

# **Using specimens from the past to understand the living world through digitization**

**Drs. Jessica L. Ware, William Kuhn, Dirk Gassmann  
and John Abbott  
Rutgers University, Newark**



# Dragonflies: Order Odonata



# Suborders



**Anisoptera** (unequal wings): Dragonflies ~3000 species

**Anisozygoptera** ~3 species

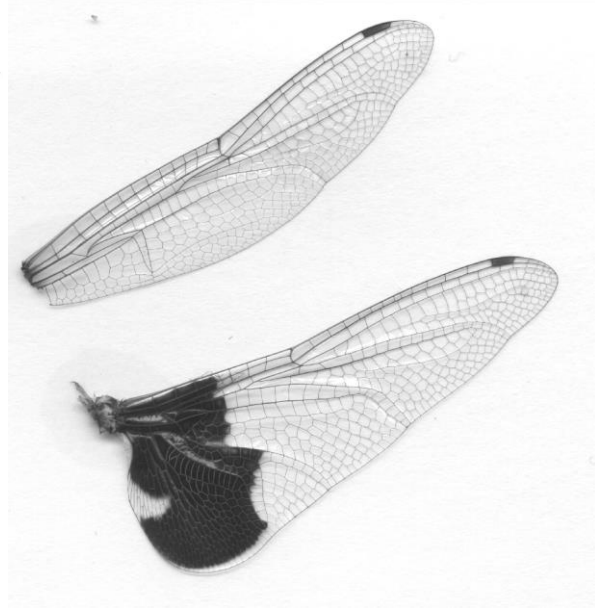
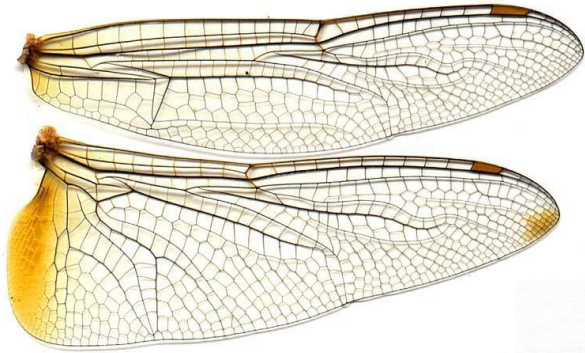
**Zygoptera**: Damselflies ~3000 species



# Perchers, Fliers, Migrators, & Homebodies

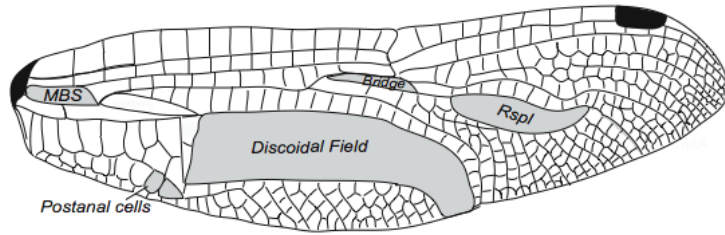


# Dragonfly flight



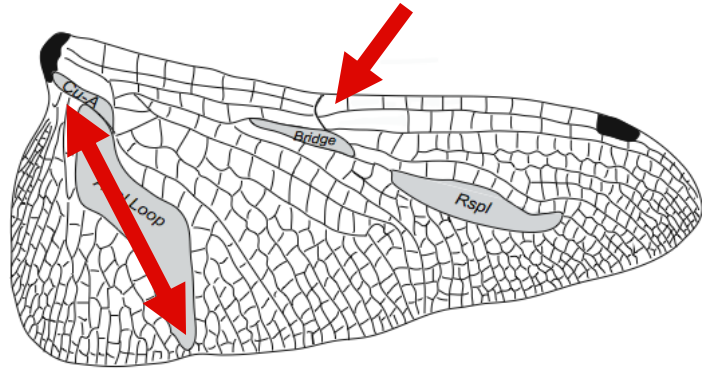
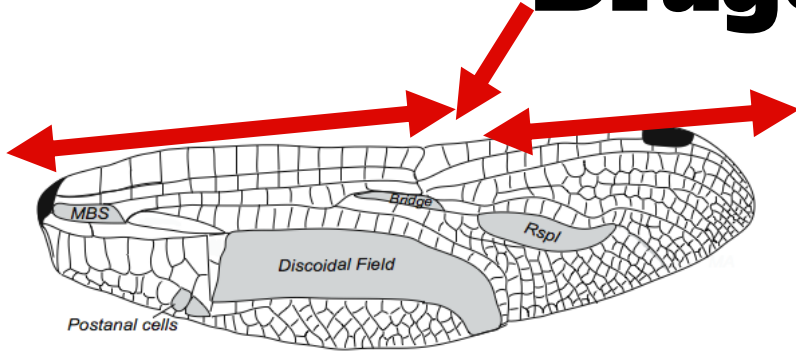
Wing venation  
affects wing  
camber, lift, and  
ultimately flight  
patterns

