Emerald growth and the importance of connectivity in transitional waters between the catchment and marine areas

Michael Elliott[1,2]

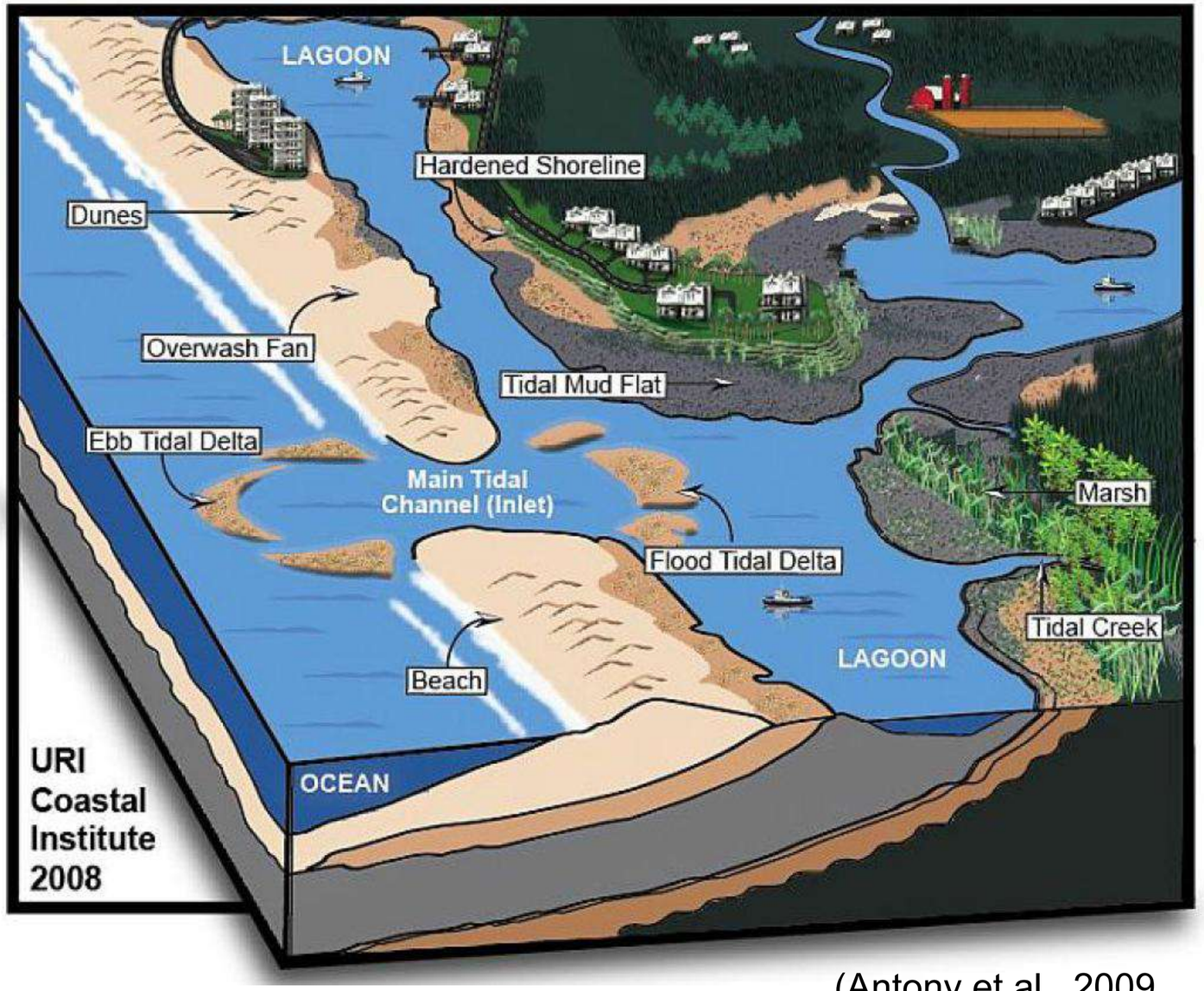
[1] Director, International Estuarine & Coastal Specialists (IECS) Ltd, Leven HU17 5LQ, UK

[2] Emeritus Professor, School of Environmental & Life Sciences, University of Hull, Hull HU6 7RX, UK

With huge thanks to Angel Borja (AZTI), Roland Cormier (DFO, Canada), Alan Whitfield (South Africa), Arturas Razinkovas-Baziukas (Klaipeda), Maciej Nyka (Gdansk), Ramunnnas Povilanslas (Klaipeda), Davide Tagliapietra (Venice†) and colleagues in IECS Ltd and other projects, and thanks to ICES and EU-CONEXUS for support

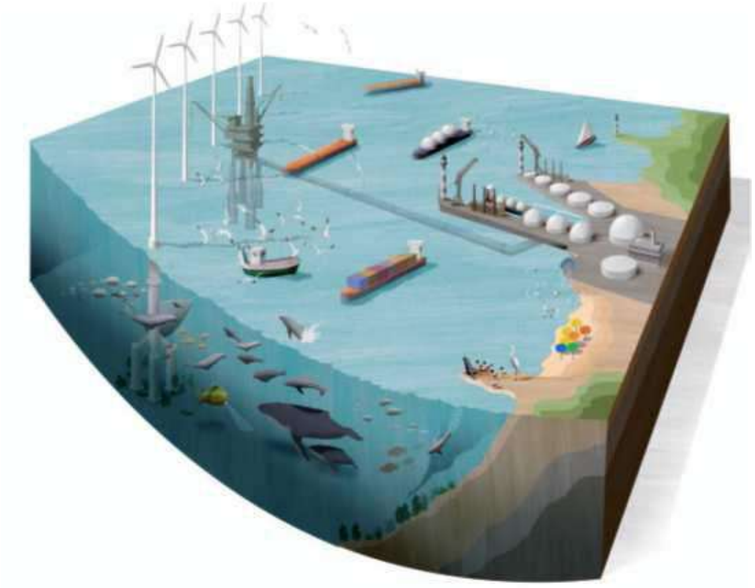
To Cover:

- What's in the concept
- What are transitional waters
- Why the need for whole system thinking
- Why the fundamental concept of connectivity
- What is involved in the management of the system (and coherence and equivalence)
- Illustrations using fishes in estuaries



(Antony et al., 2009, Ecol. & Society)

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

The MSFD, UK and Marine Scotland vision: "*clean, healthy, safe, productive, biologically diverse marine and coastal environments, managed to meet the long-term needs of people and nature*".

In other words:

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

Term	Definition/meaning
Green Economy	Employment and income are driven by public and private investment into such economic activities, infrastructure and assets that allow reduced carbon emissions and pollution, enhanced energy and resource efficiency, and prevention of the loss of biodiversity and ecosystem services
Green Growth	A means of fostering economic growth and development while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies, requiring investment and innovation
Blue Economy	A long-term strategy aimed at supporting sustainable economic growth through ocean-related sectors and activities, while improving human well-being and social equity and preserving the environment.
Blue Growth	Supporting smart, sustainable and inclusive growth in all the marine and maritime sectors as a whole.

Definitions and explanation of Blue and Green Economy and Growth (various sources)

Term	Definition/meaning
Emerald Growth	An overarching concept to address sustainable development and management issues of transitional waters within a broader river basin, coastal and marine interplay framework; the ability provided by environmental management of transitional waters to deliver the benefits from both socio-economy and the natural structure and functioning dependent on the connectivity between the transitional water and its adjoining catchment and marine/coastal areas.
Emerald Economy	This is the sum total and outcome of the ability to manage the production and consumption processes by natural and socio-economic systems in transitional waters which rely both on those features (natural and societal assets) inside the transitional water body but also those in the catchment and marine/coastal areas on which the transitional waters depends.

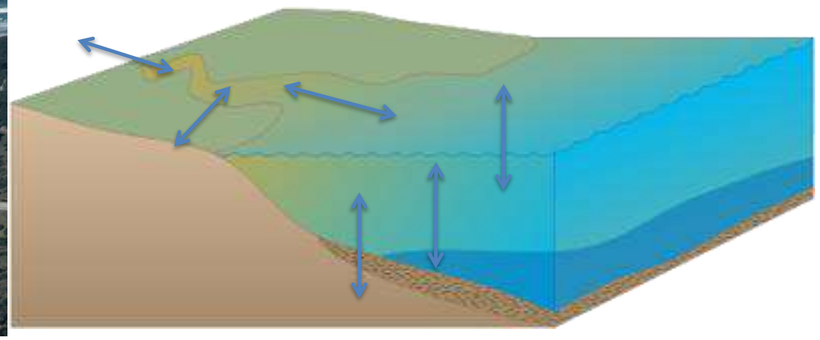
Proposed Definitions and explanation of Emerald Economy and Growth

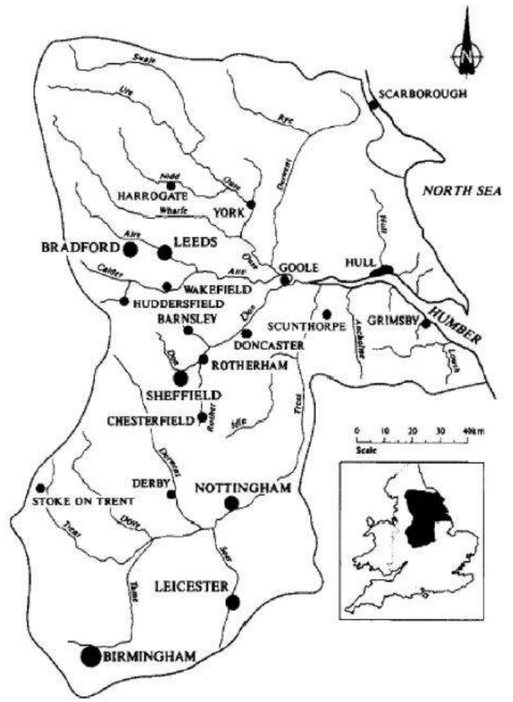
(Razinkovas-Baziukas, Elliott, Nyka, Povilanslas, Tagliapietra, in prep.)

Estuaries and other Transitional Waters – Understand the Environment - Definitions, Scales, Ecotones and Linkages

- Paradigm 1: *An estuary is an ecosystem in its own right but cannot function indefinitely on its own in isolation and that it depends largely on other ecosystems, possibly more so than do other ecosystems.*
- Paradigm 2: *As ecosystems, estuaries are more influenced by scale than any other aquatic system; their essence is in the connectivity across the various scales and within the water body they are characterised by one or more ecotones ( ).*







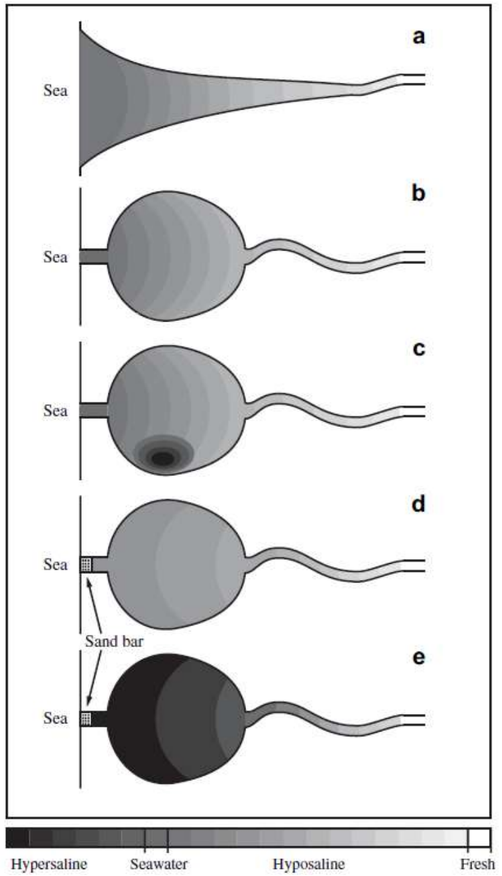

Estuarine, Coastal and Shelf Science 94 (2011) 306–314
Contents lists available at ScienceDirect
Estuarine, Coastal and Shelf Science
journal homepage: www.elsevier.com/locate/ecss
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Challenging paradigms in estuarine ecology and management

M. Elliott [a,*], A.K. Whitfield [b]

Hydromorphological and Organic Functioning

- Paradigm 3: *Hydromorphology is the key to understanding estuarine functioning but these systems are always influenced by salinity (and the resulting density/buoyancy currents) as a primary environmental driver.*
- Paradigm 4: *Although estuaries behave as sources and sinks for nutrients and organic matter, in most systems allochthonous organic inputs dominate over autochthonous organic production.*



Nutrient loadings to the Humber Estuary (full calculations given in Elliott and Boyes, 2002)

Total inputs to the Humber Estuary	Total N—2001		Total P—2001	
	t yr^{-1}	%	t yr^{-1}	%
Industry	510	0.46	3	0.03
Sewage—STWs	36,562	33.31	6925	65.05
Sewage—CSOs	2871	2.62	767	7.21
Natural vegetation	96	0.09	24	0.23
Diffuse sources (runoff from agricultural land around the estuary) (based on 1988 data)	69,740	63.53	2926	27.49
	109,779	100	10,646	100

STW—sewage treatment works; CSO—combined sewer overflows.

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Marine Pollution Bulletin 53 (2006) 136–143
MARINE POLLUTION BULLETIN
www.elsevier.com/locate/marpolbul

Organic matter and nutrient inputs to the Humber Estuary, England

Suzanne Boyes *, Michael Elliott

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Estuarine, Coastal and Shelf Science
journal homepage: www.elsevier.com/locate/ecss

Short communication

The concept of an estuary: A definition that incorporates systems which can become closed to the ocean and hypersaline

Ian C. Potter [a,*], Benjamin M. Chuwen [a], Steeg D. Hoeksema [a], Michael Elliott [b]

Variability, Resilience and Redundancy

- Paradigm 5: *Estuaries are physico-chemically more variable than other aquatic systems but estuarine communities are less diverse taxonomically and the individuals are more physiologically adapted to environmental variability than equivalent organisms in other aquatic systems.*

Diversity, Tolerances, Stress, Productivity

- Paradigm 6: *Estuaries are systems with low diversity/high biomass/high abundance and their ecological components show a diversity minimum in the oligohaline region which can be explained by the stress-subsidy concept where tolerant organisms thrive but non-tolerant organisms are absent* (*cf*. Estuarine Quality Paradox)

Pressures, Valuing, Valuation and Management

- Paradigm 7: *Estuaries have more human-induced pressures than other systems and these include both exogenic unmanaged pressures and endogenic managed pressures. Consequently their management has to not only accommodate the causes and consequences of pressures within the system but, more than other ecosystems, they need to respond to the consequences of external natural and anthropogenic influences.*

Challenges for Estuarine and Coastal Management:

- What are we trying to protect and develop and why?
- Where are the problems and what can we do about them?
- What changes and impacts do they cause 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?
- 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?

The Ecosystem Approach

- First developed by the UN Convention for Biological Diversity as a set of 12 principles.
- Defined as '*a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way*'.
- As such, its application will help to reach a balance of these three objectives of the Convention.
- It is based on applying appropriate scientific methodologies focused on levels of biological organization which encompass the essential processes, functions and interactions among organisms and their environment.
- Furthermore, it recognizes that humans, with their cultural diversity, are an integral component of ecosystems.

Ecosystem-Based Management

“Ecosystem-based approach (to management), an 'ecosystem-based approach' or 'ecosystem-based management’:

is an integrated approach to management of human activities that considers the entire ecosystem including humans. The goal is to maintain ecosystems in a healthy, clean, productive and resilient condition, so that they can provide humans with the services and goods upon which we depend. It is a spatial approach that builds around a) acknowledging connections, b) cumulative impacts and c) multiple objectives”

(GES4SEAS Glossary; Papadopoulou et al., 2025, Front. Mar. Sci.*)*

EBA to EBM to EBTM Continuum (Elliott et al., 2025, OCMA)

No	EBM Principles
1	Consider Ecosystem Connections
2	Appropriate Spatial and Temporal Scales
3	Adaptive Management
4	Use of Scientific Knowledge
5	Integrated Management
6	Stakeholder Involvement
7	Account for Dynamic Nature of Ecosystem
8	Ecological Integrity and Biodiversity
9	Sustainability
10	Recognise Coupled Social-Ecological Systems
11	Decisions reflect Societal Choice
12	Distinct Boundaries
13	Inter-disciplinarity
14	Appropriate Monitoring
15	Acknowledge Uncertainty
16	Acknowledge Ecosystem Resilience
17	Consider Economic Context
18	Apply the Precautionary Approach
19	Consider Cumulative Impacts
20	Organisational Change
21	Explicitly Acknowledge Trade Offs
22	Consider Effects on Adjacent Ecosystems
23	Commit to Principles of Equity
24	Develop Long Term Objectives
25	Use of All Forms of Knowledge
26	Use of Incentives

(Franco et al., in press, Front. Mar. Sci.)

