A visual identification key utilizing both gestalt and analytic approaches to identification of Carices present in North America (Plantae, Cyperaceae)

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Abstract

Images are a critical part of the identification process because they enable direct, immediate and relatively unmediated comparisons between a specimen being identified and one or more reference specimens. The Carices Interactive Visual Identification Key (CIVIK) is a novel tool for identification of North American *Carex* species, the largest vascular plant genus in North America, and two less numerous closely-related genera, *Cymophyllus* and *Kobresia*. CIVIK incorporates 1288 high-resolution tiled image sets that allow users to zoom in to view minute structures that are crucial at times for identification in these genera. Morphological data are derived from the earlier *Carex* Interactive Identification Key (CIIK) which in turn used data from the *Flora of North America* treatments. In this new iteration, images can be viewed in a grid or histogram format, allowing multiple representations of data. In both formats the images are fully zoomable.

Keywords

Visual key, identification, *Carex*, *Cymophyllus*, *Kobresia*, interactive identification, identification, sedges

Introduction

The last ten years may be remembered for the rebirth of plant taxonomy and systematics in a new guise, computational biodiversity informatics. For much of the earth, and North America in particular, botanical information that once required substantial effort to acquire is now reliably provided in seconds by such websites as the Global Biodiversity Information Facility (GBIF), Flora of North America, Missouri Botanical Garden's Tropicos, Encyclopedi

a of Life, United States Plants Database, and emerging regional herbarium networks. Plant biodiversity is now literally at everyone's fingertips.

State of the art plant identification systems

Traditional biological identification systems today are of two primary types; analytic and gestalt (K. Thiele, pers. comm. 2013). Two forms of analytic keys commonly used today are dichotomous and interactive matrix-based keys. Both are primarily text-based question systems that can yield static images upon the final determination. Conversely, gestalt keys, use an identifiable image of the organism in question. Similar to what is seen in field guides.

Analytic matrix-based keys are considered to be state of the art today The University Of Queensland 2006 due to their ability to scale up across hundreds of taxa. To use, users select characters to achieve a determination of the unknown taxon using a four-panel informational interface. The information panels often represented are 'characters available', 'characters chosen', 'entities available', and entities discarded'. Within this format, it is possible to insert thumbnail-sized, static images to accompany the text if the taxa numbers are relatively small (< 100). But when taxa numbers are higher (>100), their inclusion results in the information panel becoming too long to be usable, e.g. the Carices used here would require copious scrolling across its many meters of length.

Visual keys borrow from both gestalt and analytic methods. They use character matrices for initial pruning of the image set analytically. After a few characters choices the many hundreds of small images are reduced to a manageable set of bigger images. Now gestalt methods take over as the images become larger and truly informative. With this hybrid of functionality, featuring the best of both gestalt and analysis, a novel identification method is created that can cater to the neophyte as well as the expert.

Carex, Kobresia, and Cymophyllous: a model for scalability

Carex is the largest vascular plant genus in North America (Ball and Reznicek 2002). With two closely related genera, *Kobresia* and *Cymophyllus*, it forms the Carices of North America; all three are members of the family *Cyperaceae*, commonly called sedges but often erroneously referred to as grasses. These three genera share a number of basic morphological characteristics including having linear leaves and a fruit enclosed in a bag-like structure called a perigynium. All have small flowers that lack large, colorful petals and sepals. Plus they share one other important characteristic: they are difficult to identify. Nevertheless, they are morphologically distinct and relatively easily recognizable as a group.

The new visual key

The data used in this project are primarily derived from an interactive identification program to *Carex* that has been online since 2006 at both Utah State University and

Louisiana State University (http://www.herbarium.lsu.edu/keys/carex/carex.html). During this time it has been consistently revised and is currently in version 21. (Suppl. materials 3, 4). Web statistics have been tracked from 2007. Data show that numerous individuals worldwide, government agencies, students in classrooms, and participants in identification workshops have repeatedly used the keys. Many users have graciously suggested revisions and clarifications that have increased their usability and performance. The key presented here reflects contributions from several individuals, innumerable field trips, and countless hours in herbaria both identifying and imaging specimens. It is only with such collaboration and effort that an image key to such a large genus can be created.

Goals

My goal in this project was to create an easy to use identification resource that maximized the value of high resolution images while enabling users to explore the distribution of morphological diversity within the genera. Query-able images. For example, to answer questions such as: how are species with trigonous achenes geographically distributed across Canada by province or territory? How common are species with two-sided achenes in species with leaf blades more than 10 mm wide? These sorts of hypotheses are easily answered in histogram mode Fig. 4. Because for the first time, side-by-side image comparisons are possible across species permitting comparative examination and discrimination among closely-related members of any complex, of which there are many, within the Carices. CIVIK is seen here: http://www.herbarium2.lsu.edu/aba/http://www.herbarium2.lsu.edu/aba/

Project description

Title: Development of visual identification tool

Study area description: This key is designed for use in North America, including Mexico. The original descriptive data was derived from Flora of North America (Ball and Reznicek 2002) and (Mackenzie 1940). My images come from fieldwork focused in eastern North America while other individuals have contributed images from other locations across North America.

