Disturbance and Restoration of Streams

P. S. Lake

Prelude

"One of the penalties of an ecological education is that one lives alone in a world of wounds. Much of the damage inflicted on land is quite invisible to laymen."

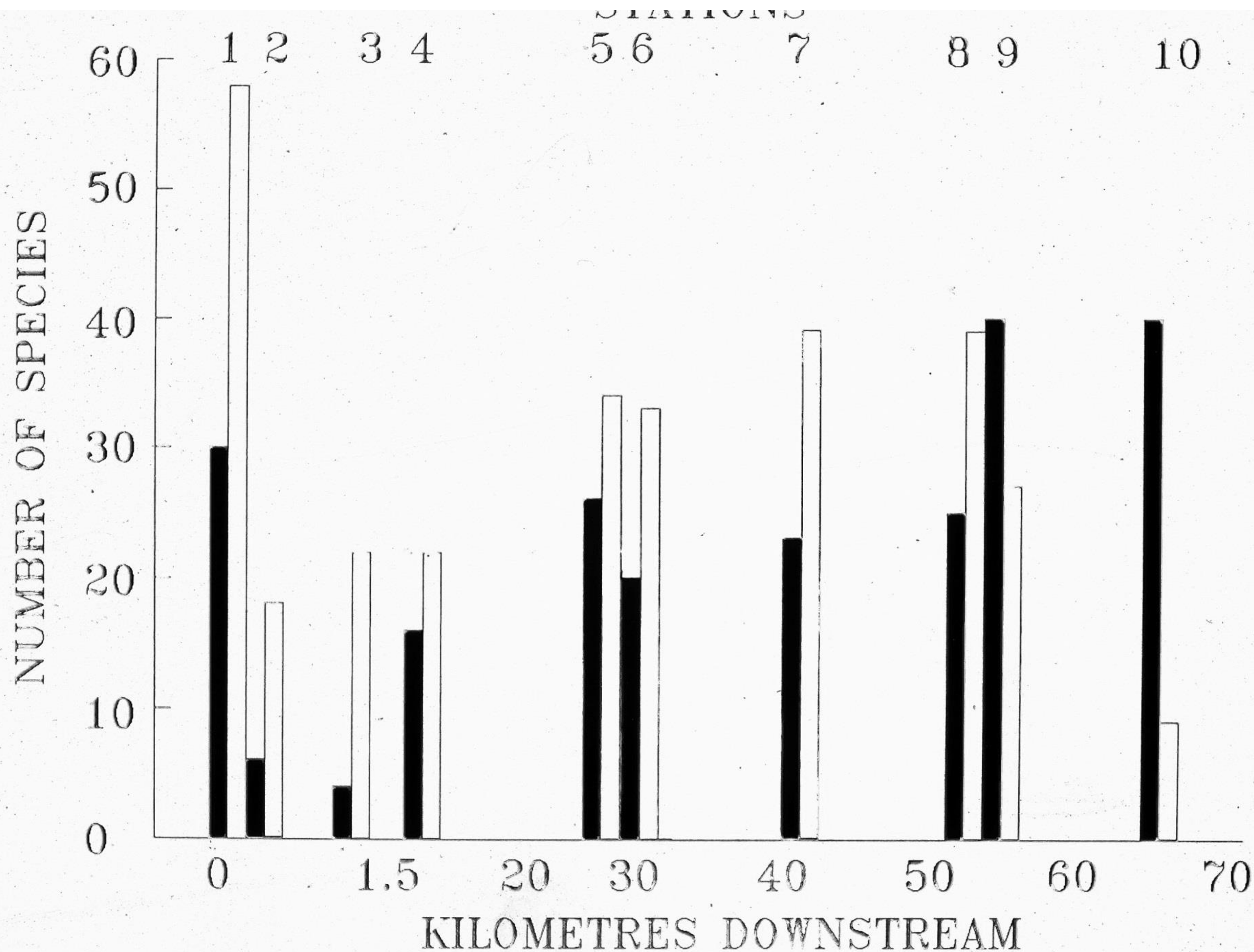
Aldo Leopold "Round River. From the Journals of Aldo Leopold" ed., L. B. Leopold. Oxford U.P. 1953.

Read: 1963.

Lake George Mining Co., 1952, Captains Flat, N.S.W.

