UNIVERSITY
OF HULL

Problems and successes in water management – causes, consequences and responses

Michael Elliott

Professor of Estuarine & Coastal Sciences

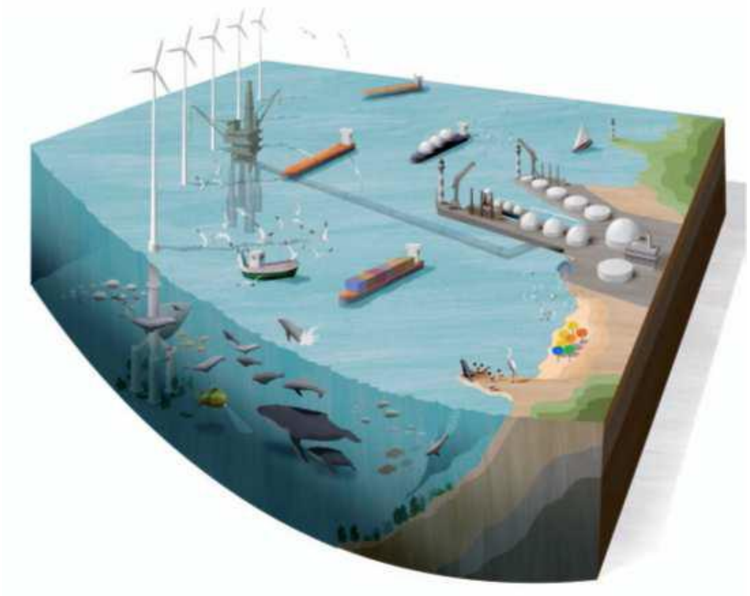
Department of Biological & Marine Sciences, University of Hull, Hull, HU6 7RX, UK;

Director

International Estuarine & Coastal Specialists (IECS) Ltd, Leven, HU17 5LQ, UK.

International Estuarine and Coastal Specialists

Challenges for estuarine/marine science & management:



There is only one big idea: *how to maintain and protect ecological structure and functioning while at the same time allowing the system to produce ecosystem services from which we derive societal benefits.*

- Recovery/coping with historical legacy
- Endangered coastal and marine ecosystem functions
- Legal & administrative framework
- Economic prosperity and delivery of societal benefits
- Coping with climate change & moving baselines

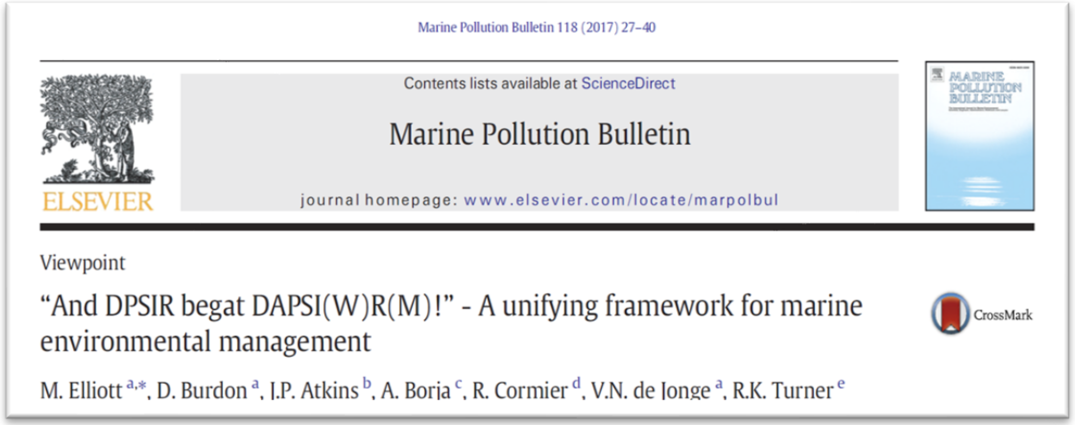
In other words:

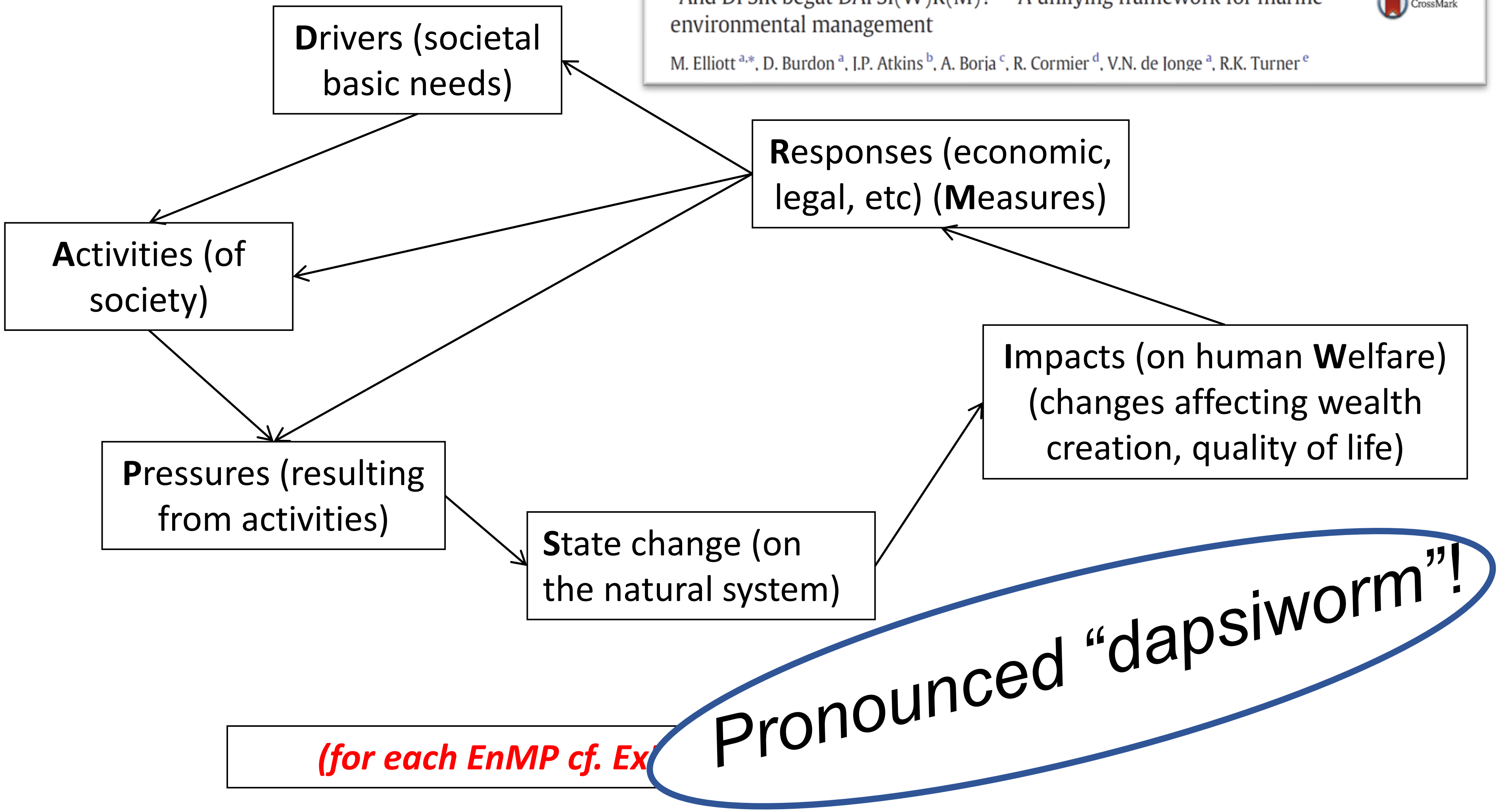
"to look after the natural stuff and deliver the human stuff"

Environmental Management Questions:

- Where are the problems & What changes do they cause?
- What is the impact of these on ecosystem structure and functioning?
- What are the repercussions for ecosystem valuation based on economy-ecology interactions?
- What are the future environmental changes and economic futures?
- What governance framework is there, what do stakeholders need?
- What can we do about the problems?
- Where are the risks and how to address them now and in the future?
- What are the governance successes, failures and implications?
- How ‘good’ is the decision-making?
- What are the bottlenecks, showstoppers and train-wrecks?

DAPSI(W)R(M) framework


Marine Pollution Bulletin 118 (2017) 27–40
Contents lists available at ScienceDirect
Marine Pollution Bulletin
journal homepage: www.elsevier.com/locate/marpolbul
ELSEVIER
Viewpoint
"And DPSIR begat DAPSI(W)R(M)!" - A unifying framework for marine environmental management
M. Elliott [a,*], D. Burdon [a], J.P. Atkins [b], A. Borja [c], R. Cormier [d], V.N. de Jonge [a], R.K. Turner [e]



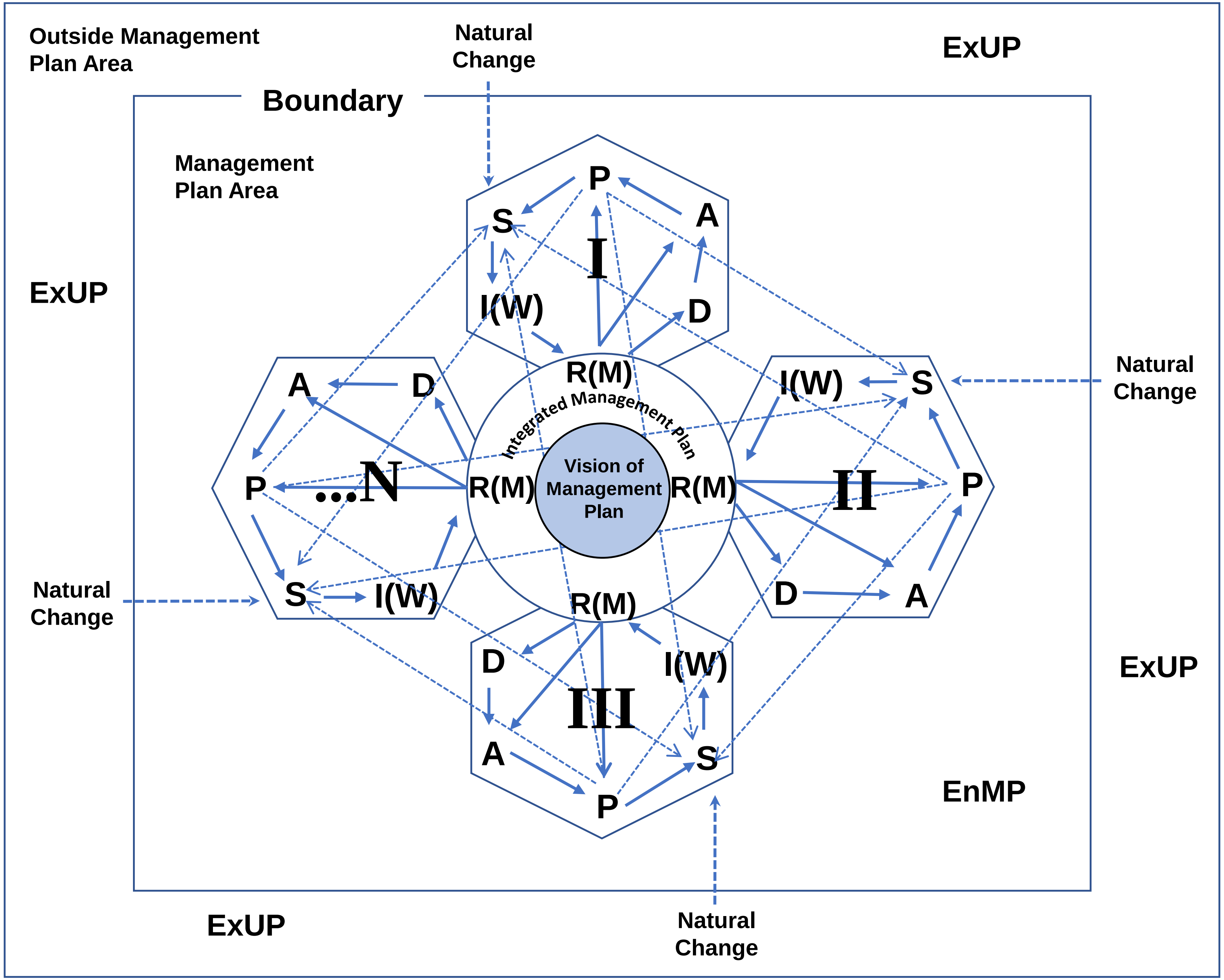
Activities contributing to Endogenic Managed Pressures

(Elliott et al 2017)

Activity
Aquaculture
Extraction of living resources
Transport & Shipping
Renewable Energy
Non-renewable (fossil fuel) Energy
Non-renewable (nuclear) Energy
Extraction of non-living resources
Navigational Dredging
Coastal Infrastructure
Land-based Industry
Agriculture
Tourism/Recreation
Military
Research
Carbon Sequestration

Pressures
Smothering
Substratum loss
Changes in siltation
Abrasion
Selective extraction of non-living resources (habitat removal)
Underwater noise
Litter
Thermal regime change
Salinity regime change
Introduction of synthetic compounds
Introduction of non-synthetic compounds
Introduction of radionuclides
Introduction of other substances

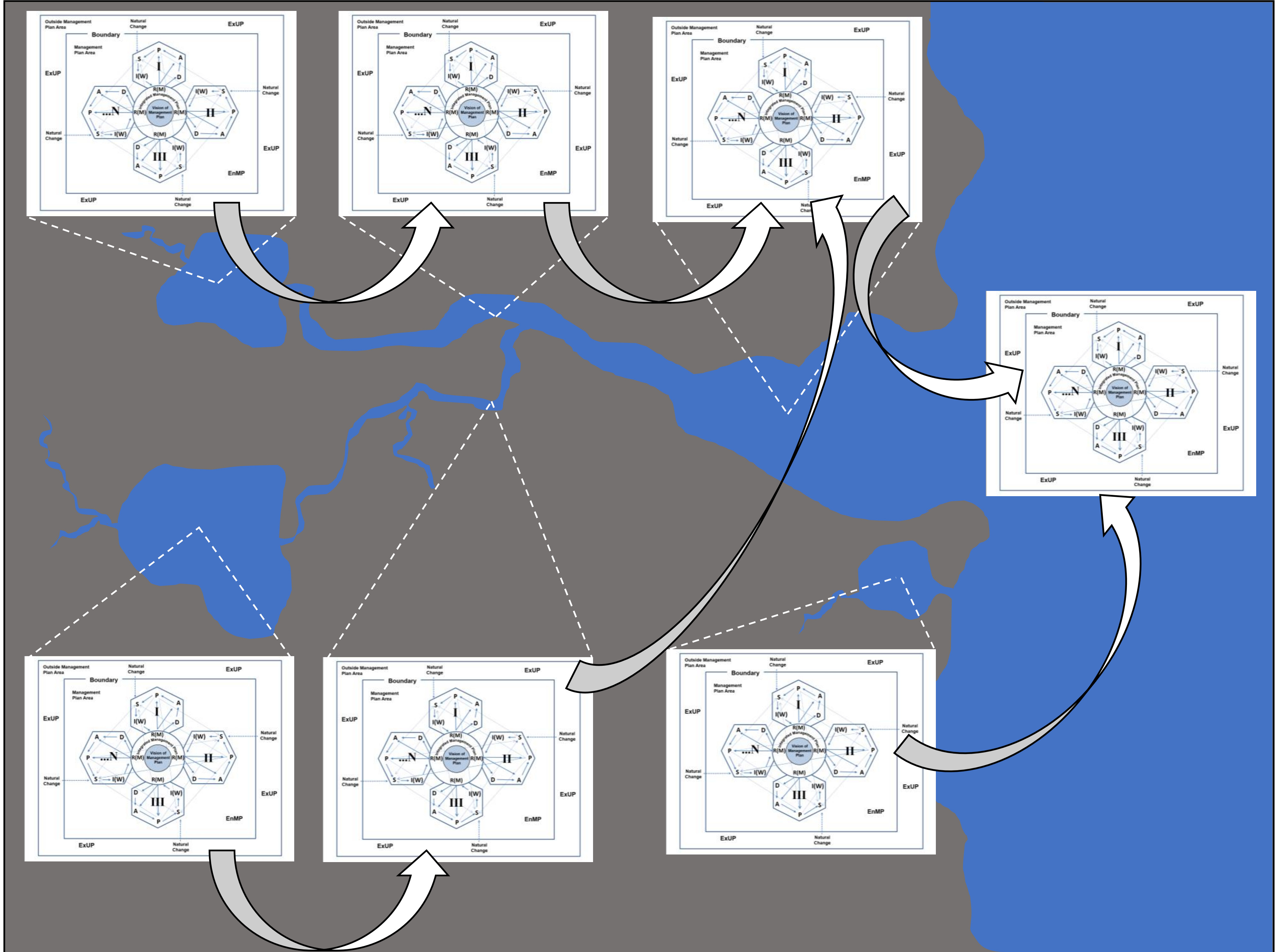
Nitrogen and phosphorus enrichment
Input of organic matter
Introduction of microbial pathogens
Introduction of non-indigenous species and translocations
Selective extraction of species
Death or injury by collision
Barrier to species movement
Emergence regime change
Water flow rate changes
pH changes
Electromagnetic changes
Change in wave exposure



Outside Management Plan Area
Natural Change
ExUP
Boundary
Management Plan Area
ExUP
P
A
S
I
I(W)
D
R(M)
A
D
I(W)
S
Integrated Management Plan
Natural Change
P
...N
R(M)
Vision of Management Plan
R(M)
II
P
Natural Change
S
I(W)
D
A
R(M)
D
I(W)
ExUP
III
A
S
P
EnMP
ExUP
Natural Change

Exogenic Unmanaged Pressures (from Elliott et al 2017)

Pressure	Description
Thermal regime change	Temperature change (average, range, variability) climate change (large scale)
Salinity regime change	Temperature change (average, range, variability) due climate change (large scale)
Emergence regime change	Change in natural sea level (mean, variation, range) due climate change (large scale) and isostatic rebound
Water flow rate changes	Change in currents (speed, direction, variability) due climate change (large scale)
pH changes	Change in pH (mean, variation, range) due climate change (large scale), volcanic activity (local)
Change in wave exposure	Change in size, number, distribution and/or periodicity of waves along a coast due to climate change (large scale).


Outside Management Plan Area
Natural Change
ExUP
Boundary
Management Plan Area
I
II
III
...N
P
A
D
S
I(W)
R(M)
Integrated Management Plan
Vision of Management Plan
EnMP

Unhealthy systems?

