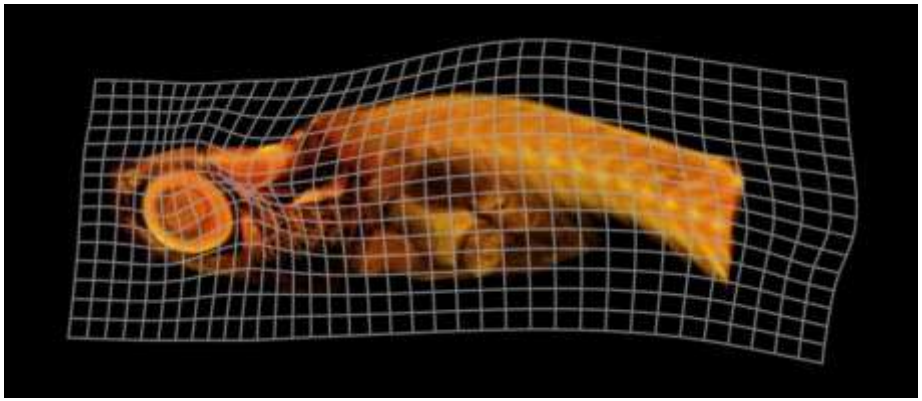
MORPHOMETRICS FOR EVODEVO

Studying developmental variation with geometric morphometric image analysis



Christine Mayer

Brian Metscher, Gerd B. Müller, Philipp Mitteröcker

INTRODUCTION

ONTOGENETIC DEVELOPMENT

change of shape in developing embryos

quantitative change of existing features

emergence of novel structures and tissue properties

qualitative change

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➡ How to jointly quantify both of these processes?

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- How to jointly quantify both of these processes?
- Why do we need quantification?
  - variation of development in a population
  - connect developmental biology to evolutionary theory

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quantitative change of existing features

emergence of novel structures and tissue properties

qualitative change

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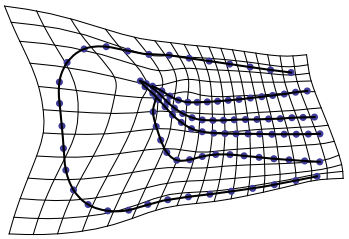
➡ Why do we need quantification?

variation of development in a population

connect developmental biology to evolutionary theory

MORPHOMETRICS



GEOMETRIC MORPHOMETRICS

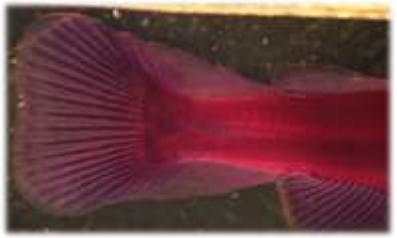
powerful tools to measure organismal form

analysis of shape change

Limitations

- specification of homologous traits (landmarks)
  (e.g., Bookstein 1991)
- all traits have to be present and measurable in all individuals
- not possible to deal with the emergence of novel traits

VOXEL-BASED MORPHOMETRY



suite of image analysis techniques in biomedicine
(e.g., Ashburner & Friston 2000)

- analysis of tissue properties
- “automatic” image registration based on all voxels
- statistical analysis of resulting gray values of voxels

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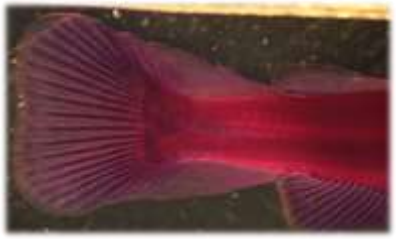


suite of image analysis techniques in biomedicine
(e.g., Ashburner & Friston 2000)

- analysis of tissue properties
- "automatic" image registration based on all voxels
- statistical analysis of resulting gray values of voxels

Limitations

- no prior specification of homologous structures
- imperfect registration leads to strong signals at the edges of structures (Bookstein 2001)
- averages & variance-covariance patterns may not be biologically interpretable