Produced by:
Gemma Smith

‘Societal Economic Sectors’



URBAN & INDUSTRIAL USES



LIVING RESOURCE EXTRACTION



ENERGY PRODUCTION



TRANSPORT



PHYSICAL RESTRUCTURING



LIVING RESOURCE CULTIVATION



TOURISM & LEISURE



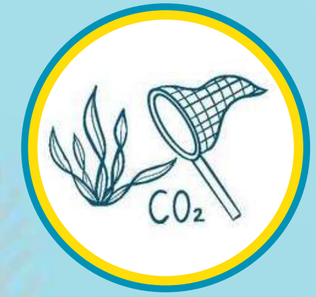
NON-LIVING RESOURCE EXTRACTION



SECURITY & DEFENCE



EDUCATION AND RESEARCH



CARBON CAPUTRE



CONSERVATION & RESTORATION



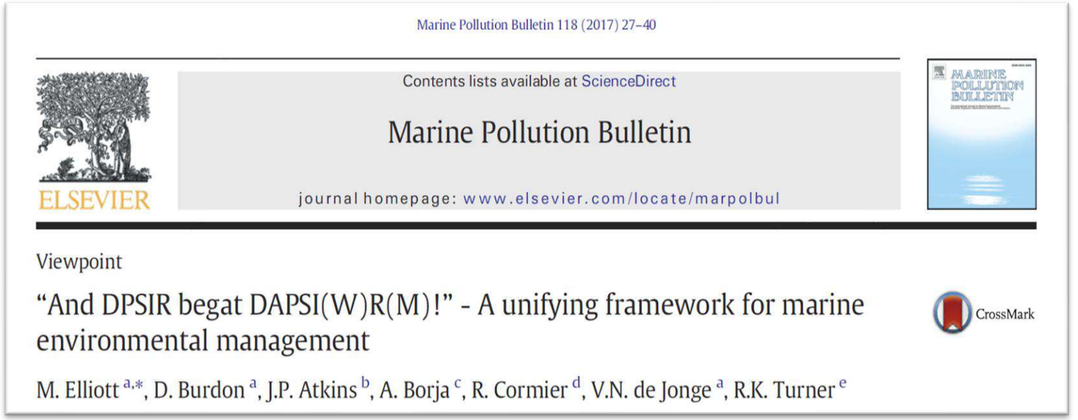
BLUE ECONOMY

ACTIVITY SECTOR

MSFD THEME

ADDITIONAL SECTOR

Cause-Consequence-Response (DAPSI(W)R(M)) management framework


Marine Pollution Bulletin 118 (2017) 27–40

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Marine Pollution Bulletin

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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]

Drivers (societal basic needs)

Activities (of society)

Responses (economic, legal, etc) (**M**easures)

Pressures (resulting from activities)

State change (on the natural system)

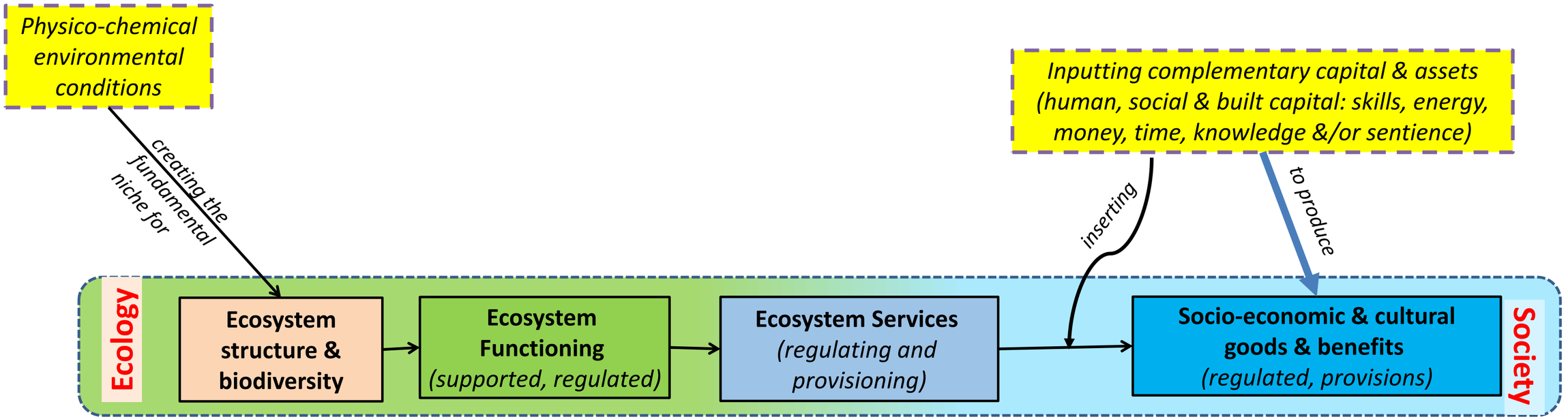
Impacts (on human **W**elfare) (changes affecting wealth creation, quality of life)

(for each EnMP cf. Ex

Pronounced "dapsiworm"!

(Elliott 2023 Mar Poll Bull)

Elliott, M. (2023). https://doi.org/10.1016/j.marpolbul.2023.115177



Marine Pollution Bulletin 193 (2023) 115177

Contents lists available at ScienceDirect

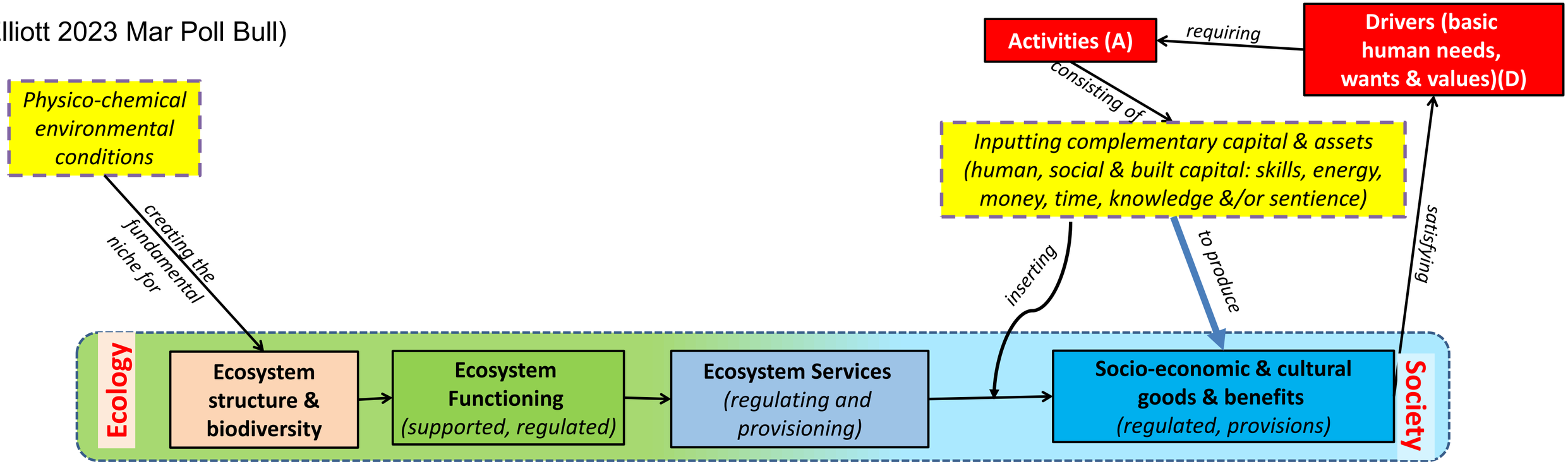
Marine Pollution Bulletin

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

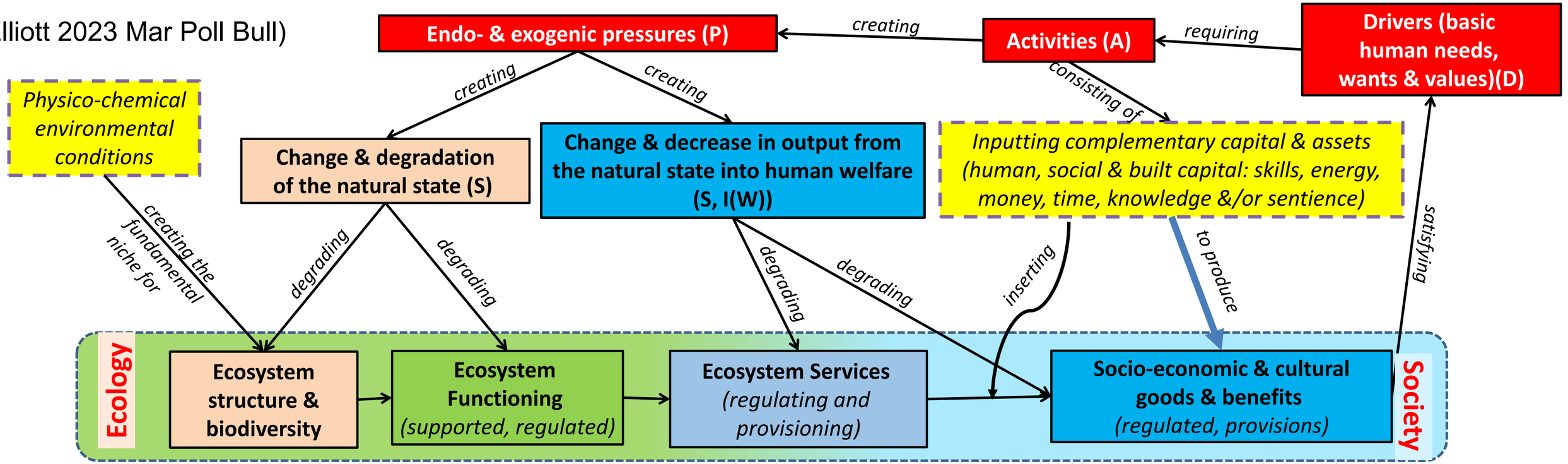
Editorial

Marine Ecosystem Services and Integrated Management: "*There's a crack, a crack in everything, that's how the light gets in*"!

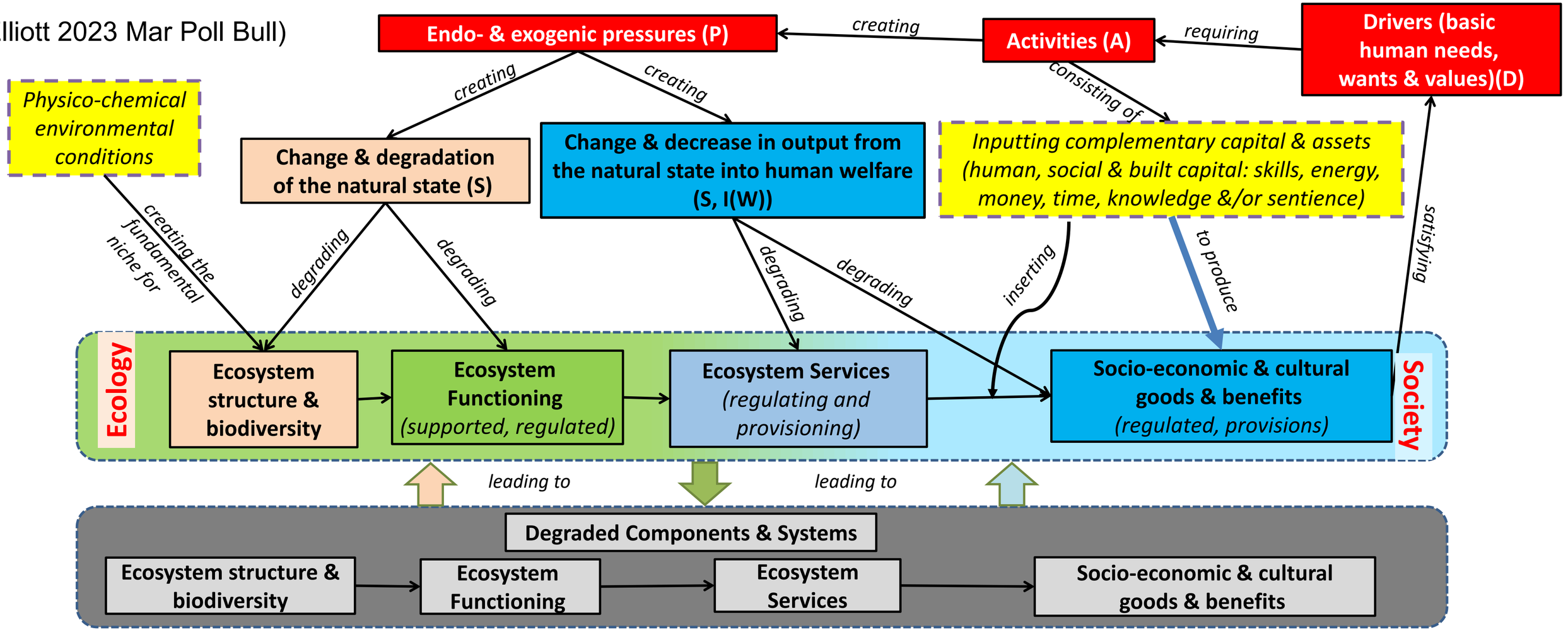
(Elliott 2023 Mar Poll Bull)



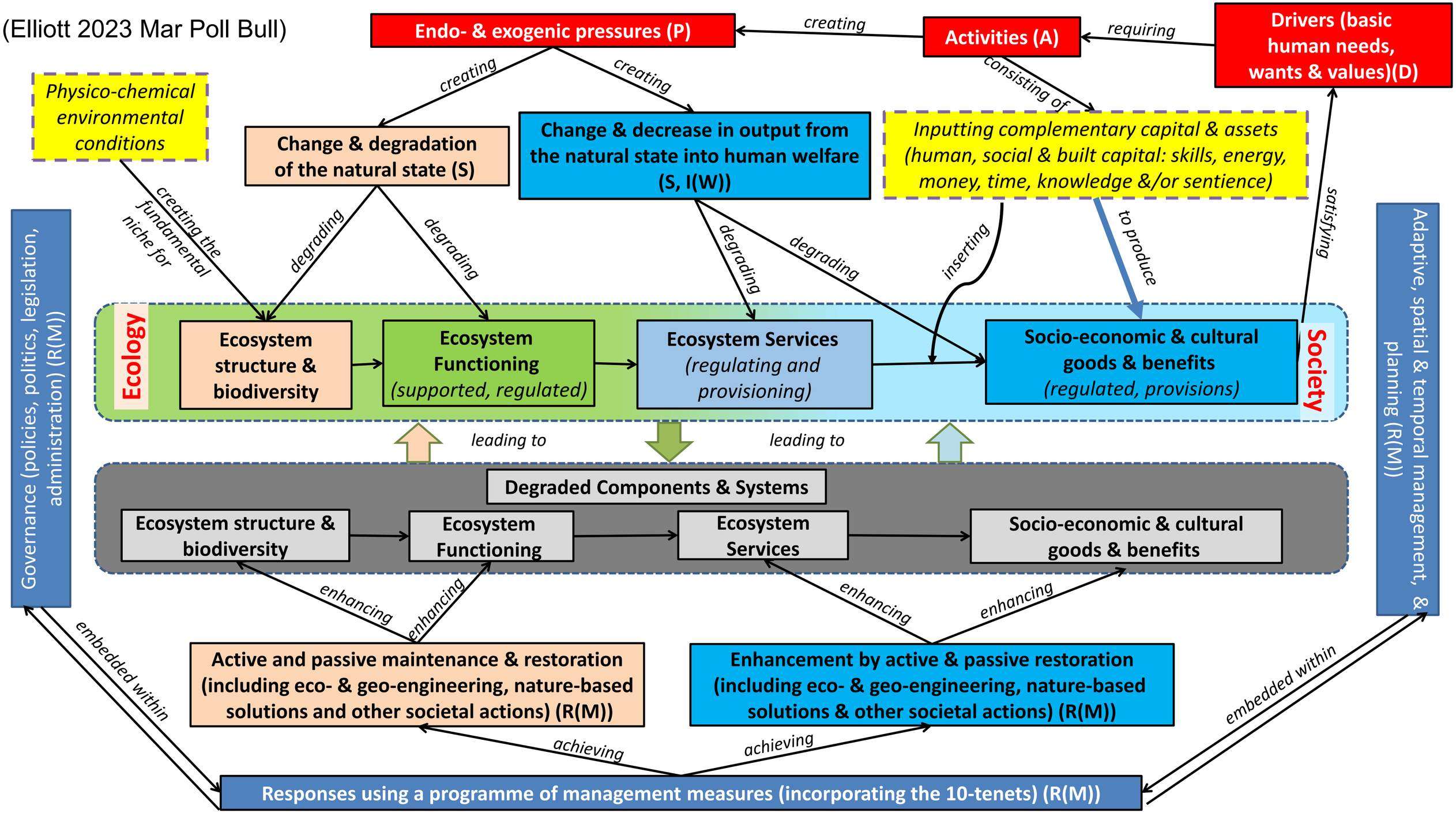
(Elliott 2023 Mar Poll Bull)



