Challenges for Freshwater Ecological Investigation in the 21st century

CIEEM Meeting, Athlone 2019

Mary Kelly-Quinn (mary.kelly-quinn@ucd.ie)

Structure of talk

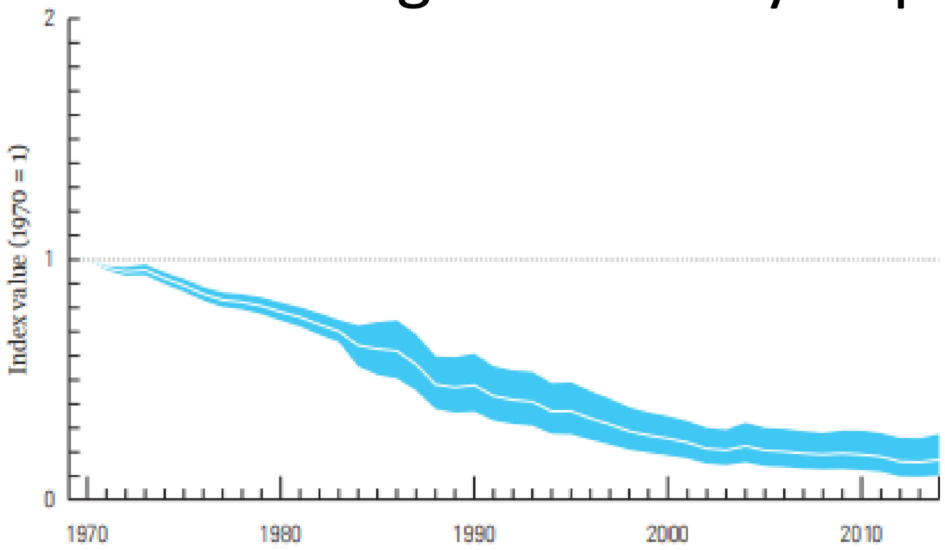
- Freshwater – the resource
- Concerns – Global context
  – Irish freshwaters
- Key challenges
  Multiple stressors
  The 'Master Stressor'
  Making the link to impact on ecosystem services (goods & benefits we derive)

Freshwater – the lifeblood of the planet

- Freshwaters provide a disproportionately high amount of ecosystem services.
- These services are provided by biodiversity and associated ecological processes.
- Globally freshwaters support at least 126,000 plant and animal species (1 in 10) in <1% of Earth's surface water habitats.

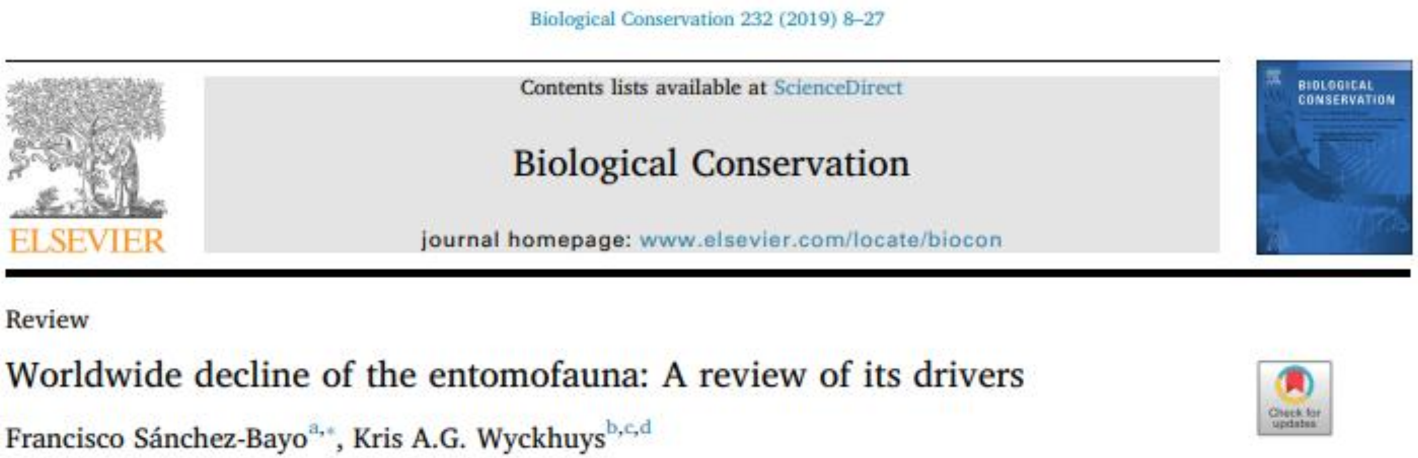
Global context

➢ Alarming biodiversity losses, higher than in terrestrial and marine systems, threatening their ability to provide essential ecosystem services.



Living Planet Report (2018) WWF

Freshwater Living Planet Index – WWF 2018 (Living Planet Report) - file:///C:/Users/UCD/Downloads/lpr2018_full_report_spreads%20(1).pdf


Biological Conservation 232 (2019) 8–27

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Biological Conservation

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

ELSEVIER

Review

Worldwide decline of the entomofauna: A review of its drivers

Francisco Sánchez-Bayo[a,*], Kris A.G. Wyckhuys[b,c,d]

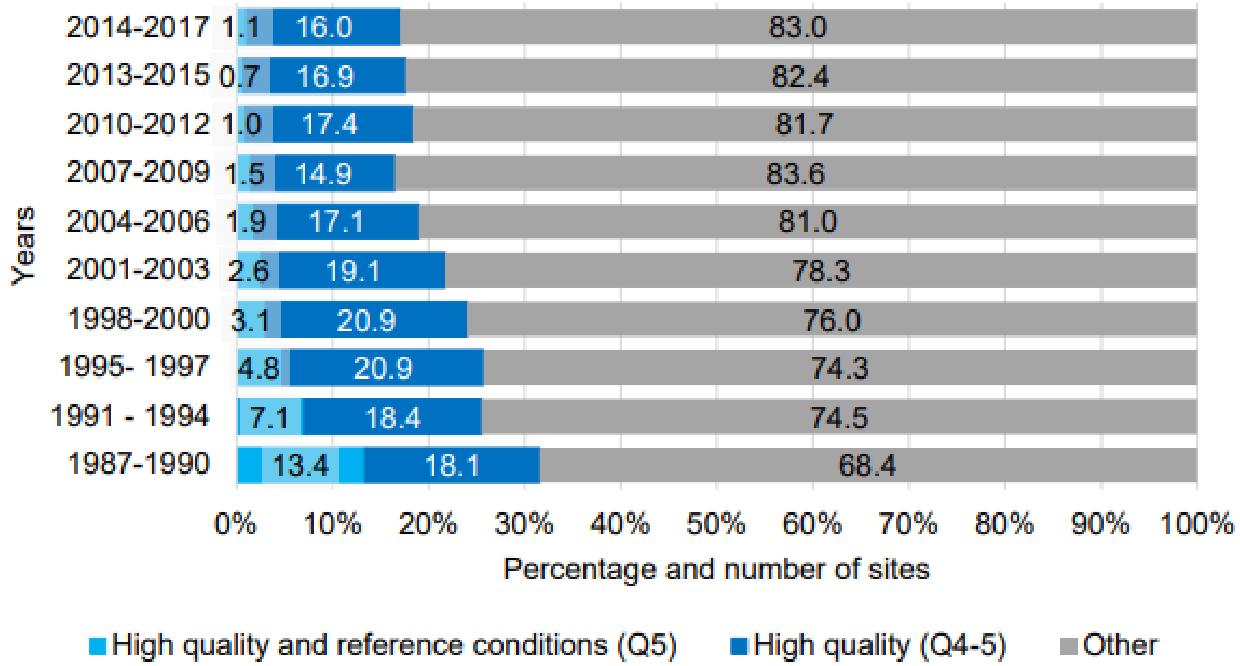
Four major aquatic taxa (Odonata, Plecoptera, Trichoptera and Ephemeroptera) have already lost a considerable proportion of species.