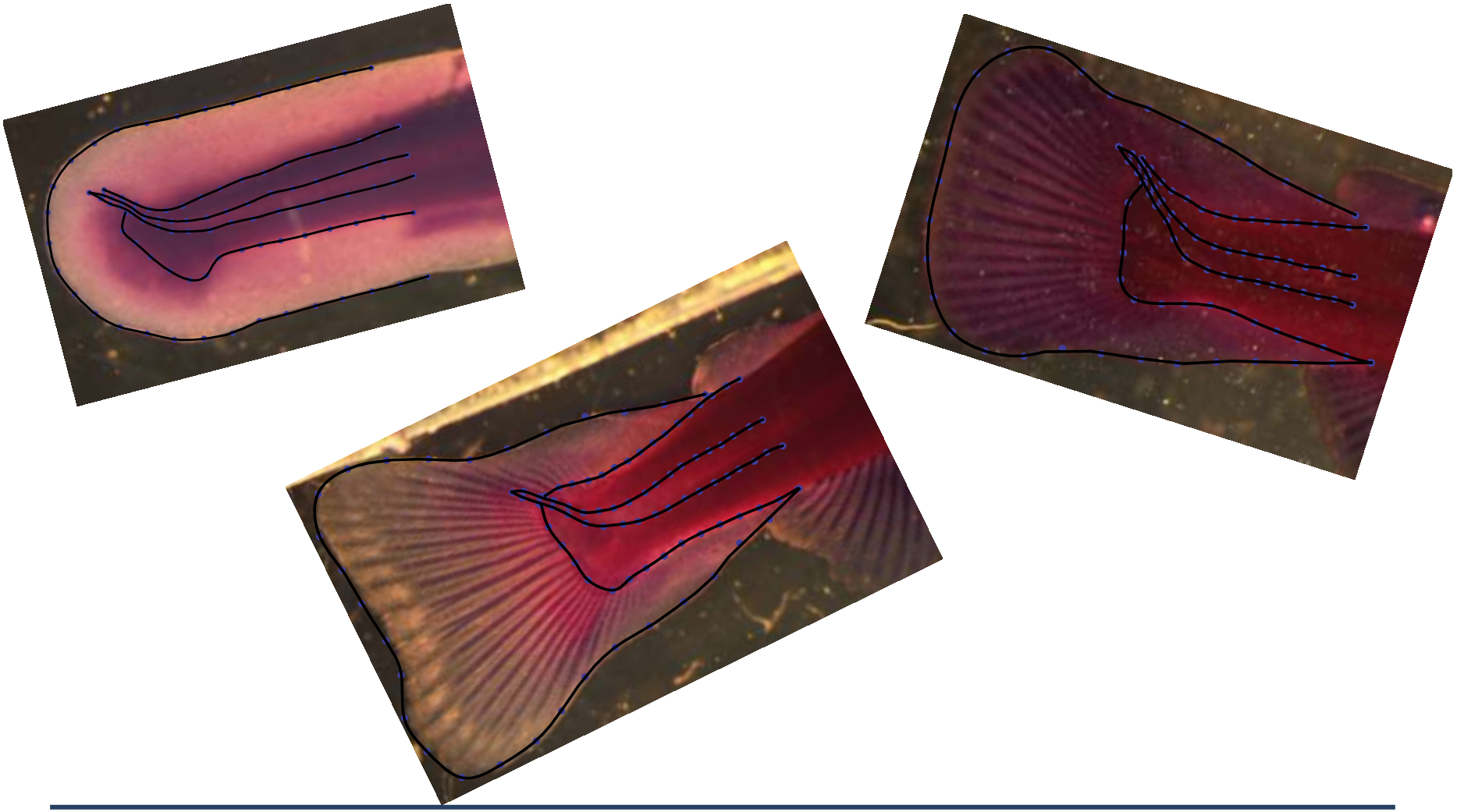
GEOMETRIC MORPHOMETRIC IMAGE ANALYSIS

combining modern morphometrics & image analysis

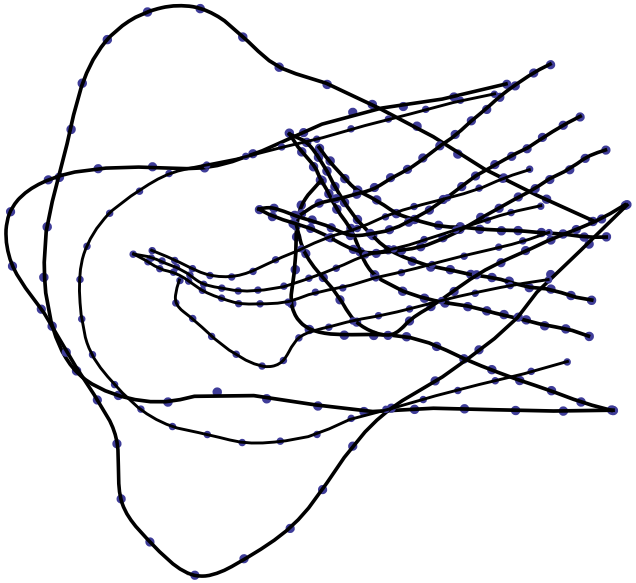
- parametrization of homologous structures by Procrustes shape coordinates
  (e.g., Rohlf & Slice 1990)

- non-affine registration (using thin-plate spline interpolation) of the 2D or 3D images based on the measured landmarks

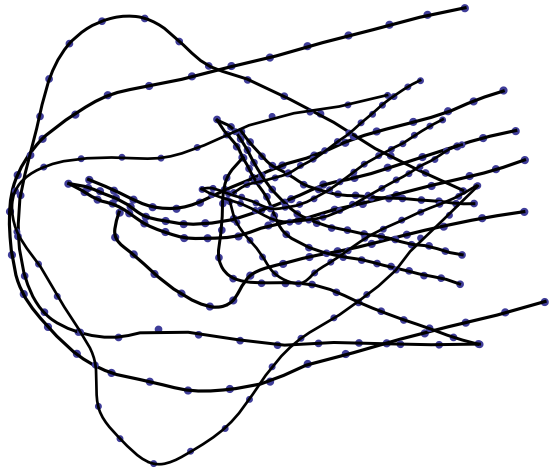
GEOMETRIC MORPHOMETRIC IMAGE ANALYSIS



GEOMETRIC MORPHOMETRIC IMAGE ANALYSIS



GEOMETRIC MORPHOMETRIC IMAGE ANALYSIS



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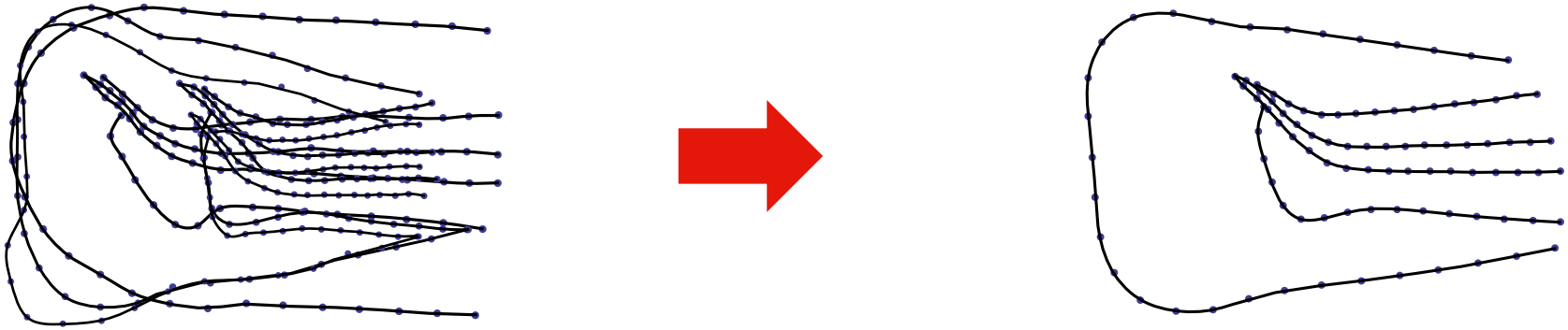

