Using permanent plots to monitor effects of soil subsidence

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Soil subsidence

- gas extraction at Ameland-East started in 1986
- soil subsidence in ~circular area, radius ≈ 6 km
- subsidence increased ~linearly over time
- max. subsidence ~30 cm

Ecological effects

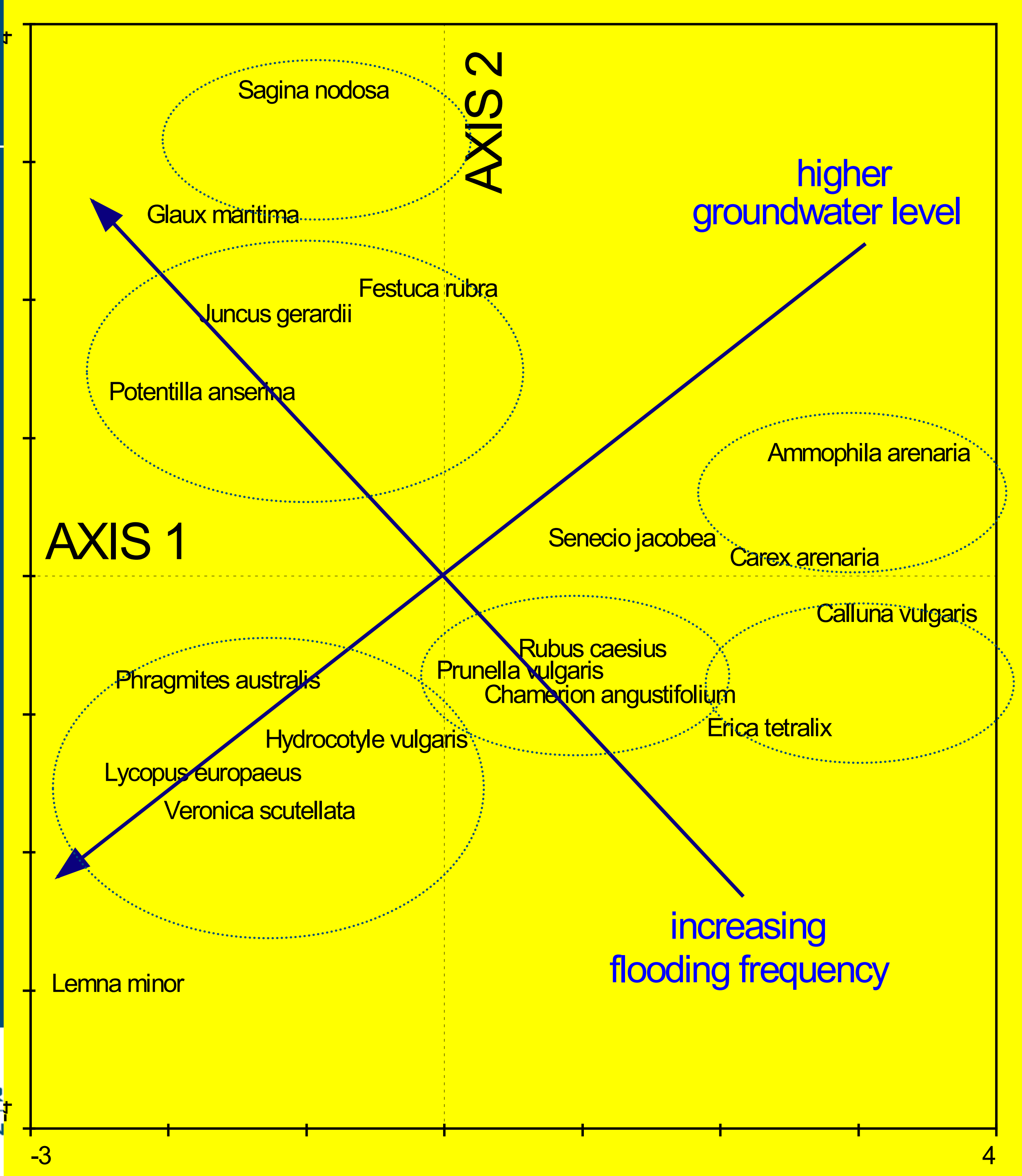
- soil subsidence may affect influence of salt water or fresh water on the vegetation
- main question: will this lead to a loss of biodiversity?
- vegetation changes anyhow...
- so the questions are if the observed changes can:
  - be explained from soil subsidence?
  - be interpreted as a loss of biodiversity?