Design description:

1. IMAGES

1.1. Contributors

Steve Matson and Tony Reznicek both sent a DVD copy of their *Carex* field images. Lowell Urbatsch contributed his teaching-microscopy-images (http://www.herbarium.lsu.edu/keys/eee/b52.html). My images were collected from many field sites primarily in the north-eastern United States. The New York Botanical Garden Press granted the use of the plates of both North American Cariceae volumes (Mackenzie 1940). The remaining images were

found on the World Wide Web (WWW) and their owners (Forest Starr, Kim Starr, Nhy Nyugen, Ann Debolt) contacted by email to request permission for their use. The remaining image contributor, Robert Mohlenbrock, had made the image used here available on www.Plants.gov so it could be used without seeking permission.

1.2. Processing of images

To manage the large image numbers (e.g., Matson hundreds of images; Jones, many thousands), each set of images from each owner was segregated on a local drive. Predictably, across this many image contributors, naming conventions differed greatly, thus significant renaming of image files was required. The basic convention used was to include the taxon name, type of image, and the author in the file name. Another issue of note was the fact that many of these images had been prepared for delivery via the WWW, and had been re-sized. Larger file sizes were selected for inclusion while those that were originally designed as thumbnails were not used. Rarely, older images that were scanned from slides were either cropped or otherwise manipulated with Photoshop CS 3. Lastly, rotation of images for appropriate orientation was also often required.

1.2.1 Image sizes

Image sizes are variable and range from 40 K to over 13 MB. Line drawings and most images by Jones are at 2848 X 4288 with a maximal bit depth of 24. Matson's images were more variable as some images had been prepared for web use. They range from 2592 X 3888 to 550 X 689 with variable bit depths. Other contributed images are of intermediate sizes.

1.3. Imaging of Mackenzie's plates

New York Botanical Garden Press gave permission to image the plates in K. K. Mackenzie's two volume treatment of Carices of North America (Mackenzie 1940) for use in this project. All plates were imaged with a traditional copy stand, using a Nikon 300D camera with a 1:1 macro lens, and two halogen desk lamps for illumination using JPEG format. All images required batch-processing in Photoshop CS3 for color and a minor defect in skew. Additionally, to limit total file size of the project, the images were reduced to approximately one megabyte from three megabytes by resizing.

2. DATA FOR CXML CREATION

2.1. Primary data via export

The dataset was derived from an export of CIIK (http://www.herbarium.lsu.edu/keys/carex/carex.html) in comma separated values (CSV) from LUCID 3.4 Identification Software (The University Of Queensland 2006). These data were the template for the new secondary dataset (Fig. 1). The exported data were imported into Excel 2010 and the Excel PivotViewer plug-in generated the Commerce eXtensible Markup Language (CXML) version of the data (Suppl. material 1). This plugin has since been deprecated in favor of a command line tool, Pauthor (Microsoft 2010b, Microsoft 2010a).

2.2. Dependent software

.NET Framework (Microsoft 2007)

Visual Studio 2010 / 2012

Silverlight 4 Tools for Visual Studio 2010

Silverlight Software Development Kit (SDK)

Silverlight 4 Toolkit

PivotViewer SDK

2.3. Interface considerations in a micro-ontology

In Pivot Viewer with the Silverlight 4 format, the characters and states (C&S) are located in the searchable information pane on left, with the displayable information pane on right. This left pane is of a fixed width, lacking word-wrapping functions (Fig. 2). If all C&S information data mined were used, extensive scrolling would be required and thereby reduce the usability of the key. For this reason, long text strings in the C&S were edited for brevity. A 'less is more' approach was taken, with C&S being restricted to those that would be appropriate in an ontology.

2.4. Clustering issues in the graphical mode require a "normalization character state"

Visual keys require a normalization character state; or the image numbers must be standardized for graphical display

If image numbers between species are not consistent, a representative or semantic image is required. This leading image permits true one-to-one comparisons over any number of taxa. Without it, accurate representations of the data would be obscured due to clustering. For this reason, only those taxa with a line drawing are presented here to allow for a one-to-one comparison across taxa. It was done early in development as a work-around to the differing number of images per taxon problem. Later unpublished works of this type deal with this issue in multiple ways (see 'Additional information').

To use this normalization character, select 'Image by' at the base of the left information pane, then select 'Mackenzie, K. K.' from the information panel. Now, only grey scale images are used in a portrait format with an attention to the aspect ratio. All images are presented in the same fashion and uniformity in a grey scale that is easy to visually interpret. This ad-hoc commitment to Mackenzie's species list was done for this reason.

2.5. Data and images together

Images were added in small batches in a new Excel file. Character data were copy-pasted from the secondary spreadsheet to the third instance of Excel to form the final building file across multiple monitors.

2.6. Tertiary data

The completed third spreadsheet is now run using the 'New collection tool' by selecting its icon in the ribbon panel of Excel. It generates two primary products; image tiles in numerous folders and a CXML file (Suppl. material 1). The control leverages Deepzoom technology (Microsoft 2008) to create a deep zoom image library (DZI) and deep zoom collection files (DZC) like those seen on Google or Bing maps (Fig. 3). This geometric series of images supports the zoom-ability of images. As the user zooms in, things get geometrically resolved without the penalty associated with a large image download. As users pan through a collection, they can see only what they desire.