# Dragonfly flight



Stiffness varies along length of the wing with vein density and thickness

# Dragonfly flight



Certain wing traits are correlated with specific flight styles

# Dragonfly collections: invaluable



<u>Collection name</u>	<u># spp.</u>
Florida State Collection	2728
150K	
Ware Lab Collection	373
4K	
Smithsonian Collection	253

M.L.





# Dragonfly collections: invaluable



Harness information in  
collections



# TOWD Project

**Targeted Odonata Wing Digitization (TOWD) project**

# TOWD project scanning protocol

This side **face up** on scanner.

⊕

**Targeted Odonata Wing Digitization (TOWD) Project Scanning Frame v2.0**

**C. VOUCHER BARCODE**

<b>C</b>	
----------	--

**D. DATABASE LABEL**

<b>D</b>	<b>A</b>
----------	----------

**E. COLOR STANDARD & SCALE**

<b>E</b>	<b>B</b>
----------	----------

**F. LABEL CARD**

**F**

**How to prepare this scanning frame:**

- (1) Print this document, double-sided, on a single sheet of white cardstock (preferably) or white printer paper. Be sure to select *Actual size (not Fit)* in the print menu.
- (2) Using a knife and ruler, neatly cut out and remove regions A–D and F–G.
- (3) Prepare the WGK and RGB color standards and affix them to the appropriate regions (above the printed scale) with tape or glue.
- (4) Place the completed frame on the scanner with the side labeled *face down* on the glass. Line up the arrow in the upper-right side of the *face up* side with the arrow on the scanner. Use tape to hold the frame in place during scanning.
- (5) Your scanning frame is now complete! The corners of the scan region are marked by arrows; use these arrows as guides when selecting the scan region in the scan preview window.

**G. FULL BODY**


<b>G</b>	
----------	--

⊕

This side **face down** on scanner glass.

⊕

(5) corner of scan region


<b>A</b> (2) cut & remove	<b>C</b> (2) cut & remove
<b>D</b> (2) cut & remove	<b>D</b> (2) cut & remove
<b>B</b> (2) cut & remove	<b>E</b> (3) Affix RGB standard here. (3) Affix WGK standard here.  1 cm TOWD SCANNING FRAME v2.0
<b>F</b> (2) cut & remove	
<b>G</b> (2) cut & remove	