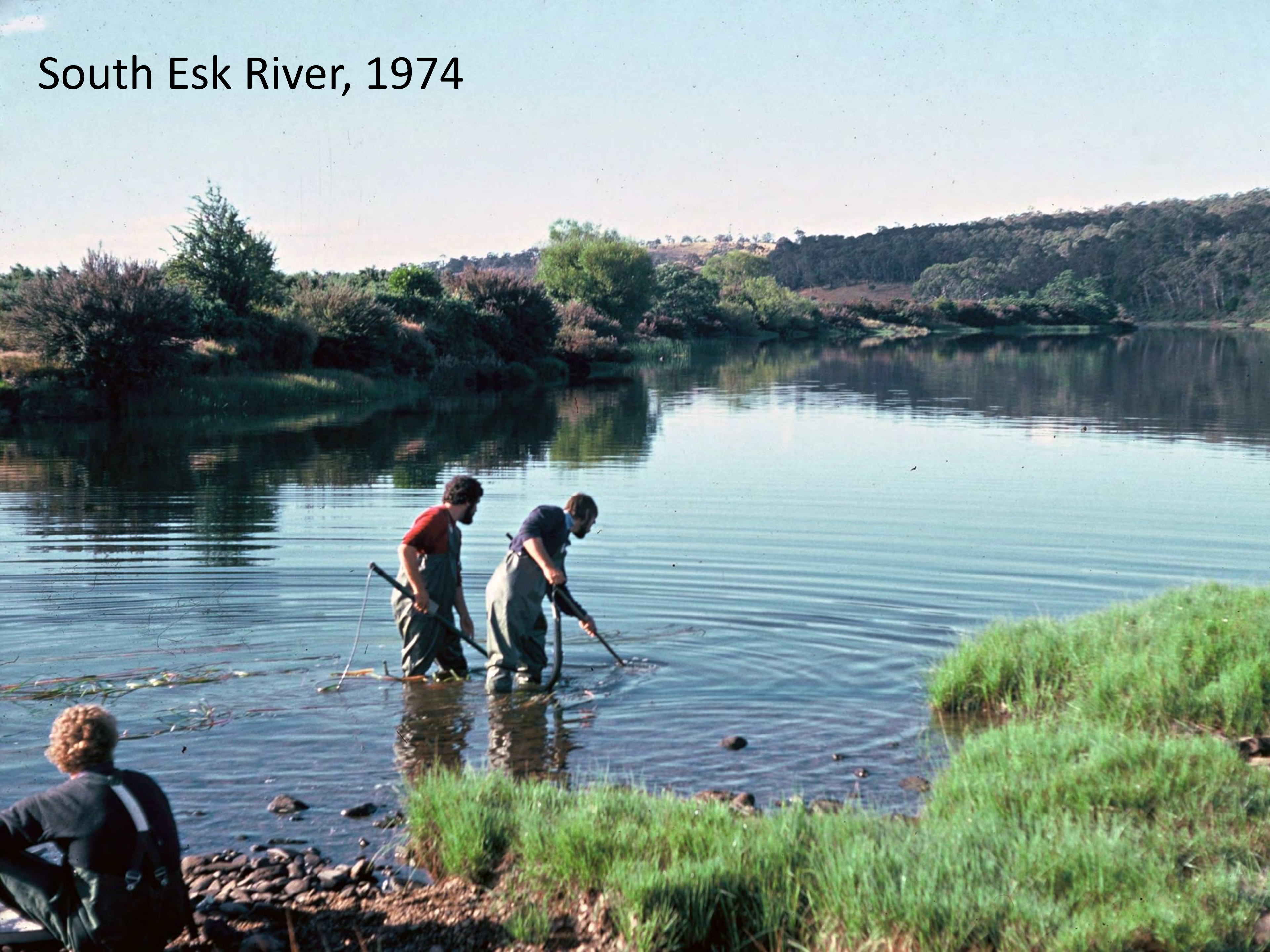
Molonglo River.
Heavy metals (Z+Cu) + AMD.

Black (Lake 1963) clear (Norris 1985) ---Sloane & Norris (2002)



Aberfoyle Tin NL, 1982.

Rossarden, Tasmania. Tin and Tungsten (W). Cd, Zn.


South Esk River, 1974

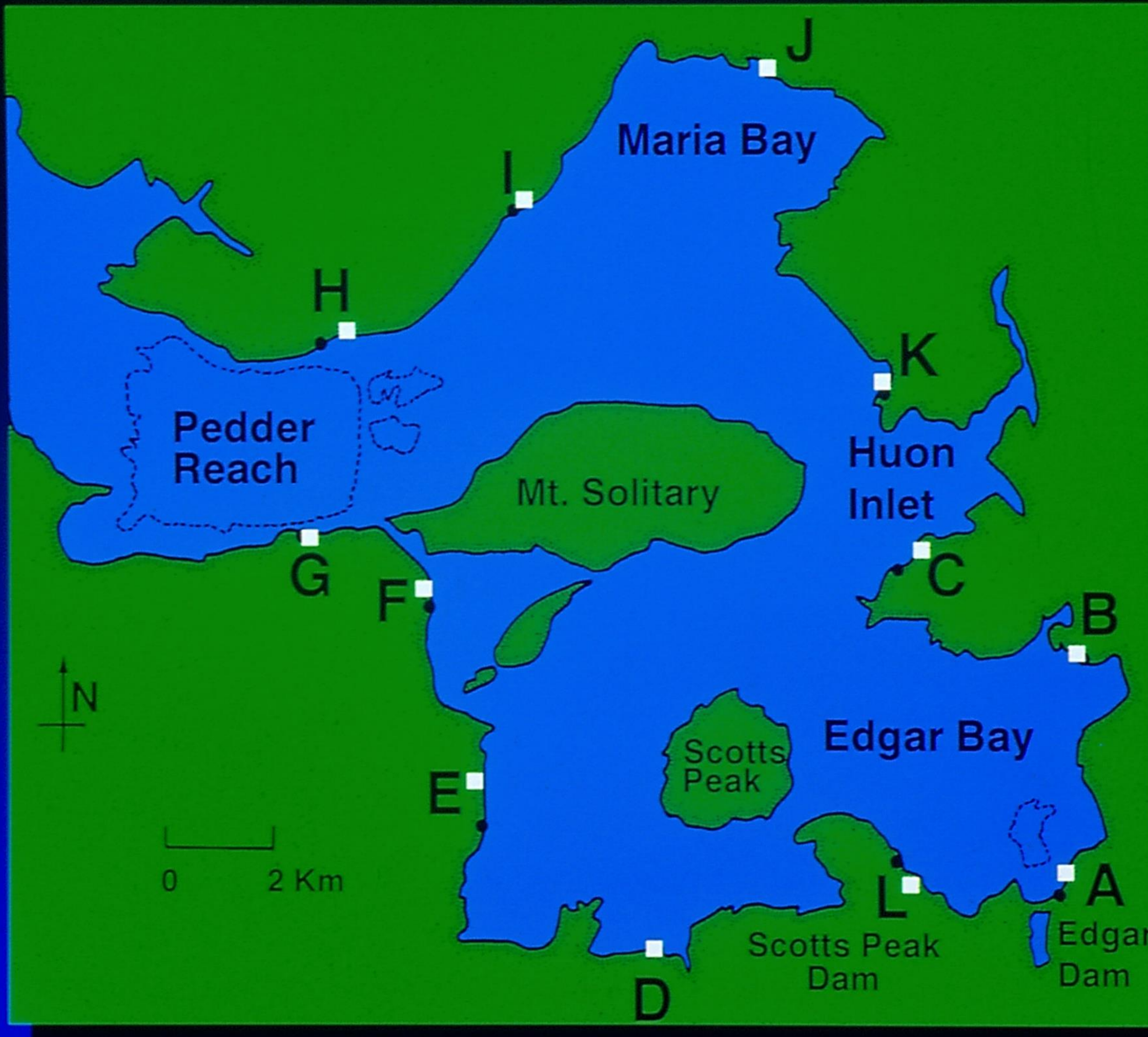
Lake Pedder, south west Tasmania.

