Department of Sustainability and Environment

Modelling Ecosystems

Freshwater Wetlands in the Face of Salinisation and Climate Change

Changhao Jin

Freshwater Wetlands

- Wetlands are among the most biologically productive and diverse ecosystems on Earth.
- Wetlands are vitally important for water quality, trapping sediments, removing excess nutrients and mitigating floods.
- Wetlands are also among the most threatened ecosystems of our planet.
- In Victoria, 37 per cent of natural wetland area has been lost since European settlement.
- Key threats: drainage
  - drought
  - altered water regimes
  - salinisation
  - grazing
  - increased nutrient load
  - climate change
- Climate change and salinity are two large-scale and long-term ecosystem drivers that are likely to increase in strength and spatial scale in the next 30-50 years in Australia.

Secondary Salinisation

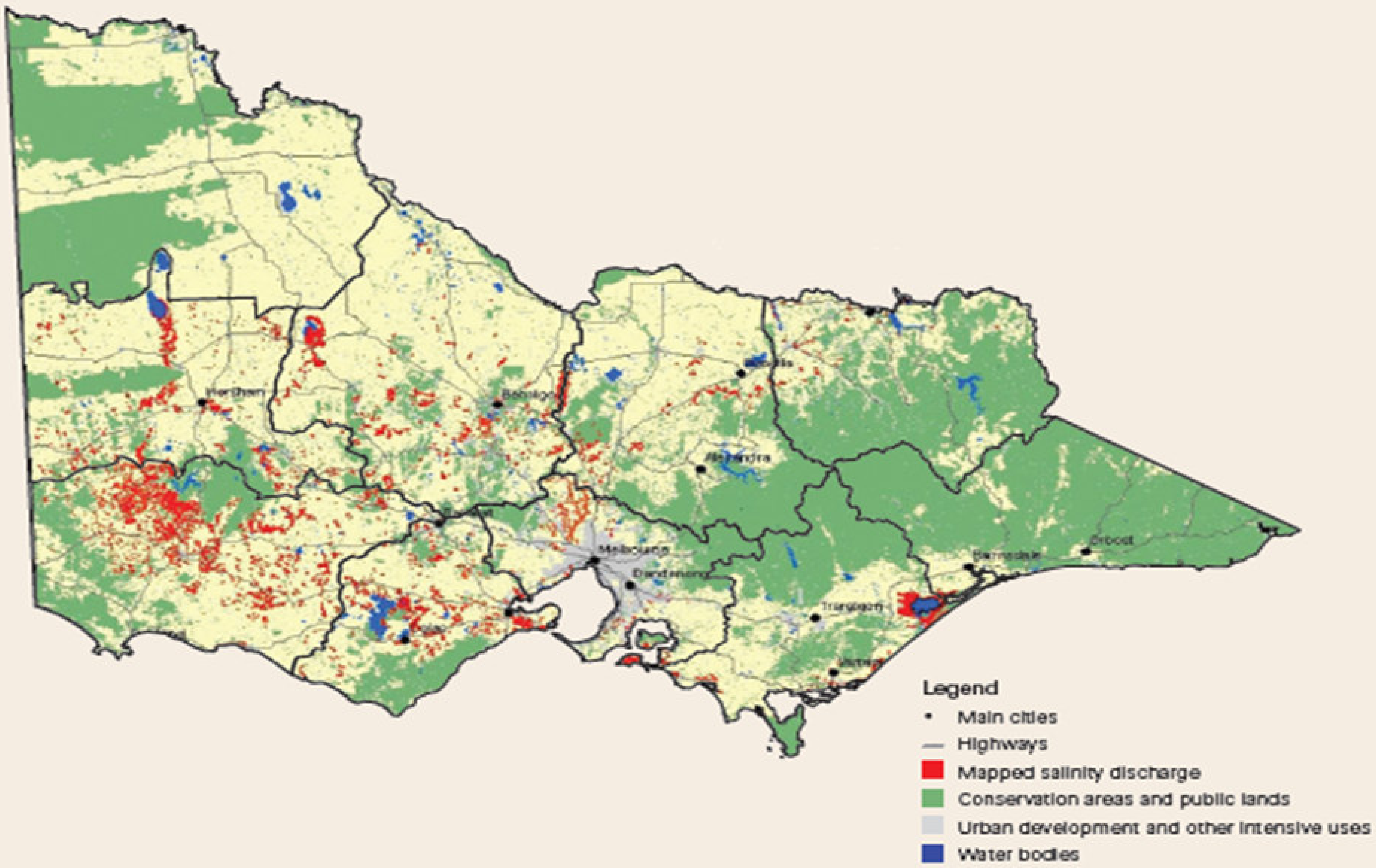
- Secondary salinisation is a human-induced process that changes the water and salt cycles, resulting in salinity increase in soil and water.

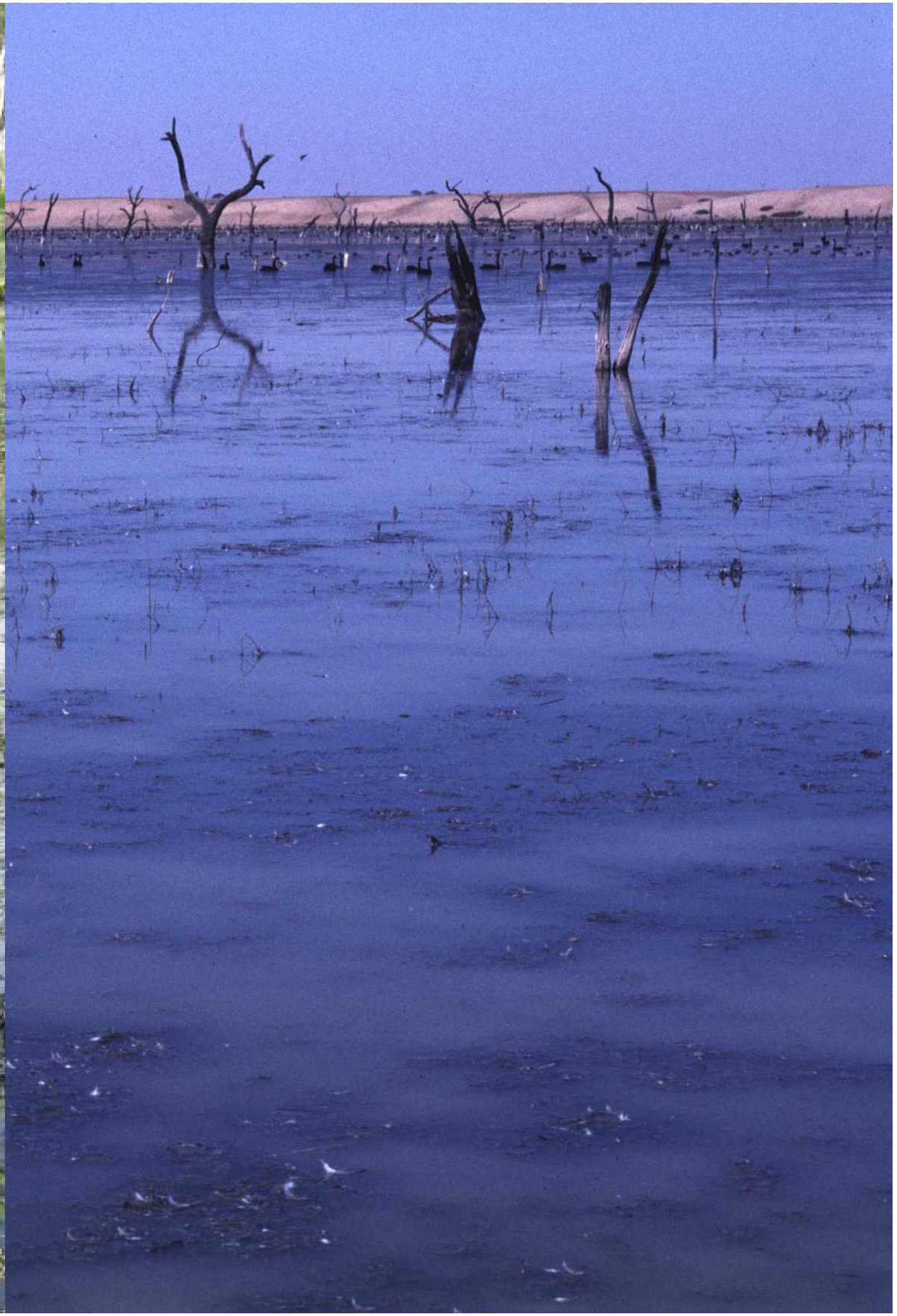
- Major causes: Vegetation removal
  Agricultural development
  Urban development

- 670,000 hectares in Victoria had a high potential to develop dryland salinity.

- By 2050, the area was expected to be 3.1 million hectares.

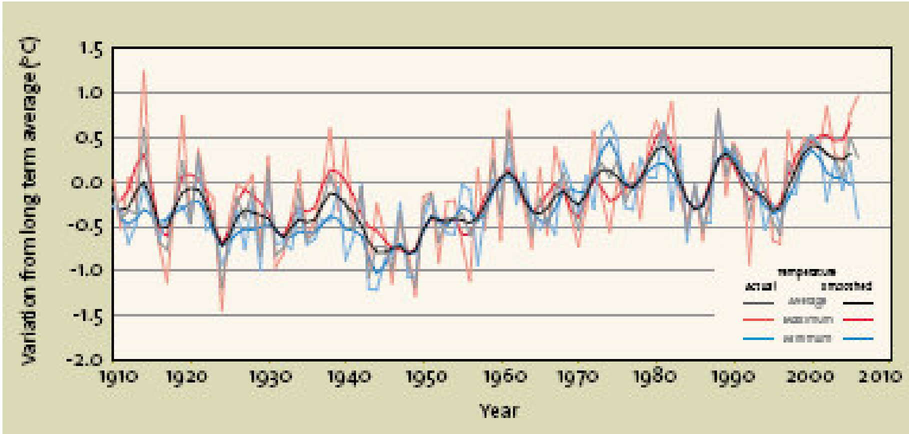
Mapped Salinity Discharge Across Victoria

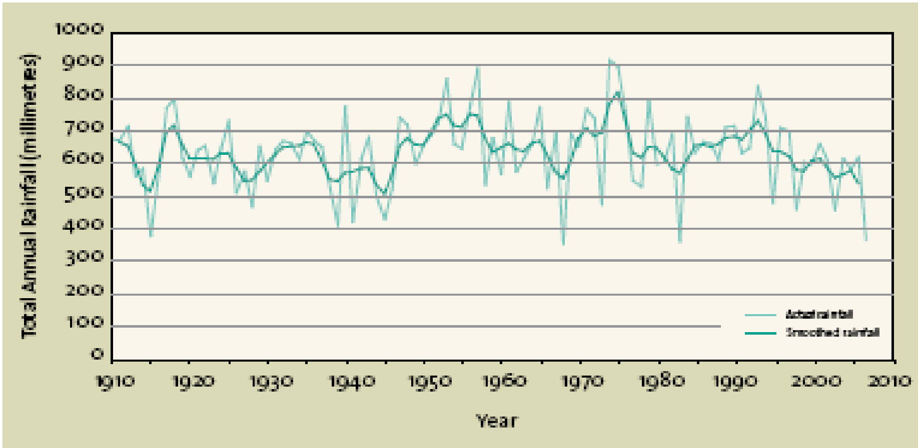


Observed Changes in Victoria's Climate

- Climate change involves changes in the average climate and increasing climate variability.
- Annual average temperatures have increased by about 0.6 degrees Celsius since 1950.
- Victoria has experienced substantial rainfall declines since 1950.

