% modified waterway length within a HUC 12 unit
fed_dam_summary_2005	average normal storage (in acre-feet) within a HUC 12 unit
ground_HUCS2	sum of average daily rate of permitted withdrawal per HUC 12 unit
invasive_animals_2007	number of species per HUC 12 unit
riparian_landcov_2003	% agricultural land within 90 meters of freshwater
surface_HUCS2	sum of average daily rate of permitted withdrawal per HUC 12 unit
verified_impaired_2008	scaled impairment of each HUC 12 unit
WCS_summary_2007	density of water control structures within each HUC 12 unit
wtd_rd_density	density of roads within a HUC 12 unit
intermediate data layers—used to create summary layers above	
ground_ADR_final	point file showing location and average daily rate of permitted withdrawal
surface_ADR_final	point file showing location and average daily rate of permitted withdrawal
water_ctrl_strucs	point file showing locations of water control structures
confacs_in_FL_P_scores	point file showing locations of petroleum contaminated facilities
verified_impaired_2008	% of HUC 12 unit impaired by nutrients
	% of HUC 12 unit impaired by turbidity
	% of HUC 12 unit impaired by conductivity
	% of HUC 12 unit impaired by pesticides in fish tissue or dioxin
	% of HUC 12 unit impaired by coliforms
	% of HUC 12 unit impaired by metals
	% of HUC 12 unit impaired by BOD/DO
	% of HUC 12 unit impaired by bacteria
	% of HUC 12 unit impaired by uni-ionized NH_3
fish_final_HUC12	number of exotic/non-native invasive fish species per HUC 12 unit

DATA LAYER	THREAT ASSESSMENT METRIC
other data available	
HUC12_landscape_2003	N_INDEX*
	PFOR*
	PWETL*
	PSHRB*
	PNG*
	PNBAR*
	U_INDEX*
	PURB*
	PMBAR*
	PAGT*
	PAGP*
	PAGC*
	EXOTIC*
	*these metrics are available for the entire HUC 12 unit as well as the HUC 12 unit excluding both a 90 m and 30 m buffer zone around freshwater
parcel_summary	% of HUC 12 unit classified as selected land use code (e.g. dairy, mining lands)
riparian_landcov_2003	RNAT0*
	RFOR0*
	RWETL0*
	RSHRB0*
	RNG0*
	RNBAR0*
	RHUM0*
	RURB0*
	RMBAR0*
	RAGT0*
	RAGP0*
	RAGC0*
	RUSER0*
	*these metrics are available for riparian landcover analysis adjacent (0 m) to freshwater as well as for riparian landcover analysis within both a 30 m and a 90 m buffer zone surrounding freshwater for each HUC 12 unit
roads_streams_2006	density of road/stream crossings within a HUC 12 unit
selected_LU_2007	location of parcels of selected land use code (e.g. dairy, mining lands)
confacs_scores_2008	summary of density weighted average petroleum contamination scores within a HUC 12 unit

APPENDIX B

Category I non-native/exotic invasive aquatic plant species classified as “established” in Florida, 1982-2007, and included in the composite assessment/index at the HUC 12 level.

Scientific Name	Common Name
Urochloa mutica/Brachiaria mutica	Para grass
Casuarina equisetifolia	Australian pine, beach sheoak
Casuarina glauca	suckering Australian pine, gray sheoak
Colocasia esculenta	wild taro
Eichhornia crassipes	water-hyacinth
Hydrilla verticillata	hydrilla
Hygrophila polysperma	green hygro
Hymenachne amplexicaulis	West Indian marsh grass
Ipomoea aquatica	waterspinach
Ludwigia octovalvis/peruviana	Peruvian primrose willow
Lygodium japonicum	Japanese climbing fern
Lygodium microphyllum	Old World climbing fern
Melaleuca quinquenervia	melaleuca, paper bark
Panicum repens	torpedo grass
Pennisetum purpureum	Napier grass
Pennisetum spp.	--
Pistia stratiotes	waterlettuce
Sapium sebiferum	popcorn tree, chinese tallow tree
Schinus terebinthifolius	Brazilian pepper
Solanum tampicense	wetland nightshade, aquatic soda apple

APPENDIX C

The 77 non-native/exotic invasive aquatic animal species are classified as "established" in Florida, 1982-2007, and are included in the composite assessment/index at the HUC 12 level.