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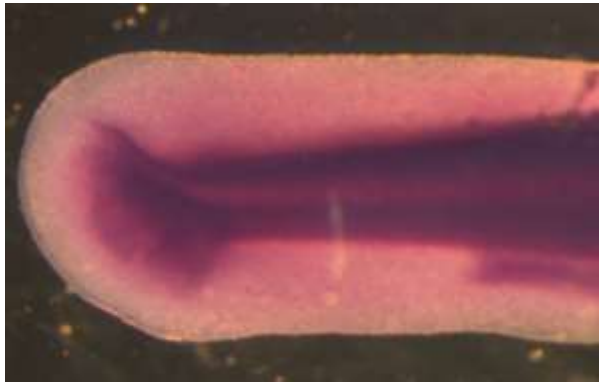
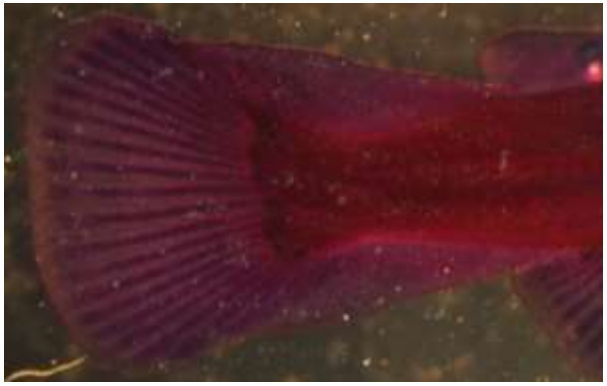
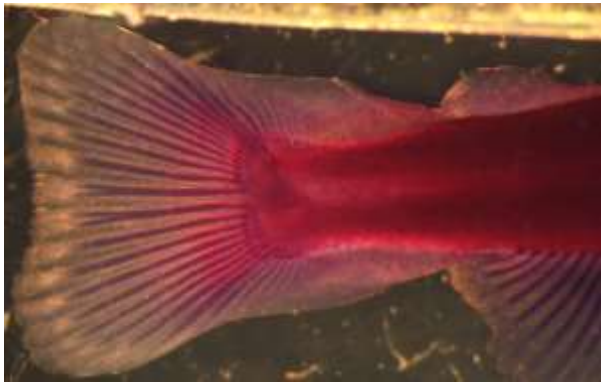

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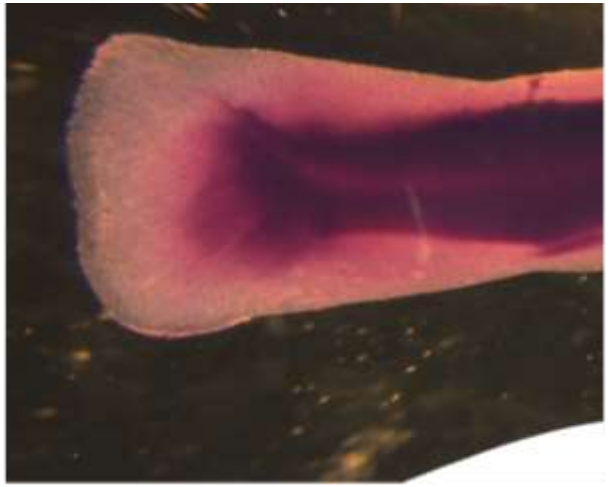
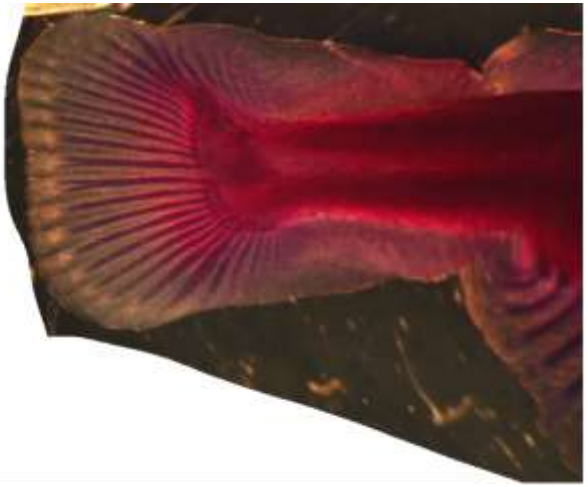
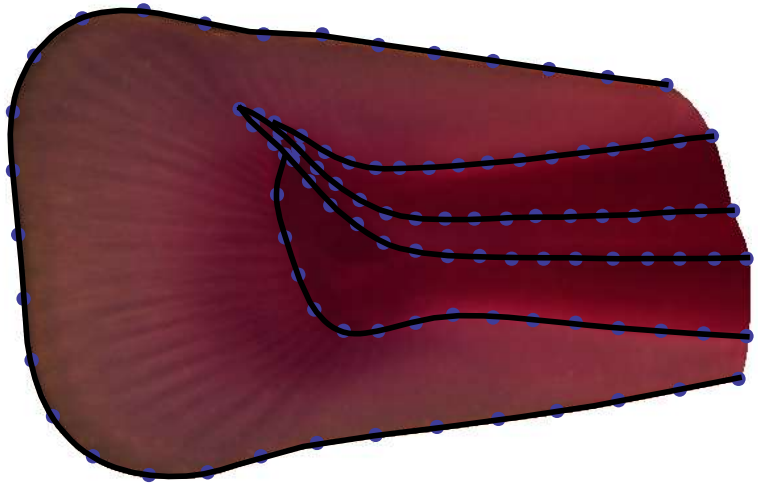