Medical (*1) –

- Diagnosis
- Prognosis
- Treatment
- Recovery

Prevention

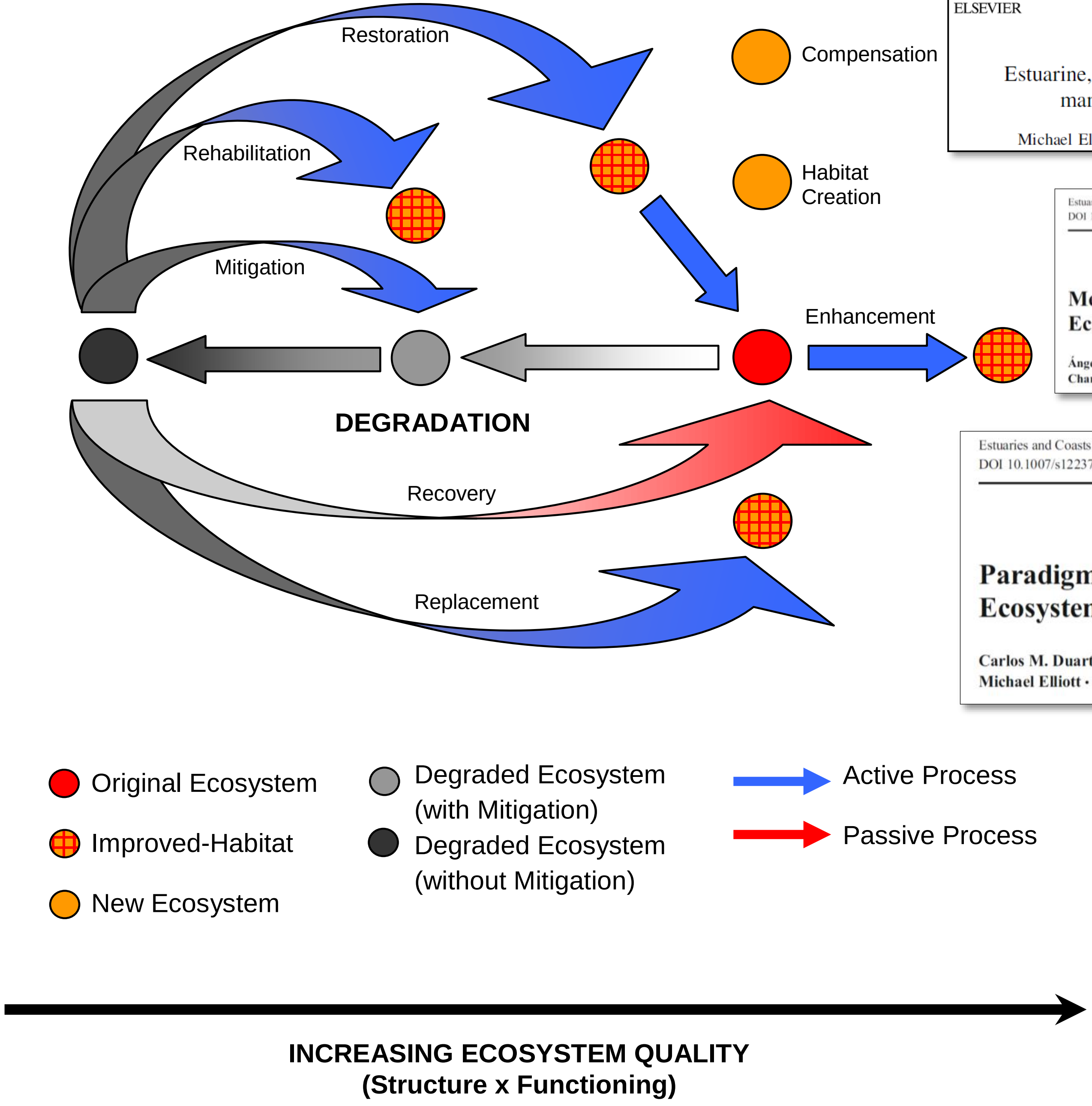
(*1 Steevens et al 2001 - Human Ecol. Risk Ass.)

Environmental –

- Assessment (*2)
- Prediction
- Remediation/Creation/ Restoration
- Prevention

(2 using extension of symptoms for the diagnosis of ecosystem pathology)*

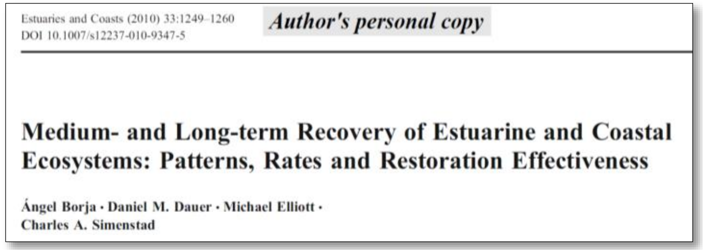
Comparison of the health of medical and environmental systems (modified from Elliott & Cutts 2004; see Tett et al., MEPS 2013)



Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Estuarine, Coastal and Shelf Science 74 (2007) 349–366
ESTUARINE COASTAL AND SHELF SCIENCE
www.elsevier.com/locate/ecss

Estuarine, coastal and marine ecosystem restoration: Confusing management and science — A revision of concepts

Michael Elliott [a,*], Daryl Burdon [a], Krystal L. Hemingway [a], Sabine E. Apitz [b]

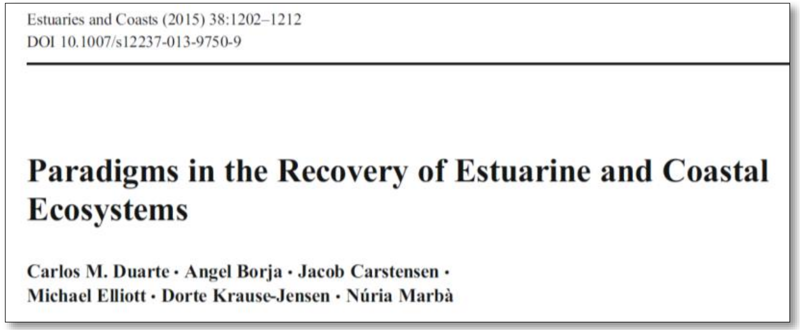


Estuaries and Coasts (2010) 33:1249–1260
DOI 10.1007/s12237-010-9347-5

Author's personal copy

Medium- and Long-term Recovery of Estuarine and Coastal Ecosystems: Patterns, Rates and Restoration Effectiveness

Ángel Borja · Daniel M. Dauer · Michael Elliott · Charles A. Simenstad



Estuaries and Coasts (2015) 38:1202–1212
DOI 10.1007/s12237-013-9750-9

Paradigms in the Recovery of Estuarine and Coastal Ecosystems

Carlos M. Duarte · Angel Borja · Jacob Carstensen · Michael Elliott · Dorte Krause-Jensen · Núria Marbà

Why Recreate/Restore/Offset?

1. Policy
2. Obligations
3. Objectives
4. Law
5. Due diligence
6. Green credentials
7. Rectify historical losses (restore or increase ecological and socio-economic carrying capacity, ecosystem services and societal benefits)

Voluntary offsets

Enforced offsets

Legally binding

Economic incentives

Restore/Recreate what?

Shape + connectivity

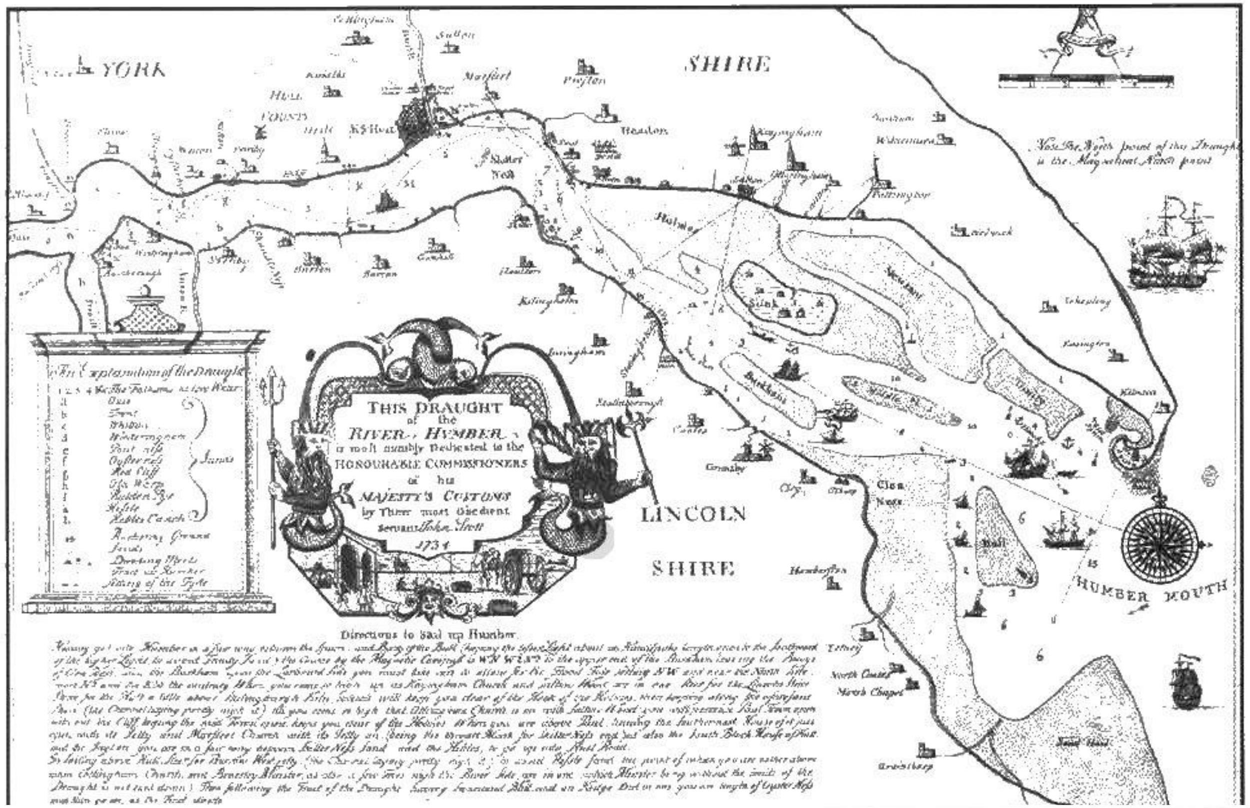
- Hydrodynamics
- Ecotones
- Supply of water
- Supply of organic matter
- Supply of recruiting organisms

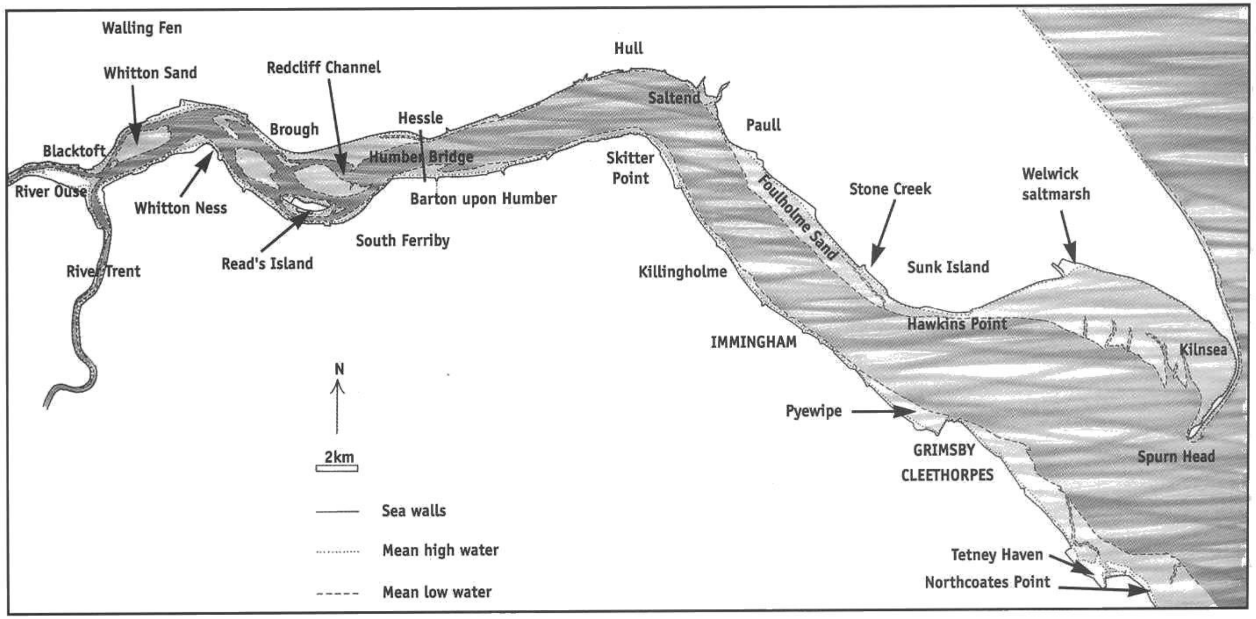
Surface area

- Biogeochemical/ storage area, sequestration (reactive surface)
- productive surface (feeding area, nursery area)
- resistance to anthropogenic change (size, water storage, RSLR)

Habitat complexity (ecotones)

- refuge area/nursery areas
-Productive surface
-Resilience
- ‘Spillover’ - nursery delivery to external fishery/populations





Land claim in the Humber (since the Scott chart, 1794)

Coastal squeeze – anthropogenic and exogenic

IECS 1993; Murby 2001; http://www.hull.ac.uk/iecs

Habitat Restoration - Managed Realignment

Humber Estuary - Chowder Ness, June 2006

High degree of site preparation

NB Compensation Scheme (with Welwick saltmarsh) for Port Development (gain:loss = 2.5:1)

Management?

Elephant in the room: is MR a viable tool in high turbidity estuaries or just a politically expedient tool to meet Directive compliance? Is it just good for the regulators and industry, but not for the estuarine system? Can it be improved as a tool or do we look for alternatives?

2007 cf. 2015

What do we want from a site and is it actually deliverable e.g. SPA/SAC specifics?

Current techniques potentially fail to deliver for some defined offset metrics unless there is considerable management.

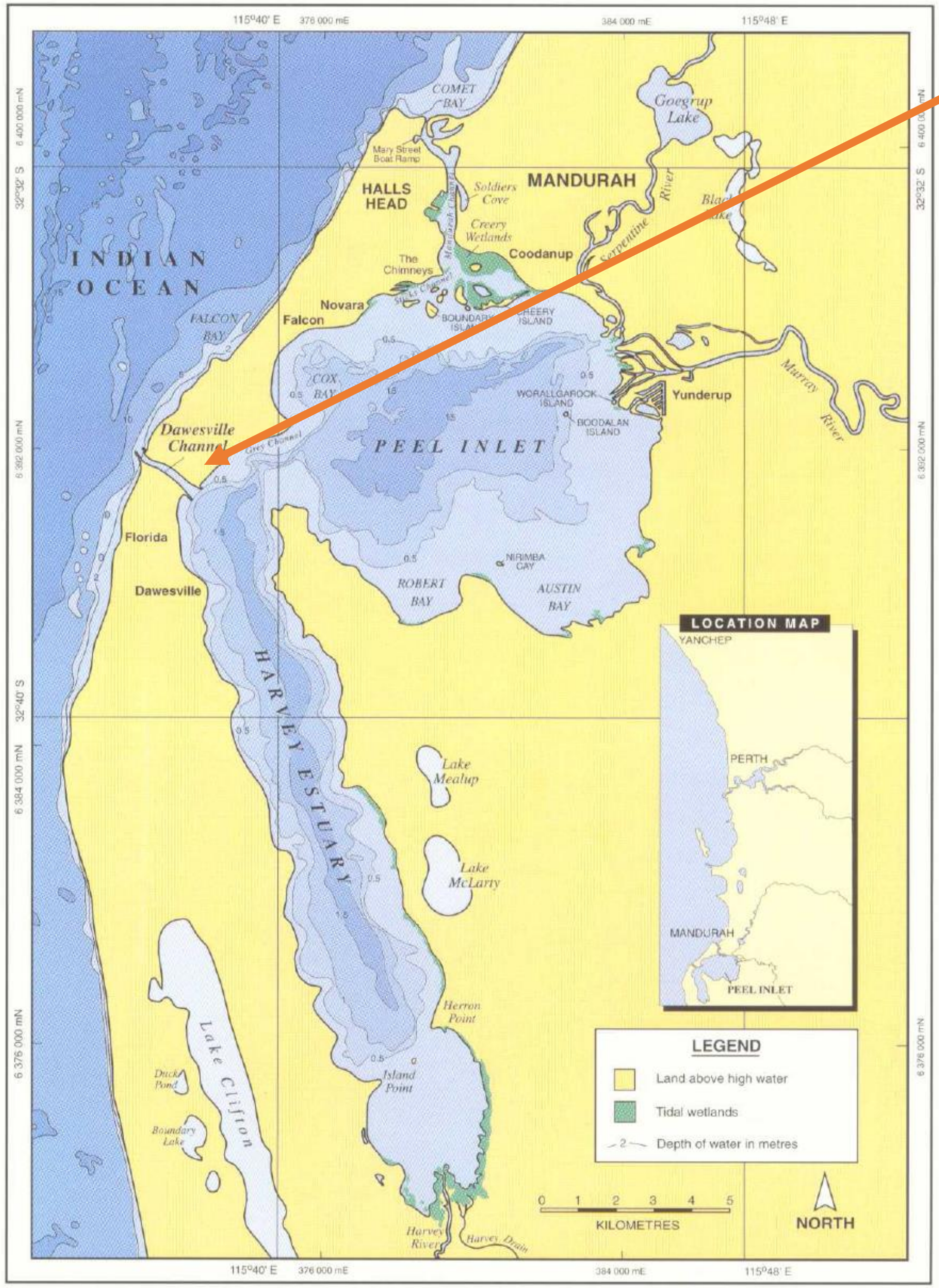
But:

Opportunity for other habitats/ species delivery as well as other EcoServs.

Opportunities for new techniques but constraints on their trial (cost/consenting).

Management aims need to either drive location or be driven by the prevalent physico-chemical conditions. Offset outside the estuary?

