Multiple stressors – a challenge for freshwater assessment and impact mitigation

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Structure of the presentation

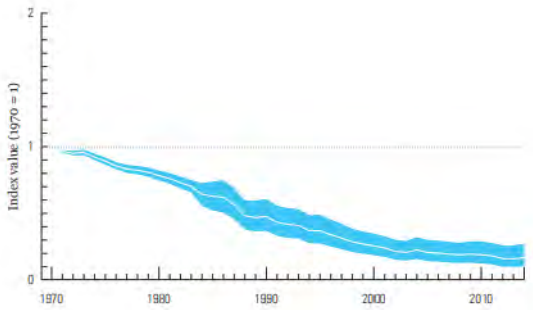
- What the 21st century brings to freshwaters
- Pressures vs stressor
- Key Pressures & Stressors
- How multiple stressor may impact aquatic ecology
- Finding from Irish experiments
- What it means for assessment & management of freshwaters.

Freshwater – the lifeblood of the planet

- Freshwaters provide a disproportionately high amount of ecosystem services.
- These services are underpinned by biodiversity and associated ecological processes.
- Globally freshwaters support at least 10% of all known animal and plant species in <3% of Earth's surface.

Welcome to the 21st Century

- Over 1500 contaminants have been found in freshwaters
  - Top guns: Nutrients, , Organic Waste, Sediment, Pesticides
- C.900 contaminants of emerging concern (NORMAN Network) - industrial compounds, pharmaceuticals, personal-care products, biocides, …….
- Surface waters have been drained, straightened, over-abstracted, fragmented …….
- Freshwater biodiversity is declining at a faster rate than on land or in the sea.
- Alarming losses globally (Reid et al. 2018 & Living Planet Report)



Living Planet Report (2018) WWF

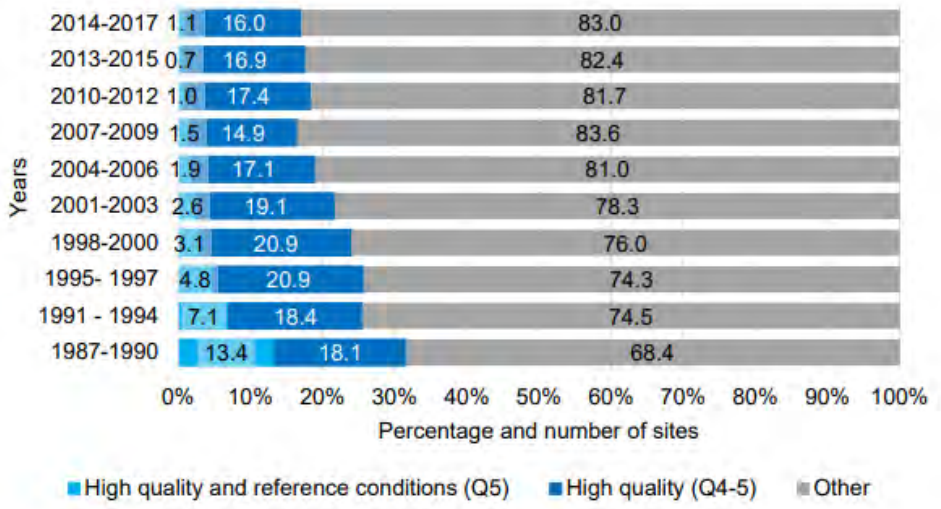
- Four key groups (Odonata, Plecoptera, Trichoptera and Ephemeroptera) have already lost a considerable proportion of species (Sánchez-Bayo et al. 2019).
- **'The Biodiversity crisis in freshwaters has deepened'** - '**Invisible tragedy**'(Reid et al. (2018)

1.Living Planet Report - https://c402277.ssl.cf1.rackcdn.com/publications/1187/files/original/LPR2018_Full_Report_Spreads.pdf
2. Reid, A. J., Carlson, A. K., Creed, I. F., Eliason, E. J., Gell, P. A., Johnson, P. T., … Cooke, S. J. (2019). Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews* 94, 840-873.
3. Sánchez-Bayo, F., & Wyckhuys, K. A. G. (2019). Worldwide decline of the entomofauna: A review of its drivers. *Biological Conservation* 232, 8–27.