➢ **Declines are outpacing efforts to address the problems**

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. 2017)*

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

Welcome to the freshwater environment of the 21st century

- **Over 1500 contaminants** have been found in freshwaters

  Top guns: Nutrients, Sediment, Pesticides

- **C.900 contaminants of emerging concern** (NORMAN Network) - industrial compounds, pharmaceuticals, personal-care products, biocides, and plant protection products……….

Emerging pollutants in the EU: 10 years of NORMAN in support of environmental policies and regulations

Valeria Dulio, Bert van Bavel, Eva Brorström-Lundén, Joop Harmsen, Juliane Hollender, Martin Schlabach, Jaroslav Slobodnik, Kevin Thomas and Jan Koschorreck

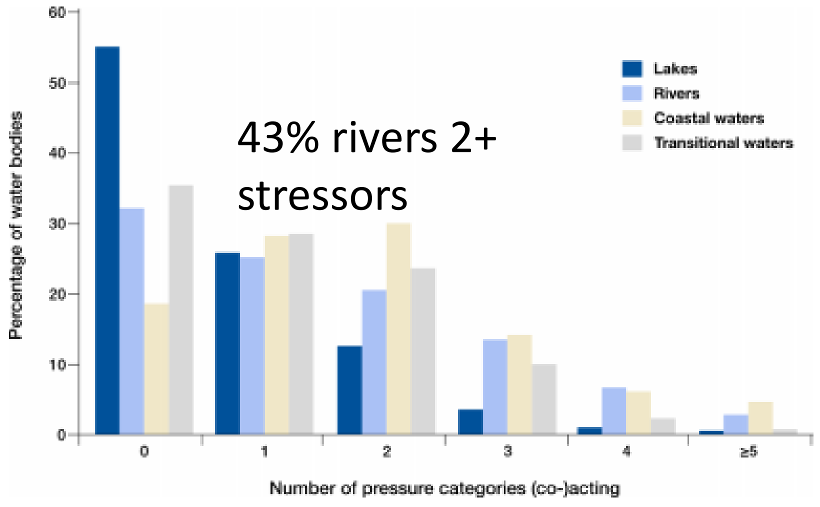
Environmental Sciences Europe Bridging Science and Regulation at the Regional and European Level 2018 30:5

- Extensive **habitat degradation** incl. flow regulation and habitat fragmentation
- Invasive species

Further challenges

- Most freshwater are subjected to more than one stressors acting simultaneously – multiple stressor environments include physical habitat degradation.

- Climate change (temperature/flow) is set to further alter community composition, ecosystem processes (e.g. decomposition), life histories, traits and responses to stressors.



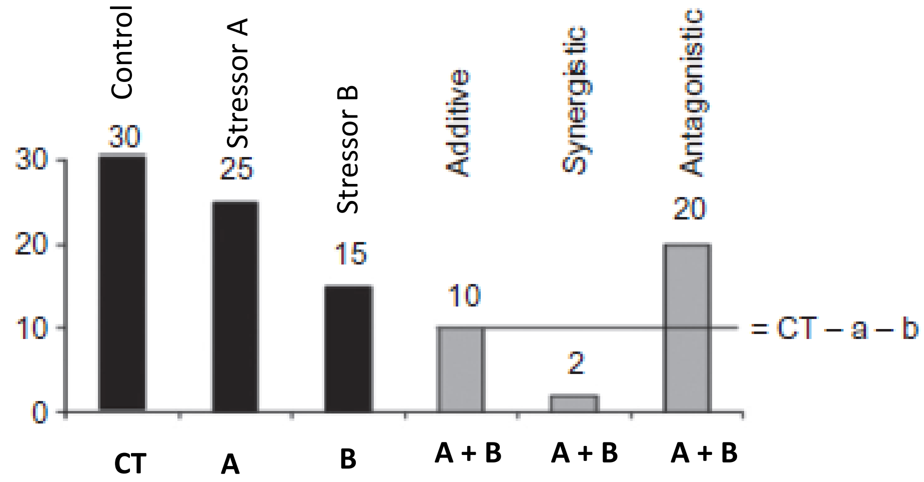
EEA, 2018. European waters – Assessment of status and pressures 2018. EEA Report No 4/2018, European Environment Agency. https://www.eea.europa.eu/publications/ state-of-water/at_download/file

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'. Stressors are thus (putative) causes in a cause and-effect chain.
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.

The growing number and range of stressors from human activities challenges our ability to detect the impacting stressors and target appropriate measures

When Stressors Meet

- Additive: effect is equal to the sum of the single stressor effects
- 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)



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

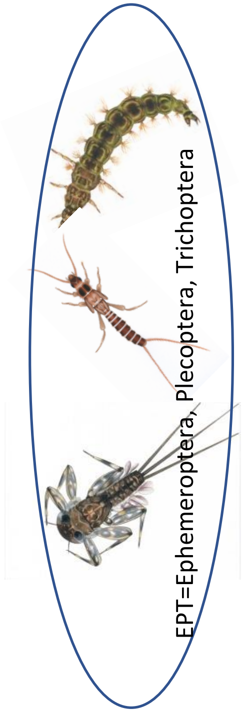
Unknown stressor interactions challenge freshwater investigations and management by posing risks of "ecological surprises (*unexpected ecosystem behaviour/shifts to a new ecological state*)."

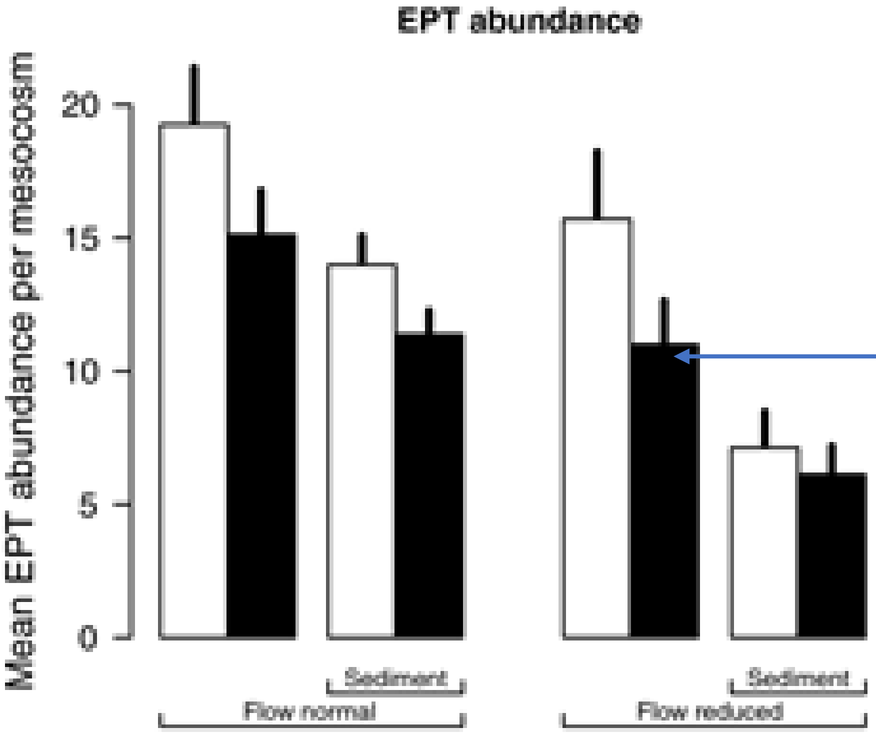
How the stressors interact will determine likely outcome of interventions

