Geometric morphometrics as a useful tool for visualising and analysing deformities in fish

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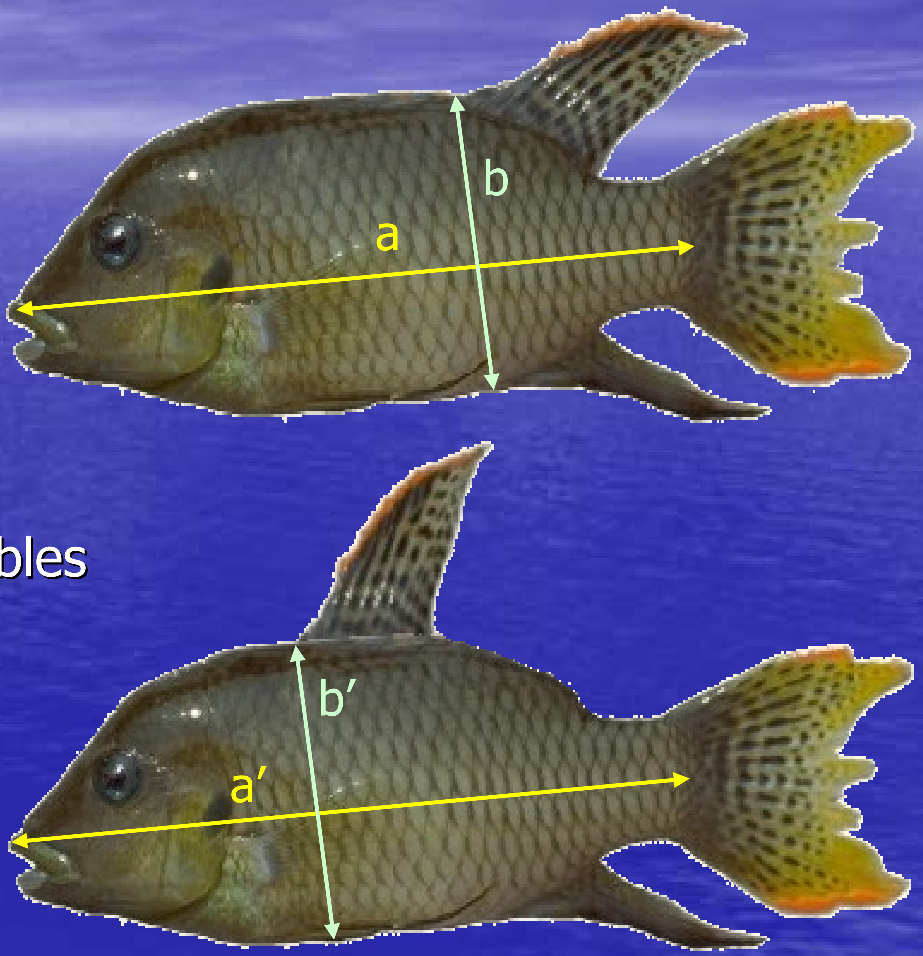
Why "morphometrics"?

- Measuring biological variation
  - growth - development
  - interspecific variation – species-specific features
  - intraspecific variation – phenotypic plasticity
  - deformations

Traditional "morphometrics"

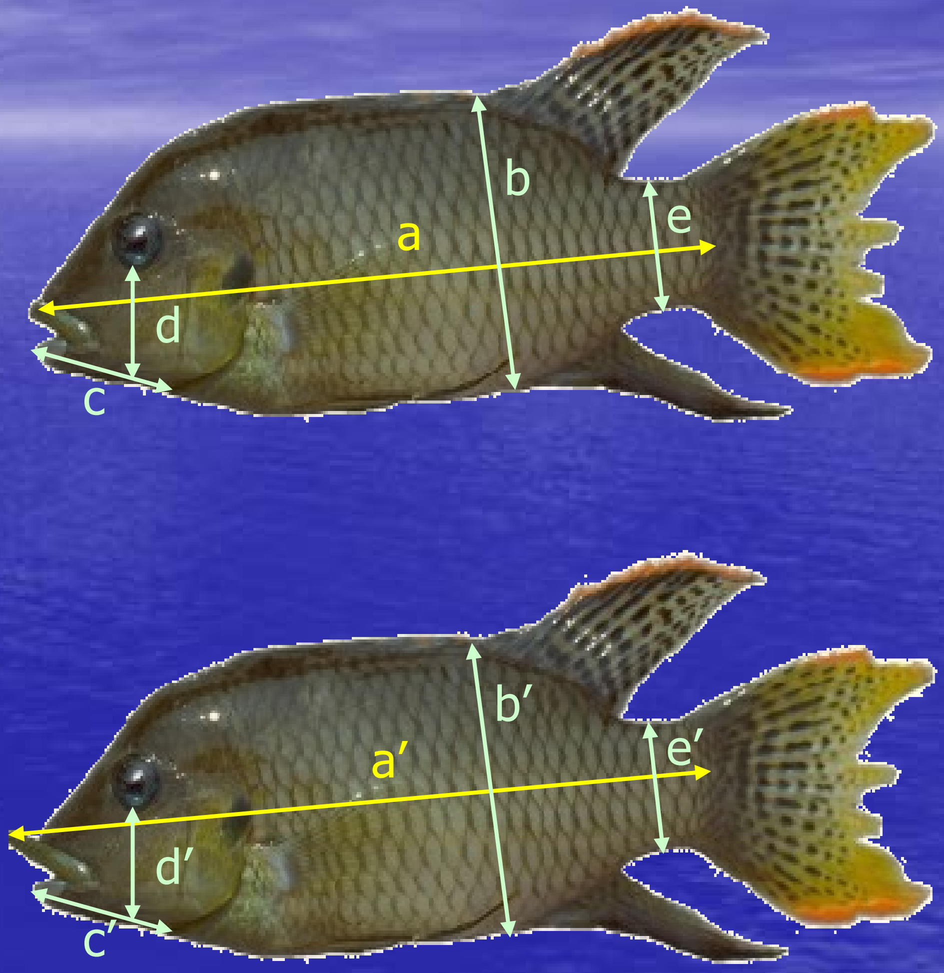
- Length measurements
  - advantages
    - easy to measure
    - easy to analyse
      - PCA, DFA, ...
  - disadvantages
    - size variables, not shape variables
    - unsufficient model of shape



a=a′
b=b′
→ 'shapes' are equal

Traditional "morphometrics"

- Length ratios
  - advantages
    - standardised, size removal
  - disadvantages
    - reduces variation
    - size removal incomplete
      - always dependent of size
    - size removal erroneous