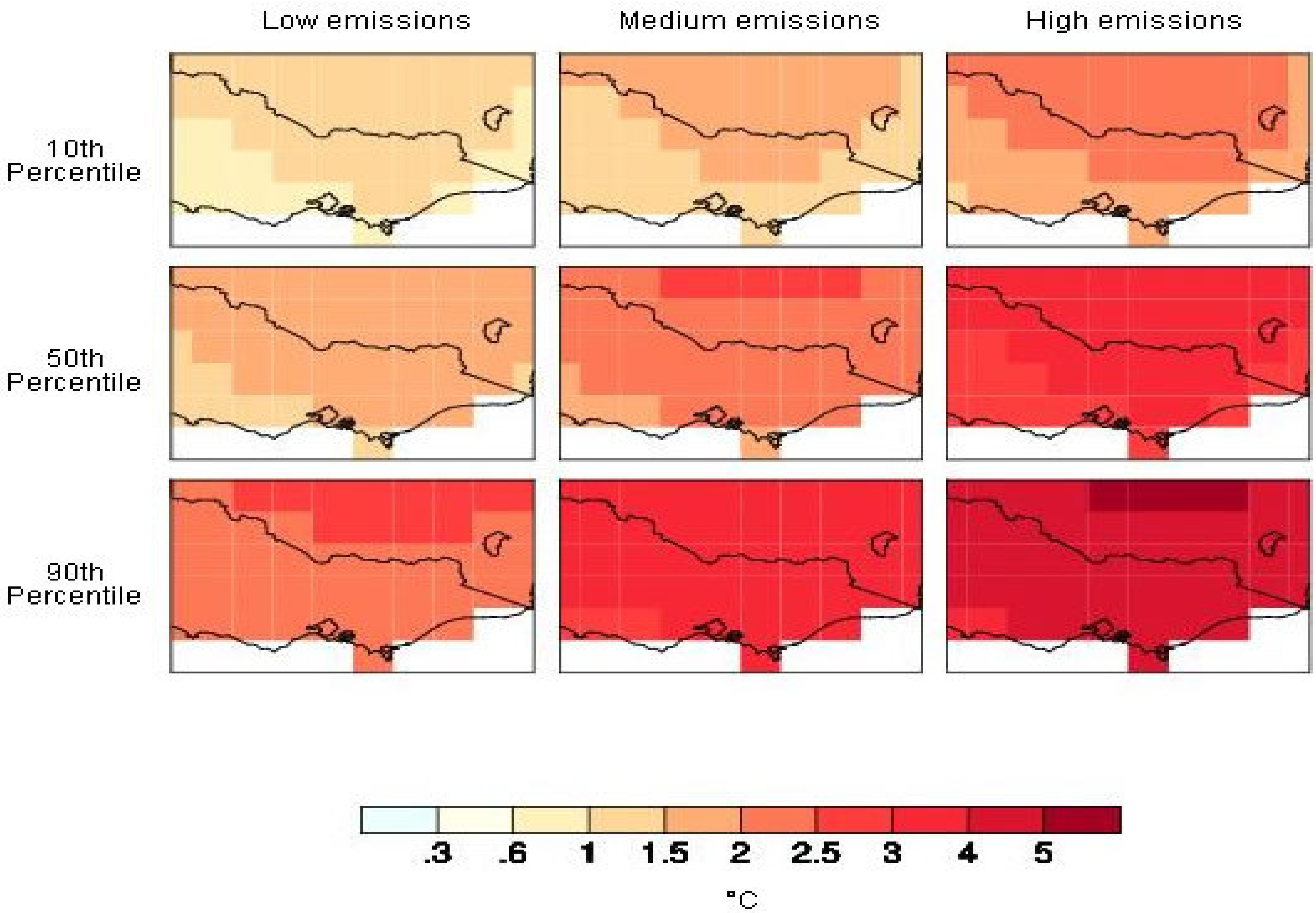




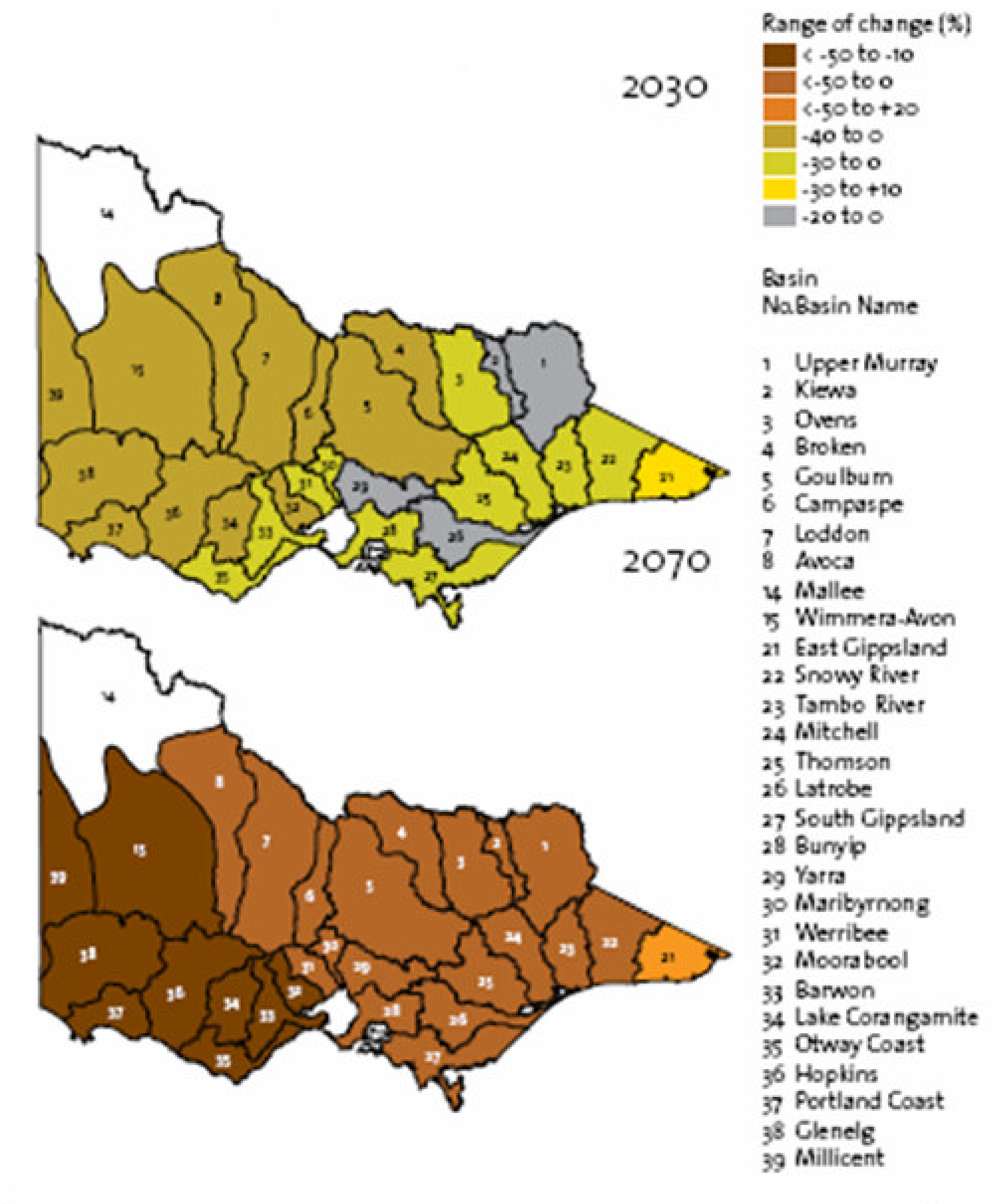
Projected Victoria's Future Climate

- Further increases in temperature
- Rainfall decreases are likely
- The frequency of extreme maximum temperatures will increase
- Extreme daily rainfall events may become more intense and more frequent in many regions
- Droughts may become more frequent and more intense

Victoria Temperature Change 2070 Summer



Projected Changes in Average Annual Runoff



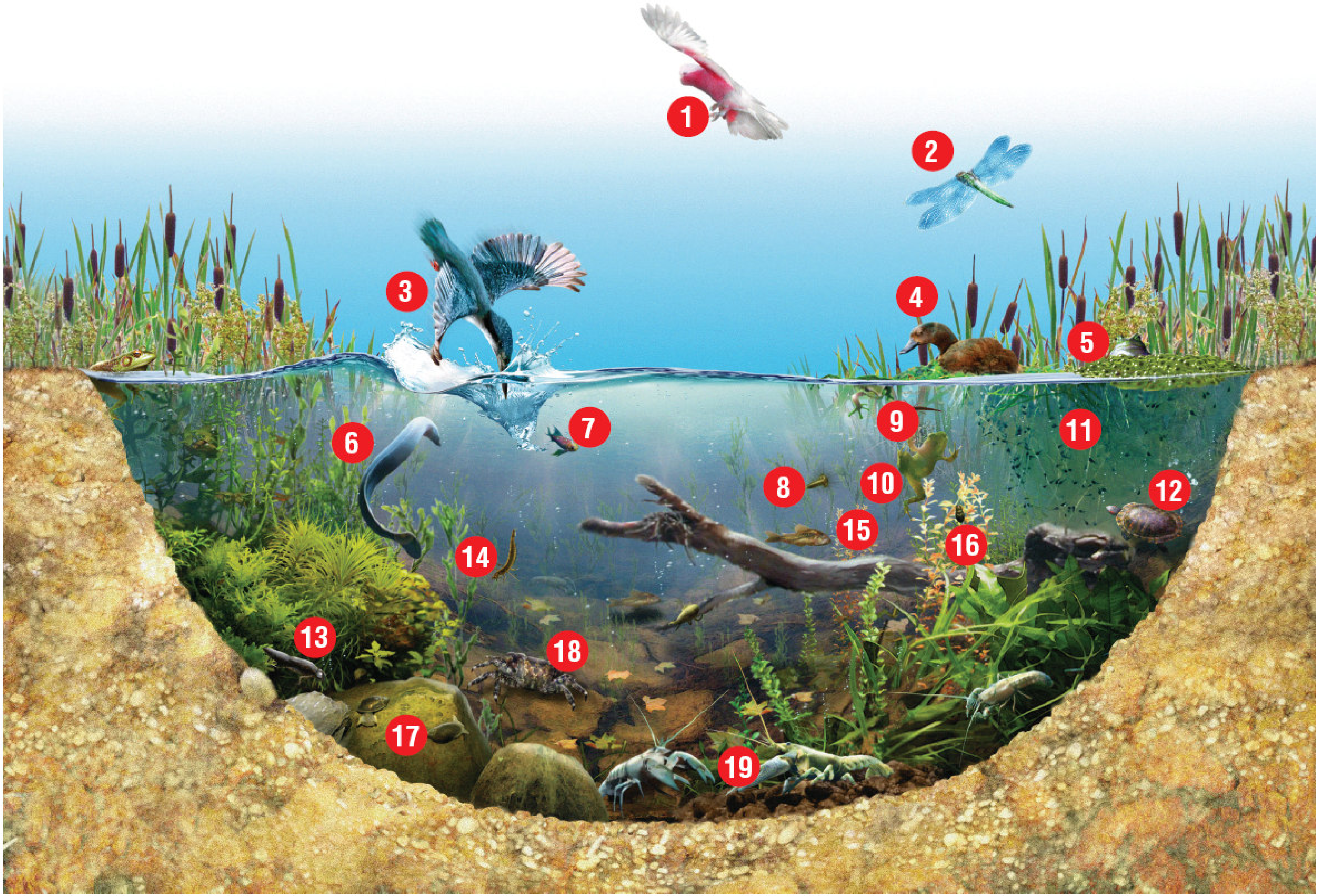
Key Issues

- Stability: ecosystem dynamics and behaviour when its initial biodiversity state changes
  Will initial states approach a stable state?