Monitoring

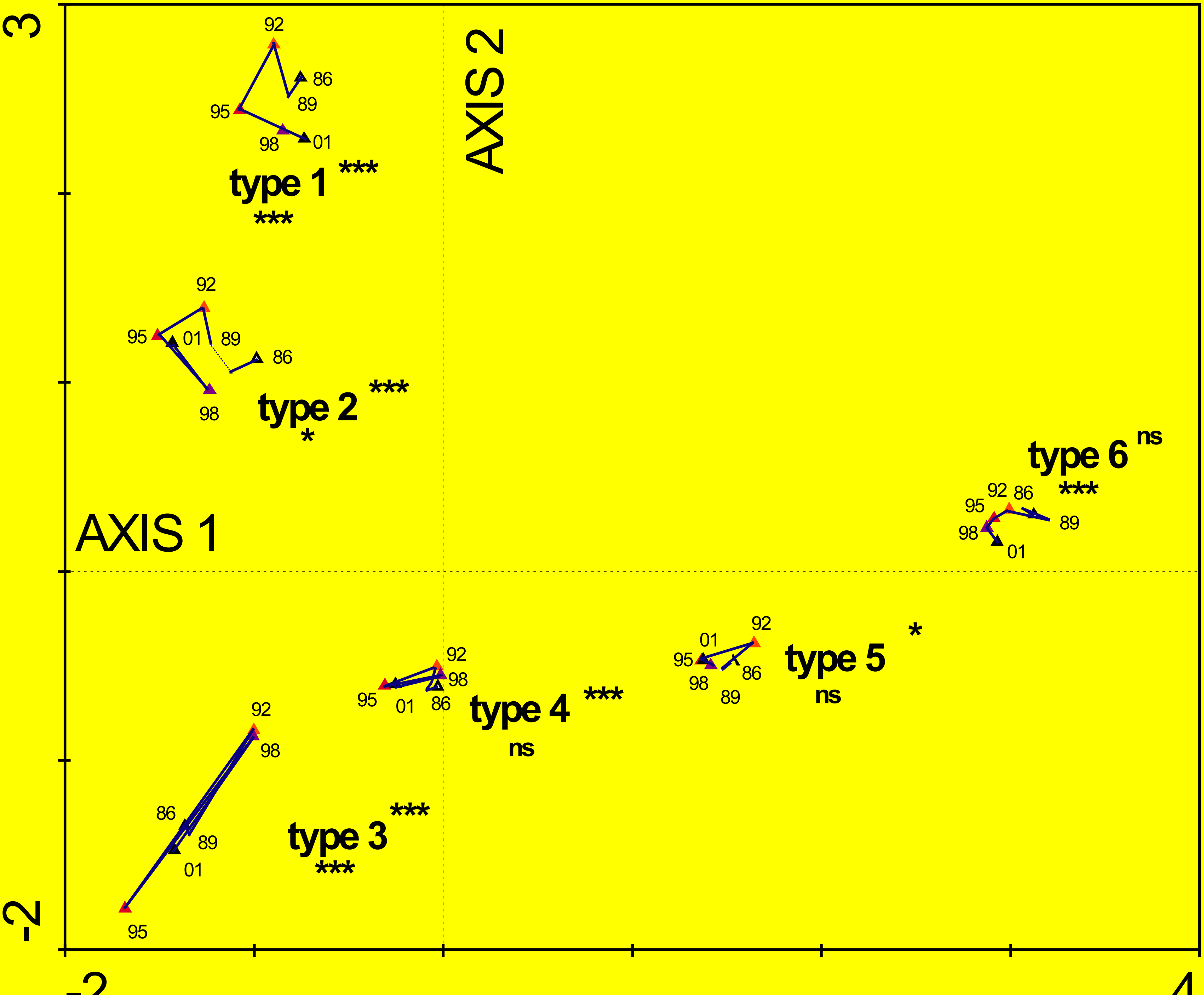
- 65 permanent plots (2 X 2 m^2) located in 5 transects
- monitoring at 3-year intervals (1986 - 2001)
- cover % vascular plants, mosses, lichens
- phreatic level (monthly)
- weather conditions (precipitation, evaporation, sea level) (continuously, from weather stations)
- soil chemical analysis (once)