2.6.1 Issues completing tertiary data for image tiles and CXML

Hardware and software issues were experienced at all stages. Testing revealed that while tiling a few hundred high resolution images with PivotViewer is manageable, using over a thousand high-resolution images made Excel unstable. Memory allocation as well as the processor spiking issues - limited development time and resulted in extended periods of waiting for test builds overnight or on a build across many days. The creation of the image tiles is best attempted with a state-of-the-art computer with a solid state drive. CIVIK total tile-set and cxml build-time was approximately 12 hours for the final presented build (Fig. 4).

3. Deployable image tiles sizes

The DZI files are nearly four gigabytes in file size and comprise over 250,000 image-tile files in over 18,000 folders with an associated CXML of 3.3 megabytes in size. A Silverlight application package (XAP) file is also required to drive the application.

4. Compile with Visual Studio

To compile with Visual Studio, open a new instance of a Silverlight application for the web in Visual Studio. Now add the references to PivotViewer on the main Extensible Application Markup Language (XAML) page in UserControl. Then add the URL to the CXML file to the XAML.CS code behind file. Then, build or compile the deployment package for placement on the server.

4.1 XAML and XAML.CS Code behind Files

See 'software technical features'

5. Deploy to web server

Ensure that the following Multipurpose Internet Mail Extensions (MIME) types are configured on server; significant development time was lost due to one of these settings not being in place.

• CXML - text/xml

• DZC - text/xml

• DZI - text/xml

6. History of Use

CIVIK has been tracked via Google Analytics with the other later works of visual types. These combined works reveal that 13,933 visits occurred from 116 countries in 2464 cities over a three year period. An average dwell time of two minutes across the three works of type is seen here. (See Additional information and Suppl. material 6).

7. Considerations and discussion

While Silverlight is ideal for this data format, it will be deprecated (see http://support.microsoft.com/gp/lifean45) as no future versions are scheduled for release. It will, however, be supported for ten years which will aid future works of this kind. Thankfully, HTML 5 versions are also now available for PivotViewer that enable the CXML format across all devices in a device agnostic fashion. This cross platform capability is exciting as it does not require the Silverlight runtime, so phone and tablets are enabled as well with HTML 5. HTML 5 versions have one other important advantage - a Google translate function is easily added in minutes to over 70 languages (see http://translate.google.com/about/). Opening the door to future iterations of high-resolution images supported by text that is translatable.

Funding: SLouisiana State University

Geographic coverage

Description: The identification key can be used for species occurring in United States, Canada, and Mexico. Several species have a much wider distribution, hence the key has some value in other regions as well.

Coordinates: 90 and 15 Latitude; -180 and -45 Longitude.

Taxonomic coverage

Taxa included:

Rank	Scientific Name	Common Name
genus	Carex	sedge

genus	Kobresia	sedge
genus	Cymophyllus	sedge
species	Carex abrupta Mack.	abruptbeak sedge
species	Carex abscondita Mack.	thicket sedge
species	Carex adusta Boott	lesser brown sedge
species	Carex aestivalis M.A. Curtis ex A. Gray	summer sedge
species	Carex aggregata Mack.	glomerate sedge
species	Carex alata Torr.	broadwing sedge
species	Carex albicans Willd. ex Spreng.	whitetinge sedge
species	Carex albonigra Mack.	blackandwhite sedge
species	Carex albursina E. Sheld.	white bear sedge
species	Carex alligata Boott	Hawai'i sedge
species	Carex alma L.H. Bailey	sturdy sedge
species	Carex alopecoidea Tuck.	Foxtail sedge
species	Carex amphibola Steud.	eastern narrowleaf sedge
species	Carex amplectens Mack.	claspbract sedge
species	Carex amplifolia Boott	bigleaf sedge
species	Carex annectens (E.P. Bicknell) E.P. Bicknell	yellowfruit sedge
species	Carex anthoxanthea J. Presl & C. Presl	grassyslope arctic sedge
species	Carex aperta Boott	Columbian sedge
species	Carex aquatilis Wahlenb.	water sedge
species	Carex arapahoensis Clokey	Arapaho sedge
species	Carex arcta Boott	northern cluster sedge
species	Carex arctata Boott	drooping woodland sedge
species	Carex arenaria L.	sand sedge
species	Carex arkansana (L.H. Bailey) L.H. Bailey	Arkansas sedge
species	Carex assiniboinensis W. Boott	Assiniboia sedge
species	Carex atherodes Spreng.	wheat sedge
species	Carex athrostachya Olney	slenderbeak sedge
species	Carex atlantica L. H. Bailey	prickly bog sedge
species	Carex atrata L.	black scale sedge