Multiple Stressor Impacts

Some examples

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



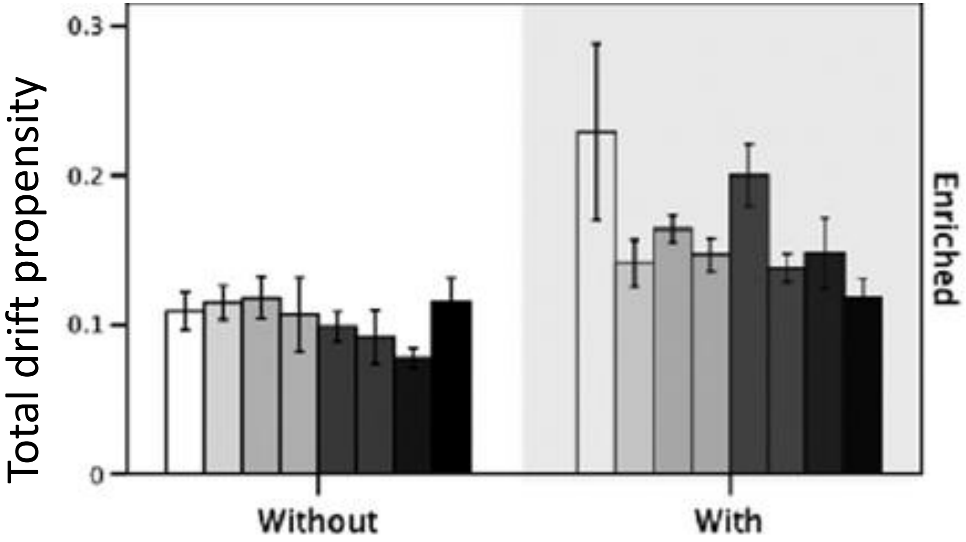


Responses of EPT abundance to the manipulated stressors (**nutrient addition, sediment addition and flow velocity reduction**). Black bars represent treatments with **nutrient enrichment** and white bars treatments without enrichment. Error bars represent standard errors. Sample size for each treatment 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.

Piggott et al. (2015) – sediment, nutrients and temperature in mesocosms - recorded mainly additive and antagonistic (positive and negative) interactions but also some synergistic

- Synergistic effect detected for total drift propensity to the combined effect of nutrients and sediment
- Antagonistic: e.g. nutrient X sediment interaction- less negative than predicted – e.g. less individuals leaving the mesocosms (drifting) when enriched conditions provided a nutrient subsidy.
- **Sediment – a key stressor,** negative effects of sediment were often stronger at higher temperatures.



Total drift propensity = numbers drifting per 3 days/benthic abundance

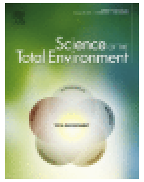
Piggott, J. J., Townsend, C. R. & Matthaei, C. D. (2015). Climate warming and agricultural stressors interact to determine stream macroinvertebrate community dynamics. *Global Change Biology* 21: 1887-1906.

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



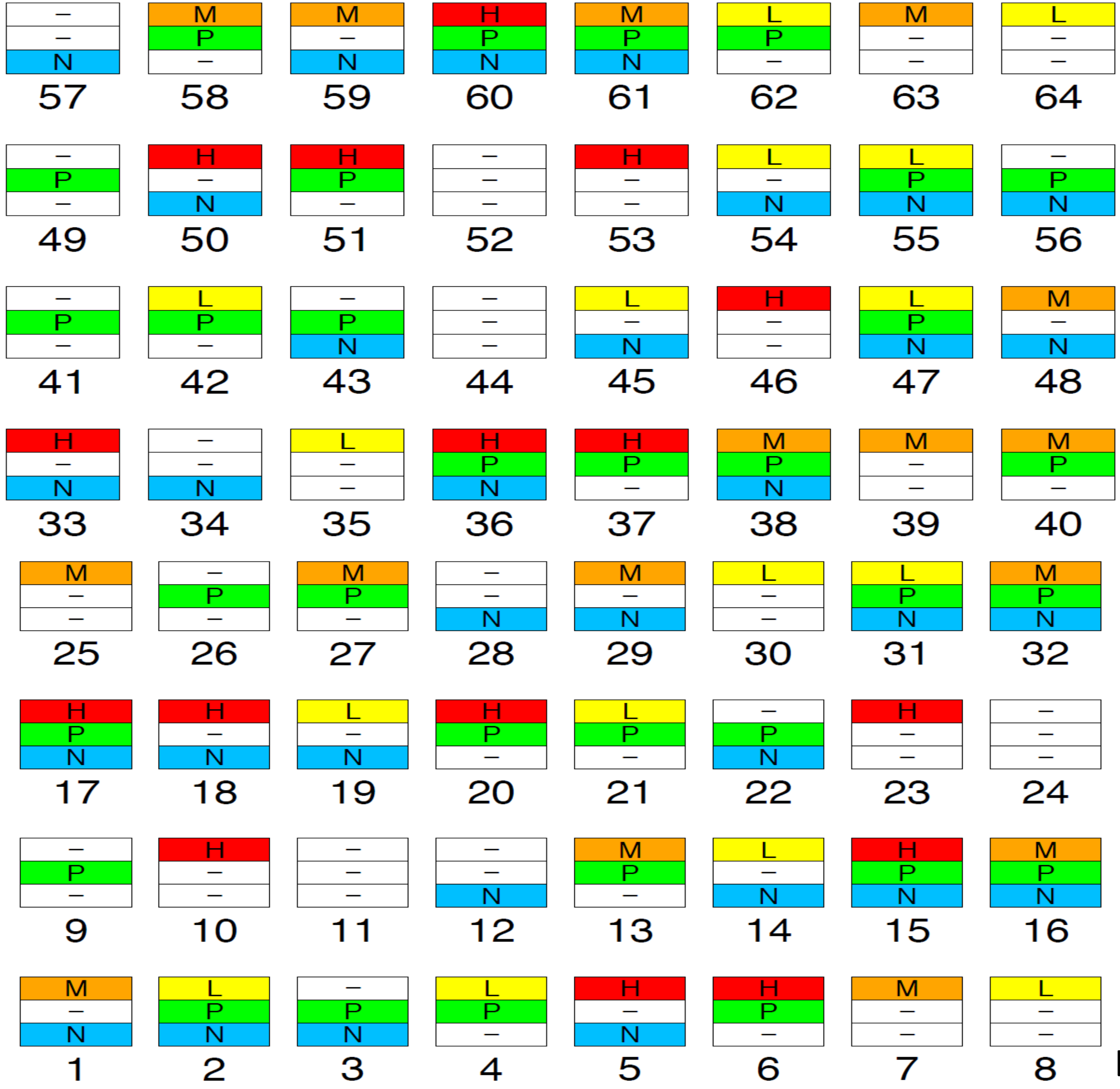
Multiple-stressor effects of sediment, phosphorus and nitrogen on stream macroinvertebrate communities