Vegetation analysis

- 65 plots, 6 points in time, 276 species
- simple typology
  - sandy salt marsh; clayey salt marsh; pool shores; eutrophicated dune vegetation; dune heath; white dune
- ordination by DCA
- characterise vegetation by
  - scores on DCA axes (1 - 3)
  - biodiversity measures: 'CCV' and number of species
- ordination diagrams can be used to characterise the changes by tracking the 'path' of each type over time



AXIS 2
AXIS 1
higher
groundwater level
increasing
flooding frequency
Sagina nodosa
Glaux maritima
Festuca rubra
Juncus gerardii
Potentilla anserina
Ammophila arenaria
Senecio jacobea
Carex arenaria
Calluna vulgaris
Rubus caesius
Prunella vulgaris
Chamerion angustifolium
Erica tetralix
Phragmites australis
Hydrocotyle vulgaris
Lycopus europaeus
Veronica scutellata
Lemna minor
-3
4

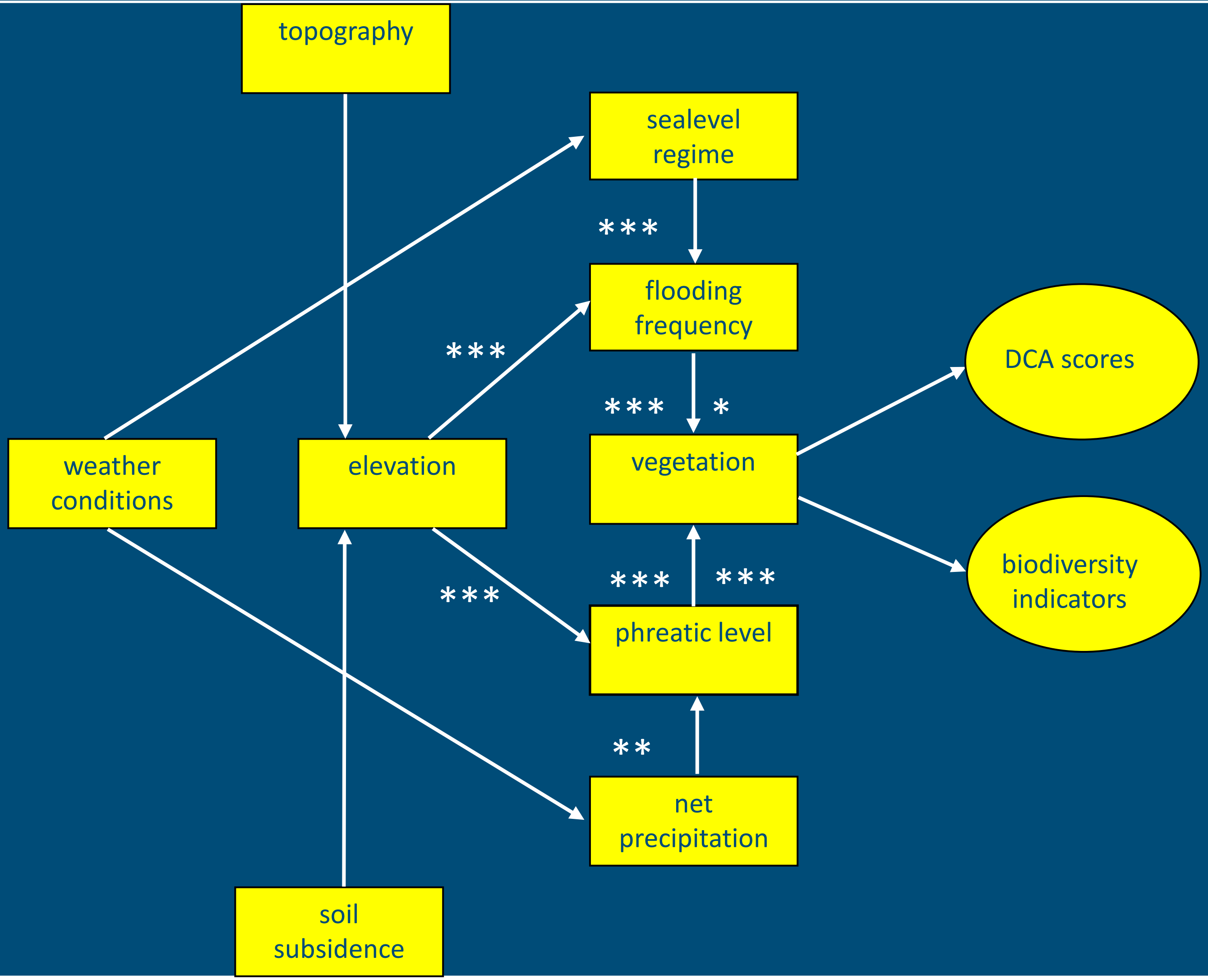