- Resilience and sensitivity: ecosystem dynamics and behaviour when its initial biodiversity state and the environment change
  Will the ecosystem maintain similar ecological function?

  - Effects of salinity
  - Effects of seasonal variability
  - Impacts of climate change

- How does initial wetland condition influence system dynamics?



1. Galah 2. Dragonfly 3. Kingfisher 4. Duck 5. Frog 6. Freshwater eel 7.Rainbow fish 8. Mosquito larva, wriggler 9. Damselfly nymph 10. Froglet 11. Tadpoles 12. Freshwater turtle 13. Great diving beetle larva 14. Whirligig beetle larva 15. Mosquito fish 16. Water boatman 17. Freshwater snails 18. Freshwater crab 19. Freshwater yabbies.

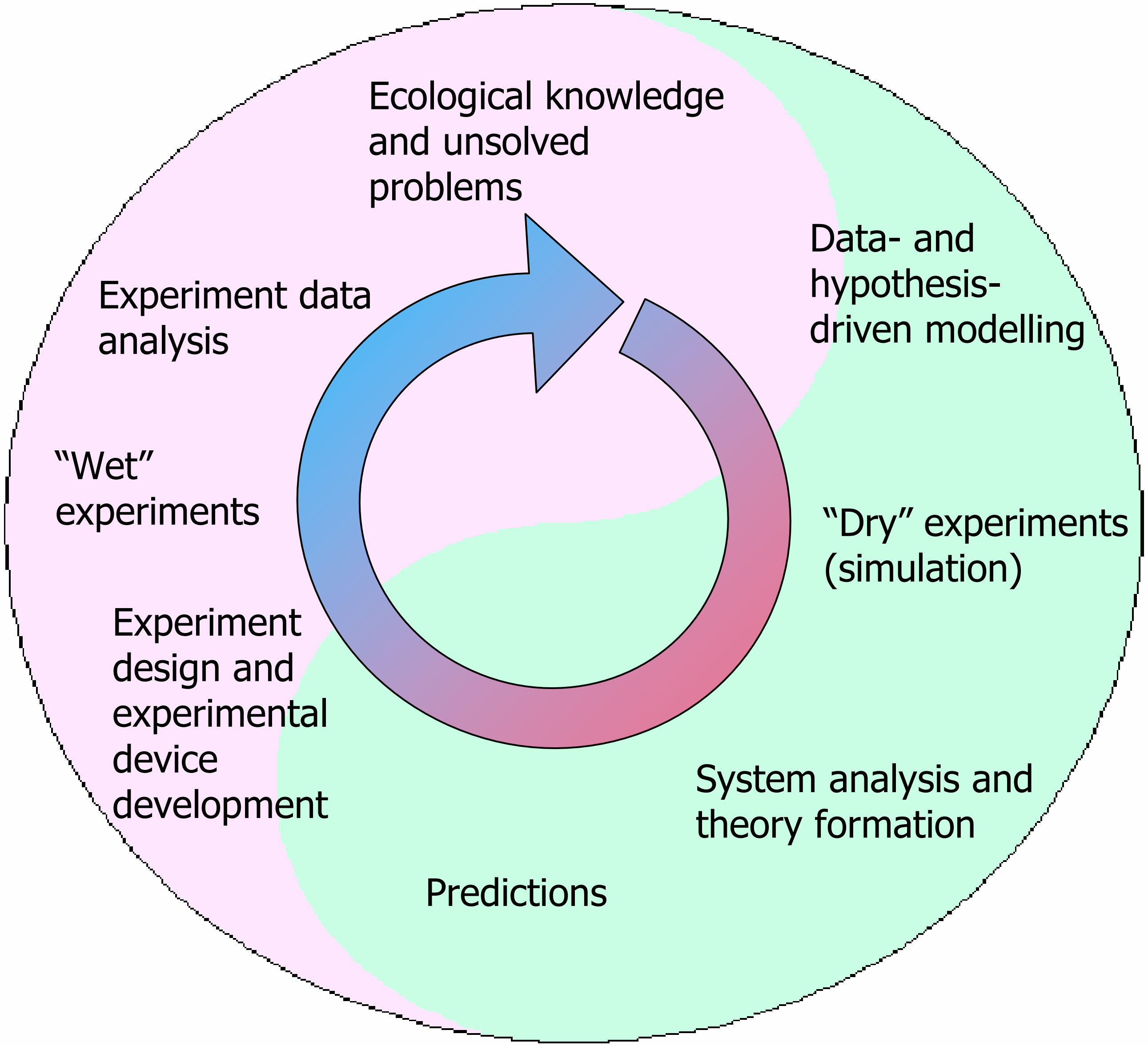
Wetland Ecosystem as a Complex System

- A wetland ecosystem comprises a large number of biotic and abiotic components
- Complex interactions between species
- Complex interactions between species and their environment
- Emergent system properties and behaviours arise from self-organisation of interacting components of an ecosystem
- The complex system as a whole cannot be fully understood simply by analysing its components

"How can it be that writing down a few simple and elegant formulae, like short poems governed by strict rules such as those of the sonnet or the waka, can predict universal regularities of Nature?"

Murray Gell-Mann

Multidisciplinary Approach



Modelling

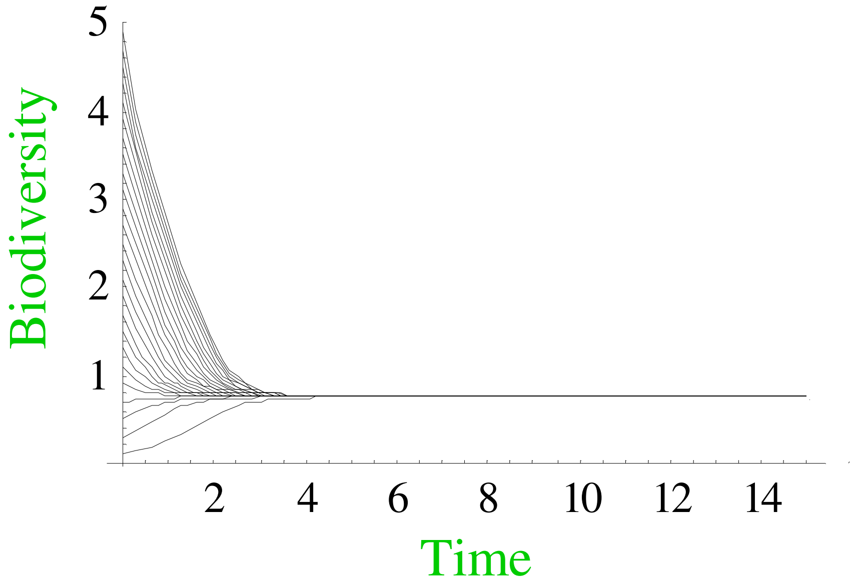
- Ecosystem state variable: species richness

- Species richness is maintained by the fundamental ecological processes: migration, extinction and speciation

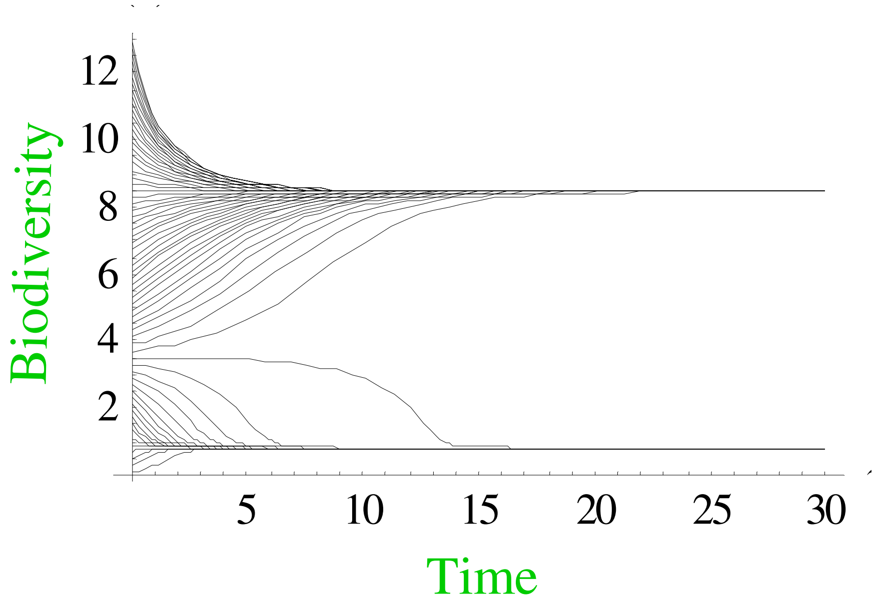
- Converted processes appropriate for mathematical representations of wetland ecosystems:
  - Diversification in the absence of disturbance
  - Biodiversity loss due to salinisation
  - Seasonal variability

