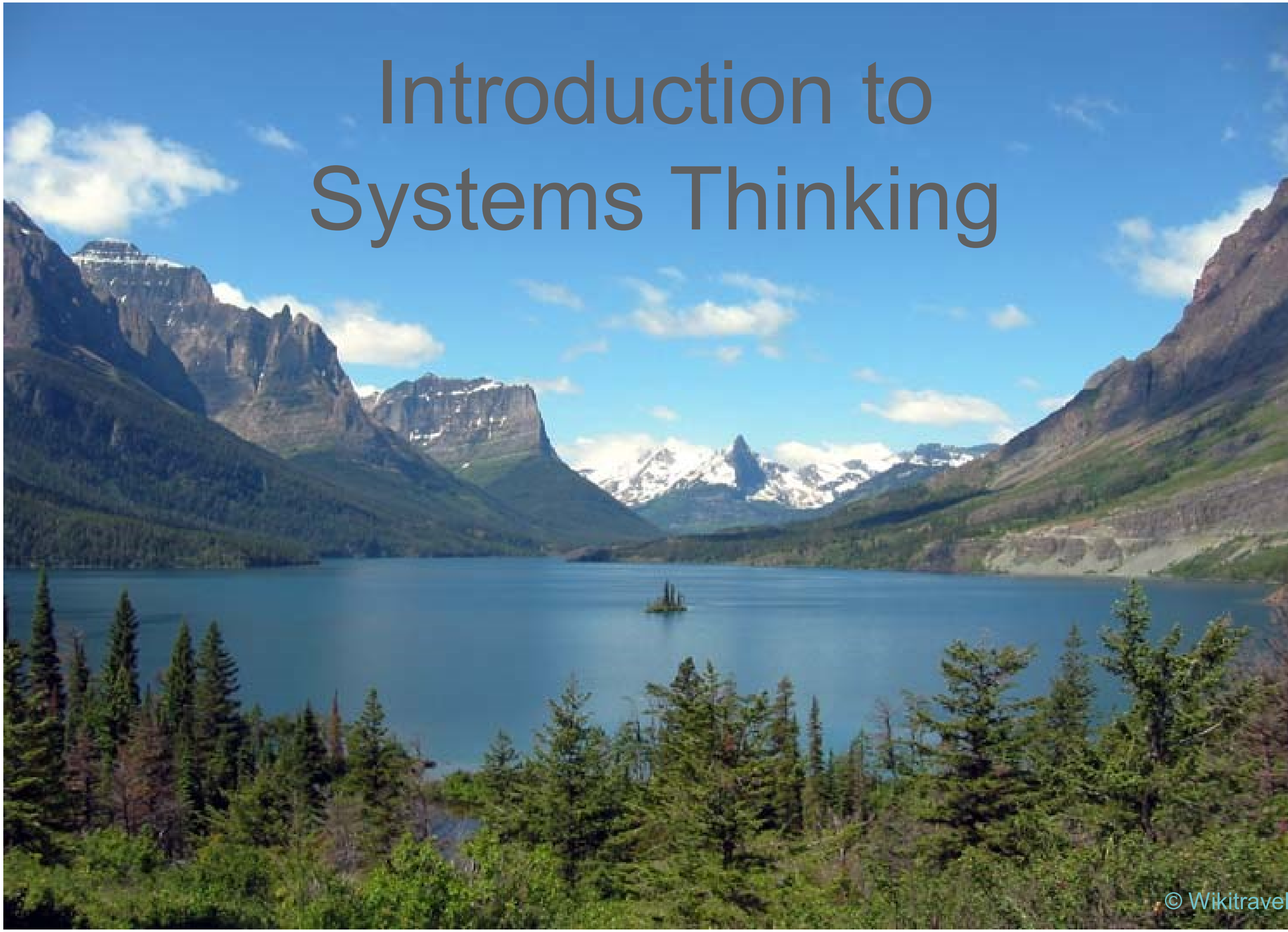
Introduction to Systems Thinking



Australian National University

Barry Newell & Katrina Proust

2017

Australian National University

What is a System?

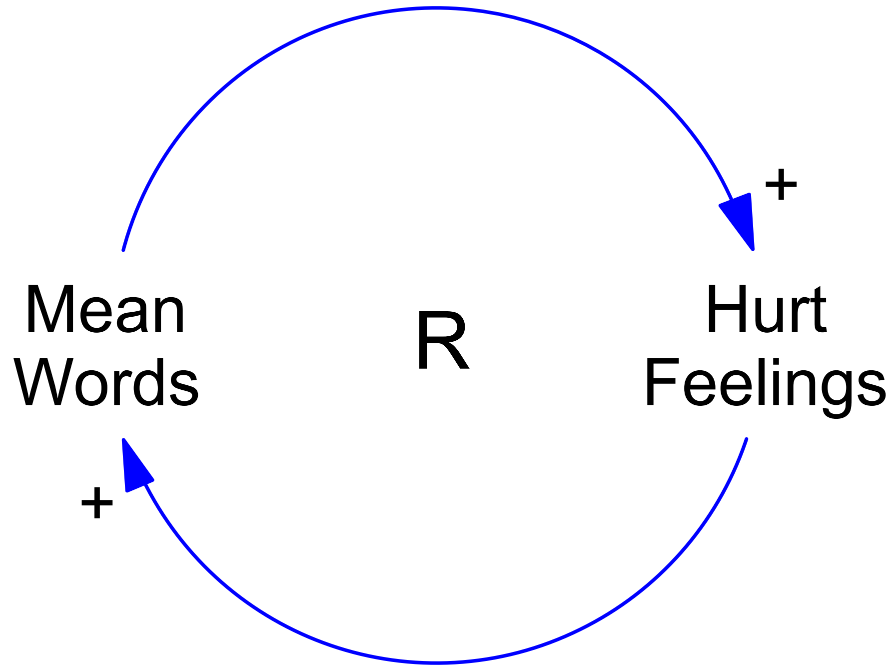
In this workshop the word ‘system’ will always mean ‘feedback system’.

A feedback system is something composed of separate parts that interact to affect each others' behaviour over time.

You cannot understand the behaviour of such a system by studying only the behaviour of the parts taken separately.

Dynamic Complexity

Feedback makes a system dynamically complex & causes unexpected outcomes that are almost always unwanted.



Feedback diagram produced by three 1st grade boys in the Borton Primary School in Tucson, Arizona.
Richardson (2011).

Why have all the eagles gone?

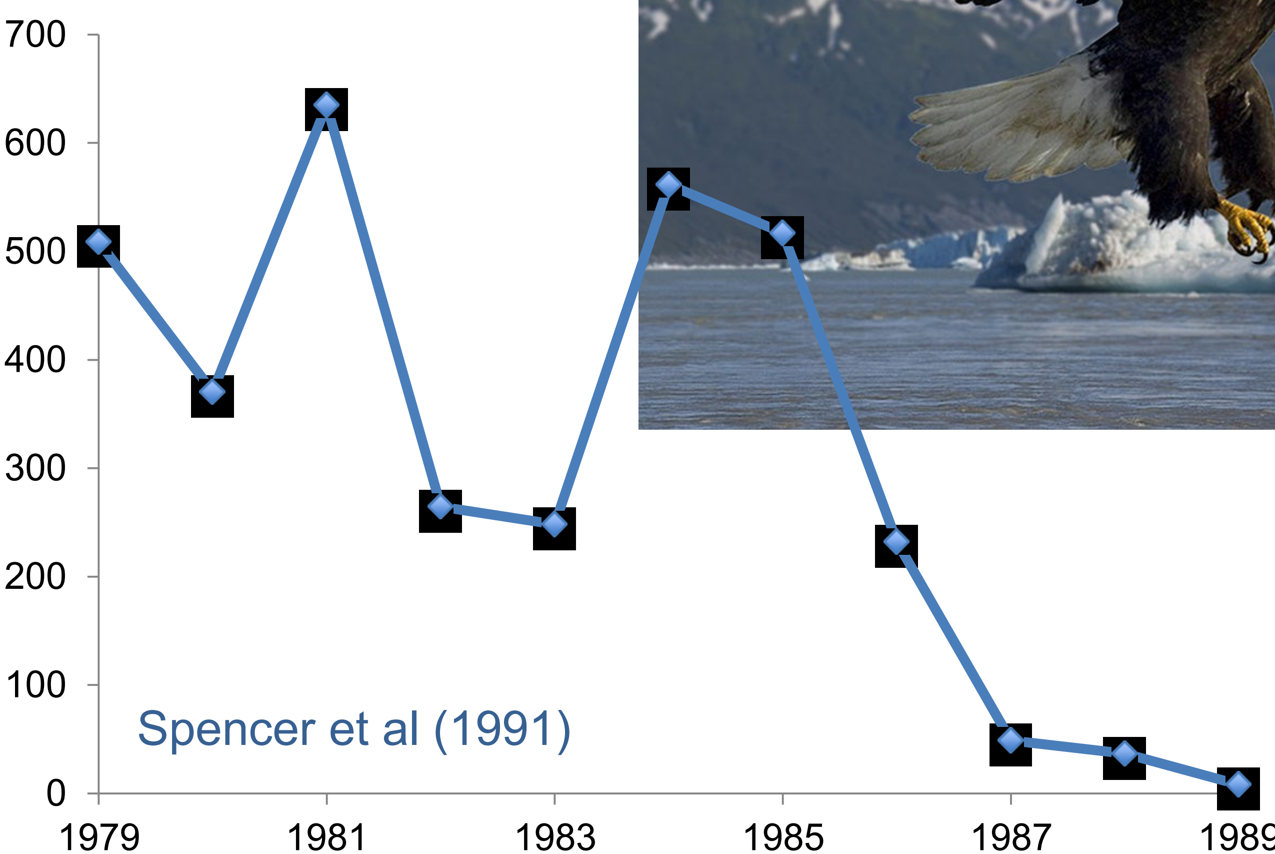
Bald eagles migrate annually from Canada, where they spend the summer, to western USA. In the autumn they could be seen in large numbers in McDonald Creek, Glacier National Park.

Laura Whitehouse USFWS

Australian National University

Why have all the eagles gone?

In the late 1970s-early 1980s it was not unusual to see 400 eagles at a time in McDonald Creek



But, by 1987-1989 they had become rare in the area. Why?

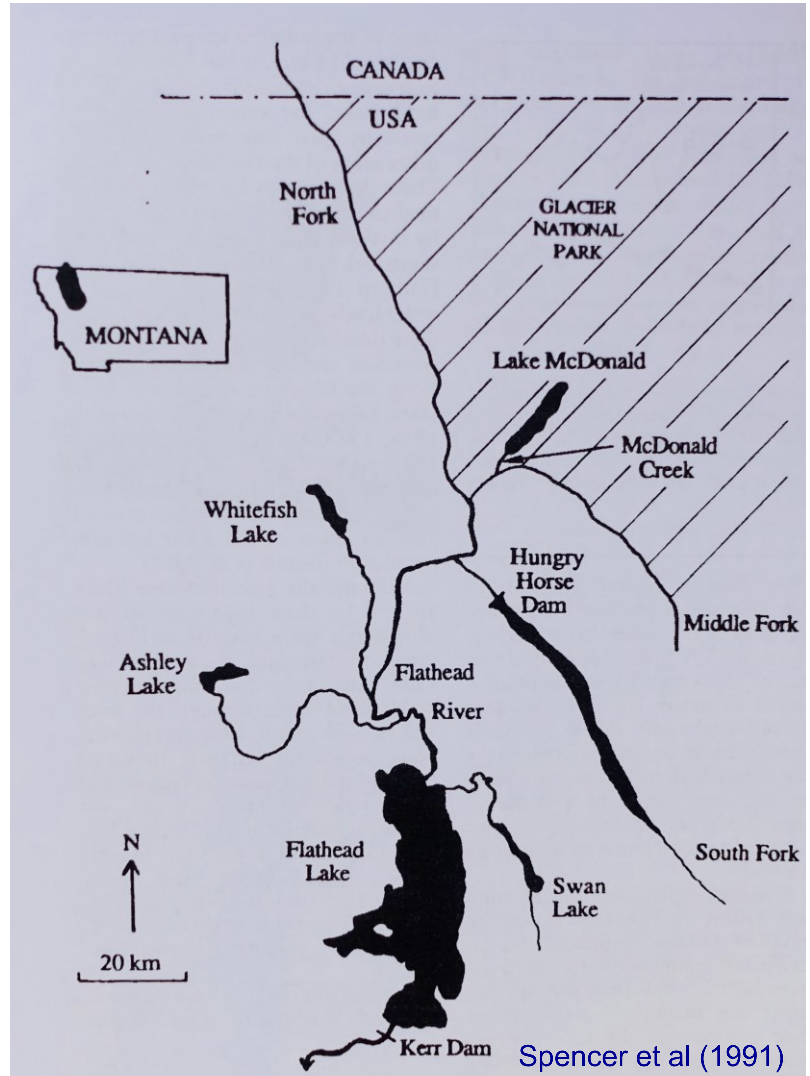
Shrimp to Feed Salmon

Sockeye (Kokanee) Salmon
(*Oncorhynchus nerka*)

PublicDomainPictures

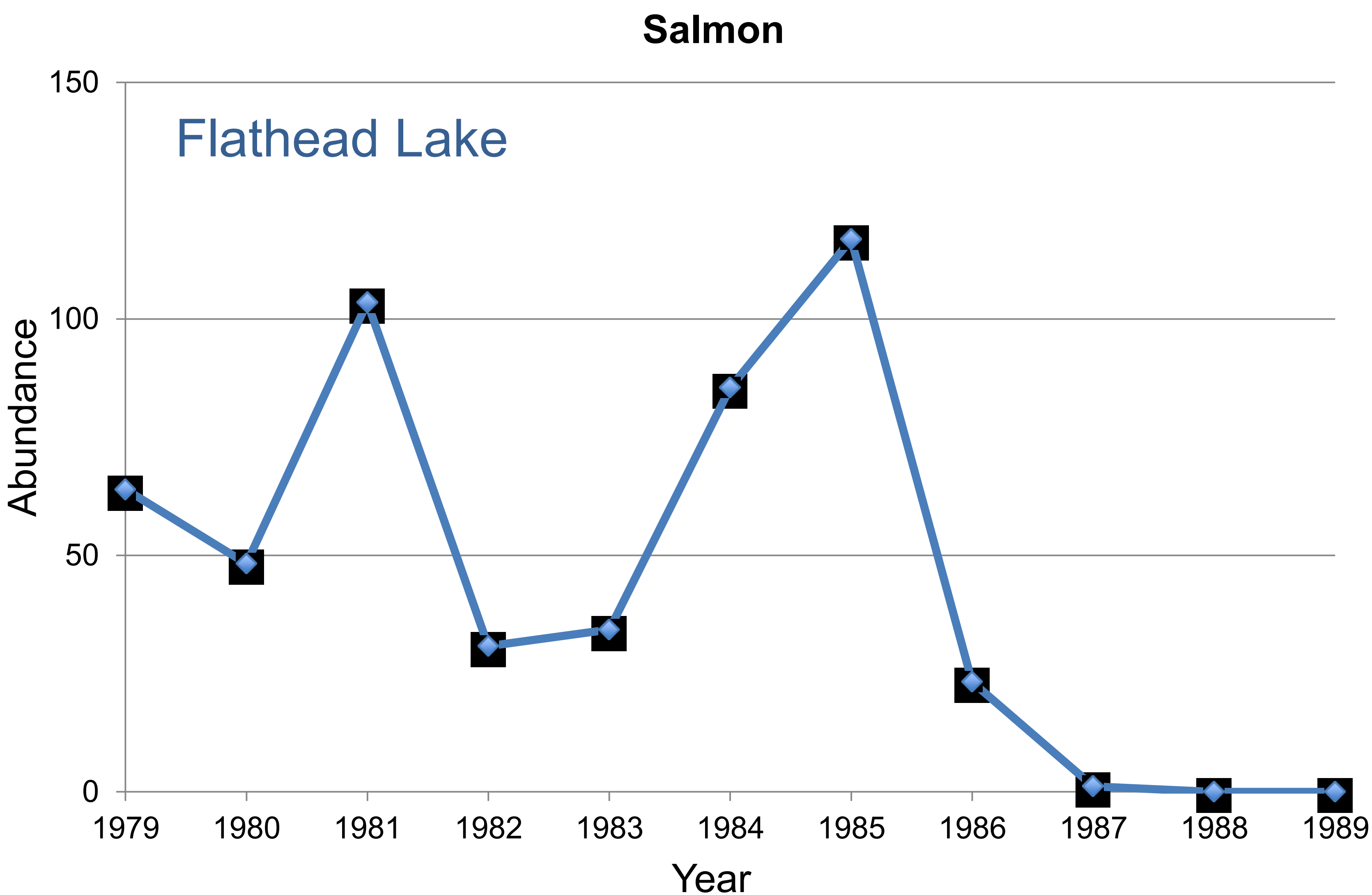
Opossum Shrimp (*Mysis relicta*)

