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

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Dragonflies: Order Odonata

Suborders

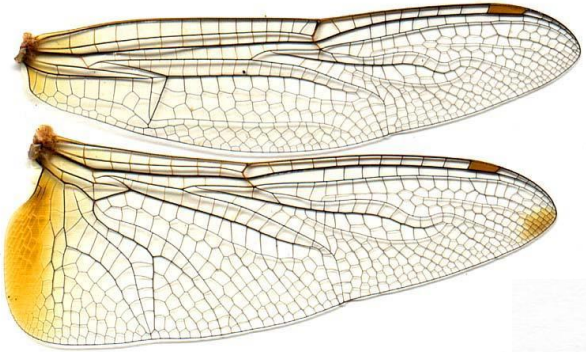
Anisoptera (unequal wings): Dragonflies ~3000 species

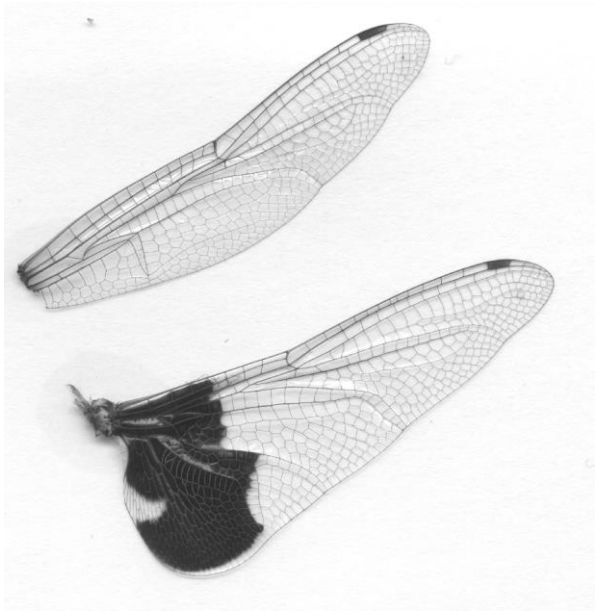
Anisozygoptera ~3 species

Zygoptera: Damselflies ~3000 species

Perchers, Fliers, Migrators, & Homebodies

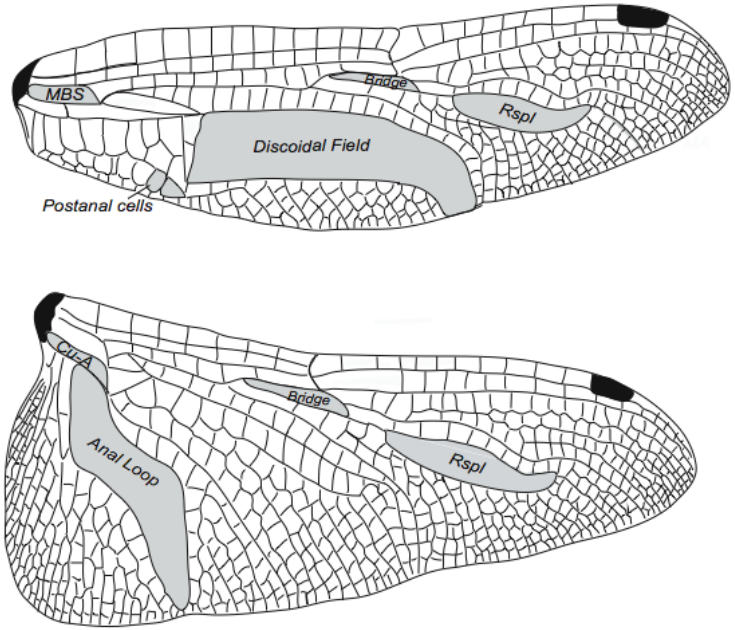
Dragonfly flight





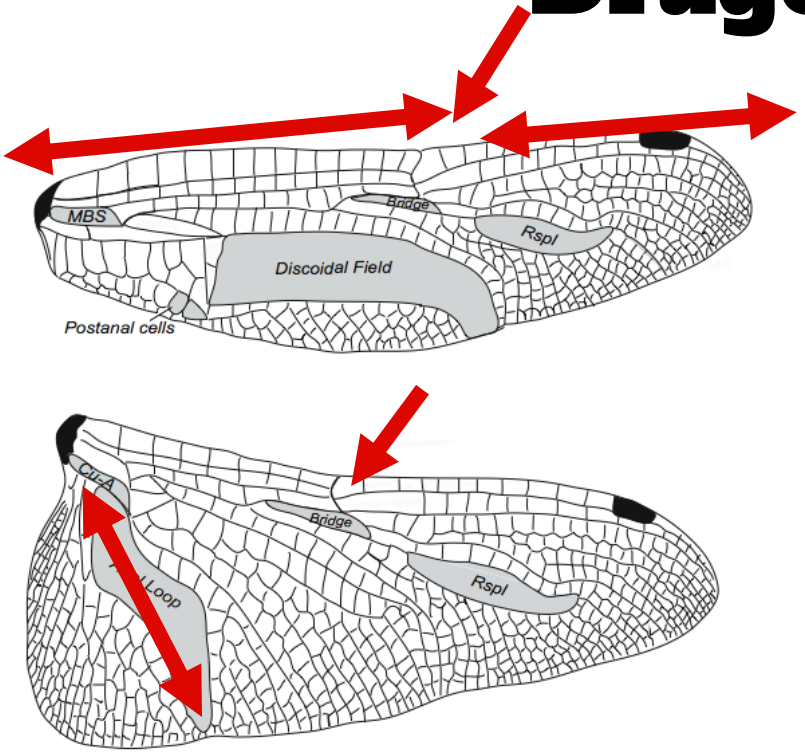
Wing venation affects wing camber, lift, and ultimately flight patterns