a≠a′ = standard length

b=b′ b/a ≠b′/a′

c=c′ c/a ≠c′/a′

d=d′ d/a ≠d′/a′ → 'shapes' are completely different

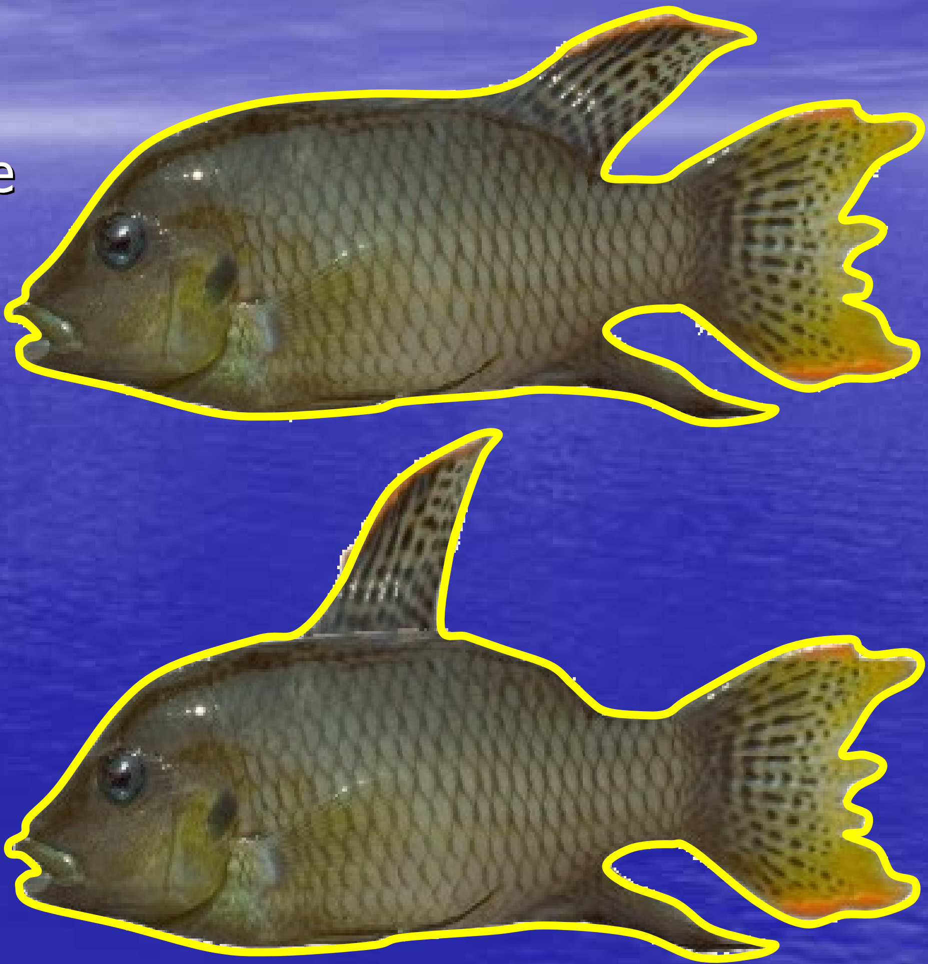
e=e′ e/a ≠e′/a′

Solution to the problems?

Geometric Morphometrics

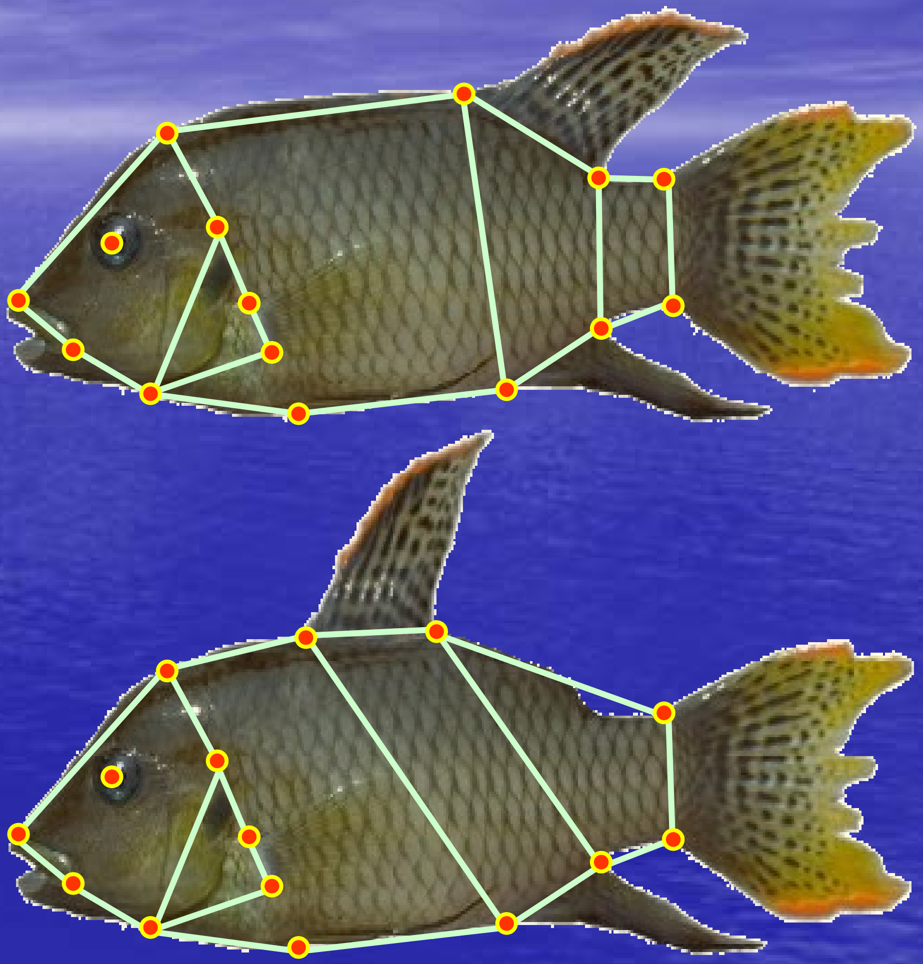
Data types

- Outlines
  - advantages
    - very good model of true shape
      - especially rounded shapes
    - mathematical model
      - shape parameters
      - statistics allowed
        - PCA, DFA, ...
  - disadvantages
    - not good for certain shapes
      - shape changes within the outline model
      - shapes with pointed outlines
    - no link to actual shape variation in specimens



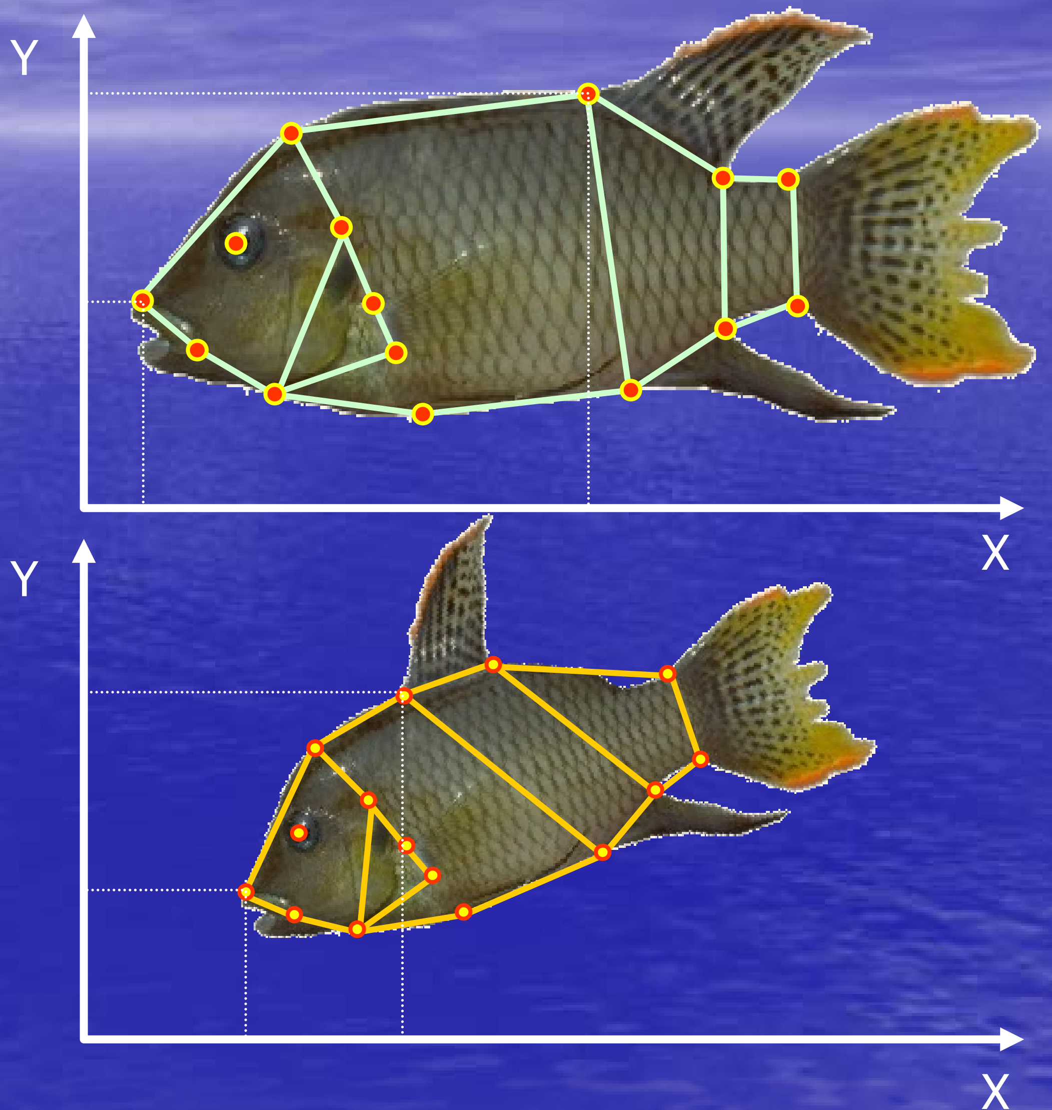
Data types

- Landmarks
  - advantages
    - good model of true shape
      - homologous points
      - also shapes within shapes
    - mathematical model
      - shape parameters
      - statistics allowed
        - PCA, DFA, ...
    - deformation grids
      - visualisation of shape differences
  - disadvantages
    - not good for certain shapes
      - rounded shapes