(5) corner of scan region

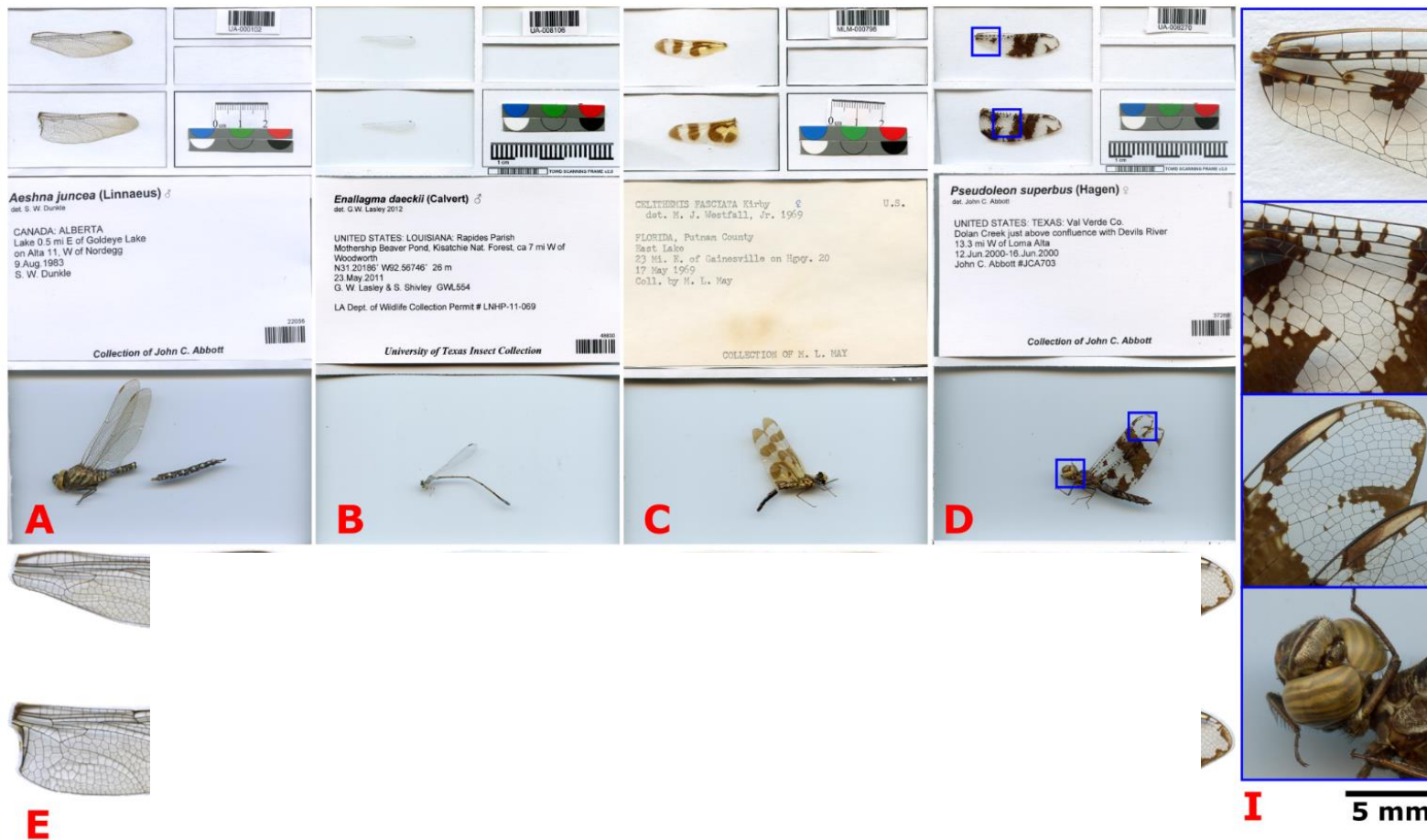
(5) corner of scan region

⊕

⊕

(4) 