Peel-Harvey Estuary (WA) – EcoEng to solve a WQ problem:



Opening of Dawesville Channel in 1994

+ve

better water quality, fewer odour problems, better recreation fishery, more residential areas

-ve

poorer prawn fishery, still circulation problems, increased mosquitos, still eutrophication in certain areas, remediation not accompanied by land-use changes

Peel-Harvey system – an ideal test case: ARC Project:

Murdoch University

University of Hull

The University of Western Australia
Achieve International Excellence

Southern Cross University

Shire of Murray

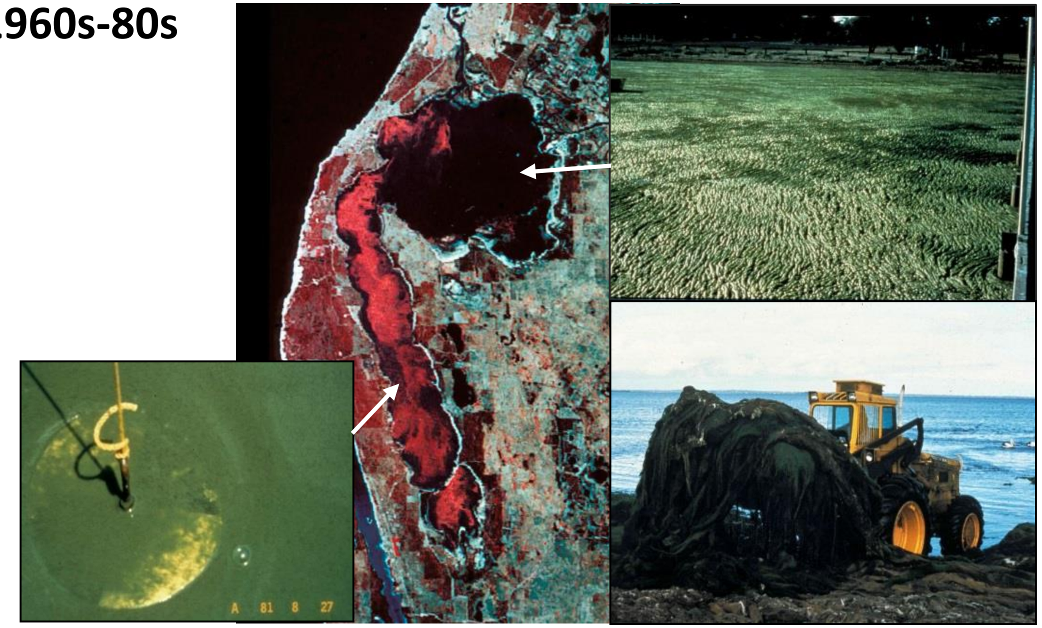
City of Mandurah

Government of Western Australia
Department of the Premier and Cabinet

Government of Western Australia
Department of Water and Environmental Regulation

PHCC
Working Together

1960s-80s



1994

Transform Peel
An integrated approach to building regional resilience

Impediments to achieving restoration success:

Barriers to strategy development:

- High-level policy and organisational barriers
- Approach and methodological barriers
- Resource considerations (financial, organisational)
- Inter- and intra-group relationships
- Lack of shared vision and understanding

Barriers to strategy implementation:

- Cultural and/or policy
- Technical capacity and ability
- Resourcing (staff, finance)
- Trust and relationships

Solutions - The 10-tenets:

To be successful, management measures or responses to changes resulting from human activities should be:

- Ecologically sustainable
- Technologically feasible
- Economically viable
- Socially desirable/tolerable
- Legally permissible
- Administratively achievable
- Politically expedient
- Ethically defensible (morally correct)
- Culturally inclusive
- Effectively communicable


Marine Pollution Bulletin 74 (2013) 1–5
Contents lists available at ScienceDirect
Marine Pollution Bulletin
journal homepage: www.elsevier.com/locate/marpolbul
Editorial
The *10-tenets* for integrated, successful and sustainable marine management


ENVIRONMENTAL SCIENCE & POLICY 51 (2015) 181–191
Available online at www.sciencedirect.com
ScienceDirect
journal homepage: www.elsevier.com/locate/envsci
The 10-tenets of adaptive management and sustainability: An holistic framework for understanding and managing the socio-ecological system

*Steve Barnard**, *Michael Elliott*

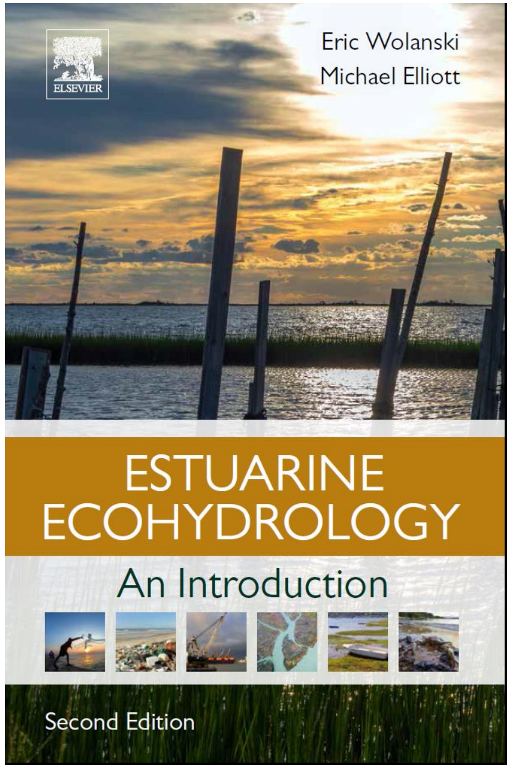
(NB spellcheck - not "a good night in Scotland"!)

Estuarine Ecohydrology

The science and understanding of the links between the physical functioning and the means by which it creates the appropriate ecological functioning of an estuary. It assumes that the ecology is primarily driven by the physics, which in turn affects the biological processes operating within a system.

It includes changing the physiography and manipulating the freshwater flows from the catchment and it is also influenced by the anthropogenic users and uses of the estuary, some of which will have modified and impacted both the physics and the ecology.

It is that knowledge which guides the management of the entire river basin from the headwaters down to the coastal zone, which Ecohydrology views as an ecosystem.



Estuarine Ecological Engineering

Uses ecohydrology knowledge to modify and achieve our ecological aims for an area by Engineering:

(1) the physics, including changing the physiography and manipulating the freshwater flows from the catchment, to produce the ecological niches which in turn lets the ecology and habitats develop, especially if the colonising species are ecological engineers (Type A Ecoengineering).

(2) the ecology, by restocking or replanting, in turn creating habitats or letting the ecological engineer species modify habitats, thus enhancing the physical-biological links (Type B Ecoengineering).

Ecoengineering initiatives often aim to accelerate natural rehabilitation and sometimes harness dynamic variability. However, they often only achieve establishing a static system (the desired state) even if this does not include all natural successional processes and stages.

Category	Ecohydrological measure type
Hydrology / Morphology	Measure to reduce tidal range, asymmetry and pumping effects and/or dissipate wave energy
	Other measures for flood protection
	Other measures to stabilise coasts or improve morphological conditions
	Measure to decrease the need for dredging
	Zoning measures
	Measures to stop or reverse subsidence due to extraction of water and minerals
	Measure to restore longitudinal or lateral connectivity

Ecohydrological measure categories (see Elliott et al 2016 for examples)

Category	Ecohydrological measure type
Physical / Chemical Quality	Measure to reduce nutrient loading (point and diffuse sources)
	Measure to reduce persistent pollutant loading (point and diffuse sources)
	Measure to improve oxygen conditions
	Measure to reduce physical loading (e.g. heat input by cooling water entries)
	Measure to reduce sediment inputs and sediment loading

Ecohydrological measure categories

(see Elliott et al 2016 for examples)

Category	Ecohydrological measure type
Biology/ ecology	Measure to develop and/or protect specific habitats
	Measure to develop and/or protect specific species
	Measures to retain or restore natural gradients & processes, transition & connection
	Measure to prevent introduction of or to eradicate/ control against invasive species
	Measure for direct human benefit of ecological attributes
Human safety	Measure for early warning/evacuation of natural disasters
	Measure for improved resilience of housing and industry

Ecological Engineering - Principles:

(1) ecohydrological principles should be used to ensure a suitable and sustainable physico-chemical system
(2) the design should encompass local features and so be site-specific
(3) the design parameters and features should be kept simple in order to deliver the functioning required
(4) the design should use energy inside the system or coming from outside, such as flow conditions and working with nature, and that the system should be kept simple to minimise the information required for it execution, and lastly
(5) the EcoEng design should aid the natural and social systems and so should have an ethical dimension; this may involve ‘over-engineering the design in order to protect human safety and property.

This therefore ensures the wins for safety, economy & ecology

(Modified from Bergen et al 2001 Ecol. Eng. 18: 201-210)


Estuarine, Coastal and Shelf Science 176 (2016) 12–35

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

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

Ecoengineering with Ecohydrology: Successes and failures in estuarine restoration

Michael Elliott [a, b, c, *], Lucas Mander [a], Krysia Mazik [a], Charles Simenstad [d], Fiona Valesini [b], Alan Whitfield [c], Eric Wolanski [e, f]

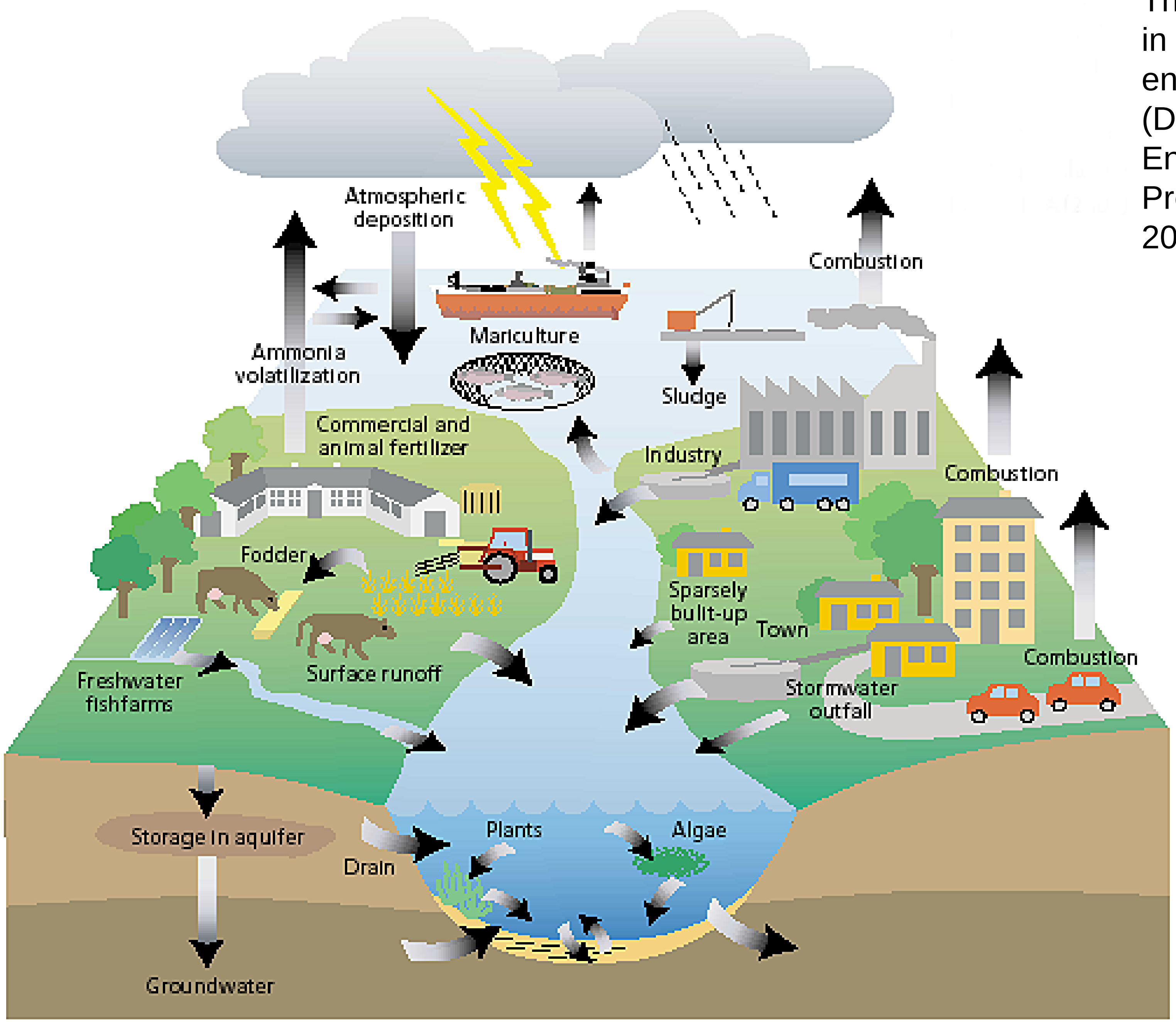
What?	Cause?	Reverse?
Land-claim	Wetland removal/dyke construction	Restocking with vegetation, reconnection, resculpting
DO sag	Waste discharges	Reduction/treatment of inputs, reoxygenation, bubbling
Bivalve biogenic reef loss	Siltation, overharvesting,	Adaptation, flushing, regulation, restocking
Eutrophication	Poor flushing, excess nutrients	Reconnection, regulation
Biota kills	Toxin input, WQ problems	Regulation, industry removal
Coral reef loss	Siltation, direct damage, bleaching	Run-off controls, re-creation, global rethinking,
Loss of fish	Overharvesting, climate change, hydrodynamic barriers	Restocking, rethinking, adaptation, regulation

What?	Cause?	Reverse?
Salinity change	Upstream abstraction, impediments to flow	Removal, reconnection
Loss of seagrass	Smothering, nutrient excess, disease, hydrographic change	Reduction, removal, reconnection, replanting
Loss of flow	Diversion, abstraction, structures	Reconnection, reallocation
Seabed extraction	Aggregate removal, loss of sediment fraction	Reseeding, regulation, reallocation
Taxonomic changes	Non-indigenous species influx	Removal, eradication, prevention

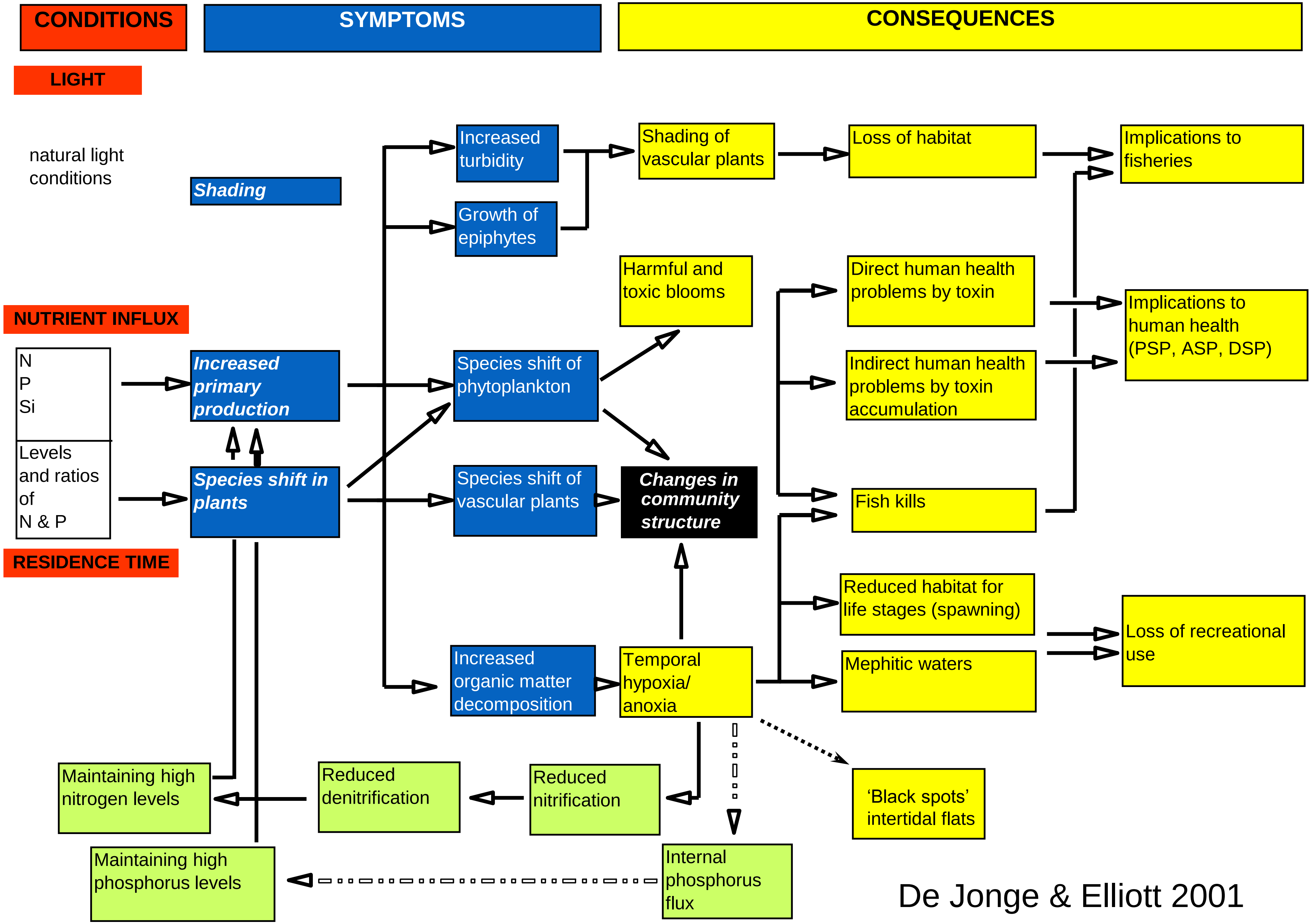
So what is the problem and solution and why doesn't it always work?

Categories of Problem	Categories of Solutions
Enrichment by substances Loss of surface and habitat Biotic compound loss or change Over-extraction of resources Water and connectivity loss	reversal, restocking, regulation, reconnection, re-sculpting, removal, revision, restoration, replanting, reduction, reallocation, reseeding, reoxygenation

Perhaps we don't know our R's from our …….?



The nitrogen cycle in the aquatic environment (Danish Environmental Protection Agency, 2000).