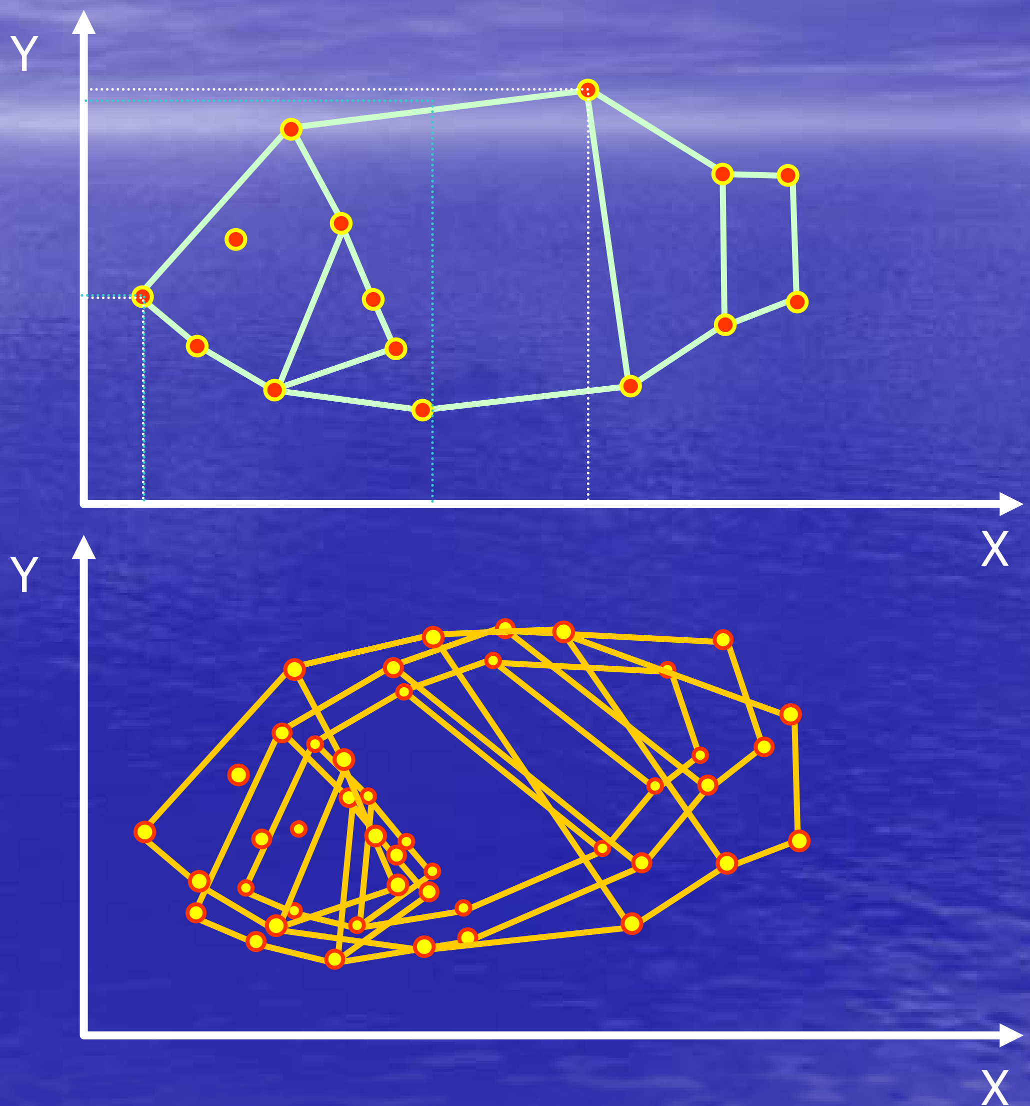
Landmark-based morphometrics

- Thin Plate Splines
  - data
    - Cartesian coordinates
      - 2D, 3D



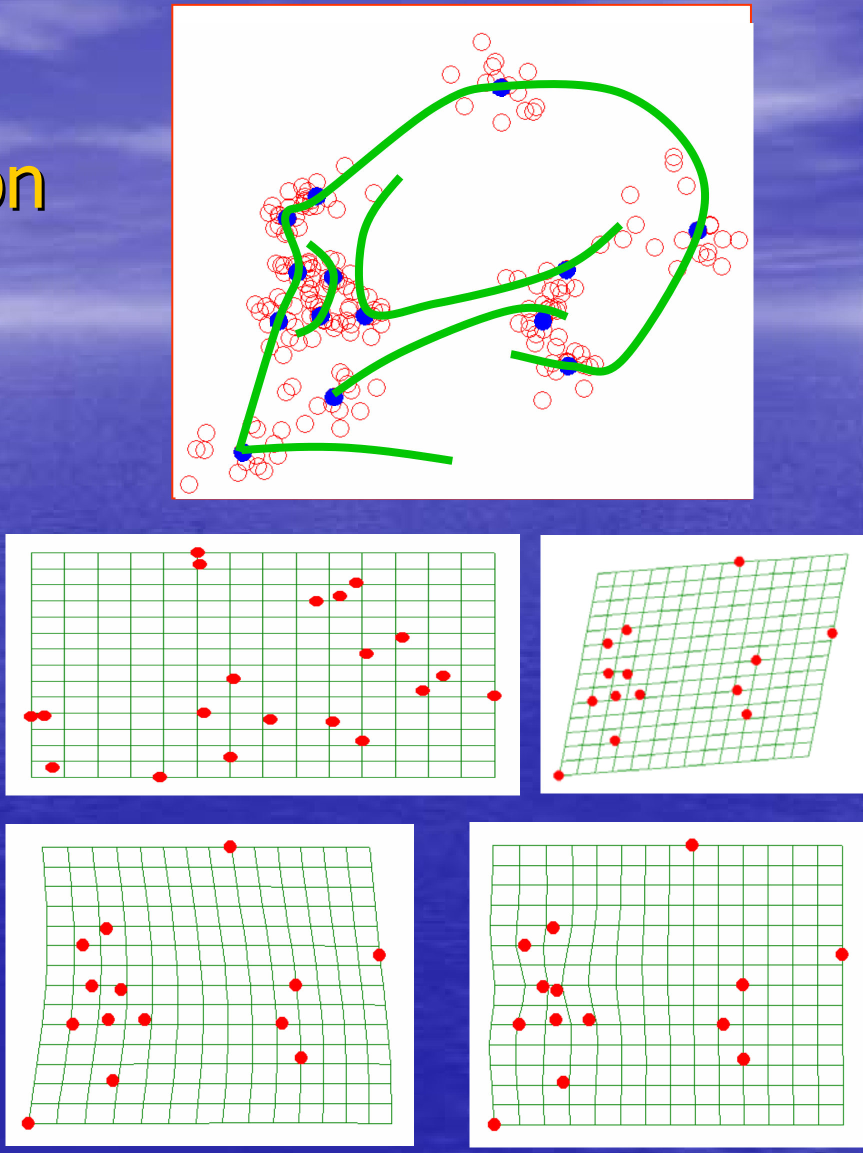
Landmark-based morphometrics

- Thin Plate Splines
  - data
    - Cartesian coordinates
      - 2D, 3D
  - standardisation
    - Generalised Procrustes Analysis
      - size
      - rotation
      - position
    - only true shape remains