- Pristine, remote lake with a remarkable, glacial sand beach, endemic fish (*Galaxias pedderensis)* and ~5 spp., of invertebrates.

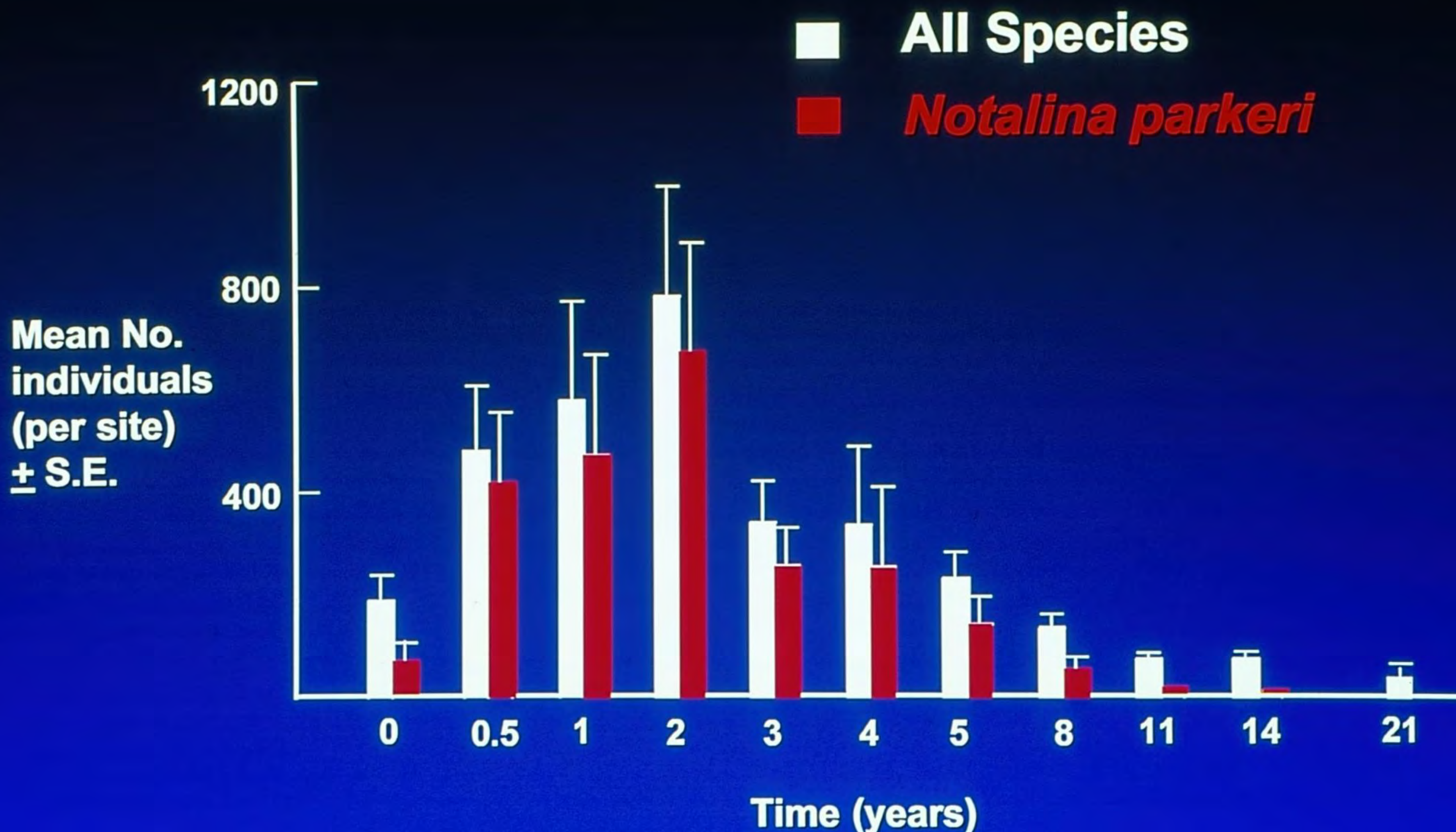
- Flooded by two dams to produce hydro-electricity in 1973

- Sampled annually for 21 years.

- Initial “trophic upsurge” then a steady decline to paucity.


J
Maria Bay
I
H
K
Pedder
Reach
Mt. Solitary
Huon
Inlet
G
C
F
B
N
Edgar Bay
Scotts
Peak
E
0
2 Km
L
A
Edgar
Dam
Scotts Peak
Dam
D

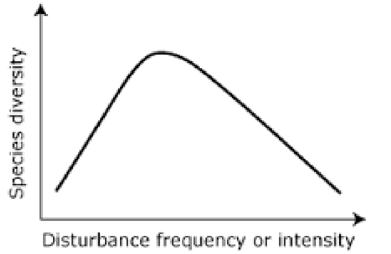

L327HT



All Species
Notalina parkeri
1200
800
400
Mean No. individuals (per site) ± S.E.
0
0.5
1
2
3
4
5
8
11
14
21
Time (years)

Ecological Disturbance

- Interest triggered by Connell J.H (1978) *Intermediate Disturbance Hypothesis*



- Disturbances are forces with the potential capability to disrupt populations, communities and ecosystems. Defined by their type, strength, duration and spatial extent---not by their impacts.