De Jonge & Elliott 2001

Symptoms of Ecosystem Pathology:

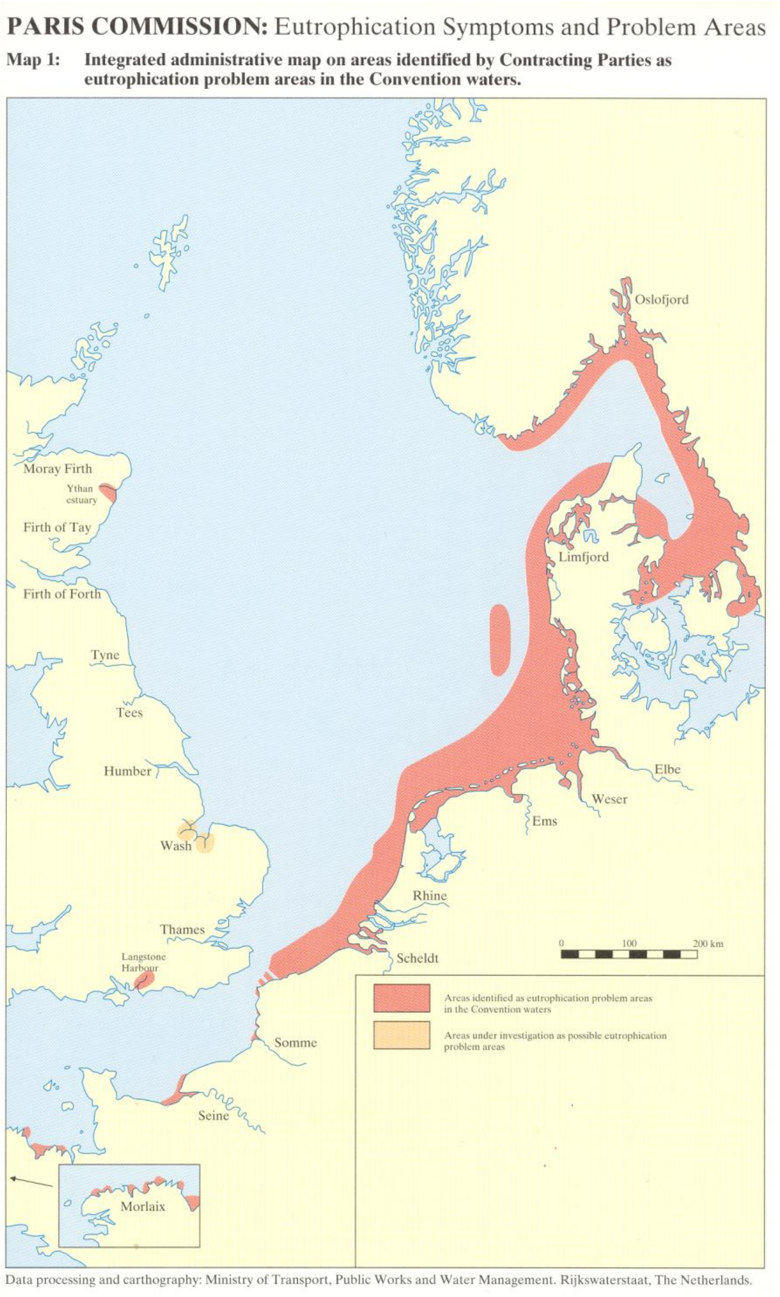
Noxious, nuisance and toxic microalgae and macroalgae

Presence of toxic microalgal blooms: *Alexandrium* sp. & *Dinophysis* sp.

Red tides & fish & bird kills

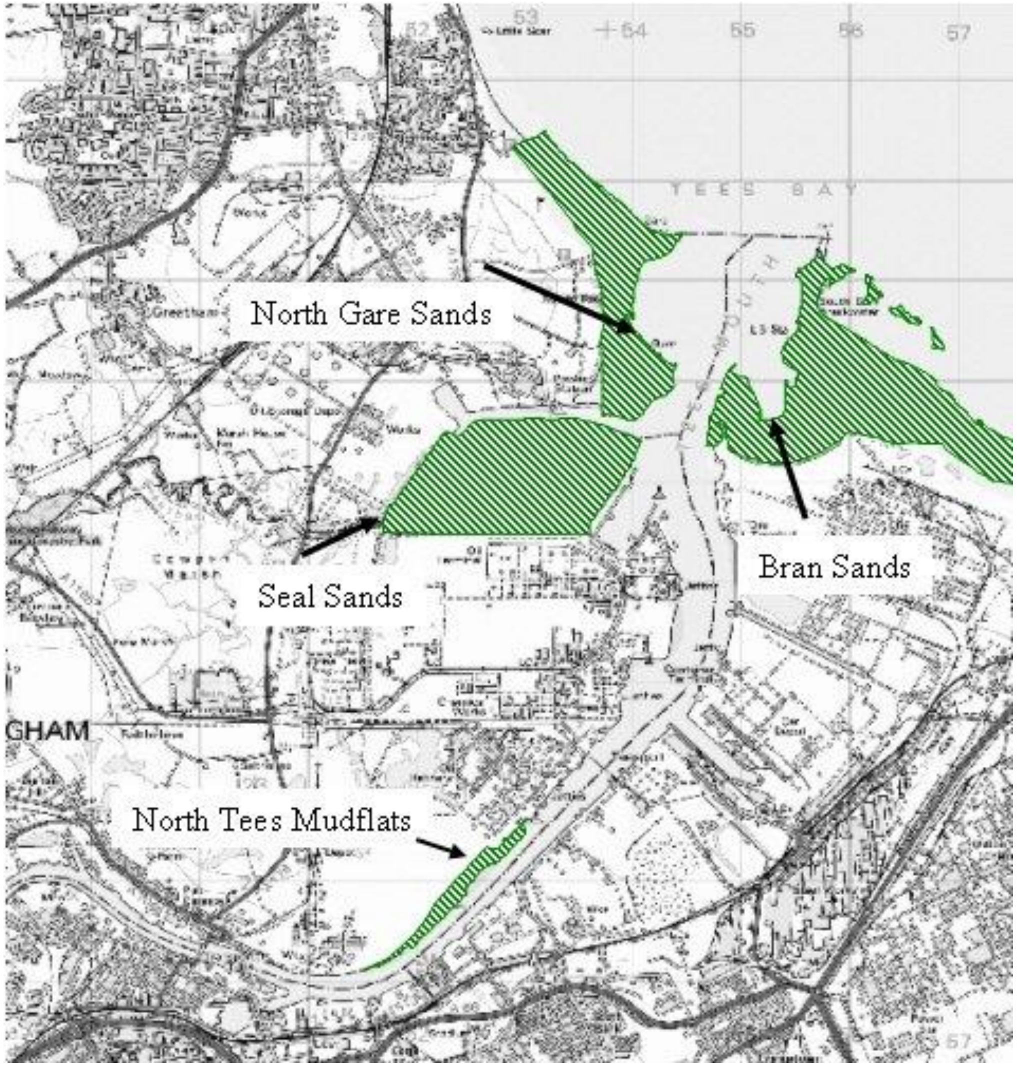
From ‘normal’ seabed organisms - many species, all sizes To Polluted seabed community - few species, small organisms

Symptoms of ecosystem pathology: macroalgal mats



Sources of point and diffuse anthropogenic inputs (Carpenter *et al*., 1998; Novotny & Olem, 1994; Smith *et al*., 1999; D'Arcy *et al*., 2000; Elliott & Boyes, 2002).

Point Sources	**Diffuse Sources**
• Waste water effluent (municipal & industrial); • Point run-off and leachate from waste disposal sites; • Run-off and infiltration from animal feedstuffs; • Discharges from minewaters, oil fields, and unsewered industrial sites; • Storm sewer outfalls from urban conglomerations; • Overflows of combined storm and foul sewers; • Point run-off from construction sites.	• Run-off from agriculture (including return flows from irrigated agriculture; • Inputs from vegetation - reedbeds, saltmarsh, algae, and die-off from freshwater plankton; • Septic tank leachage and run-off from failed septic systems; • Run-off from construction sites; • Non-point discharges from abandoned mines; • Atmospheric deposition over a water surface; • Activities on land that generate contaminants, such as forestry, wetland conversion, construction, and development of land or waterways; • The extent and significance of diffuse pollution is predominantly related to the occurrence of meteorological events.



The Tees Estuary - NE England (designated conservation areas shown)

Q. What is the relationship between existing and planned STW discharges and HSD designation?

Table 3 Effects of eutrophication on estuarine and coastal marine ecosystems (Smith, 1998; Smith *et al.*, 1999; Bricker *et al.*, 1999; Elliott & Read, 2001; Elliott *et al.*, 2002)

Effects
• Increased biomass of marine phytoplankton and epiphytic algae
• Shifts in phytoplankton species composition to taxa that may be toxic or inedible (e.g., bloom-forming dinoflagellates)
• Increases in nuisance blooms of gelatinous zooplankton, toxic blooms and tainting phytoplankton forms
• Changes in macroalgal production, biomass, and species composition, leading to elevated chlorophyll-*a* concentrations
• Occurrence of blooms of micro-algae which may be a nuisance (and cause aesthetic pollution) through foaming (e.g. *Phaeocystis*, *Chaetoceros socialis*)
• Changes in vascular plant production, biomass, and species composition
• Reduced water clarity
• Decreases in the perceived aesthetic value of the water body
• Elevated pH and dissolved oxygen depletion in the water column
• Mortalities of higher organisms through effects of neurotoxins with associated shifts in composition towards less desirable animal species
• Increased probability of kills of recreationally and commercially important animal species
• Nuisance macroalgal mat formation to hinder fishing and navigation
• Hindrance to intertidal feeding by wading birds and ducks

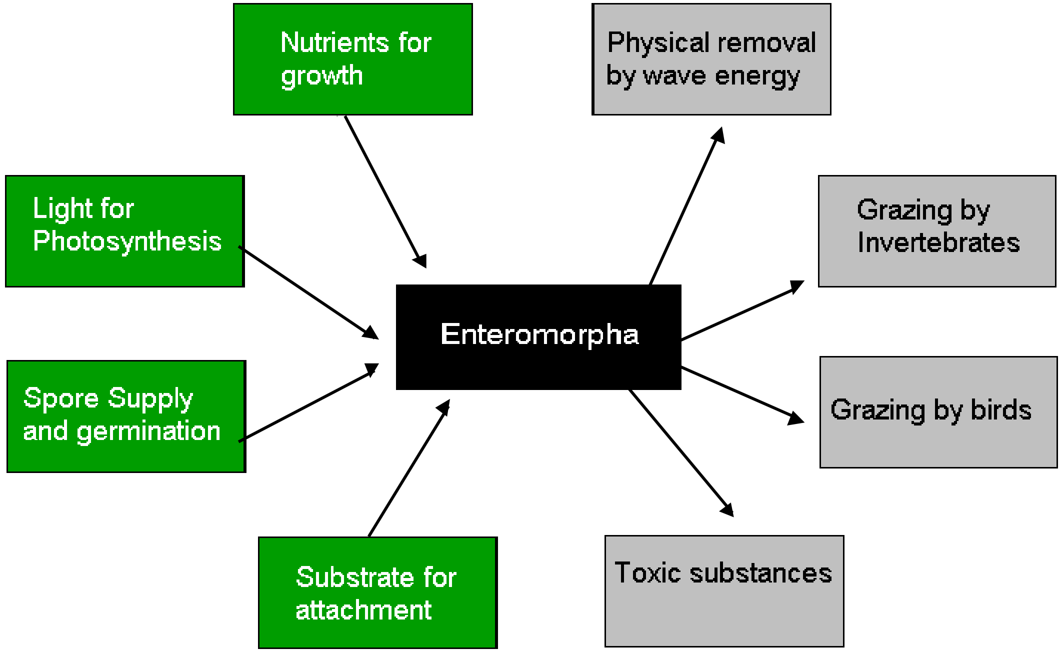
KISS(*)

- *Eutrophic - anthropogenic undesirable consequences (cf. pollution);*
- *Eutrophication - process of becoming eutrophic;*
- *Organic enrichment - natural state;*
- *Hypernutrification - nutrient excess (cf. contamination)*

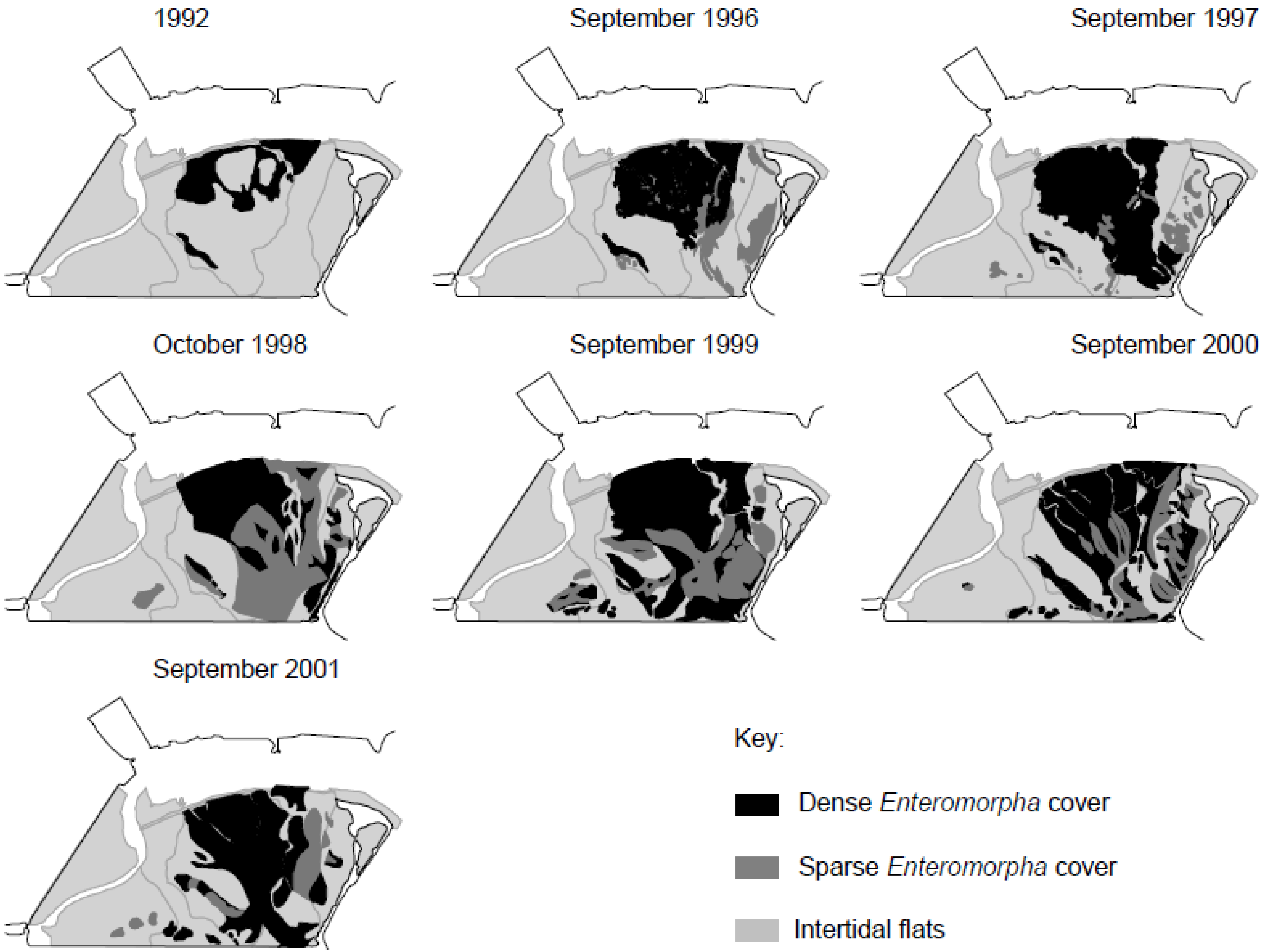
(keep it simple, stupid)*

Plate 6. Where the algal mat is thick, the underlying sediment is cut off from the atmosphere and becomes starved of oxygen. This creates a black anoxic layer as seen here, directly under the mat.

Plate 7. In some areas where the mats are dense, water currents and eddies twist the layers of algae into ropes.



Main Concern - macroalgal mats affecting conservation objectives (wading bird feeding for *Natura* 2000 site)

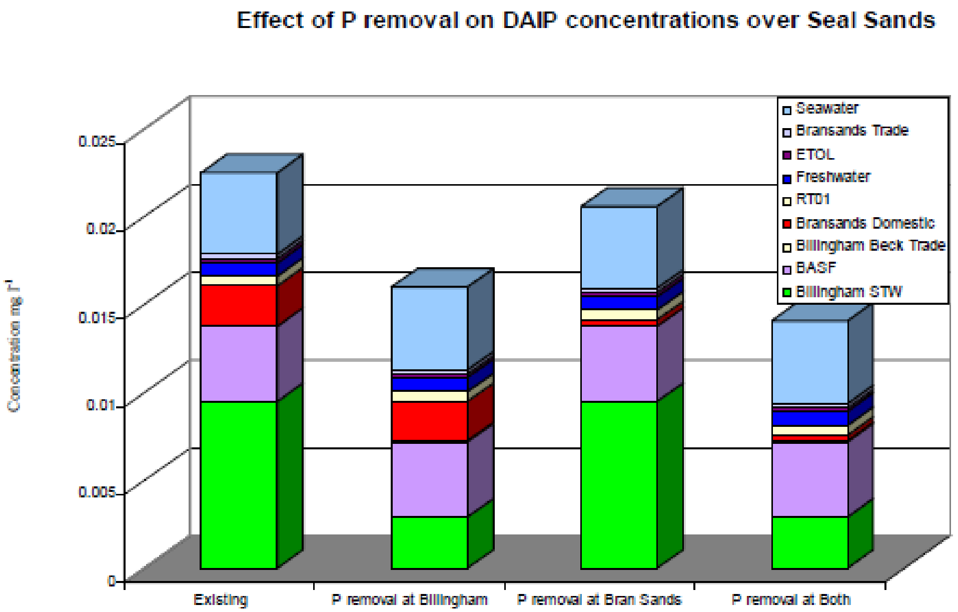


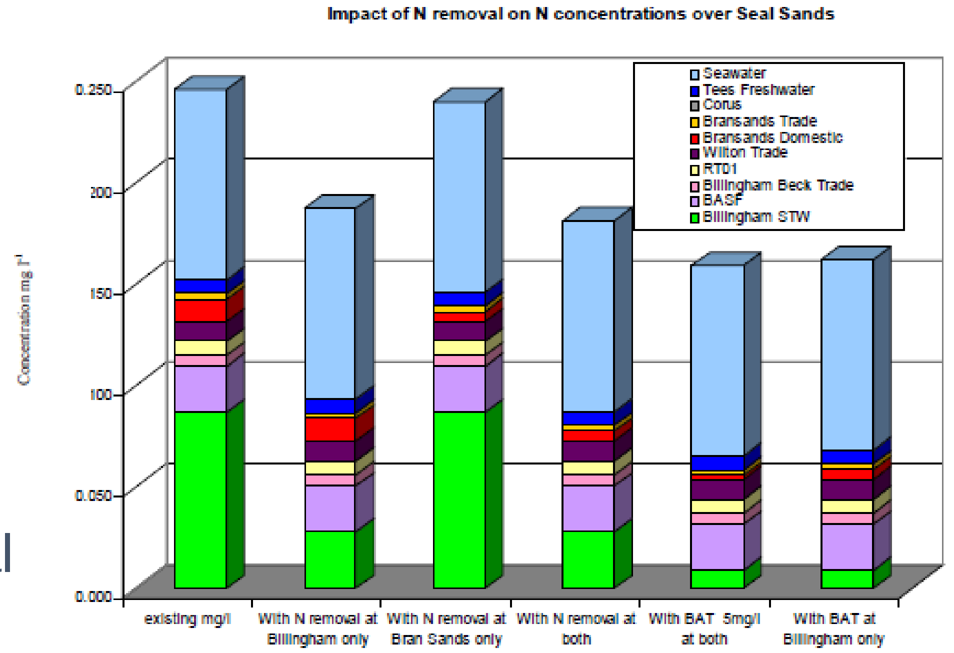
The coverage of Enteromorpha on Seal Sands 1992-2001