GEOMETRIC MORPHOMETRIC IMAGE ANALYSIS



GEOMETRIC MORPHOMETRIC IMAGE ANALYSIS

- form of homologous structures is parameterized by Procrustes shape coordinates & centroid size

- tissue properties are parameterized by registered images

GEOMETRIC MORPHOMETRIC IMAGE ANALYSIS

- form of homologous structures is parameterized by Procrustes shape coordinates & centroid size

- tissue properties are parameterized by registered images

two different mathematical spaces

Procrustes form space

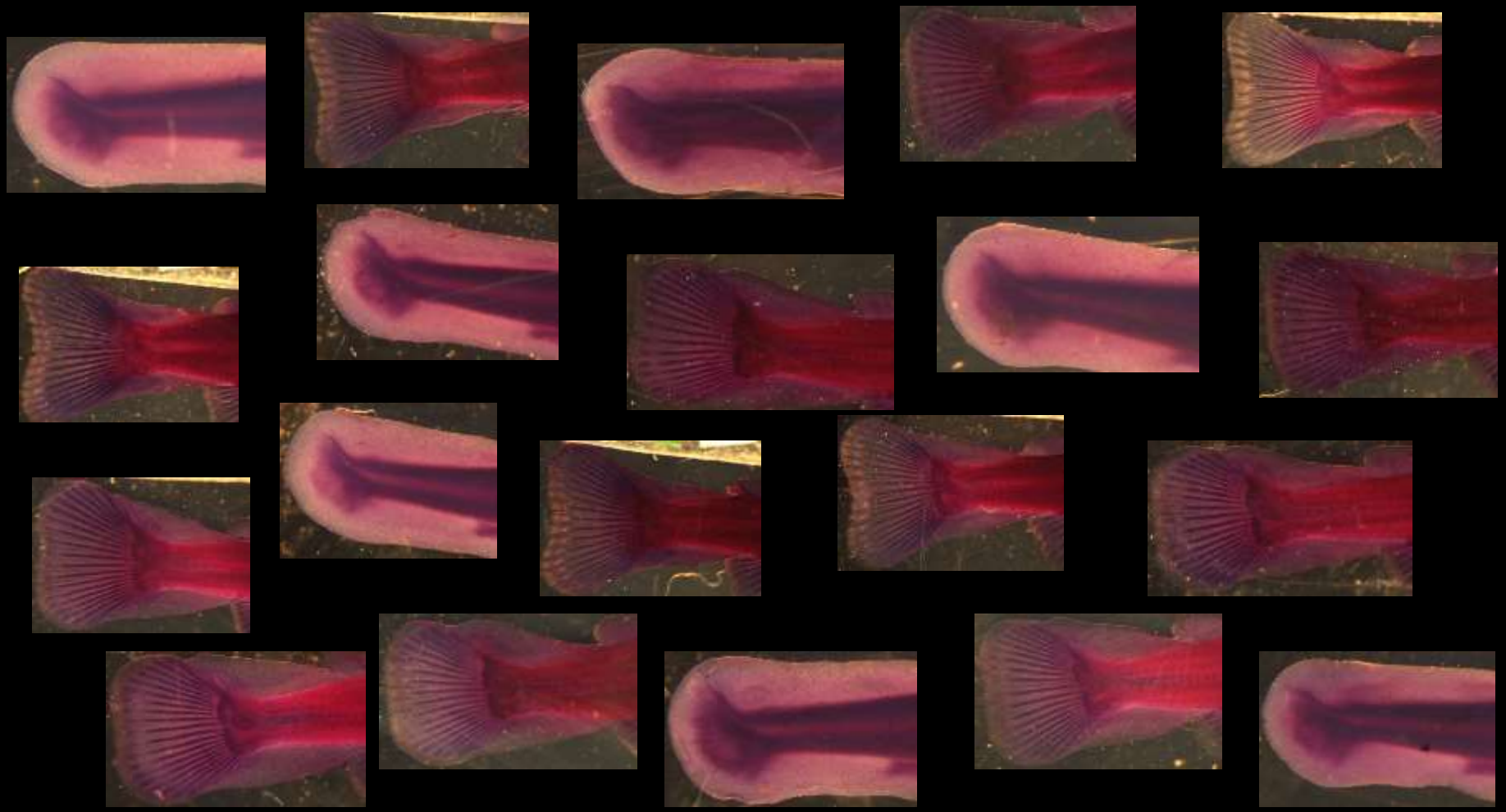
Image space

GEOMETRIC MORPHOMETRIC IMAGE ANALYSIS

ADVANTAGES

- information on homology is maintained
- means and variances can be computed
- observe spatial patterns of tissue densities
- observe emergence of novel structures
- visualization of statistical results