Dragonfly flight



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

Dragonfly flight



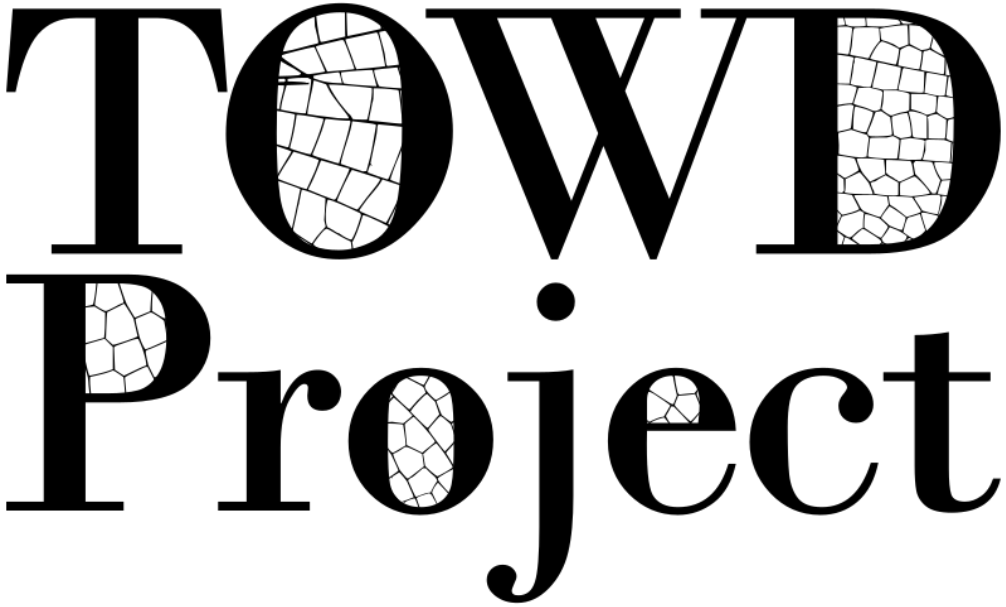
Certain wing traits are correlated with specific flight styles

Dragonfly collections: invaluable

Collection name	# spp.	#specimens
Florida State Collection	2728	150K
Ware Lab Collection	373	4K
Smithsonian Collection	253	
M.L.		