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]

UCD DUBLIN

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

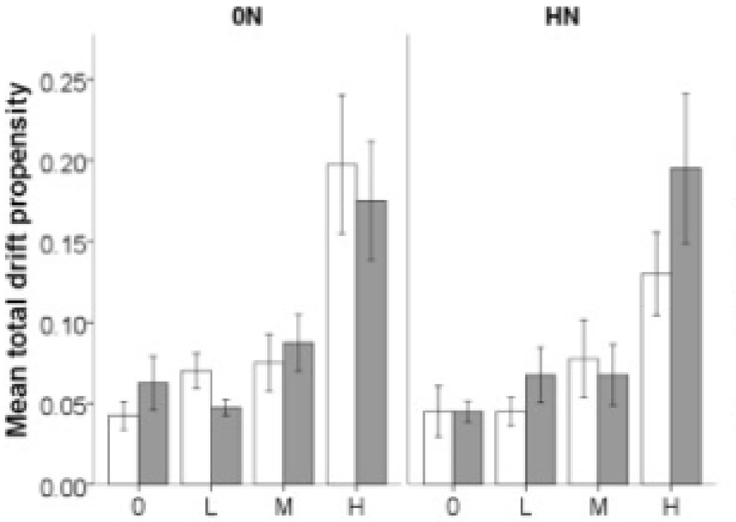
Macroinvertebrate sampling

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

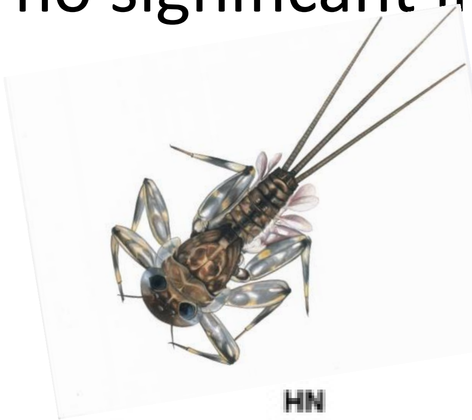
Entire contents of each channel collected on final day of sampling

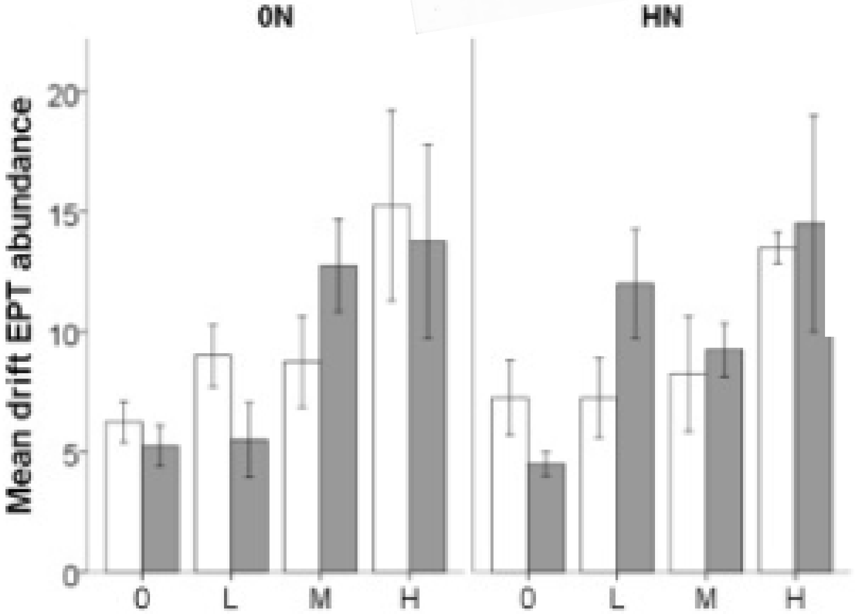
Macroinvertebrates drifting

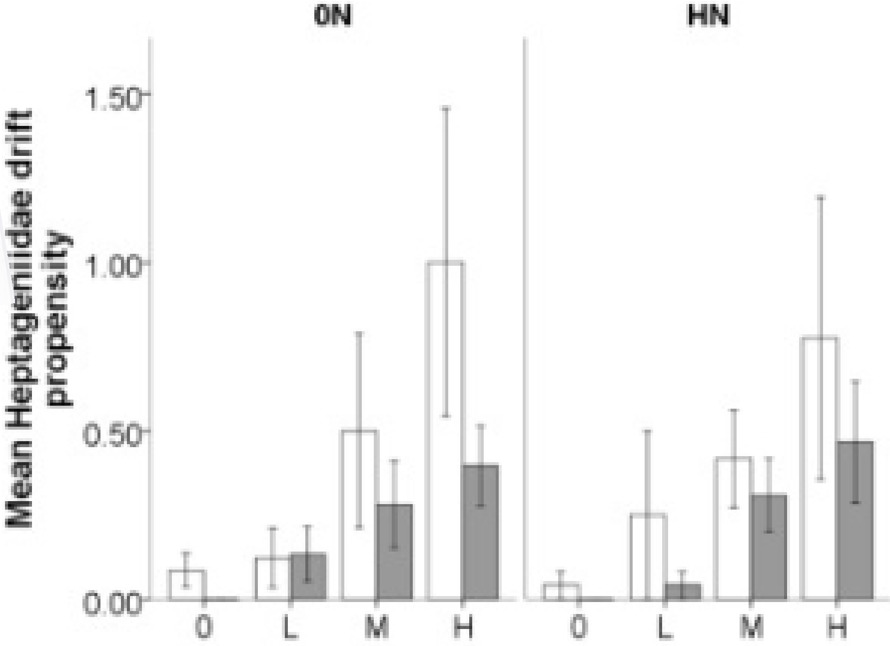
Sediment was the main stressor – no significant interactions with nutrients