GEOMETRIC MORPHOMETRIC IMAGE ANALYSIS



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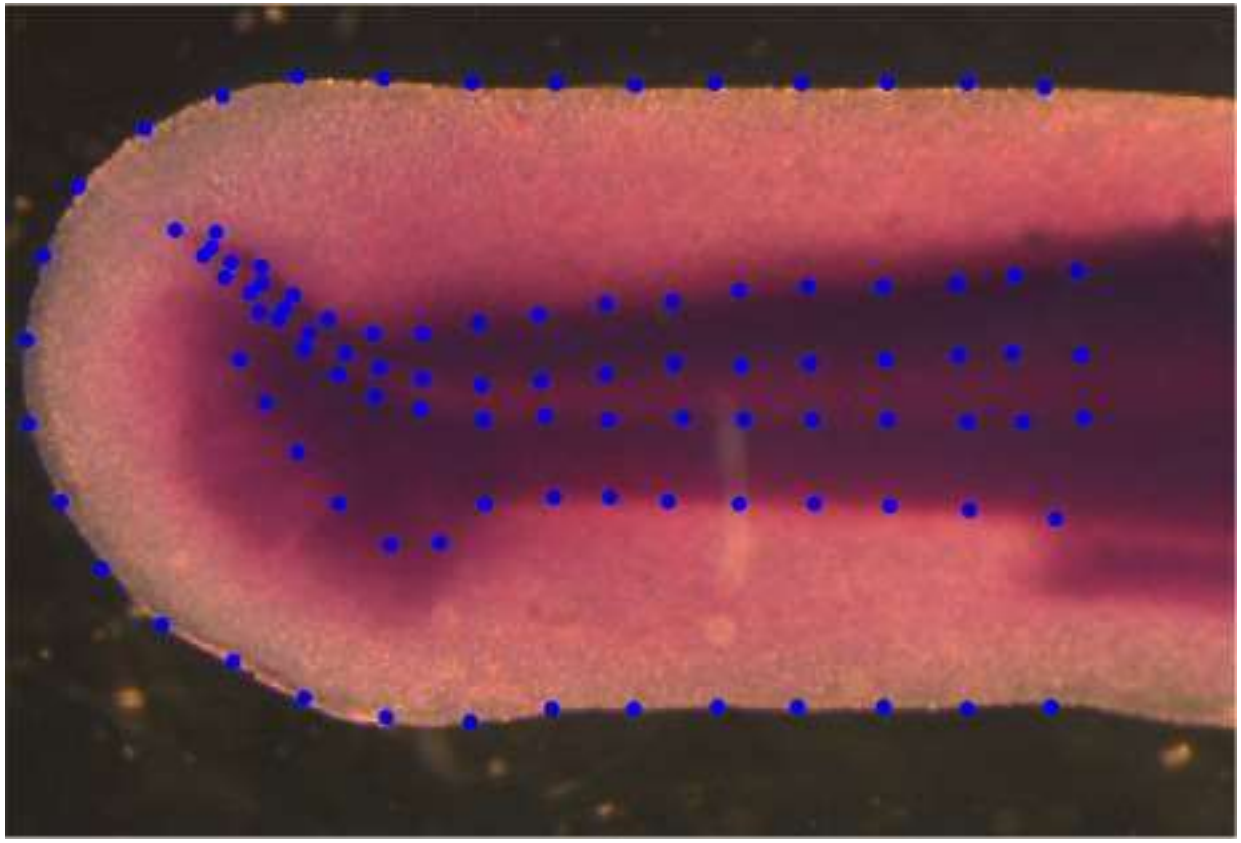
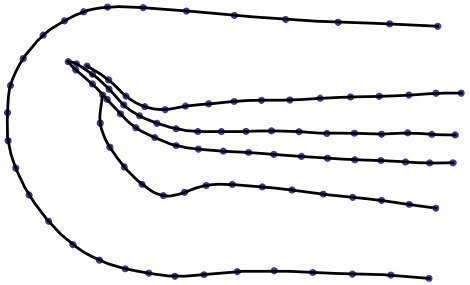


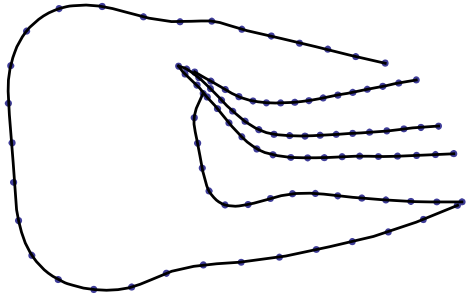
GEOMETRIC MORPHOMETRIC IMAGE ANALYSIS

Shape

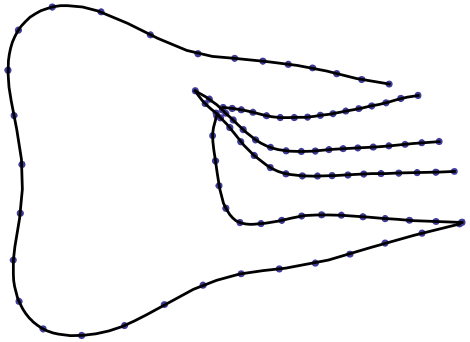
O. mykiss
21 dpf



O. mykiss
40 dpf



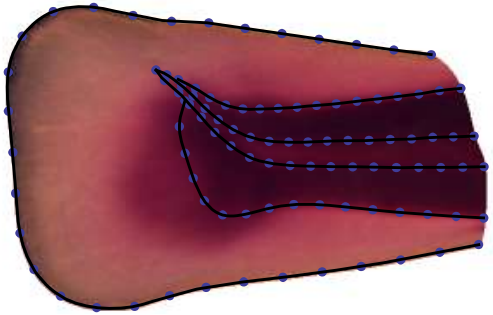
O. mykiss
56 dpf



GEOMETRIC MORPHOMETRIC IMAGE ANALYSIS

Tissue density

O. mykiss
21 dpf



O. mykiss
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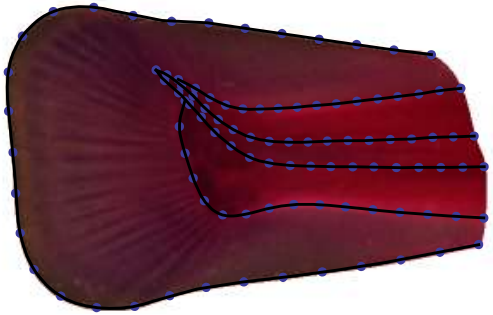

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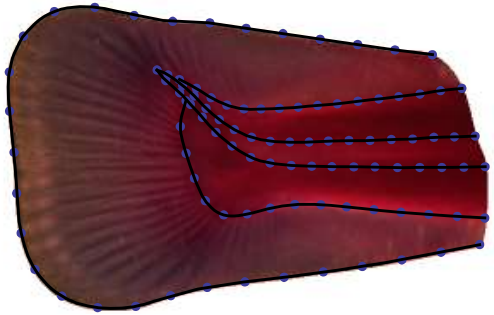
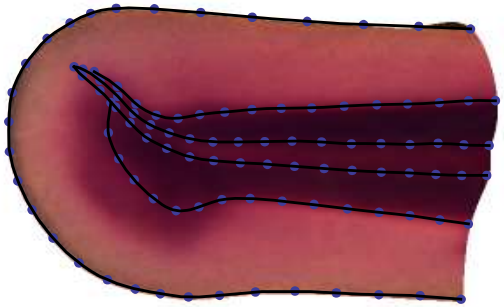