species	Carex atratiformis Britton	scrabrous black sedge
species	Carex atrofusca Schkuhr	darkbrown sedge
species	Carex atrosquama Mack.	lesser blackscale sedge
species	Carex aurea Nutt.	golden sedge
species	Carex austrina Mack.	southern sedge
species	Carex austrocaroliniana L.H. Bailey	tarheel sedge
species	Carex aztecica Mack.	Aztec sedge
species	Carex backii Boott	Back's sedge
species	Carex baileyi Britton	Bailey's sedge
species	Carex baltzellii Chapm.	Baltzell's sedge
species	Carex barrattii Torr. ex Schwein.	Barratt's sedge
species	Carex bebbii (L. H. Bailey) Olney ex Fernald	Bebb's sedge
species	Carex bella L.H. Bailey	southwestern showy sedge
species	Carex bicknellii Britton & A.Br.	Bicknell's sedge
species	Carex bicolor Bellardi ex All.	two-color sedge
species	Carex bigelowii Torr. ex Schwein.	Bigelow's sedge
species	Carex biltmoreana Mack.	stiff sedge
species	Carex blanda Dewey	eastern woodland sedge
species	Carex bolanderi Olney	Bolander's sedge
species	Carex boliviensis Van Heurck & Müll. Arg.	Bolivian sedge
species	Carex breweri Boott	Brewer's sedge
species	Carex brizoides L.	
species	Carex bromoides Willd.	brome-like sedge
species	Carex brunnescens (Pers.) Poir.	brownish sedge
species	Carex bullata Willd.	button sedge
species	Carex bushii Mack.	Bush's sedge
species	Carex buxbaumii Wahlenb.	Buxbaum's sedge
species	Carex californica L.H. Bailey	California sedge
species	Carex canescens L.	silvery sedge
species	Carex capillaris L.	hair-like sedge
species	Carex capitata Sol.	capitate sedge

species	Carex careyana Torr. ex Dewey	Carey's sedge
species	Carex caroliniana Schwein.	Carolina sedge
species	Carex caryophyllea Latourr.	vernal sedge
species	Carex castanea Wahlenb.	chestnut sedge
species	Carex cephaloidea (Dewey) Dewey ex Boott	thinleaf sedge
species	Carex cephalophora Muhl. ex Willd.	oval-leaf sedge
species	Carex cherokeensis Schwein.	Cherokee sedge
species	Carex chihuahuensis Mack.	Chihuahuan sedge
species	Carex chordorrhiza L.	creeping sedge
species	Carex circinnata C.A.Mey.	coiled sedge
species	Carex collinsii Nutt.	Collins' sedge
species	Carex communis L.H. Bailey	fibrousroot sedge
species	Carex comosa Boott	longhair sedge
species	Carex complanata Torr. & Hook.	hirsute sedge
species	Carex concinna R. Br.	low northern sedge
species	Carex concinnoides Mack.	northwestern sedge
species	Carex conjuncta Boott	soft fox sedge
species	Carex conoidea Willd.	openfield sedge
species	Carex crawei Dewey ex Torr.	Crawe's sedge
species	Carex crawfordii Fernald	Craweford's sedge
species	Carex crebriflora Wiegand	coastal plain sedge
species	Carex crinita Lam.	fringed sedge
species	Carex cristatella Britton & A.Br.	crested sedge
species	Carex crus-corvi Shuttlew. ex Kunze	ravenfoot sedge
species	Carex cryptolepis Mack.	northeastern sedge
species	Carex cumulata (L.H. Bailey) Mack.	clustered sedge
species	Carex cusickii Mack.	Cusick's sedge
species	Carex dasycarpa Muhl.	sandywoods sedge
species	Carex davisii Schwein. & Torr.	Davis' sedge
species	Carex davyi Mack.	Davy's sedge
species	Carex debilis Michx.	white edge sedge

species	Carex decomposita Muhl.	cypressknee sedge
species	Carex deflexa Hornem.	northern sedge
species	Carex densa (L.H. Bailey) L.H. Bailey	dense sedge
species	Carex deweyana Schwein.	Dewey's sedge
species	Carex diandra Schrank	lesser panicled sedge
species	Carex digitalis Willd.	slender woodland sedge
species	Carex donnell-smithii L.H. Bailey	Donell's sedge
species	Carex douglasii Boott	Douglas' sedge
species	Carex ebenea Rydb.	ebony sedge
species	Carex eburnea Boott	bristleleaf sedge
species	Carex egglestonii Mack.	Eggleston's sedge
species	Carex elliottii Schwein. & Torr.	Elliott's sedge
species	Carex elynoides Holm	blackroot sedge
species	Carex emoryi Dewey	Emory's sedge
species	Carex engelmannii L.H. Bailey	Engelmann's sedge
species	Carex exilis Dewey	coastal sedge
species	Carex exsiccata L.H. Bailey	western inflated sedge
species	Carex festucacea Schkuhr ex Willd.	fescue sedge
species	Carex feta L. H. Bailey	greensheath sedge
species	Carex filifolia Nutt.	threadleaf sedge
species	Carex fissa Mack.	hammock sedge
species	Carex flacca Schreb.	heath sedge
species	Carex flaccosperma Dewey	thinfruit sedge
species	Carex flava L.	yellow sedge
species	Carex floridana Schwein.	Florida sedge
species	Carex foenea Willd.	dry-spike sedge
species	Carex folliculata L.	norther long sedge
species	Carex formosa Dewey	handsome sedge
species	Carex fracta Mack.	fragile sheath sedge
species	Carex frankii Kunth	Frank's sedge
species	Carex garberi Fernald	elk sedge