Wetlands in a constant environment

Stability

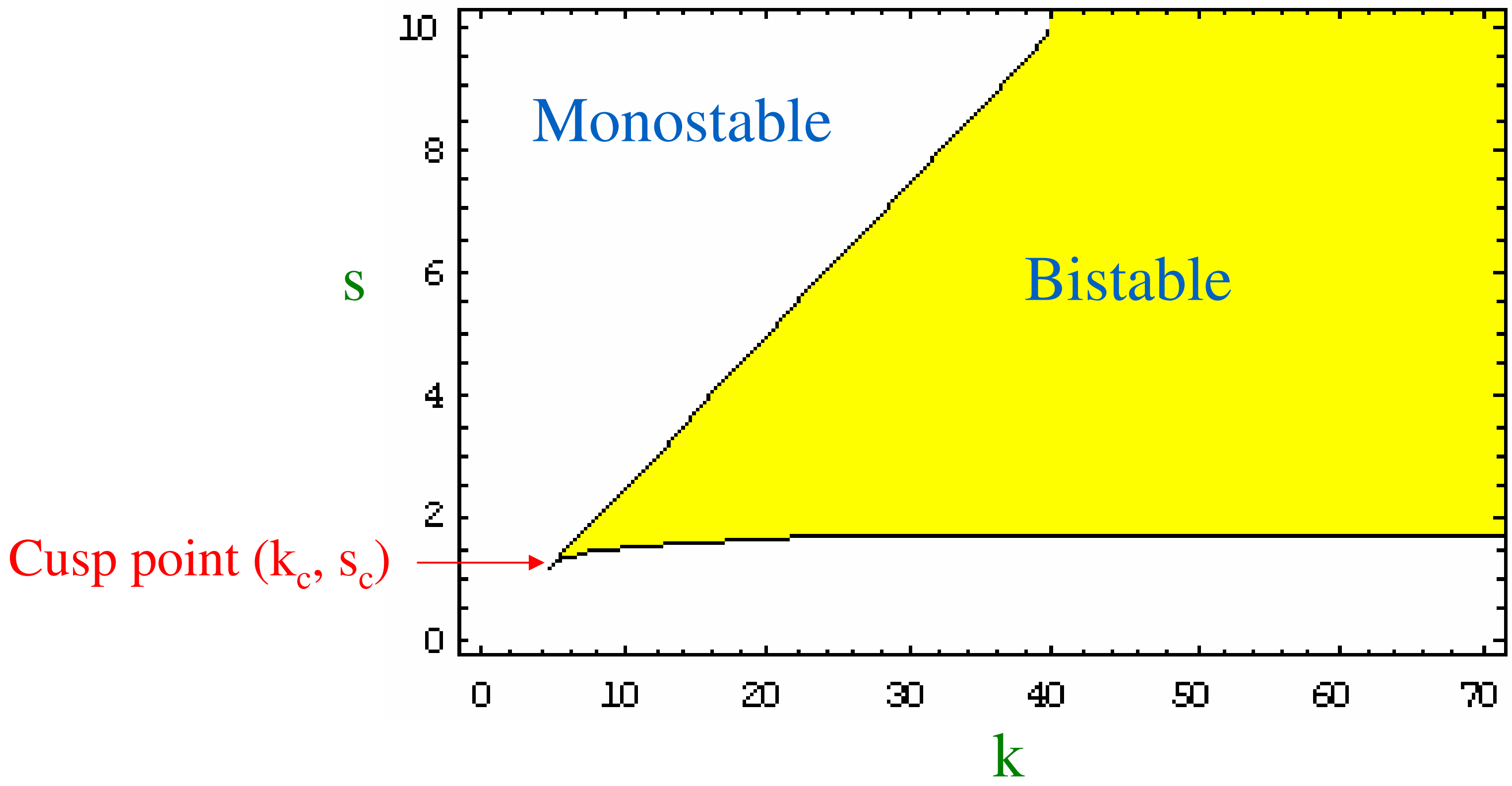


Monostability



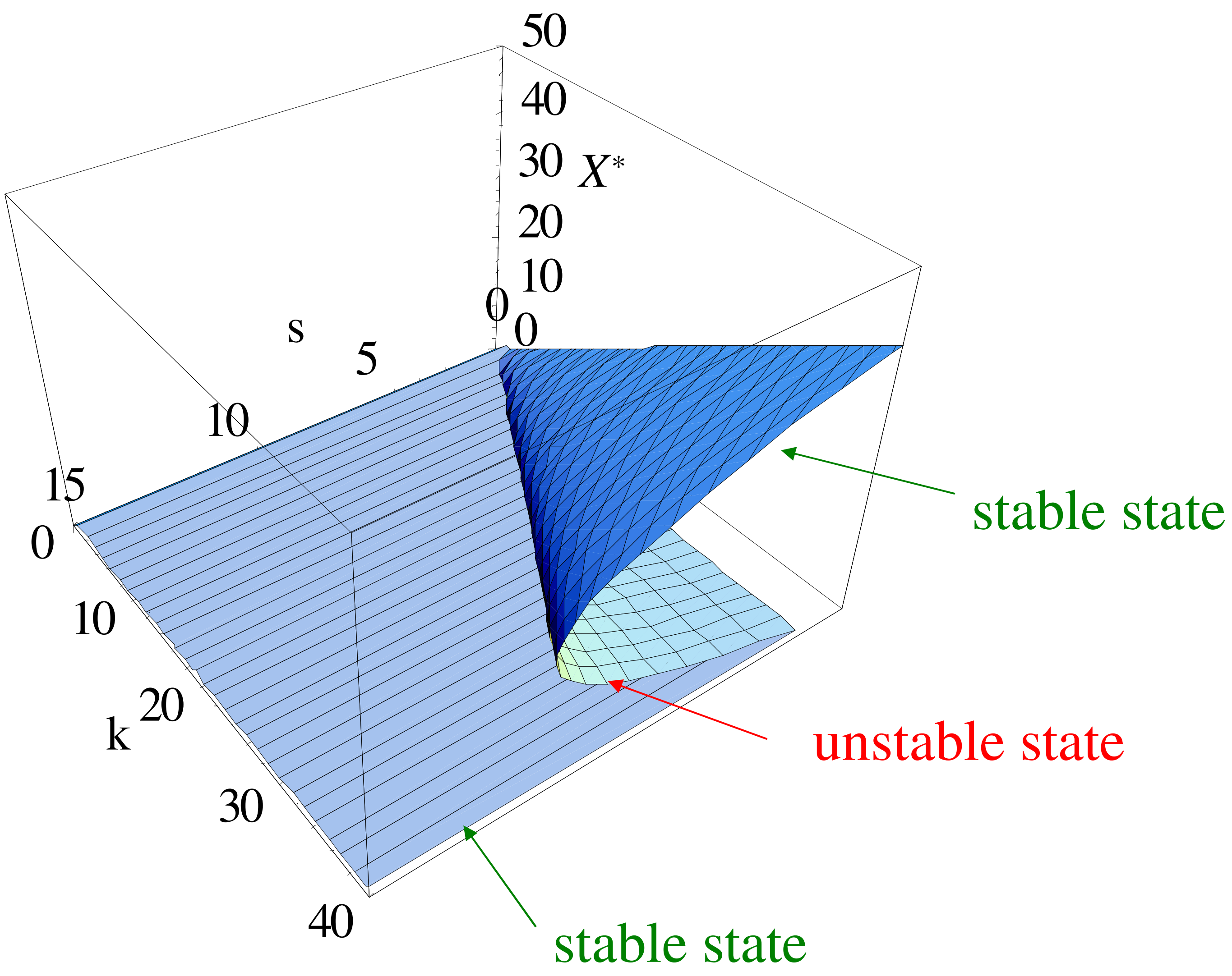
Bistability

Parameter Space

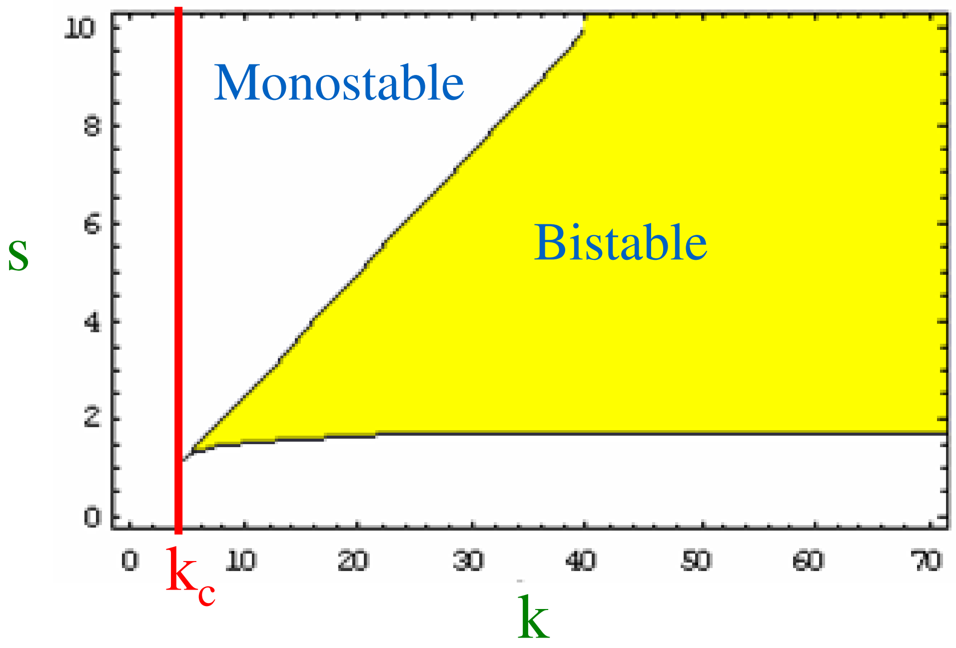


- Wetland quality parameter *k*
- Salinity parameter *s*

Equilibrium Biodiversity-Scape



Classification of Wetlands



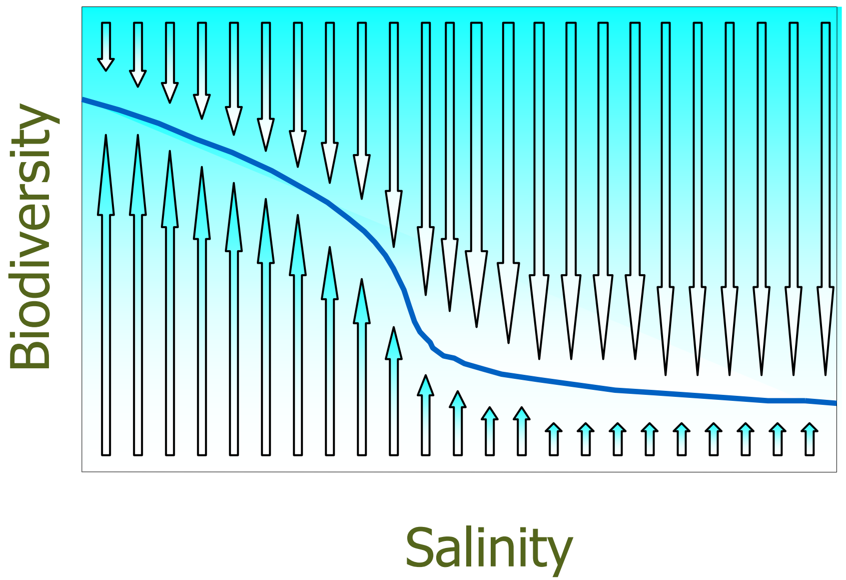
Type 1 wetlands: low quality with $k < k_c$

Type 2 wetlands: high quality with $k > k_c$

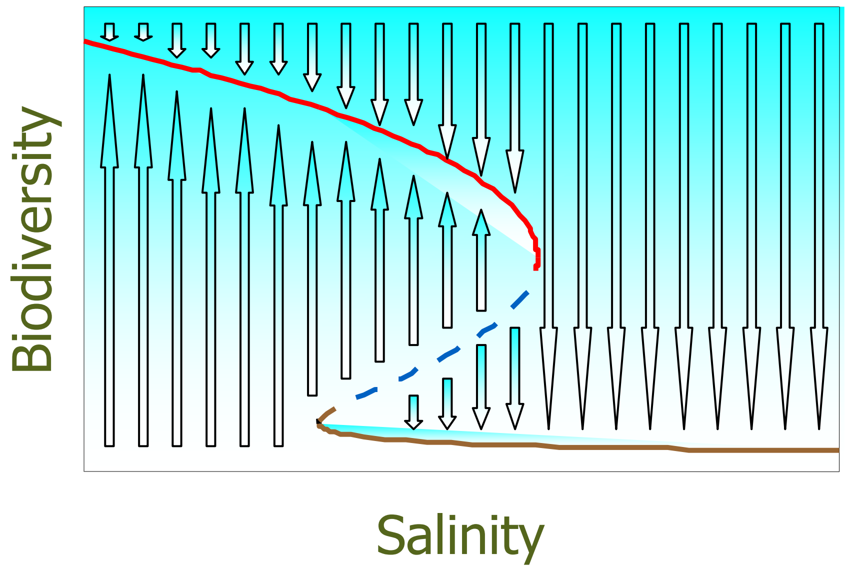
Effects of Salinity

Two types of wetland responses to changing salinity:

Type 1 wetlands: graded response



Type 2 wetlands: hysteretic response



Hysteresis: a retardation of a system response when the changing control variable reverses.