Per Harald Olsen/NTNU



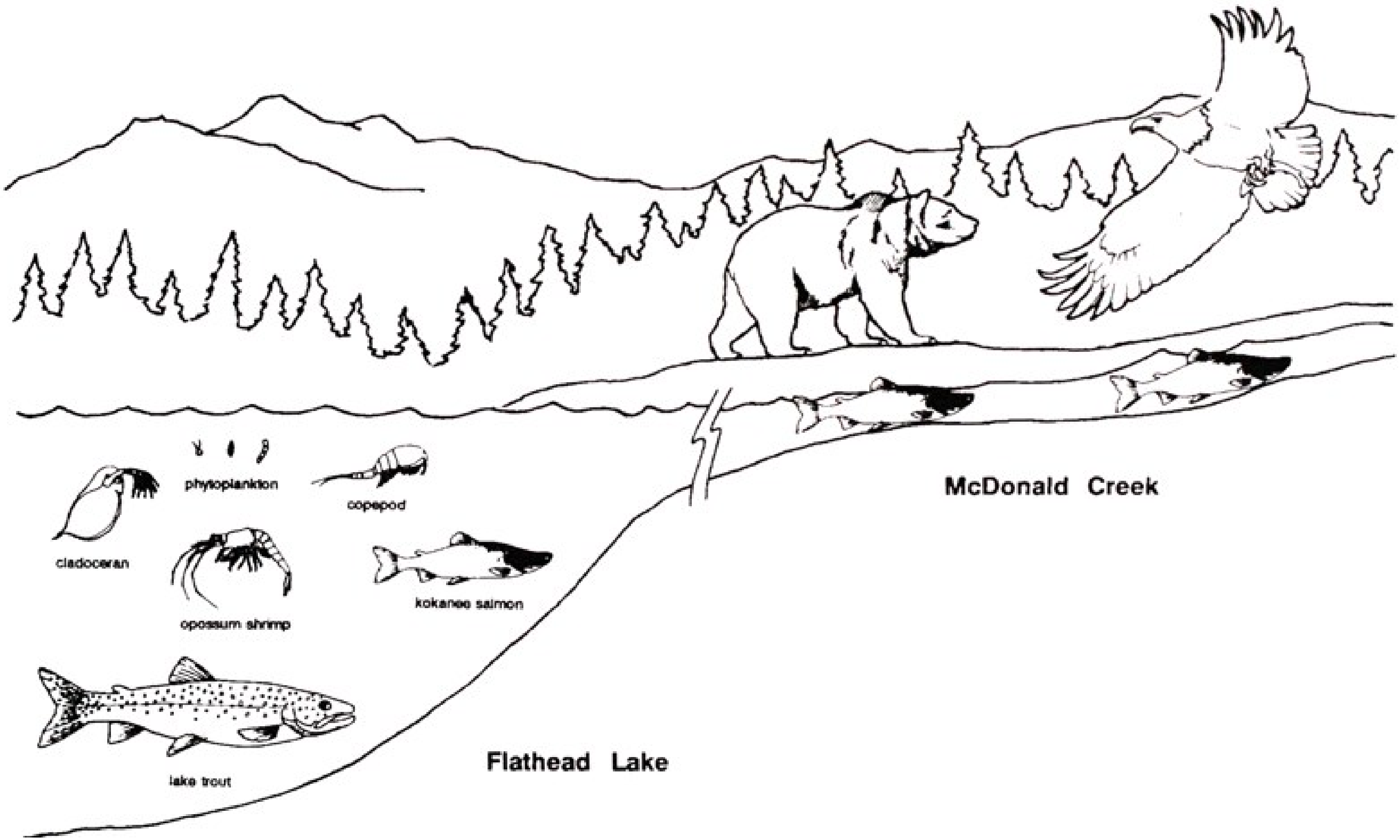
Spencer et al (1991)

Unexpected Outcome



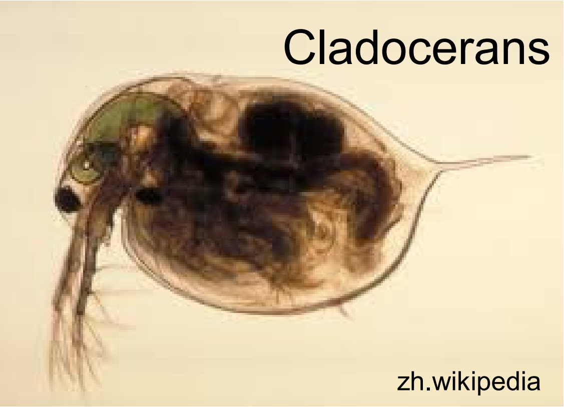
Based on Spencer et al (1991) Figure 4

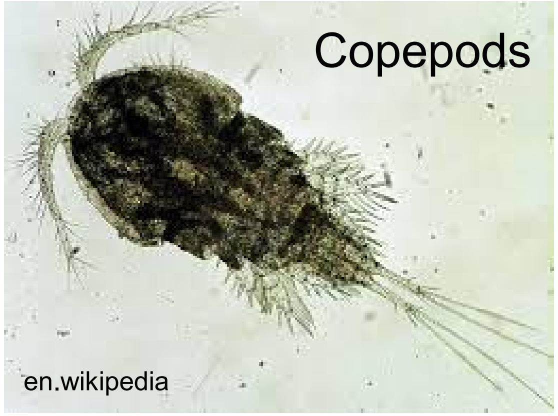
Disrupted Food Web

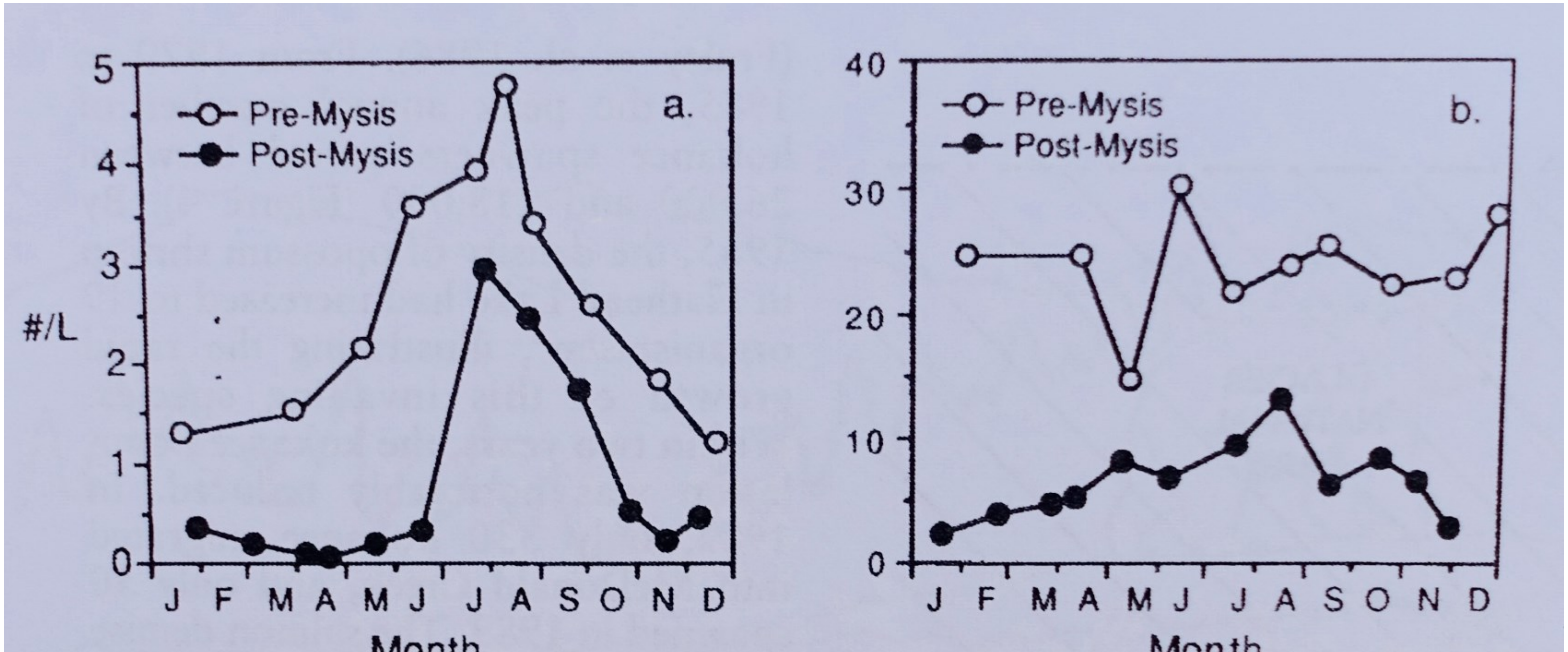


Spencer et al. 1991, *BioScience*, 41, 14-21.

Zooplankton Decline







Spencer et al 1991

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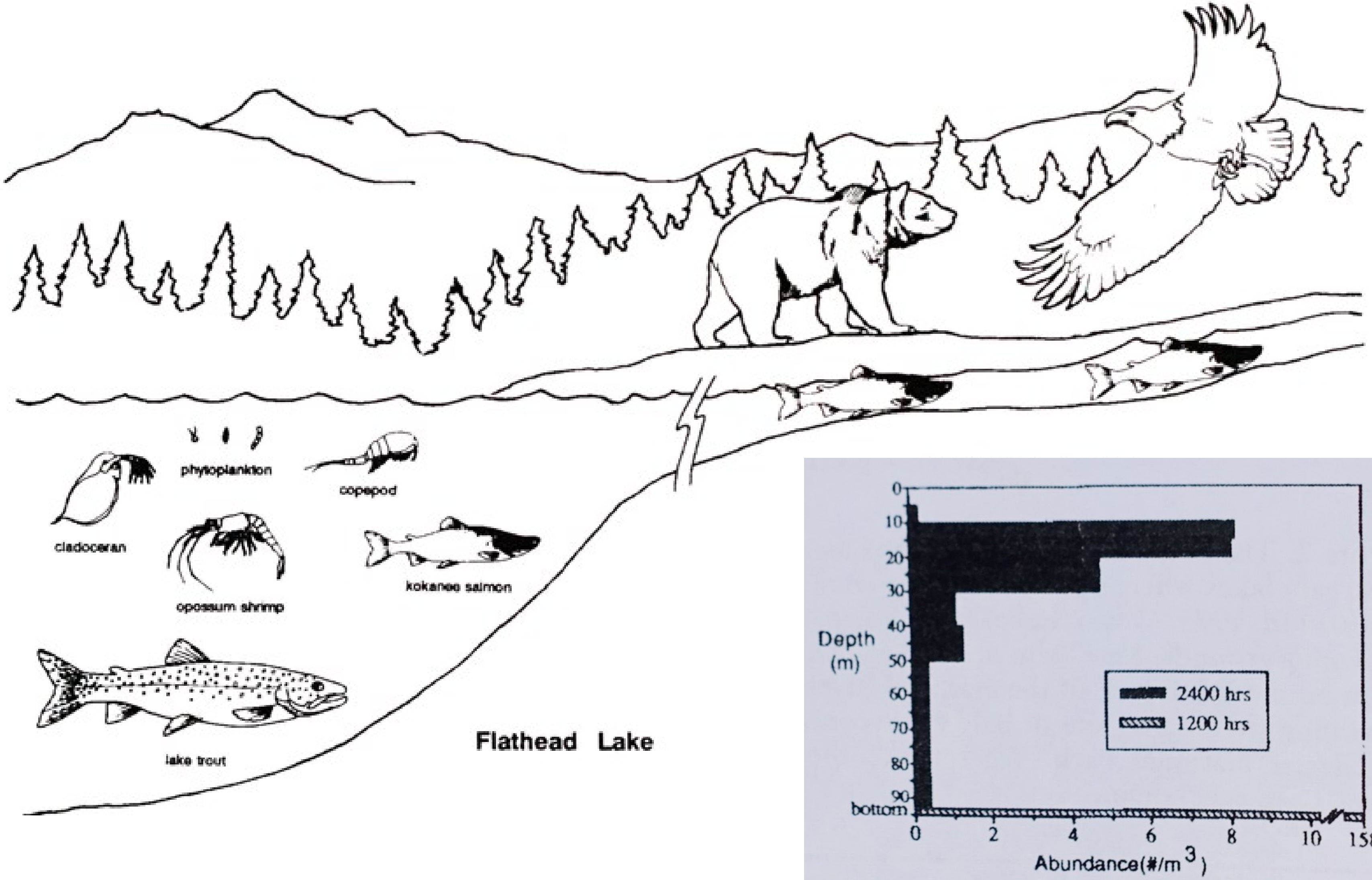
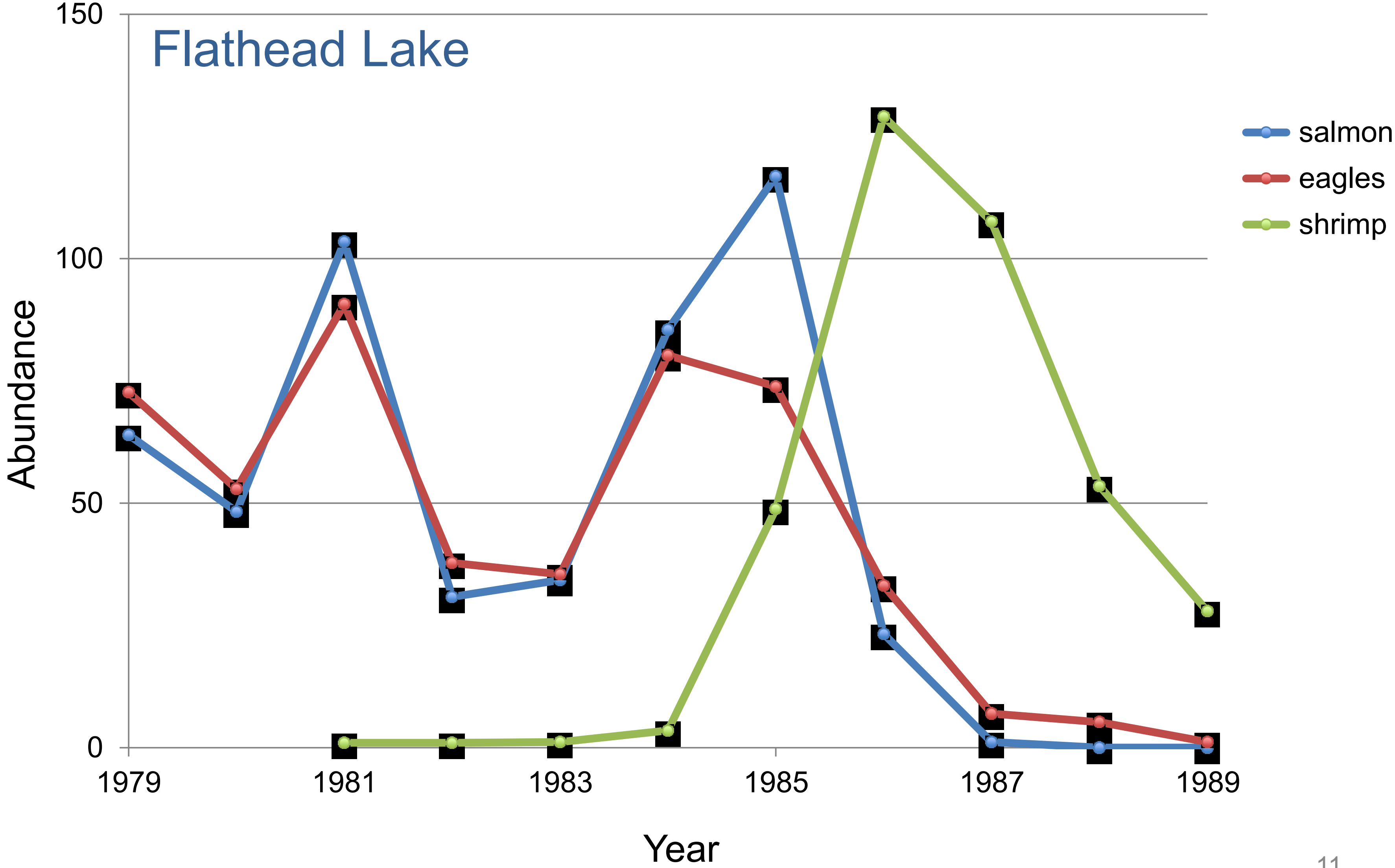
Shrimp Escape Salmon



