

The evolution of novel fruit morphology in a tribe of mustards:

Can structural changes in the pericarp
influence geographic distribution?

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A typical mustard siliques



elongated siliques
longitudinally dehiscent
free, unprotected seeds
no segmentation of fruit
thin, fleshy valve

Invasive garlic mustard,
Alliaria petiolata

A mustard in the tribe Brassiceae
Cakile edentula



shortened siliques
indehiscent
protected propagules
lateral segmentation of fruit
corky pericarp



Cakile edentula growing on a sandy beach





The heteromorphic fruit segments
of *Cakile* strongly influence
its dispersal.





New England



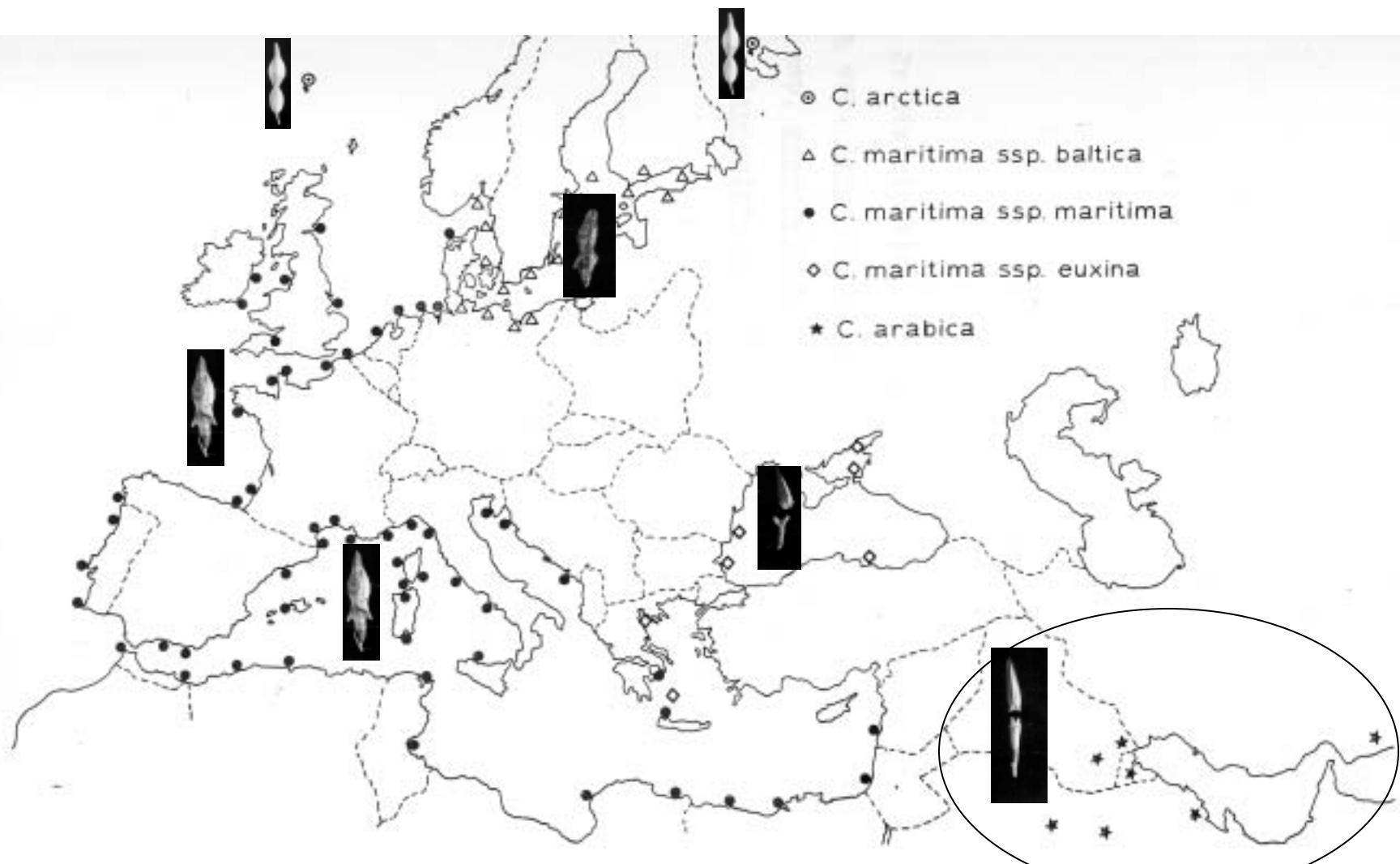
Scotland



Iceland

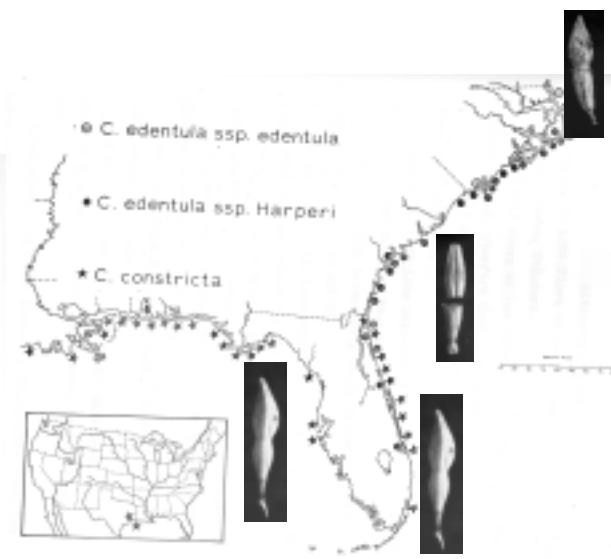
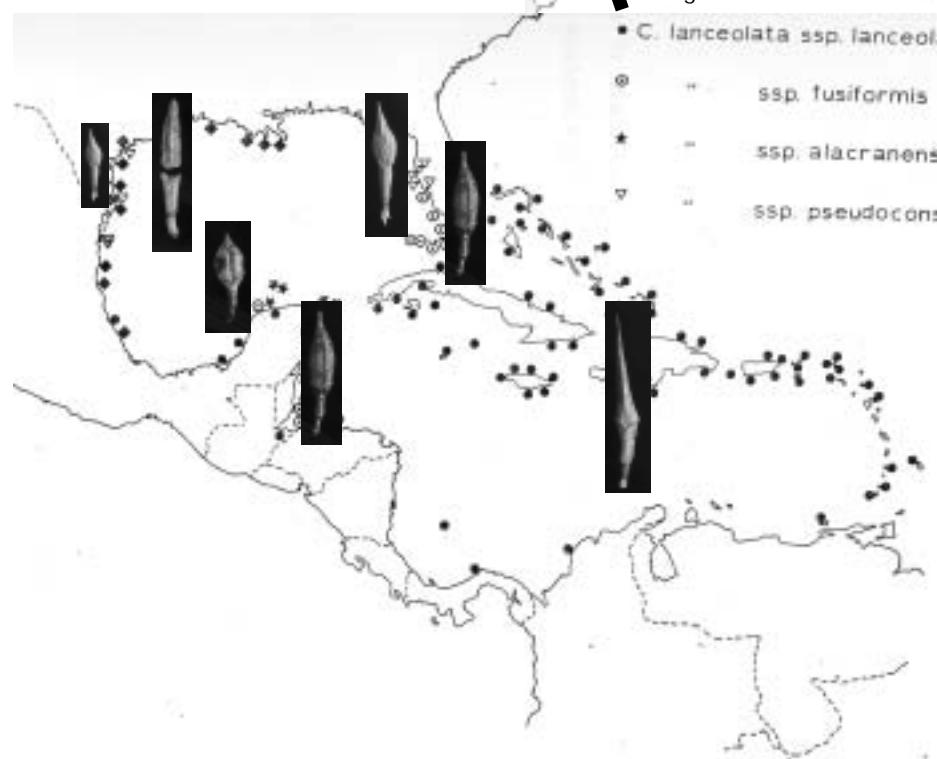
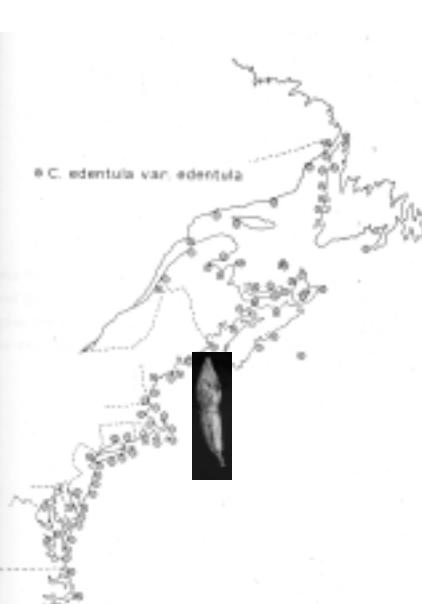