Sediment cover levels



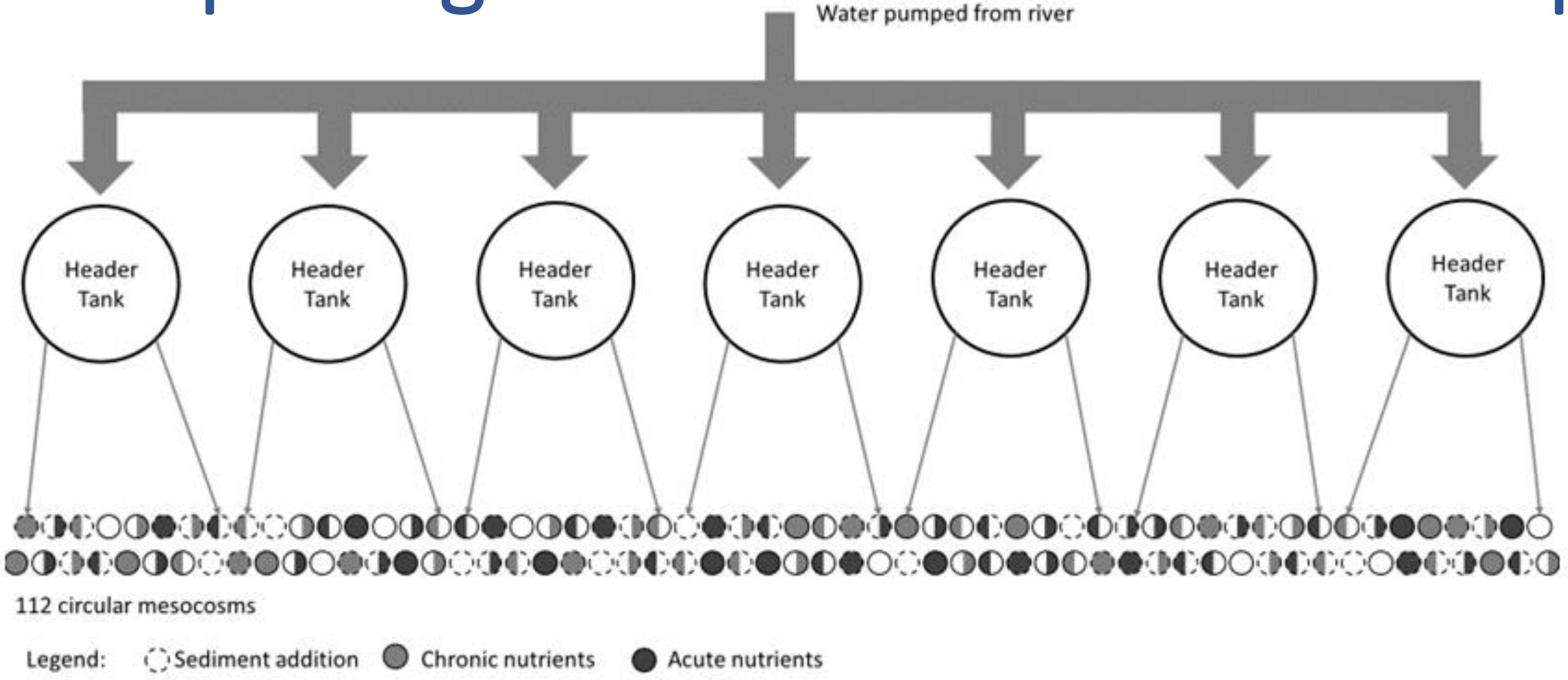




Dark bars = P addition;
White bars – no P added
ON = No N addition
HN = High N addition

Responses of total drift propensity, drift EPT abundance, and Heptageniidae drift propensity. 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.

Most Impacting - acute or chronic nutrient pollution?



- **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.

Key Results

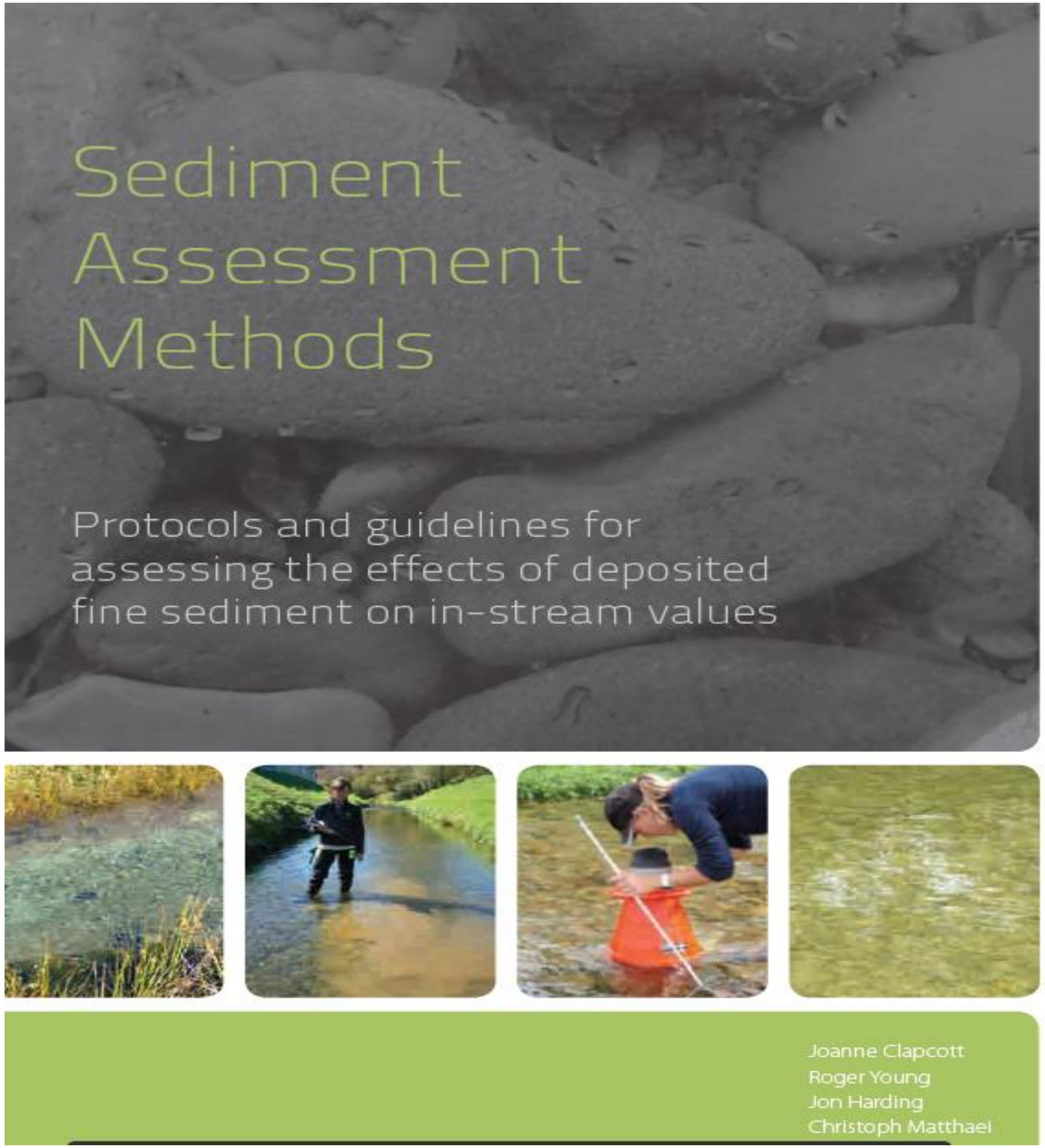
- **1st 48hours:** Sediment was the dominant driver of drift responses at community and species level (few interactions with nutrients) *- sediment deposition can potentially have major detrimental effects on local stream macroinvertebrate communities in a very short period of time compared to other 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, two following the first acute pulse, and four following the second acute pulse.
- 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

How do we measure **deposited (most impacting) (fine)**sediment?