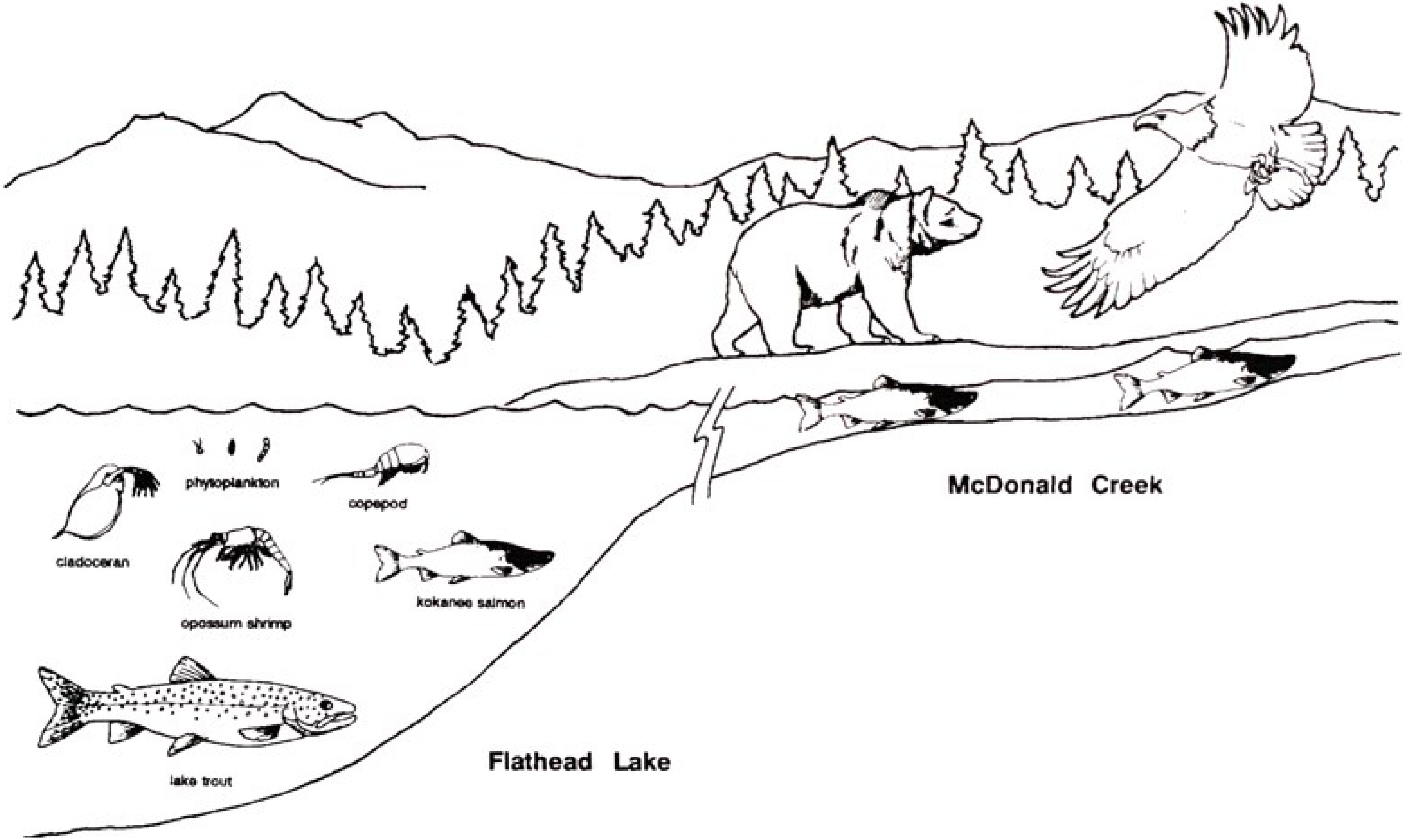
Spencer et al. 1991, *BioScience*, 41, 14-21.

Shrimp Decline



Based on Spencer et al (1991) Figure 4

Lake Trout Love Shrimp



Spencer et al. 1991, *BioScience*, 41, 14-21.

Ecosystem Dynamics

We can use system dynamics (SD) to increase our understanding of complex system behaviour.

SD explanations are focused on cause and effect. How and <u>why</u> things change over time.

We can use the basic SD building blocks:

Stocks – number or amount of things accumulated.

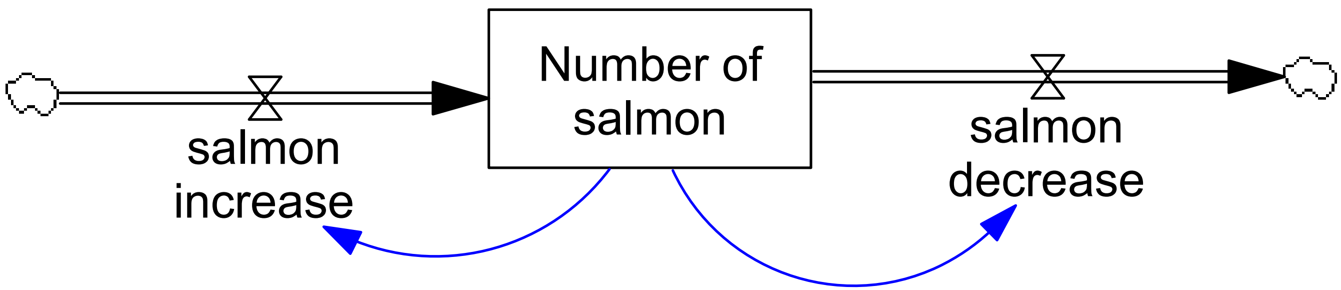
Flows – processes that change the amounts accumulated.

Influence Links – by which stocks affect flow rates.

Stocks & Flows

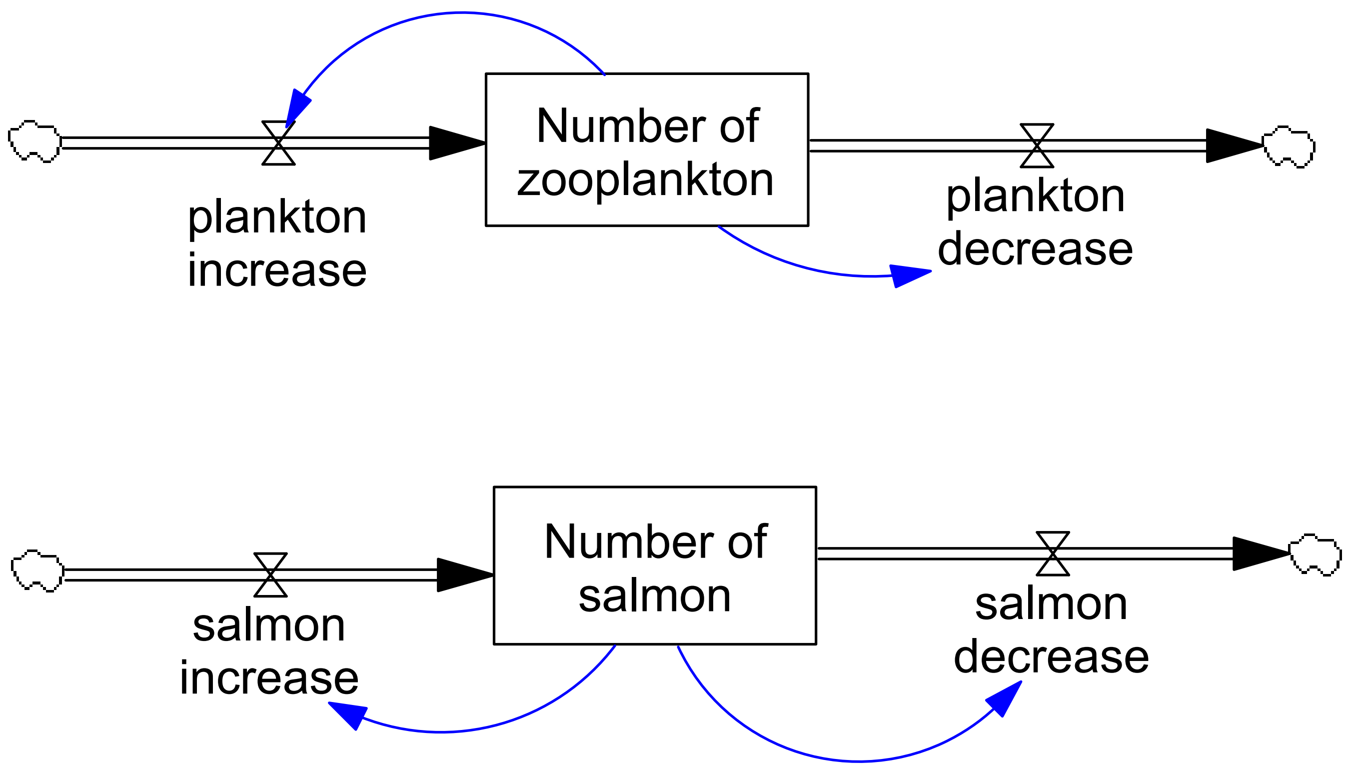
In this diagram there is a single stock. It is represented by the rectangle labelled “Number of salmon”.

There are two flows. Represented by the arrows with ‘tap’ symbols. The inflow process “salmon increase” (e.g., birth) adds salmon to the stock. The outflow process “salmon decrease” (e.g., death) removes salmon from the stock.



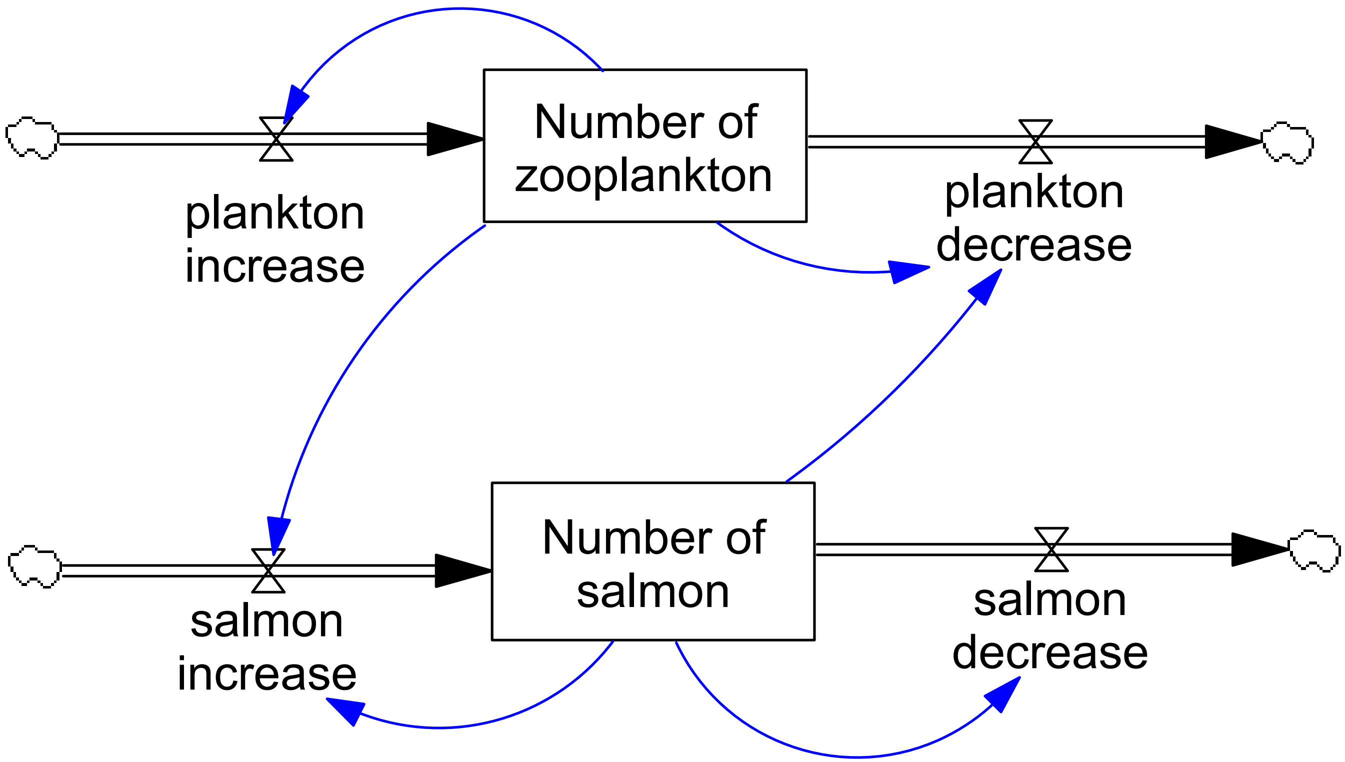
The blue arrows represent processes whereby the ‘level’ of the stock (i.e., the amount accumulated) affects the rates of flow.

Births & Deaths



The populations of all the creatures living in the lake show this kind of behaviour. Numbers drive increase and decrease in numbers via the feedback loops.