Saudi Arabia

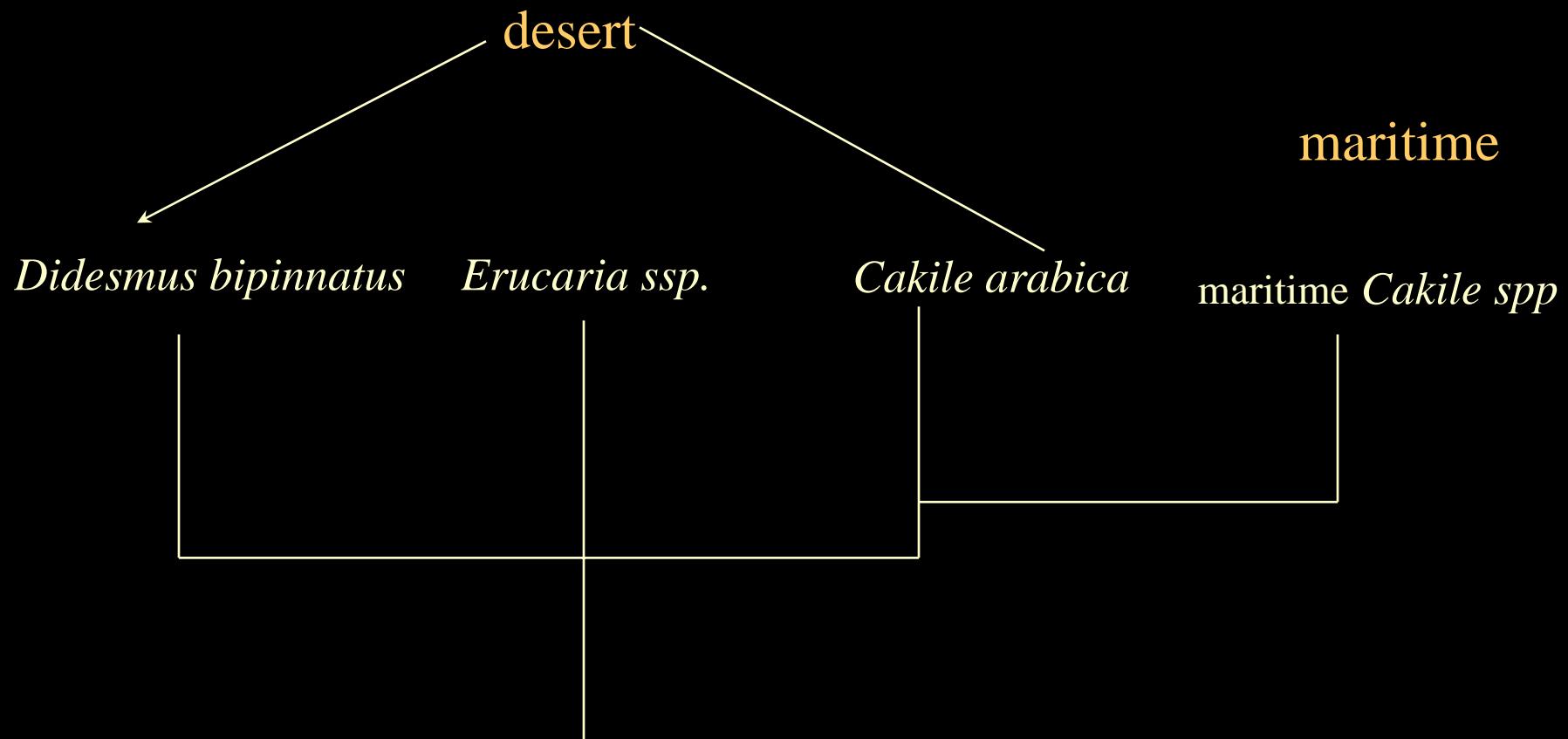


ancestral *Cakile* sp.

Cakile arabica



Cakile made a transition from a desert to a maritime habitat and experienced a consequent increase in global range.



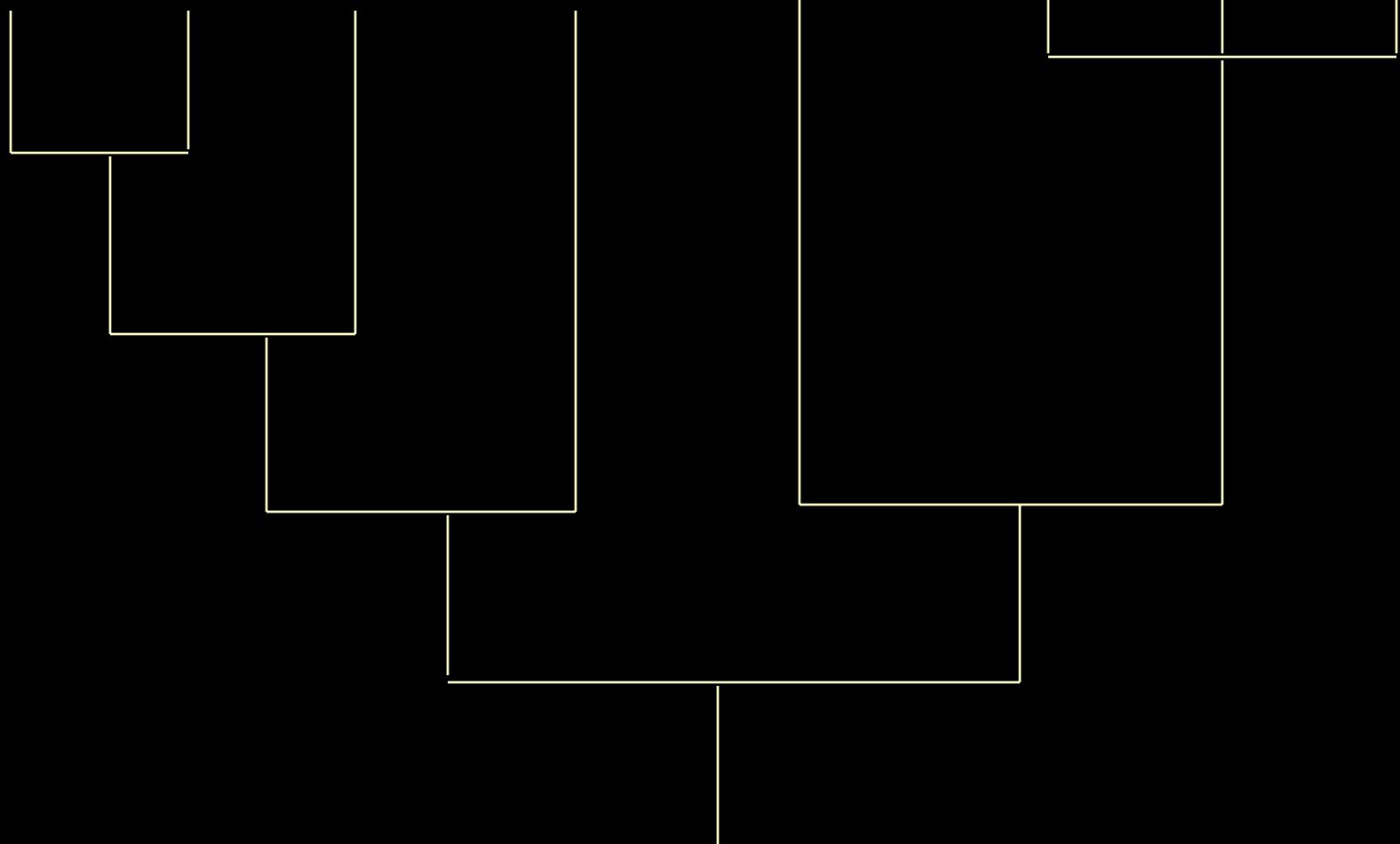
Geographic distribution and dispersal



- a. Indehiscence, to result in protected propagules
- b. "Joint", that causes segmentation
- c. Pericarp structure, that enables buoyancy

desert annuals, ruderal species

Brassica *Sinapsis* *Muricaria* *Crambe* *Crambella* *Didesmus* *Erucaria* *Cakile*