(Elliott 2023 Mar Poll Bull)

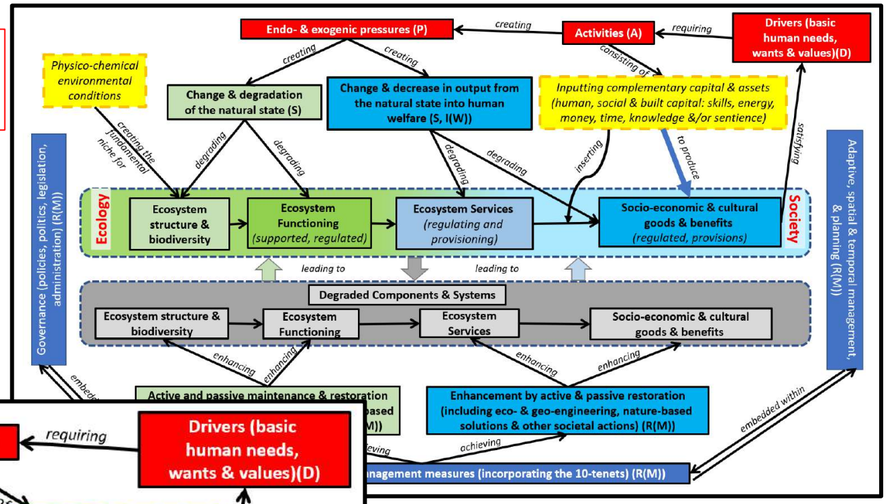


(Elliott 2023 Mar Poll Bull)



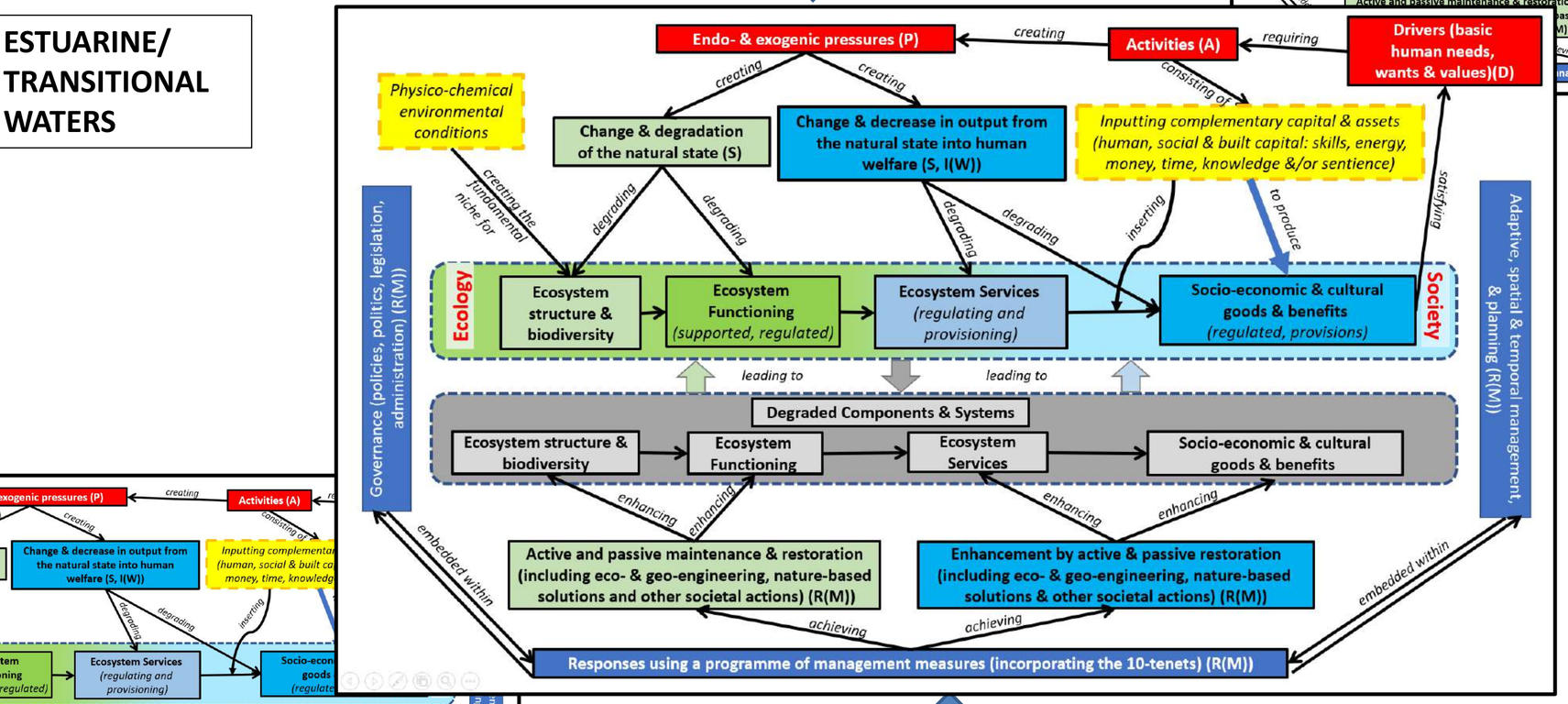
The coast to estuary to catchment social-ecological continuum

Connectivity to and from the coast

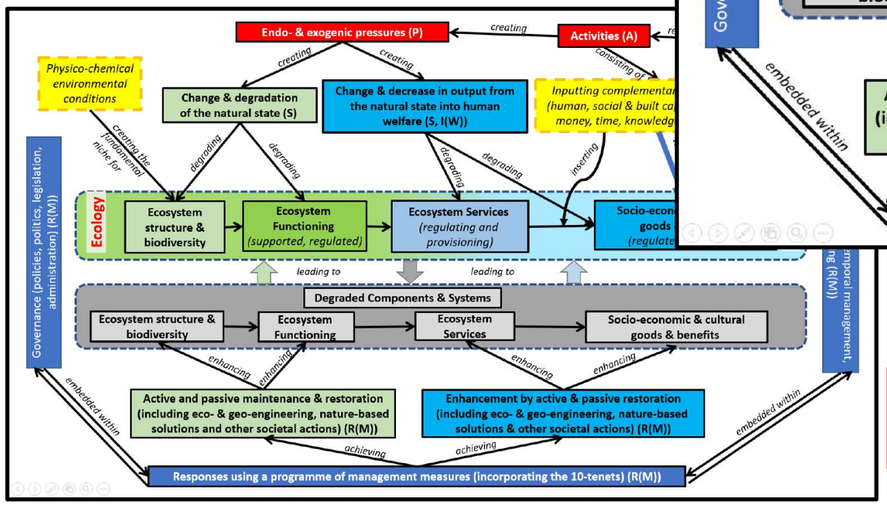


COAST & MARINE

ESTUARINE/ TRANSITIONAL WATERS

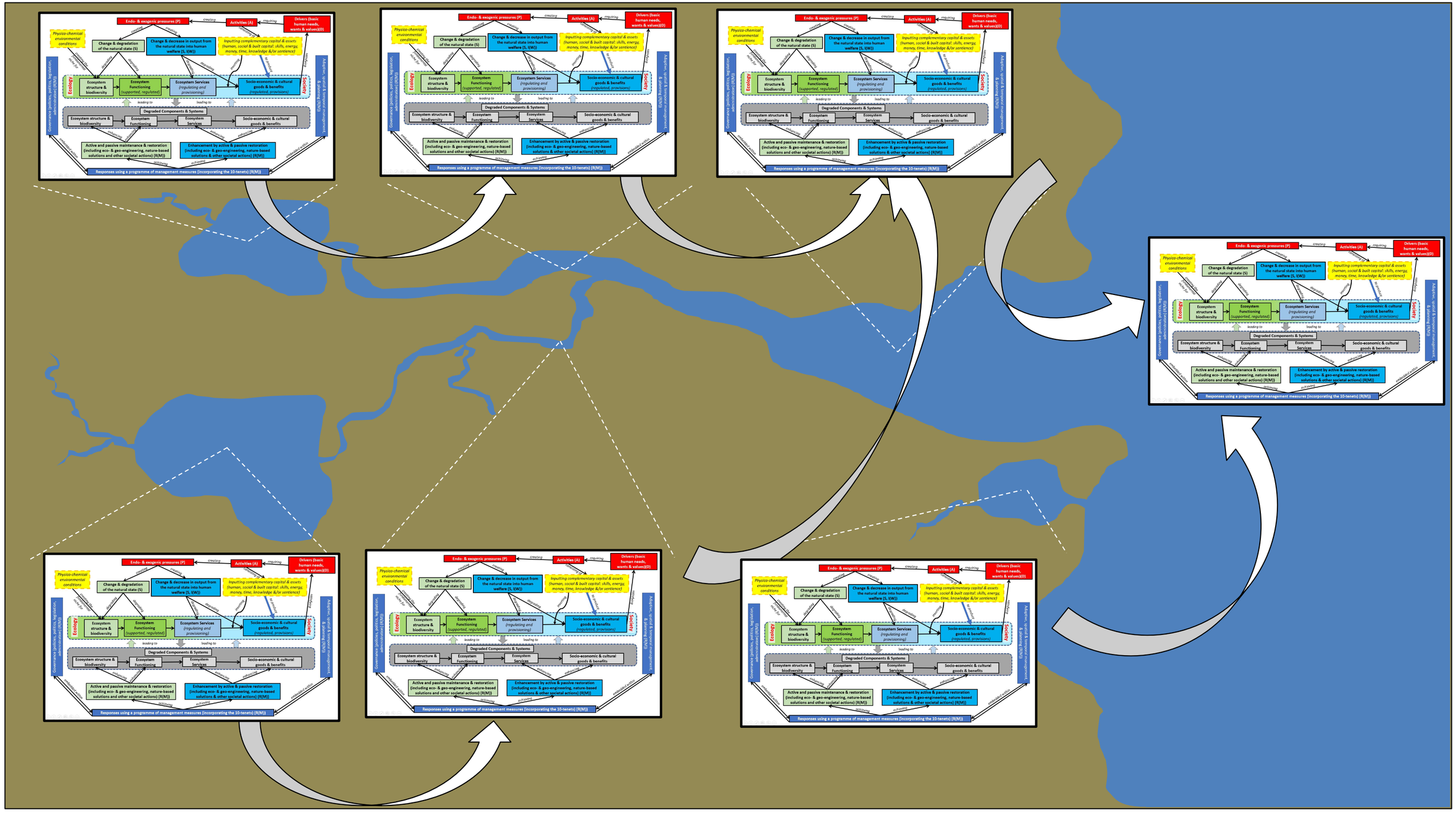


CATCHMENT



Connectivity to and from the catchment

Estuarine ecotone boundaries


Endo- & exogenic pressures (P)
creating
Activities (A)
requiring
Drivers (basic human needs, wants & values)(D)
Physico-chemical environmental conditions
Change & degradation of the natural state (S)
Change & decrease in output from the natural state into human welfare (S, I(W))
Inputting complementary capital & assets (human, social & built capital: skills, energy, money, time, knowledge &/or sentience)
Ecology
Ecosystem structure & biodiversity
Ecosystem Functioning (supported, regulated)
Ecosystem Services (regulating and provisioning)
Socio-economic & cultural goods & benefits (regulated, provisions)
Society
Degraded Components & Systems
Ecosystem structure & biodiversity
Ecosystem Functioning
Ecosystem Services
Socio-economic & cultural goods & benefits
leading to
Active and passive maintenance & restoration (including eco- & geo-engineering, nature-based solutions and other societal actions) (R(M))
Enhancement by active & passive restoration (including eco- & geo-engineering, nature-based solutions & other societal actions) (R(M))
Responses using a programme of management measures (incorporating the 10-tenets) (R(M))
Governance (policies, politics, legislation, administration) (R(M))
Adaptive, spatial & temporal management (R(M))
Adaptive, spatial & temporal management (R(M))

(Elliott 2023 Mar. Poll. Bull.)

MARINE ENVIRONMENT

NATURAL DOMAIN

Natural Capital

Ecosystem features that are internally and externally regulated, supported and provided, and which can be valued in ecological terms:

- Ecosystem structure (stocks): *e.g. marine habitats, species, biodiversity*
- Ecosystem functioning (flows): *e.g. primary production; gamete and larval supply; water and nutrient cycling; formation of physiography, habitats, conductivity and barriers; physico-chemical and biological controls; carbon flows and storage*

Ecosystem Services

The components and products (stocks) and functions (flows) provided by nature with a capacity and potential to be societal goods and benefits:

- Provisioning aspects (i.e. materials and structures provided by a fully-functioning marine ecosystem): *e.g. vertebrates, invertebrates, macrophytes; genetic resources; water and minerals; places and seascapes*
- Regulating processes: *e.g. climate regulation; natural hazard protection; waste breakdown and detoxification*

HUMAN DOMAIN

Inputting Complementary Capital and Human Assets (Activities)

The introduction of time, money, energy, skills and knowledge and the ability of being sentient as necessary to release the societal goods and benefits

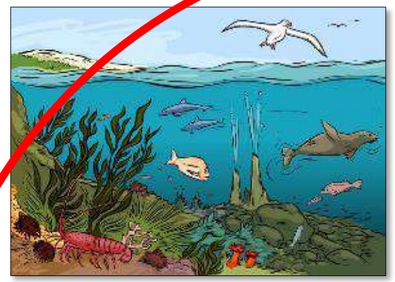
From Ecosystem Service flows to Societal Benefits flows

Societal Goods and Benefits (well-being and the fulfilment of basic human needs)

(to be valued in monetary/non-monetary, material/non-material and/or tangible/non-tangible terms)

- Extracted provisions: *e.g. wild, gathered and farmed food and fish feed; fertilisers, energy as fuel and biofuels; medicines and biotechnology*
- Environmental regulation, hazard and risk reduction including safety: *e.g. suitable climate, sea defences and erosion protection; waste burial, removal and neutralization*
- Cultural, aesthetic and health benefits (interaction provisions): *e.g. tourism, ecotourism and recreation; ornaments and aquaria; spiritual well-being and satisfaction; education and research*

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



Ecosystem Structure and Functioning (Stocks & Processes)



Ecosystem Services (Flows)



Input of Human Capital*

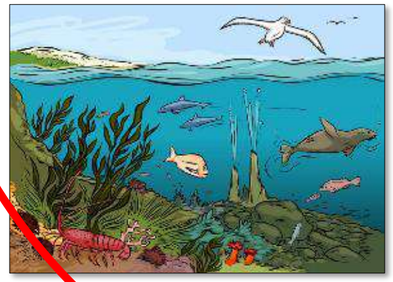


Societal Goods & Benefits (Well-being)

Ecological valuation

Socio-ecological valuation

Socio-economic valuation









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

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

Hazard & Risk Typology: Source of Problems & Cause for Management

Hazards in Estuaries & Coast leading to Risk (depending on assets)
A) Surface hydrological hazards (e.g. flooding)
B) Surface physiographic removal by natural processes - chronic/long-term (e.g. erosion)
C) Surface physiographic removal by human actions - chronic/long-term (e.g. land-claim, space removal)
D) Surface physiographic removal - acute/short-term (e.g. cliff failure)
E) Climatological hazards - acute/short term (e.g. storminess)
F) Climatological hazards - chronic/long term (e.g. NAO changes, sea-level rise)
G) Tectonic hazards - acute/short term (e.g. earthquakes, land-slip)
H) Tectonic hazards - chronic/ long term (e.g. subsidence, isostatic rebound)

= Risk Assessment & Risk Management (RA&RM):

- Hazard Identification:
- Risk Assessment:
- Risk Management:
- Risk Communication:

(Modified and Expanded from Elliott et al., 2014, 2019; See Elliott & Kennish 2024 – Treatise on Estuarine & Coastal Science, Volume 6, Elsevier)



6.1 A Synthesis of Anthropogenic Impacts and Solutions in Estuarine and Coastal Environments

Michael Elliott, International Estuarine & Coastal Specialists (IECS) Ltd., Leven, United Kingdom and School of Environmental Sciences, University of Hull, Hull, United Kingdom
Michael J Kennish, Department of Marine and Coastal Sciences, School of Environmental and Biological Sciences, Rutgers University, New Brunswick, NJ, United States

Hazard in Estuaries & Coast leading to Risk (depending on assets)

I) Anthropogenic microbial biohazards (e.g. sewage pollution)
J) Anthropogenic macrobial biohazards (e.g. non-indigenous species)
K) Anthropogenic introduced technological hazards (e.g. infrastructure, sediments)
L) Anthropogenic extractive technological hazards (e.g. fishing, aggregates)
M) Anthropogenic acute chemical hazards (e.g. oil spills)
N) Anthropogenic chronic chemical hazards (e.g. diffuse and point-source contaminants)
O) Anthropogenic acute geopolitical hazards (e.g. wars, unrest, terrorism)
P) Anthropogenic chronic geopolitical hazards (e.g. human migrations, civil-war)

All hazards caused or exacerbated by climate change or the societal responses to climate change!!