- Pulse, Press (Bender *et al.,* 1984) and Ramp disturbances (Lake 2000) and responses.

Disturbances within Disturbances

- Distinct disturbances nested within enveloping disturbances.
  - Droughts—ramps of water loss, high temperatures, low water quality, loss of connectivity etc.
  - Climate change with ramps (sea level rise, temperature increase, acidification).

Compound Disturbances

- Natural e.g. drought and fire
  - Effect on streams: recovery from catchment-riparian fire impact exacerbated by drought cf., fire alone. (Verkaik *et al.,* 2015).
  - Sites: Idaho, Catalonia, Victoria, Australia.
  - Recovery complete (~1year) in IDA and CAT, but not in VIC.

- Non-natural e.g. urbanization
  - **Urban stream syndrome** (Walsh *et al*., 2005). Impermeable catchment surfaces (press), flash flooding (pulse), pollution (pulse, press), habitat loss (ramp) riparian disconnection (press) etc.

Contemporary and legacy disturbances in streams.

- In many cases the assessment of disturbances acting on streams is focused on current disturbances alone.
- Legacy disturbances result from past interventions on both catchments and streams and may still be acting.
- Assessment involves ecological history to adequately realize current state. Rarely done.
- Examples: “arroyos”, SW USA (Turner *et al*.,2003), sand-bed streams, Victoria (Davis & Finlayson 2000), urbanized stream, California, (Beller *et al*., 2016).

Disturbances and Legacies

- Agriculture on catchments
  - Direct and indirect disturbances to streams with legacies.

C. Muir (2014) "The Broken Promise of Agricultural Progress".

e.g., North-western NSW

Natives "dispersed"
↓
Cattle grazing
↓
Land Clearing - Sheep
↓
Ploughing - Wheat & Cattle grazing
↓
Dust storms - soil loss

- A litany of linked disturbances in one land-water scape.
- Ecological effects??
- A shunned history of "slow violence"
- "Broken lands"
- Unrestorable?

Flow regulation - Macquarie Marshes
↓
Cotton

Recovery from Disturbance

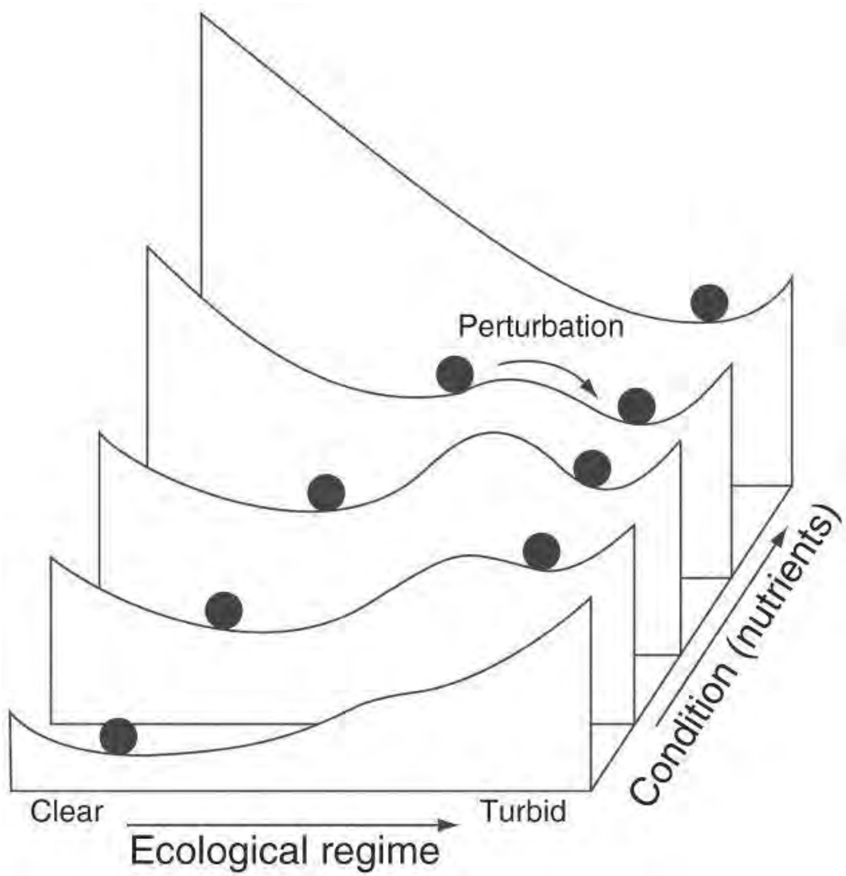
- **Resistance**: the capacity of an ecological system to resist the forces of a disturbance.
- **Resilience**: the capacity of an impacted ecological system to recover after a disturbance.
- Both concepts in this resistance-resilience framework are measurable after disturbance.
- However………