species	Carex geophila Mack.	White Mountain sedge
species	Carex geyeri Boott	Geyer's sedge
species	Carex gigantea Rudge	giant sedge
species	Carex glacialis Mack.	glacial sedge
species	Carex glareosa Schkuhr ex Wahlenb.	lesser salt marsh sedge
species	Carex glaucescens Elliott	southern waxy sedge
species	Carex glaucodea Tuck. ex Olney	blue sedge
species	Carex globosa Boott	roundfruit sedge
species	Carex gmelinii Hook. & Arn.	Gmelin's sedge
species	Carex gracillima Schwein.	graceful sedge
species	Carex granularis Muhl. ex Willd.	limestone meadow sedge
species	Carex gravida L.H. Bailey	heavy sedge
species	Carex grayi J. Carey	Gray's sedge
species	Carex grisea Wahlenb.	inflated narrow-leaf sedge
species	Carex gynandra Schwein.	nodding sedge
species	Carex gynocrates Wormsk.	northern bog sedge
species	Carex gynodynama Olney	Olney's hairy sedge
species	Carex halliana L.H. Bailey	Hall's sedge
species	Carex hallii Olney	deer sedge
species	Carex harfordii Mack.	Harford's sedge
species	Carex hassei L.H. Bailey	salt sedge
species	Carex haydenii Dewey	Hayden's sedge
species	Carex helleri Mack.	Heller's sedge
species	Carex hendersonii L. H. Bailey	Henderson's sedge
species	Carex heteroneura S.Watson	different-nerve sedge
species	Carex hirsutella Mack.	fuzzy sedge
species	Carex hirta L.	hammer sedge
species	Carex hirtifolia Mack.	pubescent sedge
species	Carex hirtissima W. Boott	fuzzy sedge
species	Carex hitchcockiana Dewey	Hitchcock's sedge
species	Carex holostoma Drejer	arctic marsh sedge

species	Carex hoodii Boott	Hood's sedge
species	Carex hookeriana Dewey	Hooker's sedge
species	Carex hormathodes Fernald	marsh straw sedge
species	Carex houghtoniana Torr. ex Dewey	Houghton's sedge
species	Carex hyalina Boott	tissue sedge
species	Carex hyalinolepis Steud	shoreline sedge
species	Carex hystericina Muhl. ex Willd.	bottlebrush sedge
species	Carex idahoa L. H. Bailey	Idaho sedge
species	Carex illota L. H. Bailey	sheep sedge
species	Carex incurviformis Mack.	coastal sand sedge
species	Carex inops L. H. Bailey	long-stolon sedge
species	Carex integra Mack.	smoothbeak sedge
species	Carex interior L. H. Bailey	inland sedge
species	Carex interrupta Boeckeler	greenfruit sedge
species	Carex intumescens Rudge	greater bladder sedge
species	Carex jamesii Schwein.	James' sedge
species	Carex jonesii L.H. Bailey	Jones' sedge
species	Carex joorii L.H. Bailey	cypress swamp sedge
species	Carex lacustris Willd.	hairy sedge? (lake sedge)
species	Carex laeviculmis Meinsh.	smoothstem sedge
species	Carex laxiculmis Schwein.	spreading sedge
species	Carex laxiflora Lam.	broad looseflower sedge
species	Carex leavenworthii Dewey	Leavenworth's sedge
species	Carex lemmonii W. Boott	Lemmon's sedge
species	Carex lenticularis Michx.	lakeshore sedge
species	Carex leporinella Mack.	Sierra hare sedge
species	Carex leptalea Wahlenb.	bristlystalked sedge
species	Carex leptonervia (Fernald) Fernald	nerveless woodland sedge
species	Carex limosa L.	mud sedge
species	Carex livida (Wahlenb.) Willd.	livid sedge
species	Carex loliacea L.	ryegrass sedge

species	Carex lonchocarpa Willd. ex Spreng.	southern long sedge
species	Carex longii Mack.	Long's sedge
species	Carex louisianica L. H. Bailey	Louisiana sedge
species	Carex lucorum Willd.	Blue Ridge sedge
species	Carex lupuliformis Sartwell ex Dewey	false hop sedge
species	Carex lupulina Muhl. ex Willd.	hop sedge
species	Carex lurida Wahlenb.	shallow sedge
species	Carex luzulina Olney	woodrush sedge
species	Carex lyngbyei Hornem.	Lyngbye's sedge
species	Carex macloviana d'Urv.	thickhead sedge
species	Carex macrocephala Willd. ex Spreng.	largehead sedge
species	Carex macrochaeta C. A. Mey.	longawn sedge
species	Carex marina Dewey	sea sedge
species	Carex mariposana L.H. Bailey ex Mack.	Mariposa sedge
species	Carex meadii Dewey	Mead's sedge
species	Carex membranacea Hook.	fragile sedge
species	Carex merritt-fernaldii Mack.	Fernald's sedge
species	Carex mertensii Prescott ex Bong.	Mertens' sedge
species	Carex michauxiana Boeckeler	Michaux's sedge
species	Carex microdonta Torr.	littletooth sedge
species	Carex microglochin Wahlenb.	fewseeded bog sedge
species	Carex micropoda C. A. Mey.	
species	Carex microptera Mack.	small wing sedge
species	Carex misera Buckley	wretched sedge
species	Carex mitchelliana M. A. Curtis	Mitchell's sedge
species	Carex molesta Mack.	troublesome sedge
species	Carex muehlenbergii Willd.	Muehlenberg's sedge
species	Carex multicaulis L.H. Bailey	manystem sedge
species	Carex multicostata Mack.	manyrib sedge
species	Carex muricata L.	rough sedge
species	Carex muskingumensis Schwein.	Muskingum sedge