Ocean & Coastal Management 93 (2014) 88–99

Contents lists available at ScienceDirect

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Review

A typology of marine and estuarine hazards and risks as vectors of change: A review for vulnerable coasts and their management

Michael Elliott [a,*], Nicholas D. Cutts [a], Anna Trono [b]

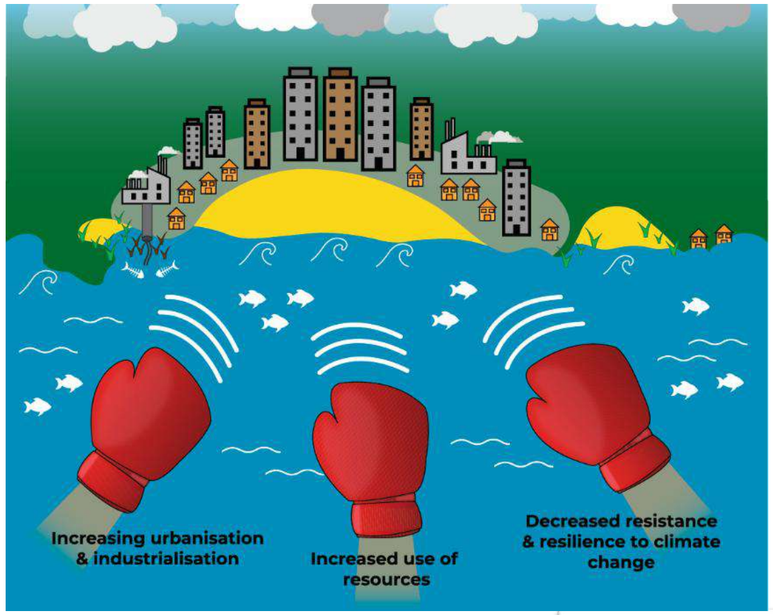
What needs managing? - Hazards, risks and their prevention, from single activities to whole areas

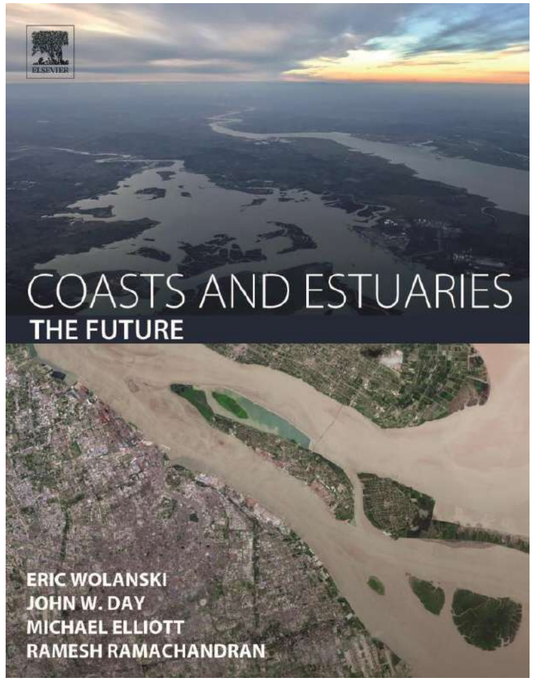
Exogenic unmanaged pressures ***(where the consequences are managed in the management area but the causes require global action)***	**Endogenic managed pressures** ***(where the causes and consequences are managed within the management area)***
Alien species	New infrastructure
Sea level rise (or loss?)	Energy generation
Increased temperature	Petrochemical industries
Increased storminess	Dredging and navigation
Flooding and erosion	Wetland loss and gain
Changes to catchment run-off	Urban discharges
Repercussions of NAO	Mine-water discharges
Agricultural runoff in catchment	Subsidence
Saline ingression	Historical pollution residues

And opportunities!

The ‘Triple Whammy’ – Present & future threats for estuaries and coasts worldwide

- Increased industrialisation and urbanisation
- Increased use of physical (space, energy, water, etc.) and biological (fish, shellfish) resources
- Decreased resistance and resilience to climate change (temperature, acidification, storminess, species distribution changes, alien species, etc)






Chapter 1

A Synthesis: What Is the Future for Coasts, Estuaries, Deltas and Other Transitional Habitats in 2050 and Beyond?

Michael Elliott*, John W. Day†, Ramesh Ramachandran‡, Eric Wolanski§


Marine Pollution Bulletin 163 (2021) 111832

Contents lists available at ScienceDirect

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Editorial

The ‘triple whammy’ of coasts under threat – Why we should be worried!

(Defeo & Elliott Mar. Poll. Bull. 2021)

Activity-footprint

That area and/or time, based on the duration, intensity and frequency of an activity which ideally has been legally sanctioned by a regulator in an authorisation, licence, permit or consent.

Pressures-footprint

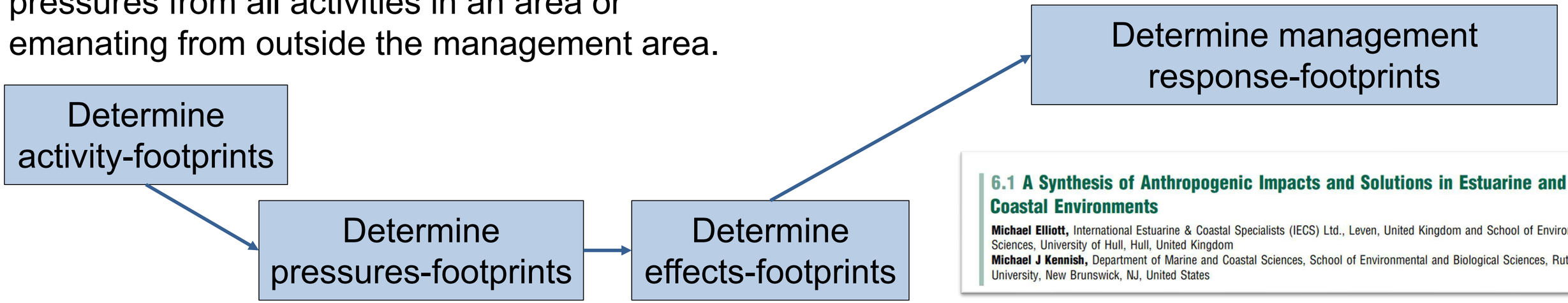
The mechanism(s) of change resulting from a given activity or all the activities in an area once avoidance and mitigation measures have been employed (the endogenic managed pressures).

Effects-footprint

The spatial (extent), temporal (duration), intensity, persistence and frequency characteristics resulting from (a) a single pressure from a marine activity, (b) all the pressures from that activity, (c) all the pressures from all activities in an area, or (d) all pressures from all activities in an area or emanating from outside the management area.

Management response-footprint

The area and/or time covered by the marine management action and measures (or programme of measures), including the distribution range of a species.



6.1 A Synthesis of Anthropogenic Impacts and Solutions in Estuarine and Coastal Environments

Michael Elliott, International Estuarine & Coastal Specialists (IECS) Ltd., Leven, United Kingdom and School of Environmental Sciences, University of Hull, Hull, United Kingdom
Michael J Kennish, Department of Marine and Coastal Sciences, School of Environmental and Biological Sciences, Rutgers University, New Brunswick, NJ, United States

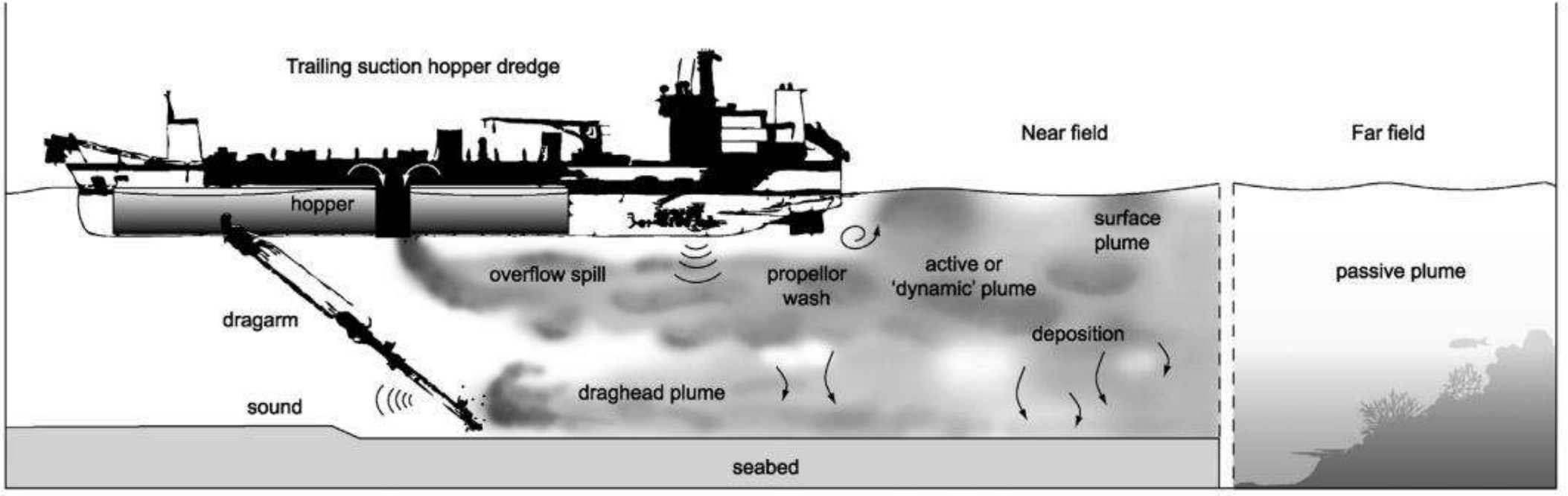
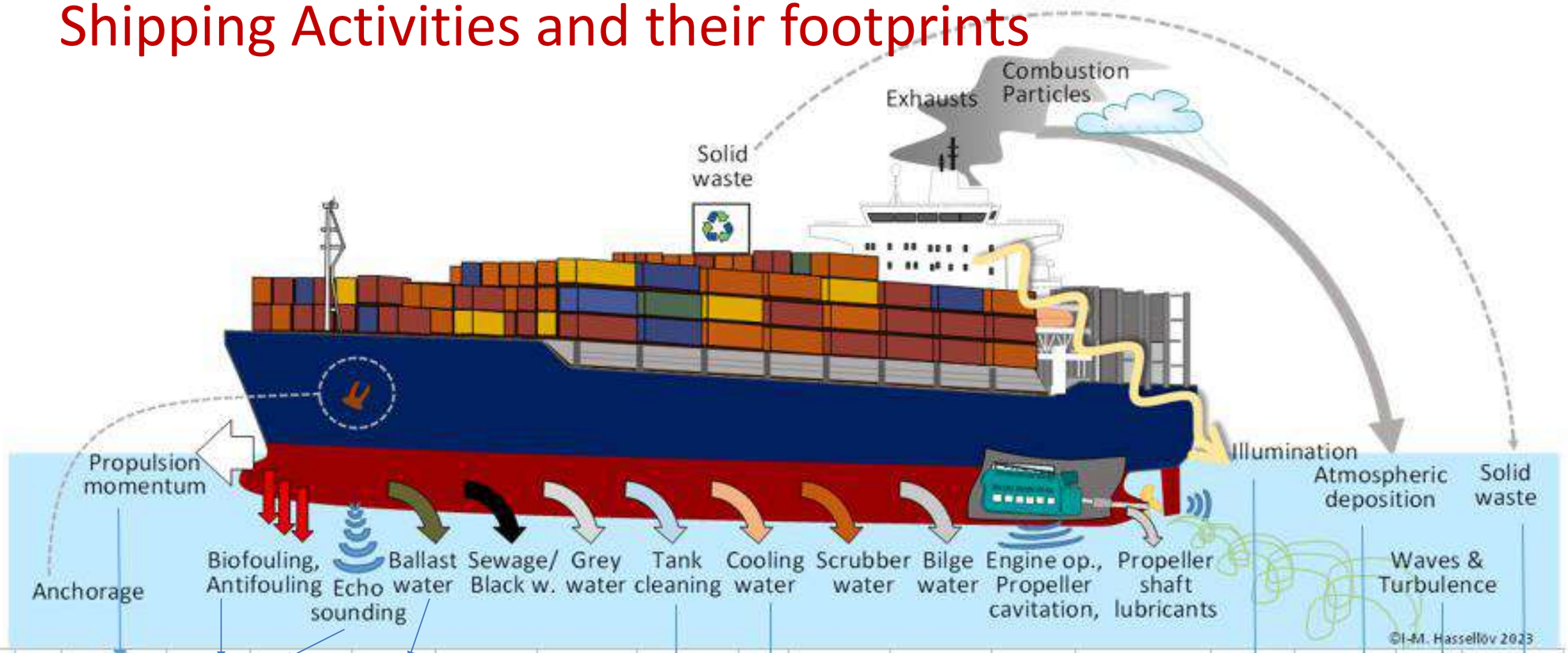


Fig. 2. Stylized representation of plume generation by a trailing suction hopper dredge, the most commonly used of the hydraulic dredges for soft sediments (see Foster et al., 2010). Turbidity is generated at the drag-head and at the surface if sediment-laden water inside the hopper is allowed to discharge (overflow). This can occur from the ship's sides but usually through a vertical shaft inside the hopper, exiting below water level (Foster et al., 2010; VBKO, 2003).

Please cite this article as: Jones, R., et al., Assessing the impacts of sediments from dredging on corals, Marine Pollution Bulletin (2015), http://dx.doi.org/10.1016/j.marpolbul.2015.10.049

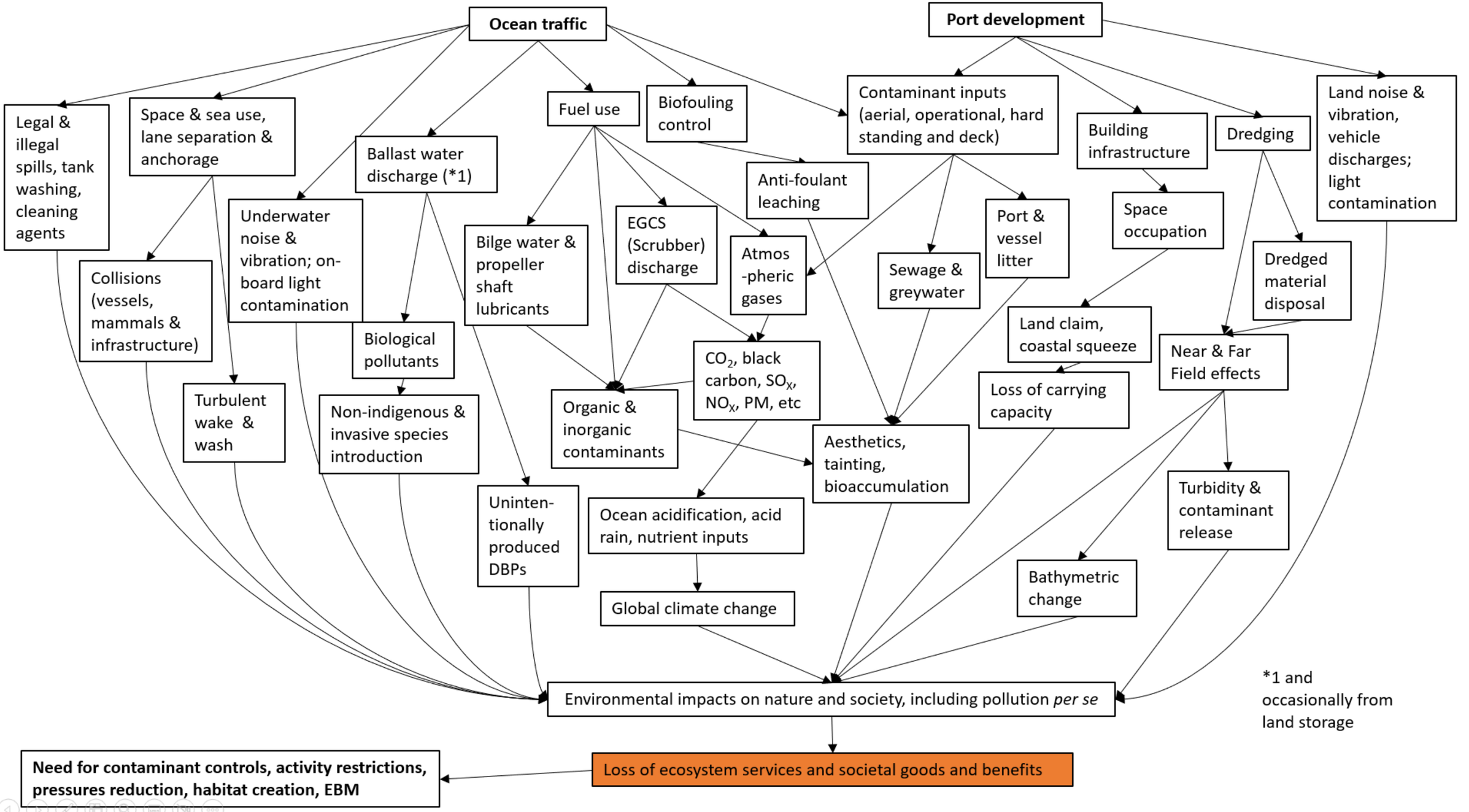
Shipping Activities and their footprints

Shipping regulations govern where and how e.g. discharges are permitted



Activity characteristics																	
Continuous		X	X	X	X				X	X		X	X		X	X	
Intermittent	X					X	X	X			X			X			X
Spatial extent area	X	X?	XX	XX	X?									X?	XXX	X	
Spatial extent volume					X?	X	X	X	X	X	X	X?	X	X?		X	X

(from Ida-Maja Hassellöv, Chalmers Uni, Gothenburg)



Horrendogram of the environmental consequences of ports, shipping and navigation (Elliott & Hassellöv in press)

Challenges for management (RA&RM; OA&OM):

Risk Assessment:

- Where are the problems and what changes do they cause? (ExUP & EnMP)
- What is their impact 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?