Irish Freshwaters

Significant water quality challenges*

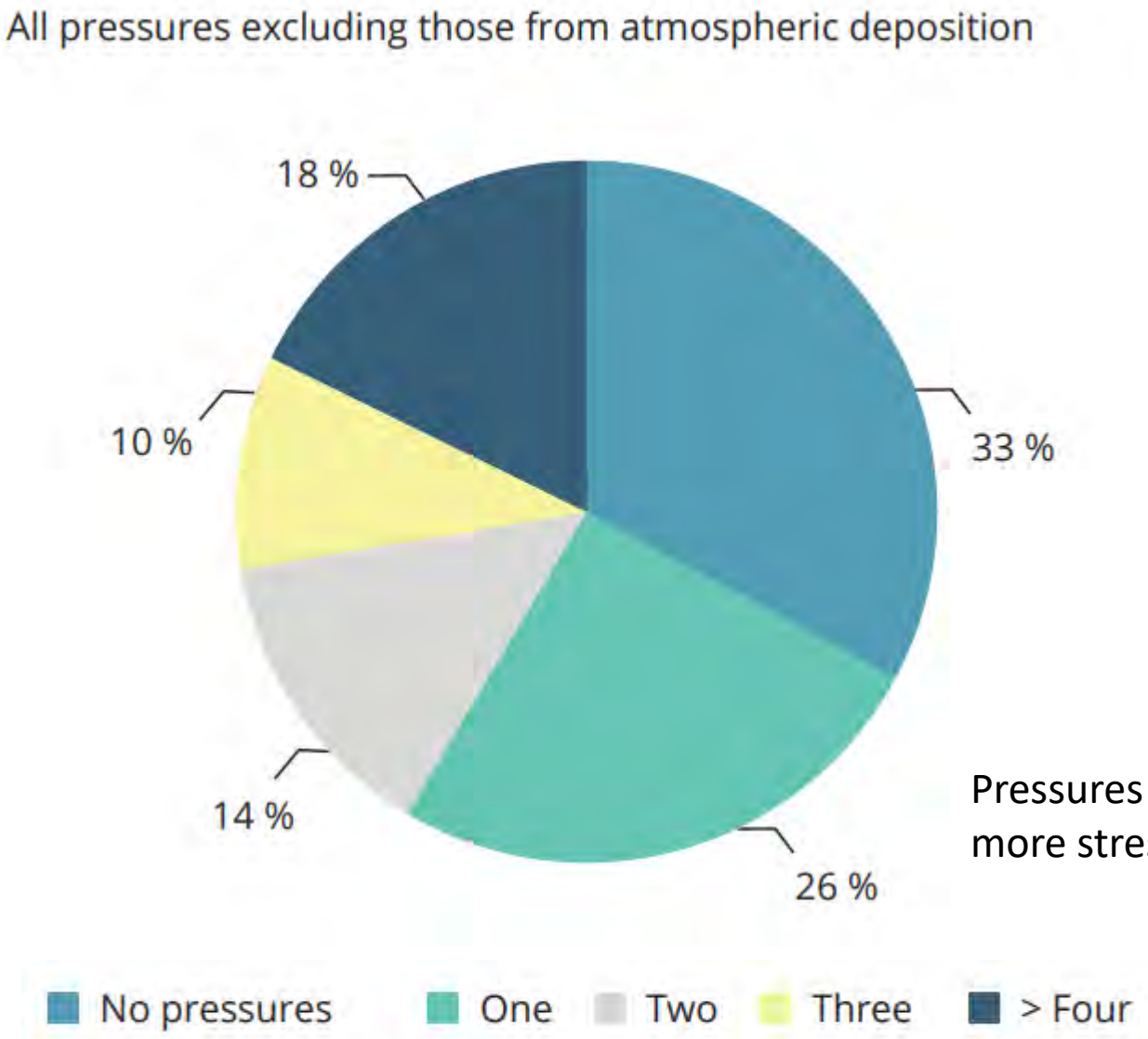
- Continuing decline in water quality – 3% deterioration since 2015.
- 44% of water bodies at moderate status or worse = biodiversity loss & ecosystem services degradation.
- Further loss of high-status river sites- now 17%, compared to 31.6% in the 1987–1990 period.



*'The declines seen in our rivers' indicators are an early warning signal that **trends in water quality may be at a turning point and heading in the wrong direction'*** (Trodd et al. 2018)

Declines are outpacing efforts to address the problems

*Trodd, W. and O'Boyle, S. 2018. Water Quality in 2017: *An Indicators Report.* Environmental Protection Agency. Ireland.



Pressures yield one or more stressors

From: European Environment Agency (2018) European waters Assessment of status and pressures 2018. EEA Report No. 7/2018

Stressors

Refers to the environmental variable that is the putative cause of the response or impact - more specific than pressure.

Stressor – defined in Piggott et al. (2015) as 'a variable that, as a result of human activity, exceeds its range of normal variation and affects individual taxa, community composition, or ecosystem functioning relative to a reference condition'.

Anthropogenic focus

From: Piggott, J. J., C. R. Townsend & C. D. Matthaei (2015) Reconceptualizing synergism and antagonism among multiple stressors. *Ecology and Evolution* 5: 1538–1540.

Stressor: 'Any external abiotic or biotic factor derived from human intervention, which moves a receptor (ecosystem) out of its normal operating range, causing either subsidy or stress'

From: Sabater et al. (2018) Multiple stressors in River Ecosystems: Chapter 1

Importantly: A single pressure may yield several stressors

e.g. Diffuse pollution (pressure) → phosphate, nitrate, fine sediment……

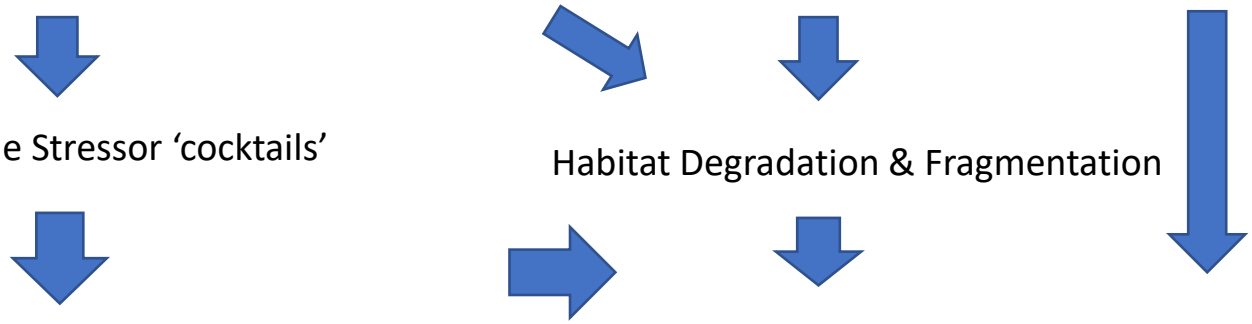
They vary in their intensity, frequency and scale

Pulse (short discrete) vs press (sustained) vs ramp (increase in intensity) characteristics – influences the potential ecological impacts