Simplified from Warwick and Black 1997



Brassica nigra



Sinapis arvensis

Erucaria cakiloidia





Erucaria hispanica



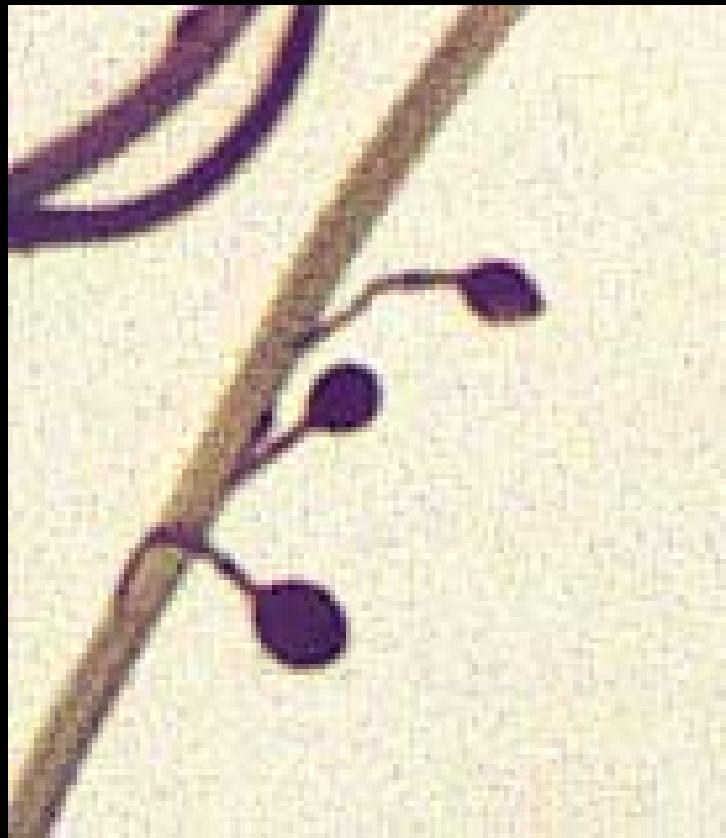
Erucaria aegiceras



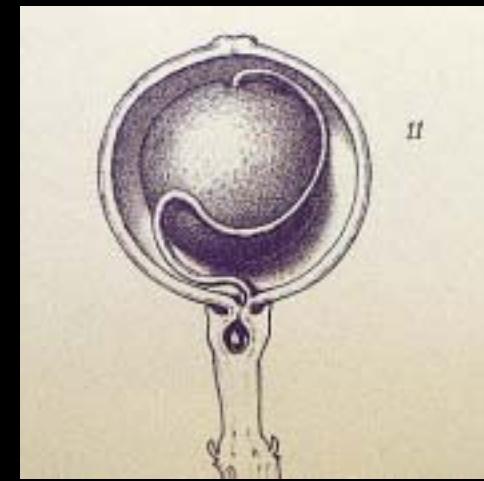
Didesmus bipinnata



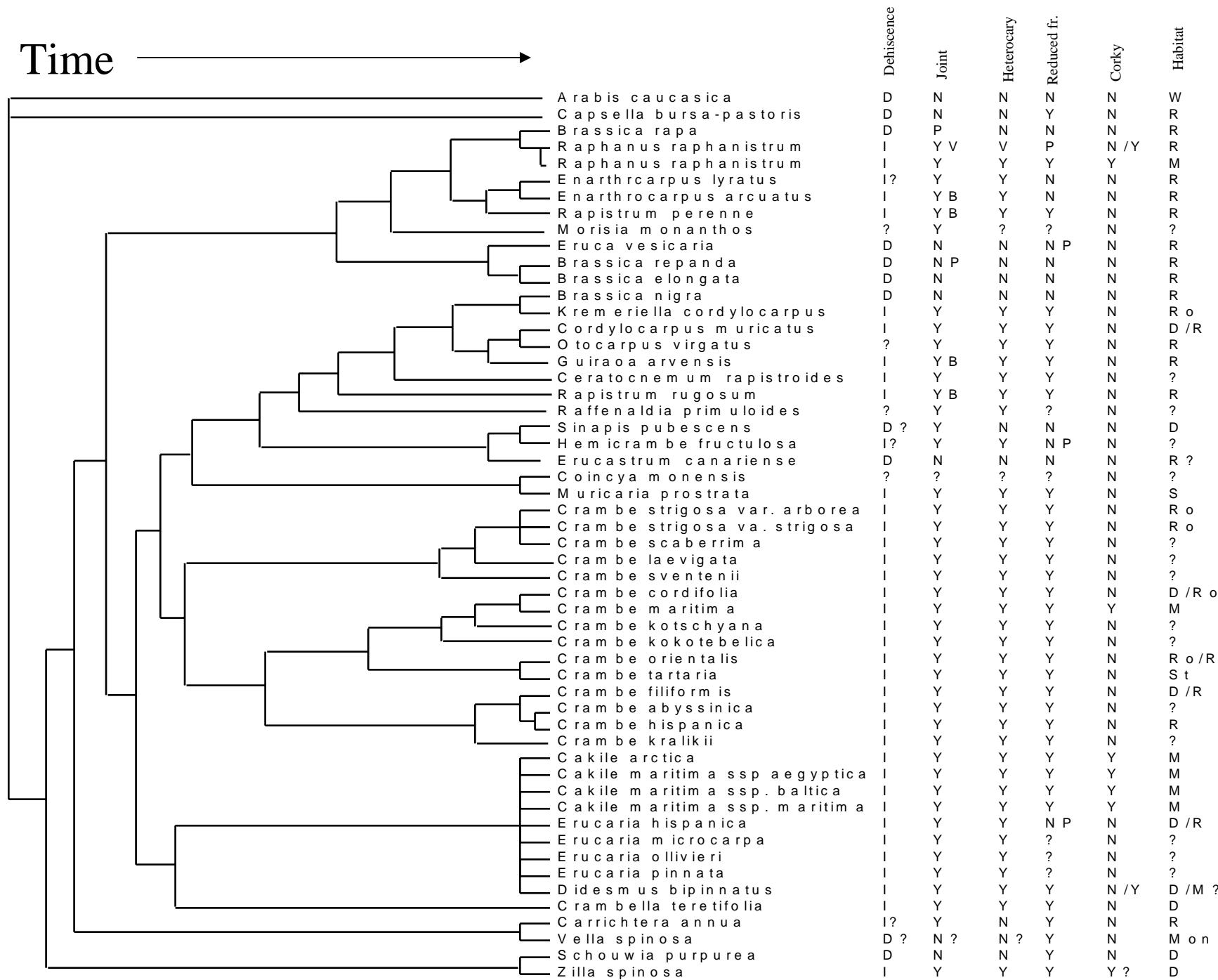
Muricaria prostrata



Crambella teretifolia

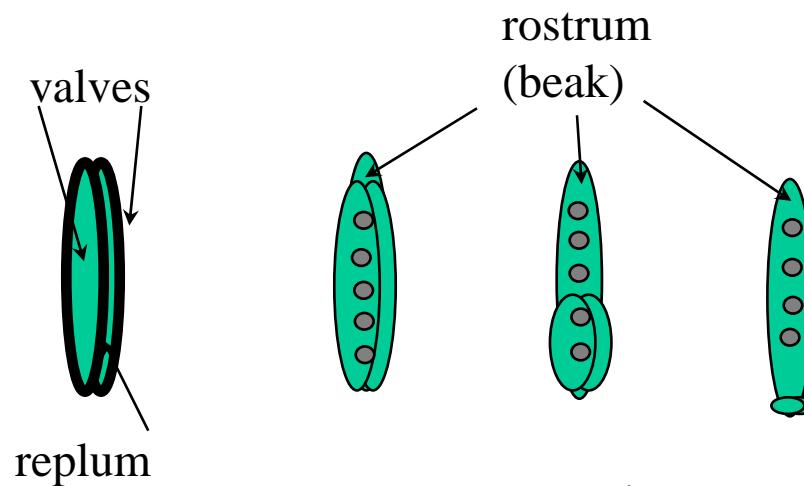


Time

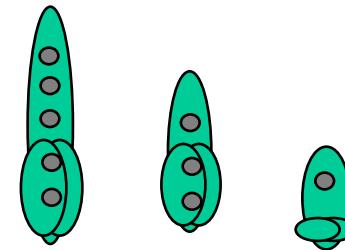
Indehiscence

Joint



- a. Indehiscence, to result in protected propagules
- b. "Joint", that causes segmentation
- c. Pericarp structure, that enables buoyancy

Fruit reduction

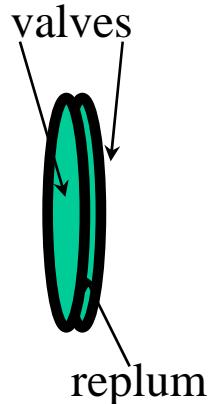


Corky pericarp

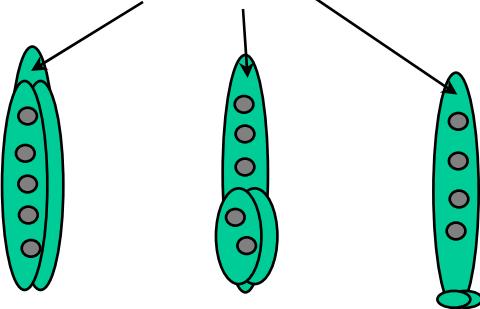


Indehiscence and the joint

Ancestral siliques



rostrum
(beak)

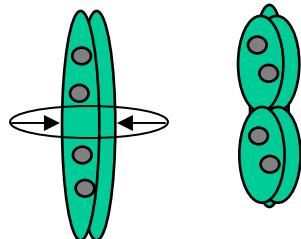