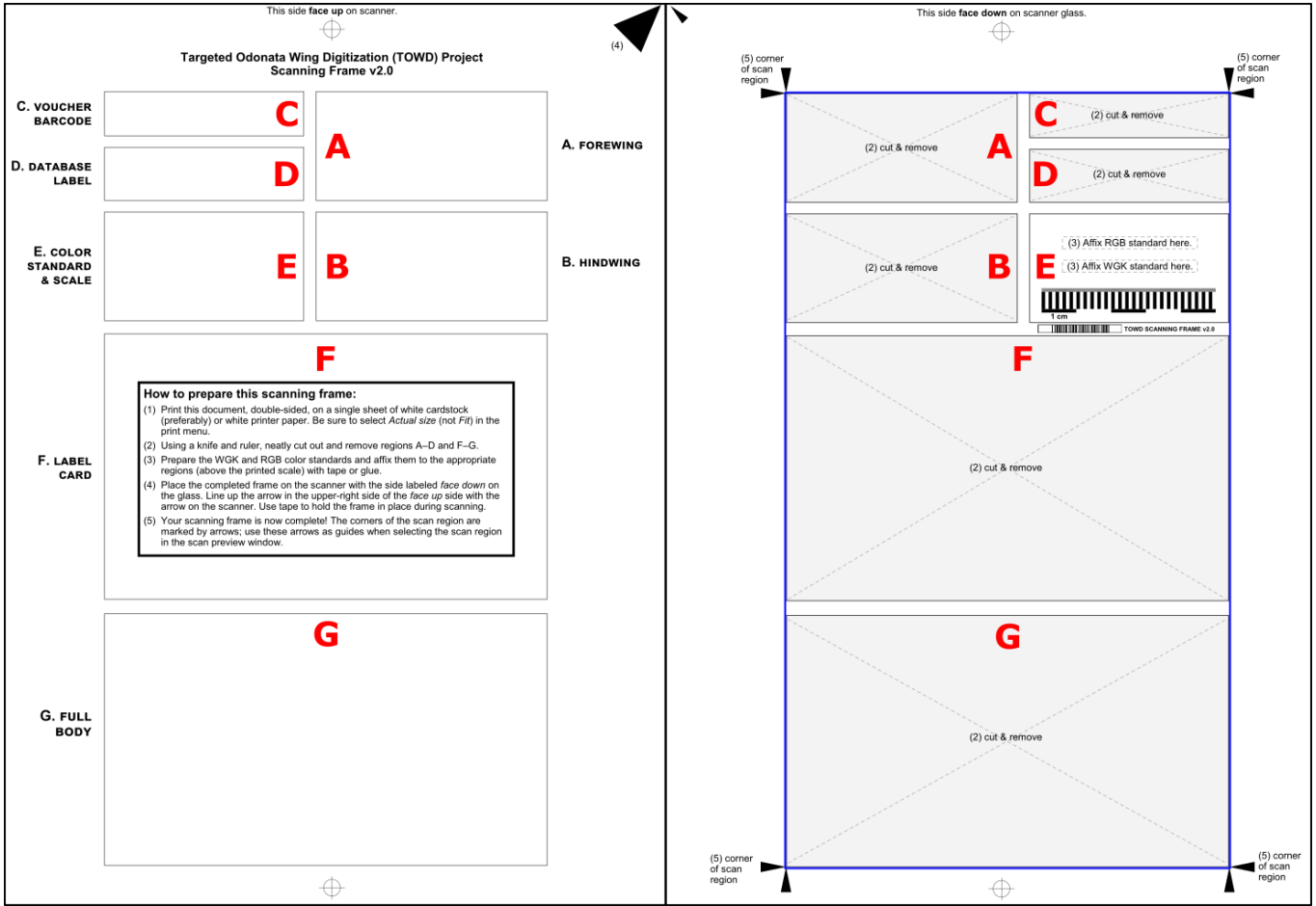
Dragonfly collections: invaluable treasures