Drivers & Pressures & Stressors

Drivers Land-use: Agriculture, Urbanisation, Abstraction, Industry, Transport, Recreation ……

Pressures Diffuse & Point Source Pollution | Flow regulation | Climate Change | Invasive Species



Multiple Stressor 'cocktails'

Habitat Degradation & Fragmentation

Nutrients, Acidity, **Sediment**, Priority & Dangerous Substances, Pathogens

Micropollutants (e.g. personal care products), Microplastics

Water Quality, Biodiversity & Ecosystem Services Losses

Freshwater Research to date has revealed

- 'Large variation in impact-response relationship across biological groups and freshwater systems'
- Sensitivity to various stressors differs among biota
- Many factors moderate the response of biota to stressors
- 'Non-linear and often lagged-responses of biota to stressors'
- 'When two or more stressors are present they can interact to amplify or dampen each other's effects'

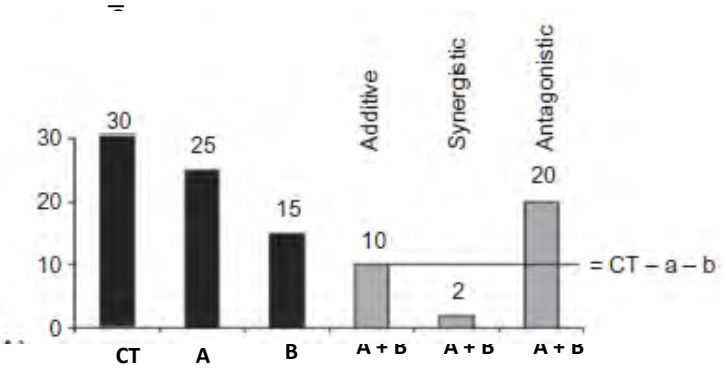
From: P. Nõges et al. (2016). Quantified biotic and abiotic responses to multiple stress in freshwater, marine and ground waters. *Science of the Total Environment* 540, 43-52. 219 papers reviewed

When Stressors Meet

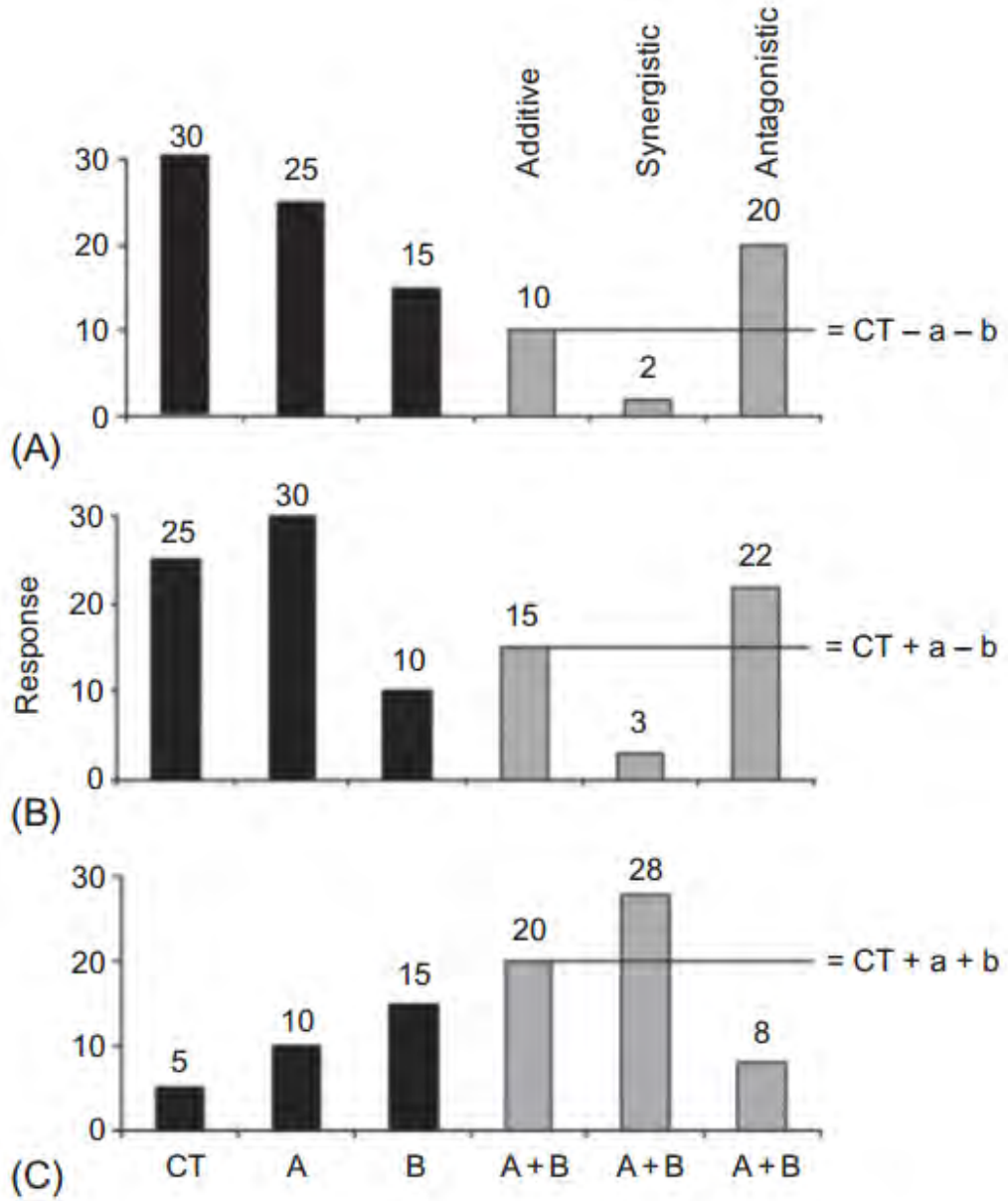
- One stressor may dominate
- Additive: effect is equal to the sum of the single stressor effects (no interaction)

Interactions

- Synergistic: a larger cumulative effect relative to the individual stressor effects.
- Antagonistic: a cumulative effect that is less than additive (less positive or less negative). Antagonist vs non-antagonist
- Antagonistic does not mean 'no impact'
- Reversals – effect of an individual stressor is reversed by another – leads to 'ecological surprises' (*unexpected ecosystem behaviour/shifts to a new ecological state*).