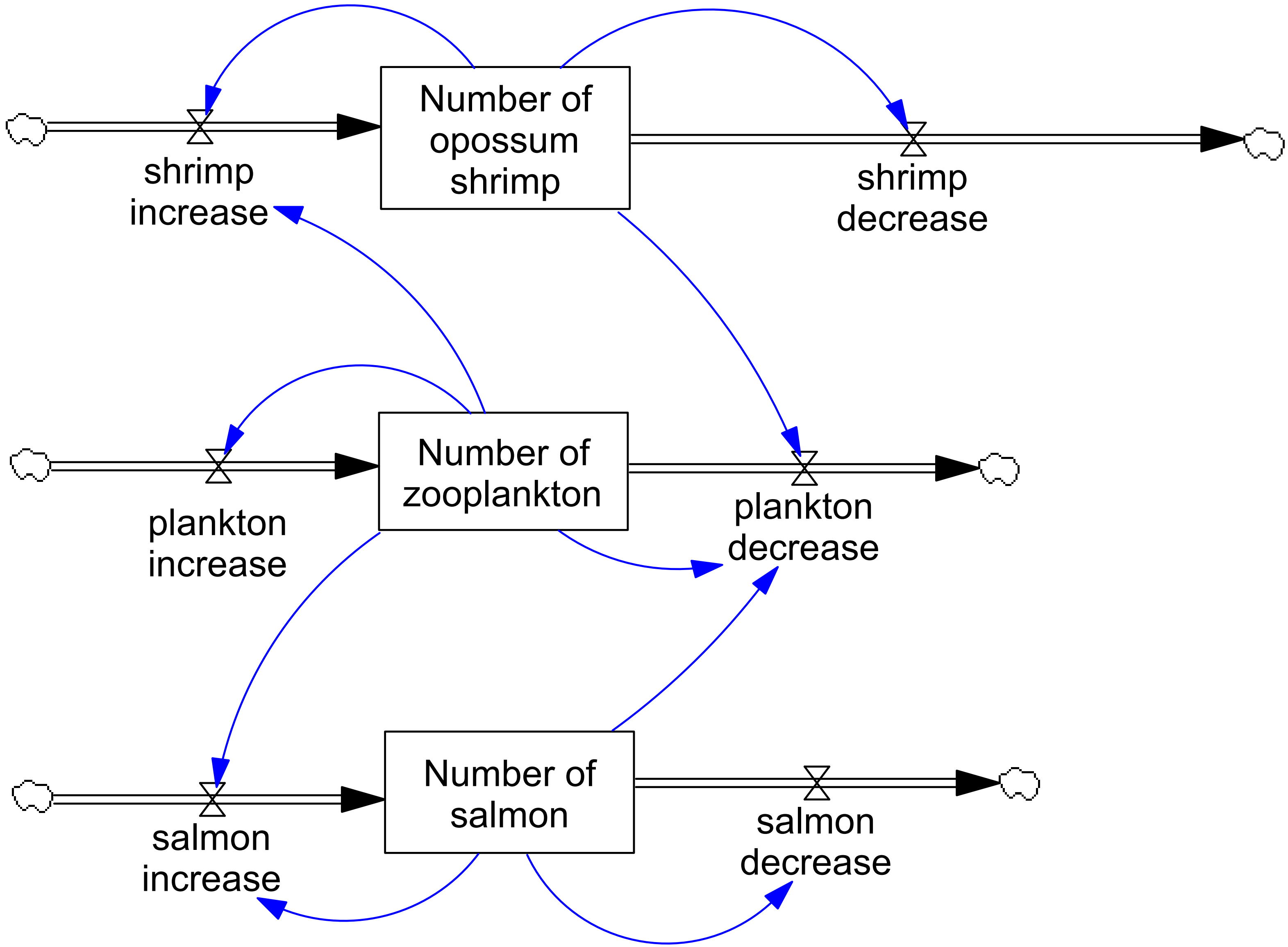
Predators & Prey



The salmon and zooplankton interact to form a “predator-prey” system

Simulate

Introduced Predator

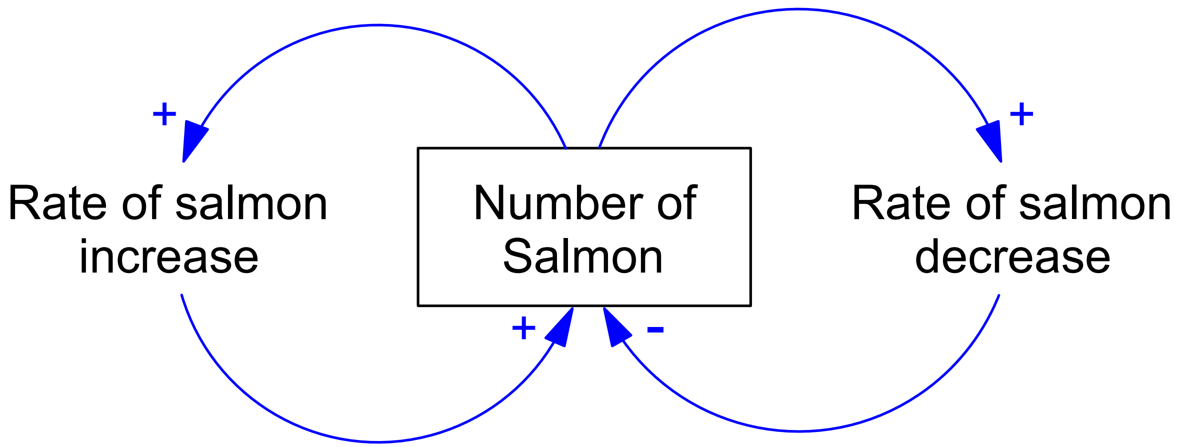


Feedback Loops

While the inflow and outflow processes (double-lined arrows with taps) affect the level of the stock, the level of the stock affects the rates of flows.

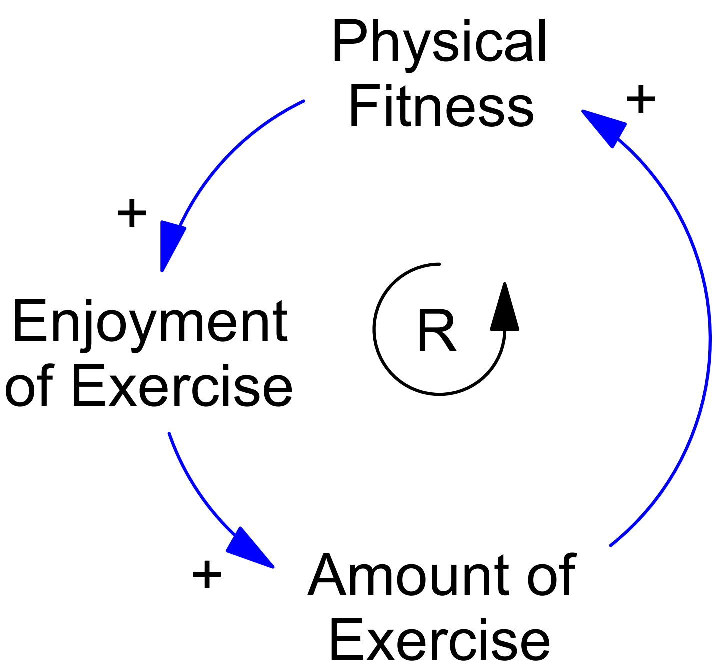
That is, the influence links (blue arrows) complete ‘causal loops’. A change in the level of the stock will change the flow rates, and will cause the stock to change differently over time.

When feedback operates a change in a state variable causes further changes in the same variable.

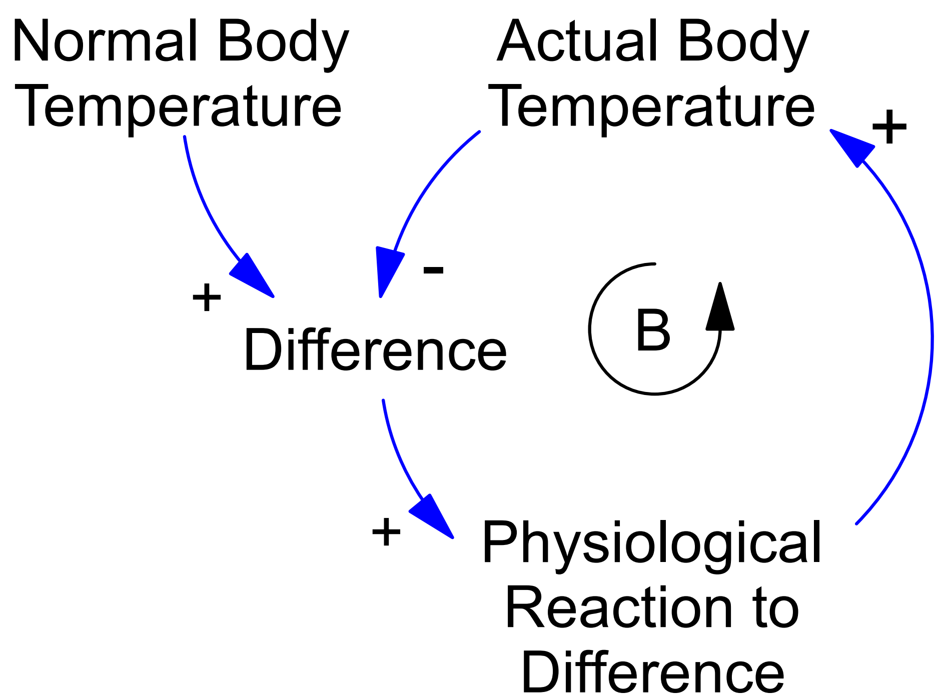


Two Types of Feedback

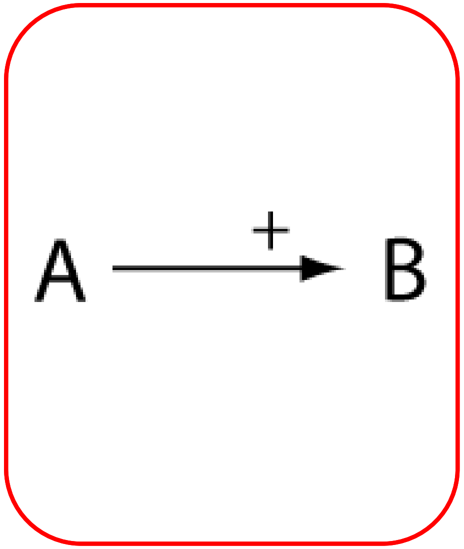
Reinforcing feedback amplifies change

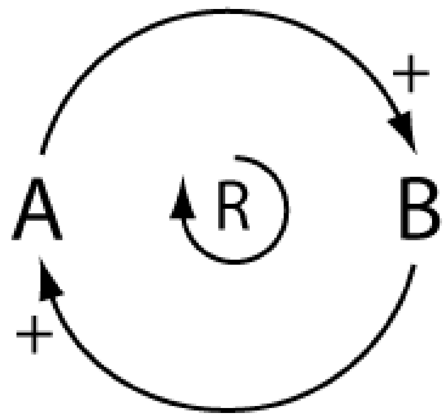


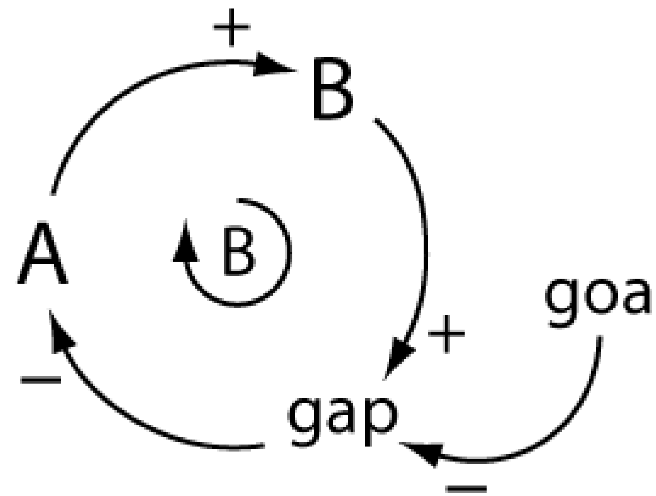
Balancing feedback resists change



Counter-intuitive Behaviour

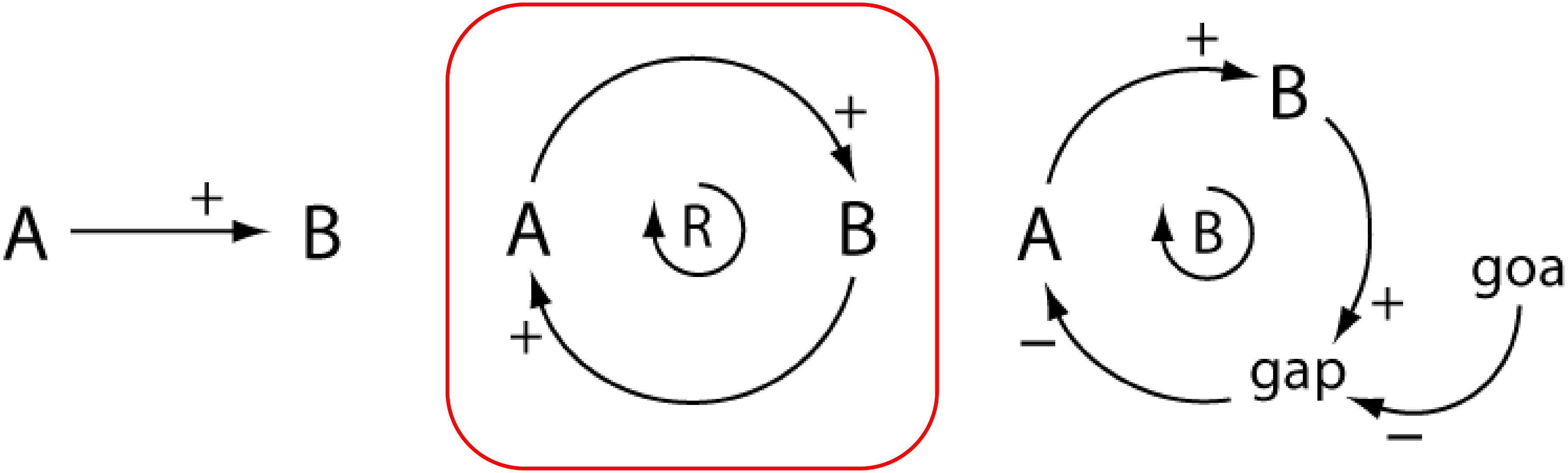






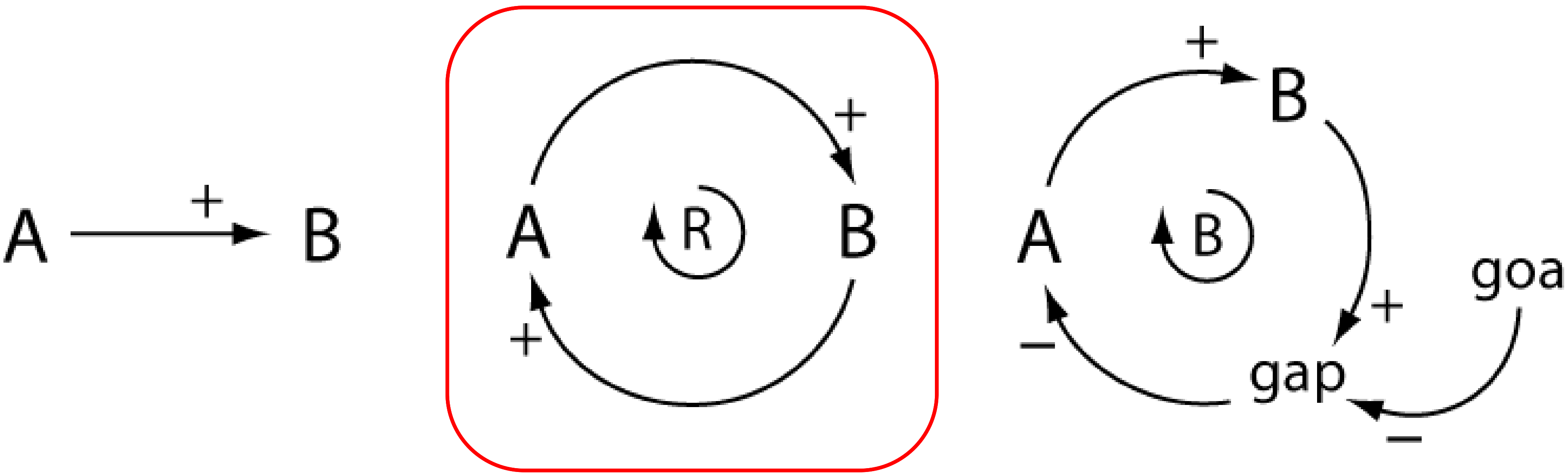
It is common for people to intuitively assume that a change in A will cause a proportional change in B. This is the assumption of “linear causation”. Double A and you will double B. Halve A and you will halve B.