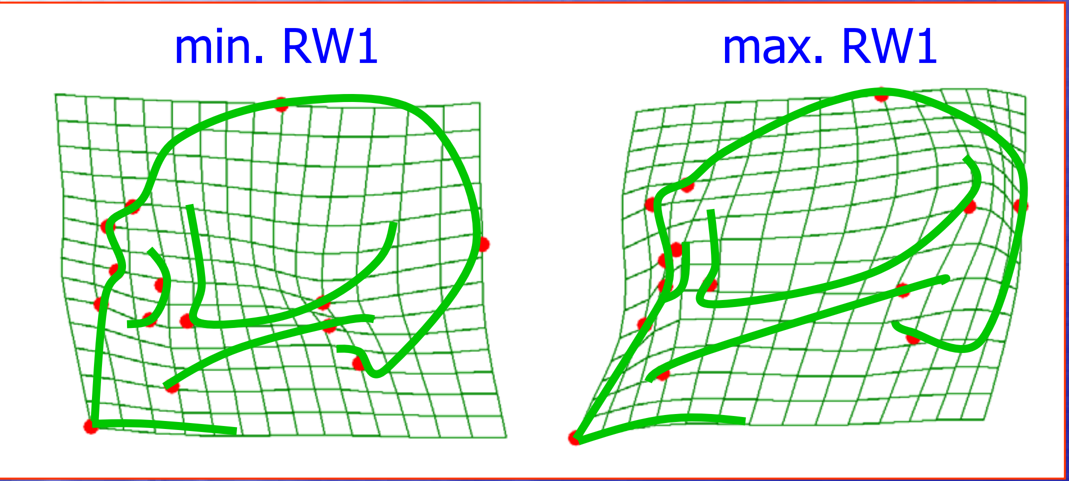
Thin Plate Splines

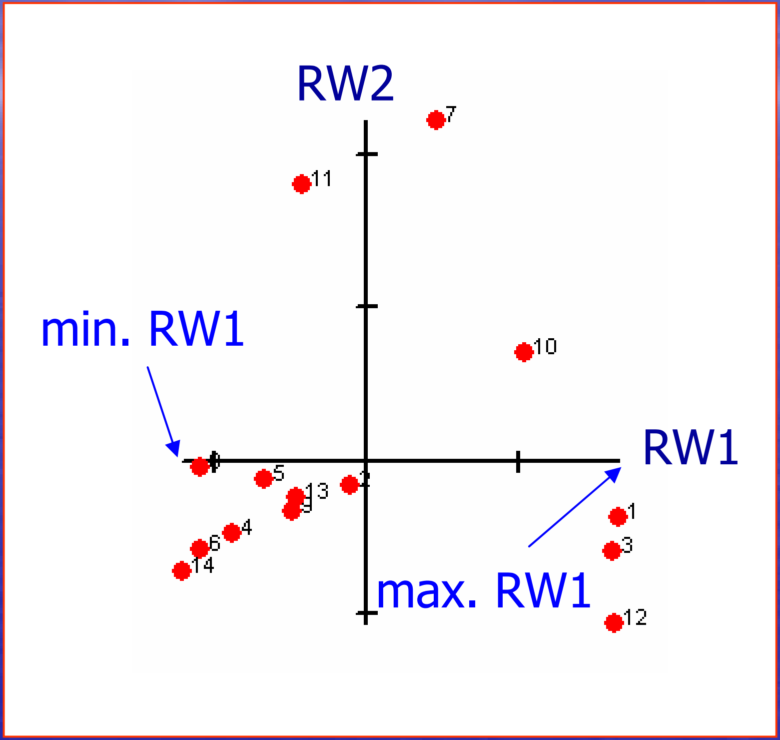
- Shape variation decomposition
  - reference shape
    - consensus
  - new shape variables
    - partial warps
      - uniform shape variation
        - compression
        - shear
      - non-uniform shape variation
        - overall deformation
        - localised deformation
    - partial warp scores
      - weight matrix



Thin Plate Splines

- Shape variation analysis
  - Relative warp analysis
    - PCA on partial warp scores
    - visualisation of shape variation





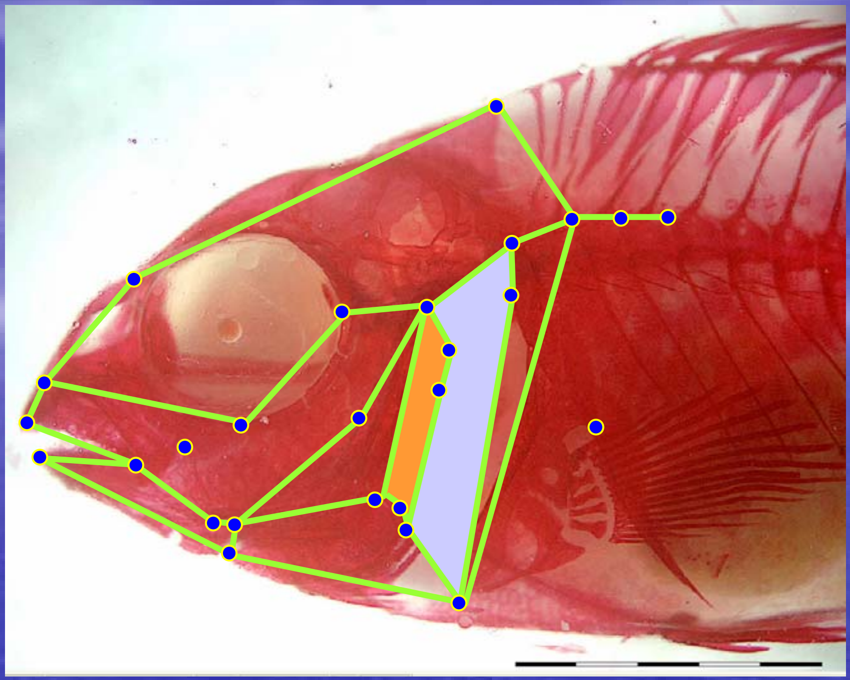
  - DFA
    - on partial warp scores
    - between-group shape differences