From: Sabater et al. (2018) Multiple stressors in River Ecosystems: Chapter 1



Types of interactions between stressors.
control (CT),
stressor A,
stressor B, or the interaction of the two stressors (A+B).

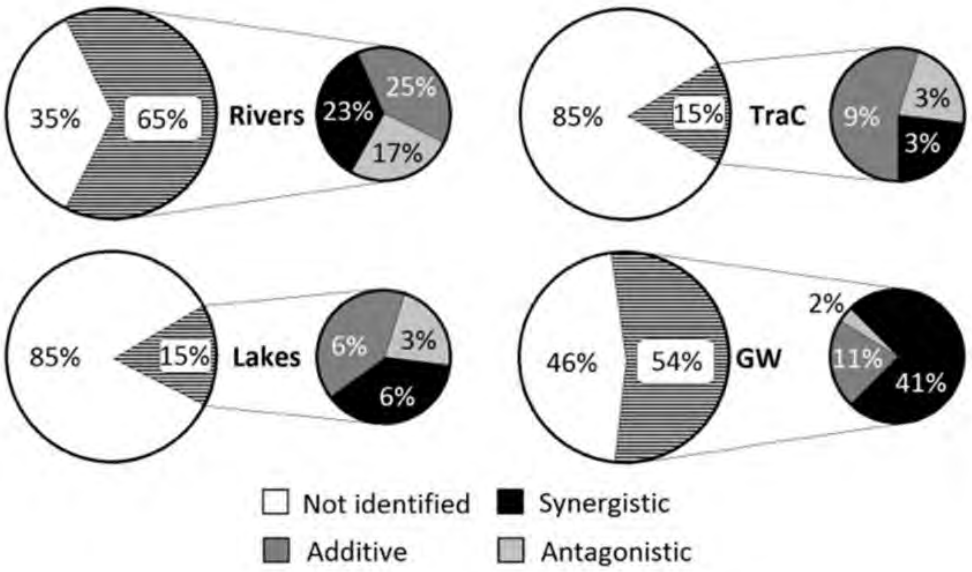
The interaction types may be double negative (Panel A), opposing (Panel B), or double positive (Panel C).

From: Sabater et al. (2018) Multiple stressors in River Ecosystems: Chapter 1
Se also: Piggott et al. (2015) Piggott, J. J., C. R. Townsend & C. D. Matthaei (2015) Reconceptualizing synergism and antagonism among multiple stressors. *Ecology and Evolution* 5, 1538–1540.

Factors may moderate the impact of a stressor

- Intensity and duration of the stress (pulse, press or ramp)
- Resistance of the biological communities (or its components) to change (e.g. traits that convey tolerance) – sensitivity to the stressors.
- Habitat heterogeneity (facilitates refugia) – can convey resilience.
- Windows of opportunity for re-colonistaion

All responses to multiple stressors have been recorded



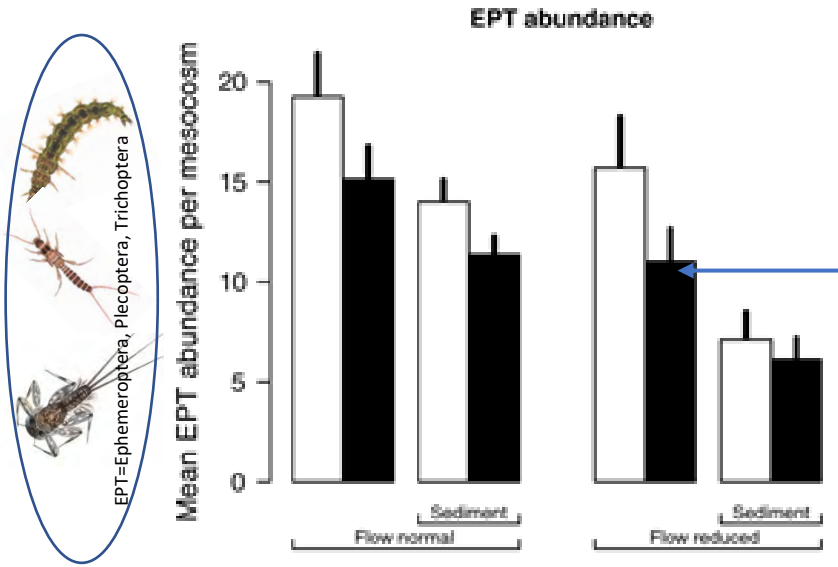
Interactions between stressors in multiple stress relationships described for different aquatic environments. TraC – transitional and coastal waters; GW – groundwaters.

From: P. Nõges et al. (2016). Quantified biotic and abiotic responses to multiple stress in freshwater, marine and ground waters. Science of the Total Environment, 540,43-52. 219 papers reviewed

Jackson et al. (2016) using 88 papers reported high prevalence of antagonistic responses.

Response depends on the stressor combinations, receptors, biota and response variables measured.

- Elbrecht et al. (2016)* - sediment had the greatest negative impact and there were few interactions between stressors, effects were mainly additive.