Harness information in collections

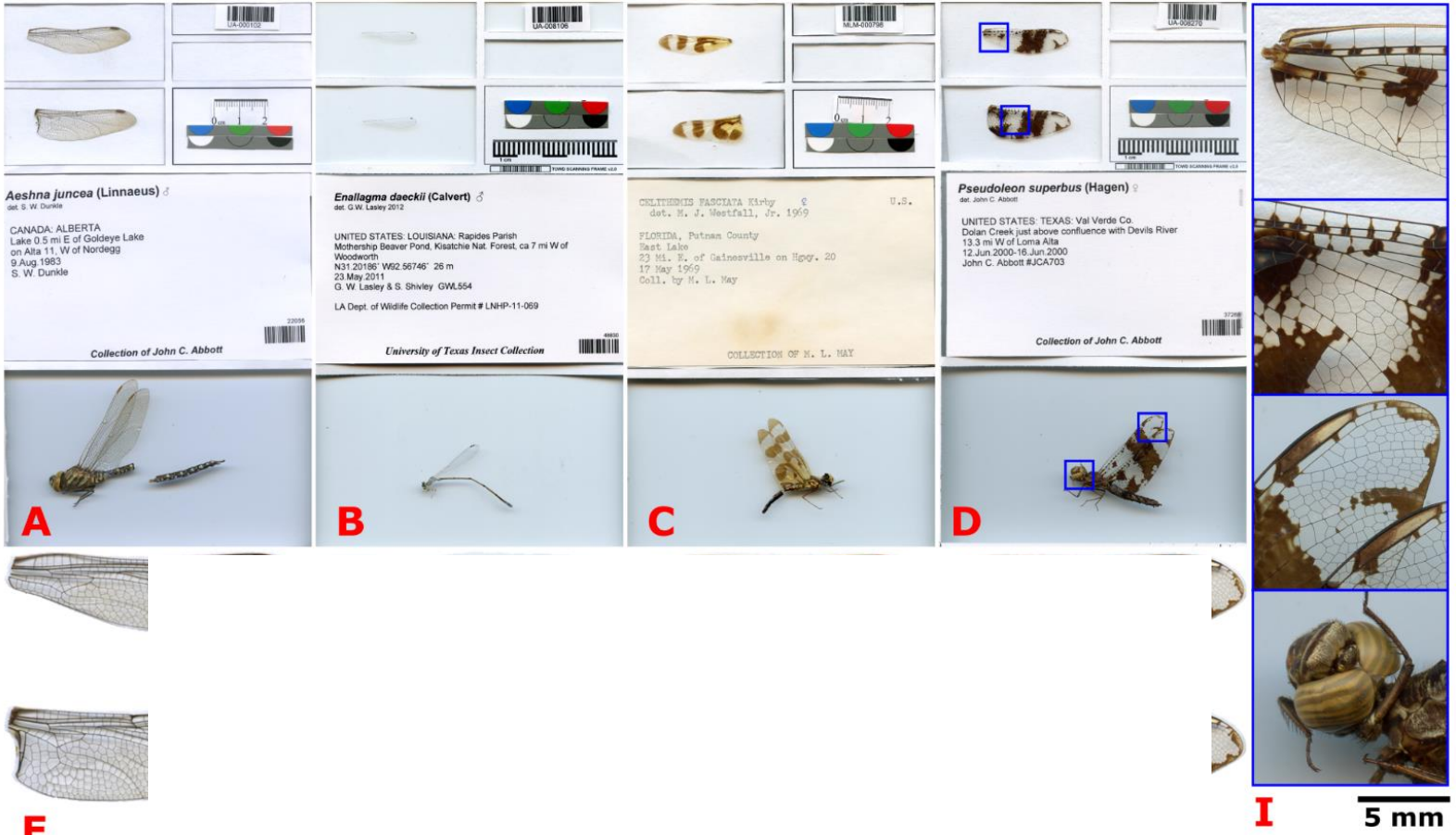


Targeted Odonata Wing Digitization (TOWD) project

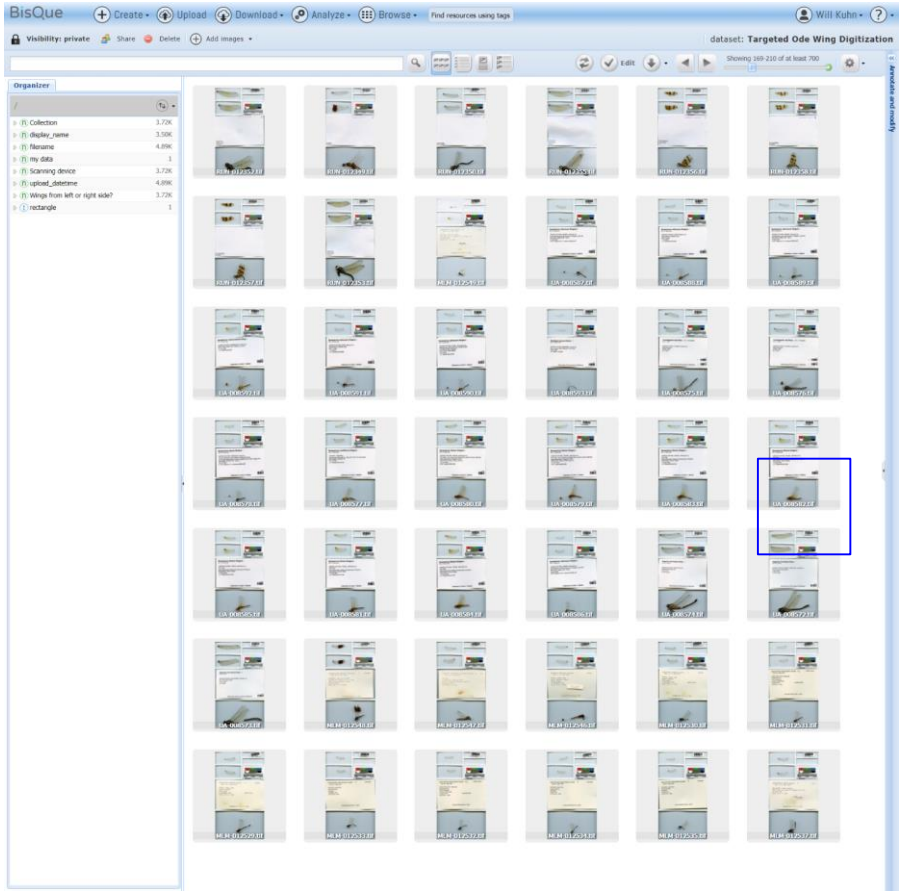
TOWD project scanning protocol

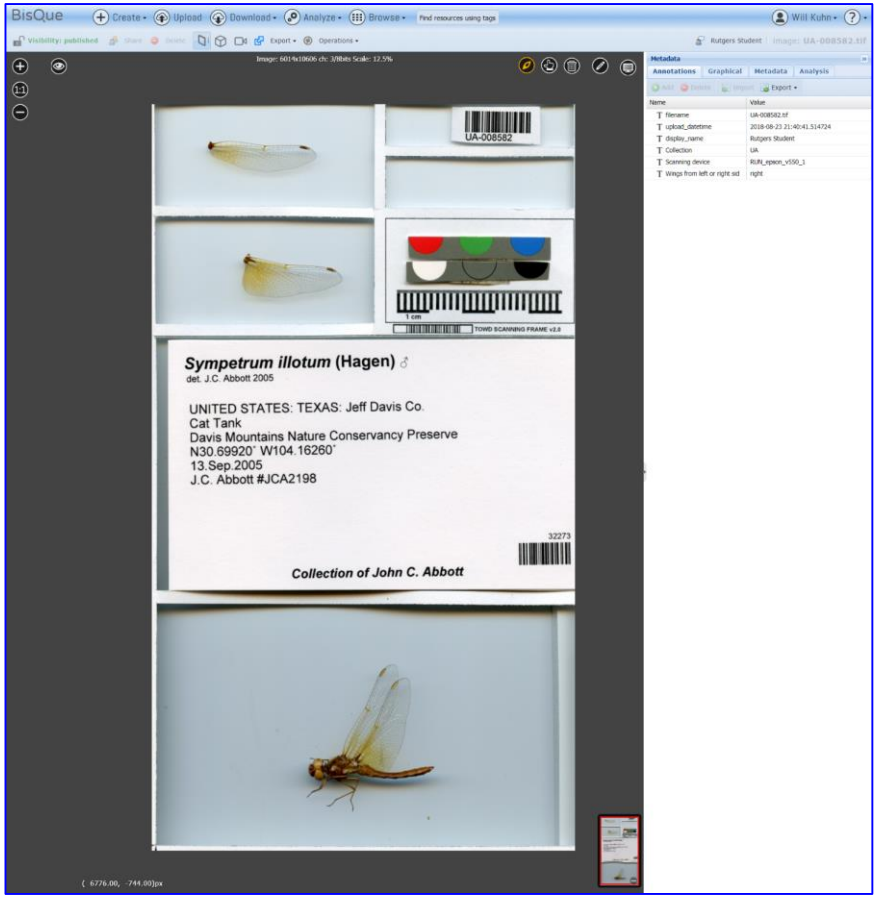


TOWD project scanning protocol



TOWD project

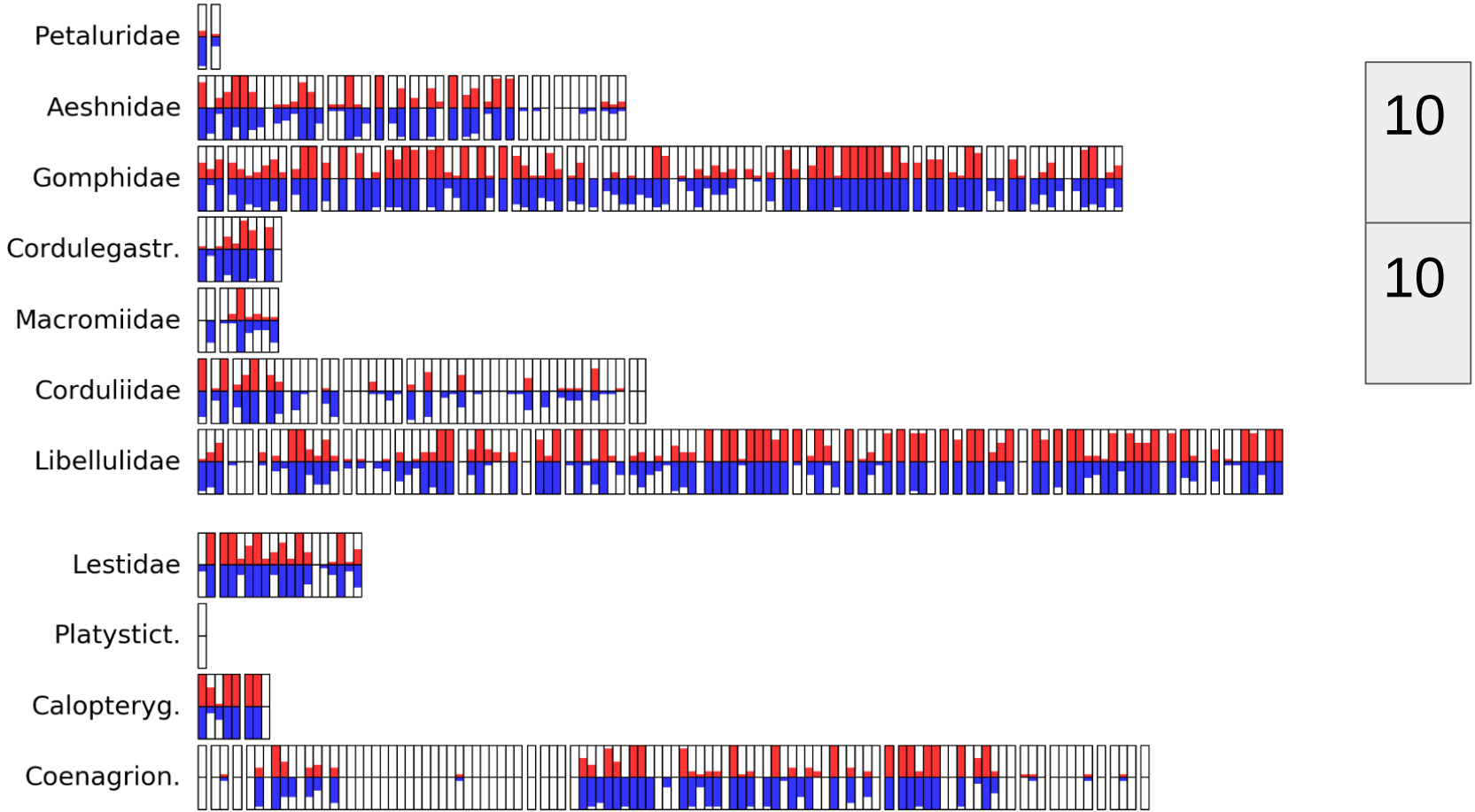




TOWD project

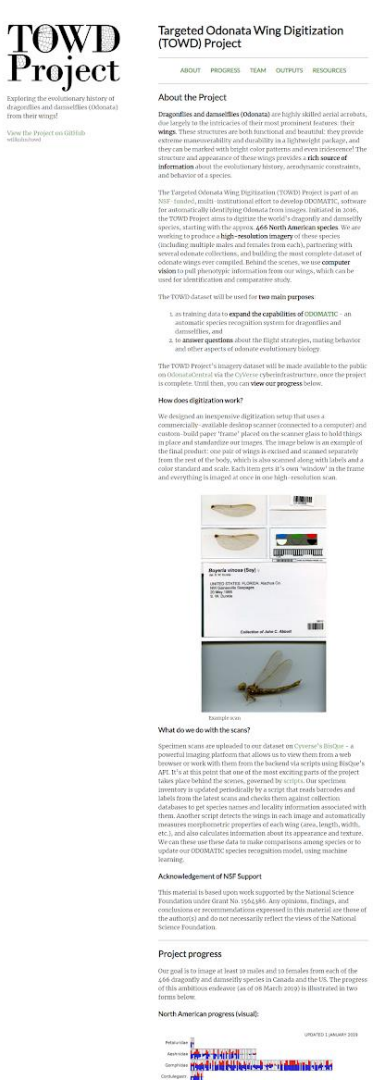
TOWD project

UPDATED 8 MARCH 2019



TOWD project

More information at:
https://willkuhn.github.io/towd/



TOWD Project

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

View the Project on GitHub
willkuhnwd

Targeted Odonata Wing Digitization (TOWD) Project

ABOUT PROGRESS TEAM OUTPUTS RESOURCES

About the Project

Dragonflies and damselflies (Odonata) are highly skilled aerial acrobats, due largely to the intricacies of their most prominent features: their **wings.** These structures are both functional and beautiful: they provide extreme maneuverability and durability 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 automatically identifying Odonata from images. Initiated