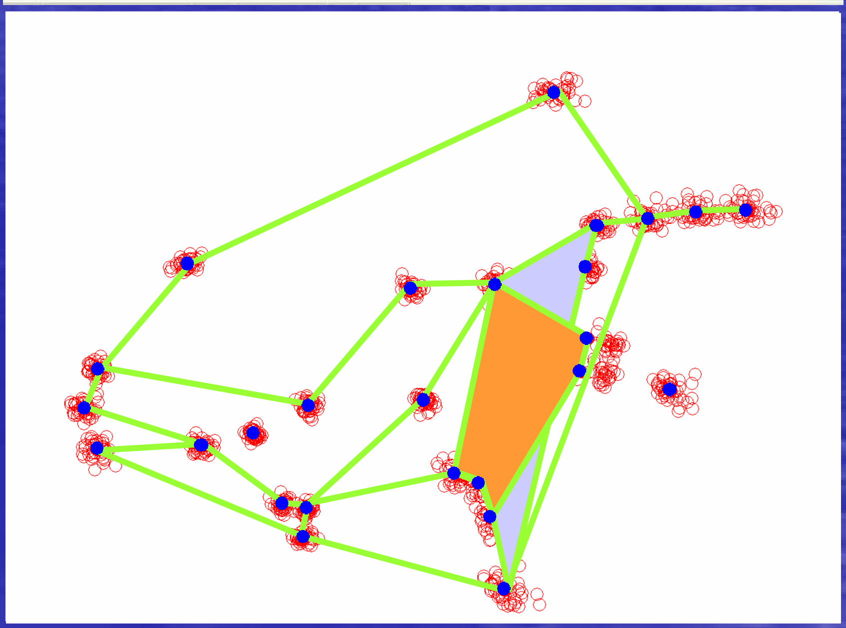
Geometric morphometrics

Application for studying deformations in *Sparus aurata*

Data acquisition

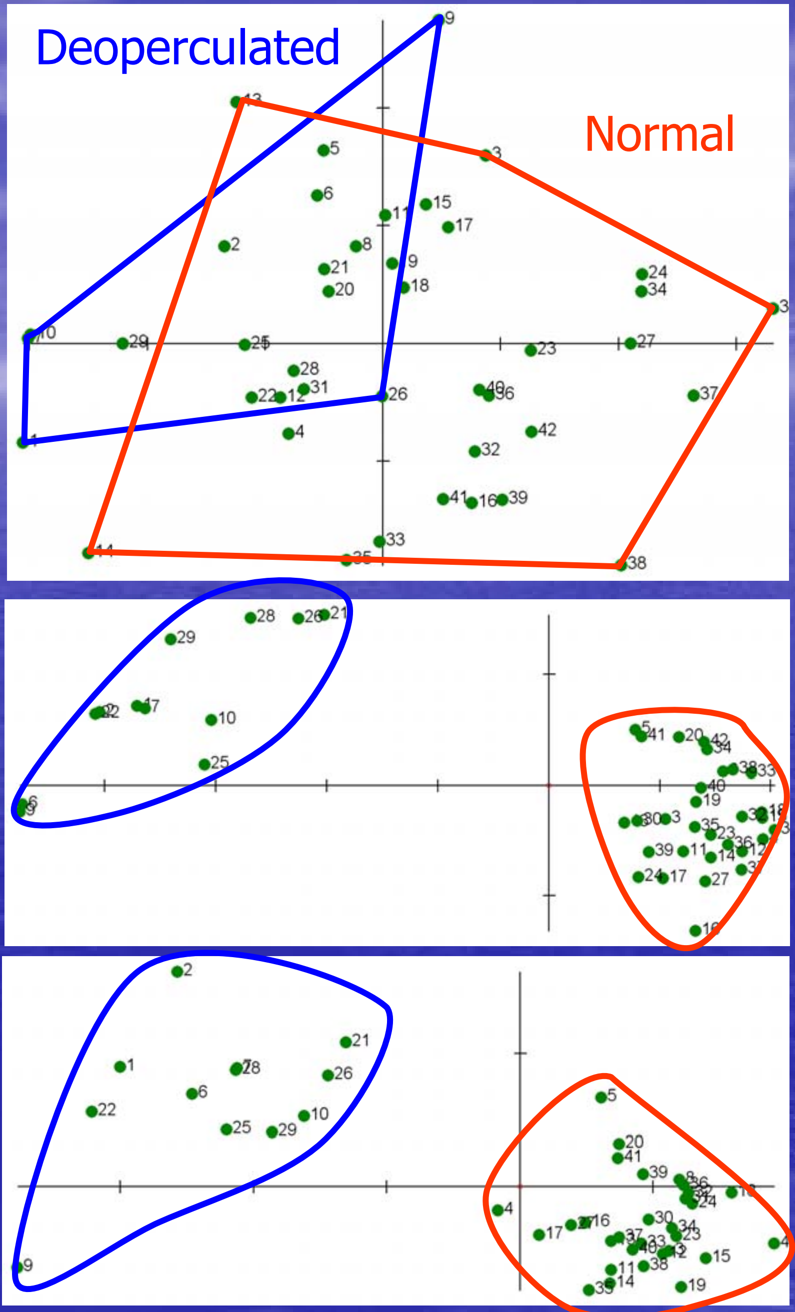
- Digital images
  - specimens n=40
- Landmark digitisation
  - number of landmarks
    - 26 (type 1 & 2)
- GPA
  - consensus
  - specimens





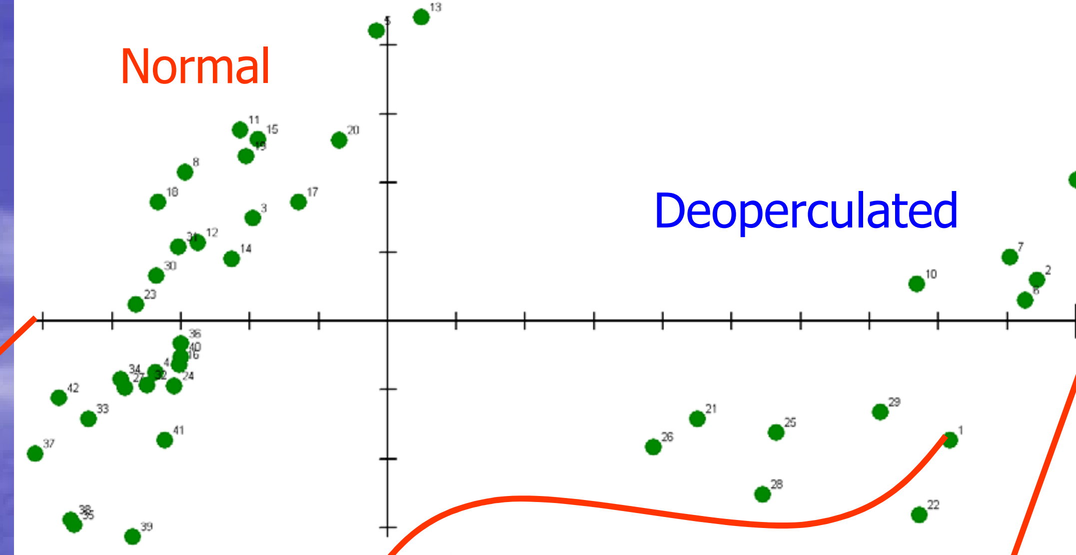
Data analysis

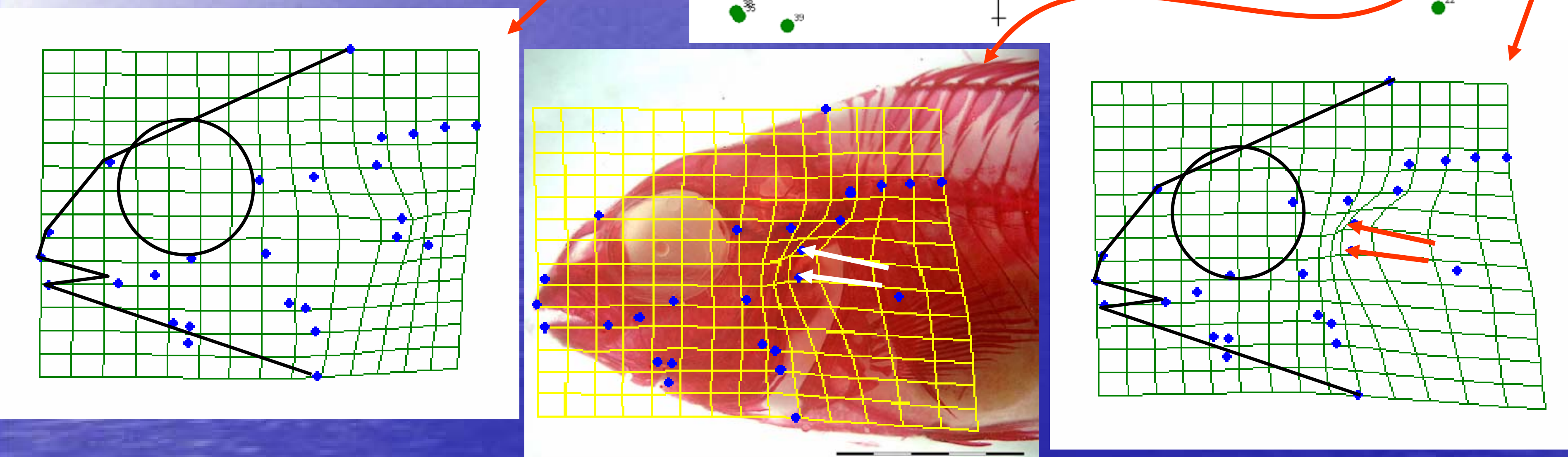
- Partial warp decomposition
  - uniform variation
    - no clustering
  - non-uniform variation
    - partial warp 9
      - normal and deoperculated cluster
      - normal less variation
    - partial warp 12
      - normal and deoperculated cluster
      - normal less variation