Indehiscence and joint formation are due to migration of the valve-replum boundary.

Homology between joint and the ancestral valve-replum boundary

No evidence of ancestral dehiscence zone in the distal segment

OR



Heteroarthrocarpy

The joint is a completely novel feature.

No homology between joint and the ancestral valve-replum boundary

Ancestral dehiscence zone may be present in the distal segment

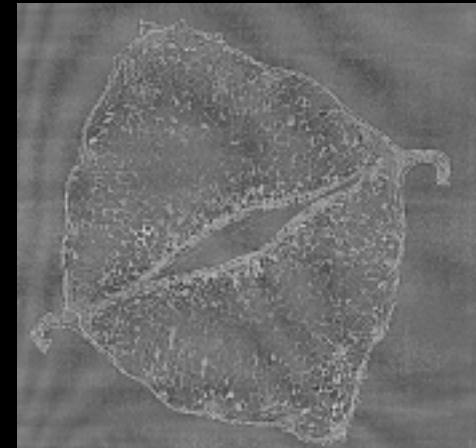
Dehiscence to indehiscence



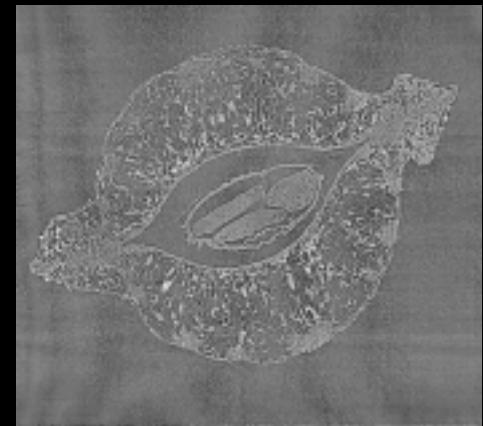
Alliaria petiolata



Arabidopsis thaliana



Distal segment



Proximal segment

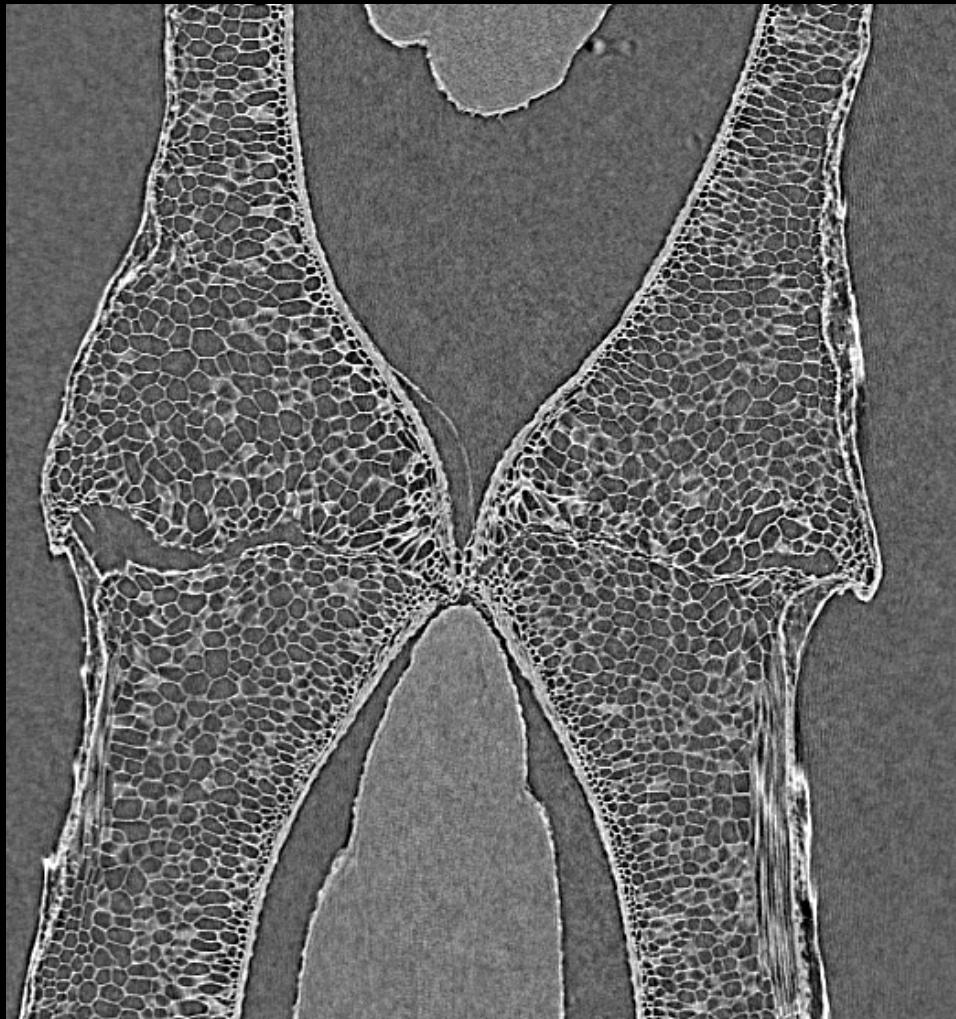
Cakile maritima

Developmental genetics, histology, x-ray imaging

Question: Linking developmental genetics with X-ray imaging

Is it possible to image the products of reporter genes
to characterize the 3-D expression of candidate genes?