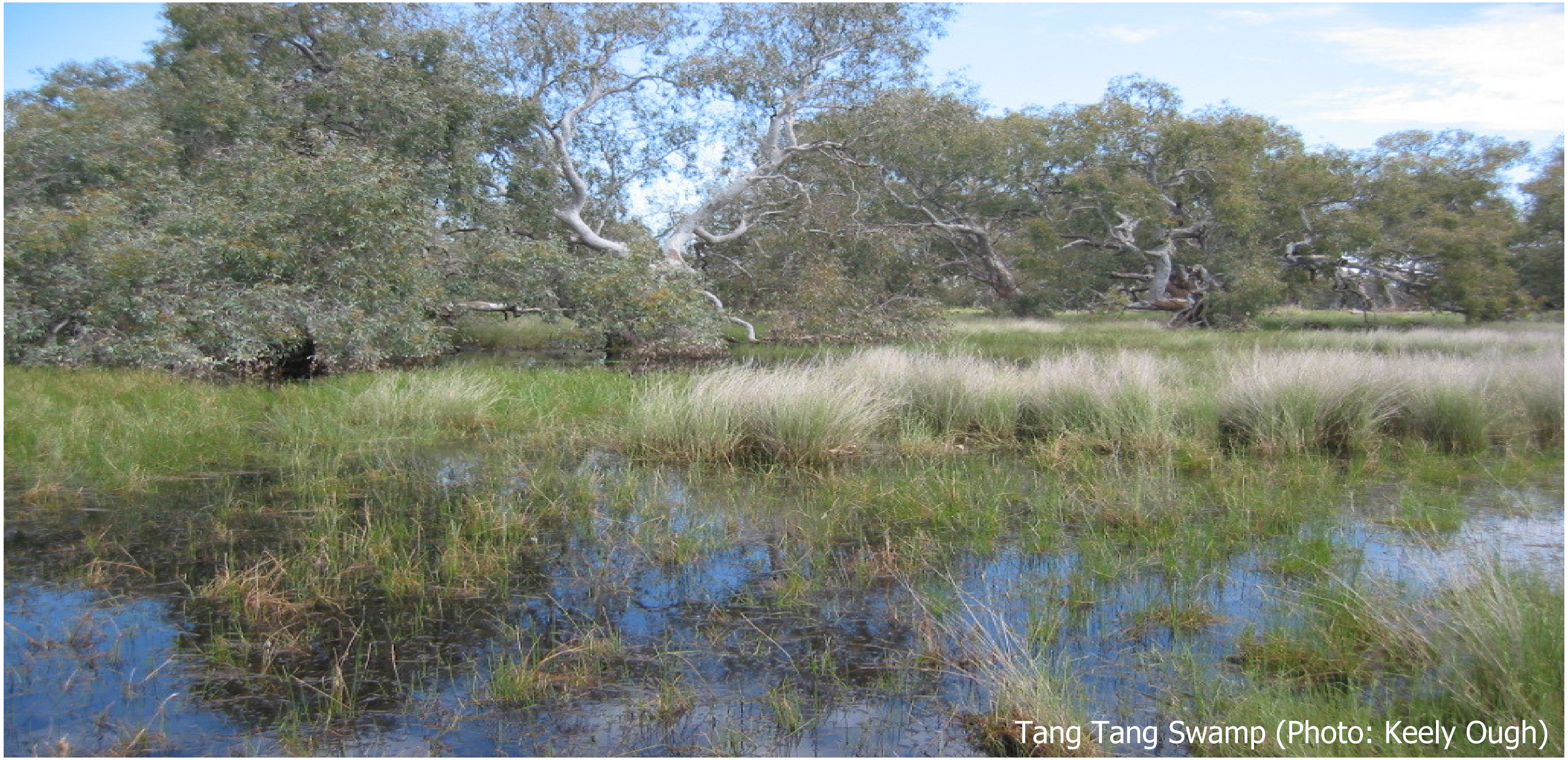
Type 1 Wetlands

- A type 1 wetland has poor condition, low biodiversity and the associated simple community even in the absence of salinisation.
- Wetland condition: the average physical, chemical and biological conditions of a natural, undisturbed wetland.

Lake Cullen (Photo: Kimberley James)

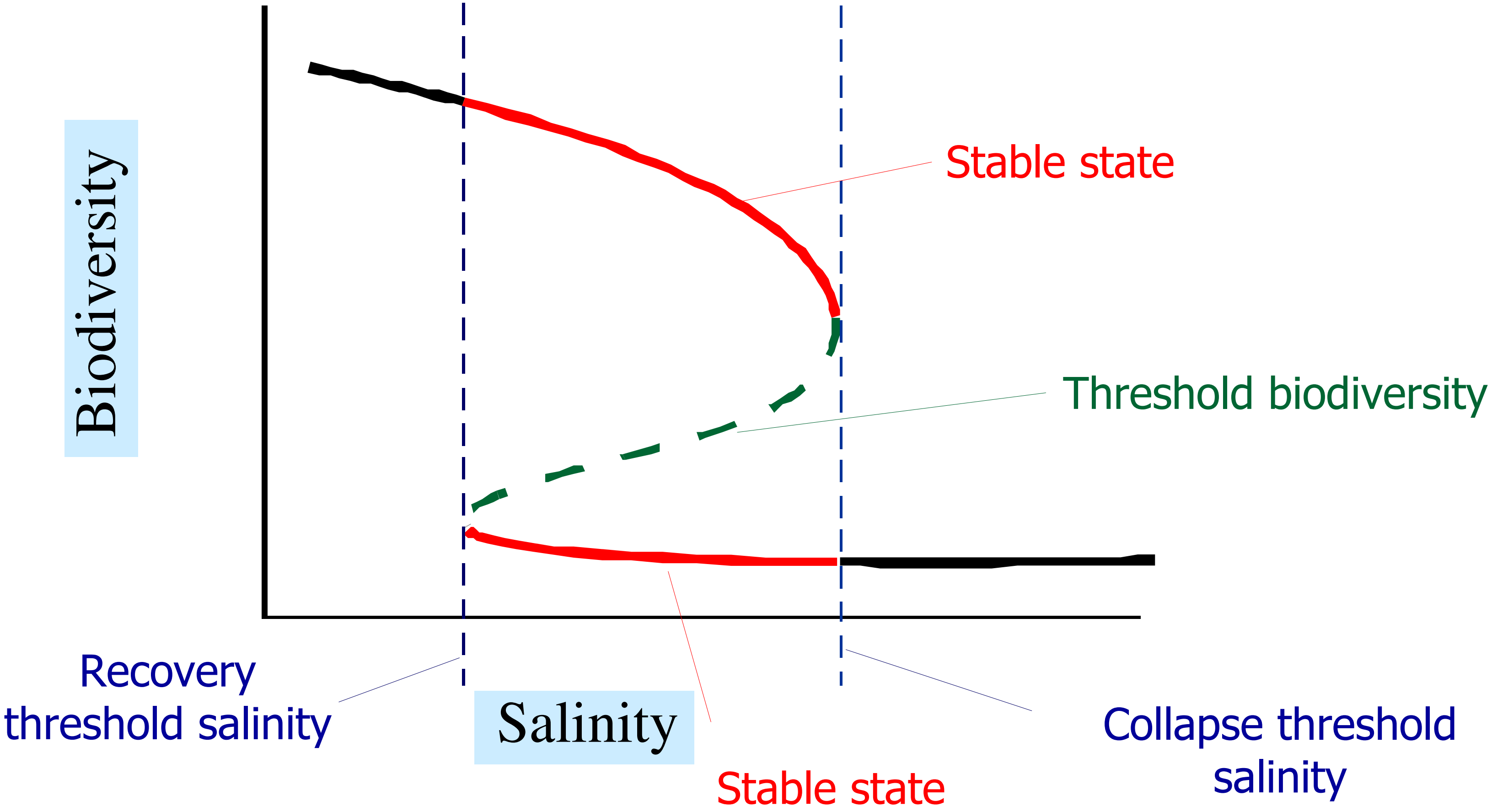
Type 2 Wetlands

A type 2 wetland has good condition, high biodiversity and the associated complex community prior to salinisation.