AXIS 1
AXIS 2
3
-2
-2
4
type 1 ***
***
type 2 ***
*
type 3 ***
***
type 4 ***
ns
type 5 *
ns
type 6 ns
***
86
89
92
95
98
01

Interpretation of ordination diagram

- temporal changes often statistically significant, but small compared to spatial differences
- diagram can be used to infer environmental changes that caused the vegetation changes
- temporal changes mostly oscillatory, small linear component
- track down the cause of changes by using multiple regression to dissolve the spatial pattern and the temporal change into:
  - a constant component, due to topography
  - a linear component, due to soil subsidence
  - an oscillatory component, due to weather fluctuations

Cause - effect chain . . .

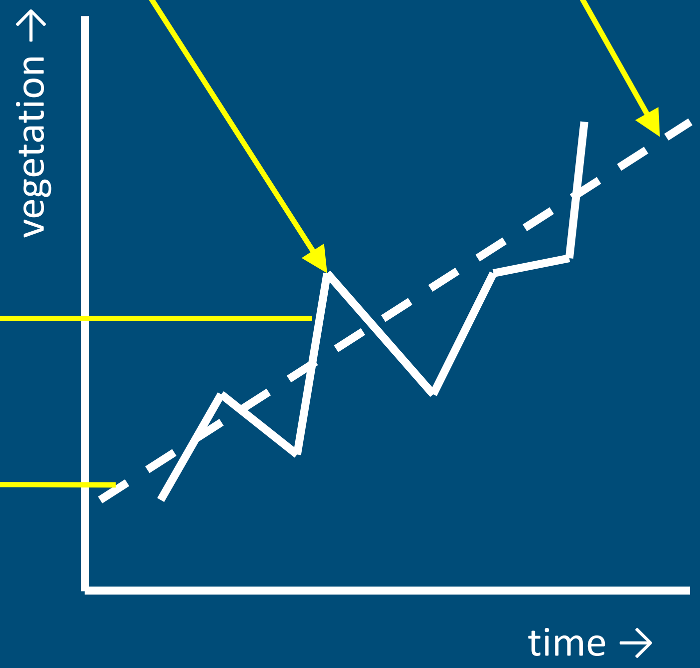


Dissolution of temporal signal

vegetation change = f (weather , soil subsidence)

compare this component with:

- net precipitation
- flooding frequency



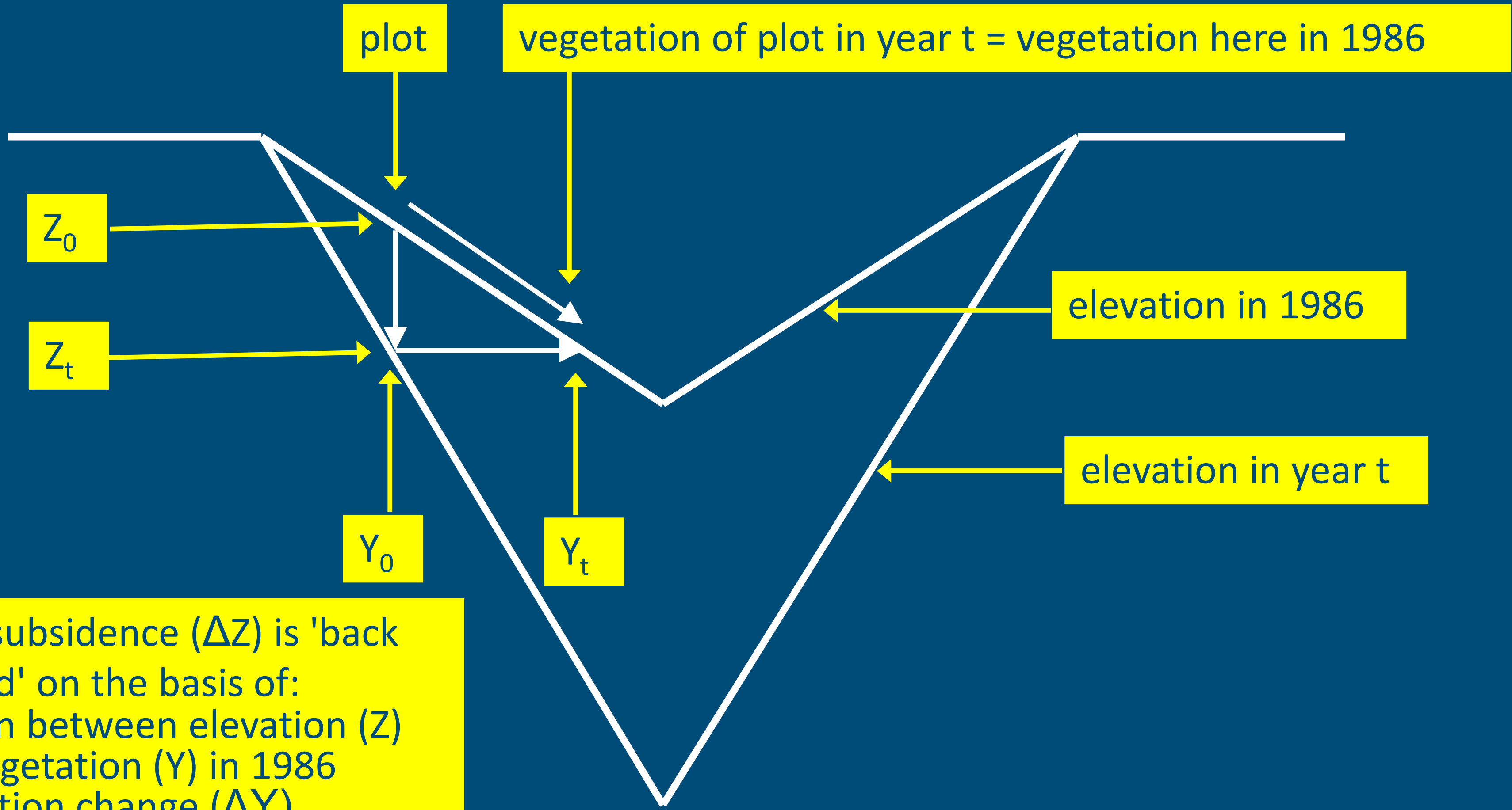
compare this component with:

- soil subsidence
- ? ? ?

Caution!