GEOMETRIC MORPHOMETRIC IMAGE ANALYSIS

Shape **and** Tissue density

O. mykiss
21 dpf



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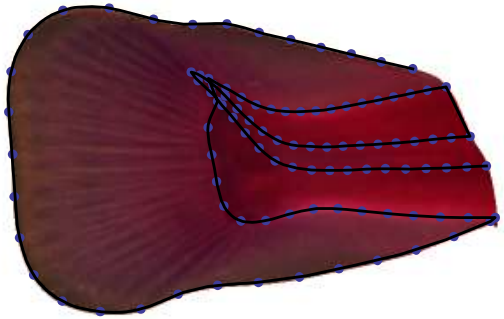

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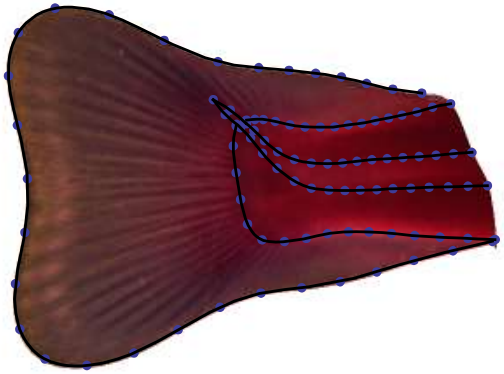
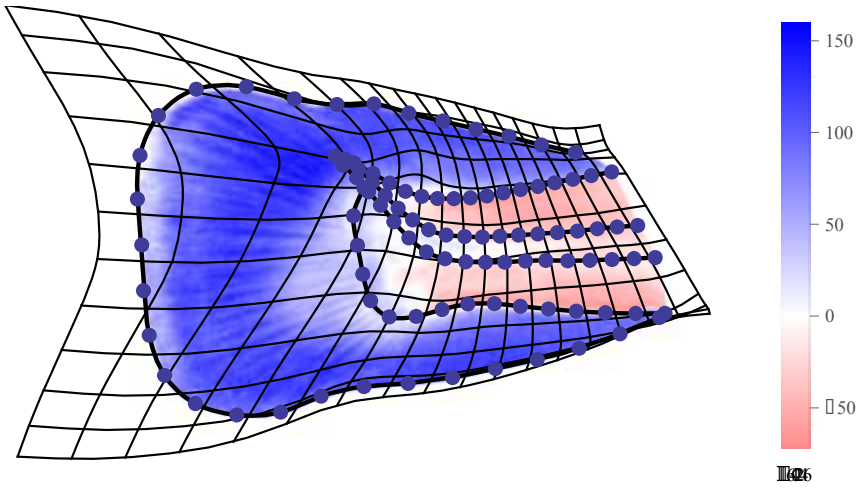


GEOMETRIC MORPHOMETRIC IMAGE ANALYSIS

Change of shape and tissue density between

21 dpf → 40 dpf



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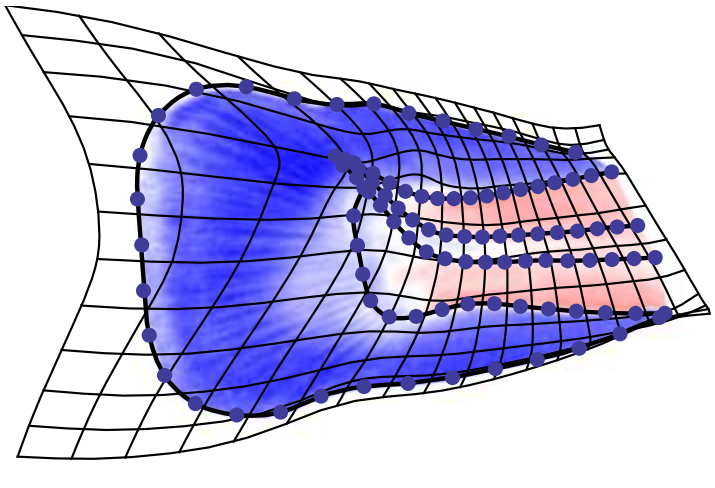
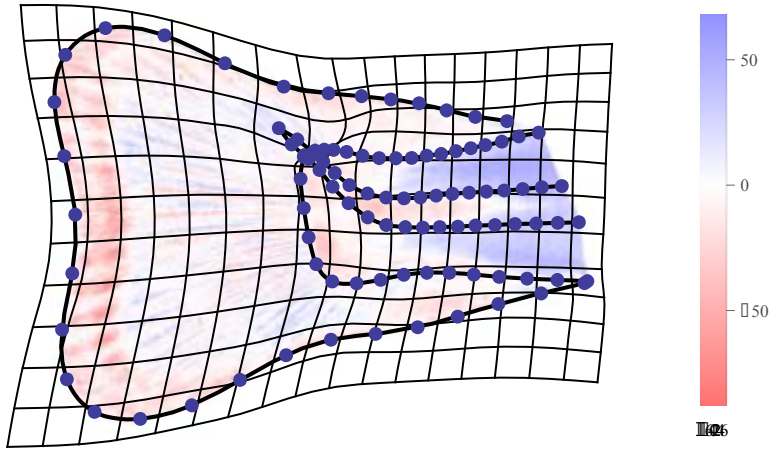