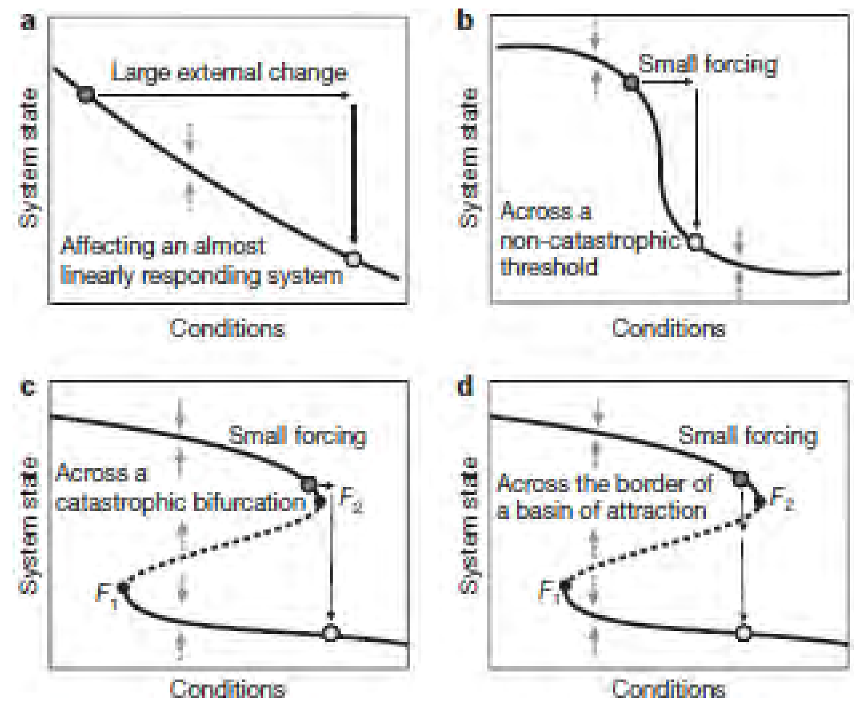
Resilience and Change

- Ecological Resilience has been defined as ‘*a measure of the persistence of systems and their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables*’. (Holling 1973).

- No mention of resistance (subsumed?). What and how do you measure?

Alternative Stable States (ASS's, MSS's) /Regime Shifts





Scheffer et al. 2009 *Nature* **461**

Ecological Resilience

- "*Resilience refers to the size of the valley, or basin of attraction, around a state—corresponds to the maximum perturbation that can be taken without crossing a threshold to an alternative stable state*". Gunderson & Holling (2001).

- ASS formed in regime shift by stark change across a threshold.

- Stark nature of thresholds stressed.

- Supported initially by ASS formation in temperate shallow lakes (Carpenter, Scheffer).

- Core concept of resilience thinking—Walker & Salt (2006).

- An immense inventory of ASS detections has been compiled.

Criteria for Regime Shifts/MSS's

1. Changes occur at same site (no space for time substitution.)

2. States are normal for locality.

3. Not lab or short-term (generation duration) studies.

4. Ideally single disturbance (pulse) and quantified

5. Characterized by sharp transition.

6. Stark change with distinct thresholds.

Questioning and re-assessment I.

- Schröder *et al.,* (2006) - reviewed 35 cases; 10 +ve in short-term lab expts, only 3 in the field.

- Petraitis (2013) “Multiple Stable States in Natural Ecosystems” questioned both theory and practice (7 criteria). 3 +ve cases including his own. Use of catastrophe theory (cusp, butterfly).

- Mac Nally *et al*., (2014) searched for stark changes in estuarine/nearshore community studies. 376 papers narrowed to 98 but only 8 where “a stark ecological change was plausibly linked with a pressure change.”

Questioning and re-assessment II

- Freshwater ecosystems: Capon *et al*., (2015).

135 papers (80% >2000) narrowed to 27 meeting essential criteria.

  - 19 with pressure-driven, non-linear changes.
  - 6 ASS's in shallow temperate lakes.
  - Only 5 of 19 monitored after release of pressure (duration of shift?)

"little empirical evidence for regime shifts and changes between multiple or alternative stable states."

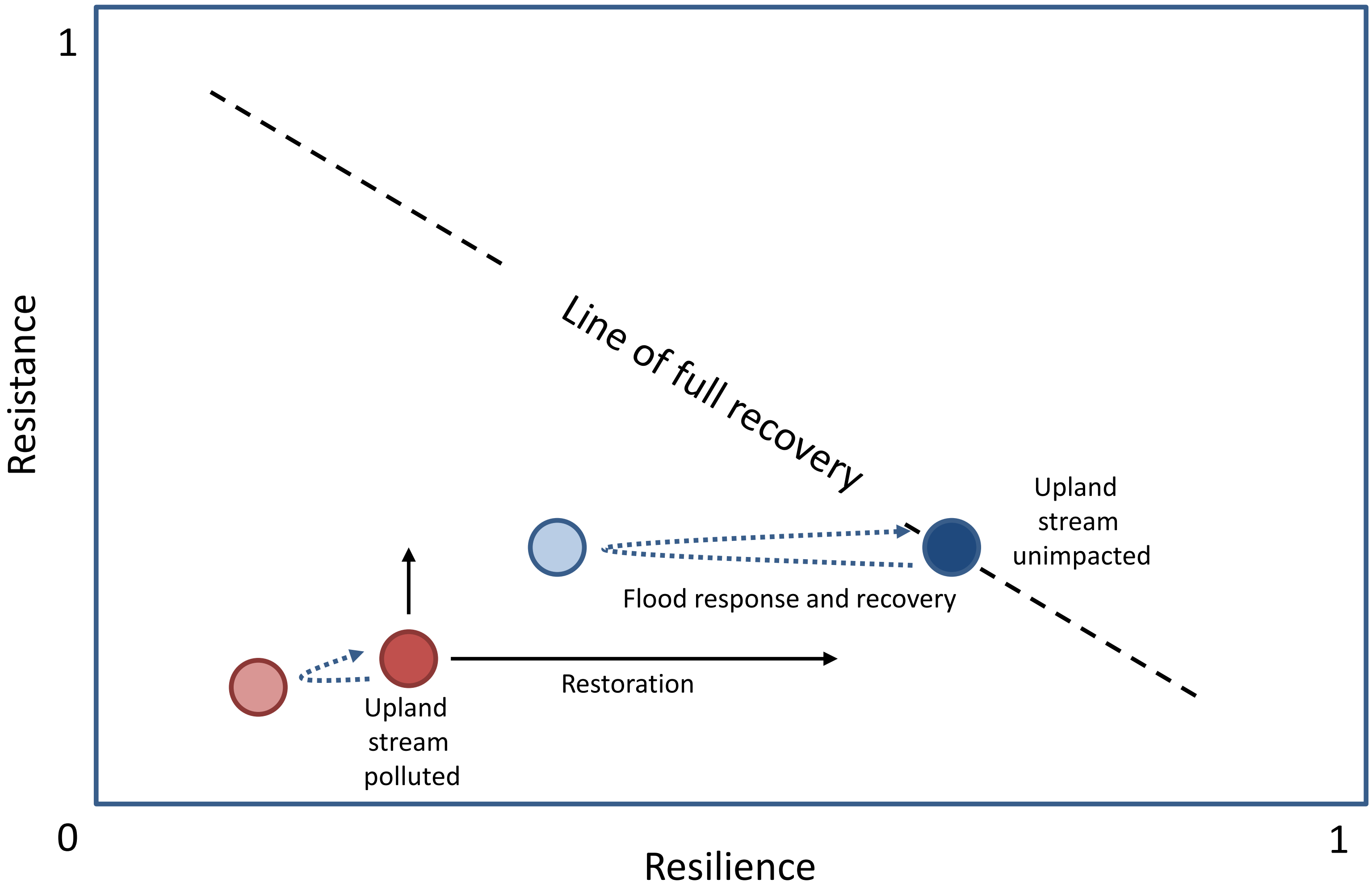
Ecological resilience ? Thresholds? ASS's?