Data analysis

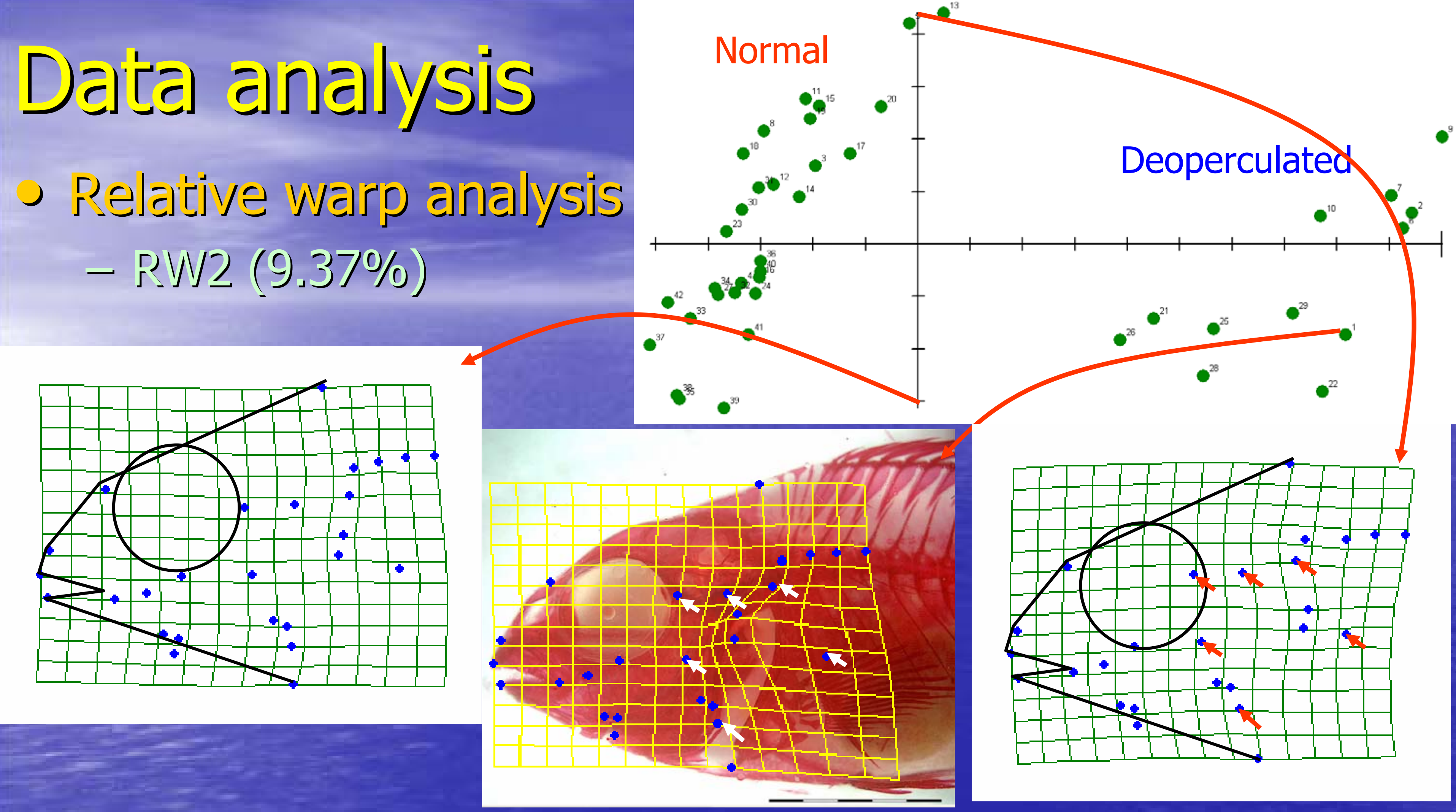
- Relative warp analysis
  - RW1 (60.25%)





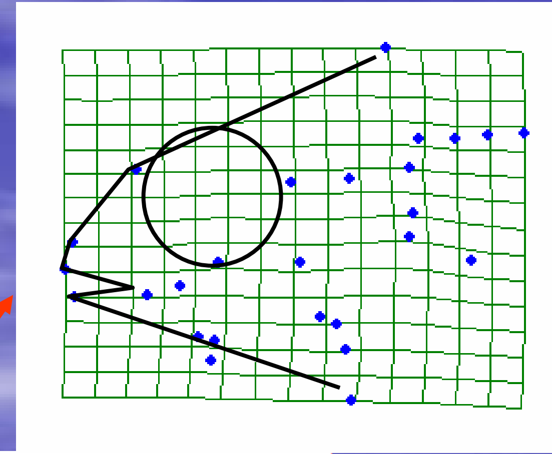
Data analysis

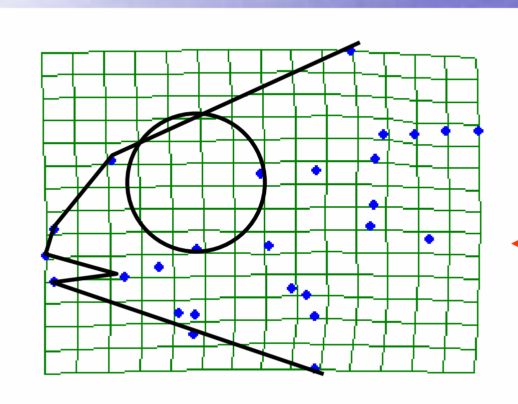
- Relative warp analysis
  - RW2 (9.37%)

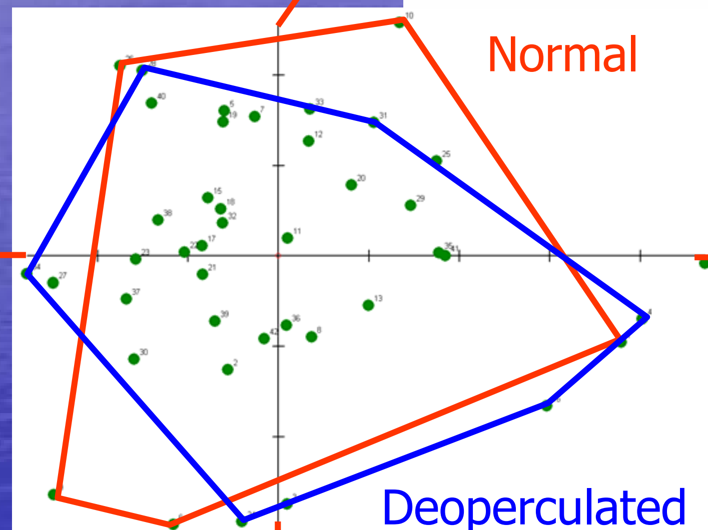


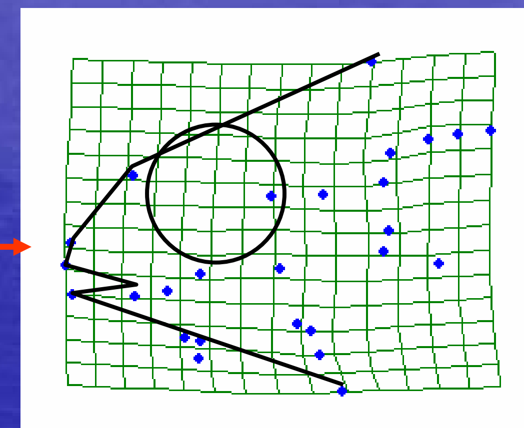
Data analysis

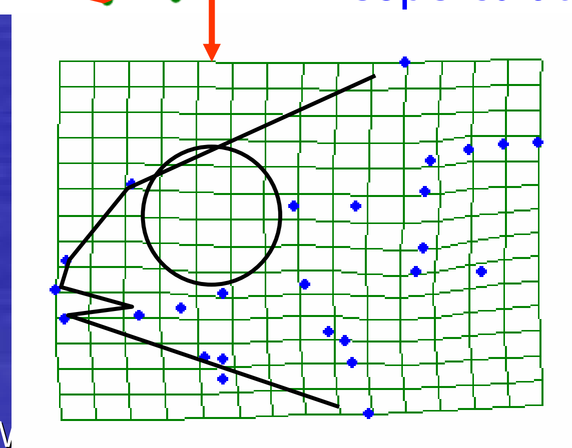
- Relative warp analysis
  - RW3 (7.38%)