in 2016, 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 imagery** of these species (including multiple males and females from each), partnering with several odonate collections, and building the most complete dataset of odonate 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 on OdonataCentral 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 commercially-available desktop scanner (connected to a computer) and custom-build paper "frame" 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 excised and scanned separately from the rest of the body, which is also scanned along with labels and a color standard and scale. Each item gets it's own 'window' in the frame and everything is imaged at once in one high-resolution scan.

Example scan

What do we do with the scans?

Specimen scans are uploaded to our dataset on CyVerse's BisQue - a powerful imaging platform that allows us to view them from a web browser or work with them from the backend via scripts using BisQue'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 collection databases 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 these use these data to make comparisons among species or 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. 1564386. 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 10 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 2019) is illustrated in two forms below.

North American progress (visual):

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

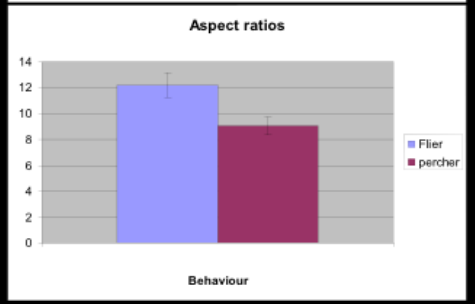
- Measurement of aerodynamic efficiency of a wing
- Ratio of wing span to mean chord of wing, with variations
- Formula 1: $AR = \frac{(wing\ length)^2}{(wing\ area)}$
- Formula 2: $AR = \frac{(outer\ length)}{(outer\ width)}$
- Formula 3: $AR = \frac{(outer\ length) * (outer\ width)}{(wing\ area)}$

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

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

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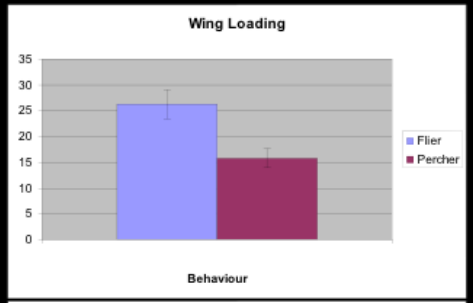

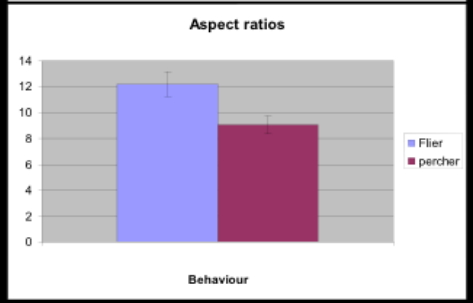

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Are there differences in aspect ratios?