- **Visual estimation**
- Resuspension of fine sediment (**resuspendable sediment**) and measurement of suspended fine sediment concentration.
- Resuspension of sediment (**Shuffle Index**)

Deposited fine sediment is defined as particles deposited on the streambed that are less than 2 mm in size.



2011

Visual estimates: Bankside or Instream

Bankside – qualitative (5 mins)

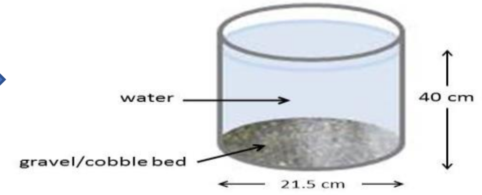
Estimate habitat length and the % streambed covered by sediment <2mm from the stream bank for each riffle, run and pool present

International Journal of Sediment Research 31 (2016) 368–375
Contents lists available at ScienceDirect
International Journal of Sediment Research
journal homepage: www.elsevier.com/locate/ijsrc

Original Research

An evaluation of visual and measurement-based methods for estimating deposited fine sediment

Elizabeth Conroy[a,*], Jonathan N. Turner[b], Anna Rymszewicz[c], Michael Bruen[c], John J. O'Sullivan[c], Mary Kelly-Quinn[a]

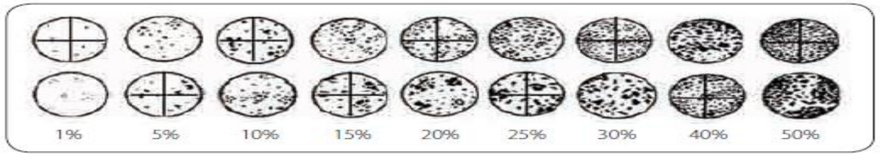


Added known amounts of sediment (sand, topsoil, peat – 50 to 300g representing 0 to 50% cover) on 2 substrate classes (50% coble/50% gravel & 25% cobble 75% gravel)

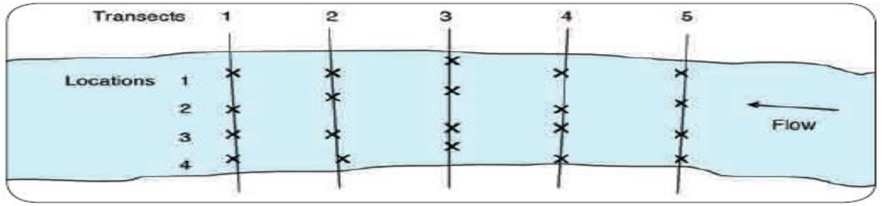
Instream – semi-quantitative (30 mins)

Useful images

Digital examples of percent cover of sediment on the streambed as seen through an underwater viewer.



An example of viewer locations (x) for the in-stream visual assessment of sediment.



Resuspendable sediment (Quorer method)

Collection of 5 samples (also measure 5 depths per cylinder) **– 30 mins**

Laboratory processing for total inorganic and organic sediment

Provides quantitative estimates & option to measure composition

Clapcott et al. recommended sediment should not exceed 20% cover or 450 g/m^2 (SIS) to protect stream biodiversity and fish habitat.

Resuspendable fine sediment (Shuffle Index)

5 minutes to complete

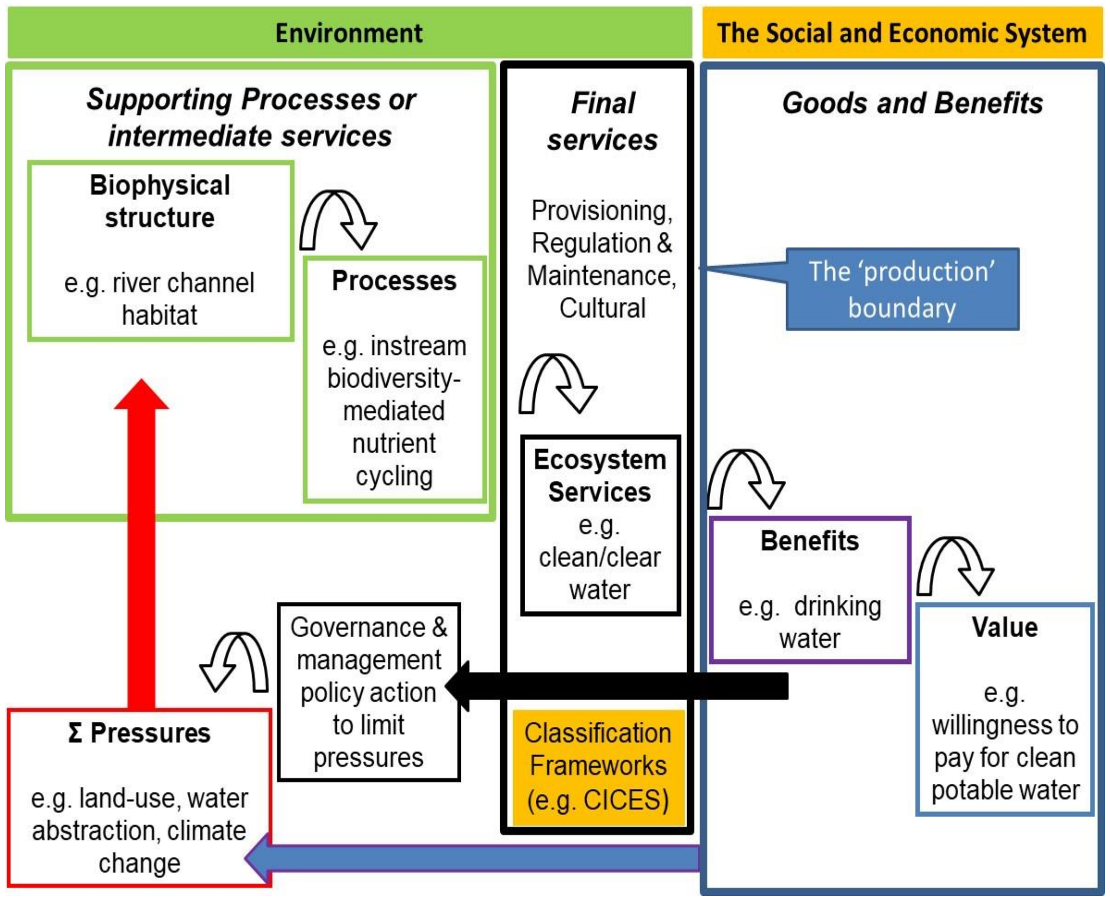
- Place white tile on stream bed in a run (measure water velocity)
- Stand 3m upstream of the tile and disturb the sediment for 5 seconds
- Allocate a score of 1 to 5 based on the visibility and duration of the plume

Making the link to Ecosystem Services

Ecosystem services link the biophysical environment and its ecological processes to socio-economic systems

We should urgently improve our comprehension of relationships between multiple stressors and good and benefits derived from ecosystems if we are to manage our ecosystems properly in multiple stressor situations

From: Acuna & Garcia Chapter 17 in Sabater et al. (2018) *Multiple Stressors in River Ecosystems*



Support of Water Resources Management Objectives?