Common Alternative

Ecosystems, communities, species, populations are altered by a range of disturbances with time, most obviously with human-created disturbances.

Rather than multiple stable states, many systems are on a slide with loss of diversity, linkages and ecological functions.

The resistance-resilience framework (Nimmo *et al*. 2015): with restoration



Restoration

- Ecological Restoration is "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (SER 2002).

- Restoration Ecology is the scientific study of ecological restoration and it advances through monitoring and experimentation to develop an understanding of how ecosystems and their components recover from disturbance.

- Ecological restoration endeavours to restore resistance and resilience to disturbed (degraded) systems.

A Crisis Discipline

- “In which we have to make decisions and choices before we have enough information to be certain that we are making the best choice, but in which we know that failure to make a choice will result in further degradation to the environment.”

The Challenge for Restoration Ecology

- Ecology has advanced through basically a reductionist process—hypotheses, experimentation, analysis, model testing—to understand selected components of ecosystems. ‘Dissection’.
- Restoration Ecology seeks to rebuild ecosystems—a process with few guidelines. Hence empirical studies testing concepts as BEF, cross-system subsidies, assemblage rules, priority rules. etc. “Reconstruction”, “Rehabilitation.”

Analysis of the science of stream restoration

- Audits of stream and river restoration projects show:
  - A small percentage of projects are effectively monitored (time duration—funding?)
  - Many monitoring projects track implementation *not* ecological responses.

- Scientifically, not much had been learnt early 2000's, in more recent times, there is clear progress.

Steps in a restoration project.

1. Assessment of damaged state.
2. Setting of goals/targets
3. Selection of indicators & design of monitoring program
4. Implementation of restorative measures
5. Evaluation of progress, success and of hypotheses
6. Reporting the findings of the project.

Assessment of damaged state

- Need to determine historical legacies, current disturbances and to anticipate extreme events. (ecological history---a neglected discipline).
- Important to rank disturbances in terms of feasibility and timing of restoration.
- Large spatial scale equates with long response time and increased funding—large scale projects may be much more effective than isolated small-scale projects. Big project or incremental actions.

Disturbance Assessment

1. Single disturbances are rare, mainly dealing with compound disturbances, interactive, synergistic and with different spatio-temporal scopes.