Counter-intuitive Behaviour

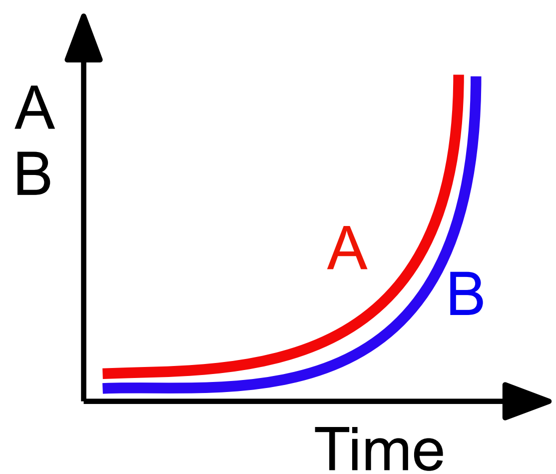


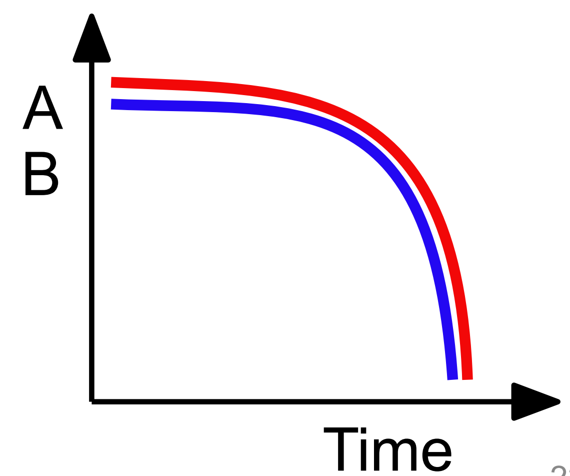
If, however, the causal structure involves reinforcing feedback, then the assumption of linear causation will be misleading. An increase in A will cause an increase in B, the increase in B will cause a further increase in A, and so on around the loop.

Counter-intuitive Behaviour

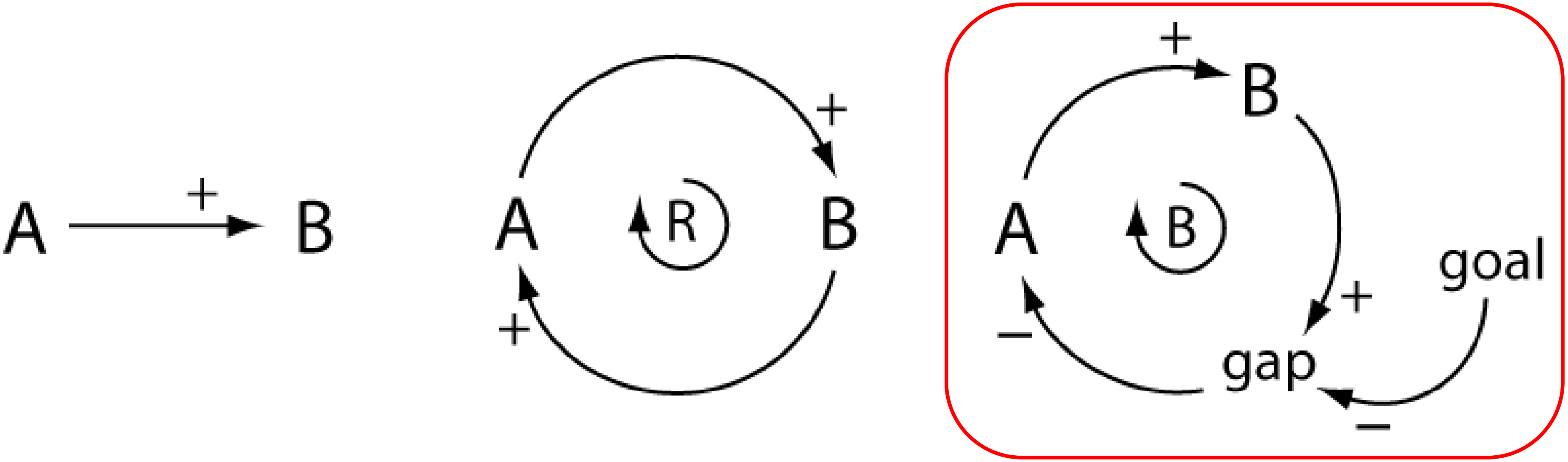


The end result will be accelerating change in both A and B.



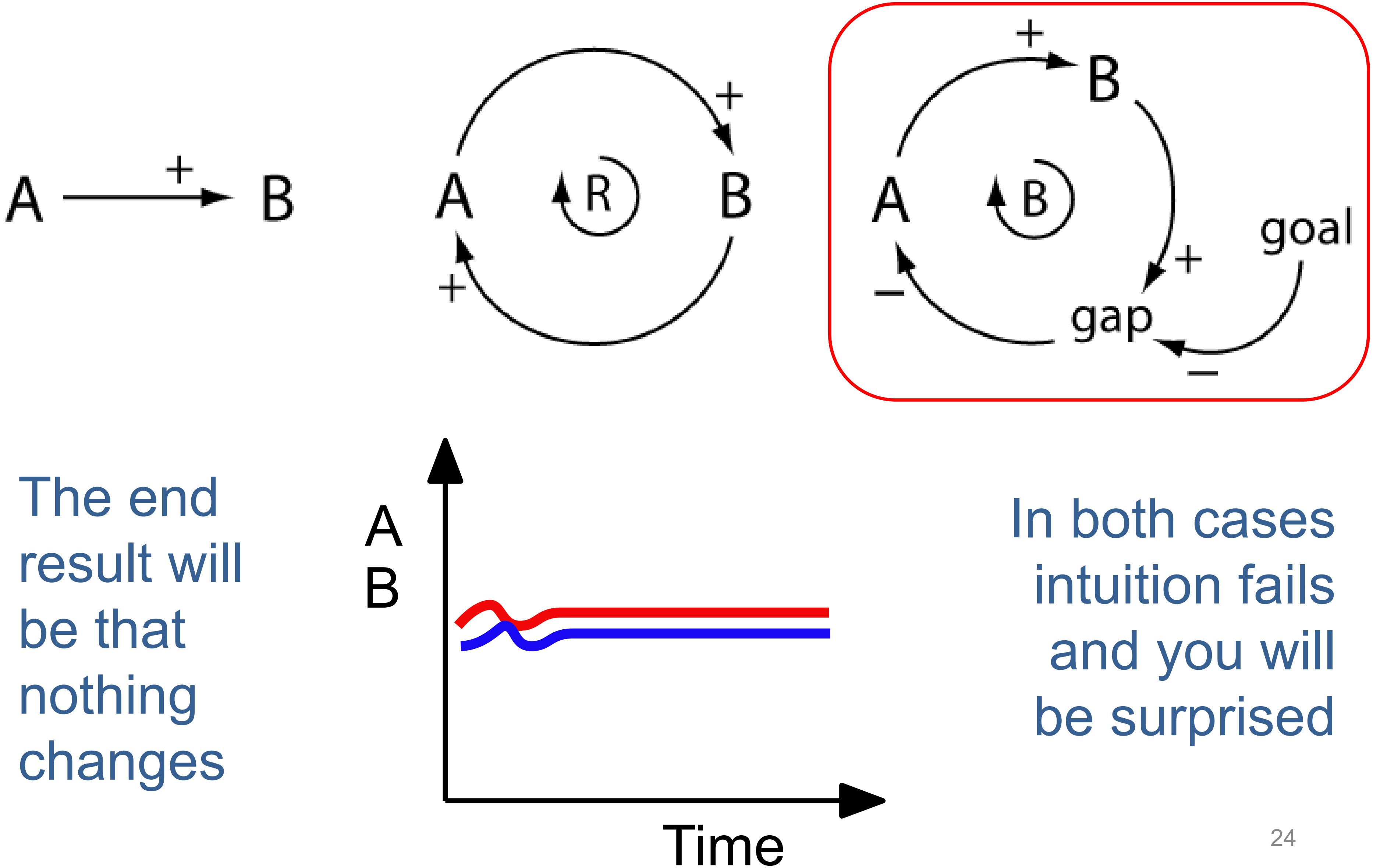


Counter-intuitive Behaviour



Similarly, if the causal structure involves balancing feedback, the linear assumption will again fail. As B moves away from its goal, then forces will be generated that reverse the change in A, and B will move back towards its goal.

Counter-intuitive Behaviour



The end result will be that nothing changes

In both cases intuition fails and you will be surprised

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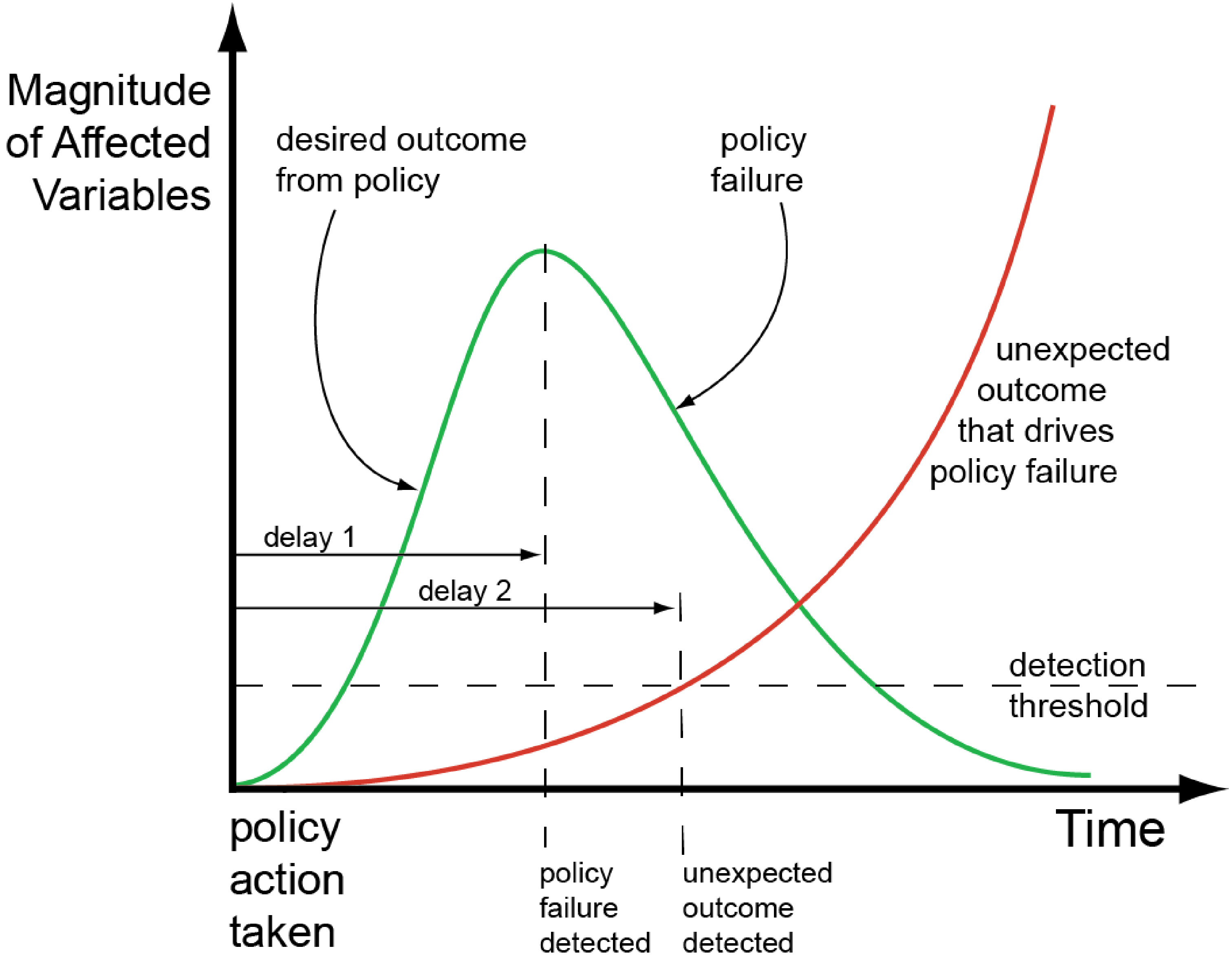
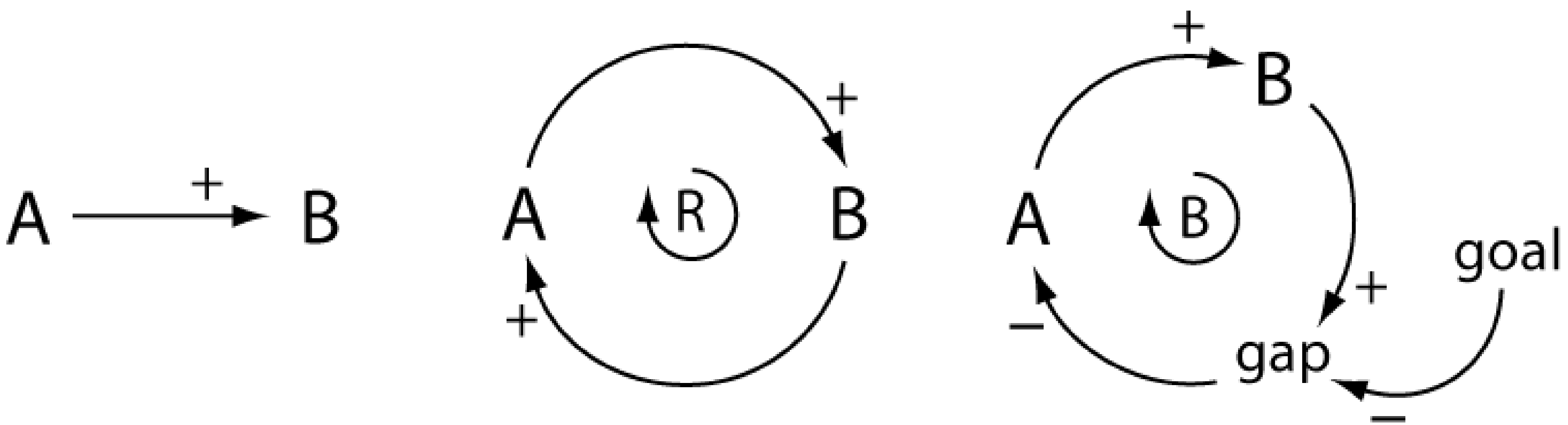
Policy Surprise



Counter-intuitive Behaviour



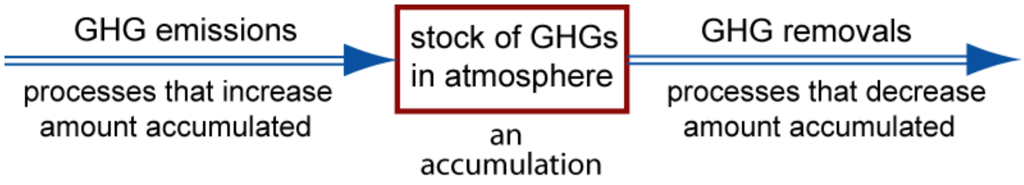
If we want to avoid "policy surprise" then it is essential that we recognise the limitations of the assumption that causation is always linear. We need 'new eyes' that allow us to see that the behaviour of a complex system is driven by a number of feedback effects.

CCM Systems-Thinking Principles

1. The Feedback Principle: Feedback effects are dominant drivers of behaviour in any social-ecological system.

2. The Holistic Principle: The behaviour of a social-ecological system emerges from the feedback interactions between its parts, and therefore cannot be optimised by optimising the behaviour of its parts taken one by one.

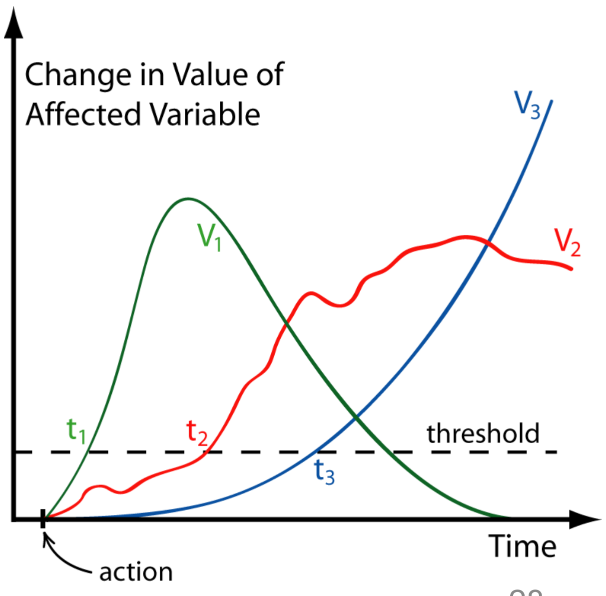
3. The Inertia Principle: The filling and draining of stocks is a pervasive process in social-ecological systems. The presence of stocks causes delayed responses, thereby giving rise to system inertia.