(Ward et al 2003 from data provided by Environment Agency)

Tees Estuary Study - Conclusions

- Aim of science to inform AMP4 capital expenditure and UWWTD compliance related to HSD;
- Onus on NWL to demonstrate no-effect rather than on statutory bodies to demonstrate an effect;
- The increase in macroalgal mats coincided with a reduction in nutrients (diffuse and point sources) and toxic substances;
- Transport patterns did not explain the cause but residence time was important;
- The main sources of nutrients, especially NH4, were planned to be removed even before the study;
- Tick-list as a pragmatic approach using ‘probability/weight of evidence approach’ (legal basis), suitable for managers and acknowledging data/information gaps;

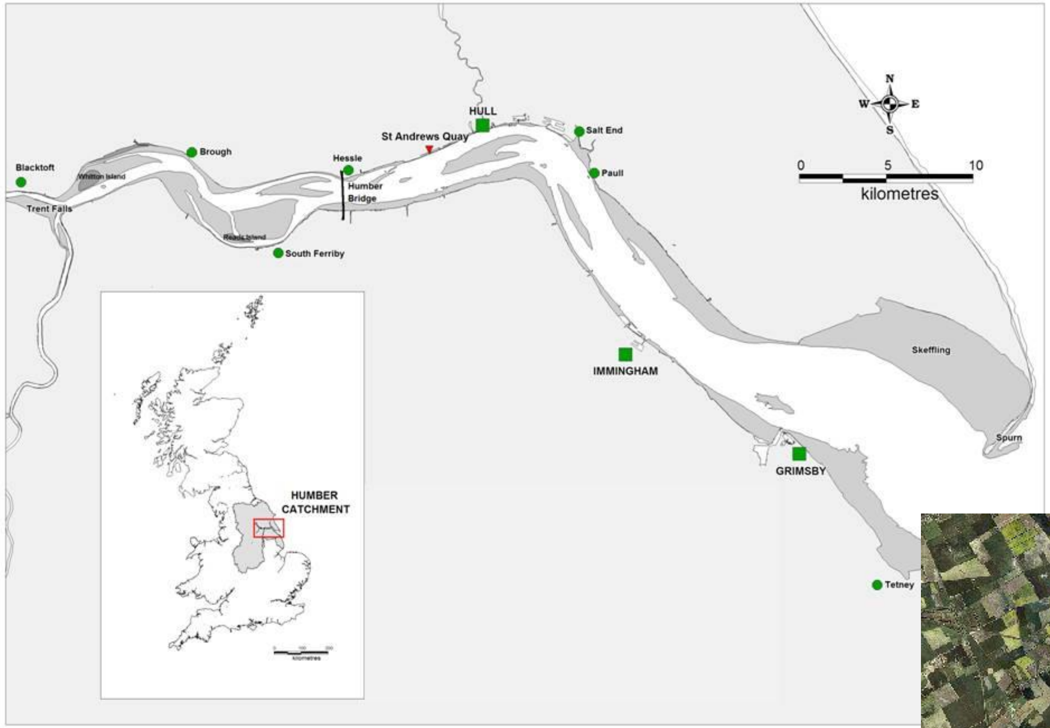




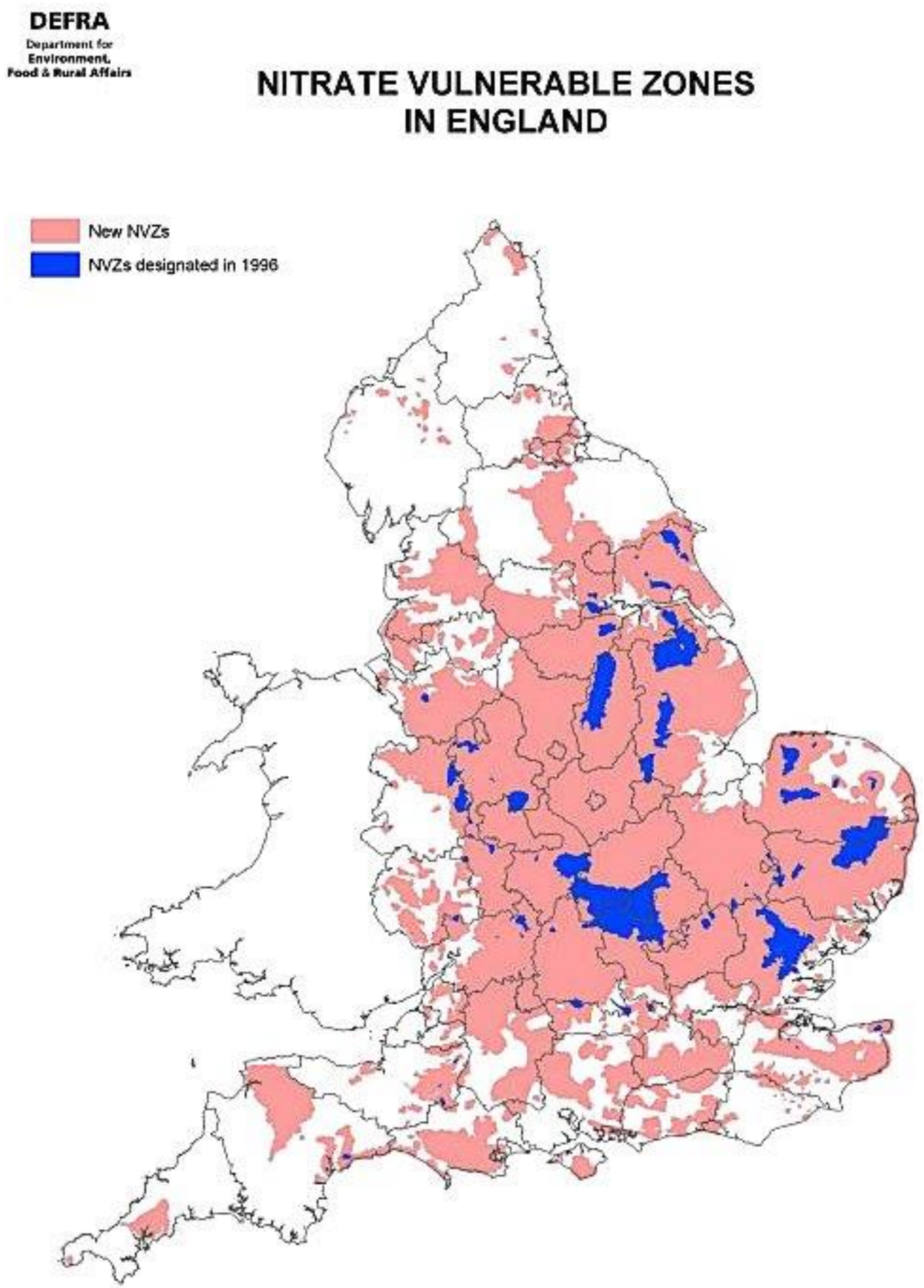
BELPLUME predictions of DAIP and DAIN conc. over Seal Sands in 2003 with differing treatment regimes (EA 2006)

The Humber Estuary - NE England

Q. Re. UWWTD - ‘is the area eutrophic or likely to become eutrophic?’ (cf. Infraction proceedings)?



Mid-Humber - Turbidity Maximum Zone - Freshwater Seawater Interface (Suspended Solids: usually 5 $g.l^{-1}$, often 14 $g.l^{-1}$, can get 75 $g.l^{-1}$!)



EU Nitrates Directive

Re-designation of Nitrate Vulnerable Zones in response to EU recommendation

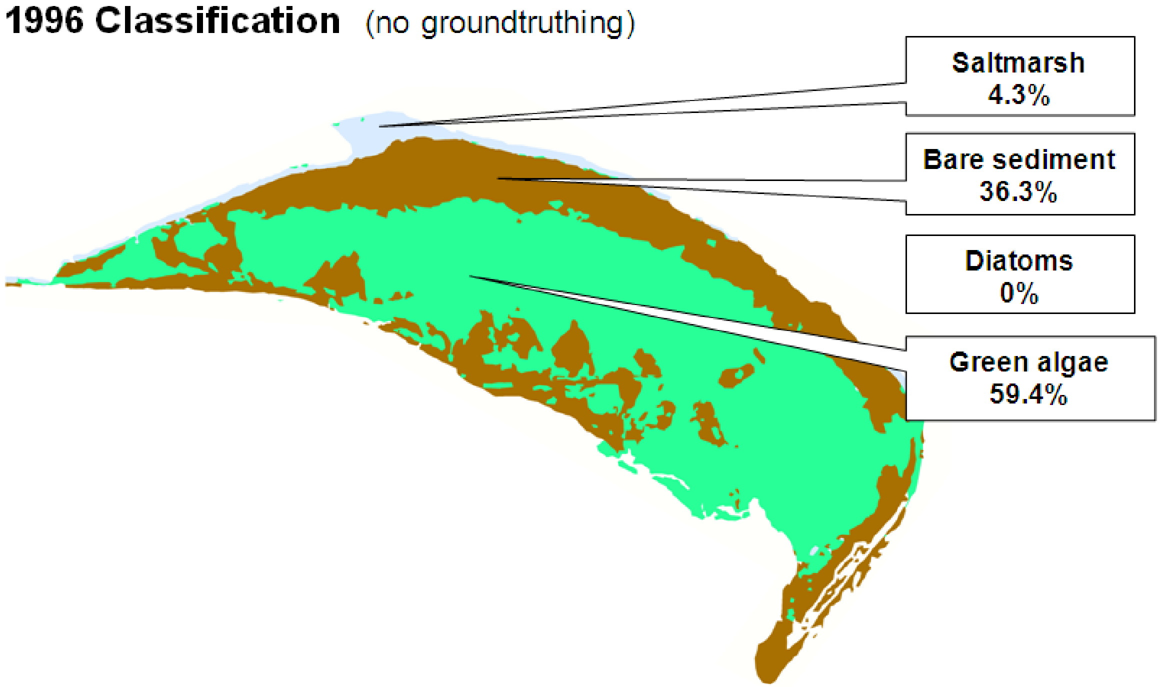
Tackling diffuse pollutants – requires changes to agricultural systems and society

Summary - Humber Infraction Proceedings

• Basis - EC concerns about nutrient levels and possible adverse environmental impact from nutrient loadings from North Sea estuaries.

• In 1996 and 2003/4 two CASI (Compact Airborne Spectrographic Imaging) flight surveys were carried out in the Humber estuary by the EA.

• The data were interpreted remotely (by JRC Ispra and a non-local ‘independent expert’) as being indicative of the widespread presence of a dense green algal growth that can be associated with eutrophication.



Summary - Humber Infraction Proceedings

- As a result, the EC raised a legal infraction case against the UK regarding the Humber and other UK estuaries,

- EC asked detailed questions during the legal process and criticised the Environment Agency's (NE) lack of information to answer them.

- Consequently, the Humber Infraction Project (HIP, 2008) addressed outstanding EC questions about quantitative evaluation of algae and nuisance species

- The onus was on the UK to demonstrate 'no problem' or 'no evidence of eutrophication'.

- IECS was commissioned by the EA to lead expert workshops and undertake groundtruthing in 2008 to quantify habitats, microphytobenthos and macroalgal patterns.

Plate 1. Bare mud. PHS021_27

Plate 2. Diatoms on mud. SK2_59

Plate 3. Mixed. PW8_34

Plate 4. Green algae (5-25%)

Plate 5. Green algae (25-50%). ALK1_1

Plate 6. Green algae (50-75%). PW7_29

Plate 7. Green algae (75-100%). ALK2_9

Plate 8. Brown algae. PW2_6

Plate 9. Saltmarsh. W3_24

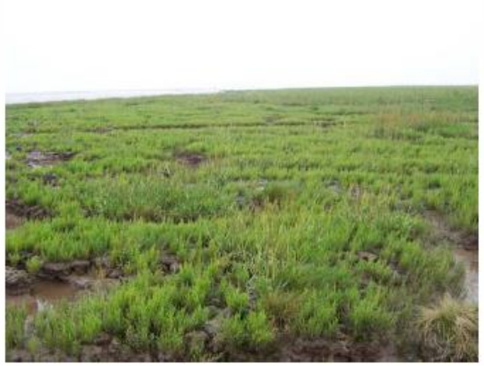


Plate 10. Saltmarsh. W21_115

Summary - Humber Infraction Proceedings

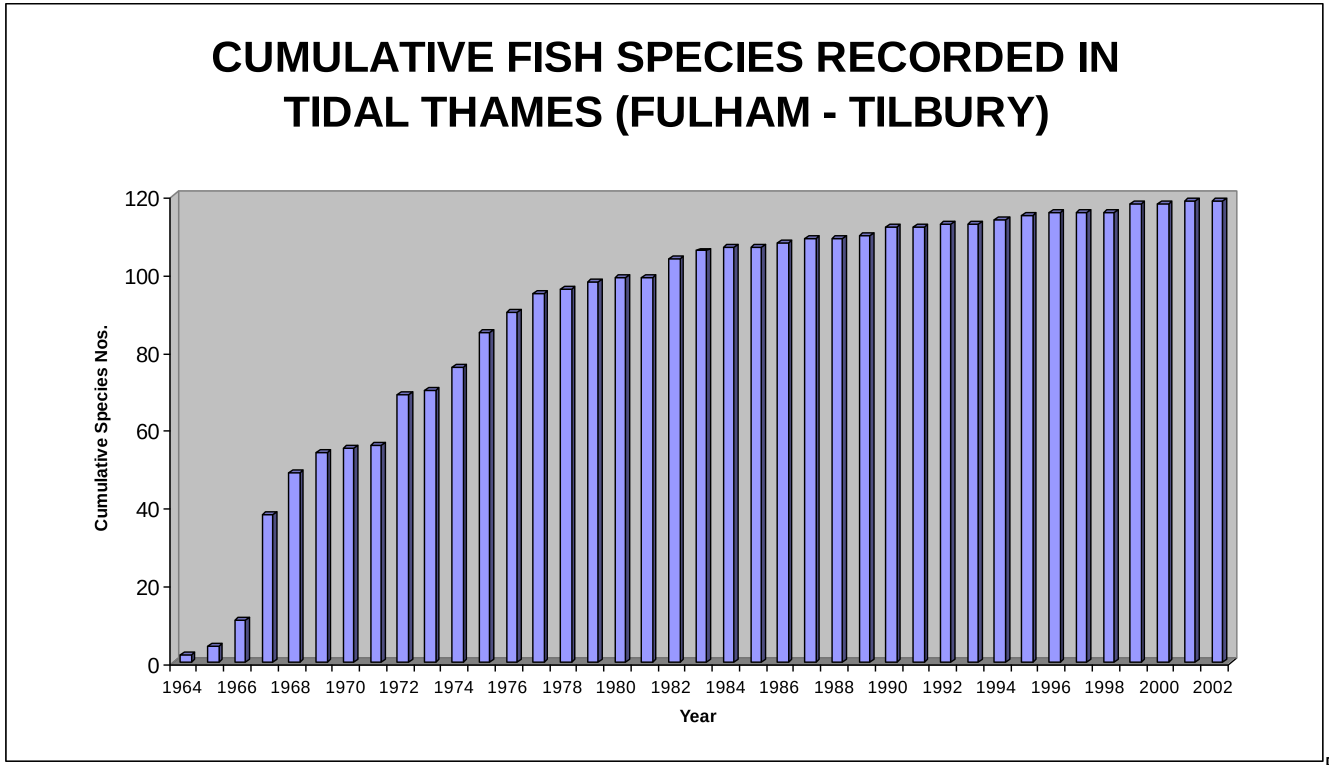
• Historic benthic data showed there were no observed change in the benthic community during this time.

• New information supported previous extensive local observations that MPB were the main primary producers present on the intertidal sediment and green macroalgae cover was only 0.8%.

• The problematic dense green algae assumed to be present during previous CASI surveys do not exist in the Humber estuary and that the dominant feature is benthic diatoms.

Habitat restoration

Restoration (rehabilitation, adaptation, re-creation, remediation and enhancement etc) – anthropogenically changed baselines – e.g. DO levels in previously polluted estuaries)



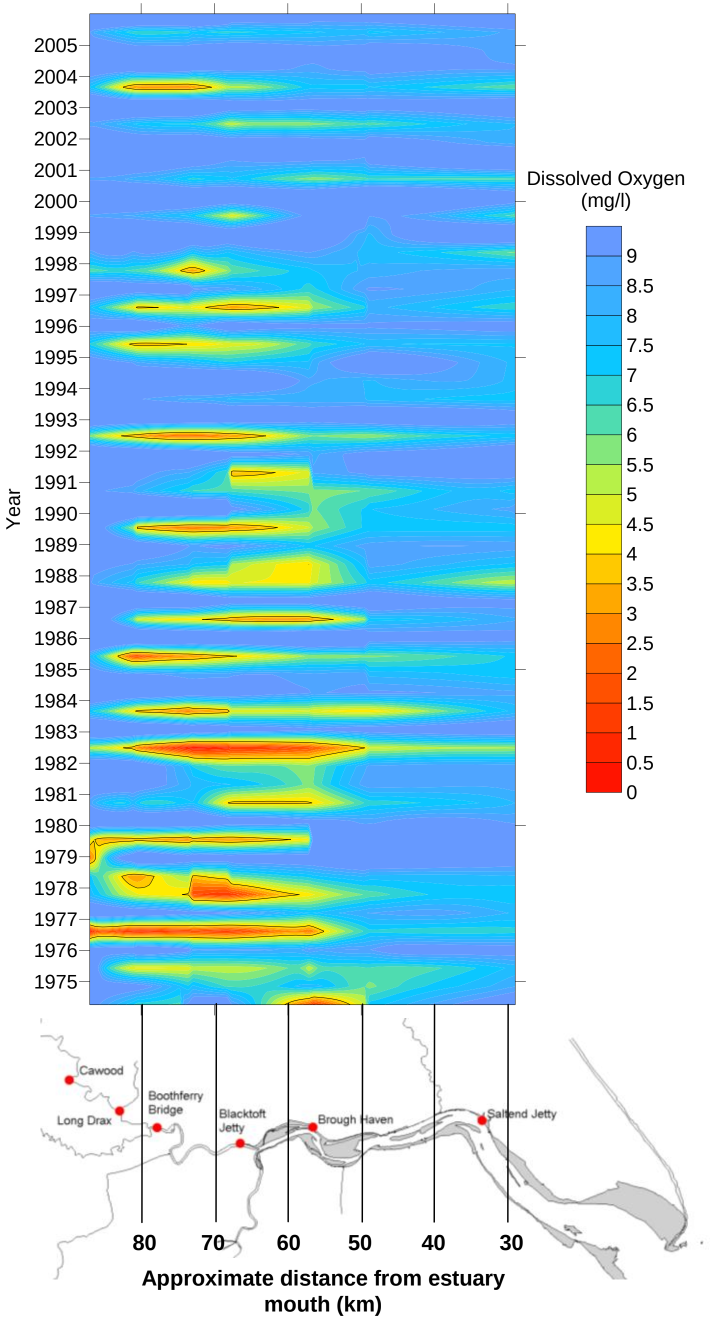


Figure 2: Monthly DO levels (mg/l) along the Humber and River Ouse. 1974 to 2005

The black line represents the 4 mg/l threshold for fish passage

Summary - Humber Infraction Proceedings

• Macroalgal (green and brown) distribution is limited to rocky / stony areas and areas of saltmarsh with areas of dense algae (75-100% cover) being present in very small, isolated patches.