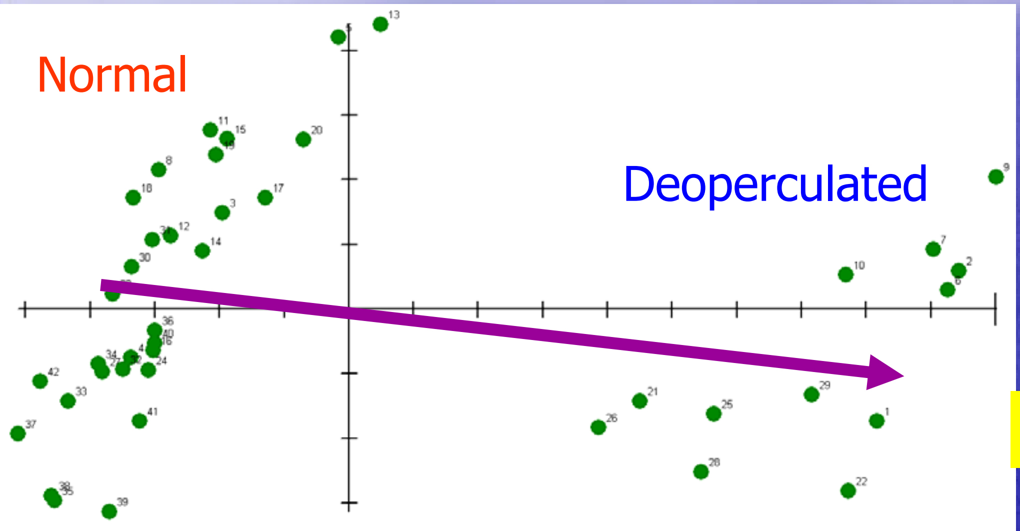


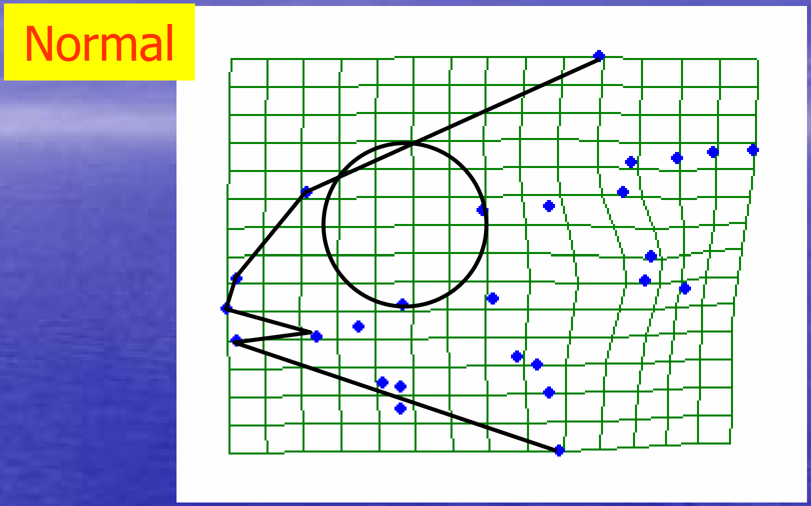


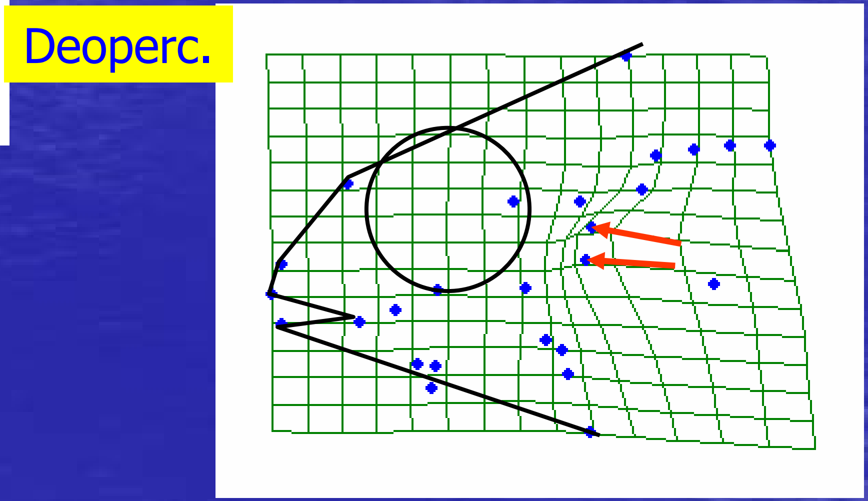
  - RW4 (4.67%)

Trends in shape changes

- Normal to deoperculated
  - shape changes



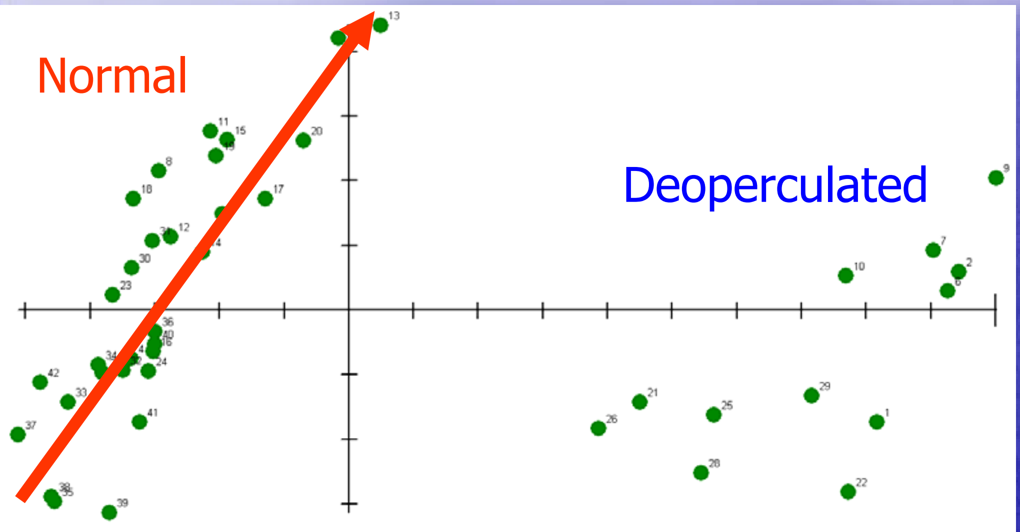




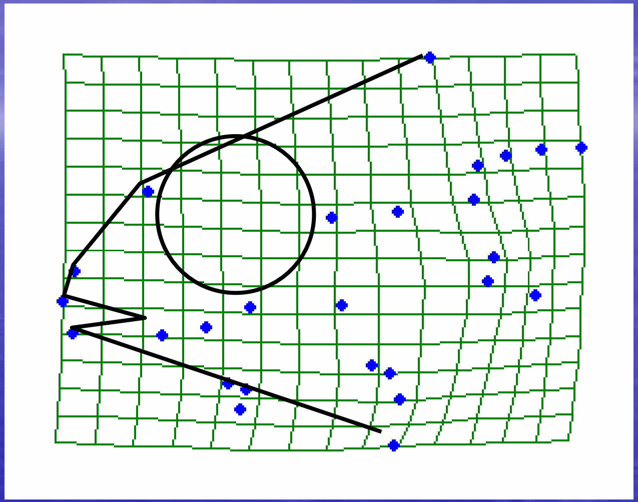
  - not size related
  - distrupt variation
    - developmental treshold?
    - early onset of deformation?

Trends in shape changes

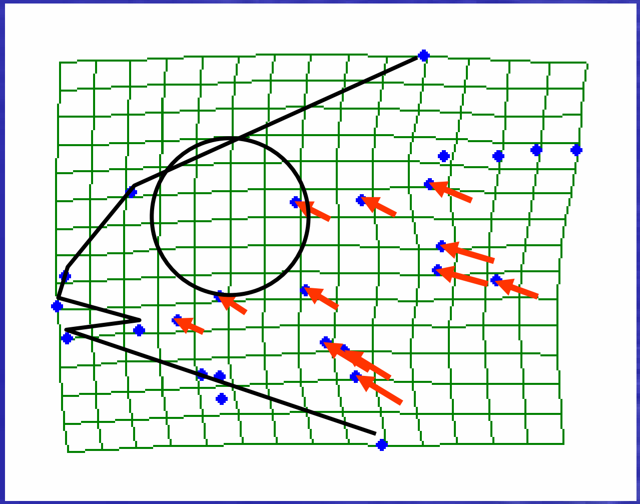
- Normal
  - shape changes



min



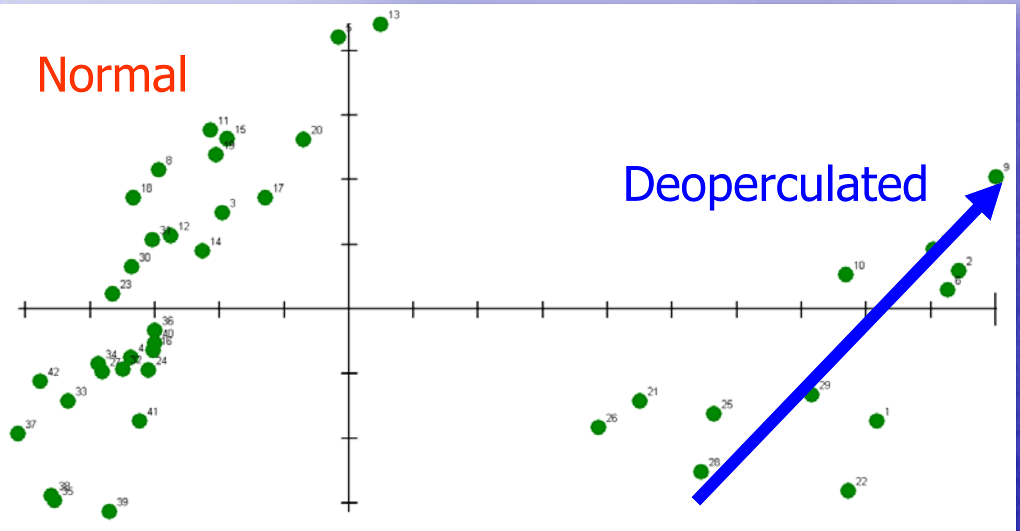
max.