- by using this model, any monotonous change may lead to a significant effect of soil subsidence
- other (maybe unknown) environmental variables may also monotonously change over time
- therefore, a check on the regression coefficient of soil subsidence has to be performed
- this is done by estimating the effect of elevation at the start of the monitoring, and comparing this effect to the effect of soil subsidence
- this can be formulated as a testable hypothesis

Back predict soil subsidence from vegetation change



the soil subsidence (ΔZ) is 'back predicted' on the basis of:

- relation between elevation (Z) and vegetation (Y) in 1986
- vegetation change (ΔY) since 1986

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Outline of back prediction method

- Denote vegetation condition (DCA - $AX_{1...3}$ or biodiversity index) as Y
- Y = f (groundwater level, flooding frequency) (1)
- groundwater level, flooding frequency = f (weather, elevation) (2)
- elevation = elevation(1986) + subsidence (3)
- subsidence = f (position · time) (4)
- (1) + (2) + (3) + (4) ➔
- Y = f (elevation(1986) , position · time , weather) (5)

temp.change: ↑ constant ↑ linear ↑ oscillatory

- a comparison of the effects of elevation(1986) and position · time yields an estimate ('back prediction') of soil subsidence
- a comparison of the 'back predicted' and measured soil subsidence will tell if the subsidence can really be the cause of the changes

Result: back predicted compared to measured soil subsidence

Y variable	weather represented by:	back predicted / 'true' soil subsidence (99% conf. interval)		
		lower limit	estimate	upper limit
phreatic level	precipitation	-1.78	-0.50	0.81
AX1	precipitation	-1.12	0.19	1.41
AX2	precipitation	-4.96	2.55	13.05
AX3	precipitation	-26.95	-7.63	-2.46
(-) rotatated AX1	precipitation	0.68	2.12	3.61
(+) rotatated AX1	precipitation	-4.66	1.64	7.87
conservancy value	precipitation	-27.30	-7.93	-2.72
Nspec	precipitation	-1.88	0.77	3.16
flooding	flooding at 2 m	1.28	1.56	1.85
AX1	flooding at 2 m	0.03	0.53	1.06
AX2	flooding at 2 m	*	*	*
AX3	flooding at 2 m	-0.56	1.62	5.57
(-) rotatated AX1	flooding at 2 m	0.32	0.93	1.59
(+) rotatated AX1	flooding at 2 m	0.50	1.50	2.75
conservancy value	flooding at 2 m	-0.98	2.66	277.12
Nspec	flooding at 2 m	-0.60	0.52	1.72

- if the range contains 0:
  - ➔ linear effect is n.s.
- if the range contains 1:
  - ➔ hypothesis that change in Y is due to soil subsidence cannot be falsified
- if the upper limit is <0:
  - ➔ soil rise has to be assumed to explain the change in Y

Result: magnitude of the three components compared

variable	weather represented by:	percentage variance in the fitted values that can be explained by:		
		soil subs	weather	topography
phreatic level	precipitation	0.0%	5.8%	94.2%
AX1	precipitation	0.0%	0.1%	99.8%
AX2	precipitation	0.1%	0.0%	100.0%
(-) rotated AX1	precipitation	2.4%	0.0%	96.8%
(+) rotated AX2	precipitation	0.0%	0.0%	100.0%
Nspec	precipitation	0.0%	2.3%	94.5%
floooding	flooding at 2 m	7.3%	6.9%	88.8%
AX1	flooding at 2 m	1.3%	0.2%	98.8%
AX3	flooding at 2 m	2.7%	0.0%	98.3%
(-) rotated AX1	flooding at 2 m	3.4%	0.0%	96.6%
(+) rotated AX2	flooding at 2 m	3.4%	1.5%	96.3%
conservancy value	flooding at 2 m	2.3%	0.0%	98.0%
Nspec	flooding at 2 m	0.4%	0.0%	100.0%