Responses of EPT abundance to the manipulated stressors (**nutrient addition, sediment addition and flow velocity reduction**). Black bars represent treatments with **nutrient enrichment** and white bars treatments without enrichment. Error bars represent standard errors. Sample size for each treatment combination is n = 8 (except for the reduced velocity treatment without nutrients and sediment where n = 7.

From:* Elbrecht et al. (2016) Multiple-stressor effects on stream invertebrates: a mesocosm experiment manipulating nutrients, fine sediment and flow velocity. *Freshwater Biology* 61, 4, 362-375.

Multiple stressors in Irish agricultural streams: mesocosm studies of macroinvertebrate responses to nutrients and sediment

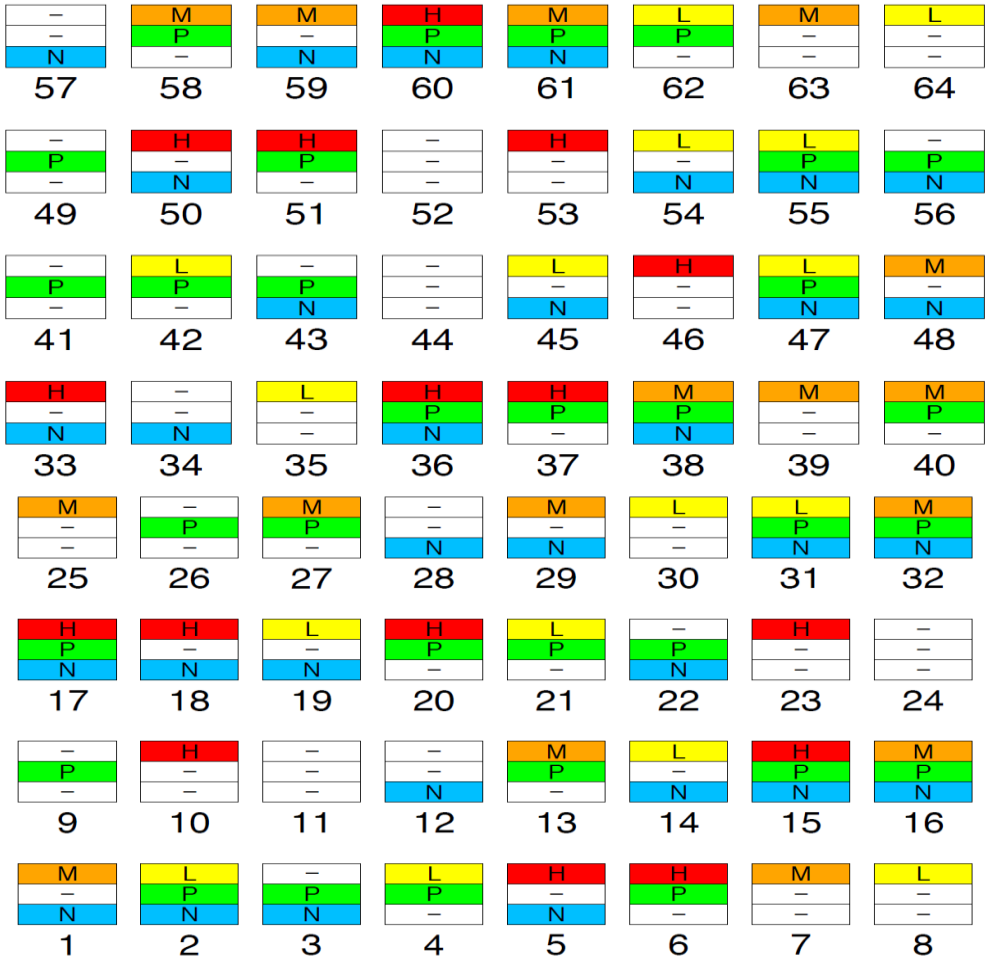
ELSEVIER

Science of The Total Environment
Volumes 637–638, 1 October 2018, Pages 577-587

Multiple-stressor effects of sediment, phosphorus and nitrogen on stream macroinvertebrate communities

Stephen J. Davis [a, b], Daire Ó hUallacháin [a], Per-Erik Mellander [c], Ann-Marie Kelly [b], Christoph D. Matthaei [e, 1], Jeremy J. Piggott [e, f, 1], Mary Kelly-Quinn [b, d, 1]

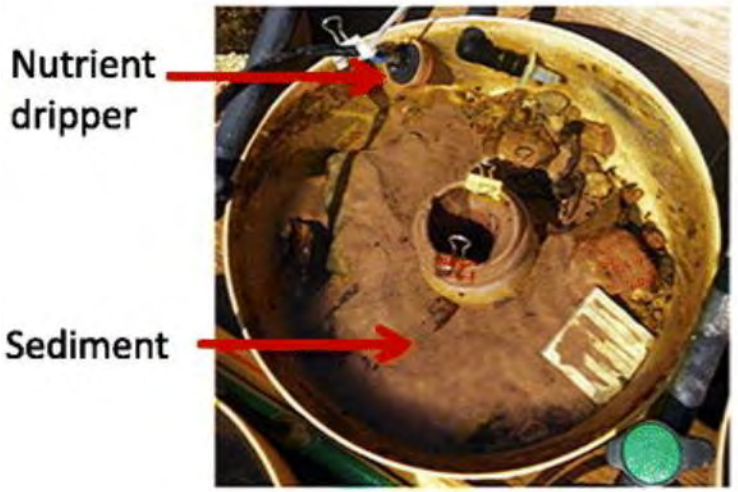
teagasc
Agriculture and Food Development Authority