# TOWD project scanning protocol

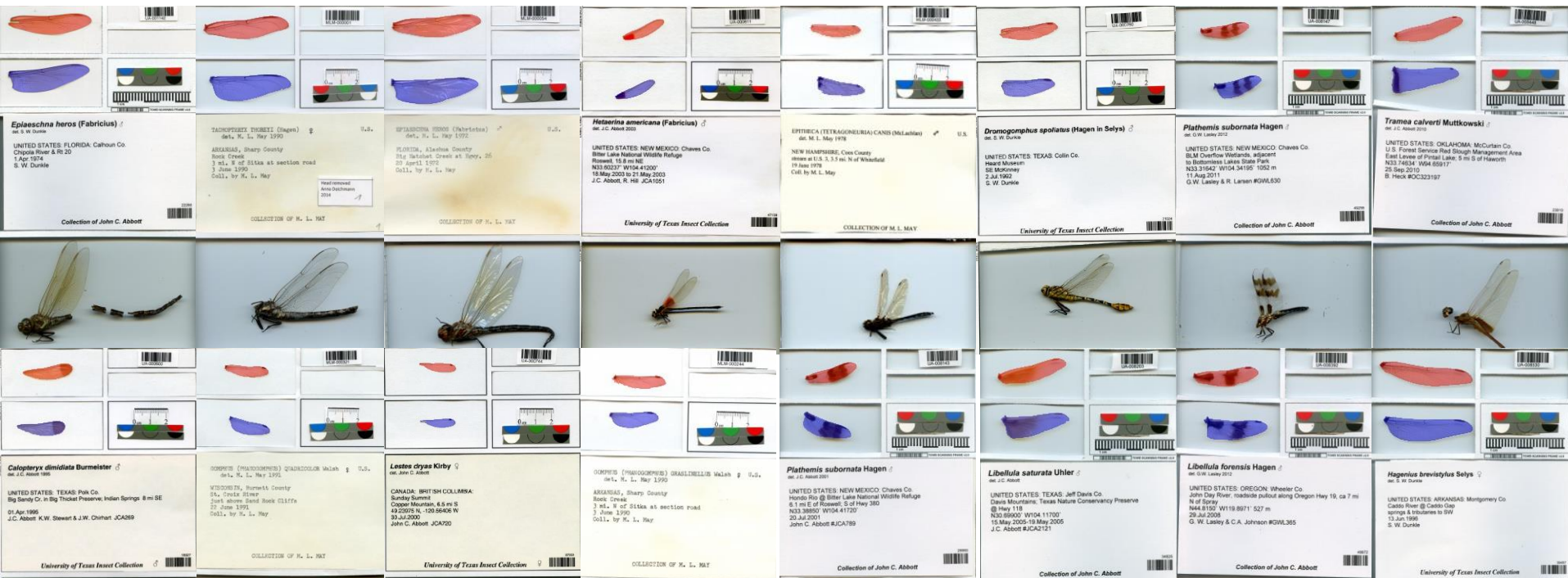


# TOWD project

The screenshot shows the BisQue web interface. The top navigation bar includes 'Create', 'Upload', 'Download', 'Analyze', and 'Browse' buttons. The user is logged in as 'Will Kuhn'. The dataset is titled 'Targeted Ode Wing Digitization'. On the left, an 'Organizer' sidebar lists various metadata fields and their counts. The main area displays a grid of 50 image thumbnails, each with a small thumbnail of the insect and a larger thumbnail of the specimen card. A blue rectangular box highlights one of the thumbnails in the grid.

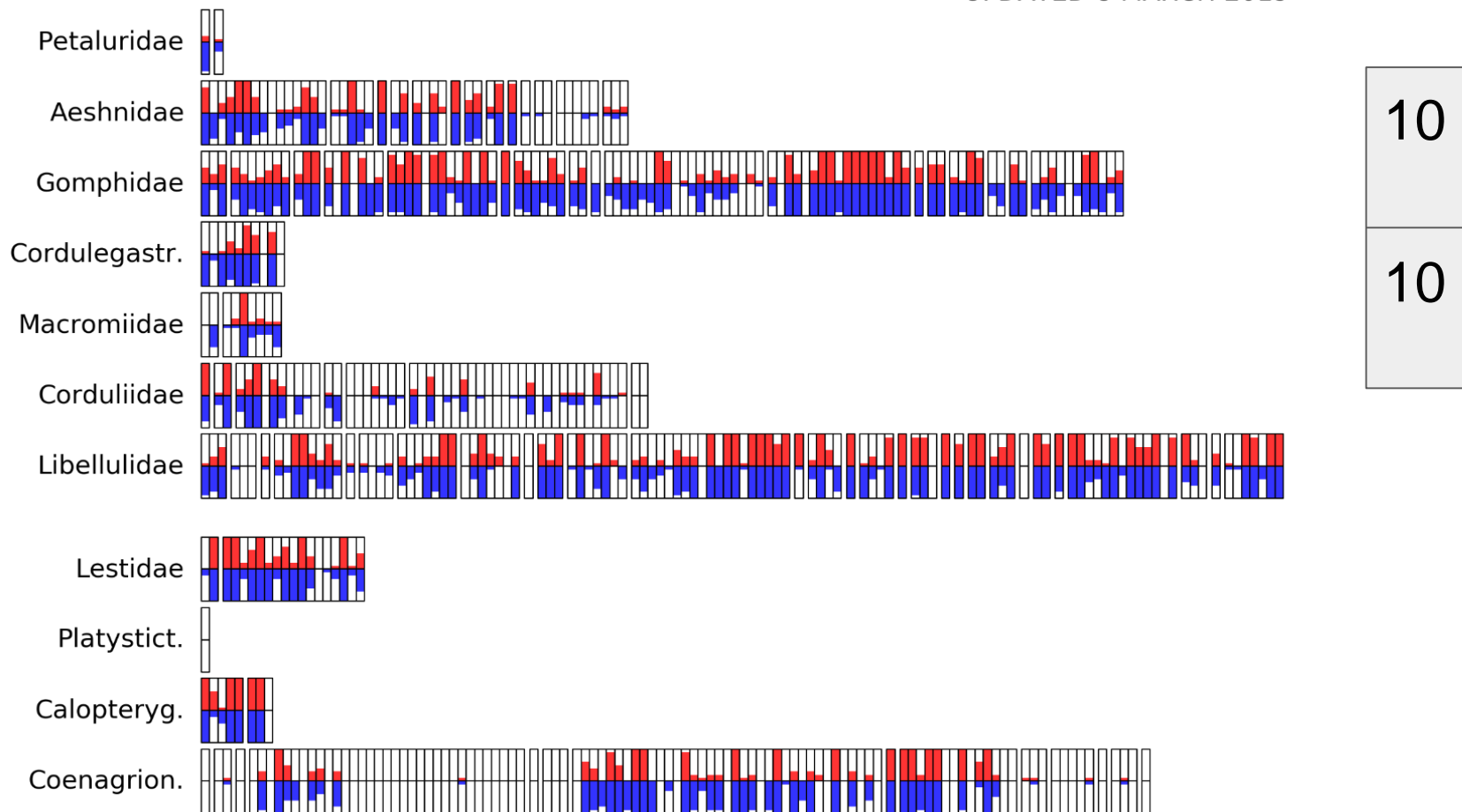
The screenshot shows a detailed view of a specimen card in the BisQue interface. The card is for *Sympetrum illotum* (Hagen) ♂, detected by J.C. Abbott in 2005. The collection location is 'UNITED STATES: TEXAS: Jeff Davis Co Cat Tank Davis Mountains Nature Conservancy Preserve N30 69920' W104.16260', dated 13 Sep 2005. The collector is J.C. Abbott #JCA2198. The card also features a barcode with the number 32273 and the text 'Collection of John C. Abbott'. A photograph of the dragonfly is visible at the bottom of the card. The interface includes a 'Metadata' sidebar on the right with tabs for 'Annotations', 'Graphical', 'Metadata', and 'Analysis'. The top navigation bar is the same as in the previous screenshot.