2. Catchment, riparian and stream disturbances.

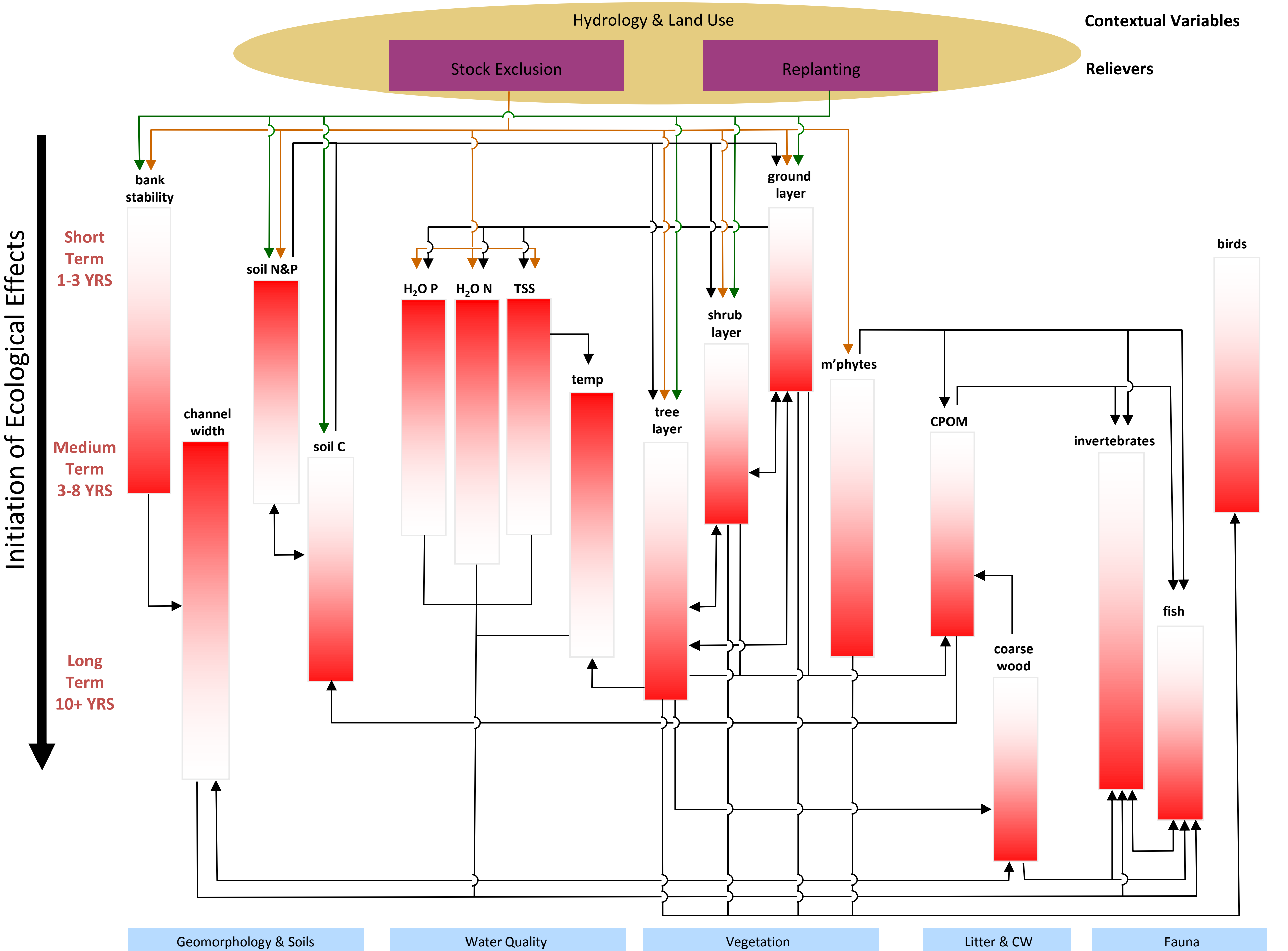
3. Point disturbances (e.g. point pollution, dam removal) cf., widespread, catchment-wide ones.

4. Problem of restoring streams with widespread disturbances and fund-limited effort?

Setting of goals/targets

- Goal setting is difficult and may take time.
  - Critical interventions required to generate ecological responses.

- Goals need to be quantifiable and set in relation to reference and/or historical states or from prior information/relevant indicators
- Anthropocene Baselines (AB's) (Keller *et al.* 2015): compromised goals, novel systems e.g., persistent invaders e.g. trout in rocky streams, *Phalaris* in riparian zones.
- Goals involve components with variable response times.
  - Planning for linkages may set schedule of actions, monitoring and responses


Hydrology & Land Use
Contextual Variables
Stock Exclusion
Replanting
Relievers
Initiation of Ecological Effects
Short Term 1-3 YRS
Medium Term 3-8 YRS
Long Term 10+ YRS
bank stability
soil N&P
channel width
soil C
H_2O P
H_2O N
TSS
temp
tree layer
shrub layer
ground layer
m'phytes
CPOM
coarse wood
invertebrates
fish
birds
Geomorphology & Soils
Water Quality
Vegetation
Litter & CW
Fauna

Extreme Events and Restoration. (Reich & Lake 2015)

- Extreme events are usually damaging disturbances (e.g. megadroughts).

- Resilience to extreme droughts possible with increases in refuges and connectivity pathways.

- Extreme floods could be very beneficial to floodplain restoration.
  - Floodplain activation vs. Floodplain maintenance & floodplain resetting floods. e.g. Opperman *et al* (2010).

- EWA's cf., natural flood pulses—fish, OM, nutrients, R.Red.G.'s. e.g. Stoffels *et al* (2014) fish.

Time

- Development rapid-- generating long-term disturbances.
- Society favours the short-term (e.g., instant gratification, politics, growth) .
- Restoration is long-term: at the pace of natural processes.(academic problem of few papers?)
- Gaining the long-term commitment is critical, very difficult (=impossible?).