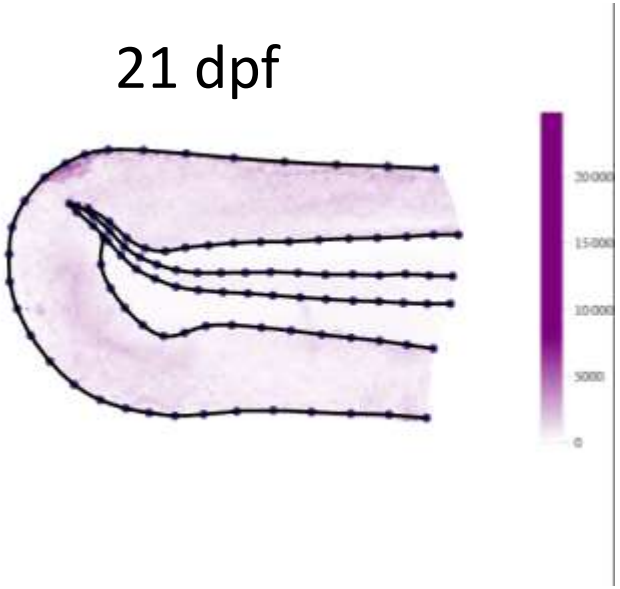
40 dpf → 56 dpf



GEOMETRIC MORPHOMETRIC IMAGE ANALYSIS

Variances of tissue density

21 dpf



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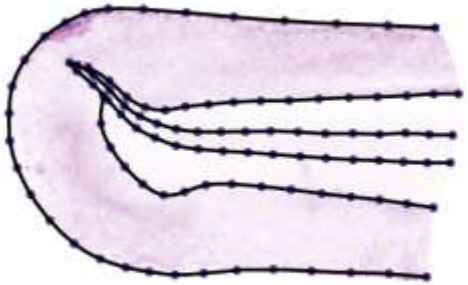
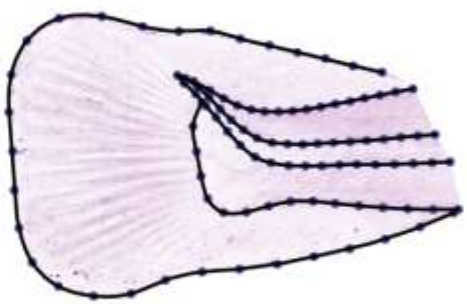
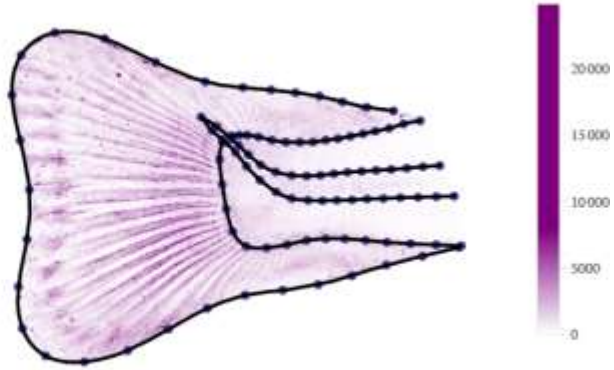
21 dpf