- Helps demonstrate the importance of healthy ecosystems to economies and to human well-being, and account for those benefits
- Helps illustrate the links between ecological health/good water quality and human wellbeing - **more easily appreciated that the WFD goal of 'good ecological status'**
- Enables a more comprehensive evaluation of the benefits and costs of measures to improve water quality.
- Is a framework to better foster stakeholder engagement and to integrate the knowledge of a range of disciplines & stakeholder groups.

ESManage

Incorporation of **E**cosystem **S**ervices values in the Integrated **Manage**ment of Irish Freshwater Resources

<u>Overall Objective</u>

Harness the knowledge and tools required to embed the ecosystem services (ES) approach into policy and practice in Ireland for sustainable management of water resources, as required by the Water Framework Directive.

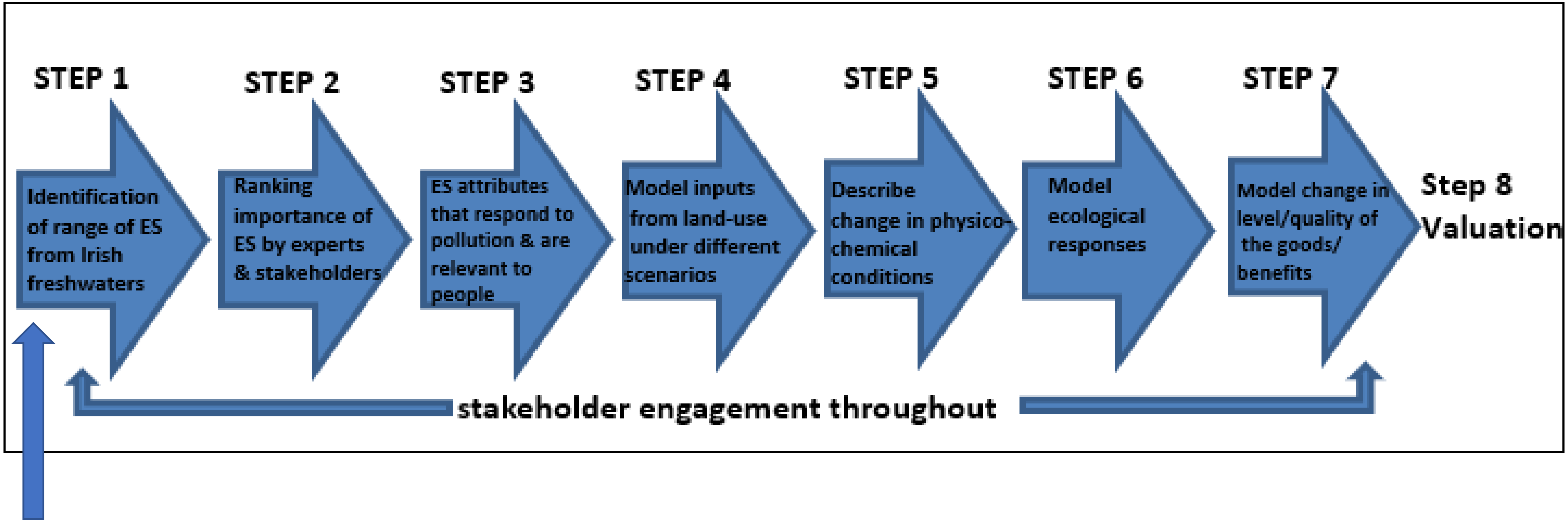
Mary Kelly-Quinn[1], Michael Bruen[2], Michael Christie[3], Thibault Hallouin[2]
Fiona Kelly[5], Ronan Matson[5], Hugh Feeley[1], Craig Bullock[4], Edel Hannigan[1] and Eva Siwicka[3]

[1] School of Biology & Environmental Science, University College Dublin, Ireland
[2] Dooge Centre for Water Resources Research, University College Dublin, Ireland
[3] Blue Island Consulting Limited, Ceredigion, Wales, United Kingdom
[4] School of Architecture, Planning and Environmental Policy, University College Dublin, Ireland
[5] Inland Fisheries Ireland, Dublin, Ireland

ESManage

epa Research
Climate - Water - Sustainability
Identifying pressures • Informing policy • Developing solutions

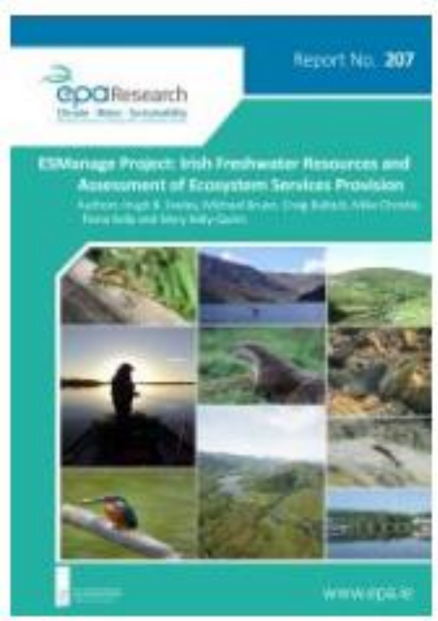
Methodological Framework (ES ident. to valuation)



Used CICES (Common International Classification of Ecosystem Services)

e.g. Provisioning Services

Division	Group	Class	Goods and Benefits	River	Lake	Groundwater & Hyporheic Zones	Wetlands	Artificial & HMWB
Nutrition	Biomass	Wild animals and their outputs	Fish (eel, trout) from wild fisheries and wildfowl (e.g. ducks) for consumption	LOW	LOW	N/A	LOW	LOW
		Animals from 'in-situ' aquaculture	In-situ farming of freshwater fish (e.g. trout) for consumption	LOW	LOW	N/A	N/A	LOW
	Water	Surface water for drinking	Abstracted surface water from rivers, lakes and other open water bodies for drinking	HIGH	HIGH	-	LOW	HIGH
		Groundwater for drinking	Abstracted groundwater	-	-	HIGH	-	-
Material	Biomass	Fibres and other materials from plants, algae and animals for direct use or processing	Algae, reeds, animal skins	LOW	LOW	N/A	LOW	LOW
		Materials from plants, algae and animals for agricultural use	N/A	N/A	N/A	N/A	N/A	N/A
		Genetic materials from all biota	Genetic material (DNA) from wild plants, algae and animals for biochemical industrial and pharmaceutical processes e.g. medicines, fermentation, detoxification; bio-prospecting activities. Potential not yet exploited	Unknown	Unknown	N/A	Unknown	Unknown
	Water	Surface water for non-drinking purposes	Abstracted surface water from rivers, lakes and other open water bodies for domestic use (washing, cleaning and other non-drinking use), irrigation, livestock consumption, industrial use (consumption and cooling) etc.	HIGH	HIGH	-		
		Ground water for non-drinking purposes	Abstracted groundwater for domestic use (washing, cleaning and other non-drinking use), irrigation, livestock consumption, industrial use (consumption and cooling) etc.	-	-	HIGH		



Other tables available in: Synthesis of current knowledge on Irish freshwater resources in the context of ecosystem services

http://epa.ie/researchandeducation/research/researchpublications/researchreports/research207.htmlSynthesis