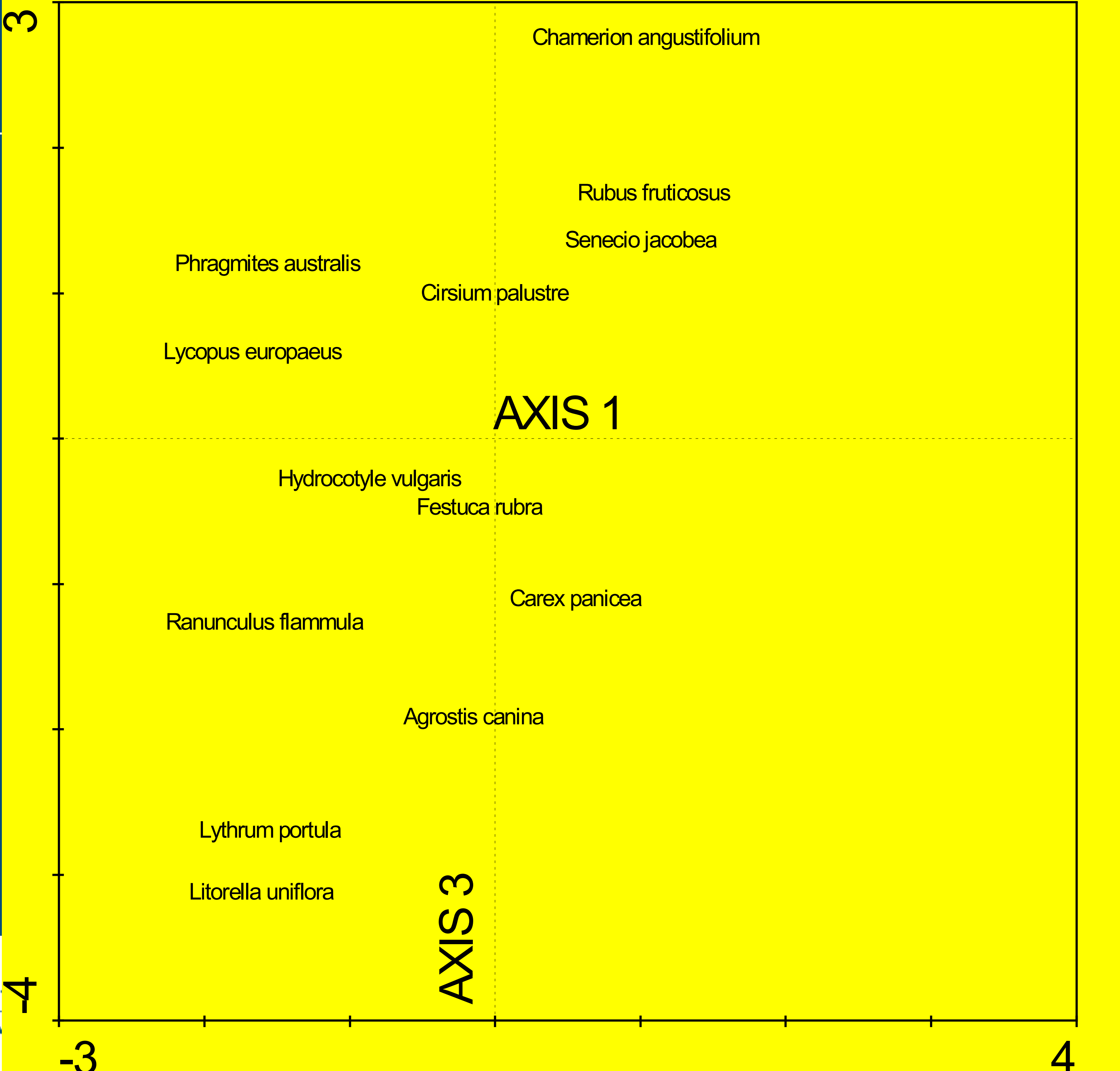
- only for those variables whose change may be due to soil subsidence
- irrespective of statistical significance