species	Carex nebraskensis Dewey	Nebraska sedge
species	Carex nervina L.H. Bailey	Sierra sedge
species	Carex neurophora Mack.	alpine nerve sedge
species	Carex nigromarginata Schwein.	black edge sedge
species	Carex normalis Mack.	greater straw sedge
species	Carex norvegica Retz.	Norway sedge
species	Carex nudata W. Boott	naked sedge
species	Carex obnupta L. H. Bailey	slough sedge
species	Carex obtusata Lilj.	obtuse sedge
species	Carex occidentalis L. H. Bailey	western sedge
species	Carex oligosperma Michx.	fewseed sedge
species	Carex oreocharis Holm	grassyslope sedge
species	Carex ormostachya Wiegand	necklace spike sedge
species	Carex oxylepis Torr. & Hook.	sharpscale sedge
species	Carex paleacea Schreb. ex Wahlenb.	chaffy sedge
species	Carex pallescens L.	pale sedge
species	Carex panicea L.	grass-like sedge
species	Carex pansa L.H. Bailey	Payson's sedge
species	Carex pauciflora Lightf.	fewflower sedge
species	Carex peckii Howe	Peck's sedge
species	Carex pedunculata Muhl. ex Willd.	longstalk sedge
species	Carex pellita Muhl ex Willd.	wooly sedge
species	Carex pensylvanica Lam.	Pensylvania sedge
species	Carex perglobosa Mack.	globe sedge
species	Carex petricosa Dewey	rockdwelling sedge
species	Carex phaeocephala Piper	dunhead sedge
species	Carex picta Steud.	Boott's sedge
species	Carex pityophila Mack.	loving sedge
species	Carex planostachys Kunze	cedar sedge
species	Carex plantaginea Lam.	plantainleaf sedge
species	Carex platyphylla J. Carey	broadleaf sedge

species	Carex podocarpa R. Br.	shortstalk sedge
species	Carex polystachya Sw. ex Wahlenb.	Caribbean sedge
species	Carex praeceptorium Mack.	early sedge
species	Carex praegracilis W. Boott	clustered field sedge
species	Carex prairea Dewey ex Alph.Wood	prairie sedge
species	Carex prasina Wahlenb.	drooping sedge
species	Carex praticola Rydb.	meadow sedge
species	Carex preslii Steud.	Presl's sedge
species	Carex projecta Mack.	necklace sedge
species	Carex proposita Mack.	Great Smoky Mountain sedge
species	Carex pseudocyperus L.	cypress-like sedge
species	Carex purpurifera Mack.	purple sedge
species	Carex radiata (Wahlenb.) Small	eastern star sedge
species	Carex rariflora (Wahlenb.) Sm.	looseflower alpine sedge
species	Carex raynoldsii Dewey	Raynolds' sedge
species	Carex recta Boott	estuary sedge
species	Carex reniformis (L.H. Bailey) Small	kidneyshape sedge
species	Carex retroflexa Muhl. ex Willd.	reflexed sedge
species	Carex rosea Willd.	rosy sedge
species	Carex rossii Boott	Ross' sedge
species	Carex rostrata Stokes	beaked sedge
species	Carex rufina Drejer	snowbed sedge
species	Carex rupestris All.	curly sedge
species	Carex sartwellii Dewey	Sartwell's sedge
species	Carex saxatilis L.	rock sedge
species	Carex scabrata Schwein.	eastern rough sedge
species	Carex scabriuscula Mack.	Siskiyou sedge
species	Carex schweinitzii Dewey ex Schwein.	Schweinitz's sedge
species	Carex scirpoidea Michx.	northern singlespike sedge
species	Carex scoparia Willd.	broom sedge
species	Carex scopulorum Holm	mountain sedge

species	Carex senta Boott	swamp carex
species	Carex seorsa Howe	weak stellate sedge
species	Carex shortiana Dewey & Torr.	Short's sedge
species	Carex simulata Mack.	analogue sedge
species	Carex socialis Mohlenbr. & Schwegman	low woodland sedge
species	Carex sparganioides Muhl. ex Willd.	bur-reed sedge
species	Carex specifica L.H. Bailey	narrowfruit sedge
species	Carex spectabilis Dewey	showy sedge
species	Carex spicata Huds.	prickly sedge
species	Carex spissa L.H.Bailey ex Hemsl.	San Diego sedge
species	Carex sprengelii Dewey ex Spreng.	Sprengel's sedge
species	Carex squarrosa L.	squarrose sedge
species	Carex sterilis Willd.	dioecious sedge
species	Carex stipata Muhl. ex Willd.	awlfruit sedge
species	Carex straminea Willd. ex Schkuhr	straw sedge
species	Carex striata Michx.	Walter's sedge
species	Carex striatula Michx.	lined sedge
species	Carex stricta Lam.	upright sedge
species	Carex styloflexa Buckley	bent sedge
species	Carex stylosa C. A. Mey.	variegated sedge
species	Carex subbracteata Mack.	smallbract sedge
species	Carex supina Willd. ex Wahlenb.	weak arctic sedge
species	Carex swanii (Fernald) Mack.	Swan's sedge
species	Carex sylvatica Huds.	European woodland sedge
species	Carex tenera Dewey	quill sedge
species	Carex tetanica Schkuhr	rigid sedge
species	Carex torreyi Tuck.	Torrey's sedge
species	Carex tribuloides Wahlenb.	blunt broom sedge
species	Carex tuckermanii Boott	Tuckerman's sedge
species	Carex turgescens Torr.	pine barren sedge
species	Carex typhina Michx.	cattail sedge