40 dpf

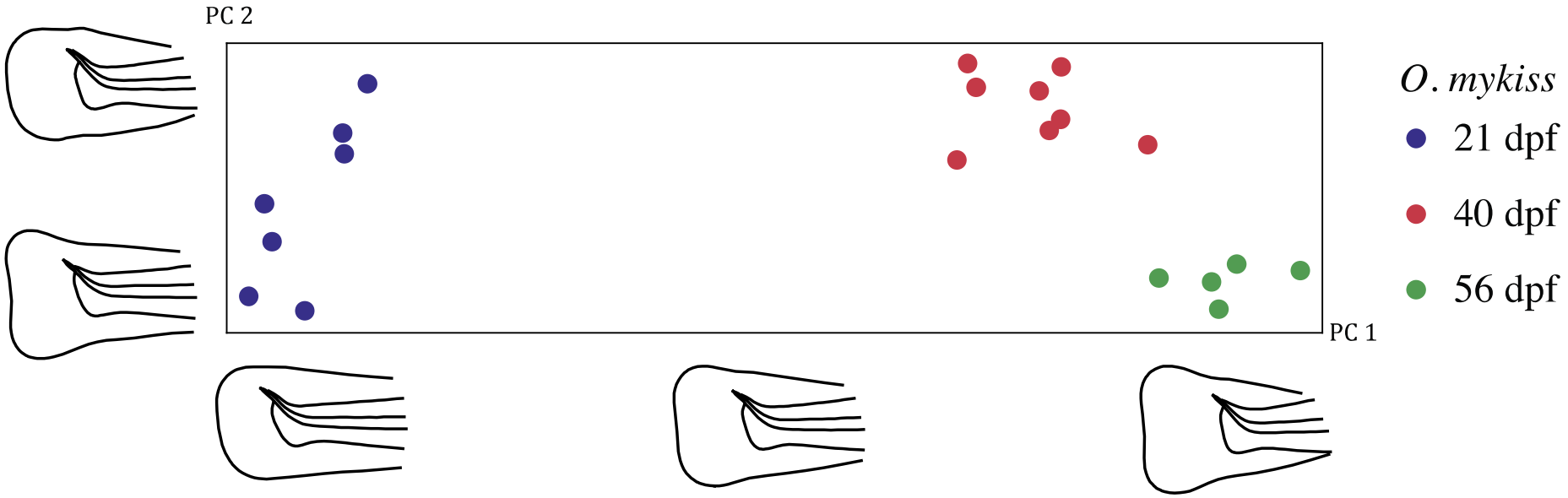


56 dpf



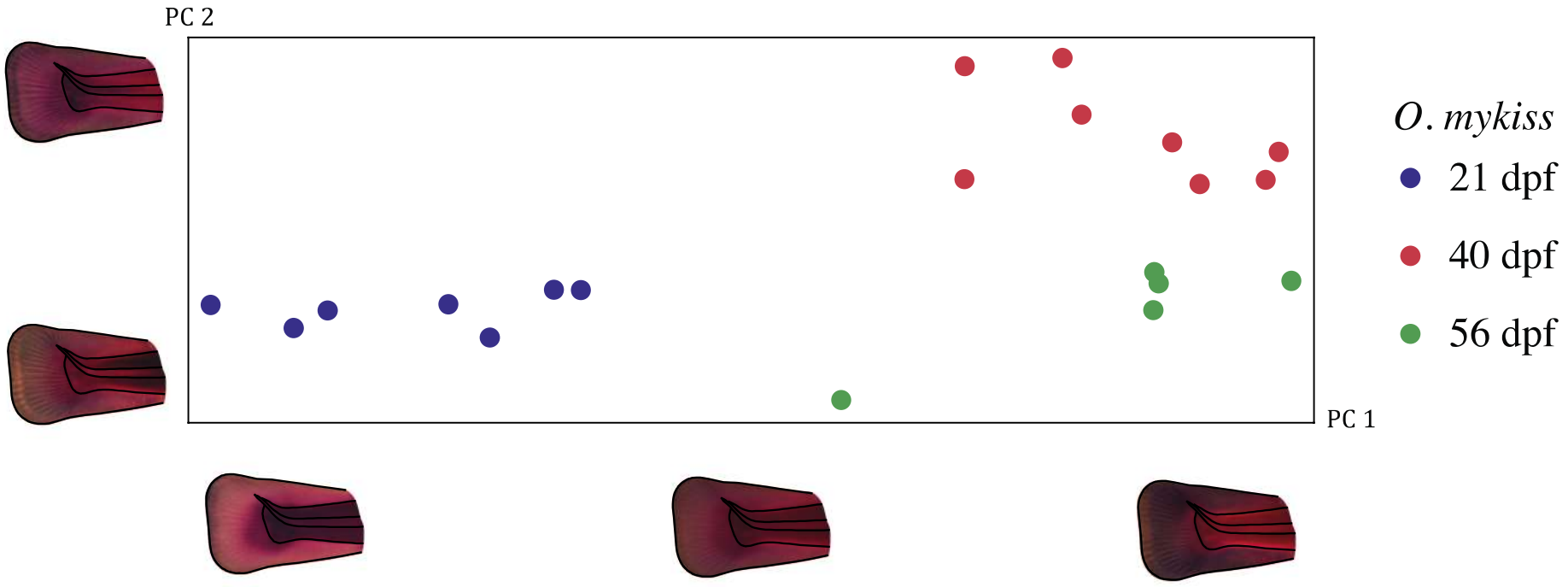
GEOMETRIC MORPHOMETRIC IMAGE ANALYSIS

PCA of fin shape



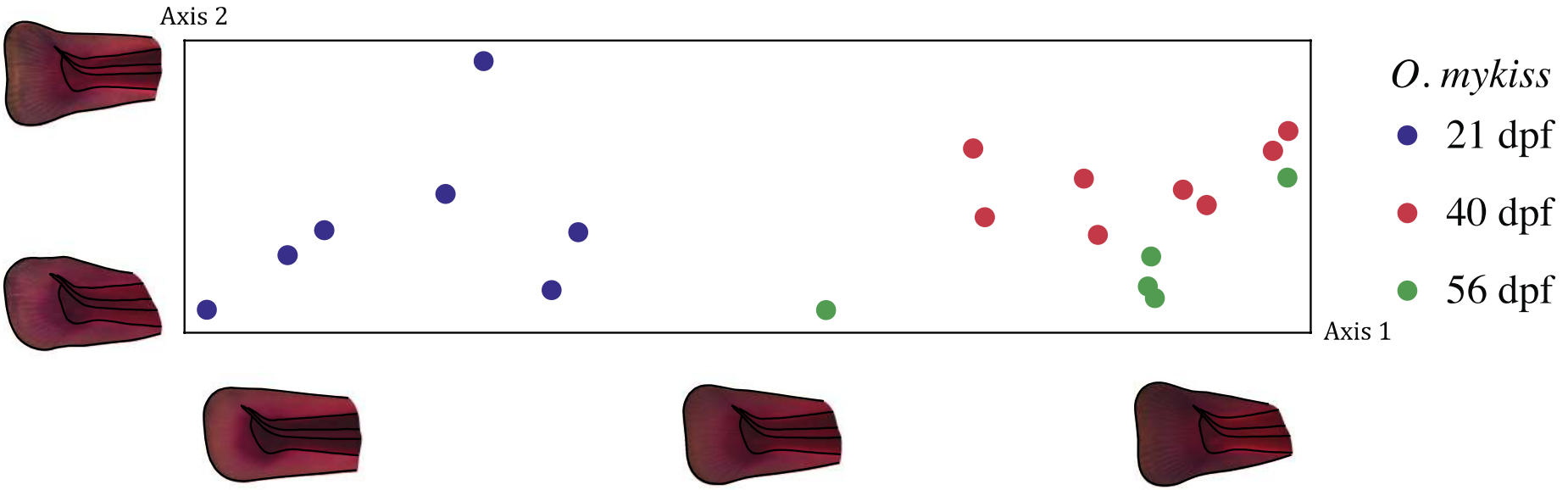
GEOMETRIC MORPHOMETRIC IMAGE ANALYSIS

PCA of tissue density



GEOMETRIC MORPHOMETRIC IMAGE ANALYSIS

Ordination of fin shape **and** tissue density



QUANTIFYING DEVELOPMENTAL VARIATION OF ZEBRAFISH

2D images of living anesthetized zebrafish

fin morphology

QUANTIFYING DEVELOPMENTAL VARIATION OF ZEBRAFISH

2D images of living anesthetized zebrafish

fin morphology

3D MicroCT images of fixed and stained zebrafish

fin and cranium

QUANTIFYING DEVELOPMENTAL VARIATION OF ZEBRAFISH

2D images of living anesthetized zebrafish

fin morphology

3D MicroCT images of fixed and stained zebrafish

fin and cranium

at least three developmental stages

THANK YOU FOR YOUR ATTENTION!

ACKNOWLEDGEMENTS

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