• Long term data sets do not indicate that the benthic communities are impoverished in any way, beyond the natural effects of variable and low salinity, high turbidity, strong currents and fine-grained, organic rich sediments.

• No nuisance algae were found in the water and the estuary health and diversity were independently reported as good.

• ‘Tick-list approach’ used in communication.

Summary - Humber Infraction Proceedings

- The work answered the outstanding EC questions and confirmed that the Humber shows no adverse environmental impact or evidence of eutrophication.

- This supports and strengthened the case already made by Environment Agency against the infraction action and designation.

- The financial repercussions of losing the infraction proceedings would have been €500-850M.

- Lessons learned:

    - Importance of local knowledge and ground-truthing;
    - Importance of good, thorough, independent and proportionate science;
    - Value/necessity of expert-judgement approach;
    - Realisation of economic and ecological consequences.

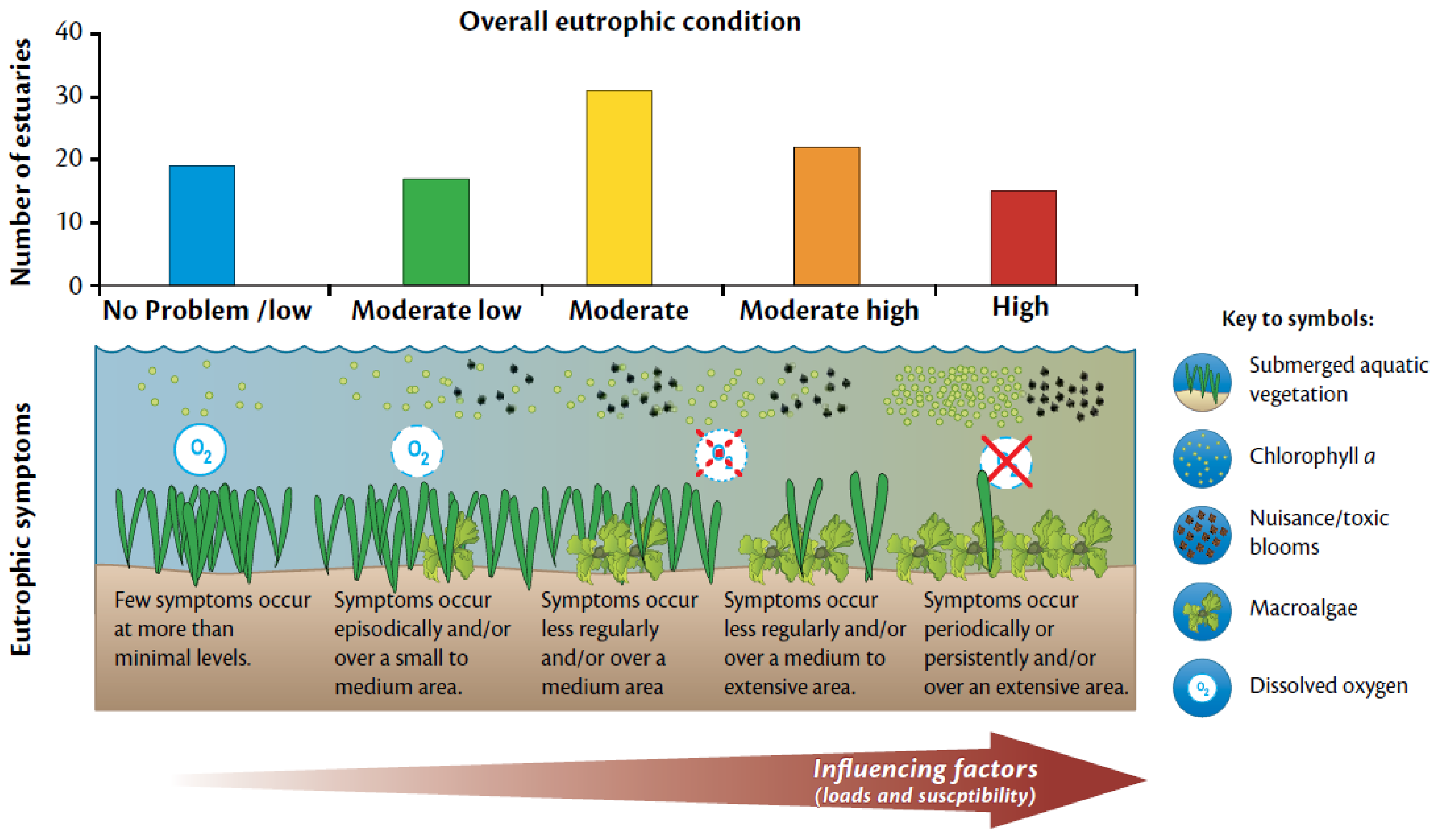
1ry & 2ry Symptoms of Eutrophication

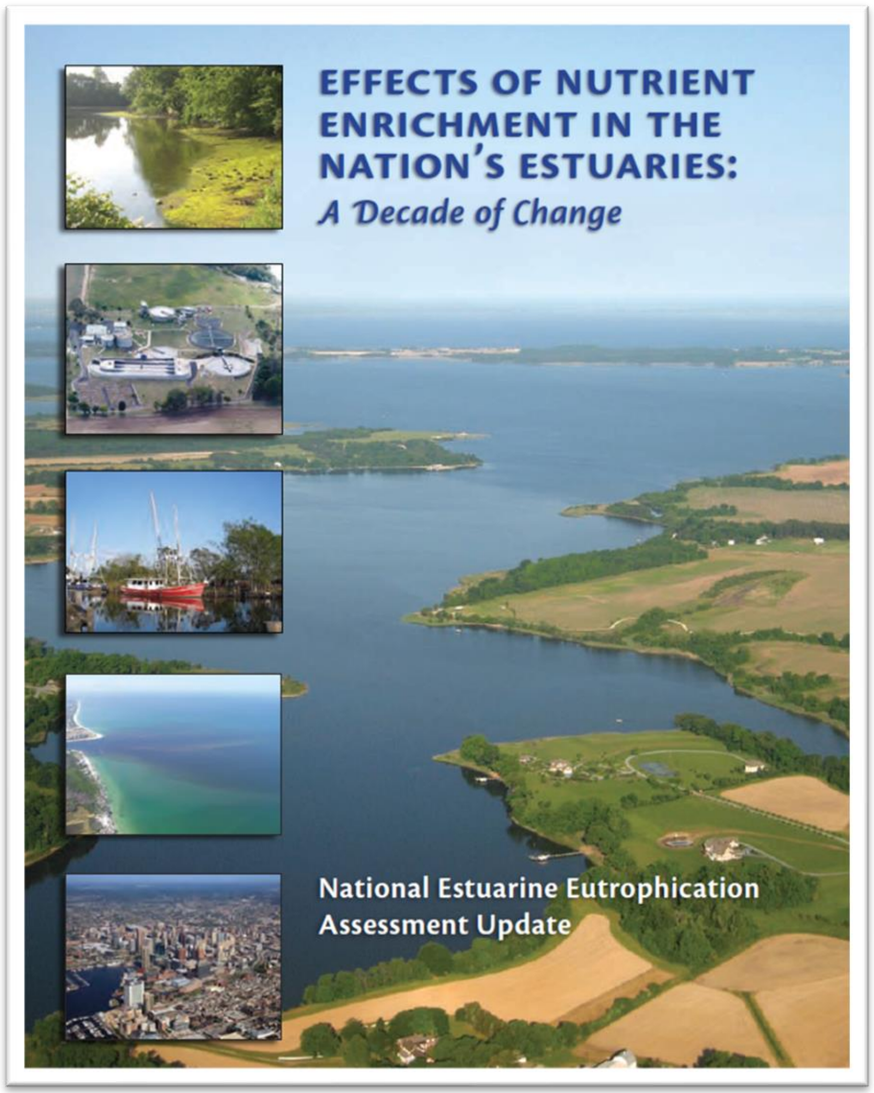
Value of tick-list approach

		Randers Fjord		Scheldt				Bay of Palma	
		Inner Fjord	**Outer Fjord***	**Estuary Plume**	**Lower Estuary**	**Upper Estuary**	**Fluvial Estuary**	**Inshore**	**Offshore**
Causes of Eutrophication	Increased nutrient inputs	✓	✓	✓	✓	✓	✓	✓	✓
	High residence time / slow flushing rate / poor levels of dilution	Short retention time 13 days		High residence time of the water masses; up to 70 days for water in upstream areas				Wind driven, poor turnover ratio	
Primary Effects	Occurrence of blooms of toxic or tainting phytoplankton forms	×	✓	✓	×	✓	×	✓	✓
	Increasing plant/algal biomass production, both at the micro and/or macro level, leading to elevated chlorophyll-*a* concentrations	×	✓	✓	✓	✓	×	✓	**?**
	Occurrence of blooms of micro-algae which may be a nuisance (and cause aesthetic pollution) through foaming (e.g. *Phaeocystis, Chaetoceros socialis*)	**?**	**?**	✓	×	✓	×	×	×
	Decline or disappearance of certain perennial plants, often replaced by annual, fast growing opportunistic species such as foliose or filamentous green algae (e.g. *Ulva, Enteromorpha*)	✓	✓	×	×	×	×	✓	**?**
	Reduced diversity of the flora (and associated fauna)	✓	✓	×	×	×	×	**?**	**?**
	Changes to photic regime through shading	✓	**?**	**-**	✓	✓	✓	✓	**?**

* Including Hevring Bay.
? Unclear from the literature.
\- No information identified within the literature sourced.

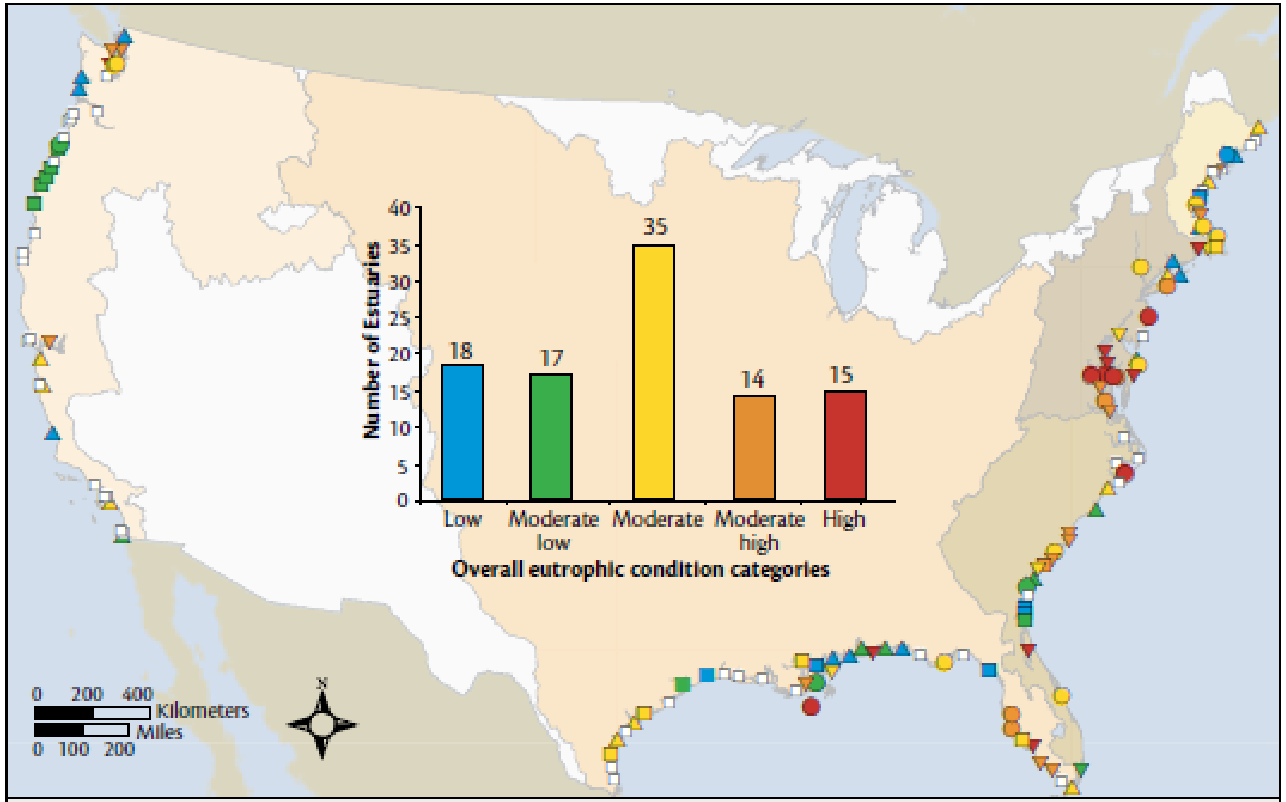
		FJORD							
		Inner Fjord	**Outer Fjord***	**Estuary Plume**	**Lower Estuary**	**Upper Estuary**	**Fluvial Estuary**	**Inshore**	**Off-shore**
Secondary Effects	Increased particulate and dissolved organic matter in seawater and sediments	✓	**?**	✓	✓	×	✓	✓	**-**
	Increased organic matter decomposition	**?**	**?**	**-**	**-**	**-**	**-**	**-**	**-**
	Nuisance macroalgal mat formation to hinder fishing and navigation	**-**	✓	**-**	**-**	**-**	**-**	×	×
	Nuisance macroalgal mat formation producing underside/sedimentary anoxic conditions	**-**	**-**	**-**	**-**	**-**	**-**	×	×
	Increase in microbial community and thus oxygen depletion	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
	.... leading to hypoxic processes such as H_2S and CH_4 production	**?**	**?**	**-**	**-**	**-**	**-**	**-**	**-**
	Development of opportunistic macrobenthic populations and thus changes along the Pearson-Rosenberg continuum	✓	✓	**?**	**?**	✓	✓	×	×
	Poor water quality, especially water column oxygen depletion, thus affecting fishes and zooplankton if a water quality barrier is produced	✓	**?**	×	×	✓	✓	✓	×
	Mortality of higher organisms through effects of neurotoxins	×	×	×	×	×	×	×	×
	Hindrance to intertidal feeding by wading birds and ducks	×	×	×	×	×	×	×	×





Eutrophication – the causes (nitrogen loads and susceptibility), resulting status and consequences (signs and symptoms)

(Bricker et al 2007.)



Overall eutrophic condition (OEC)

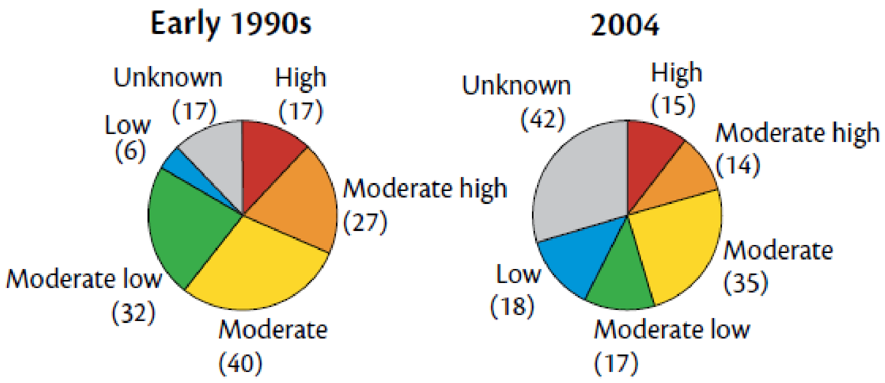
- **High:** symptoms occur periodically or persistently and/or over an extensive area.
- **Moderate high:** symptoms occur less regularly and/or over a medium to extensive area.
- **Moderate:** symptoms occur less regularly and/or over a medium area.
- **Moderate low:** symptoms occur episodically and/or over a small to medium area.
- **Low:** few symptoms occur at more than minimal levels.
- **Unknown:** Insufficient data for analysis.

Change in eutrophic condition since 1999 assessment

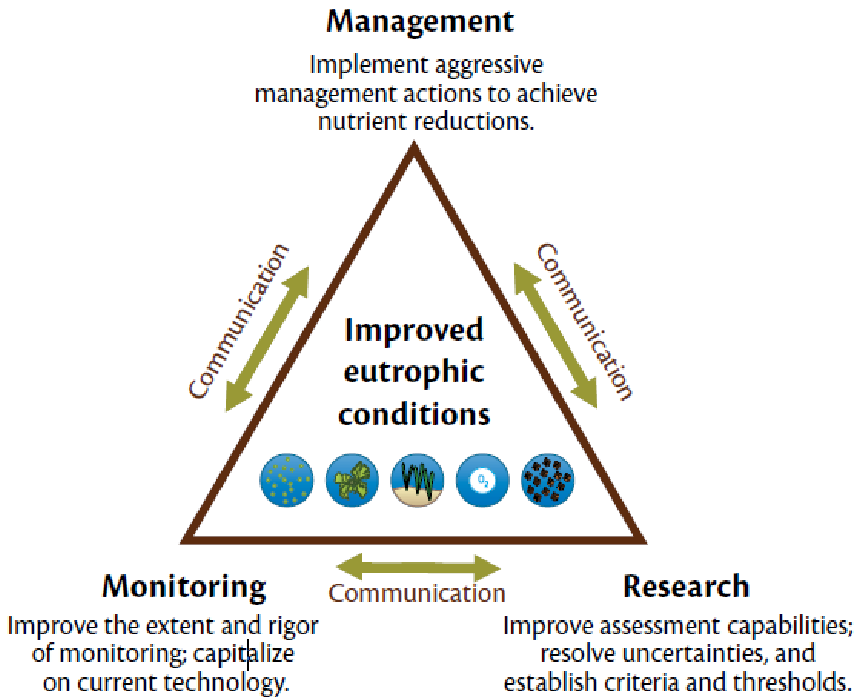
- △ Symptoms **improved** since 1999 assessment.
- ○ **No change** in symptoms since 1999 assessment.
- ▽ Symptoms **worsened** since 1999 assessment.
- □ **Insufficient data** to show trend.