Step 2: Ranking of ES by the General Public

1. **How do you use rivers?**
2. **What benefits from rivers are important to you?**

Ecosystem Services	%
Bankside activities (e.g. hiking, walking, dog walking)	14
Habitats for plant and animal nursery	13
Pleasure from knowing rivers and river wildlife exists	12
Wildlife watching	11.3
Leisure fishing and angling	11.3
Fish for consumption	8.6
Water sports (e.g. swimming, boating, kayaking)	6
Flood protection	5.2
Control of water borne fish diseases	5.2
Water purification	3.4
Drinking water	2.6
Erosion control	2.6
Renewable energy	1.7
Water for other purposes (e.g. irrigation, livestock)	0.8
Control of water borne human diseases	0.8
Carbon storage	0.8

Step 3: Selecting ES Attributes

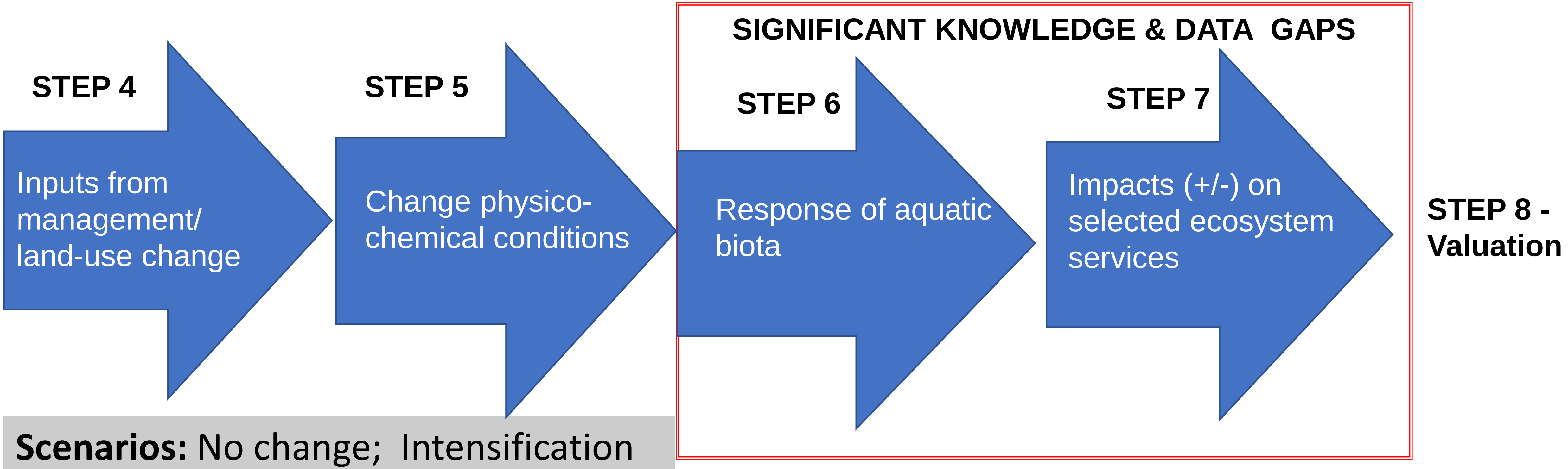
Service	Attribute
Water quality	Presence/absence of scum and filamentous algae
Water health	Risk of gastrointestinal infections
Habitat	Vegetated (non-agricultural use) riparian buffer
Wildlife	Numbers of mayfly species and numbers of dippers, kingfishers & otters
Angling	Numbers of catchable fish

Challenges:

- Identifying attributes that respond to water quality change & are perceived by people to represent the ES
- Few relevant data sets to link services and water quality

Linking changes in water quality to changes in ecosystem services

Hydrological modelling…….Bayesian Belief Network modelling



Scenarios: No change; Intensification of agriculture; Extensification of agriculture; Use of riparian buffers

Concluding Comments

Freshwater ecosystem health, resilience and maintenance of ecosystem services are challenged by multiple stressors and investigators/resources managers are equally challenged to detect the impacting stressors and find solutions to halt or reverse the decline in water quality and biodiversity loss.

- ✓ Adopt a multi-stressor perspective when investigating impacts on freshwater systems
- ✓ 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*.
- ✓ Mitigation of elevated deposited sediment should be prioritized
- ✓ Incorporate measurement of deposited sediment (plus quality of the physical habitat) into assessments

- ✓ Ideally base assessments on more than one biological group
- ✓ Use several metrics

- ✓ **Take a step out of water** and make the link to impacts on ecosystem services - goods and benefits (*particularly via cultural services)*

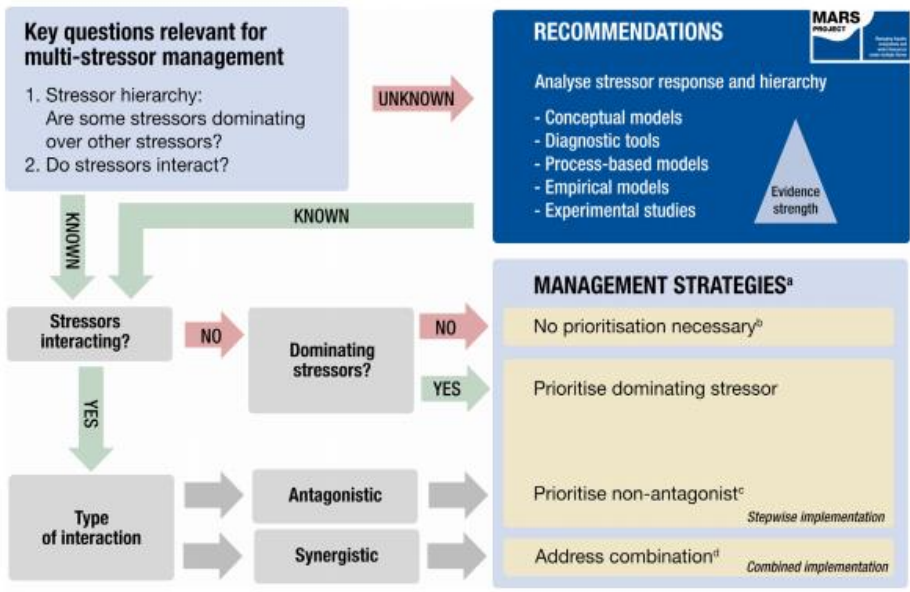


Figure 3: Key questions relevant for tackling multi-stressor conditions in River Basin Management (involving supportive MARS tools addressed in these recommendations), leading to appropriate management strategies concerning the level and type of necessary mitigation and adaptation measures.

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

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

To join our circulation list for Newsletters and Reports from the following projects contact: mary.kelly-quinn@ucd.ie

epa

- ESManage: www.ucd.ie/esmanage
- ESDecide (developing decision support)
- SSNet: www.ucd.ie/SSNet — Managing the small stream network for improved water quality, biodiversity and ecosystem services protection
- Reconnect: www.ucd.ie/reconnect — Mapping & assessing barriers on Irish rivers
- Climate change impacts on the water quality and functioning of rivers in a multi-stressor environment IRC funded – website in development