CCM Systems-Thinking Principles

4. The Surprise Principle: Any action taken in a social-ecological system will have multiple outcomes, some expected and some unexpected. The expected outcomes might occur—unexpected outcomes will always occur. The unexpected outcomes are usually unwanted and delayed— delays make it difficult to identify the triggering actions.

5. The History Principle: Knowledge of past activities and patterns of behaviour is essential in any attempt to understand how a social-ecological system works.



CCM Systems-Thinking Principles

6. *The Myopia Principle*: No one person can see the whole of a social-ecological system.

7. *The Collaboration Principle*: The boundaries of a social-ecological system cut across the boundaries of traditional disciplines, organisations, governance sectors and sub-cultures. An effective systems approach therefore requires deep collaboration between people with different backgrounds, worldviews, values and allegiances.

The Complexity Dilemma

A complex system is a set of “parts” (elements, actors). The behaviour of such a system *emerges* from feedback interactions between these parts.

Therefore, you cannot understand the behaviour of such a system by studying only the behaviour of the parts taken separately. But, when you try to study the system as a whole, you are overwhelmed by its complexity – both detail and dynamic.

The system cannot be understood as a whole, and it cannot be understood as a set of disconnected parts. That is the dilemma.

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The Complexity Dilemma

One way to escape the complexity dilemma is to look for similar behaviour (evolution over time, response to management interventions) in contexts which, at first sight, seem to be very different.

For example, if a number of apparently disparate behaviours can be shown to be just different versions of the same generic behaviour, there can be a significant reduction in the apparent complexity of the observed world.

That was the concept behind the *Systems Thinking in Practice* challenge …

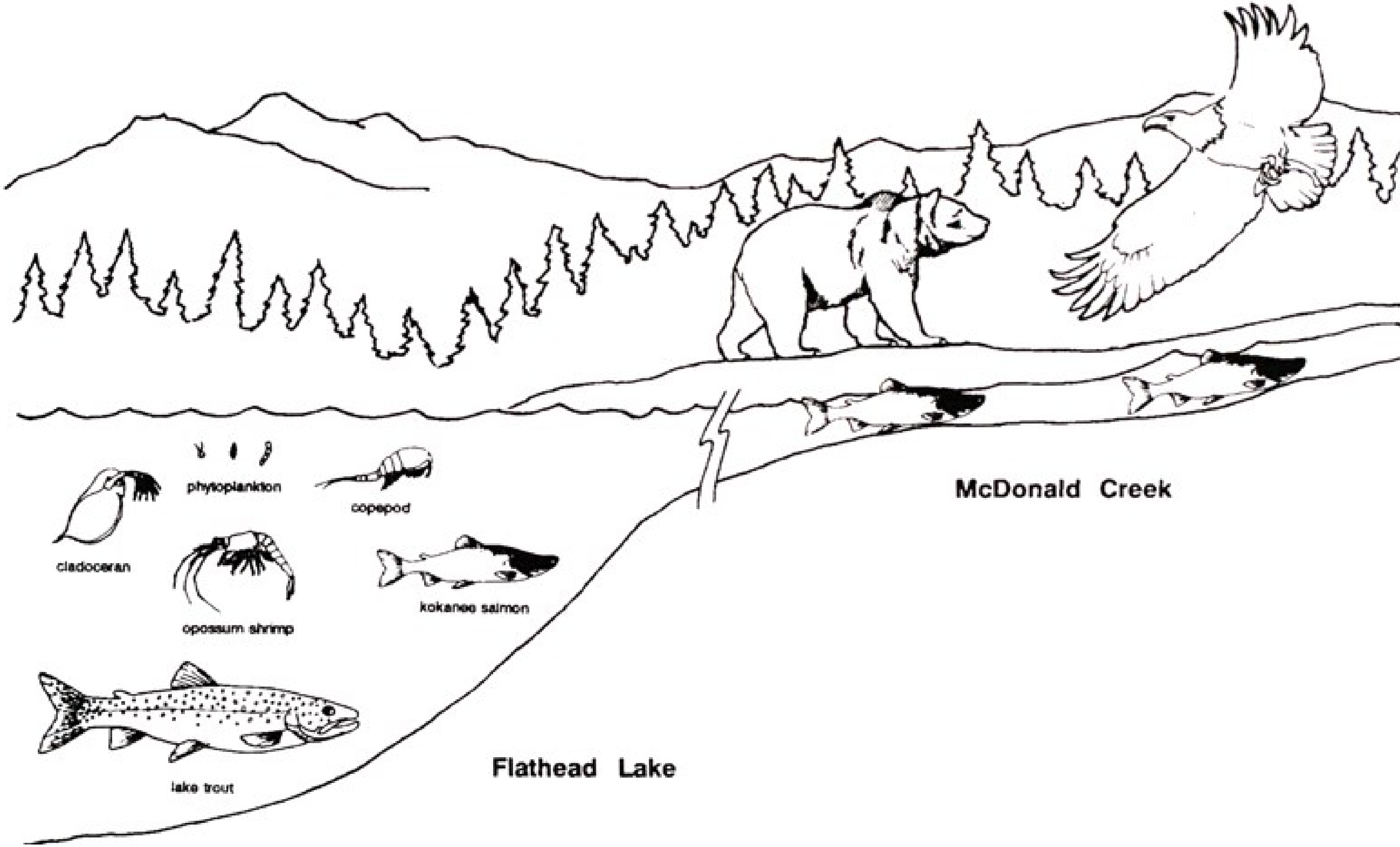
System Archetypes

One way to escape the complexity dilemma is to begin thinking in terms of “system archetypes” …

System Archetypes are simple feedback structures that occur in many different situations and that have a signature way of behaving.

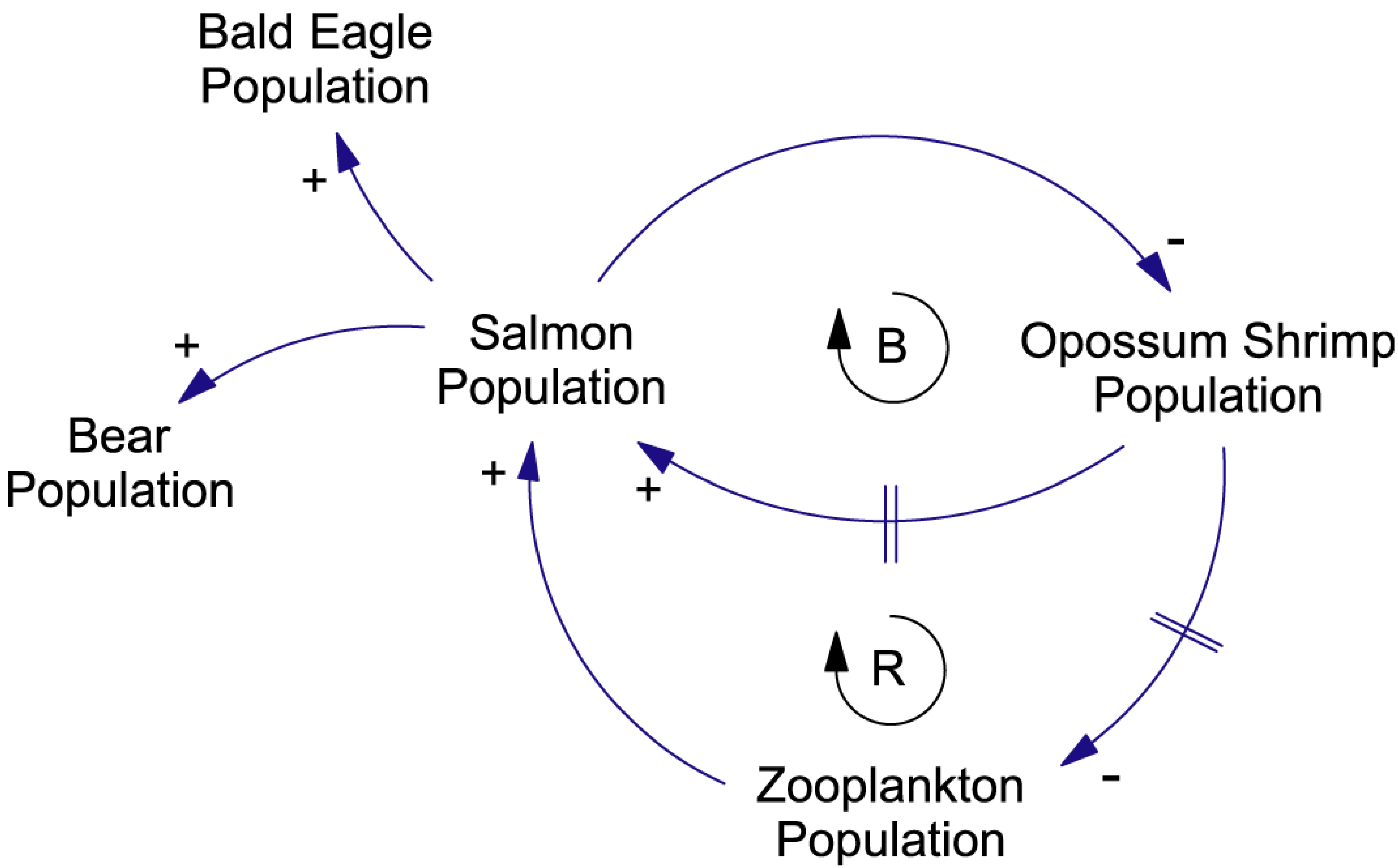
- Introducing shrimp to feed freshwater salmon
- Spraying ragweed with broad-spectrum herbicides
- Using mould ‘killers’ in bathrooms
- Planting wheat on the Great Plains

Feeding Salmon

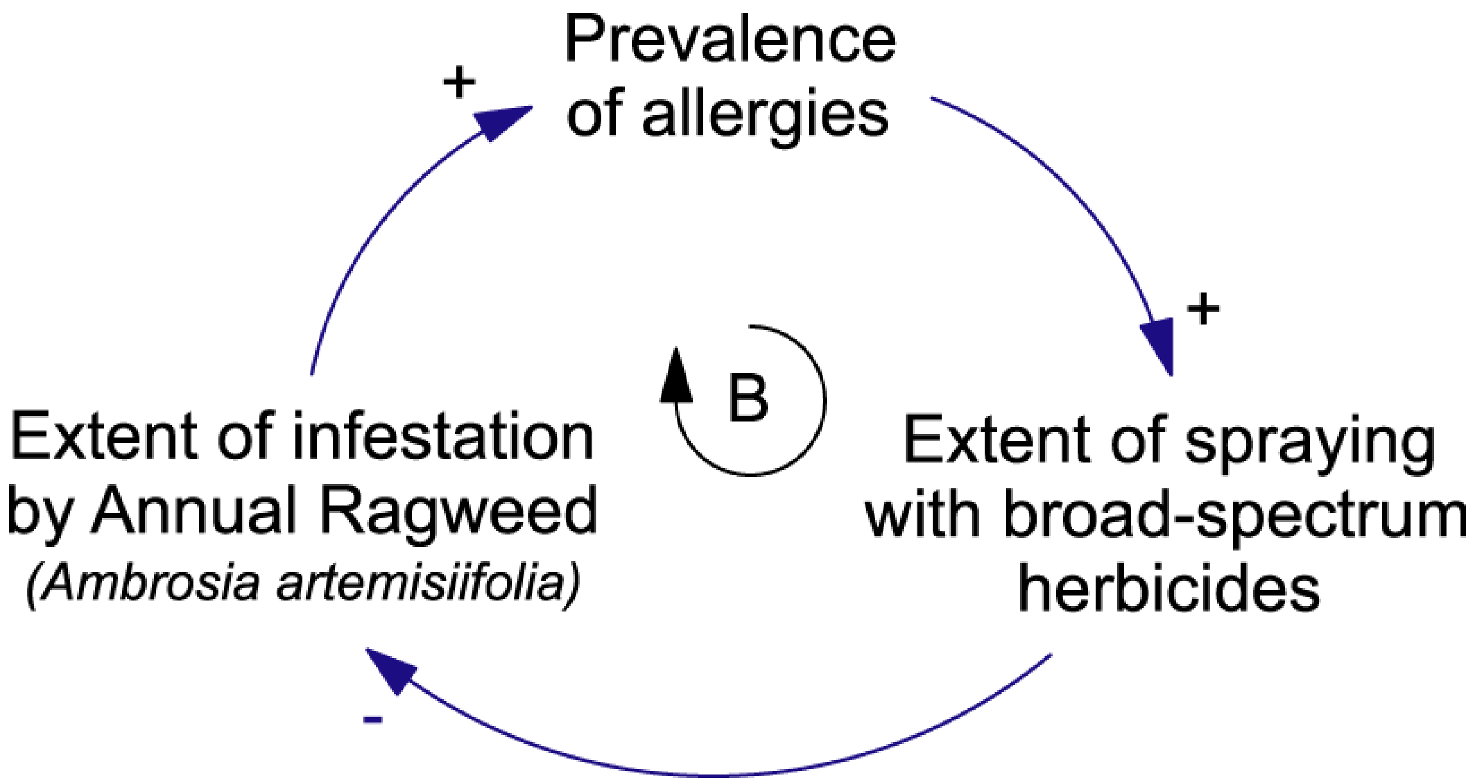


Spencer et al. 1991, *BioScience*, 41, 14-21.