# TOWD project



# TOWD project

UPDATED 8 MARCH 2019



# TOWD project

## TOWD Project

Exploring the evolutionary history of dragonflies and damselflies (Odonata) from their wings!

[View the Project on GitHub](#)

[willkuhn](#)

### Targeted Odonata Wing Digitization (TOWD) Project

[ABOUT](#) [PROGRESS](#) [TEAM](#) [OUTPUTS](#) [RESOURCES](#)

#### About the Project

**Dragonflies and damselflies (Odonata)** are highly skilled aerial acrobats, the simplest in the bird lineage of their most pronounced feature: their **wings**. These structures are both functional and beautiful. They provide extreme maneuverability and flexibility in a lightweight package, and they can be marked with bright color patterns and even iridescence! The structure and appearance of these wings provides a **rich source of information** about the evolutionary history, aerodynamic constraints, and behavior of a species.

The Targeted Odonata Wing Digitization (TOWD) Project is part of an NSF-funded, multi-institutional effort to develop ODOMATIC, software for automatic identification of Odonata from images. Initiated in 2018, the TOWD Project aims to digitize the world's dragonfly and damselfly species, starting with the approx. **466 North American species**. We are working to produce a **high-resolution image** of these species (including multiple angles and females from each), partnering with several Odonata collectors, and building the most complete dataset of Odonata wings ever compiled. Behind the scenes, we use **computer vision** to pull phenotypic information from our wings, which can be used for identification and comparative study.

The TOWD dataset will be used for **two main purposes**:

1. as training data to **expand the capabilities** of ODOMATIC – an automatic species recognition system for dragonflies and damselflies, and
2. to **answer questions** about the flight strategies, mating behavior and other aspects of odonate evolutionary biology.

The TOWD Project's imagery dataset will be made available to the public and/or in situ via the CyVerse cyberinfrastructure, once the project is complete. Until then, you can [view our progress](#) below.

#### How does digitization work?

We designed an inexpensive digitization setup that uses a commonly available desktop scanner (connected to a computer) and custom-built paper "trays" placed on the scanner glass to hold things in place and standardize our images. The image below is an example of the final product: one pair of wings is scanned and scanned separately from the rest of the body, which is also scanned along with them and a color standard and scale. Each item gets it's own "window" in the frame and everything is brought all over in one high-resolution scan.



Digitization

#### What do we do with the scans?

Specimen scans are uploaded to our dataset on [Curator's Index](#) – a powerful imaging platform that allows us to view them from a web browser or work with them from the backend via scripts using ImageJ's API. It's at this point that one of the most exciting parts of the project takes place behind the scenes, governed by scripts. Our specimen inventory is updated periodically by a script that reads barcodes and labels from the latest scans and checks them against collections. Guidelines to get species names and locality information associated with them. Another script detects the wings in each image and automatically measures morphometric properties of each wing (area, length, width, etc.) and also calculates information about its appearance and texture. We can then use these data to make comparisons among specimens to update our ODOMATIC species recognition model, using machine learning.