Selection of indicators

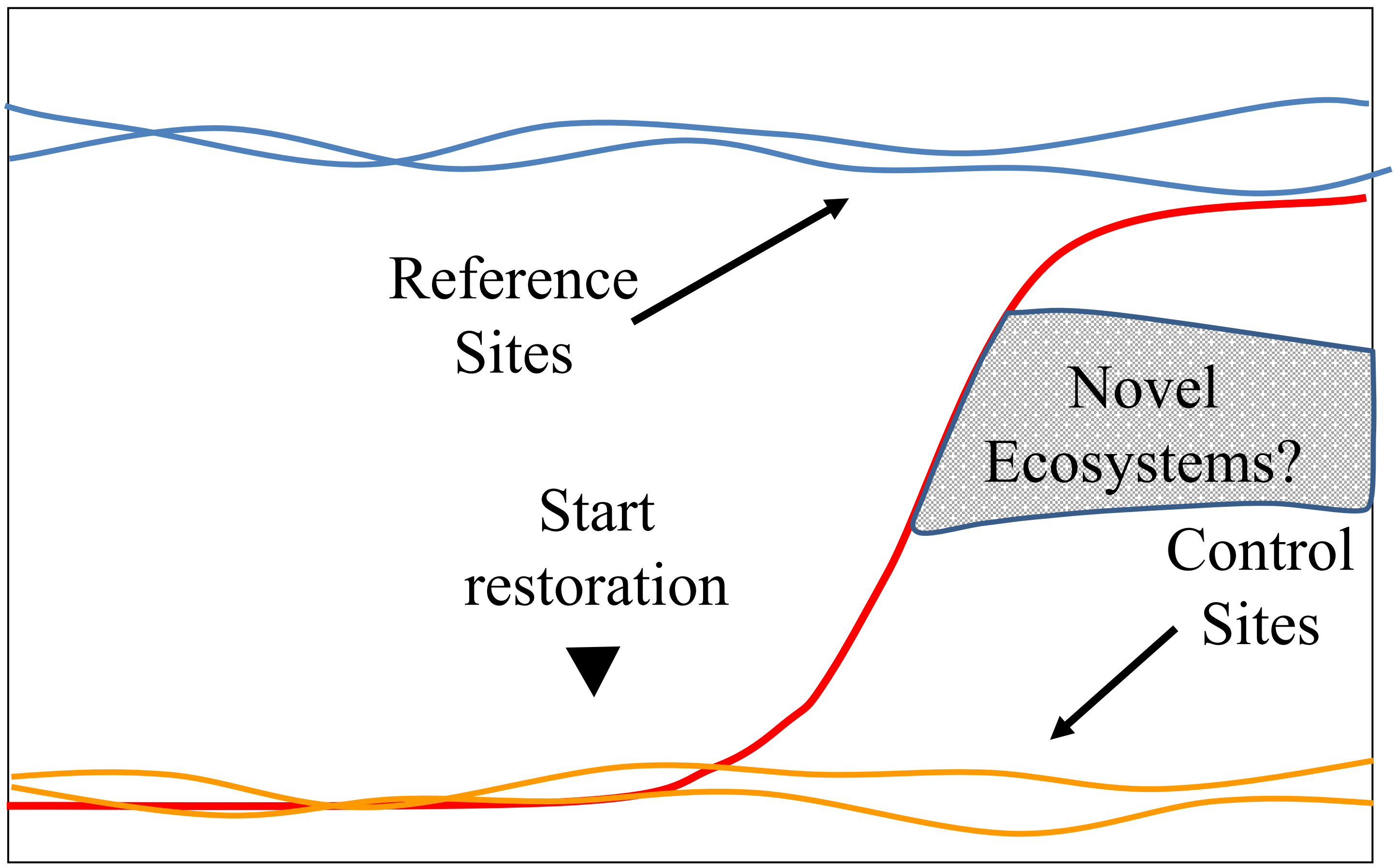
- Progress and testing of hypotheses can only be determined by rigorous monitoring of selected indicators.

- Indicators linked to goals, simple and inexpensive to measure, sensitive to changes toward goals.

- Indicators can be selected for different response times.

- Indicators are usually selected biota. Increased emphasis needed on ecological processes.

Assessing Restoration Success – novel ecosystems?



Assessing progress and success

- Analyse results for changes in implementation measures (e.g. trees, logs etc) *and* changes in response indicators (biota, ecological processes).

- Test hypotheses linking implementation measures to response indicators and links between indicators.

- Write up results and publish them---scientific literature. Levels of monitoring, analysis and reporting need improving.

Restoration Outcomes

- Full restoration is rarely possible, especially for streams in settled catchments, rivers with barriers, regulation? (natural vs anthropocene goals?)

- Restoration may end with dynamic but persistent states resilient to prevailing disturbance regime. (e.g. temporary stream communities).

- Or "restored" state may be unstable and not ecologically sustainable—may require continued intervention (active vs passive restoration---ecological tinkering).

- Restoration or not?
  - "*the distinction between creating ecological infrastructure and restoring whole ecosystems is important, and not merely a matter of semantics*" (Palmer & Ruhl 2015)

Challenges

- Act now; plan long-term.
- Effective monitoring; knowledge building.
- Connectivity is critical— lateral, longitudinal (floods) and even vertical. A major obstacle (barrier removal).
- Spatial-temporal extents matter; avoid small, isolated WOTAM's.
- Different speeds for different components. Linkage planning and rebuilding?

Challenges II

- Ecological restoration must involve ecologists.
- Ideally, river restoration is linked with catchment protection and restoration. Riparian protection of streams (riparian width? Median width 20-35m Hansen *et al.,* 2015).
- Foster and build links between communities, managers, and restorers.
- Plan for and anticipate extreme events, both natural and anthropogenic.

Challenges III

- Australia, (UK ex-colonies) with “an entrenched, narrow and individualistic view of property rights” which needs reforming for effective restoration.
  Riparian zones-floodplains.

- Resource management agencies need to commit to the long-term—ongoing implementation and monitoring (e.g. USACE).

Why Restore?

- In attempting to restore we may ameliorate loss and regain values.
- We learn from both successes and failures how to restore more effectively.
- Knowledge gained about the assembling of ecological systems.
- Knowledge gained to improve planning and prevent mistakes coming from ignorance or compromise or denial.
- In restoring we hope that it becomes a or the major activity in ecosystem management and conservation.

Disturbance vs/& Restoration ?

- Understanding stream ecosystems and their catchments depends on thorough knowledge of current disturbances, legacies of past disturbances and possible future disturbances.
- Disturbances vary in type, duration, spatial extent and may be compound. Legacy, current and forthcoming disturbances.
- Disturbances integral to stream dynamics and may aid restoration (e.g. floodplain flooding)
- "ecological resilience", thresholds, ASS's questioned. Re-discovery of resistance-resilience framework.

Disturbance vs/& Restoration II

- Restoration ecology a new "crisis discipline" developing knowledge on ecosystem structure and reconstruction.
- Improvements required in carrying out ecological restoration projects. Hypothesis testing and clear goals.
- Catchment-stream protection and restoration.
- Recognition and implementation of restoration projects that are long-term and at large spatial extents---long-term commitment.
- Strengthen the vital links between disturbance ecology and restoration ecology.

- Thanks to Paul Reich for help. I wish to thank and acknowledge the generous help, encouragement and inspiration that I’ve received over the years from colleagues, postgraduates, students and limnologists in many places and on many projects.

- Many thanks for giving me the opportunity to give this talk.