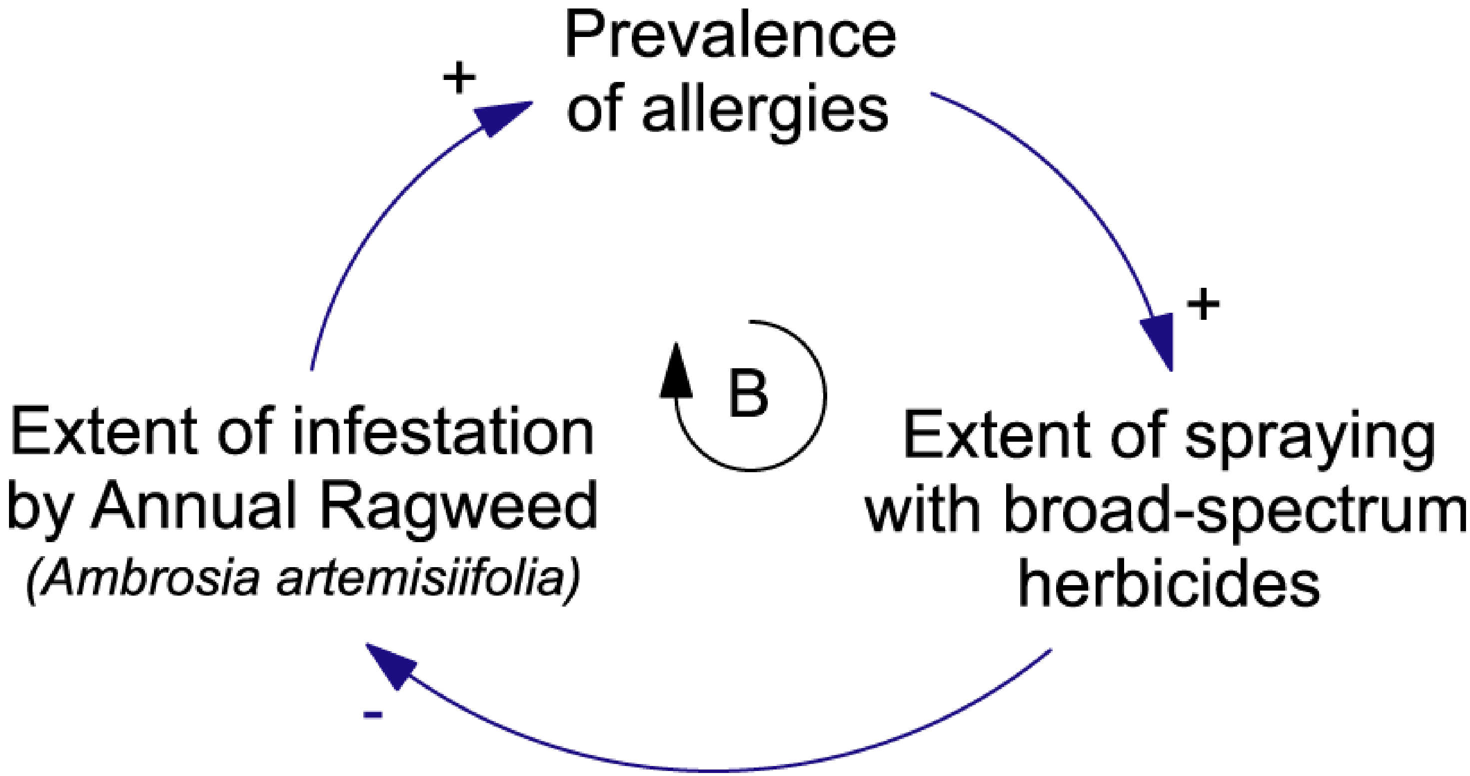
Feeding Salmon



Ragweed

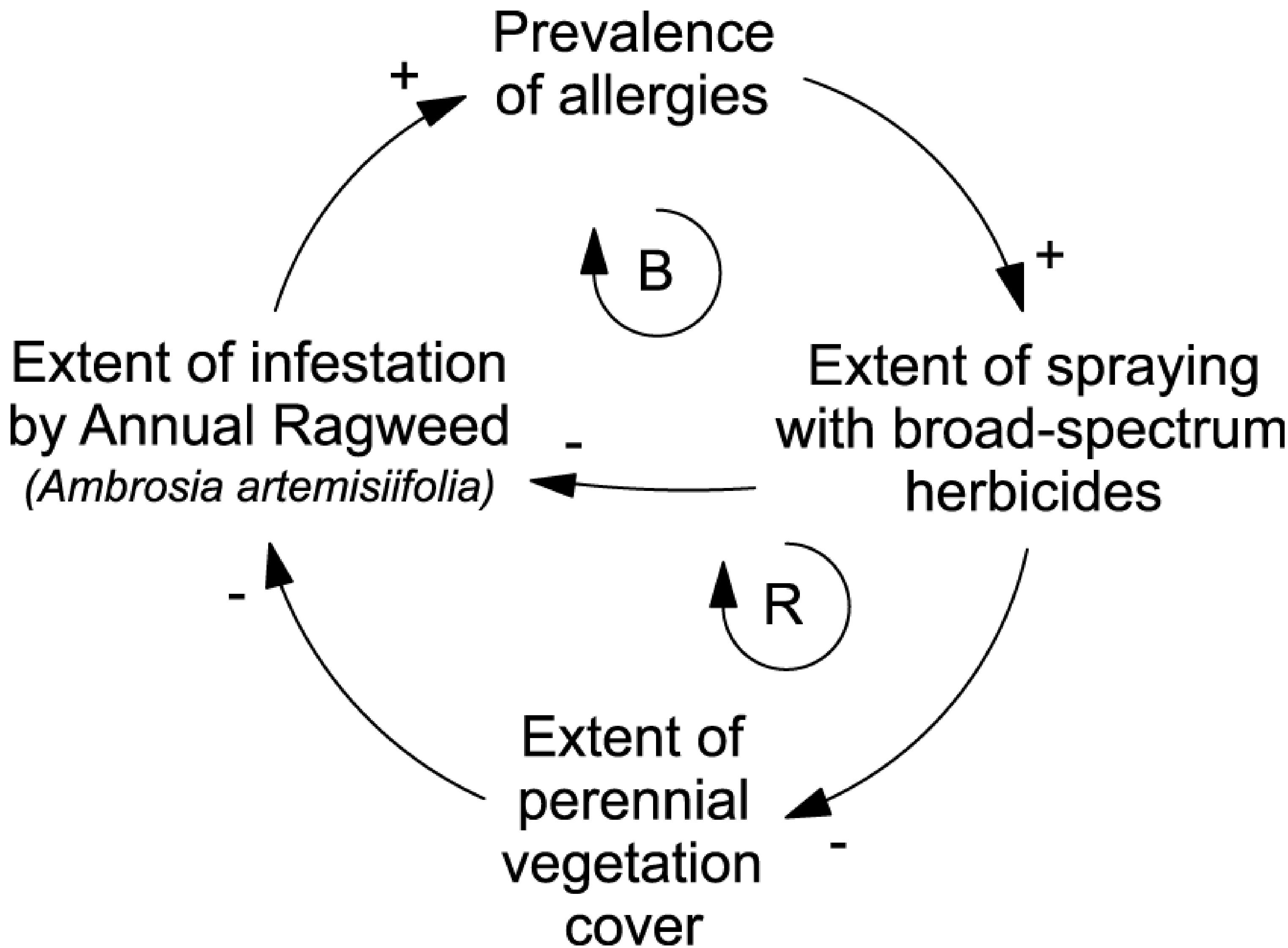

+
Prevalence of allergies
+
B
Extent of infestation by Annual Ragweed
(Ambrosia artemisiifolia)
Extent of spraying with broad-spectrum herbicides
-

Ragweed



But … leads to more ragweed next year. Why?

Ragweed


Prevalence of allergies
+
+
B
Extent of infestation by Annual Ragweed
(Ambrosia artemisiifolia)
-
Extent of spraying with broad-spectrum herbicides
R
-
-
Extent of perennial vegetation cover

Mould Killer

CHOICE Magazine

Shonky Awards 2012

– Ticketek, the other half of the Aussie ticket-sales duopoly, also add on extra

own ink and paper. How J Lo can they go? Unfortunately consumers – and even the event managers themselves – have little choice other than

for consumers and probably didn't put much of a dent in their reported $50m profit that year.

THE SHONKY FOR...

More like a squabble than a killing goes to

Exit Mould and Coles Ultra Mould Remover

When CHOICE investigated bathroom mould killers this year, we were astonished to learn that they don't actually, well, kill mould.

Mycologists – that's fungus boffins to you and me – tell us there are several reasons for this, first and foremost being that these alleged mould killers can't penetrate porous surfaces, such as grout, which is where mould tends to party. Yes, it may look nice and white post-spray, courtesy of the bleach removing the colour, and some of the surface mould may even have rubbed off, but the root structure remains entrenched in the grout ready to sprout again and party another day. But it gets worse: the bleach can actually erode and corrode grout and tiles, making them more porous – and more receptive to future mould festivities.

And did you know that the active ingredient actually deteriorates over time? While this is kind of disclosed on the packaging, the starting levels are so low anyway that after a while there's not much left but the reassuring fragrance of chlorine.

So when market leader Exit Mould, along with Coles Ultra Mould Remover (using uncannily similar wording), tells us the product "kills ingrained mould" and "penetrates porous surfaces to attack mould at the source", we're not convinced.