species	Carex umbellata Willd.	parasol sedge
species	Carex verrucosa Muhl.	warty sedge
species	Carex vesicaria L.	blister sedge
species	Carex viridula Michx.	little green sedge
species	Carex vulpina L.	true-fox sedge
species	Carex vulpinoidea Michx.	fox sedge
species	Carex willdenowii Willd.	Willdenow's sedge
species	Carex woodii Dewey	Wood's sedge
species	Carex xerantica L.H. Bailey	whitescale sedge
species	Cymophyllus fraseri (Ker Gawl.) Kartesz & Gandhi	Fraser's cymophyllous
species	Kobresia simpliciuscula (Wahlenb.) Mack.	simple bog sedge

Usage licence

Characters used in the key

1. Species
2. Country
3. U.S. state
4. Canadian province or territory
5. Section within Carex
6. Culm height
7. Blade width
8. Inflorescence type
9. Proximal spike sexuality
10. Terminal spike sexuality
11. Stigma branch number
12. Perigynium length
13. Perigynium width
14. Perigynium cross-section shape
15. Achene length
16. Achene width
17. Achene cross-section shape
18. Style: whether deciduous or persistent
19. Image author
20. Image type

Software specification

Name: Carices Interactive Visual Identification Key

Version: 1.1

Interface language: English

Platform: Silverlight runtime

Web location: http://www.herbarium2.lsu.edu/aba/

Software technical features

Main XAML page

```
UserControl x:Class="A5.MainPage"
   xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
   xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
   xmlns:d="http://schemas.microsoft.com/expression/blend/2008"
   xmlns:mc="http://schemas.openxmlformats.org/markup-compatibility/2006"
   xmlns:local="clr-namespace:System.Windows.Pivot;assembly=System.Windows.Pivot"
            mc:Ignorable="d"          d:DesignHeight="300"          d:DesignWidth="400"
Loaded="UserControl_Loaded">
   <Grid x:Name="LayoutRoot" Background="Black">
<local:PivotViewer x:Name="Pivot"/>
  </Grid>
</UserControl>
```