Perchers have significantly lower aspect ratios than fliers.

The *p*-value is .001819.

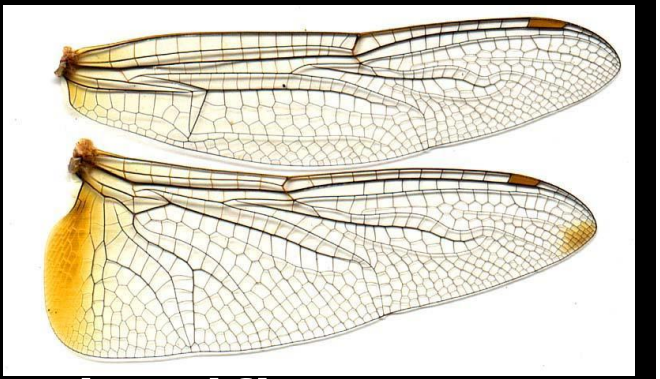
The result is significant at $p < .05$.

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

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

Tandem Oviposition may affect wing loading

Tandem Oviposition, flight style may affect wing loading

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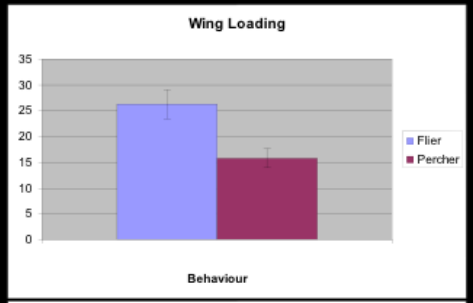

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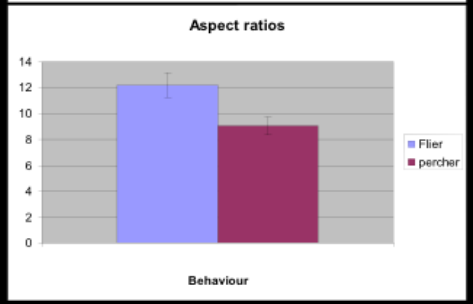

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High Aspect ratio: longer narrower wings
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More data, across families, no significant difference between perchers and fliers in terms of wing loading, p=0.51

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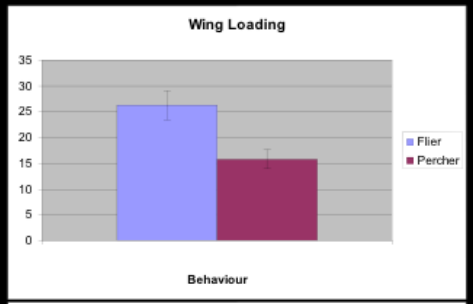

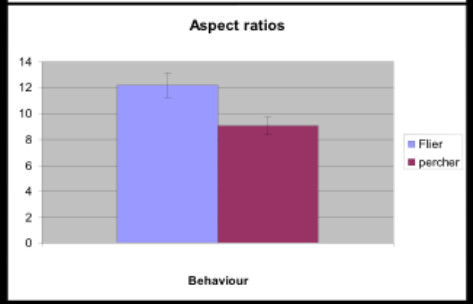

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Tandem versus *solo* ovipositing species have significantly different wing loading values, p=0.0022

What else can we gather from digitized collections?

Range

Habitat choice

Phenology

Families of Anisoptera

Austropetaliidae
Aeshnidae
Petaluridae
Gomphidae
Chlorogomphidae
Cordulegastridae
Neopetaliidae
Synthemistidae
Macromiidae
Corduliidae
Libellulidae