Joint development: SEM and X-ray imaging



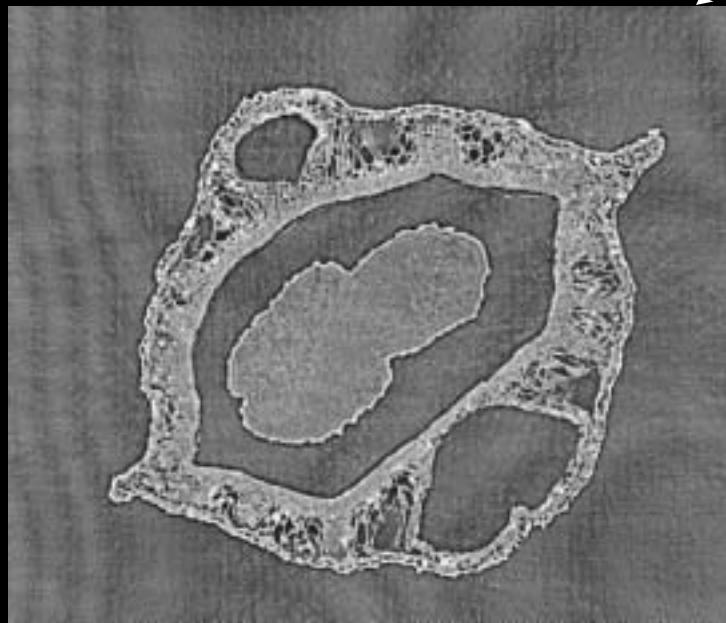
So far, imaging has been conducted only on dry samples.

For developmental studies, we need to use fully hydrated samples at different stages of development.

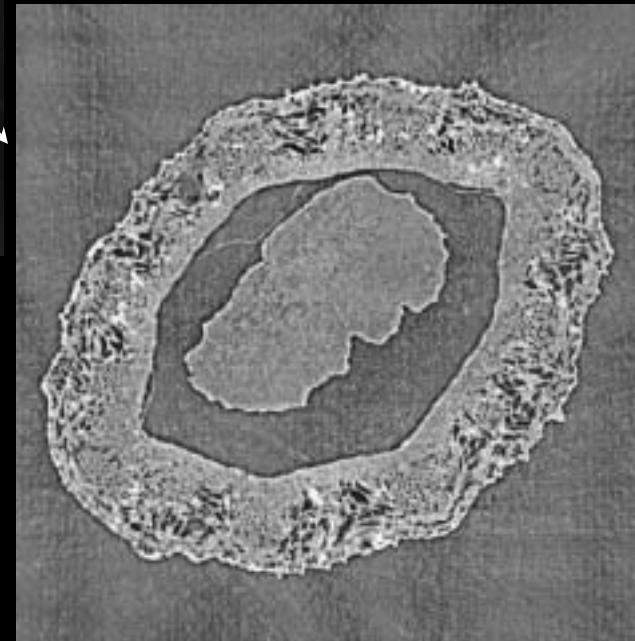
We would like to:

- a) determine the relationship between the anatomical basis of the joint and the shearing force required for detachment of the fruit segment
- b) determine whether joint anatomy is homologous across the tribe