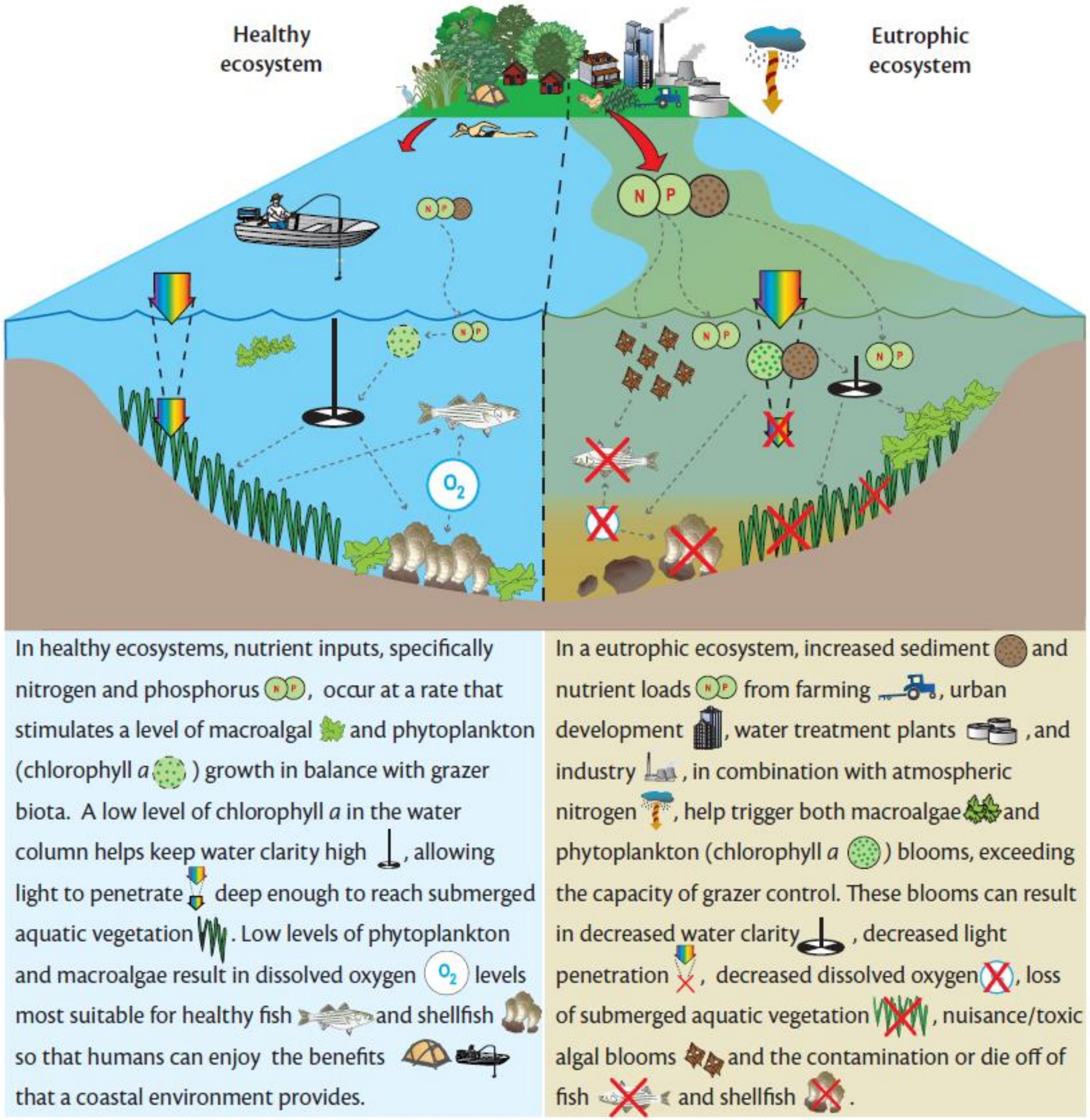
Overall results showing variable national eutrophic status

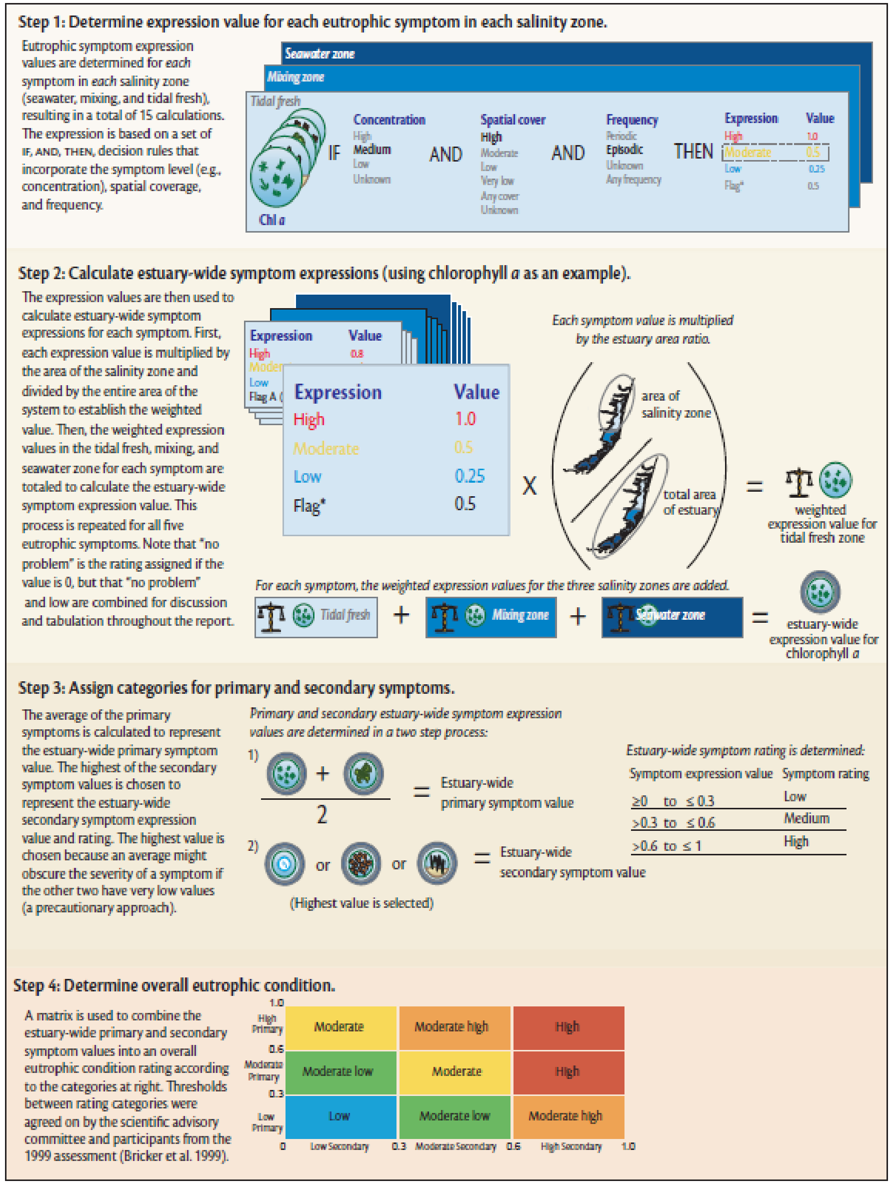
Number of estuaries in each status category in early 1990s cf. 2004



Monitoring & management requires a good understanding and fit-for-purpose science

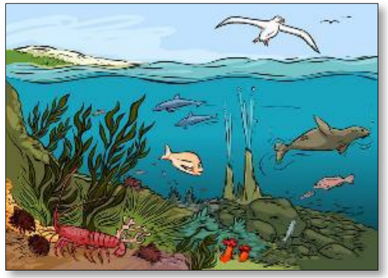






Expert judgement approach to determining overall eutrophic condition – turning 'soft intelligence' in to 'hard data' (Bricker et al, 2007).

Ecosystem services are the link between ecosystems and the goods and benefits that they provide for society

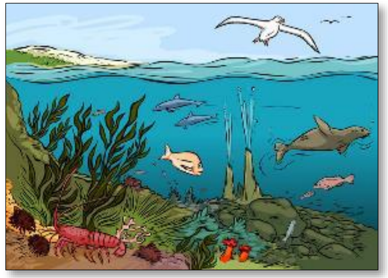


Marine Ecosystem Structure and Functioning (Stocks & Processes)

Ecosystem Services (Flows)

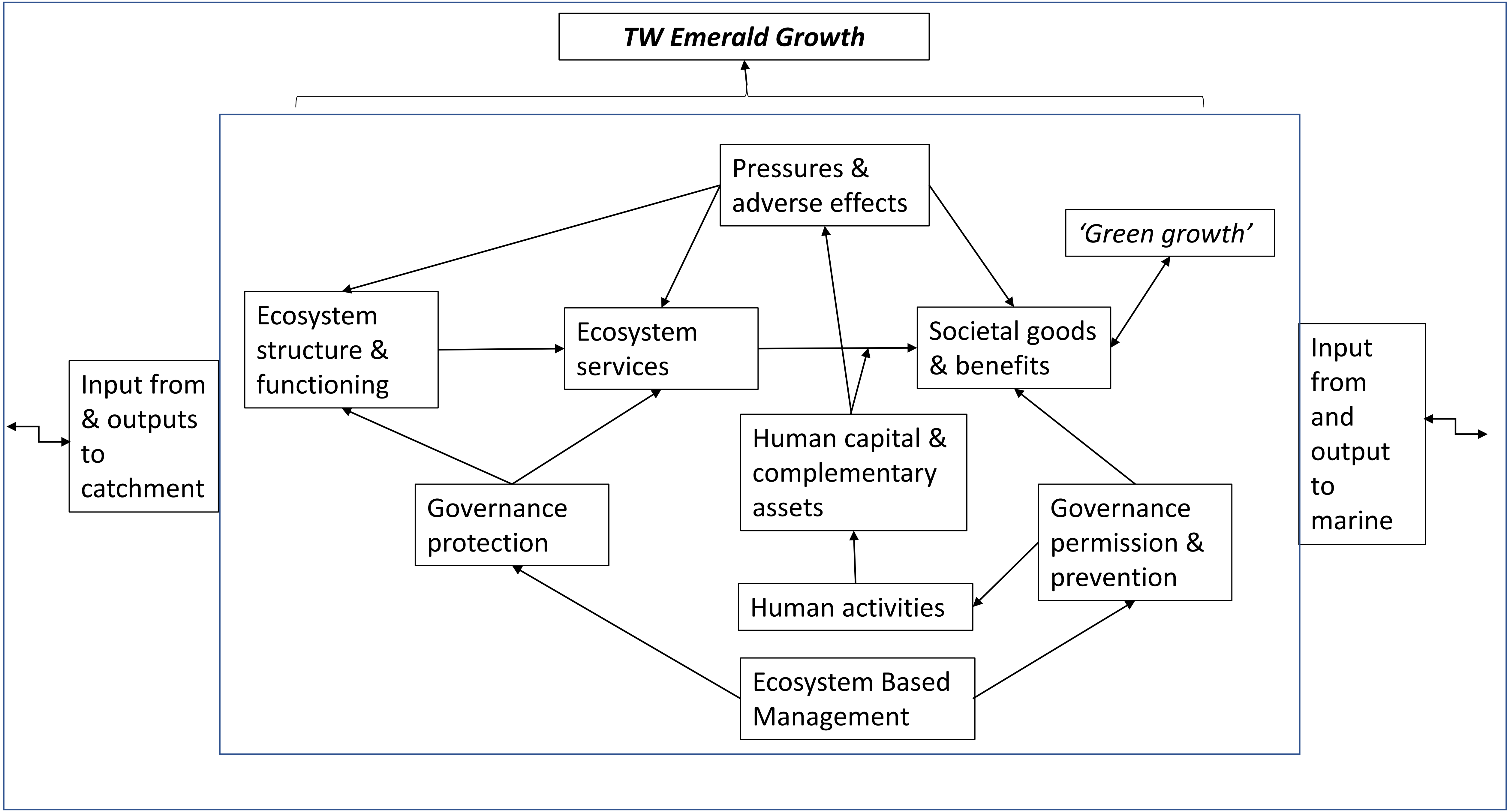
Input of Human Capital*

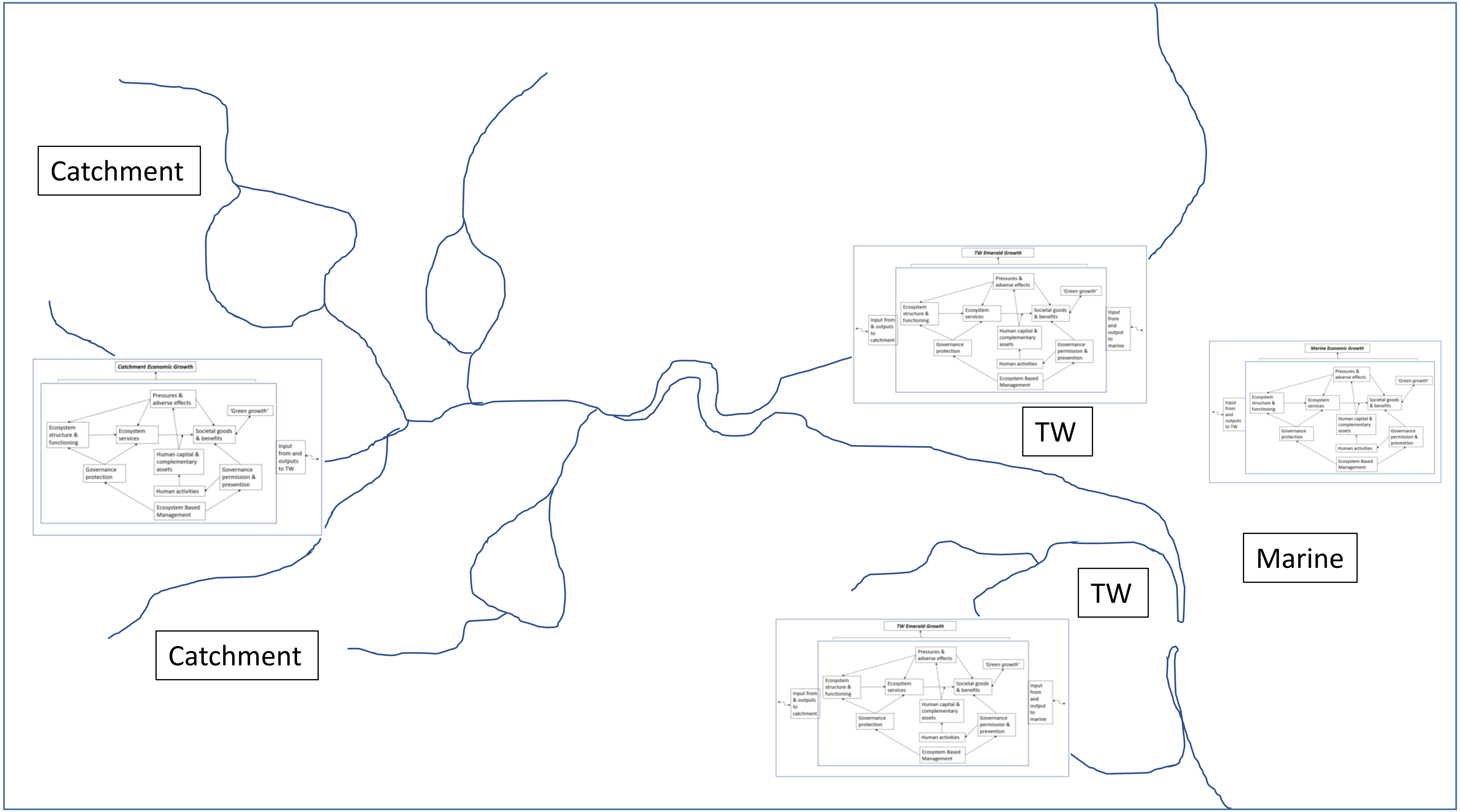
Societal Goods & Benefits (Well-being)



(* Human complementary assets – time, money, skills, energy required to obtain the goods and benefits)

"Grab them by the 'wallet' and their hearts and minds will follow!"