*

+

Amt of Mould

Exit used

−

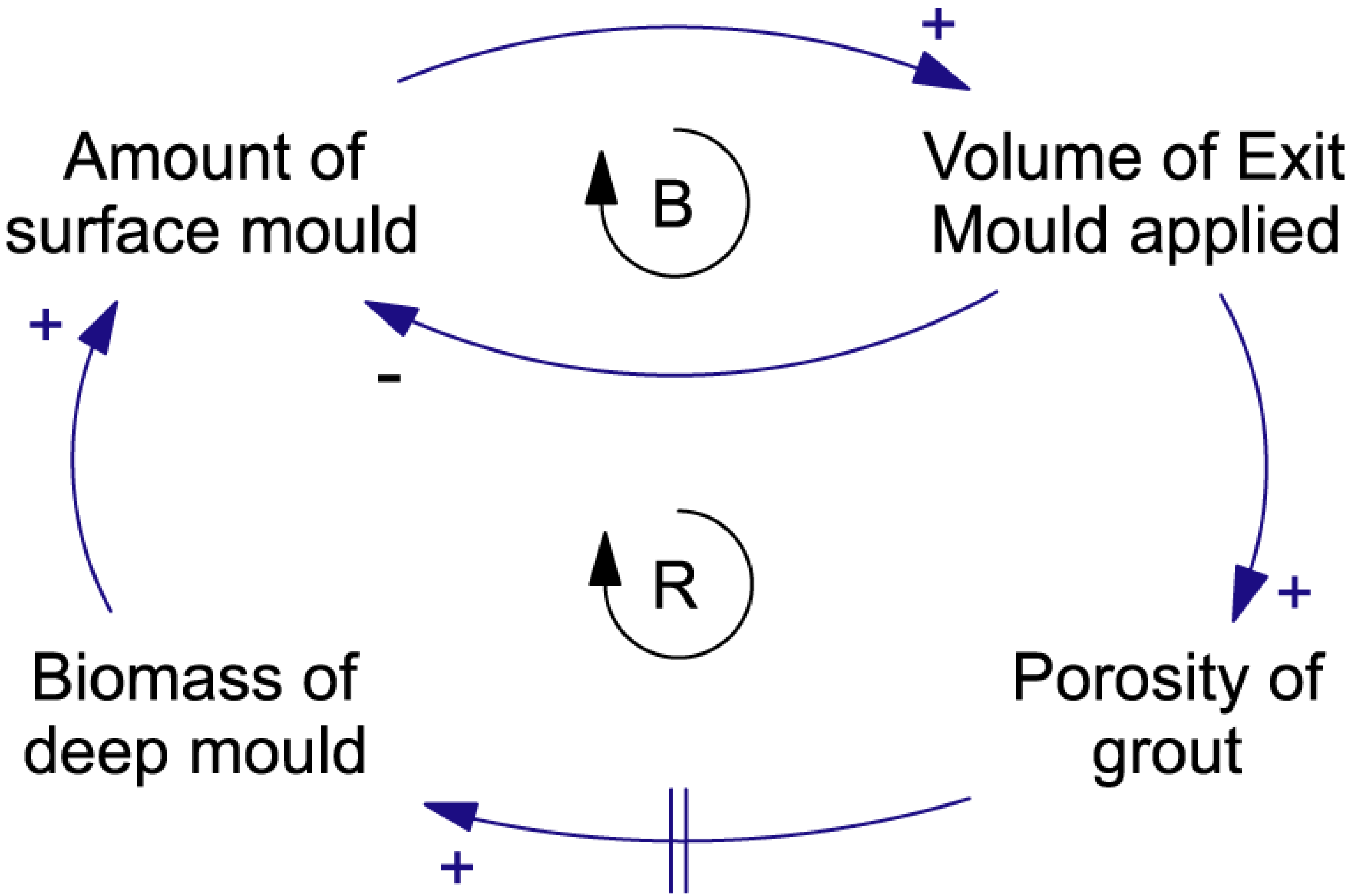
+

Surface porosity

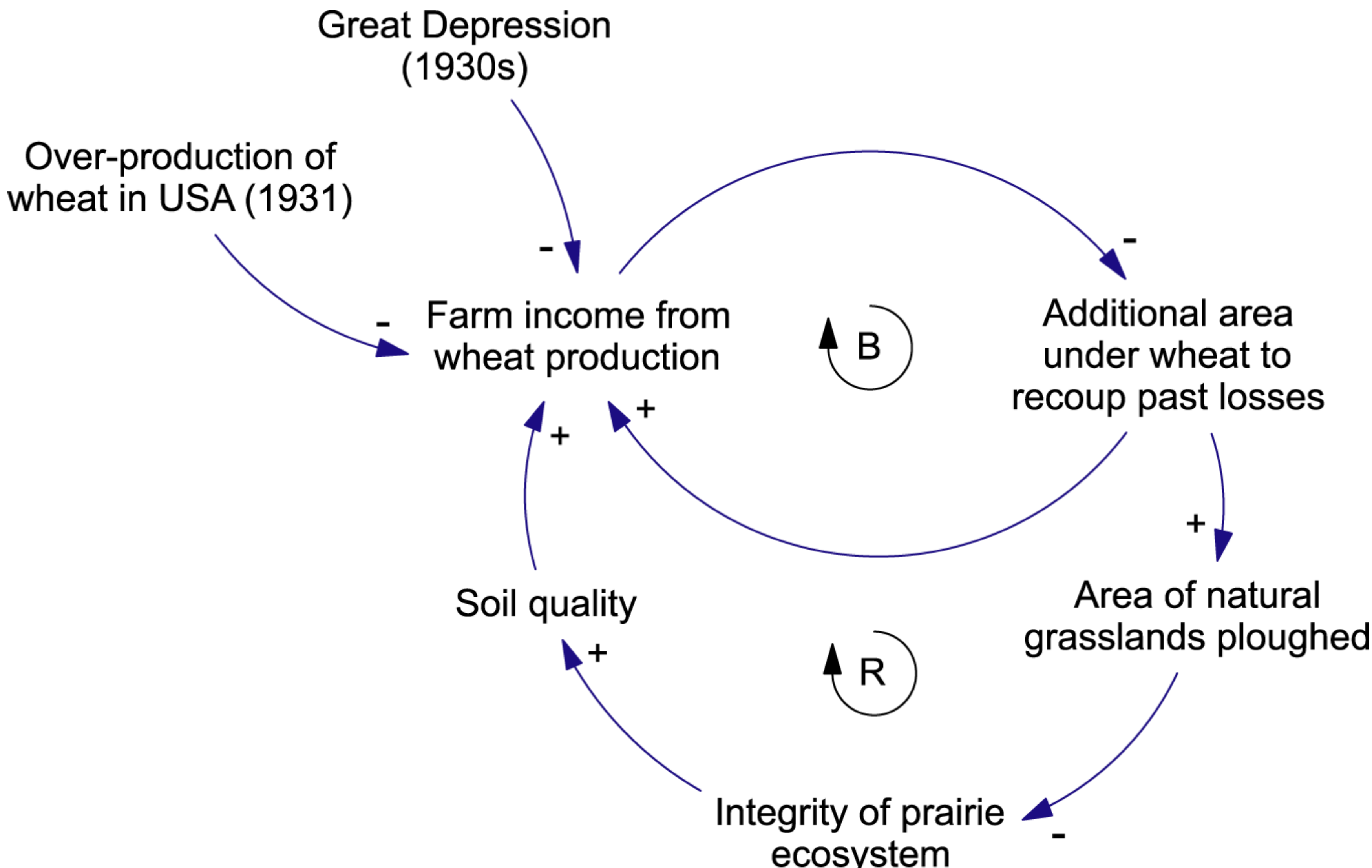
+

18 /// NOVEMBER 2012 CHOICE.COM.AU

Mould Killer



Farming the Great Plains



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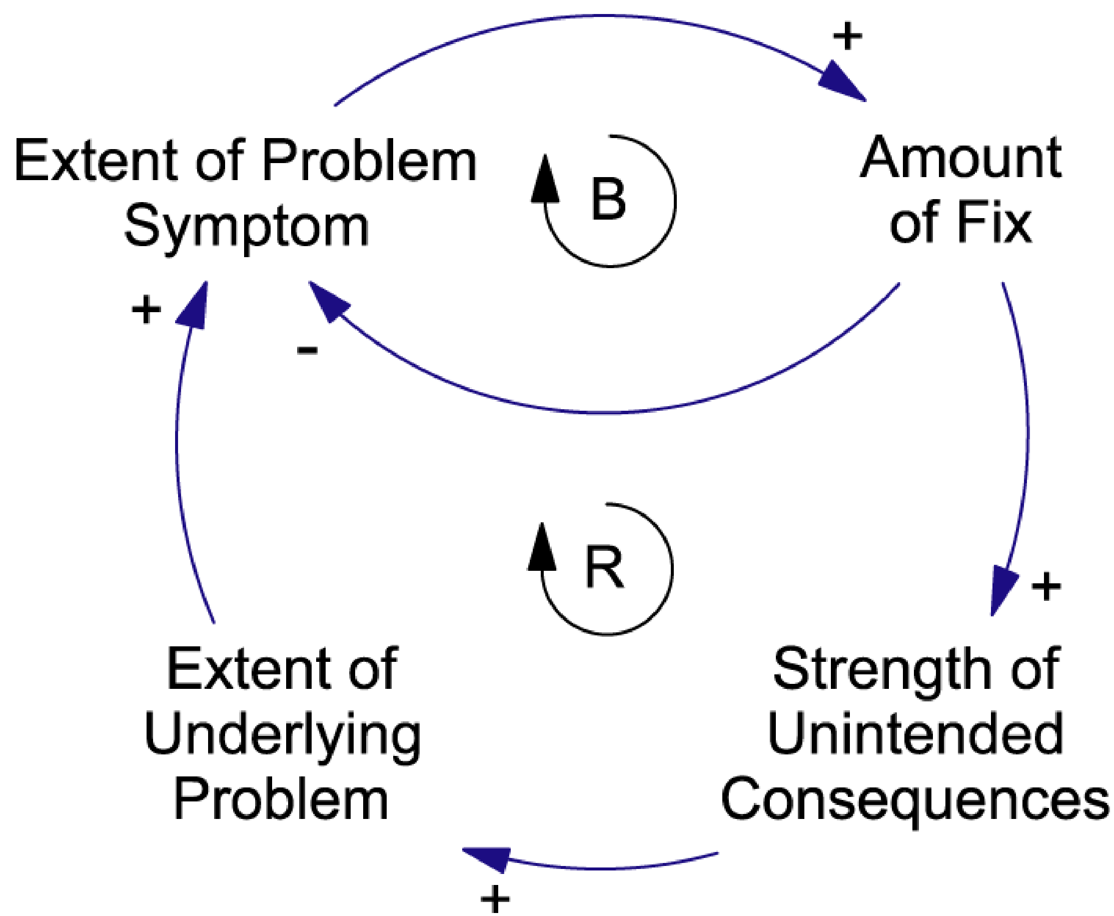
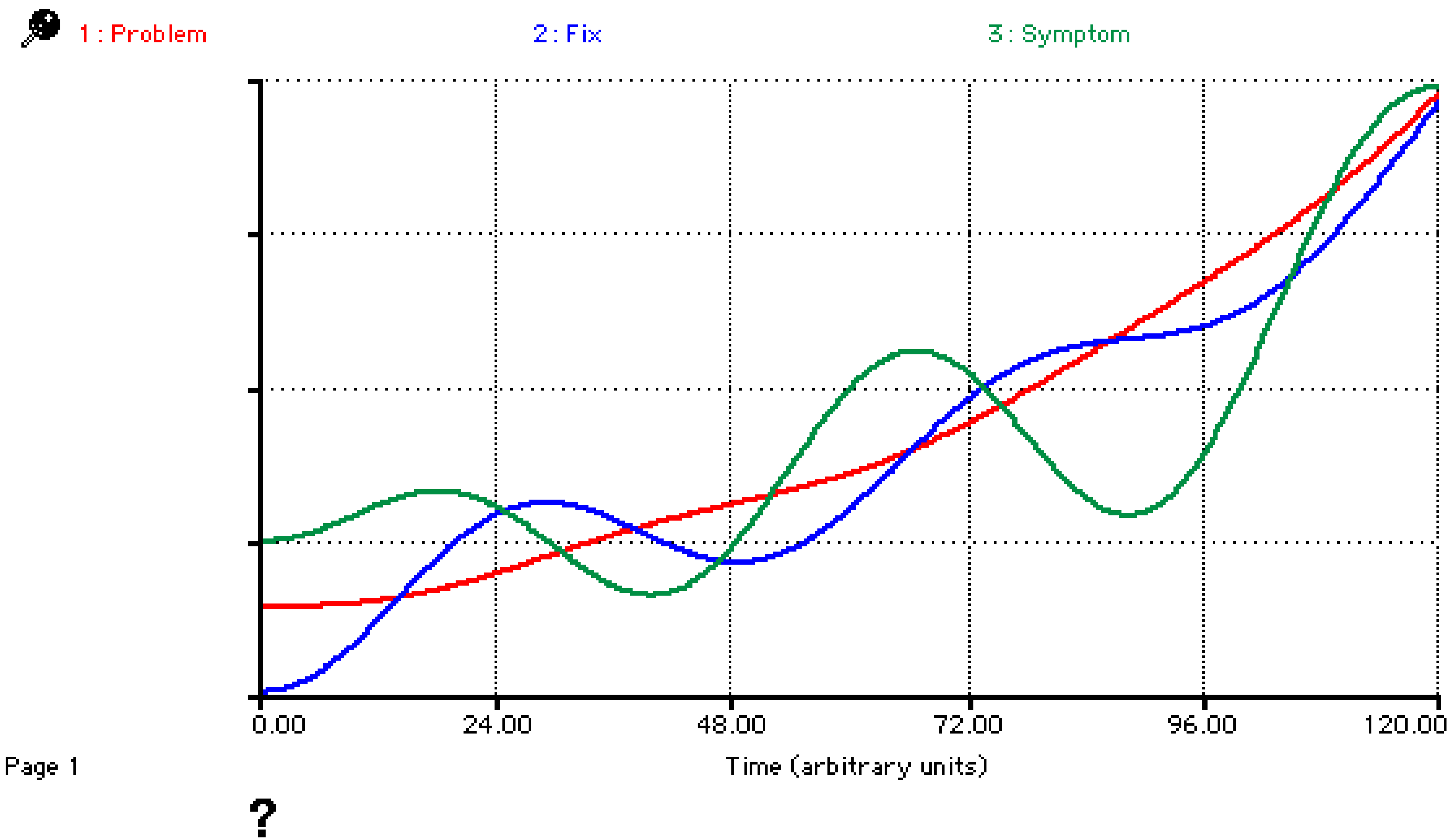
Fixes That Fail



Newell and Proust

Generic Structure

Fixes That Fail



Signature Behaviour

System Archetypes

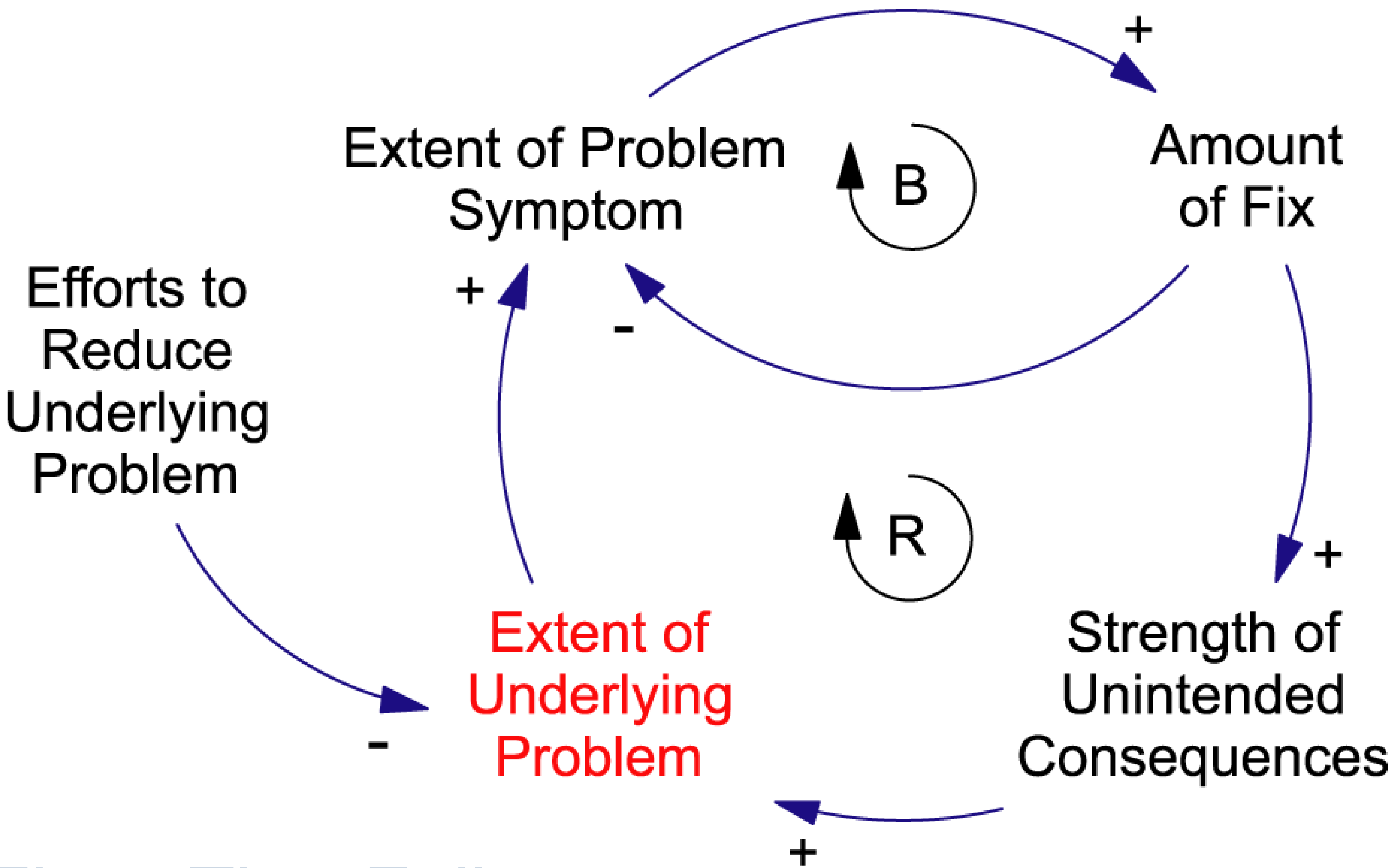
Meadows considers System Archetypes to be "system traps and opportunities".

Traps – because they can cause unexpected outcomes, such as 'fixes that fail' – barriers to effective policy implementation.

Opportunities – because, once recognised, they can help isolate powerful 'leverage points' – places in a system where small pushes can lead to large changes.

Meadows, D.H., 2009, *Thinking in Systems* (Earthscan: London)

Leverage Points

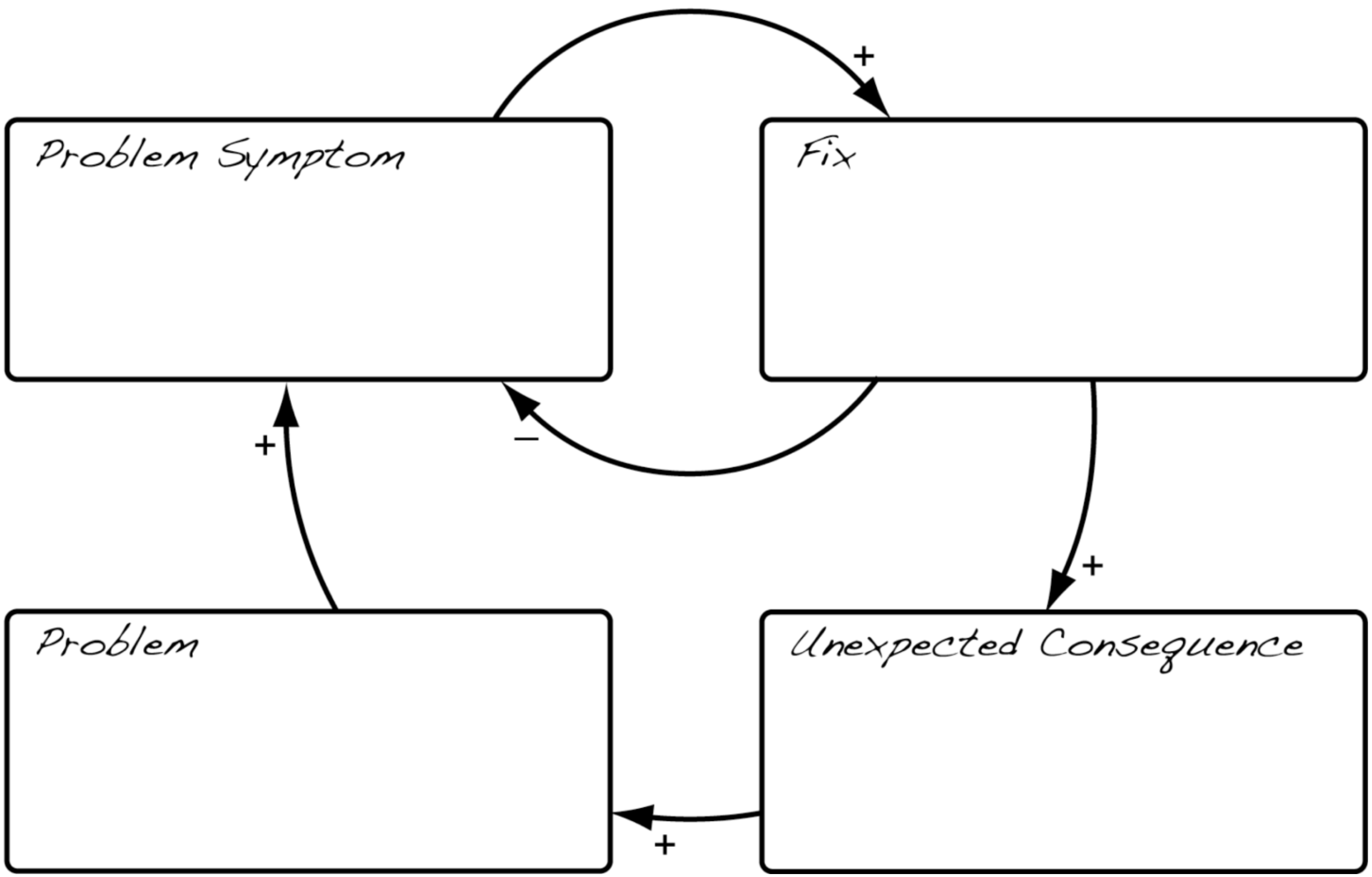


Fixes That Fail

These policies are all likely to be Fixes That Fail …

1. Constructing freeways to reduce travel time
2. Substance abuse to overcome depression
3. The war on terror
4. Constructing flood-control levees
5. Dependence on refrigerated air-conditioning
6. Engineering the climate to combat global warming
7. Using miticides to protect bee colonies from mites
8. Increasing the price of sweet alcoholic mixer drinks (“alcopops”) to discourage teenage drinking

Fixes That Fail (CCM)



System Archetype Template

The *Fixes That Fail* archetype can be used to structure a discussion of the policies on the challenge list.

1. Working in groups of 2 or 3, develop a systems explanation of the failure of one or more of the policies on the list. You can use the template provided.

2. Select one of your diagrams for presentation and discussion.

3. Nominate a group member to make the presentation using the document projector.

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Further Reading

Newell, B., and Proust, K., 2012, *Introduction to Collaborative Conceptual Modelling*, Working Paper, ANU Open Access Research. https://digitalcollections.anu.edu.au/handle/1885/9386

Newell, B., 2010, Simple Models, Powerful Ideas, *Global Environmental Change*, **22**, 776–783.

Dyball, R., and Newell, B., 2015, *Understanding Human Ecology: A systems approach to sustainability* (London: Earthscan/Routledge).

Richardson, G., 2011, Reflections on the foundations of system dynamics, *System Dynamics Review*, 27(3), 219-243.

Further Reading

Meadows, D.H., 2009, *Thinking in Systems: A Primer* (Earthscan: London). A good general introduction to system thinking and system dynamics. Easy reading.

Senge, P., 1990, *The Fifth Discipline: The Art and Practice of The Learning Organization* (Random House: Sydney). The first published discussion of system archetypes, which he calls "Nature's Templates." Easy reading.

Sterman, J.D., 2000, *Business Dynamics: Systems Thinking and Modeling for a Complex World* (Irwin McGraw-Hill: Boston). A thorough discussion. Do not be misled by the word 'business' in the title—this is a solid textbook that will be valuable to readers in all disciplines. ~1000 pages.