Pericarp structure

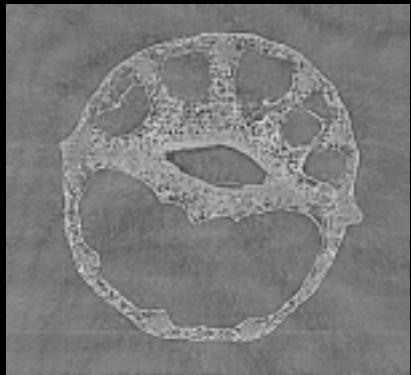


Distal segment

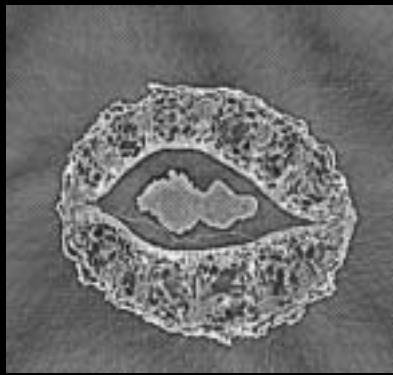


Proximal segment

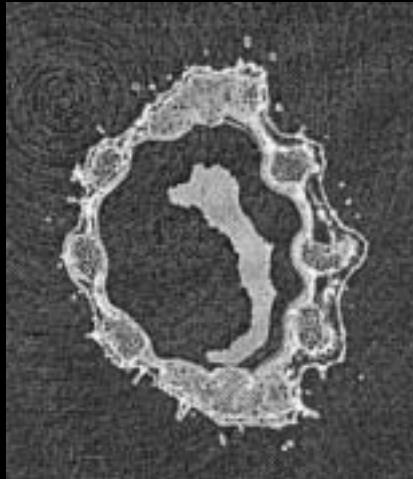
Cakile arabica



Distal segment



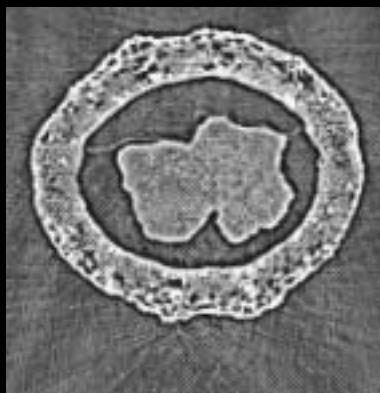
Distal segment



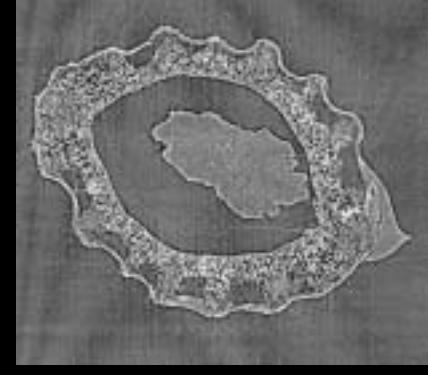
Suture near proximal



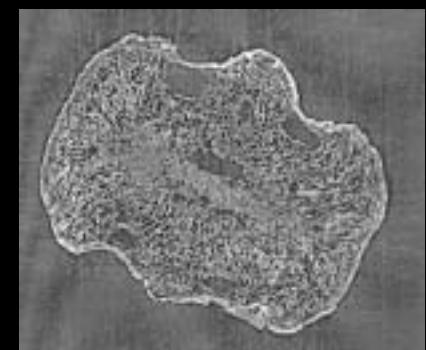
Proximal segment



Proximal segment



Distal segment



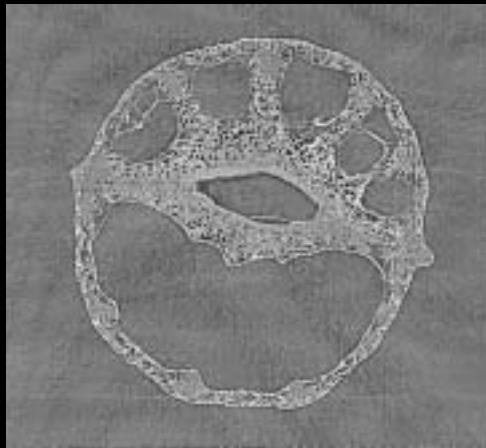
Suture zone

Erucaria hispanica

Erucaria aegiceras

Erucaria cakiloidia

Didesmus bipinnatus



Distal segment

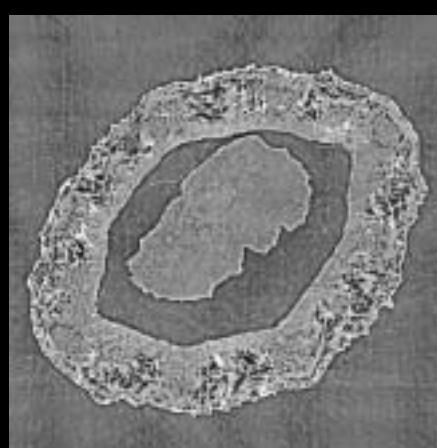


Proximal segment

Erucaria hispanica

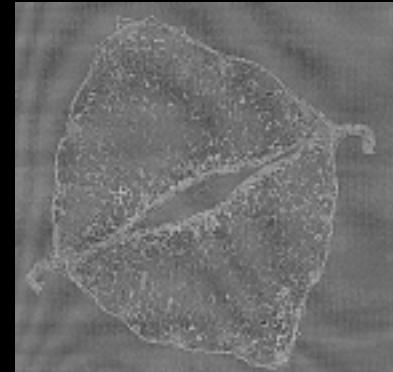


Distal segment

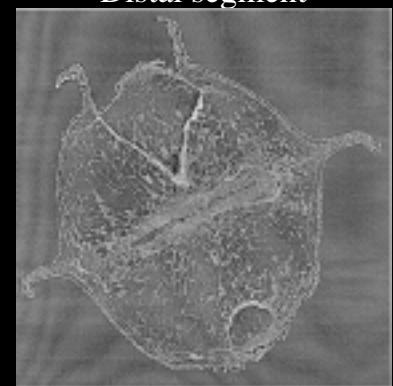


Proximal segment

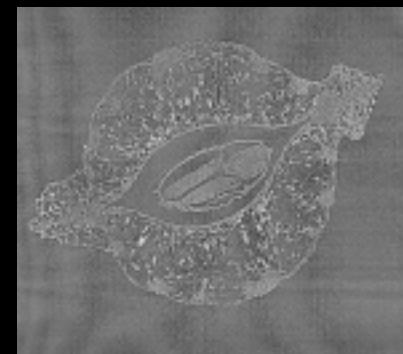
Cakile arabica



Distal segment

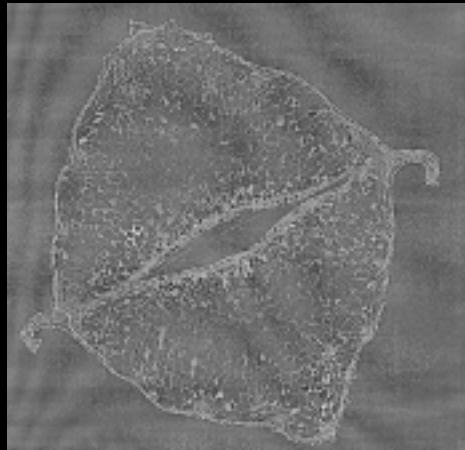


Suture zone

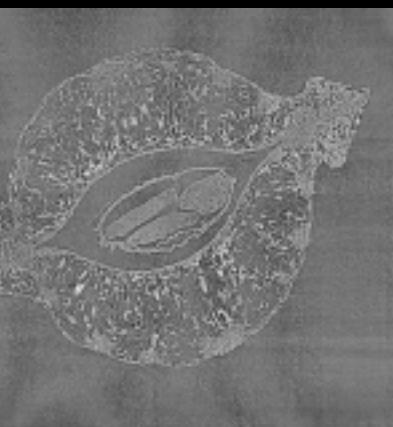


Proximal segment

Cakile maritima

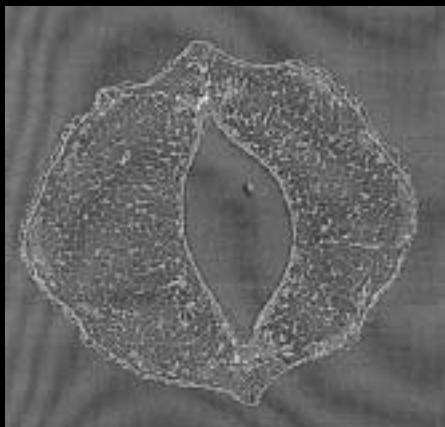


Distal segment



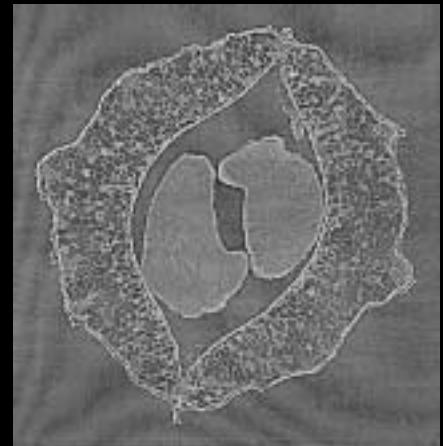
Proximal segment

Cakile maritima

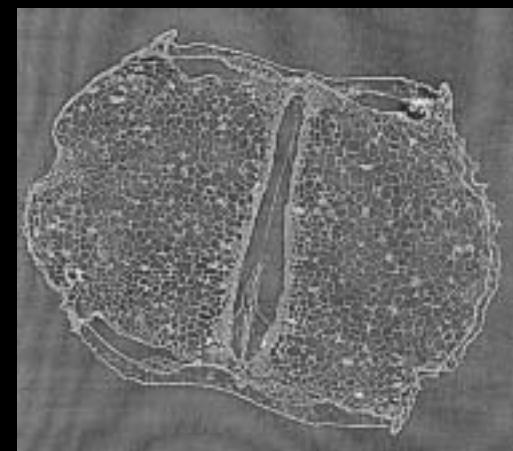


Distal segment

Cakile edentula



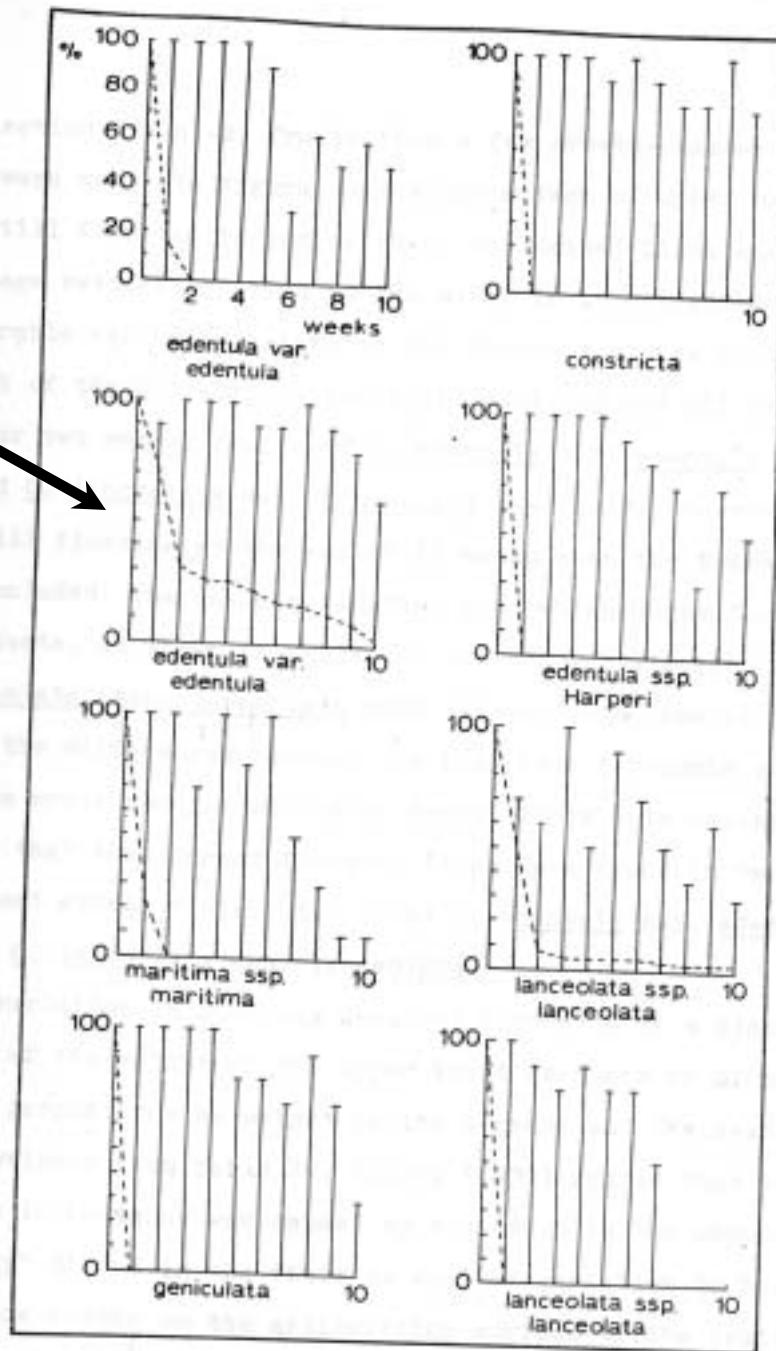
Distal segment
(proximal resembles)