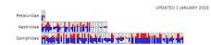
#### Acknowledgement of NSF Support

This material is based upon work supported by the National Science Foundation under grant No. 1564484. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

#### Project progress

Our goal is to image at least 30 males and 10 females from each of the 466 dragonfly and damselfly species in Canada and the US. The progress of this ambitious endeavor (as of 08 March 2023) is illustrated in two forms below.

#### North American progress (total):



UPDATED 1 January 2023



# Aspect ratios: How elongate is the wing compared to its overall area?

- Measurement of aerodynamic efficiency of a wing
- Ratio of wing span to mean chord of wing, with variations



- Formula 1:  $AR = \frac{(\text{wing length})^2}{(\text{wing area})}$
- Formula 2:  $AR = \frac{(\text{outer length})}{(\text{outer width})}$
- Formula 3:  $AR = \frac{(\text{outer length}) * (\text{outer width})}{(\text{wing area})}$

High Aspect ratio	Low Aspect ratio
Long narrow wings, Wing optimized for: long-distance flight	Short broad wings, Wing optimized for: Maneuverability, turning

**High Aspect Ratio**



**Low Aspect Ratio**



# More data on aspect ratios, better interpretations?

2007: Hand measured forewings of 85 specimens, 7 months work.

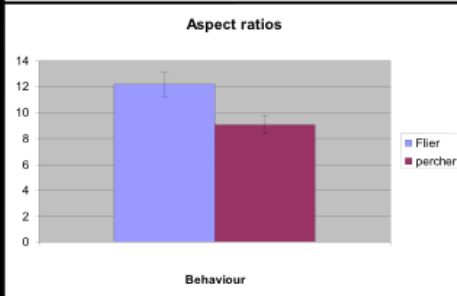
## Are there differences in overall wing characteristics?



### Significant difference in Wing Loading

P-value: 0.002945

\* mass :no significant difference between perchers and fliers



### Significant difference in Aspect Ratios

P-value 0.010

High Aspect ratio: longer narrower wings  
Low Aspect ratio: shorter, stubbier wings



# More data on aspect ratios, better interpretations?

2007: Hand measured forewings of **85** specimens, **7 months** work.

2019: Odomatic measurements for **206** specimens, 2-3 minutes of work!

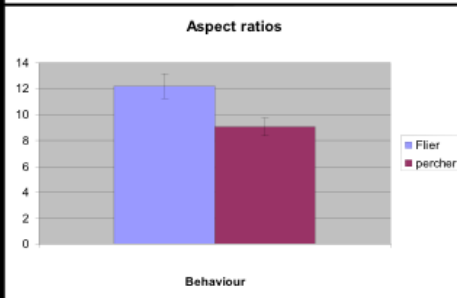
## Are there differences in overall wing characteristics?



### Significant difference in Wing Loading

P-value: 0.002945

\* mass :no significant difference between perchers and fliers



### Significant difference in Aspect Ratios

P-value 0.010

High Aspect ratio: longer narrower wings  
Low Aspect ratio: shorter, stubbier wings

## Are there differences in aspect ratios?

Perchers have significantly lower aspect ratios than fliers.

The  $p$ -value is .001819.

The result is significant at  $p < .05$ .

The standard deviation is lower than in 2007 at 0.3725

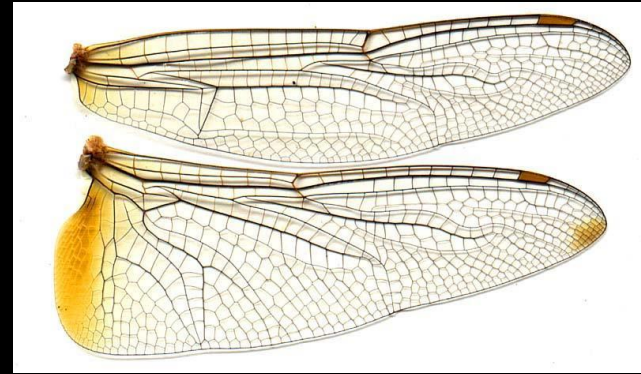


More data allows for examination of differences among FW and HW

## Forewings

Perchers have significantly lower aspect ratios than fliers,  $p$ -value= 0.001819.

The result is significant.