TW Emerald Growth
Pressures & adverse effects
'Green growth'
Ecosystem structure & functioning
Ecosystem services
Societal goods & benefits
Input from & outputs to catchment
Input from and output to marine
Human capital & complementary assets
Governance protection
Governance permission & prevention
Human activities
Ecosystem Based Management


Catchment
Catchment Economic Growth
Pressures & adverse effects
'Green growth'
Ecosystem structure & functioning
Ecosystem services
Societal goods & benefits
Human capital & complementary assets
Governance protection
Governance permission & prevention
Human activities
Ecosystem Based Management
Input from and outputs to TW
Catchment
TW Emerald Growth
Pressures & adverse effects
'Green growth'
Ecosystem structure & functioning
Ecosystem services
Societal goods & benefits
Human capital & complementary assets
Input from & outputs to catchment
Input from and output to marine
Governance protection
Governance permission & prevention
Human activities
Ecosystem Based Management
TW
Marine Economic Growth
Pressures & adverse effects
'Green growth'
Ecosystem structure & functioning
Ecosystem services
Societal goods & benefits
Human capital & complementary assets
Input from and outputs to TW
Governance protection
Governance permission & prevention
Human activities
Ecosystem Based Management
Marine
TW
TW Emerald Growth
Pressures & adverse effects
'Green growth'
Ecosystem structure & functioning
Ecosystem services
Societal goods & benefits
Human capital & complementary assets
Input from & outputs to catchment
Input from and output to marine
Governance protection
Governance permission & prevention
Human activities
Ecosystem Based Management

Total economic value of water quality improvements

Use Values			Non-Use Values
Direct Use Values	**Indirect Use Values**	**Option Values**	**Existence Values**
Recreation	Recreation	Future uses as per direct and indirect use values	Estuary and coastal zone as an object of intrinsic value, as a gift to others, and as a responsibility (stewardship)
Commercial fishing	Landscape		
Agriculture/Industry	Biodiversity value		
Drinking purposes	Aesthetic value		
Biodiversity value	Tourism/Ecotourism		
Landscape	Research/Education		
Research/Education	Human health		
Tourism/Ecotourism			
Human health			

ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Marine Pollution Bulletin 55 (2007) 591–602
MARINE POLLUTION BULLETIN
www.elsevier.com/locate/marpolbul

An application of contingent valuation and decision tree analysis to water quality improvements

Jonathan P. Atkins [a], Daryl Burdon [b,*], James H. Allen [b]

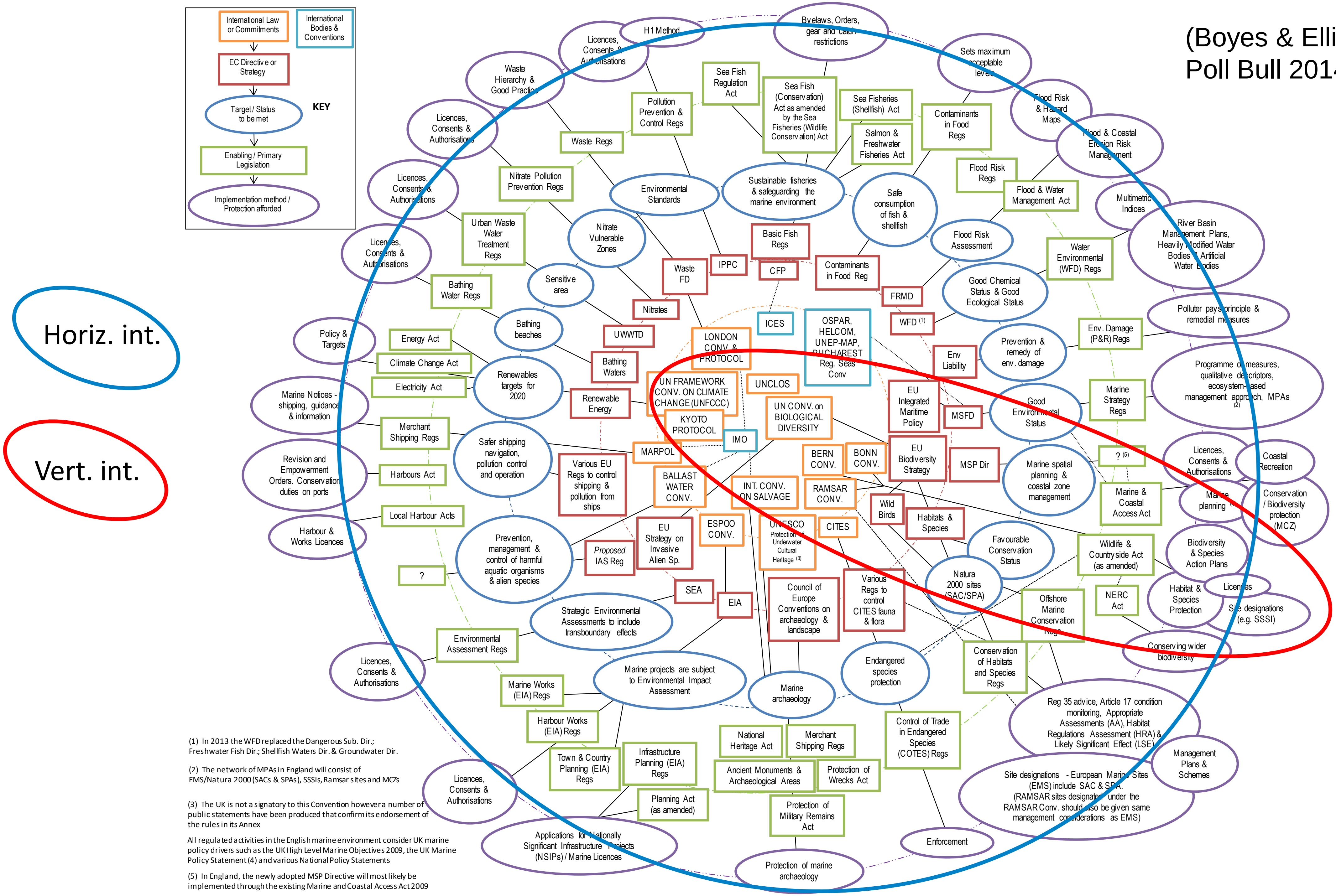
[a] Centre for Economic Policy, The Business School, University of Hull, Hull HU6 7RX, UK
[b] Institute of Estuarine and Coastal Studies (IECS), University of Hull, Hull HU6 7RX, UK

WATER RESEARCH 46 (2012) 205–217
ELSEVIER
Available online at www.sciencedirect.com
SciVerse ScienceDirect
journal homepage: www.elsevier.com/locate/watres
WATER RESEARCH

What are the costs and benefits of biodiversity recovery in a highly polluted estuary?

M. Pascual [a,b,*], A. Borja [a,*], J. Franco [a], D. Burdon [b], J.P. Atkins [c], M. Elliott [b]

(Boyes & Elliott, Mar Poll Bull 2014)



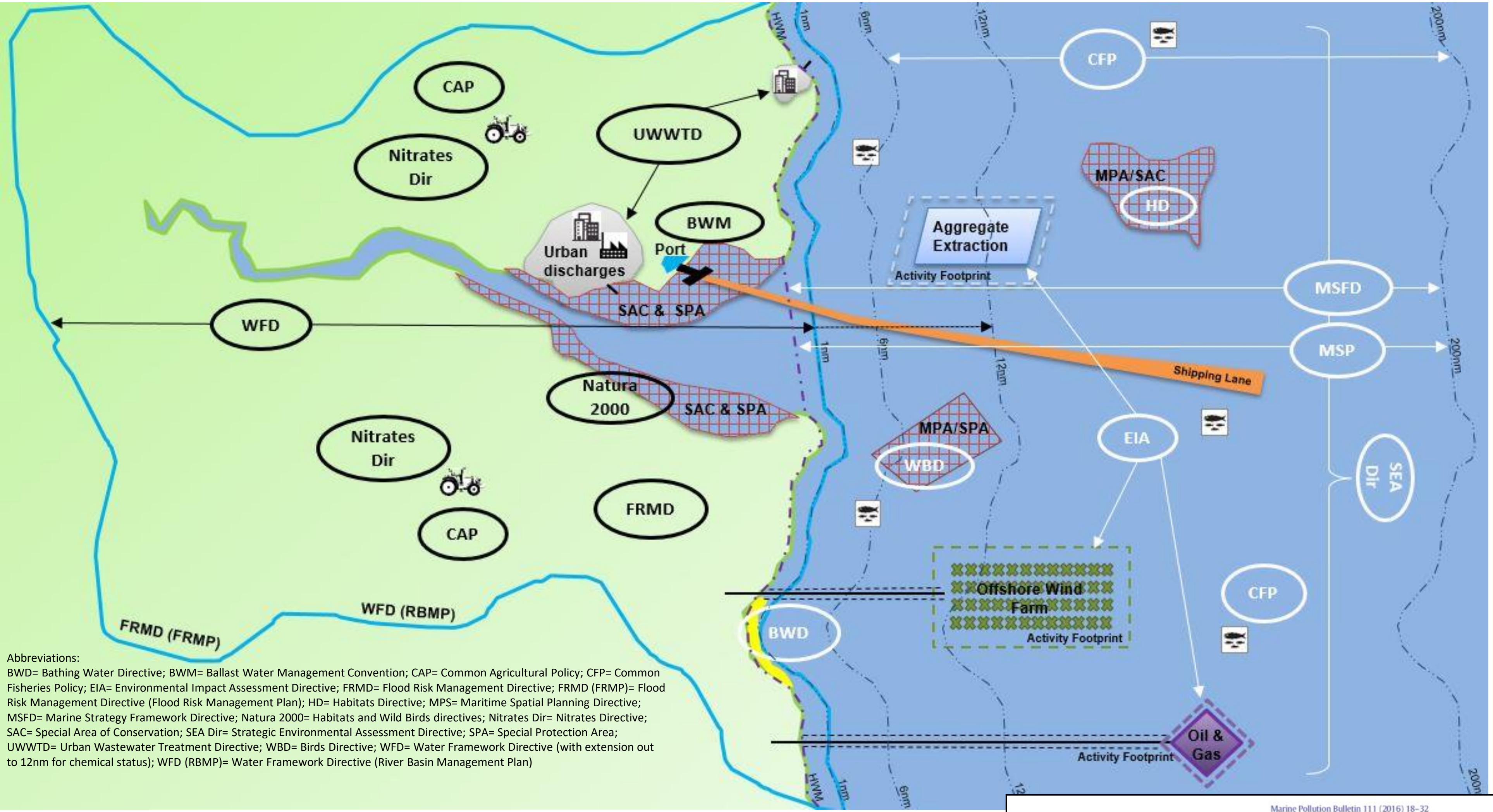
(1) In 2013 the WFD replaced the Dangerous Sub. Dir.; Freshwater Fish Dir.; Shellfish Waters Dir. & Groundwater Dir.

(2) The network of MPAs in England will consist of EMS/Natura 2000 (SACs & SPAs), SSSIs, Ramsar sites and MCZs

(3) The UK is not a signatory to this Convention however a number of public statements have been produced that confirm its endorsement of the rules in its Annex

All regulated activities in the English marine environment consider UK marine policy drivers such as the UK High Level Marine Objectives 2009, the UK Marine Policy Statement (4) and various National Policy Statements

(5) In England, the newly adopted MSP Directive will most likely be implemented through the existing Marine and Coastal Access Act 2009



Geographical scope and competencies of EU legislation


Marine Pollution Bulletin 111 (2016) 18–32

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Review

Is existing legislation fit-for-purpose to achieve Good Environmental Status in European seas?

Suzanne J. Boyes [a,*], Michael Elliott [a], Arantza Murillas-Maza [b], Nadia Papadopoulou [c], Maria C. Uyarra [b]

Pollution control, energy including renewables

Pollution Prevention & Control Regs

Waste Regs

Nitrate Pollution Prevention Regs

Environmental Standards

Urban Waste Water Treatment Regs

Nitrate Vulnerable Zones

Bathing Water Regs

Sensitive area

Waste FD

IPPC

Policy & Targets

Energy Act

Climate Change Act

Electricity Act

Bathing beaches

Nitrates

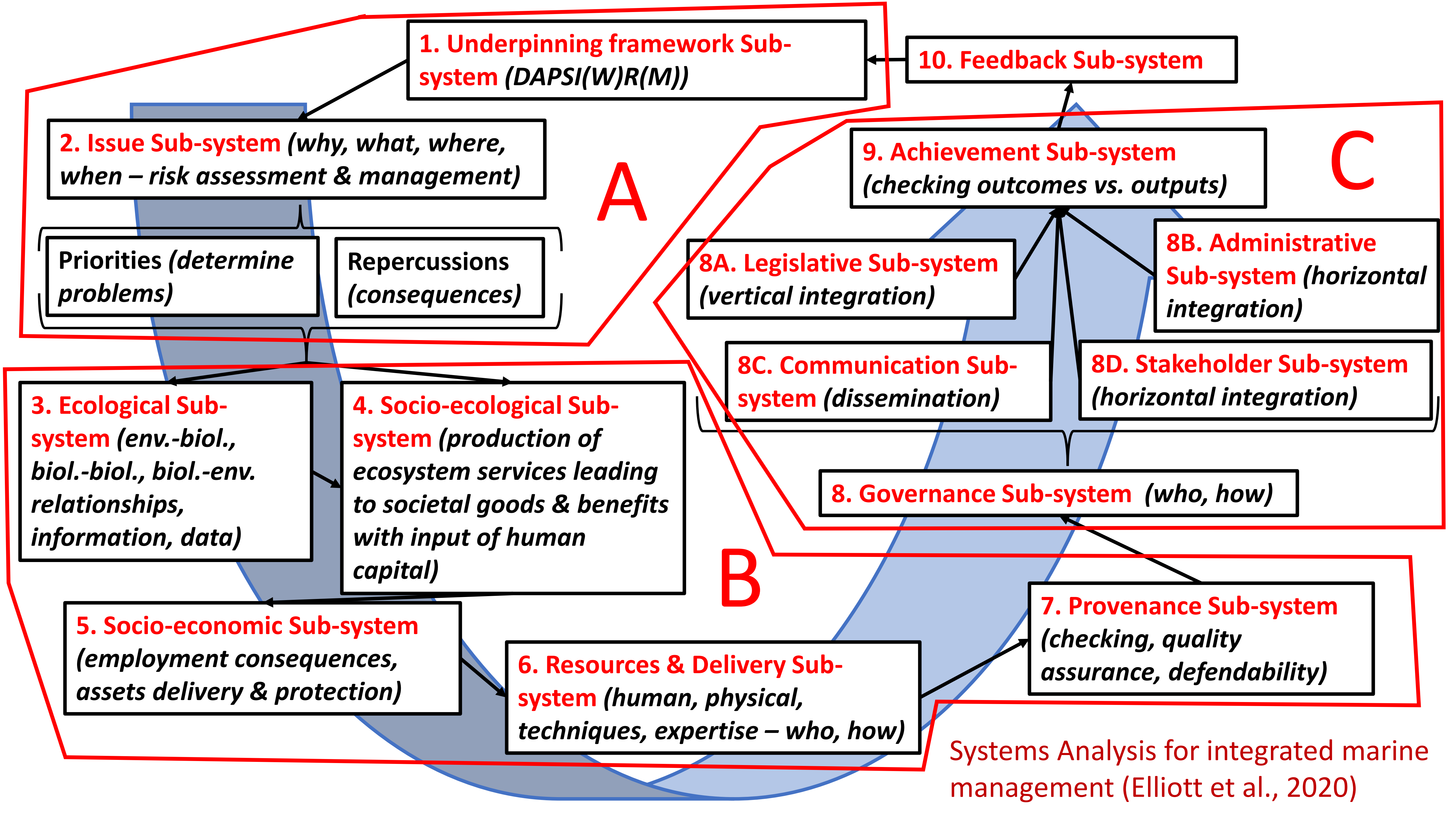
UWWTD

Bathing Waters

Renewables targets for 2020

Renewable Energy

"They do it because the law says they should!"


1. Underpinning framework Sub-system (DAPSI(W)R(M))
10. Feedback Sub-system
2. Issue Sub-system (why, what, where, when – risk assessment & management)
Priorities (determine problems)
Repercussions (consequences)
A
9. Achievement Sub-system (checking outcomes vs. outputs)
C
8A. Legislative Sub-system (vertical integration)
8B. Administrative Sub-system (horizontal integration)
8C. Communication Sub-system (dissemination)
8D. Stakeholder Sub-system (horizontal integration)
3. Ecological Sub-system (env.-biol., biol.-biol., biol.-env. relationships, information, data)
4. Socio-ecological Sub-system (production of ecosystem services leading to societal goods & benefits with input of human capital)
8. Governance Sub-system (who, how)
B
7. Provenance Sub-system (checking, quality assurance, defendability)
5. Socio-economic Sub-system (employment consequences, assets delivery & protection)
6. Resources & Delivery Sub-system (human, physical, techniques, expertise – who, how)
Systems Analysis for integrated marine management (Elliott et al., 2020)

Challenges – measuring and managing change

The need to:

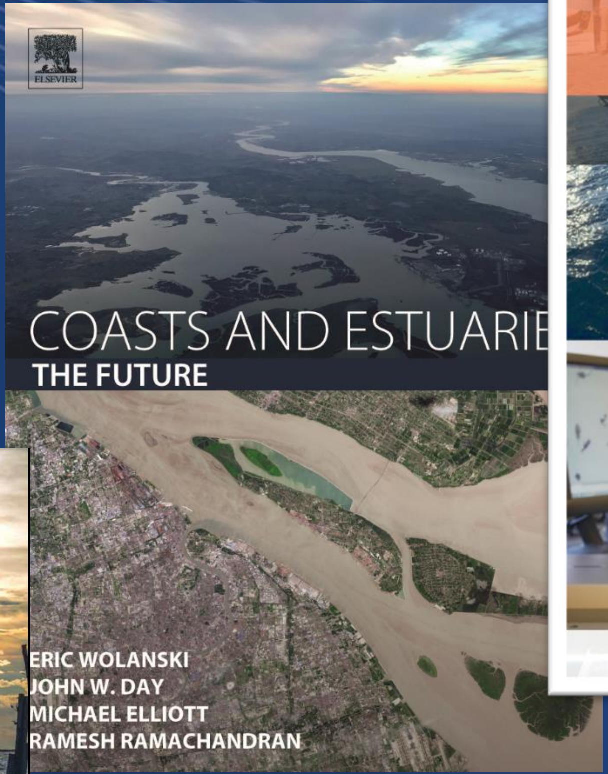
- Determine reference conditions and change against them (e.g. 4 ways in WFD – control, hindcasting, forecasting, best expert judgement)
- Allow for the natural characteristics in determining the activity, pressures, effects and management responses footprints
- Integrate the different legislative instruments such as EU Directives
- Allow for the 'assessment paradox'
- Relate to the economic costs and benefits to catch the politician's ear
- Emphasise that the system functions because of connectivity across all fields

"I suppose I'll be the one to mention the elephant in the room."

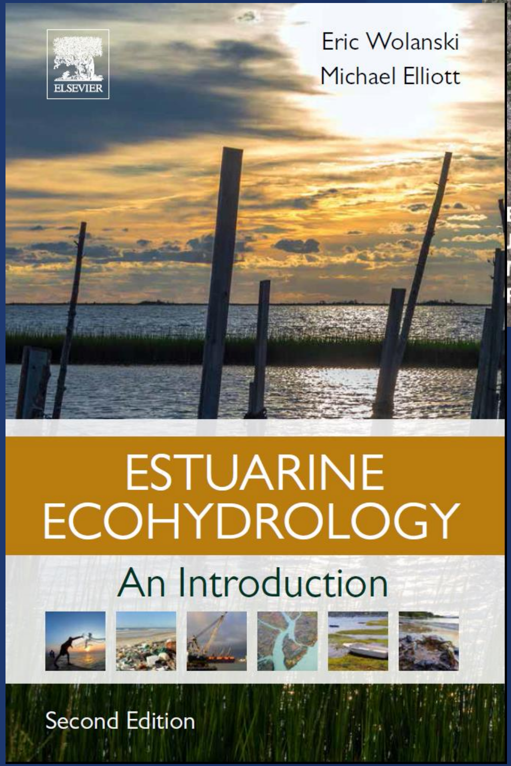
"How come it's always the old, bald-headed guy with glasses in cartoons?"

UNIVERSITY OF HULL

(Open Access book)



Thanks for listening!



https://www.iecs.ltd

International Estuarine and Coastal Specialists

Email addresses:
Mike.Elliott@hull.ac.uk;
Mike.Elliott@iecs.ltd;