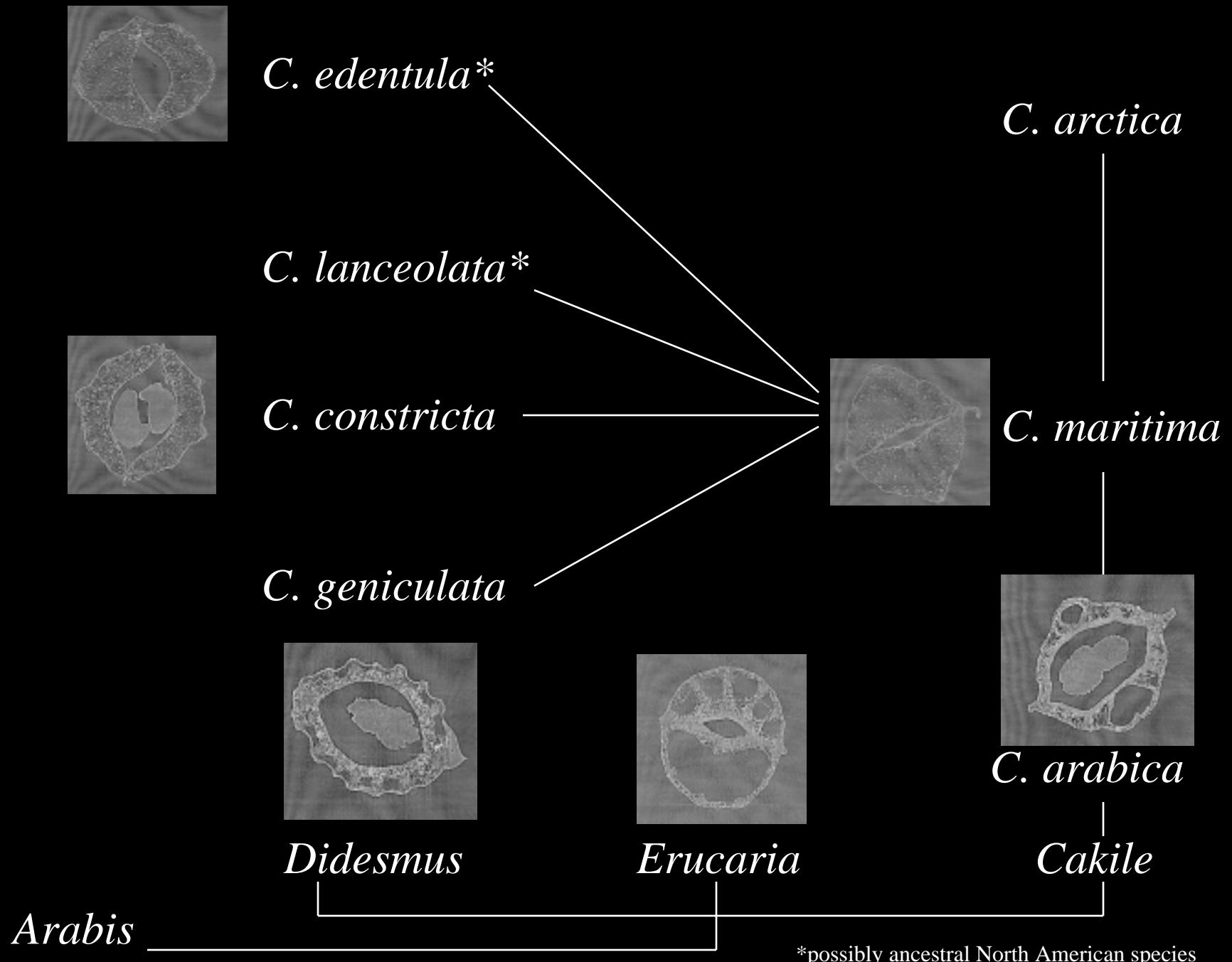
Suture zone

Cakile constricta

Best floaters



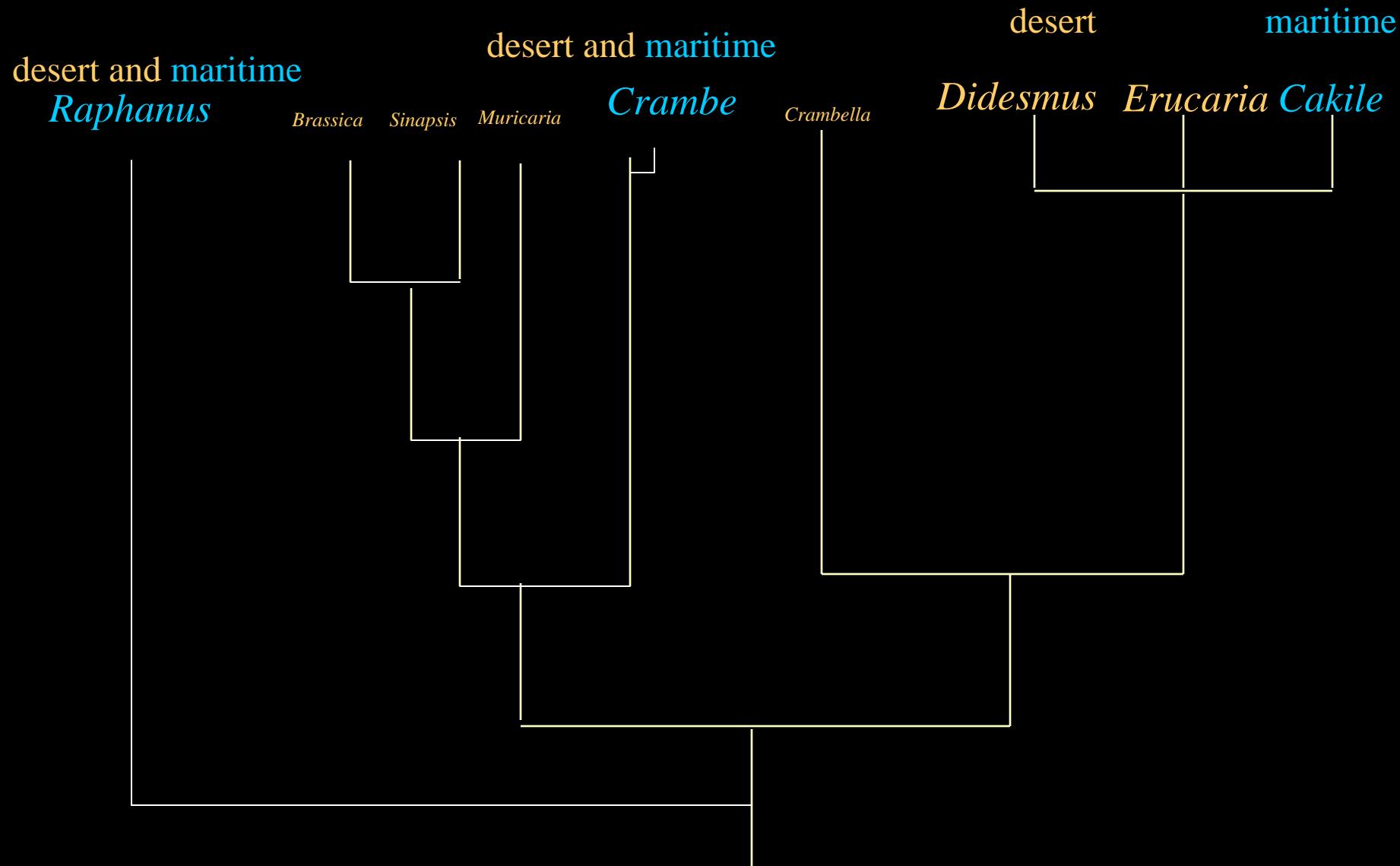
Best floaters



Pericarp structure

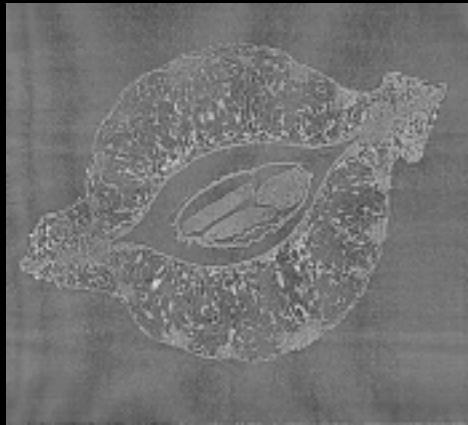
We would like to:

- a) follow a single air chamber throughout the pericarp to determine its connectivity to other chambers and to determine whether it has access to the surface of the pericarp.
- b) quantify the distribution of the sizes of air chambers in order to determine the relationship between chamber size distribution, buoyancy, and temperature regulation.

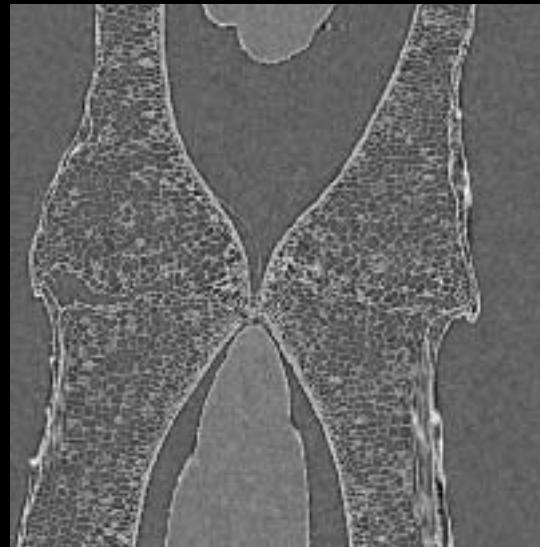


Simplified from Warwick and Black 1997