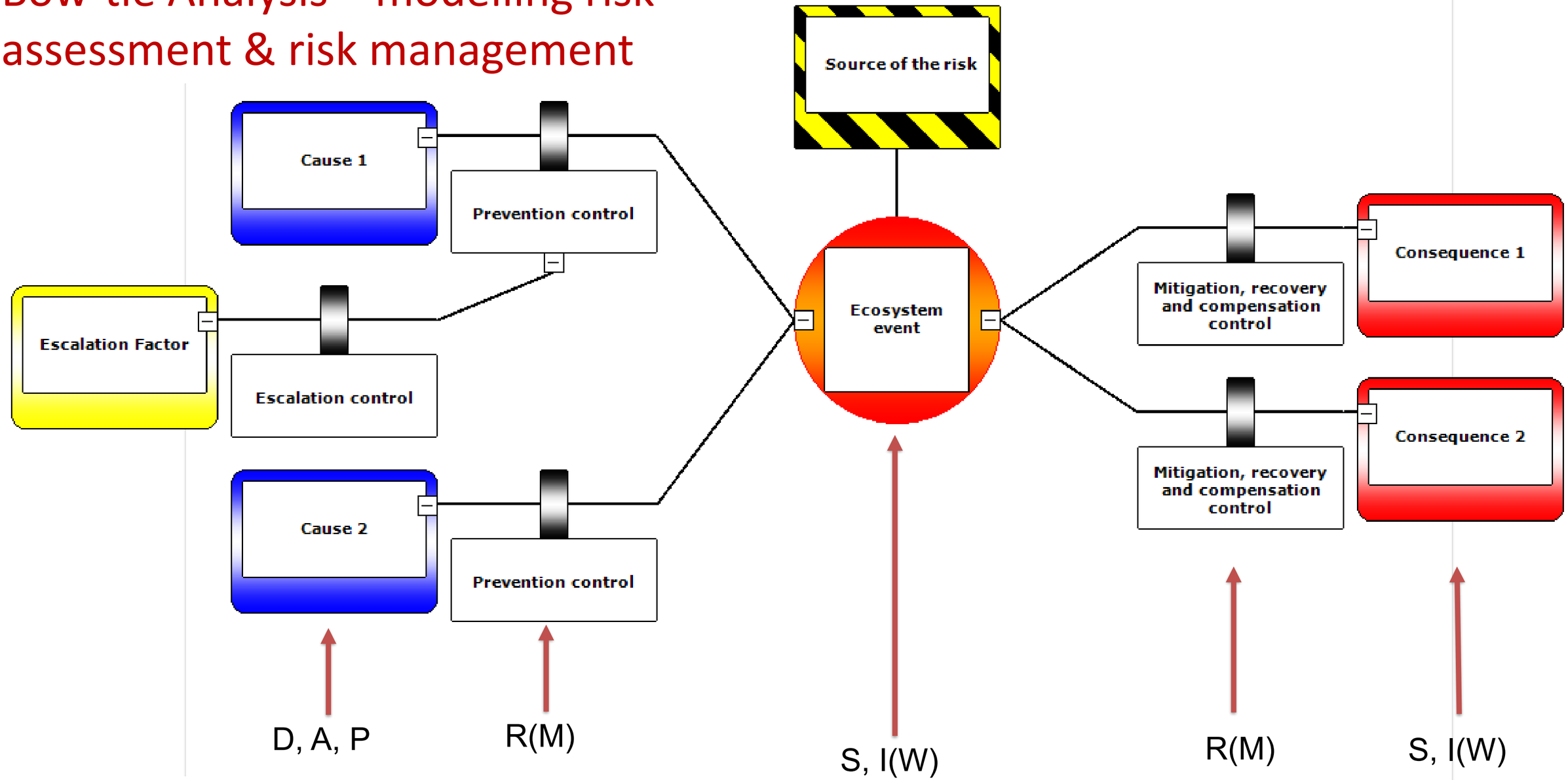
Risk Management:

- What governance framework is there, what do stakeholders need & what are successes & failures?
- What can we do about the problems, hazards & risks and how to address them now and in the future?
- How ‘good’ is the decision-making?

And the corollary: Opportunity Assessment and Management

(Elliott, 2014 Mar. Poll. Bull.; Cormier et al 2019 OCMA, and others)

Bow-tie Analysis – modelling risk assessment & risk management

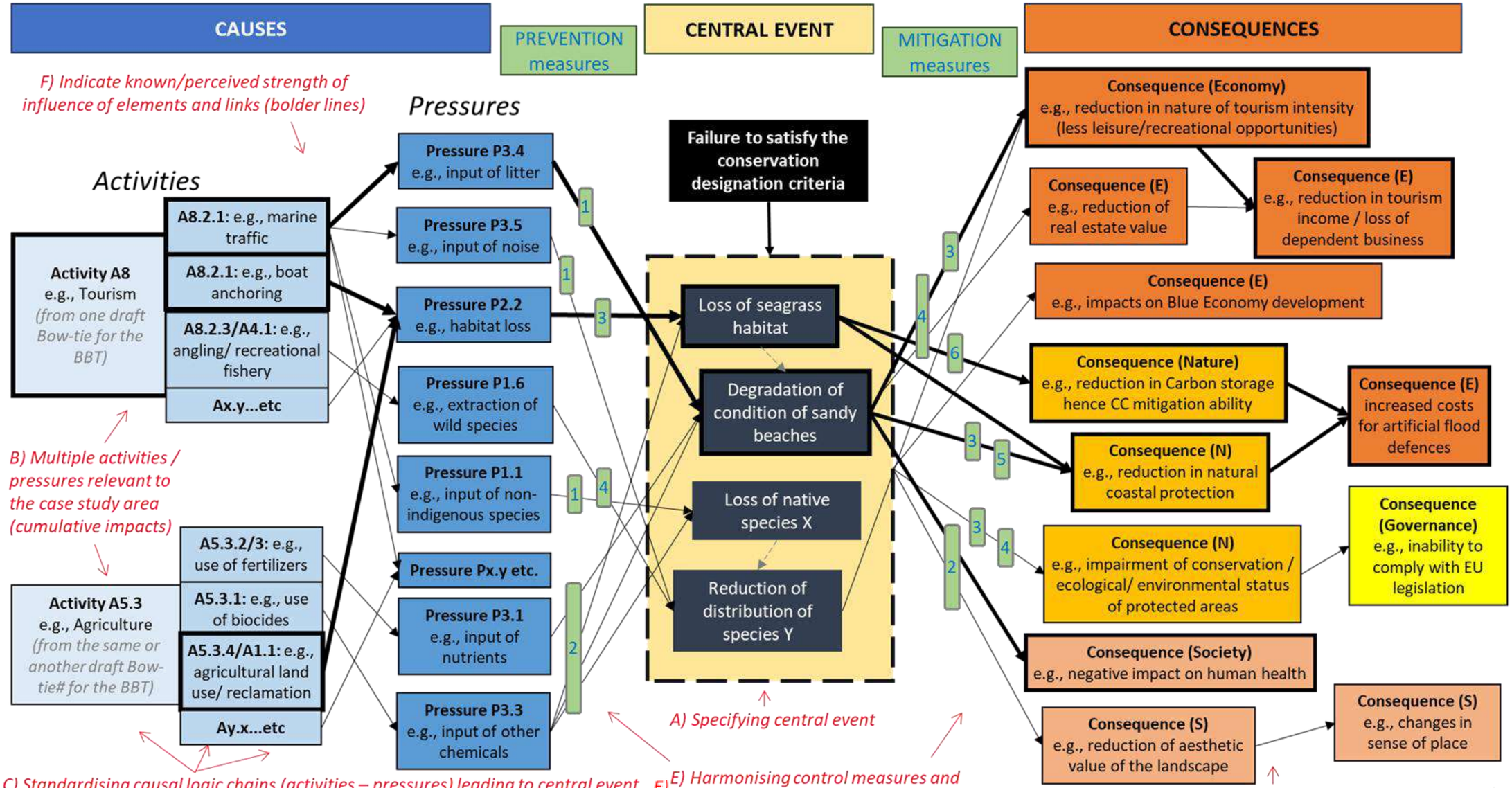


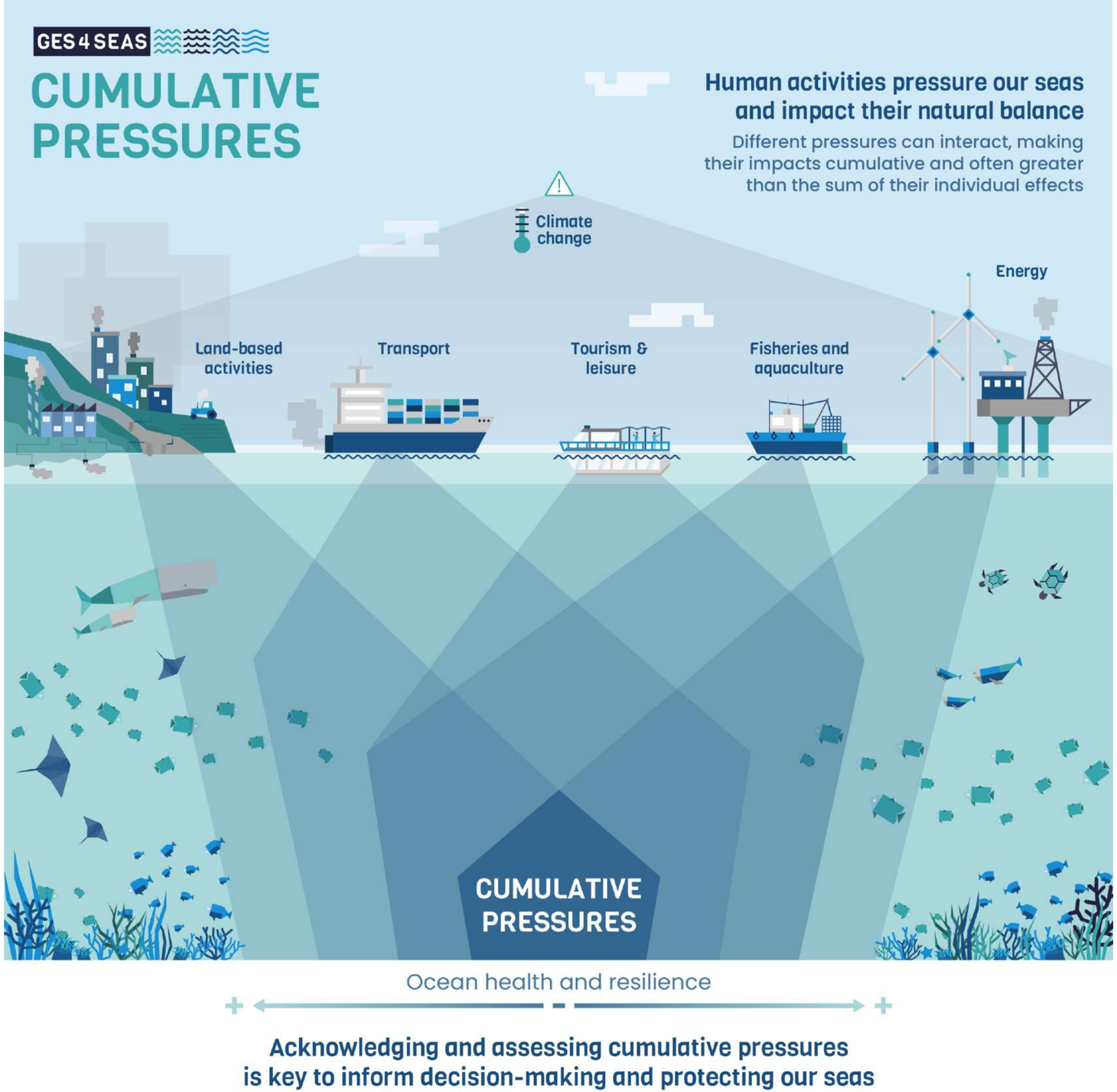
(Cormier et al., 2019, Sci. Tot. Env.)

Stakeholder consultation – to determine causes and consequences and to agree the responses throughout the sequence

Bow-tie example and steps to build it (F)

Example of final Bow-tie diagram for a PS (mock-up) *(in red are the steps to follow)*



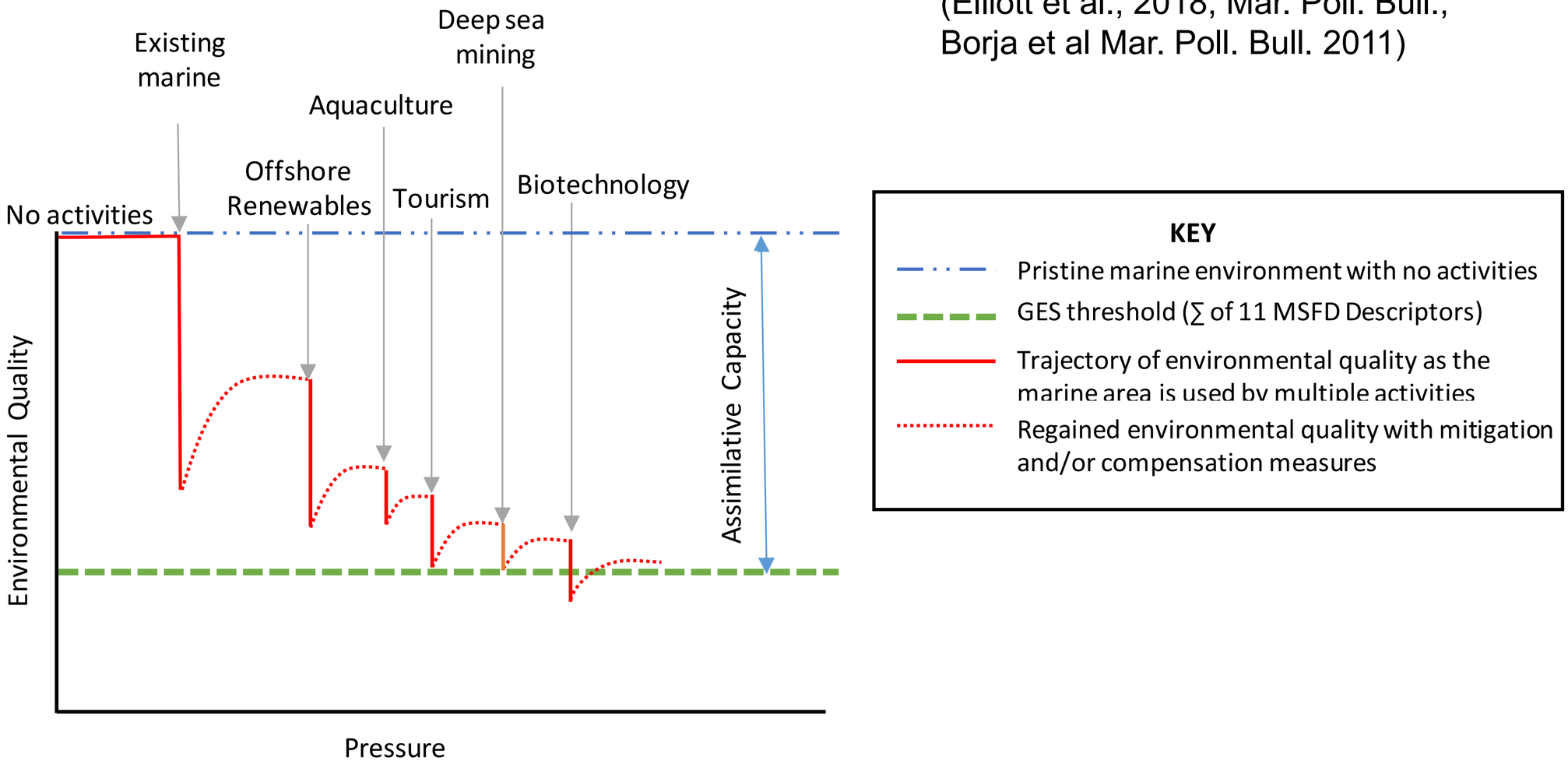


A practical definition: '*a systematic procedure for identifying and evaluating the significance of impacts from individual or multiple sources and/or activities*'.