## Hindwings

$p=0.485516$ . The result is *not* significant.

# Wing loading

- $$\text{wing loading} = \frac{\text{body mass (kg)}}{\text{wing area (m}^2\text{)}} = \frac{(\text{body mass})}{(2(\text{FW area})+2(\text{HW area}))}$$

# Tandem Oviposition may affect wing loading



# Tandem Oviposition, flight style may affect wing loading

2007: Hand measured forewings of 85 specimens, 7 months work.

2019: Odomatic measurements for 206 specimens, 2-3 minutes of work!

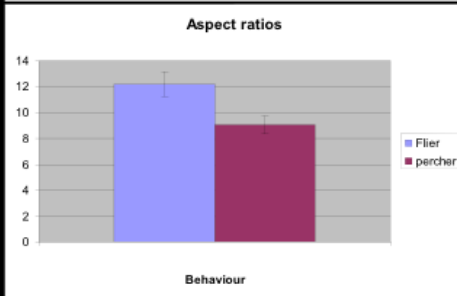
## Are there differences in overall wing characteristics?



### Significant difference in Wing Loading

P-value: 0.002945

\* mass :no significant difference between perchers and fliers



### Significant difference in Aspect Ratios

P-value 0.010

High Aspect ratio: longer narrower wings  
Low Aspect ratio: shorter, stubbier wings

More data, across families, no significant difference between perchers and fliers in terms of wing loading,  $p=0.51$



# Tandem Oviposition, flight style may affect wing loading

2007: Hand measured forewings of 85 specimens, 7 months work.

2019: Odomatic measurements for 206 specimens, 2-3 minutes of work.

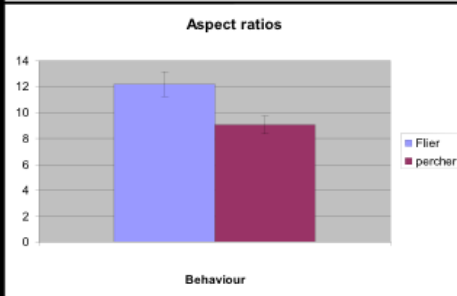
## Are there differences in overall wing characteristics?



**Significant difference in Wing Loading**

P-value: 0.002945

\* mass :no significant difference between perchers and fliers



**Significant difference in Aspect Ratios**

P-value 0.010

High Aspect ratio: longer narrower wings  
Low Aspect ratio: shorter, stubbier wings

*Tandem* versus *solo* ovipositing species have significantly different wing loading values,  $p=0.0022$





# What else can we gather from digitized collections?

Range

Habitat  
choice



Phenology

# Families of Anisoptera

Austropetaliidae

**Aeshnidae**

Petaluridae

Gomphidae

Chlorogomphidae

Cordulegastriidae

**Neopetaliidae**

Synthemistidae

Macromiidae

**Corduliidae**

**Libellulidae**

Lotic

Lentic



# Results



Libellulidae

Corduliidae



Macromiidae

Synthemistidae s.l.