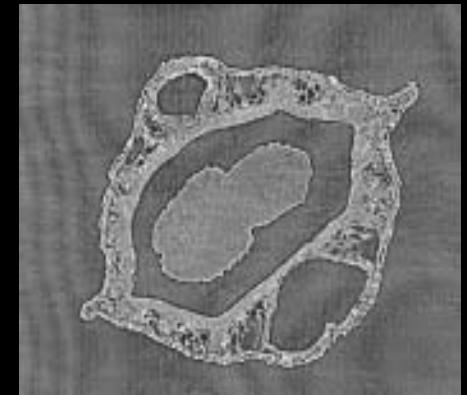
Indehiscence



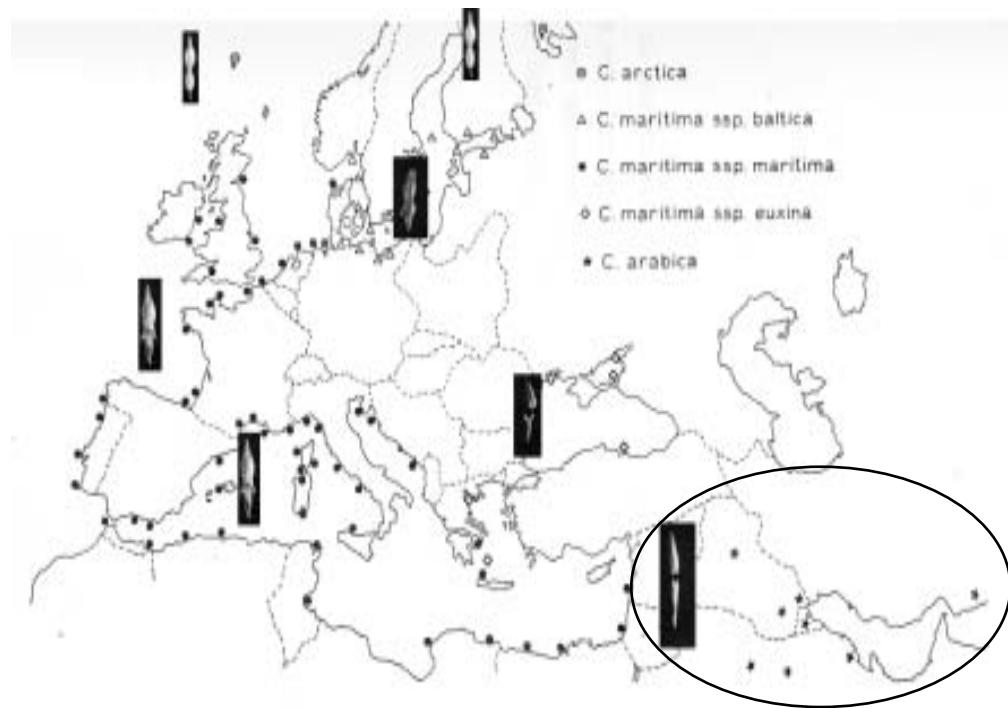
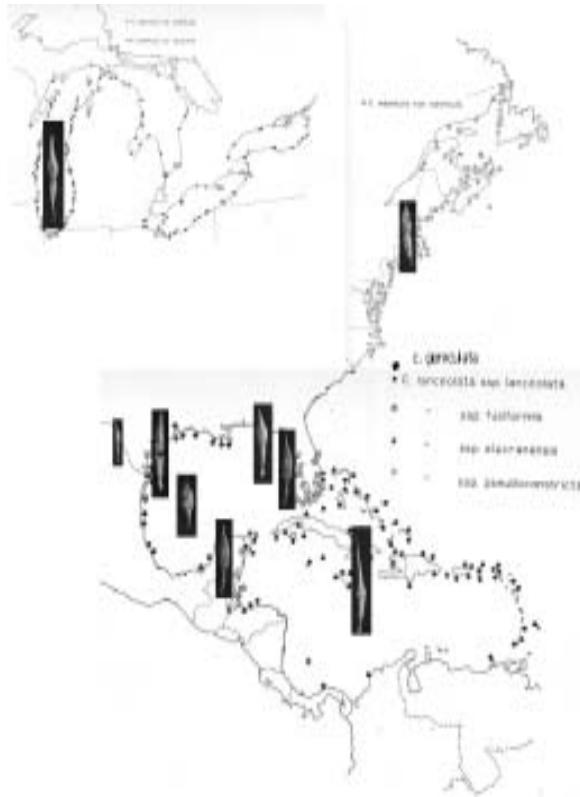
Joint development



Pericarp structure



Dispersal, divergence, and speciation



X-ray imaging applications for genetic and evolutionary studies

1. Combining with developmental genetics

Can we visualize specific gene products in 3-D over time, in fresh (or living) samples?

2. Environmental manipulations

Environment-dependent gene expression

3. Quantitative (statistical) genetics (and phylogenetics)

High throughput imaging for large sample sizes

4. Quantitative analysis of images

High throughput computation