GES4 SEAS

Environmental Quality Model incl. mitigation measures for cumulative Blue and Emerald Growth Activities

(Elliott et al., 2018, Mar. Poll. Bull.; Borja et al Mar. Poll. Bull. 2011)



Challenge – how do we cope with cumulative effects and the availability/loss of assimilative and carrying capacities?!

Examples of the creation, performance and protection of Emerald growth (1)

Topic	Example
Fisheries	Marine commercial species with nursery stages inside the transitional waters; freshwater fished species needing to migrate through the transitional waters
Fish and shellfish ecology	TW Fishes breeding outside the TW and the young stages returning via selective tidal stream transport
Water quality	WQ in the TW being dependent on the catchment for diffuse and point source inputs and the marine waters for dilution leading to the resulting concentrations
Production of organic matter	Autochthonous matter production inside the TW but allochthonous material both natural and anthropogenic, from the catchment

Examples of the creation, performance and protection of Emerald growth (2)

Topic	Example
Carbon sequestration	Labile and refractory carbon stored by macroflora and sediments in TW, originating in the catchment and in the TW
Port and navigation	Access to the port being dependent on marine channels and resultant channel development by the tides
Nutrient effects	The manifestation of eutrophic or oligotrophic conditions in the TW being dependent on the net inputs of nutrients from the catchment, their dilution in the TW and the export from the system (the role of the TW as a source or sink)

Examples of the creation, performance and protection of Emerald growth (3)

Topic	Example
Sediment cycles	The erosion and deposition cycles in the TW being dependent on the seasonal and spatial effects of sediment inputs from the marine and catchment areas, tidal pumping and the relative strength of water currents
Hydrodynamics	The water movements in the TW being influenced by the freshwater-tidal net effect
Water stratification	Dependent on the mixing characteristics as the net result of freshwater inputs from the catchment, the tidal penetration and the depth and bathymetry of the area
Hydrogeo-morphology maintenance	The physiographic characteristics (bank and bed features) are maintained to accommodate natural processes including storm-surges but also protect society and economy

Definitions for Transboundary Analysis in Marine & Estuarine Management

Connectivity – the state of being or being able to be connected; features that are linked and contiguous in some way, either naturally by ecology and hydrodynamics or by management measures (human interventions and actions); ***i.e. elements are joined/linked across boundaries***.

Coherence – the quality of being logical and consistent and/or the quality of being regarded as forming a whole; that there is a clear relationship between the parts, that the whole is greater than the sum of the individual parts; that there is a similarity in aspects in adjoining transboundary areas; that similar actions and features occur either side of a boundary or in different areas; ***i.e. actions are the same on each side of a boundary***.

Equivalence – that a relationship exists between two (or more) entities (e.g. national marine areas or estuaries), and the relationship is described as one of likeness/sameness/similarity/equality in terms of one or more potential qualities; that the same and comparable outputs and outcomes occur either side of a boundary even if the methods used differ; i.e. ***actions have the same outcome on each side of a boundary irrespective of the methods used***.

MarinePlan

(Elliott, Borja & Cormier, 2023 OCMA)

(Estuarine examples of connectivity in Elliott & Whitfield ECSS 2025)

Challenge – how do we ensure the connectivity, coherence and/or equivalence between areas and across boundaries?

Typology of Marine and Estuarine Connectivity, Coherence and Equivalence

A.In natural sciences - Physico-chemical connectivity; Ecological connectivity; nature conservation coherence, equivalence and connectivity.

B.In socio-economy - societal connectivity and equivalence; cultural connectivity and equivalence; economic connectivity, equivalence and coherence; sectoral connectivity, coherence and equivalence.

C.In marine management - connectivity of human activity-, pressures- and effects-footprints and equivalence of management response-footprints; equivalence, connectivity and coherence of monitoring, assessment and reporting.

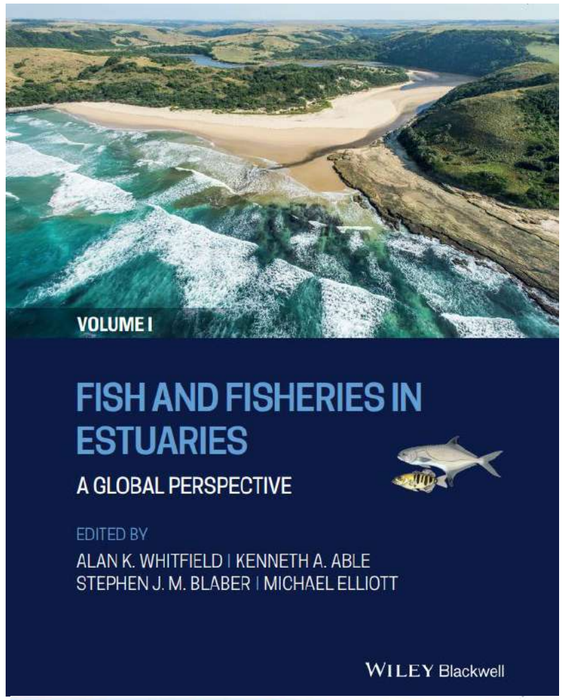
D.In marine governance - administrative equivalence; legislative equivalence; coherence and equivalence of Maritime Spatial Planning (MSP) and Marine Protected Areas (MPA)-designation; this includes equivalence of internationally-adopted principles.

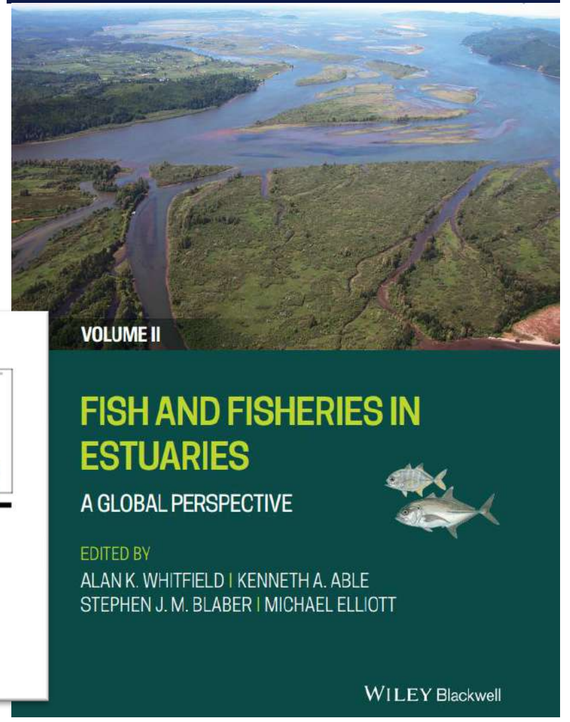
(Elliott, Borja & Cormier, 2023 OCMA)

(Estuarine examples of connectivity in Elliott & Whitfield ECSS 2025)

Example of Estuarine Fishes

- The essence of an appropriate and expected structure and function of healthy and sustainable estuarine fish communities lies in achieving and maintaining ecological connectivity between adjacent ecosystems.
- This connectivity includes a knowledge of the associated components of, and links with, both the marine and catchment areas.
- This shows the natural and social sciences aspects required to achieve healthy and sustainable estuarine fish populations and communities.
- **But management requires coherence and equivalence as well as connectivity.**






Estuarine, Coastal and Shelf Science 314 (2025) 109133
Contents lists available at ScienceDirect
Estuarine, Coastal and Shelf Science
journal homepage: www.elsevier.com/locate/ecss

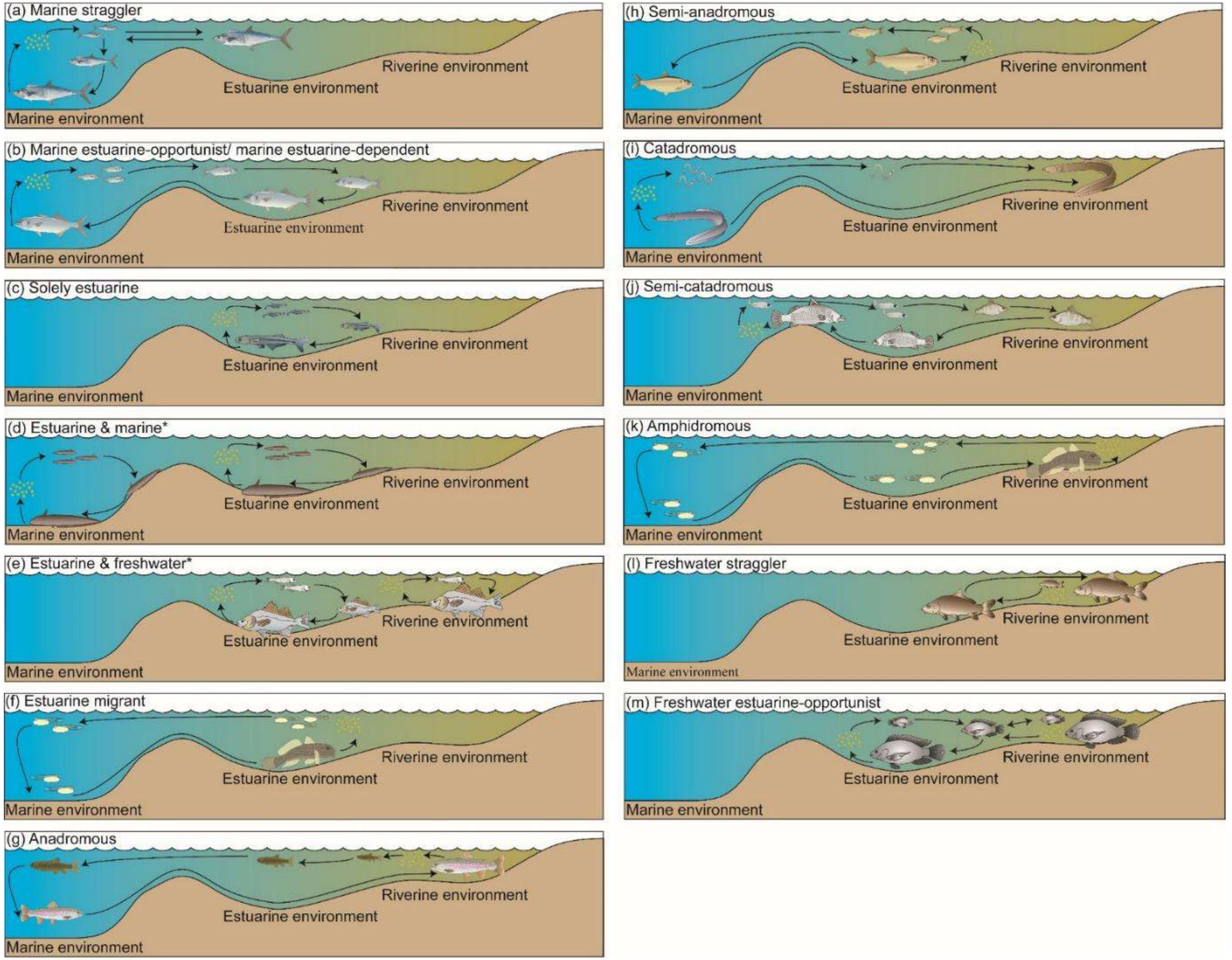
Science and management achieving connectivity, coherence and equivalence to ensure the health of estuarine fish communities

Michael Elliott [a,b,*], Alan K. Whitfield [a,c]

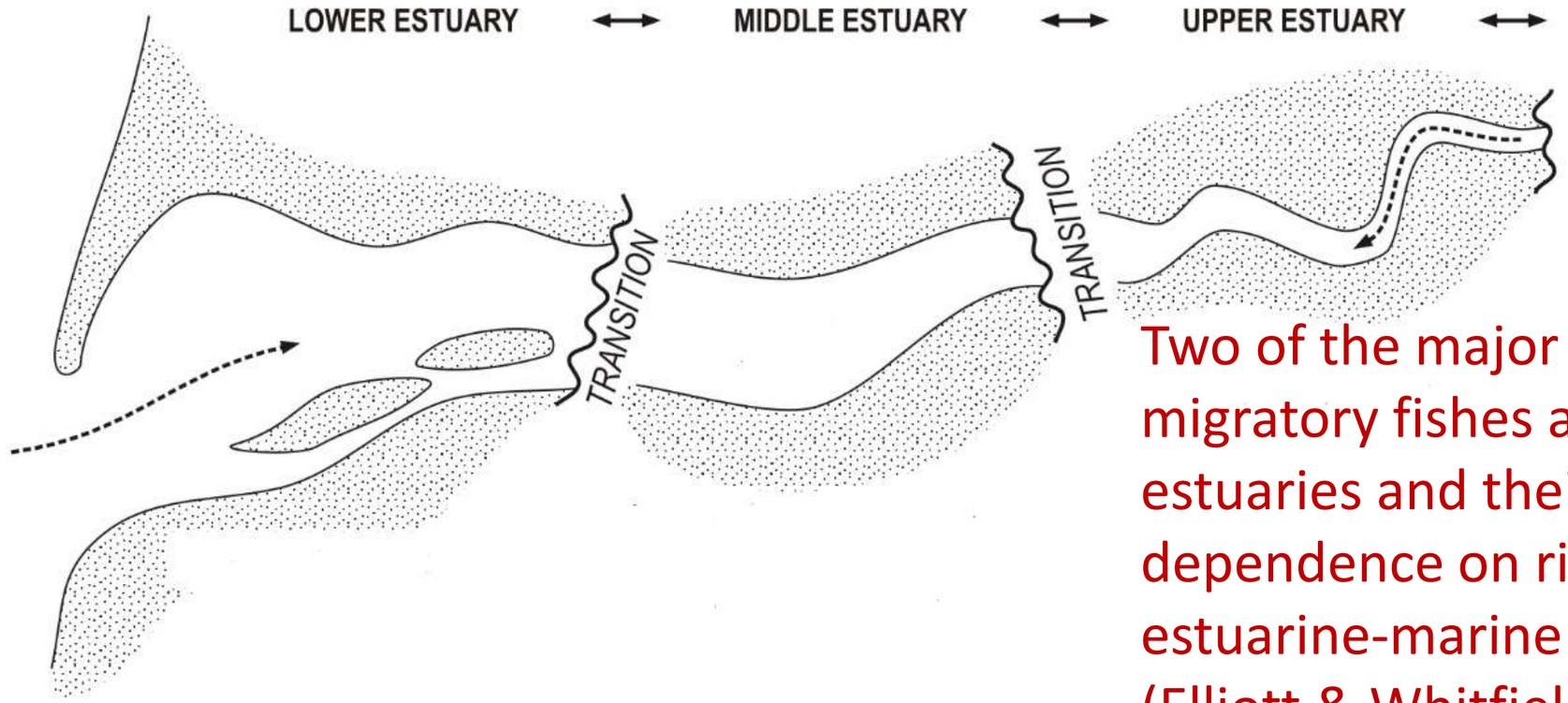

Ocean and Coastal Management 245 (2023) 106875
Contents lists available at ScienceDirect
Ocean and Coastal Management
journal homepage: www.elsevier.com/locate/ocecoaman

Managing marine resources sustainably – Ecological, societal and governance connectivity, coherence and equivalence in complex marine transboundary regions

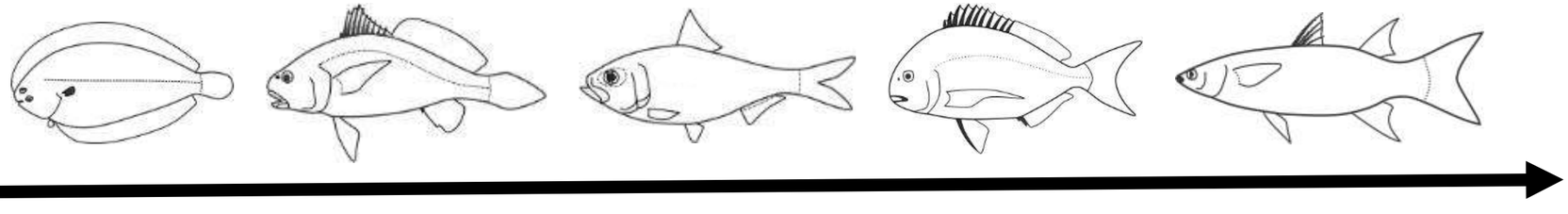
Michael Elliott [a,b,*], Ángel Borja [c], Roland Cormier [d]



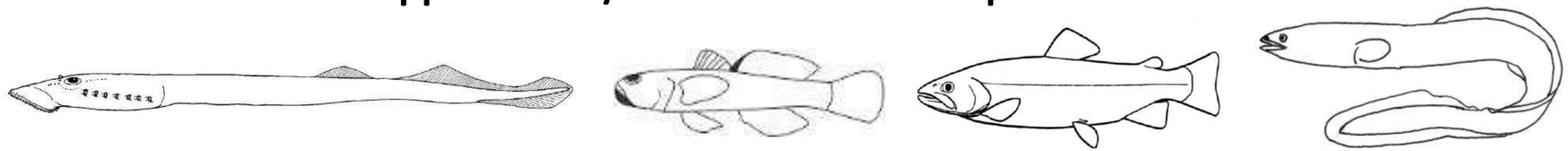
Diagrammatic representation of the different life-history styles of fishes associated with global estuaries (after Potter et al., 2015;Elliott & Whitfield 2025).