- Enriched to 6.74 mg L^{-1} for DIN and 0.14 mg L^{-1} for DRP, compared with 0.97 mg L^{-1} for DIN and 0.01 mg L^{-1} for DRP in ambient mesocosms. (used KH_2PO_4 & $NaNO_3$)
- Treatments were randomly assigned to the 64 stream channels
- Target fine sediment cover: low - 25%, medium sediment -50% and high sediment - 100%)

L=Low; M=Medium, H=High Sediment cover
P=Phosphorus addition; N=Nitrogen addition

21-day colonisation period followed by a 14-day manipulative period



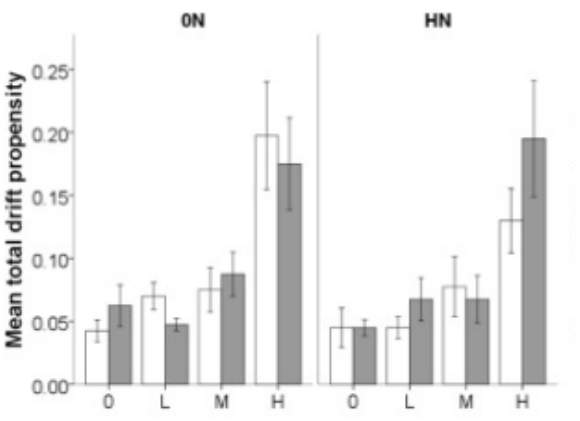
Response variables: Macroinvertebrate Drift & Taxa remaining at end of experiment

- Drift was collected after 24 hours and then every 48 hours during experimental period

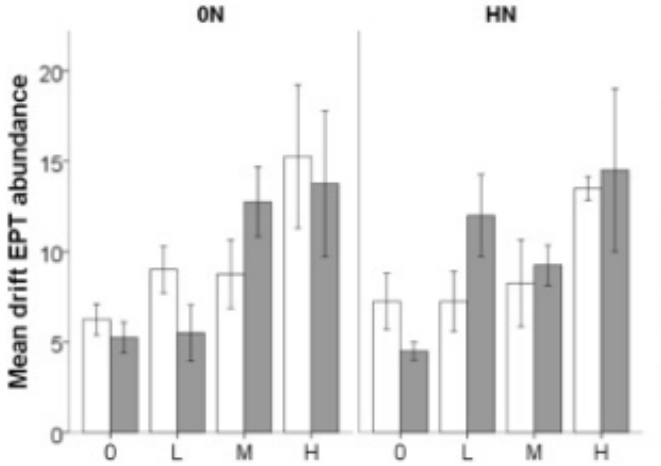
- Entire contents of each channel collected on final day of sampling

Key Results

Drift: Sediment was the dominant stressor – affected 11 of the 14 drift variables. No significant effect of N or P.



Sediment cover levels



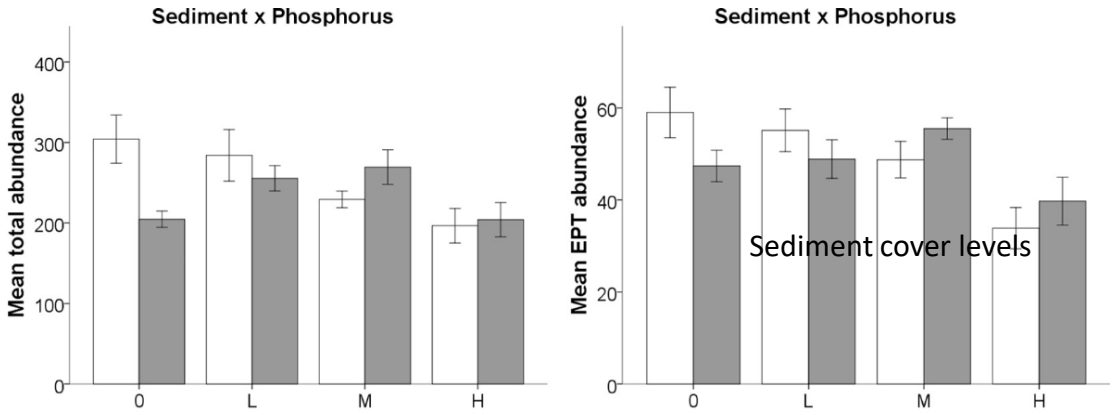
Sediment cover levels

Dark bars = P addition;
White bars – no P added
ON = No N addition
HN = High N addition

Responses of total drift propensity & drift EPT abundance. Sediment treatments are ambient (0), low (L), medium (M) and high (H), white bars represent treatments without P addition, and grey bars represent treatments with P addition.

Key Results

Benthos: Sediment addition generally decreased total & EPT abundance, particularly at high sediment levels, the extent of this decrease differed across sediment levels due to the interaction with P enrichment (antagonistic)



Most Impacting - acute or chronic nutrient pollution?

Science of the Total Environment 683 (2019) 9–20

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Chronic nutrient inputs affect stream macroinvertebrate communities more than acute inputs: An experiment manipulating phosphorus, nitrogen and sediment

Stephen J. Davis [a,b,*], Daire Ó hUallacháin [a], Per-Erik Mellander [e], Christoph D. Matthaei [d], Jeremy J. Piggott [c], Mary Kelly-Quinn [b]