XAML.CS or Code behind

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Net;
```

```
using System.Windows;
using System.Windows.Controls;
using System.Windows.Documents;
using System.Windows.Input;
using System.Windows.Media;
using System.Windows.Media.Animation;
using System.Windows.Shapes;
using System.Windows.Pivot;
namespace A10
{
    public partial class MainPage : UserControl
    {
        public MainPage()
        {
            InitializeComponent();
            Pivot.LoadCollection(
    "http://www.herbarium2.lsu.edu/aba/A10.cxml"
    , string.Empty);
        }
        private void UserControl_Loaded(object sender, RoutedEventArgs e)
        {
        }
    }
```

Additional information

Later examples of visual keys deal with the clustering problem differently. Both Silverlight and HTML 5 based grass genera of Louisiana keys use existing herbarium specimen

images to normalize, one herbarium specimen per taxon. Leveraging recent physical and vetted sources. This normalization character is select-able as 'one-to-one comparisons' at the bottom of character information panel http://www.herbarium2.lsu.edu/grass2/. Secondly, Kingdom Plantae in HTML 5 is normalized by image number only, without a selectable character state, across divisions http://www.herbarium2.lsu.edu/aca/. *Magnoliphyta* is taken at a log value due to its disparate taxa value when compared to the other divisions.

Acknowledgements

The author sincerely appreciates the ground-breaking work completed by others before this project even began. Without these prior efforts, this current CHANGE could not have been completed in this same time-frame. A sincere thank you to all the editors of Flora of North America, Volume 23, and the image contributors. To G. Wilder, J. Bissell, M. Barkworth, A. Reznicek, K. Niklas, and my Ph.D. advisor, L. Urbatsch, thank you for sharing your wisdom and support. Also, I wish to thank W. Thomas and K. Thiele, for editorial commentary provided for this manuscript.

Author contributions

Jones developed the project, and contacted the other contibutors for images. S. Matson and T. Reznicek both mailed a DVD copy of their Carex field images. L. Urbatsch's teaching-microscopy-images were copied and saved to USB thumbdrives. New York Botanical Garden Press permitted the use of the images of both North American Cariceae volumes by Mackenzie, K.K. Remaining image owners were found on the WWW and contacted by email. Thankfully, they granted permission for usage, including; F. Starr & K. Starr, N. Nyugen, and A. Debolt. R. Mohlenbrock's image was gathered from Plants.gov.

References

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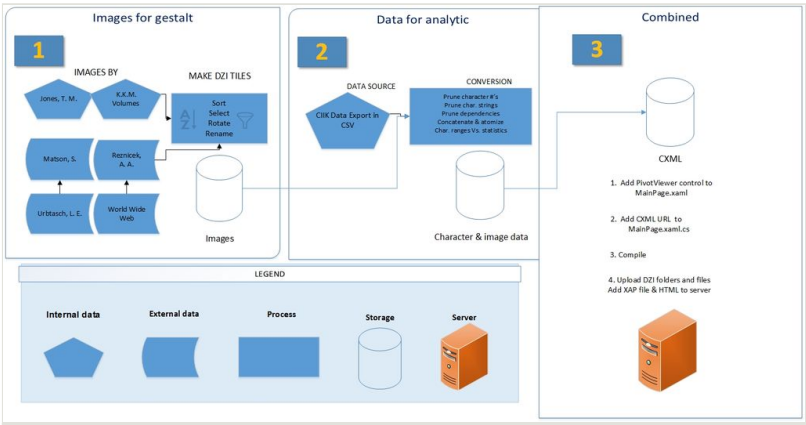

Figure 1.

Workflow of project

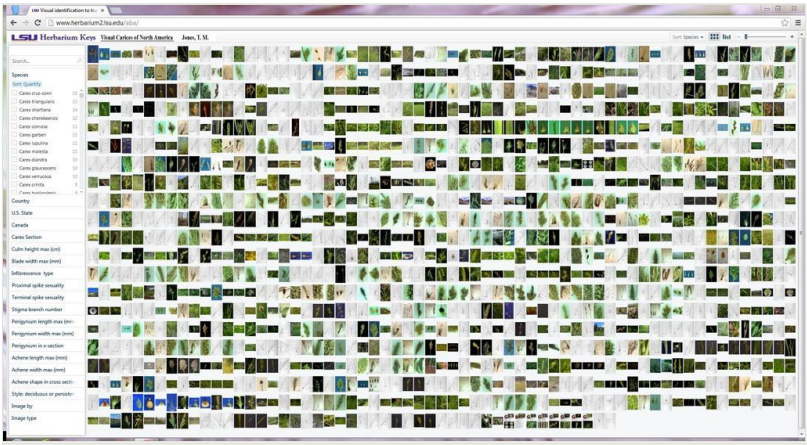

Figure 2.

The Visual Carices of North America upon instantiation in default grid setting.

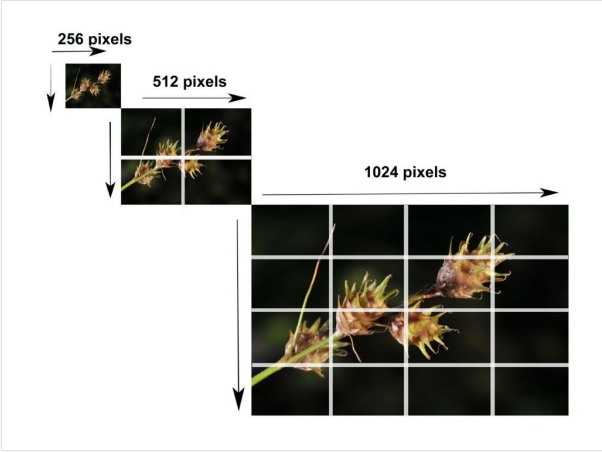

Figure 3.

Tiled image set illustrating the change in file size as well as number of images by creating a geometric series of images

Figure 4.

An Interactive Visual Identification Key to Carices of North America beta version.

Supplementary materials

Suppl. material 1: Tertiary file structure for Carices CXML file

Authors: Jones, T. M.
Data type: occurences, morphological,
Filename: A10.cxml - Download file (4.19 MB)

Suppl. material 2: Secondary Carex morphology data; cleaned and truncated for building CXML

Authors: Jones, T. M.
Data type: occurrences, morphological, images
Brief description: This file is an example of a build file for the creation of the CXML file.
Filename: 957am fixed scirpoidea space issue.xlsx - Download file (483.24 kb)

Suppl. material 3: Website data from Utah State University

Authors: Google Analytics
Data type: PDF
Brief description: Data sheet for visitiation to CIIK by country
Filename: Analytics utc.usu.edu_keys_Carex_Carex.html Location 20060531-20130630.pdf - Download file (180.01 kb)

Suppl. material 4: Website data from Louisiana State University

Authors: Google Analytics
Data type: PDF
Brief description: Data sheet for visitiation to CIIK by country
Filename: Analytics Carex key LSU Location 20060531-20130630.pdf - Download file (178.08 kb)

Suppl. material 5: Primary Carex morphology data from Lucid 3.4

Authors: Jones, T. M.
Data type: XLSX
Brief description: Export from CIIK 2013 in CSV format
Filename: Carex-all-CSV.xlsx - Download file (732.82 kb)

Suppl. material 6: CIVIK usage 2011 - 2013

Authors: Google Analytics
Data type: PDF
Brief description: This includes all visual keys developed. Here CIVIK is represented by both /aba/ and /aaa/ and iteratives.
Filename: Analytics www.herbarium2.lsu.edu_aaa_A5TestPage.html Pages 20100531-20130630.pdf - Download file (168.54 kb)

Suppl. material 7: Visual keys usage with Google Analytics

Authors: Google
Data type: analytics
Brief description: Compilation of all visual keys using Google Analytics
Filename: Analytics www.herbarium2.lsu.edu-aaa-A5TestPage.html Language 20100809-20130908.pdf - Download file (189.65 kb)