Two of the major groups of migratory fishes associated with estuaries and their relative dependence on riverine-estuarine-marine connectivity (Elliott & Whitfield 2025 ECSS)



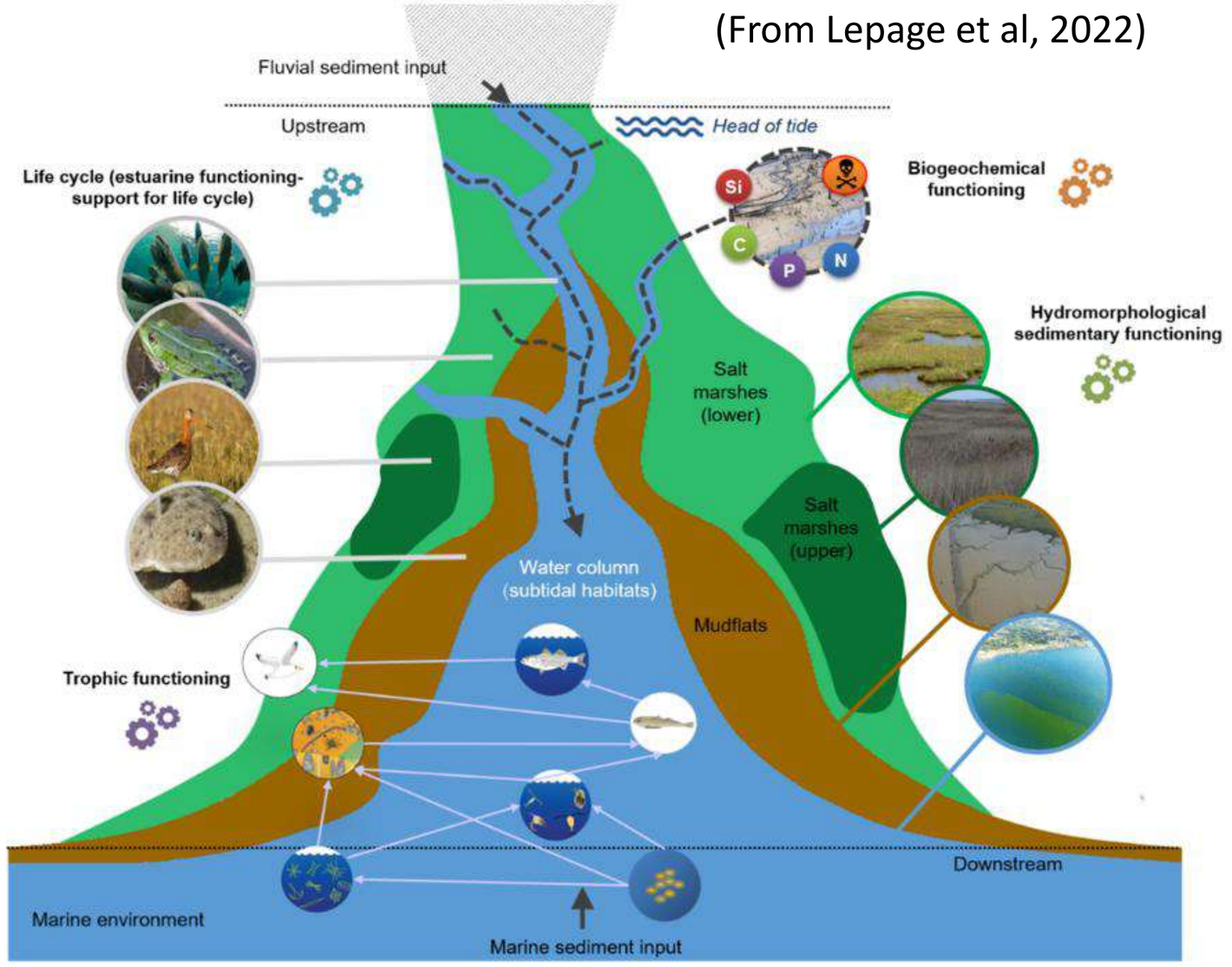
Marine species: Marine estuarine-opportunists/marine estuarine-dependents



Diadromous species: Amphidromous/anadromous/catadromous

	Meaning and relevance in an estuarine ecotone boundary* context
A. Connectivity, equivalence or coherence in natural sciences ***(i) Physico-chemical connectivity***	That the water characteristics and hydrographic patterns either side of the ecotone boundaries and between the areas on both sides of the boundaries are known and not distorted by temporary or permanent natural or human-created barriers occurring in one or both areas across the boundary.

(From Lepage et al, 2022)

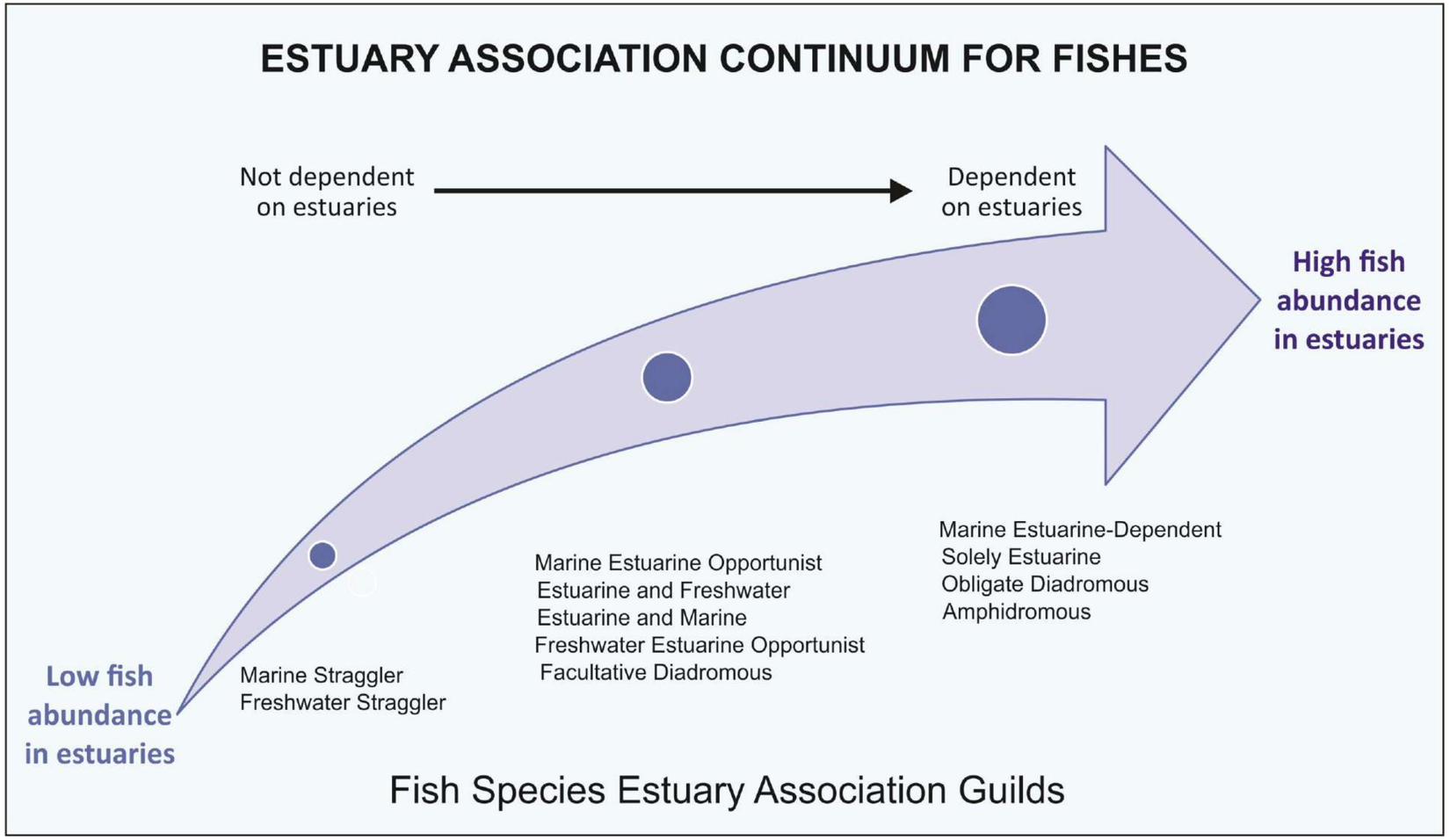


(*In this case, a boundary is regarded as any of the ecotones in the continuum from sea to estuary to catchment; where relevant a transboundary also refers to international borders as in international rivers, estuaries or catchments)

(Modified from Elliott, Borja & Cormier, 2023; Elliott and Whitfield, 2025)

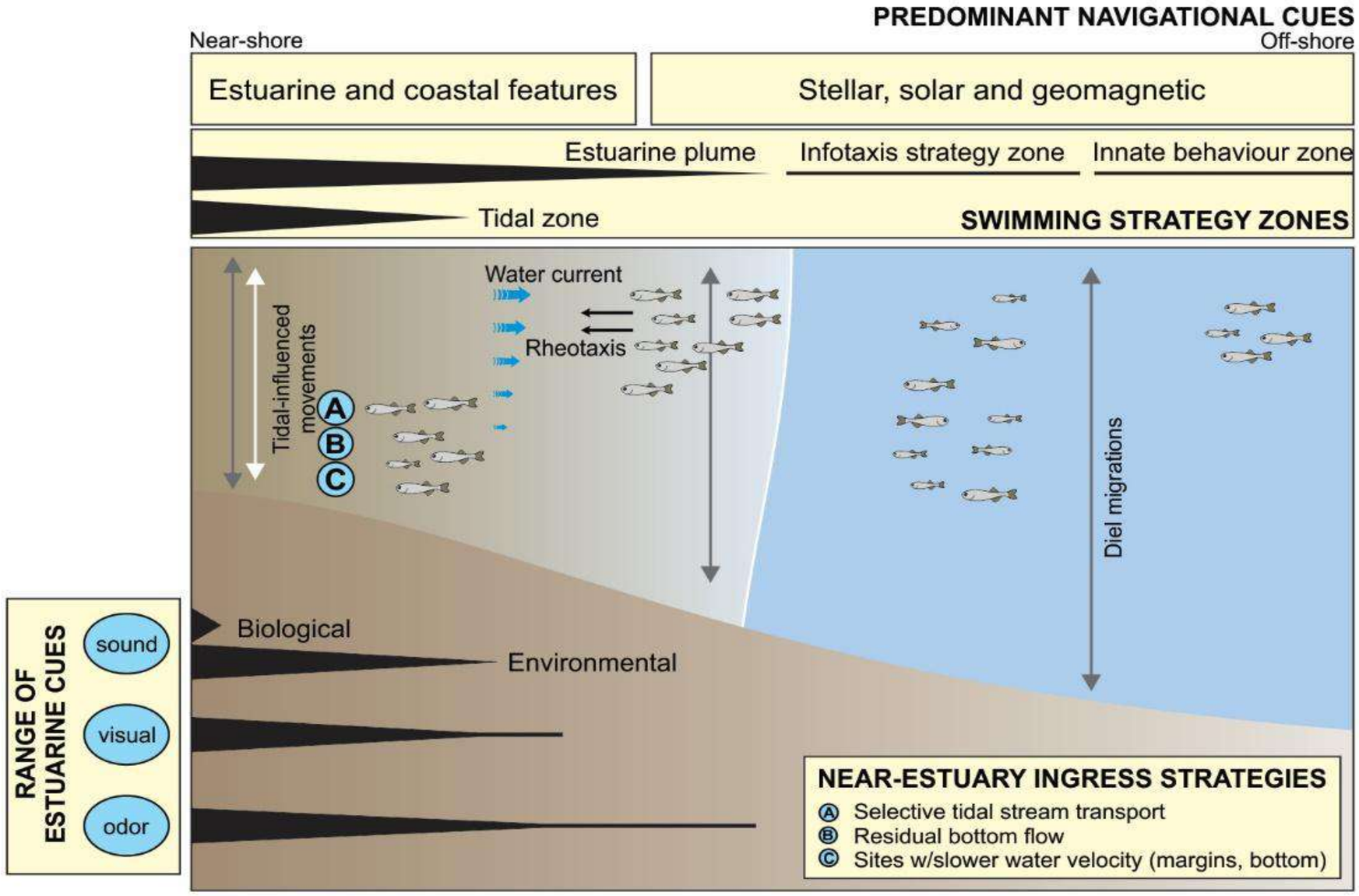
	Meaning and relevance in an estuarine ecotone boundary* context
(ii) Ecological connectivity	That the populations either side of the ecotones are connected either by migration patterns or by the larval and juvenile dispersal and settlement patterns, and that there are no temporary or permanent interferences created by natural or human structures or barriers preventing that connectivity.

(Modified from Elliott, Borja & Cormier, 2023)



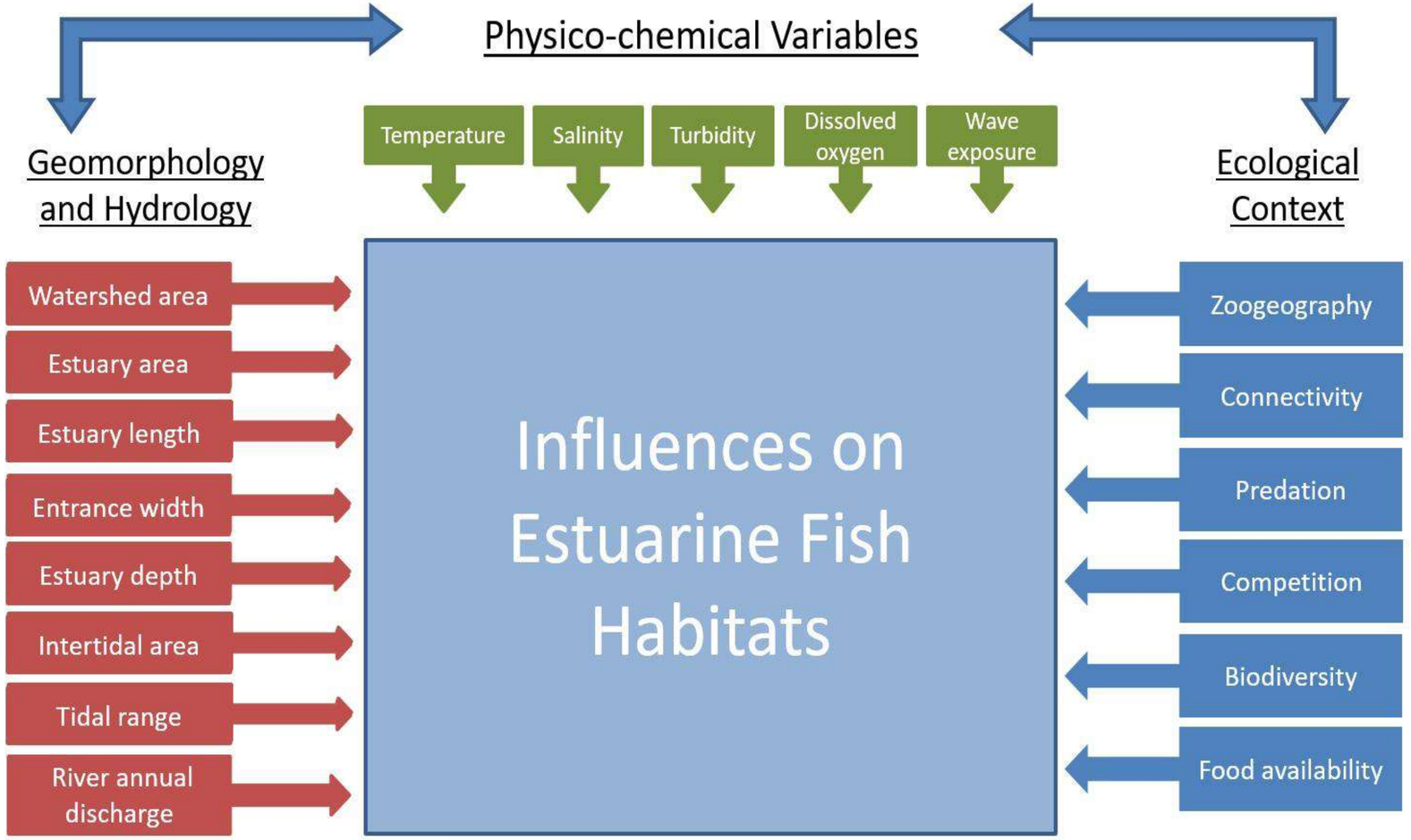
(Source: Whitfield 2023)

Recruitment of marine estuary-associated larvae – connectivity is key



(Source: Houde et al. 2022)

	Meaning and relevance in an estuarine ecotone boundary* context
(iii) Nature conservation coherence, equivalence and connectivity	That there are the same practices of nature conservation on each side of the ecotone boundaries in relation to species and habitats, that habitat units are treated equally, and that species are given the same protection, especially for highly mobile species.