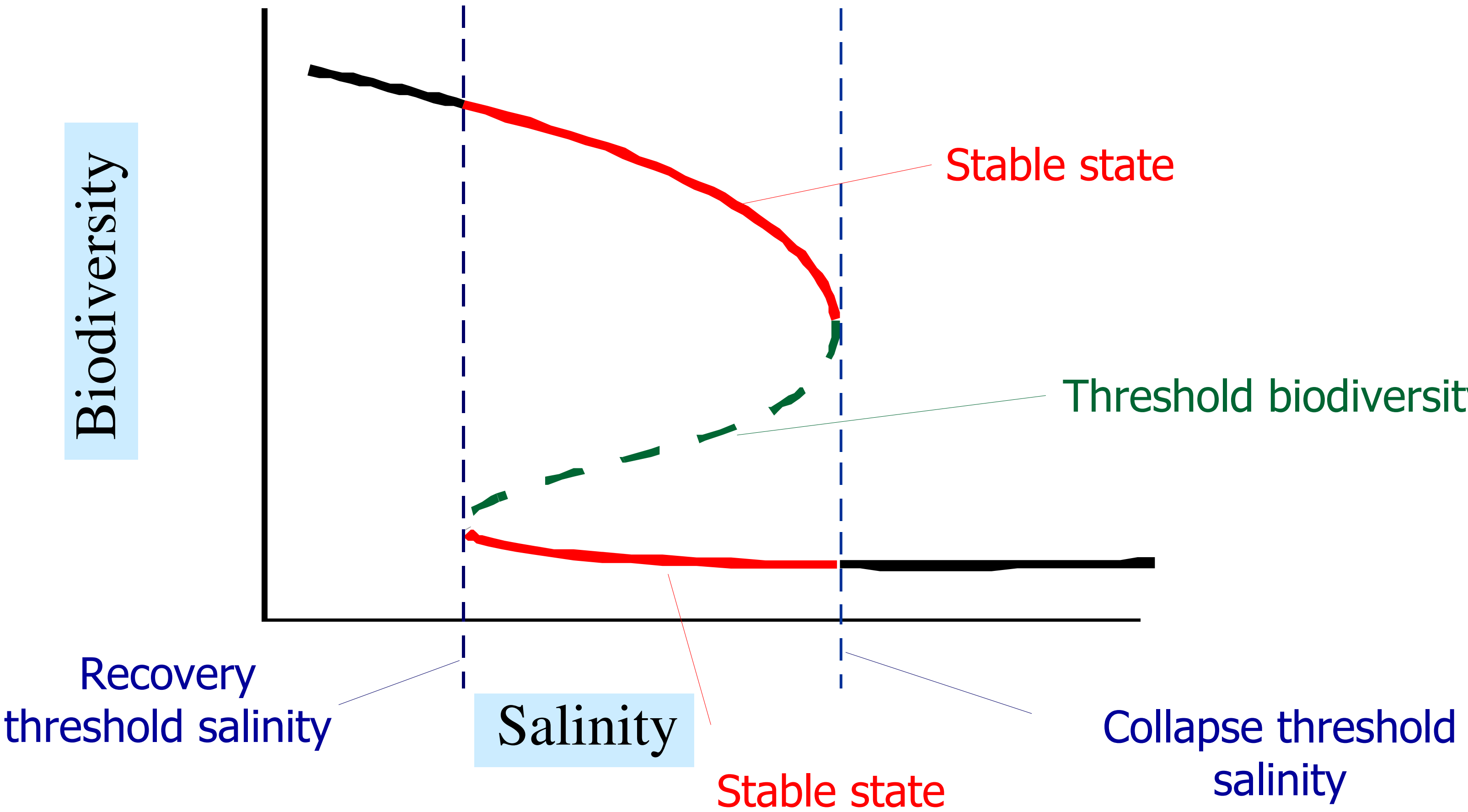
Tang Tang Swamp (Photo: Keely Ough)

Thresholds



- Two thresholds for salinity
- One threshold for biodiversity
- The threshold crossing could be irreversible

Alternative Stable States



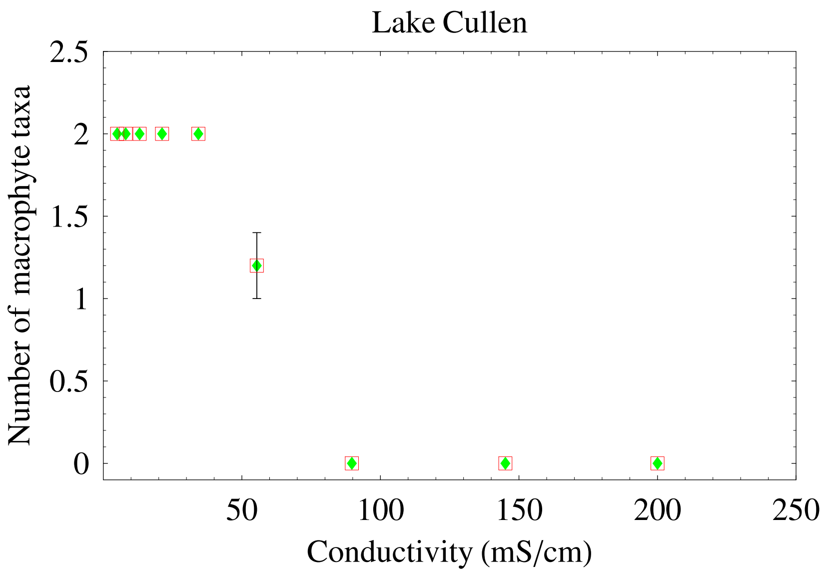
- Two alternative stable states can exist under identical environmental condition.
- The stable state on which the wetland settle is dependent on its initial state.

Experimental Evidence for Type 1 Wetlands

Experiment using sediment from Lake Cullen (~ 330 km northwest of Melbourne)

Phase 1: increasing salinity (green points)

Phase 2: then decreasing salinity (red boxes)

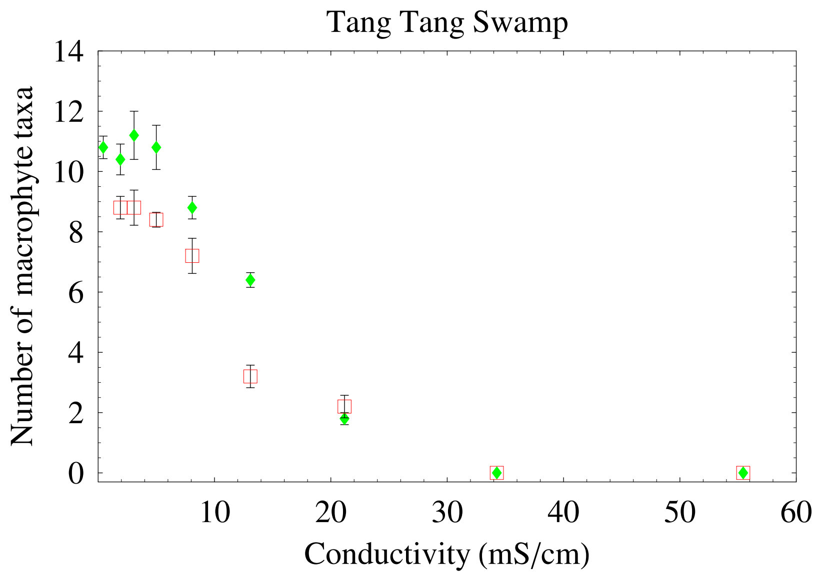


Experimental Evidence for Type 2 Wetlands

Experiment using sediment from Tang Tang Swamp (east of Rochester, central Victoria)

Phase 1: increasing salinity (green points)

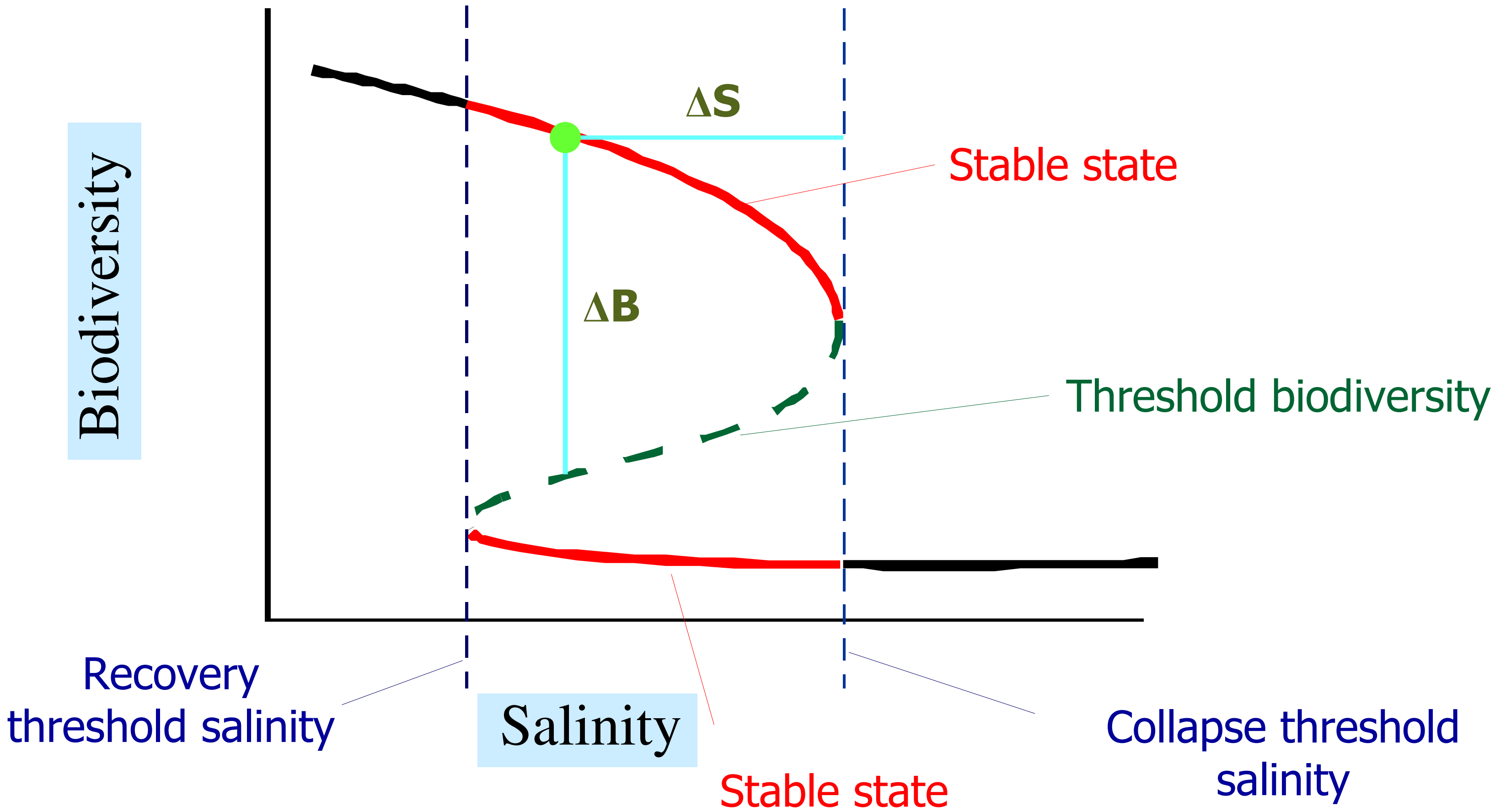
Phase 2: then decreasing salinity (red boxes)



Resilience and Sensitivity

- Ecosystem resilience: the ability of a system to maintain ecological function in the face of disturbance and variability.
- Ecosystem sensitivity: the degree of ecosystem response to a given degree of perturbation.
- Protecting and enhancing wetlands require maintaining and increasing resilience.
- Restoring wetlands requires increasing sensitivity.