Conclusions

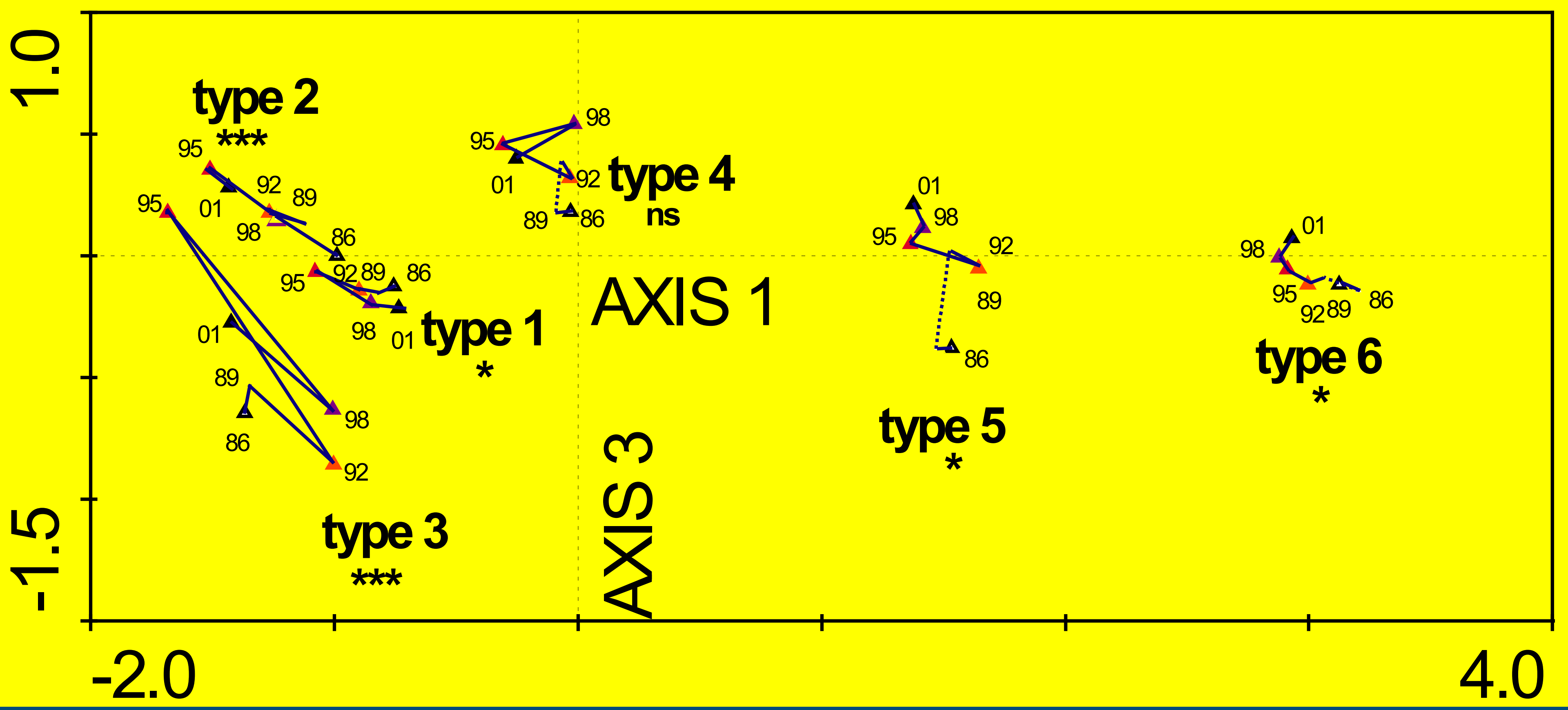
- temporal change very small compared to spatial differences
- soil subsidence and weather fluctuations have contributed about equally to the temporal changes
- the change in DCA-AX3 and in conservancy value can neither be explained from soil subsidence, nor from weather fluctuations

What caused the changes in AX3 and conservancy value?

- to explain these changes from a change in elevation, a rise in elevation has to be assumed
- both changes run markedly parallel over time, so they may have a common cause



3
-4
-3
4
AXIS 1
AXIS 3
Chamerion angustifolium
Rubus fruticosus
Senecio jacobea
Phragmites australis
Cirsium palustre
Lycopus europaeus
Hydrocotyle vulgaris
Festuca rubra
Carex panicea
Ranunculus flammula
Agrostis canina
Lythrum portula
Litorella uniflora



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Productive species seem to increase!

- has been noted by many other authors in the Dutch dunes
- generally considered as a loss of biodiversity
- cause unknown
  - 'autonomous' succession?
  - nitrogen deposition?
  - change in management?
  - collapse of rabbit population?

Afsluiting