Lotic

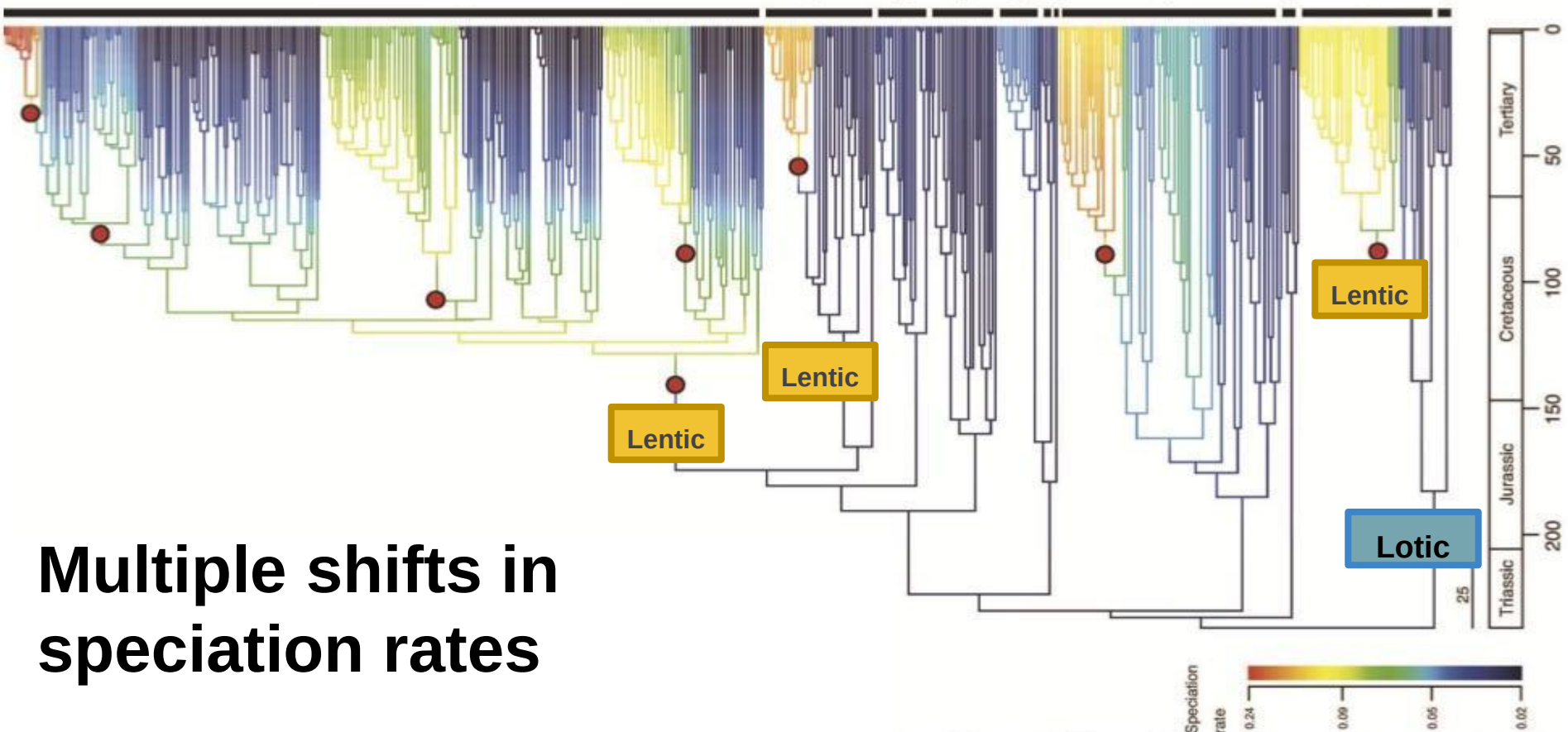
Lentic

Results

Libellulidae

Corduliidae

Aeshnidae



Multiple shifts in speciation rates

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

Acknowledgements

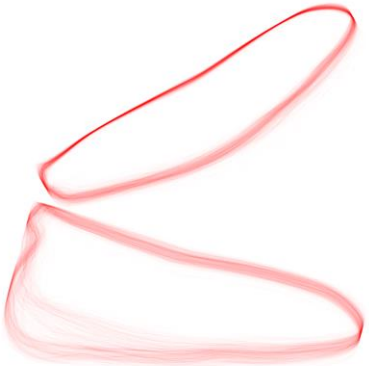
Thank you to all who shared specimens with us!

Special thanks to the following collections/collectors:

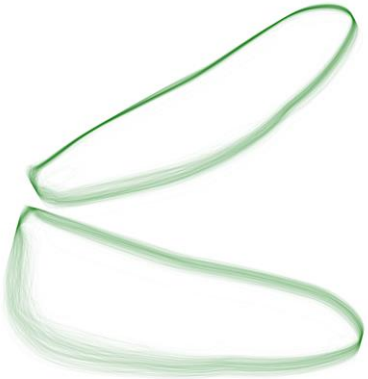
John Abbott, Christopher Beatty, Mike May, Dirk Gassmann, Rosser Garrison, Susan George, Patrick Hulick, Gwen Irons, Manpreet Kohli, Will Kuhn, Jack Kellogg, Ciara Mendoza, Stephanie Mafla Mills, Andy Rehn, Melissa Sanchez-Herrera,

Helpful images...

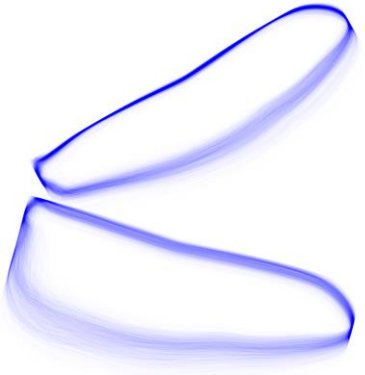
Overlays of wing outlines of libelluloid perchers, fliers and “intermediates” to show general wing shape across these groupings. Each thin line is a the wing of a single individual



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.