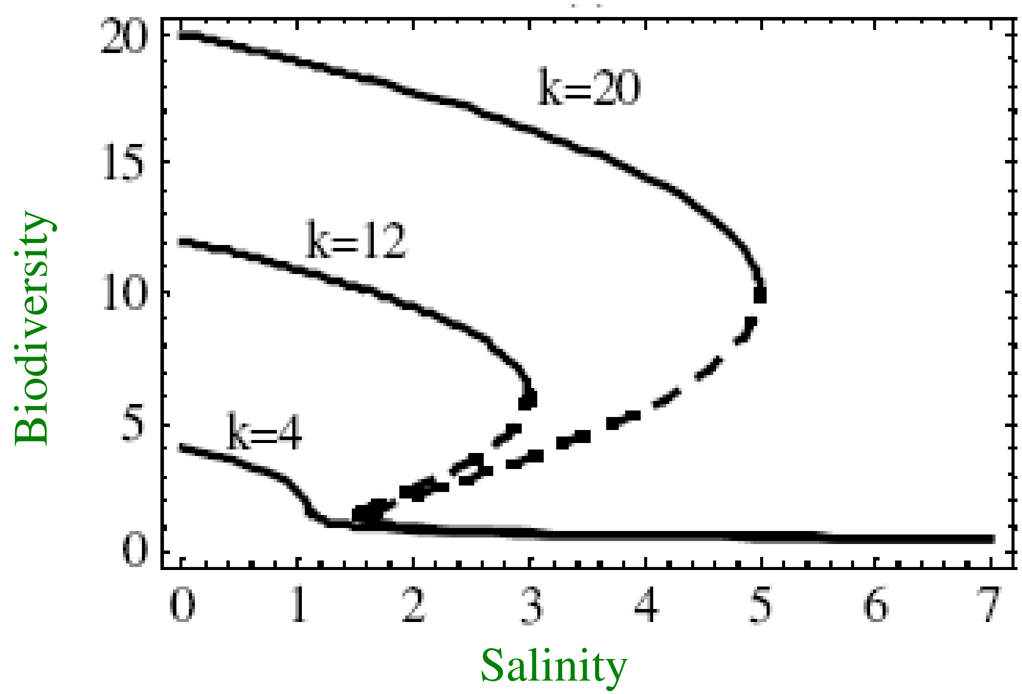
Measure of Resilience or Sensitivity



Distances to various thresholds may serve as a measure of ecosystem resilience or sensitivity.

Resilience and Sensitivity

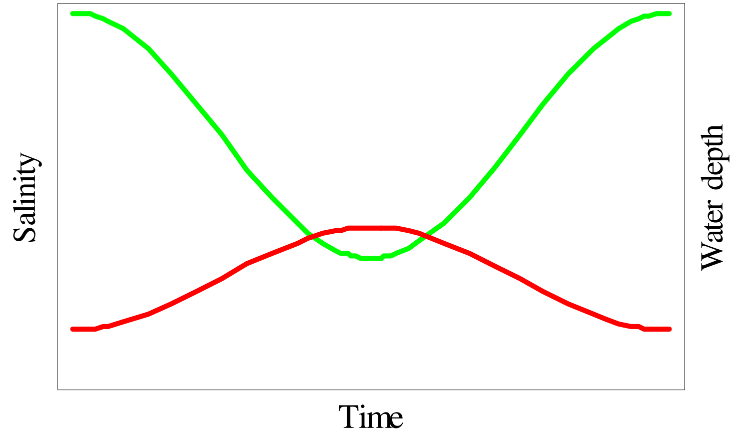
- The key to ecosystem resilience is diversity.
- Ecosystem resilience and sensitivity may vary.
- Better condition, lower salinity, and higher biodiversity enhance wetland resilience and sensitivity.

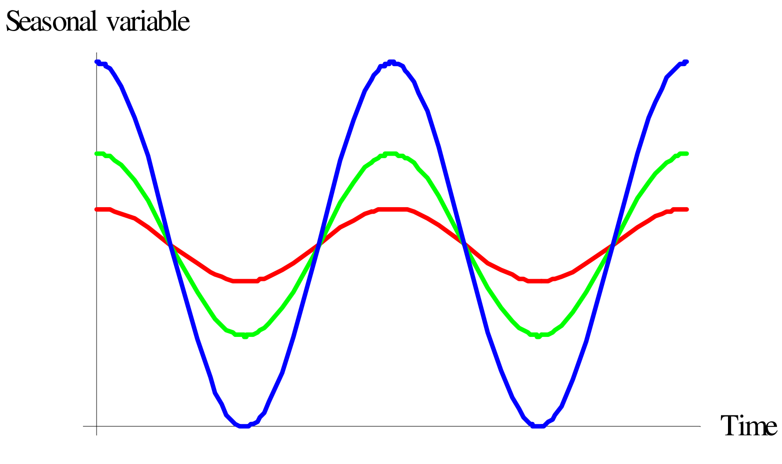


Wetlands in a seasonally changing environment

Seasonal Variability

- Many wetlands have highly variable hydrology.
- As water depth varies seasonally, salinity negatively covaries.
- Seasonality strength: the ratio of the amplitude of the seasonal variable to the mean of it.

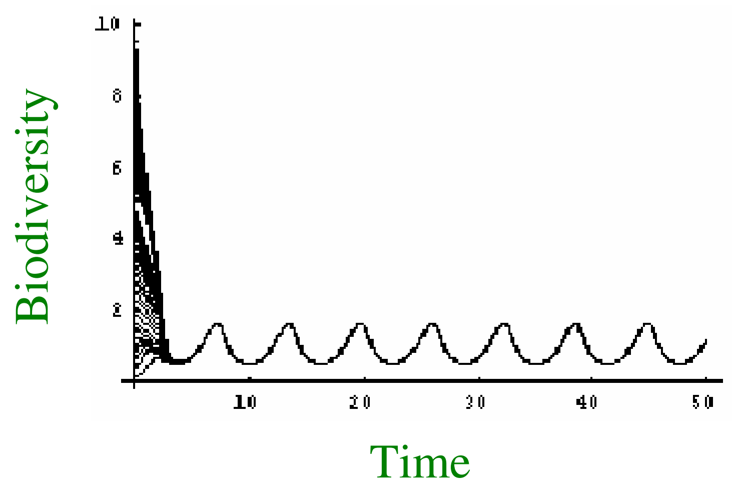




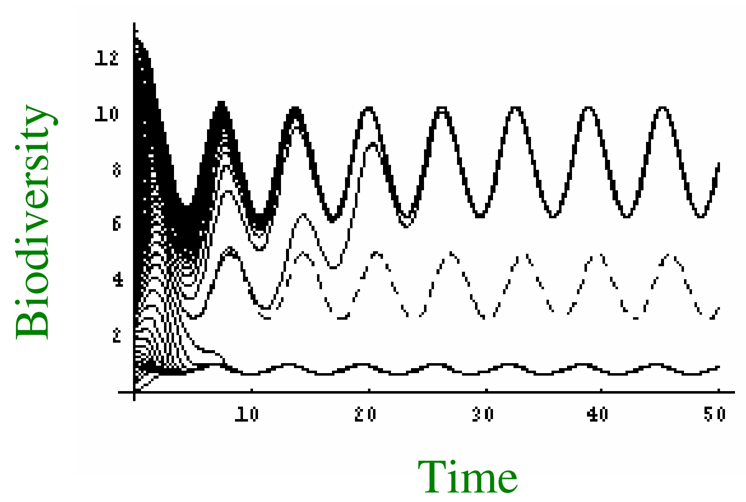
Stability

- Seasonal environmental change drives the wetland ecosystem to a stable oscillatory state of biodiversity, with the same period as the hydrological cycle.
- There are two manifestations of stability in seasonal wetlands.

Monostability

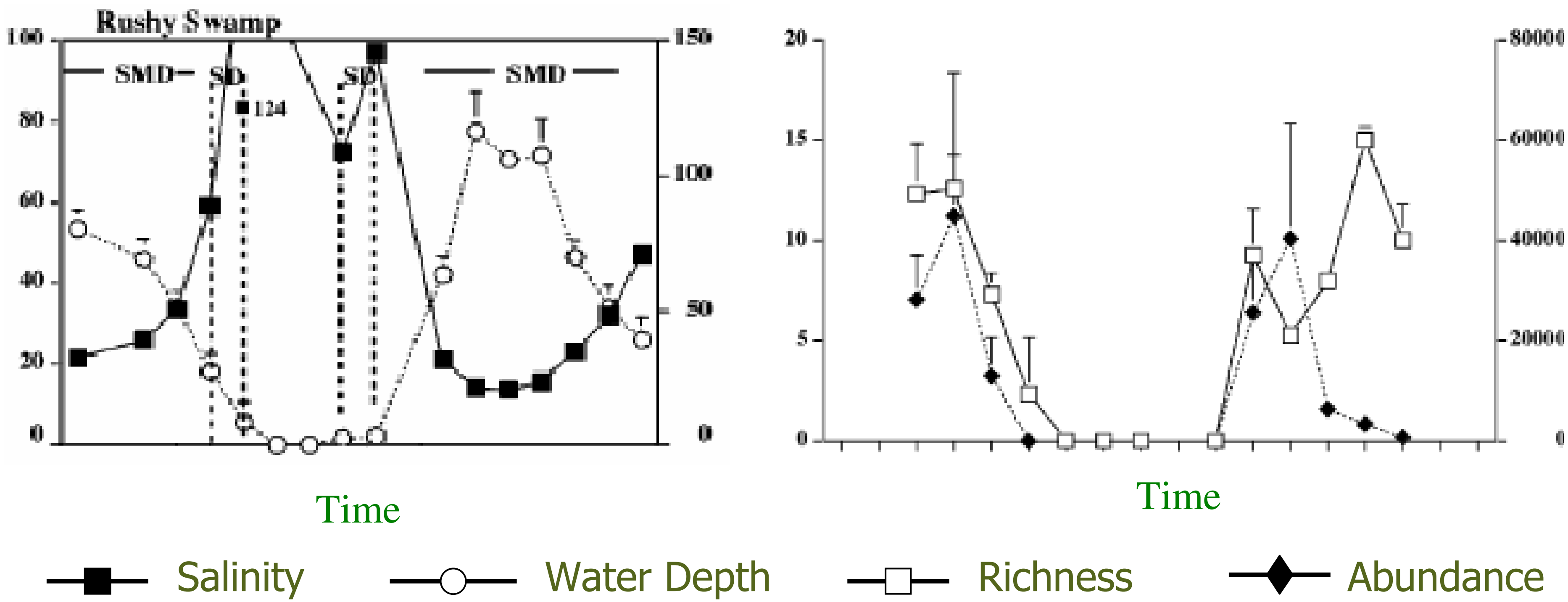


Bistability

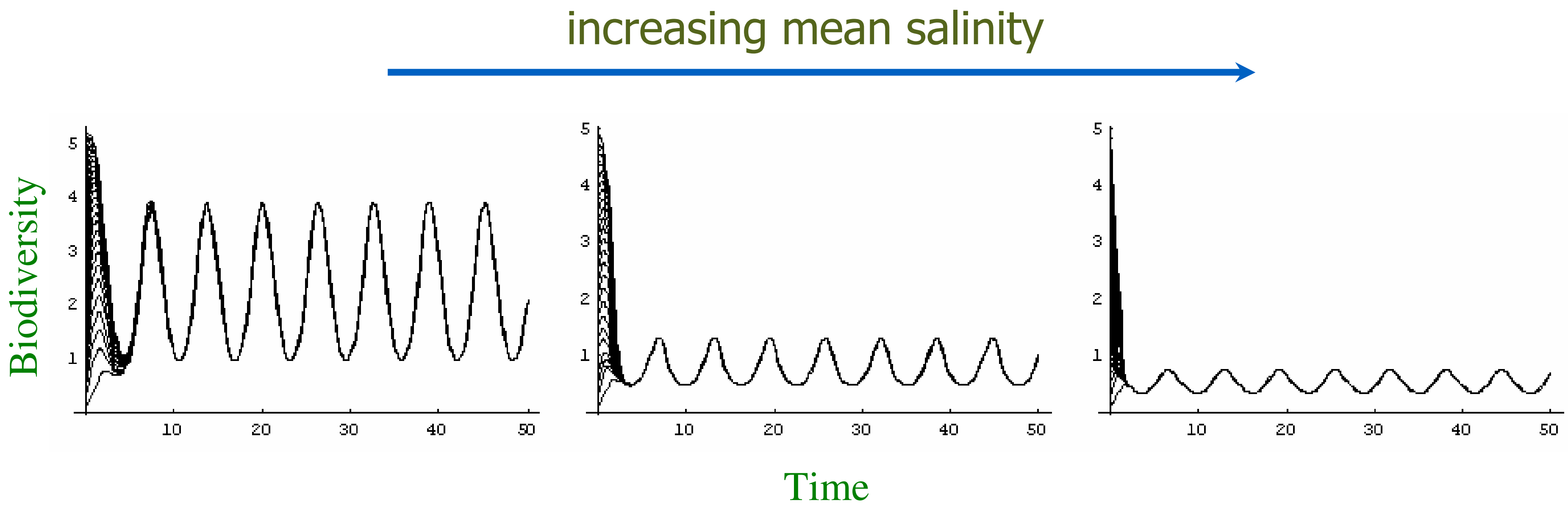


Empirical Evidence

Temporal change in invertebrate species richness in salinised wetlands in Western Australia (Strehlow *et al.*, 2005)