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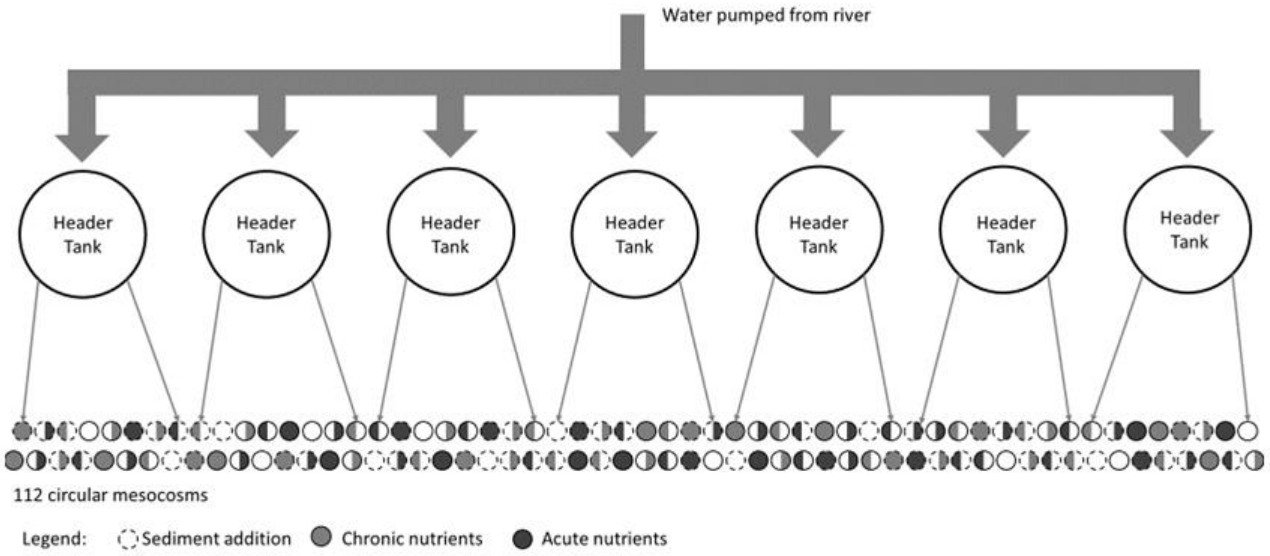


- **Chronic nutrient enrichment** - concentrated solution of either nitrate ($NaNO_3$), phosphate (KH_2PO_4) or both to achieve mean concentration as in the previous experiment
- **Nutrient pulses (Acute)** - the concentrations of N and/or P were increased in acute channels to double the concentrations of both N and P on **Day 6 & Day 13**
- **Sediment** - 5.7 ± 1.5 % with a depth of 0.1 ± 0.4 mm for ambient sediment treatments and 82.3 ± 7.0 % with a depth of 7.7 ± 3.3 mm for high sediment treatments.

Most Impacting - acute or chronic nutrient pollution?

The 14 treatment combinations of the three stressors manipulated in the experiment. There were eight replicates of each treatment combination. Note that the treatment levels chronic N and acute P, and chronic P and acute N did not appear in combination with one another in this partial factorial design.

Sediment	Nitrogen	Phosphorus	Replicates
Ambient	Ambient	Ambient	8
Ambient	Acute	Ambient	8
Ambient	Chronic	Ambient	8
Ambient	Ambient	Acute	8
Ambient	Acute	Acute	8
Ambient	Ambient	Chronic	8
Ambient	Chronic	Chronic	8
High	Ambient	Ambient	8
High	Acute	Ambient	8
High	Chronic	Ambient	8
High	Ambient	Acute	8
High	Acute	Acute	8
High	Ambient	Chronic	8
High	Chronic	Chronic	8

26 days colonisation,
18 days of manipulations

Key Results

- **1st 48hours:** Sediment was the dominant driver of drift responses at community and species level (few interactions with nutrients) *- sediment deposition can potentially have major detrimental effects on local stream macroinvertebrate communities in a very short period of time compared to other sources of pollution.*
- **48 hours after the 1st nutrient pulse:** Sediment still as a significant main effect stressor (some interactions with nutrients)
- **48 hours after the 2nd nutrient pulse:** no further response to sediment, eight of 17 drift metrics (EPT etc.) were significantly affected by N, making N the dominant driver of drift responses two weeks after stressor implementation.
- The effects of P also increased as the experiment went on, with no interpretable main effects in the first 48-hour drift.
- Chronic nutrient inputs appear to have greater negative effects than acute inputs, but further study is needed in this area.

Sediment is a Master Stressor

- Need to incorporate deposited sediment estimates in water quality investigations.
- Mitigation of excess fine sediment inputs needs to be prioritised.

'Management or restoration efforts that mitigate certain stressors (e.g., nutrient enrichment) but ignore fine sediment are unlikely to yield the desired outcomes due to a dominance of interactive effects by fine sediment impacts'.

From Matthaei & Piggott Chapter 13 in Sabater et al. (2018) Multiple stressors in River Ecosystems

Climate change brings additional stressors

- Limited research on effects of flow and temperature regime changes in a multi-stressor environment.
- Responses are likely to be complex and further complicate efforts to mitigate impacts on aquatic ecology.

How do stressor interactions affect management decisions

How stressors interact will determine likely outcome of interventions

- Removal of a dominant stressor (s) should yield a good response.
- Additive effects – easiest to interpret, tackling either stressor should yield a response.
- In the case of synergistic interactions removal of one stressor should have a positive effect but generally both stressors should to be addressed simultaneously.
- If the stressor interaction is antagonistic removal of one stressor could have an adverse outcome. Therefore, prioritise the non-antagonist or if possible both stressors.