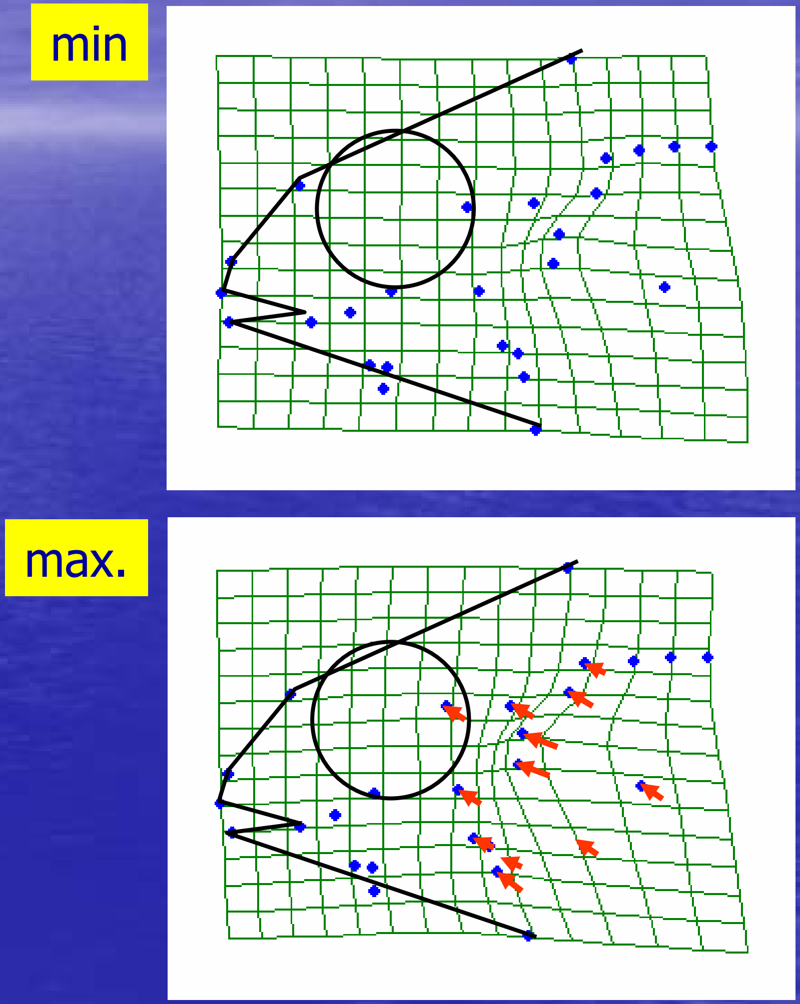


  - not size related
  - gradual variation
    - phenotypic plasticity?
    - deformities?

Trends in shape changes

- Deoperculated
  - shape changes

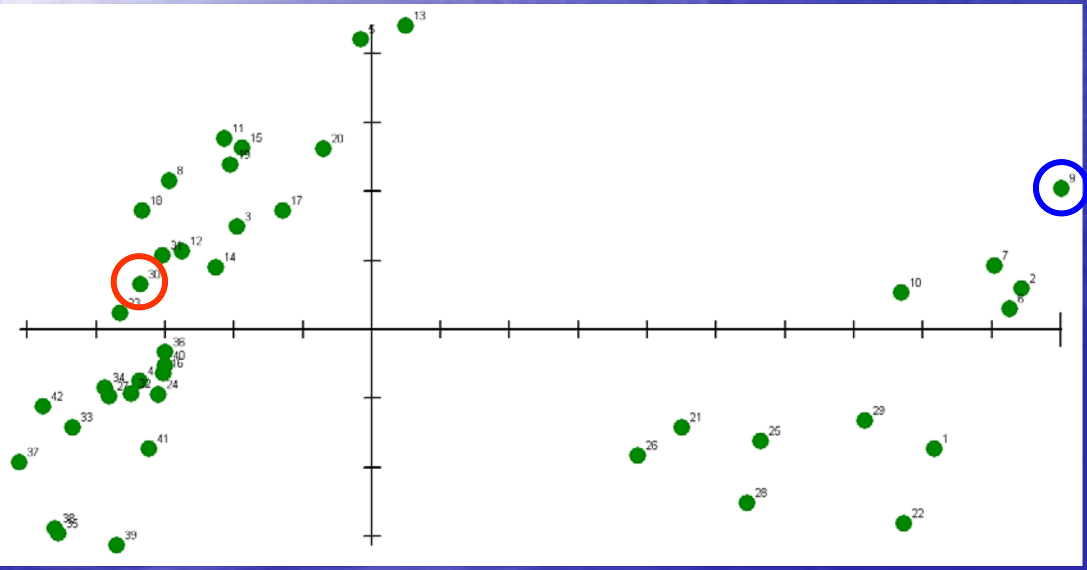




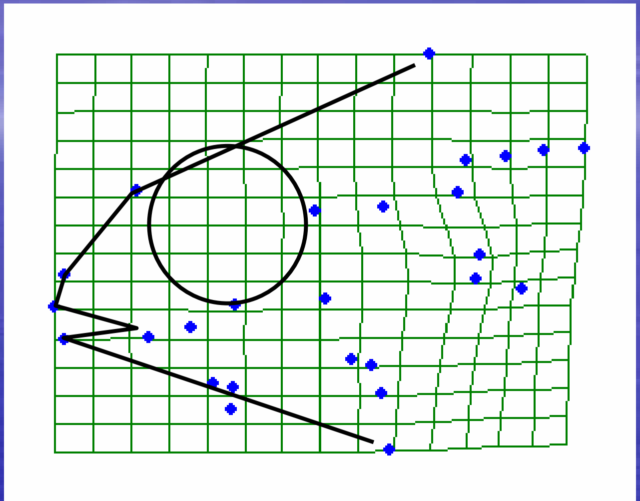
  - not size related
  - gradual variation
    - phenotypic plasticity?
    - variation larger than normal
      - different than normal phenotypic plasticity

Left-right asymmetry

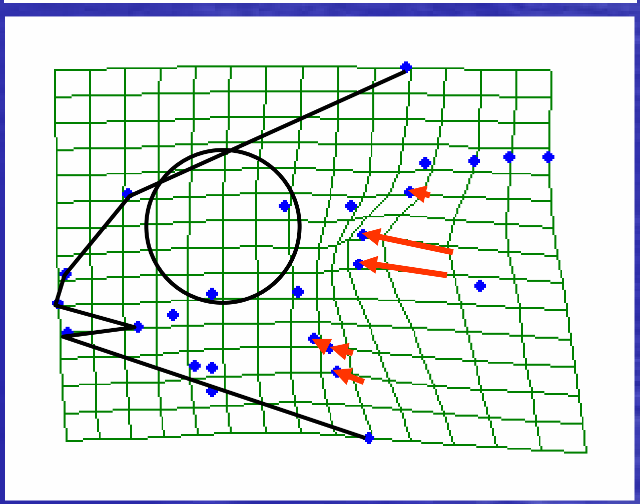
- Specimen C1-8
  - right - #30
    - normal
  - left - #9
    - strongly deoperculated



right



left



Conclusions

- Use of geometric morphometrics
  - more solid shape descriptors
  - more correct standardisation (GPA)
  - statistical analyses applicable
  - visualisation of shape variation

- Deformations in *Sparus aurata*
  - geometric morphometrics very useful
  - 'shape-gap' between normal and deoperculated
  - within-group variation not size related
  - extreme left-right asymmetry