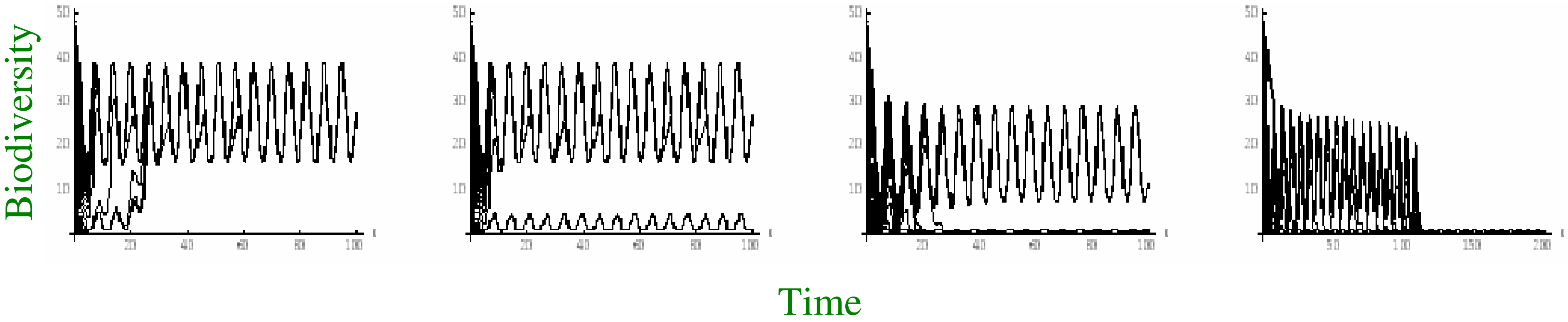
Response of Seasonal Wetlands to Changing Salinity



Type 1 (seasonal) wetlands: graded response

Response of Seasonal Wetlands to Changing Salinity

increasing mean salinity



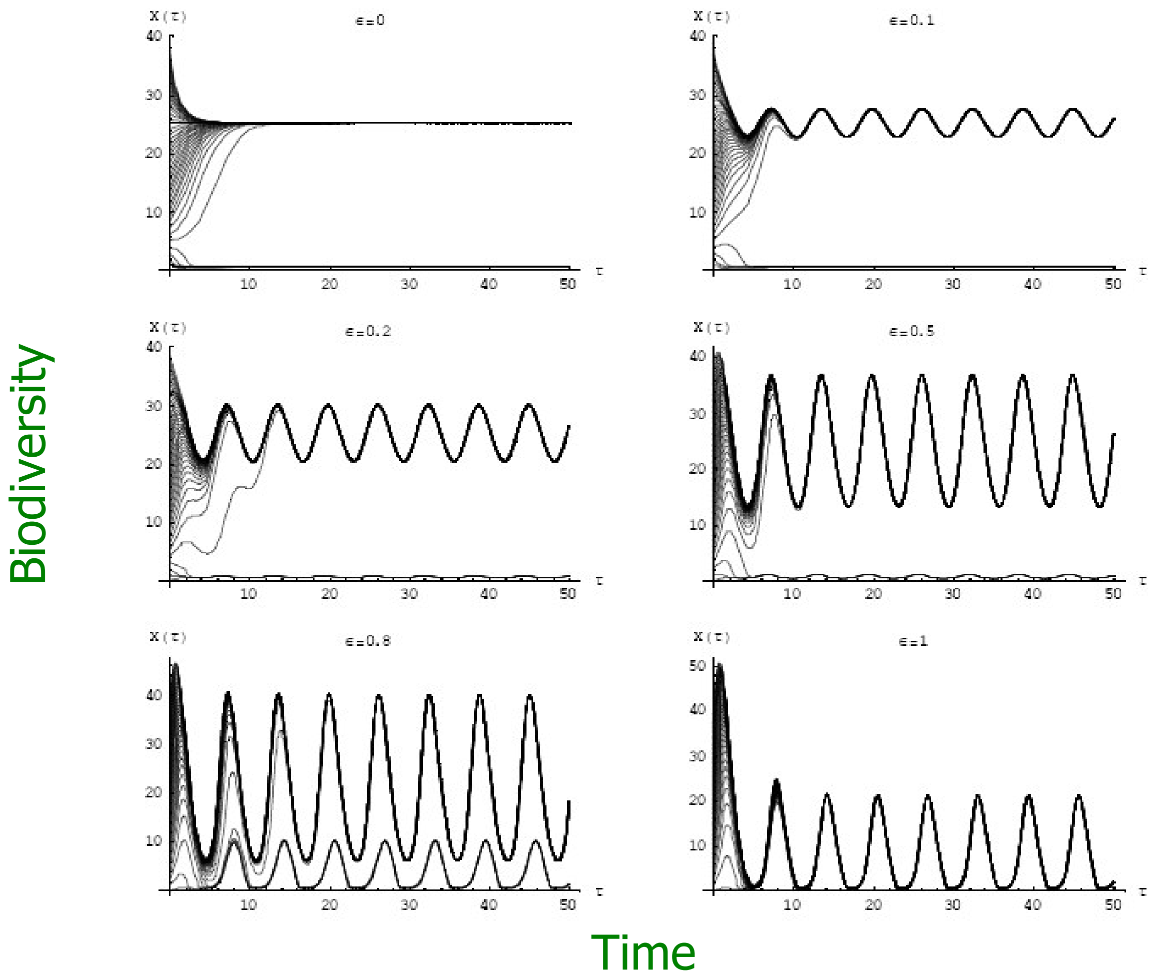
Type 2 (seasonal) wetlands: hysteretic response

collapse threshold of mean salinity

recovery threshold of mean salinity

Response of Seasonal Wetlands to Changing Seasonality Strength

Changes in the seasonality strength can induce the monostability-bistability transition.



Seasonal Ecosystem Theory

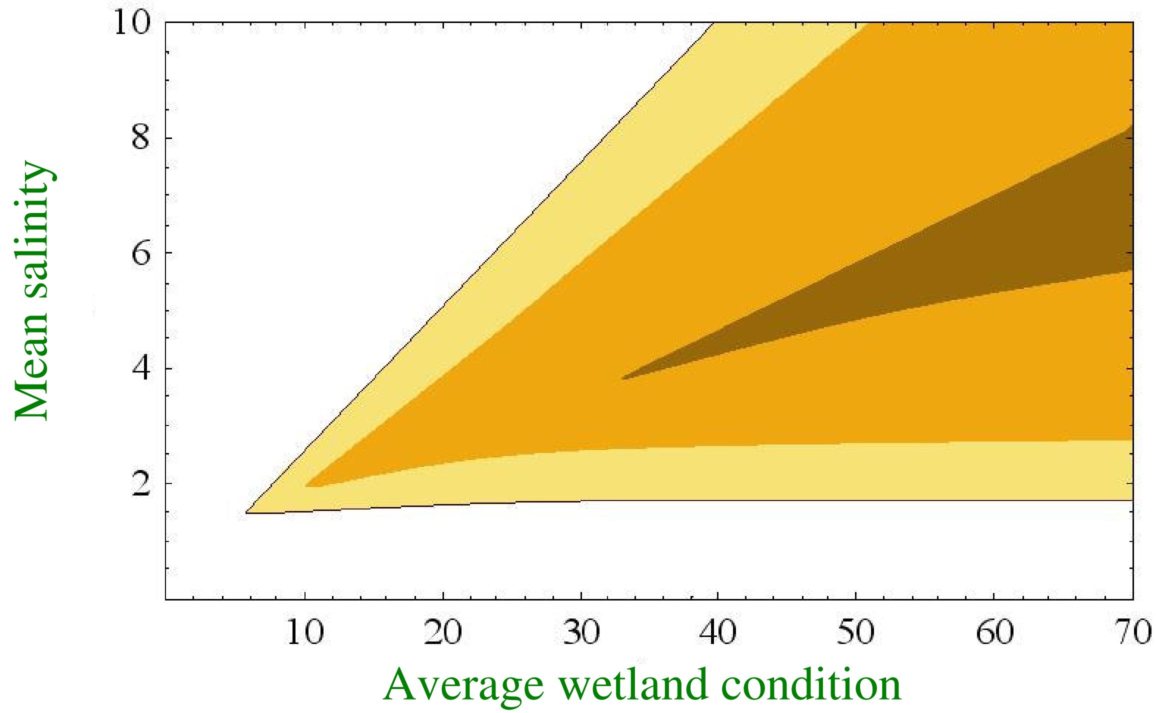
The main differences between ecosystems in a constant environment in the traditional theory of alternative stable states and seasonal ecosystems:

- Seasonal ecosystems can have alternative stable cycles rather than equilibrium points.
- Seasonal variability can influence properties of seasonal ecosystems.

Climate Change

- Increase in mean temperature and decrease in mean precipitation in some regions
  - Decline in average wetland condition
- Increase in climate variability – more extreme weather events such as heatwaves, droughts, heavy precipitation or storms
  - Increase in the seasonality strength

Impacts of Climate Change



- Decline in average wetland condition and increase in the seasonality strength decrease the collapse threshold of mean salinity and increase the recovery threshold of mean salinity.
- Climate change is likely to reduce wetland resilience and, on the other hand, increase wetland sensitivity.

Conclusion

- Wetlands exhibit monostability and bistability.
- Initial wetland condition mediates the ecological response of the wetland ecosystem to salinity and climate change.
- There are two types of wetland responses to changes in salinity: type 1 wetlands exhibit a graded response; type 2 wetlands exhibit a hysteretic response.
- Wetlands display critical behaviour: regime shifts in diversity occur at the thresholds of mean salinity, seasonality strength or initial species diversity.
- Climate change may reduce wetland resilience, but increase wetland sensitivity.
- The model predictions are in agreement with empirical data.
- Further tests are needed to improve predictability.