Cordulegastridae

Chlorogomphidae

Neopetalidae

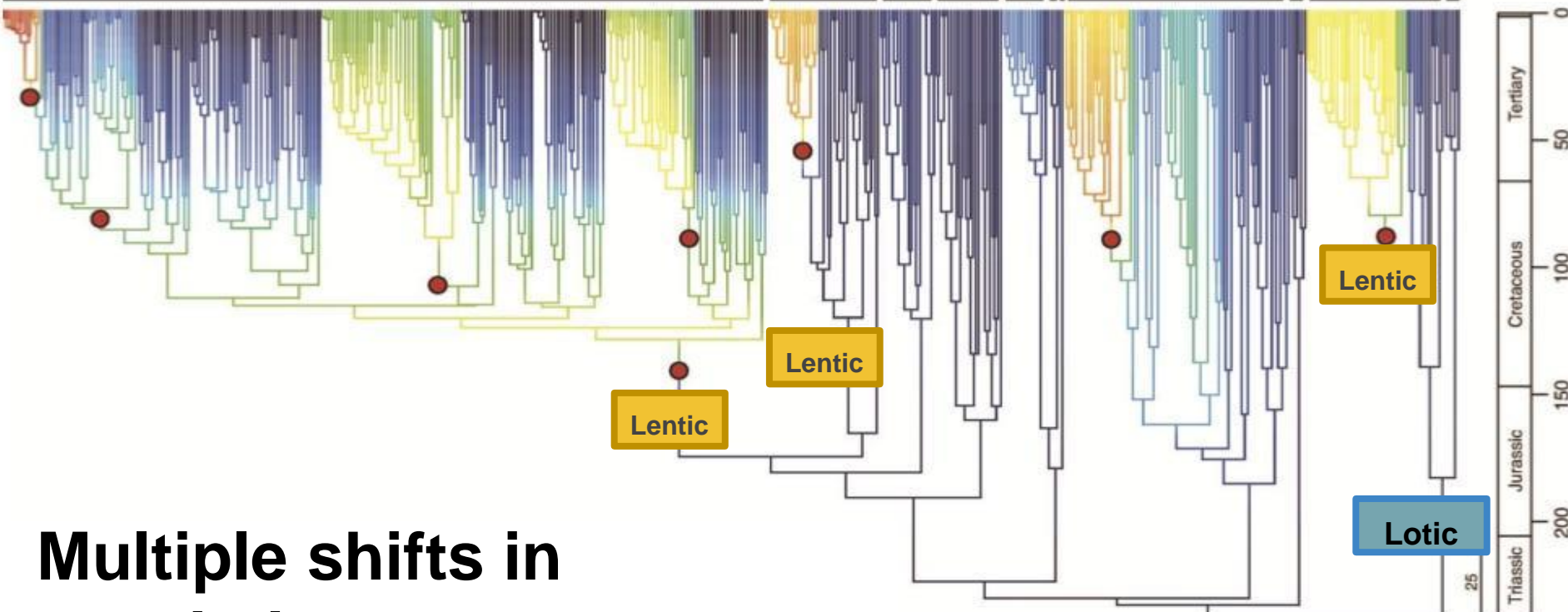
Gomphidae

Petaluridae

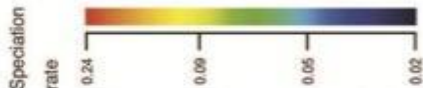
Aeshnidae



Austropetalidae



## Multiple shifts in speciation rates



**With automatic feature  
extraction and digitized  
collections, we have  
more data which affects  
ecological  
interpretations**



# Acknowledgements



Thank you to all who shared specimens with us!

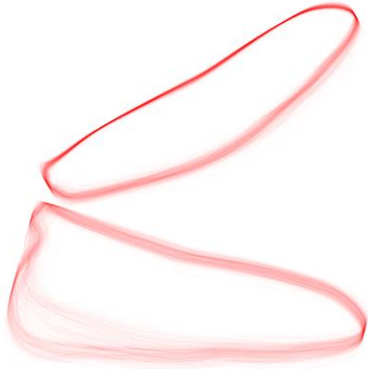
Special thanks to the  
following  
collections/collectors:

John Abbott, Christopher Beatty, Mike May, Dirk Gassmann,  
Rosser Garrison, Susan George, Patrick Hulick, Gwen Irons,  
Manpreet Kohli, Will Kuhn, Jack Kellogg, Ciara Mendoza,  
Stephanie Mafla Mills, Andy Rehn, Melissa Sanchez-Herrera.

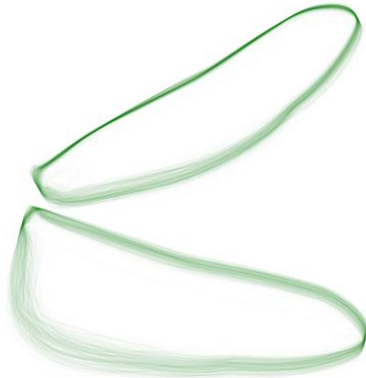


# Helpful images...

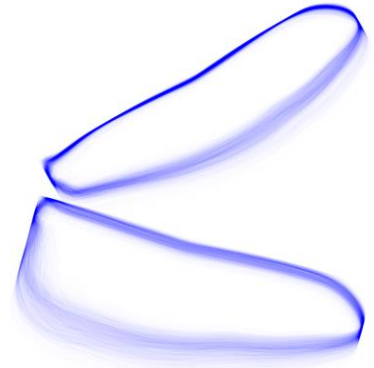
Overlays of wing outlines of libelluloid perchers, fliers and “intermediates” to show general wing shape across these groupings. Each thin line is a the wing of a single individual



Fliers



Intermediates



Perchers

# Helpful images...

Overlay of wing outlines for all individuals in our dataset (forewing in red, hindwing in blue). Each thin line represents the wing of a single individual.