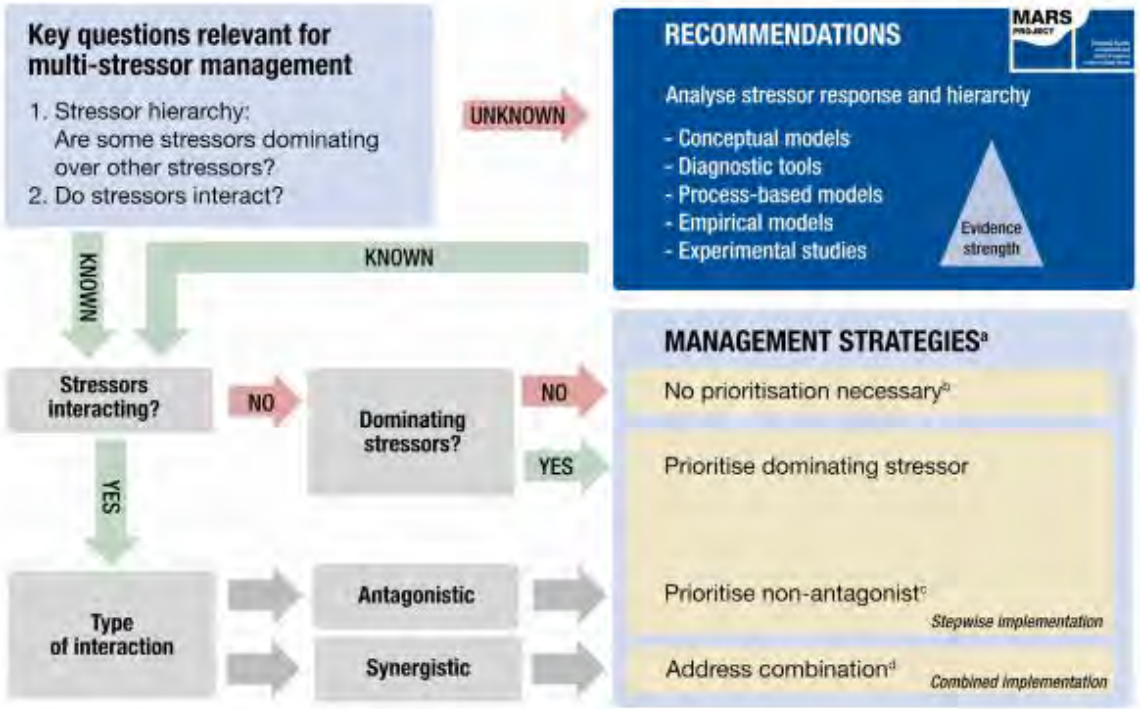
How do we investigate multi-stressor effects to identify or predict their ecological consequences

- Identify the range of stressors that are relevant to a particular catchment/sub-catchment.
- Carefully select responses variables/metrics and if possible include more than one biological indicator group.
- Identify the minimum number of stressor that need to be tackled to have a measurable effect.
- Identify (if possible) & prioritise the dominant stressor– i.e. the stressor that accounts for most of the effect.
- Stressors showing similar effect sizes need to be given equal priority.
- If stressors interact – identify the type of interaction.
- For antagonism if possible, identify the strongest stressor or the non-antagonist.
- Consider the characteristics of the stressors (pulse, press or ramp)

MARS Recommendations

on how to best assess and mitigate impacts of multiple stressors in aquatic ecosystems

Guidance taken from http://www.mars-project.eu/files/download/recommendations/MARS_Recommendations.pdf



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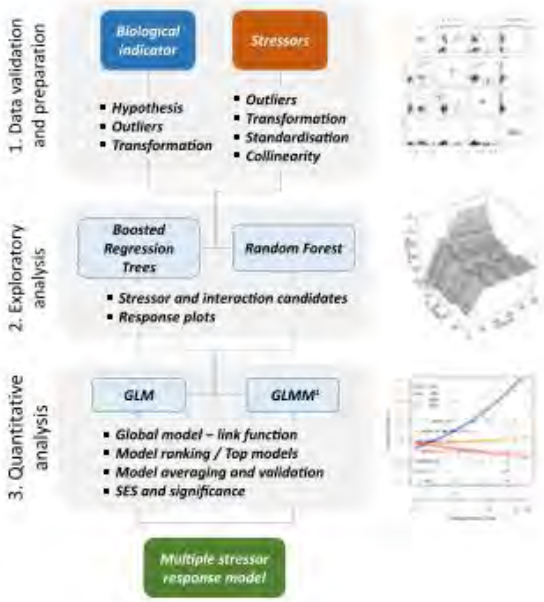
Analysing the impact of multiple stressors in aquatic biomonitoring data: A 'cookbook' with applications in R

Christian K. Feld [a,*], Pedro Segurado [b], Cayetano Gutiérrez-Cánovas [c]



Key questions relevant for tackling multi-stressor conditions in River Basin Management (involving supportive MARS tools addressed in these recommendations), leading to appropriate management strategies concerning the level and type of necessary mitigation and adaptation measures.

From: From Schinegger et al. (2018) MARS Recommendations on how to best assess and mitigate impacts of multiple stressors in aquatic environments

Concluding Comments

'The conservation of freshwater resources with climate change will depend on how well we understand and address the effects of multiple stressors, especially as the scope of human pressures increases' (Sabater et al. 2018).

- ✓ Adopt a multi-stressor perspective when investigating impacts on freshwater systems.
- ✓ Use existing data/acquire knowledge on the relative importance of different stressors (stressor hierarchy, including dominating stressors) and their impacts in order to find the best effective measures*.
- ✓ Identify & mitigate elevated deposited sediment as a priority.
- ✓ In terms of communication with the general public make the connection to ecosystem services.

*From Schinegger et al. (2018) MARS Recommendations on how to best assess and mitigate impacts of multiple stressors in aquatic environments

Sabater et al. (2018) Multiple stressors in River Ecosystems: Chapter 1).

Consult the guidance documents produced by the MARS project: http://www.mars-project.eu/index.php/aims.html

Thank you for your attention

Queries to mary.kelly-quinn@ucd.ie