Scientific Name	Common Name
Hemichromis letouneuxi	African jewelfish
Corbicula fluminea	asian clam
Monopterus albus	asian swamp eel
Heros severus	banded cichlid
Cichlasoma bimaculatum	black acara
Ctenosaura similis	black spiny-tailed iguana
Cygnus atratus	black swan
Sarotherodon melanotheron	blackchin tilapia
Ictalurus furcatus	blue catfish
Oreochromis aureus	blue tilapia
Ancistrus sp.	bristlenosed catfish
Basiliscus vittatus	brown basilisk
Hoplosternum littorale	brown hoplo
Channa marulius	bullseye snakehead
Python molurus	Burmese python
Cichla ocellaris	butterfly peacock bass
Bufo marinus	cane toad
Hydrochoerus hydrochaeris	capybara
Pomacea canaliculata	channeled applesnail
Chitala ornata	clown knife
Boa constrictor	common boa
Cyprinus carpio	common carp
Cyclura nubila	Cuban rock iguana
Osteopilus septentrionalis	Cuban treefrog
Geophagus sp.	eartheater
Haplochromis callipterus	eastern happy
Alopochen aegyptiacus	Egyptian goose
Melanoides turriculus	fawn melania
Pylodictis olivaris	flathead catfish
Bufo marinus	giant toad
Eunectes murinus	green anaconda
Iguana iguana	green iguana
Lepomis cyanellus	green sunfish
Eleutherodactylus planirostris	greenhouse frog
Pomacea insularum	island applesnail
Chichlasoma managuense	jaguar guapote
Aix galericulata	Mandarin duck
Chichlasoma urophthalmus	Mayan cichlid
Cichlasoma citrinellum	midas cichlid
Oreochromis mossambicus	Mozambique tilapia
Cairina moschata	muscovy duck

Scientific Name	**Common Name**
Cygnus olor	mute swan
Varanus niloticus	Nile monitor
Oreochromis niloticus	Nile tilapia
Myocastor coypus	nutria
Misgurnus anguillicaudatus	oriental weatherfish
Pterygoplichthys multiradiatus	Orinoco sailfin catfish
Astronotus ocellatus	oscar
Tadorna variegata	paradise shelduck
Belonesox belizanus	pike killifish
Trachemys scripta	pond slider
Porphyrio porphyrio	purple swamphen
Trachemys scripta	red-eared slider
Melanoides tuberculatus	red-rimmelania
Callonetta leucophrys	ringed teal
Cichlasoma cyanoguttatum	Rio Grande cichlid
Threskiornis aethiopicus	sacred ibis
Varanus exanthematicus	savanna monitor
Eudocimus ruber	scarlet ibis
Metynnis sp.	silver dollar
Caiman crocodilus	spectacled caiman
Pomacea bridgesii	spiketop applesnail
Macrognathus siamensis	spotfin spiny eel
Tilapia mariae	spotted tilapia
Hypostomus sp.	suckermouth catfish
Anser cygnoides	swan goose
Theraps sp	theraps hybrid
Pomacea haustrum	titan applesnail
Cygnus buccinator	trumpeter swan
Xiphophorus variatus	variable platyfish
Pterygoplichthys disjunctivus	vermiculated sailfin catfish
Clarias batrachus	walking catfish
Daphnia lumholtzi	water flea
Varanus salvator	water monitor
Eunectes notaeus	yellow anaconda
Cichlasoma salvini	yellowbelly cichlid
Tilapia buttikoferi	zebra/hornet tilapia

APPENDIX D

The original land cover dataset, FWC Vegetation and Land Cover 2003 classification (Stys et al. 2004), was reclassed to fit within the ATtiLA framework. Recoding as follows (with original on right, recoded ATtiLA value on left).

ATtiLA class	FWC class
natural vegetation, other	coastal strand
natural barren	sand/beach
forest	xeric oak scrub, sand pine scrub, sandhill, mixed pine/hardwoods, hardwood hammocks/forest, pinelands, cabbage palm/live oak hammock, tropical hardwood hammock
natural grassland	dry prairie
wetlands	freshwater marsh/wet prairie, sawgrass marsh, cattail marsh, shrub swamp, bay swamp, cypress swamp, cypress/pine/cabbage palm, mixed wetland forest, hardwood swamp, hydric hammock, bottomland hardwood forests, salt marsh, mangrove swamp, scrub mangrove
water, no data	tidal flat, open water
shrublands	shrub/brushlands
pasture	grassland, improved pasture, unimproved pasture
man made barren	bare soil/clearcut
non row crop	sugar cane, citrus
row/field crops	row/field crops
agriculture, other	other agriculture
user defined	exotic plants, australian pine, melaleuca, brazilian pepper
high-density residential	high impact urban
low-density residential	low impact urban
man made barren	extractive