(Source: Able et al. 2022)

(Modified from Elliott, Borja & Cormier, 2023)

Natural	Anthropogenic
. Increased suspended solids associated with major river flooding of estuaries . Enhanced turbidity maxima arising from increased bottom sediment scouring and changing water circulation patterns in estuaries . Seasonal freshwater flow changes – especially cessation of river base flows during prolonged droughts . Salinity changes in estuaries arising from very high or low river catchment flows . Sand berms that block the mouths of certain estuaries . Hurricanes, typhoons and cyclones that lead to temporary water level and salinity changes in estuaries	. Dissolved oxygen sags, mainly through organic pollution . Pollution plumes, especially those that are toxic to fishes . Eutrophication that completely alters water quality and natural ecosystem functioning . Intensive dredging operations that create high localised biological oxygen demand . Removal of river base flow due to relatively high freshwater demand during the dry season . Over-exploitation of certain diadromous fish species during either the immigration or emigration life stages

Management needs - Potential **temporary** barriers along the river-estuary-marine continuum inhibiting ecosystem connectivity for fishes

(Whitfield et al., 2022; Elliott & Whitfield 2025).

Natural	Anthropogenic
. **Waterfalls for non-anguillid fish species** . **Plunging rapids for certain small, sluggish fish species**	. Dams and weirs without fish bypass structures . Barriers, barrages and causeways that limit the upstream movement of certain fish species

Management needs - Potential **permanent** barriers along the river-estuary-marine continuum inhibiting ecosystem connectivity for fishes

(Whitfield et al., 2022; Elliott & Whitfield 2025).



Recovery of connectivity by removing structures – e.g. Klamath River in California (USA) in 2023 (Photo: © Katie Falkenberg, Swiftwater Films).

Marine and Estuarine Management and Governance
(who, how)

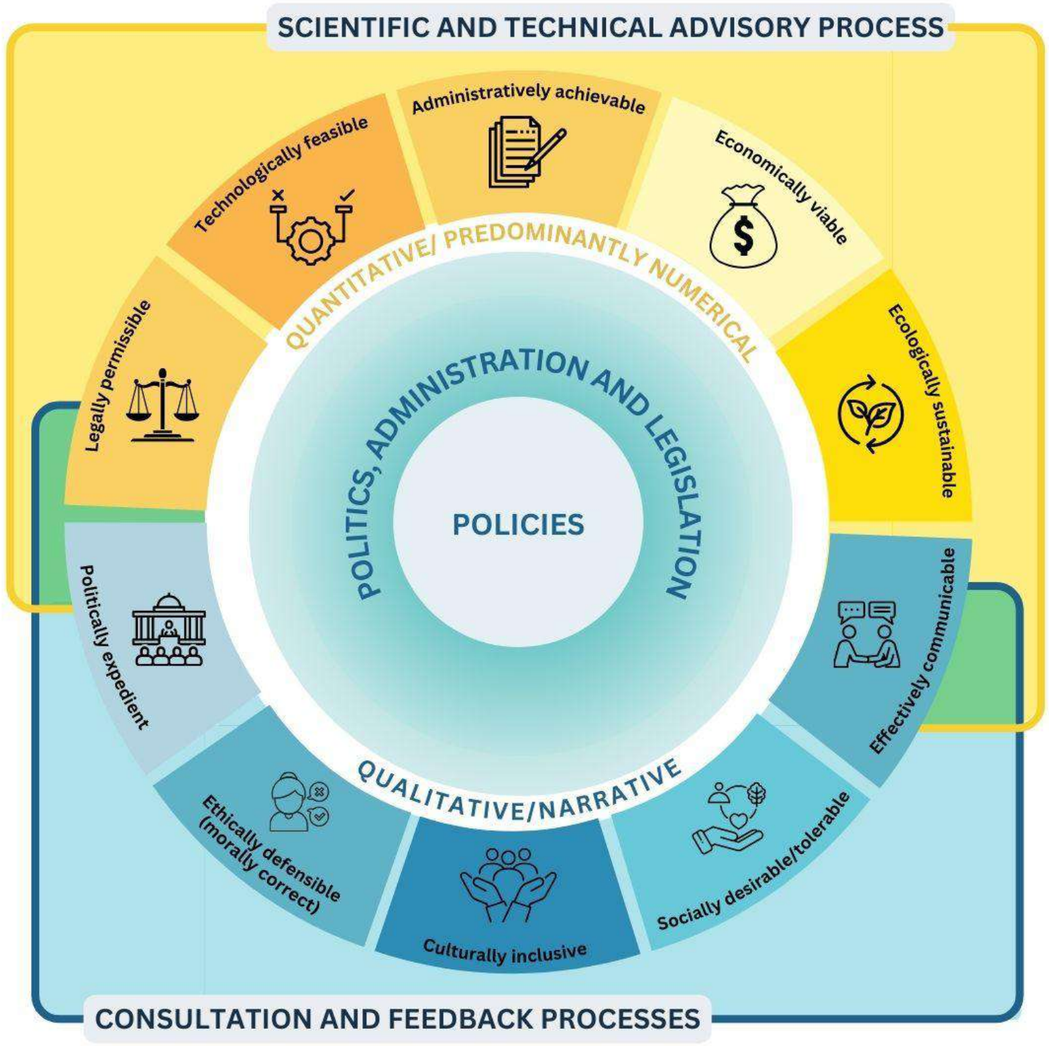
incorporating internationally recognised policies, politics, legislation and administration by horizontal and vertical integration of the management organogram to accomplish the vision of The Ecosystem Approach.

- ecologically sustainable development
- inter-generational equity
- the precautionary principle
- conservation of biological diversity and ecological integrity
- ecological valuation
- economic valuation of environmental factors
- the ‘damager debt’ / ‘polluter pays’ principle
- waste minimisation, and
- public participation - the role of individuals and ethics.

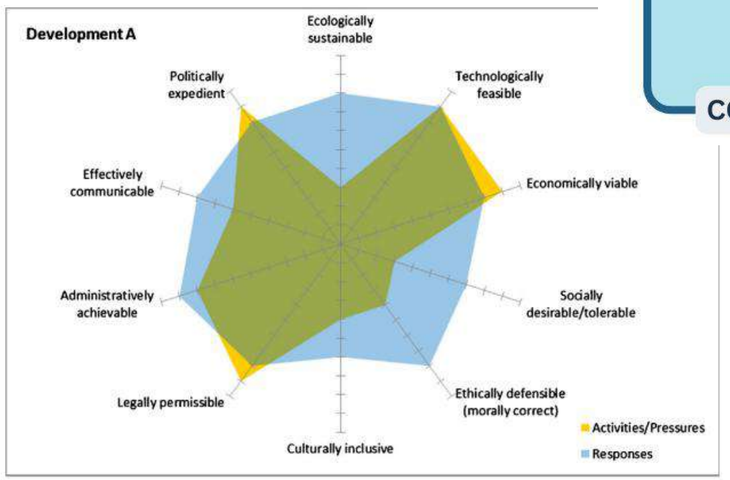
Solutions - The 10-tenets:

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



(Elliott 2013 Mar. Poll. Bull.; Elliott et al., OCMA 2025, + Cormier et al., in prep., and other papers)



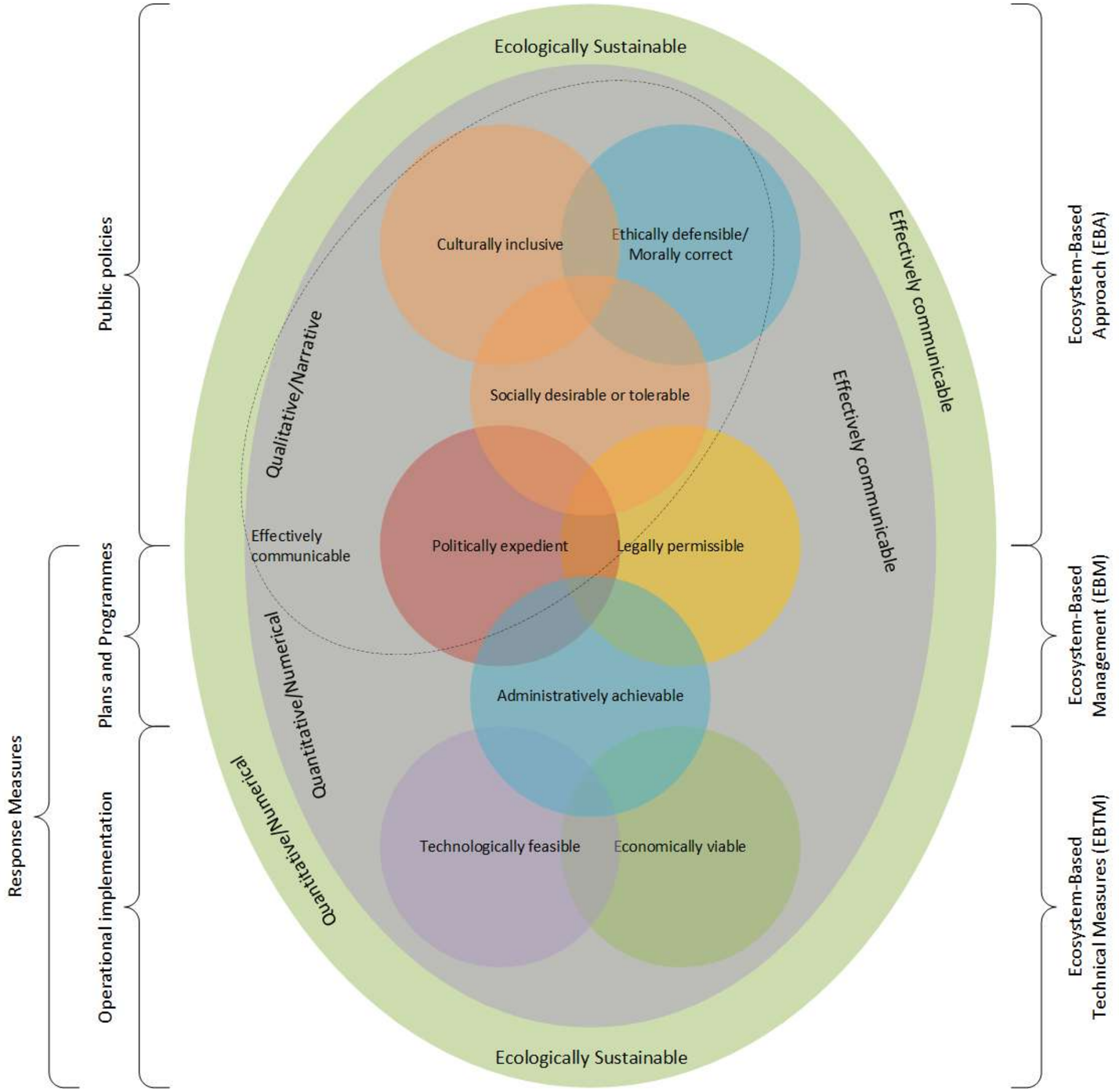
(NB spellcheck - not "10 Tennents – that's a good night in Scotland"!)



10 tenets of successful and sustainable environmental management – disciplines, data and information required – objective ways of determining success

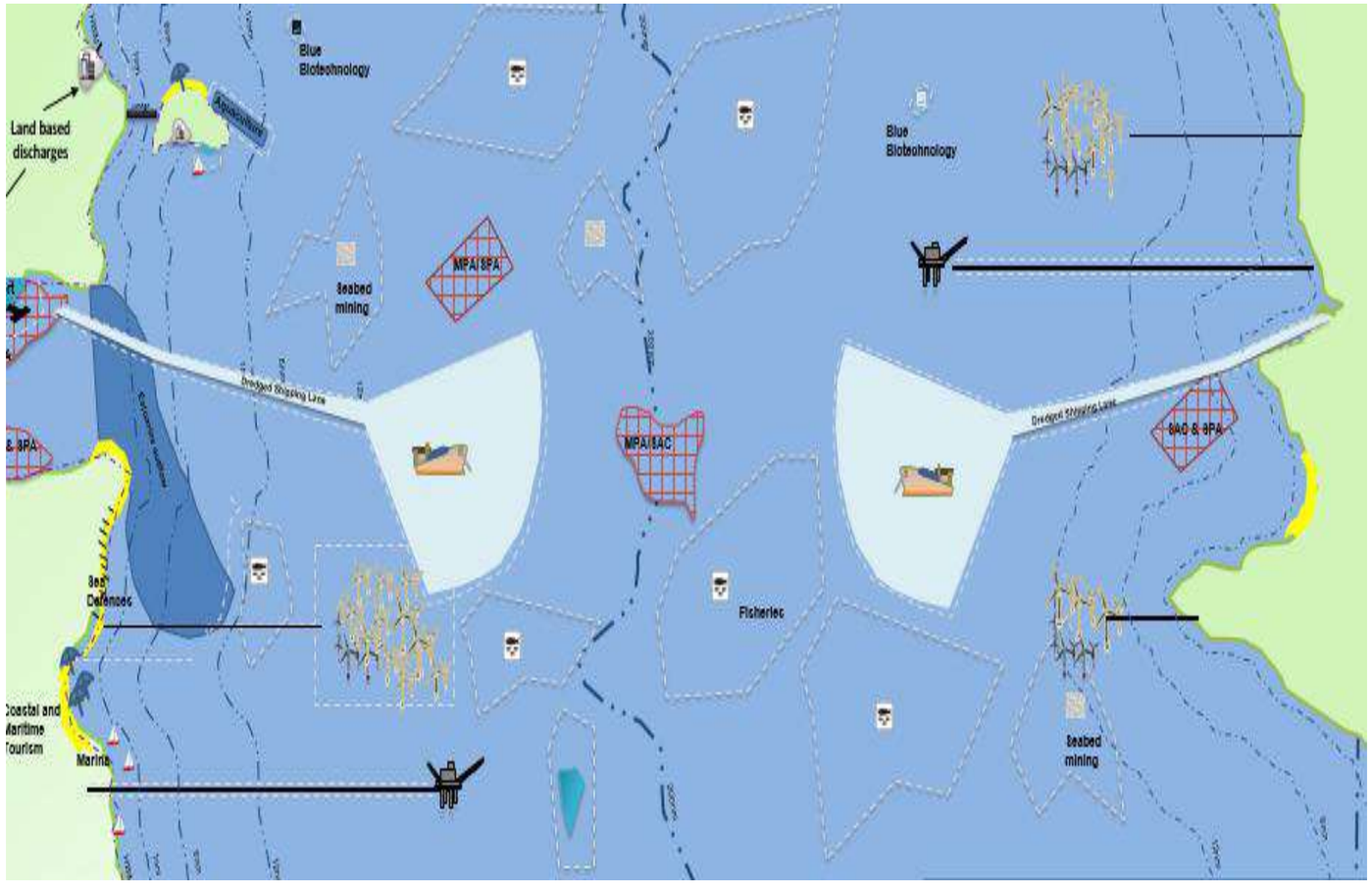
Ecosystem-Based Approach (EBA) to Ecosystem-Based Management (EBM) to Ecosystem-Based Technical Measures (EBTM)

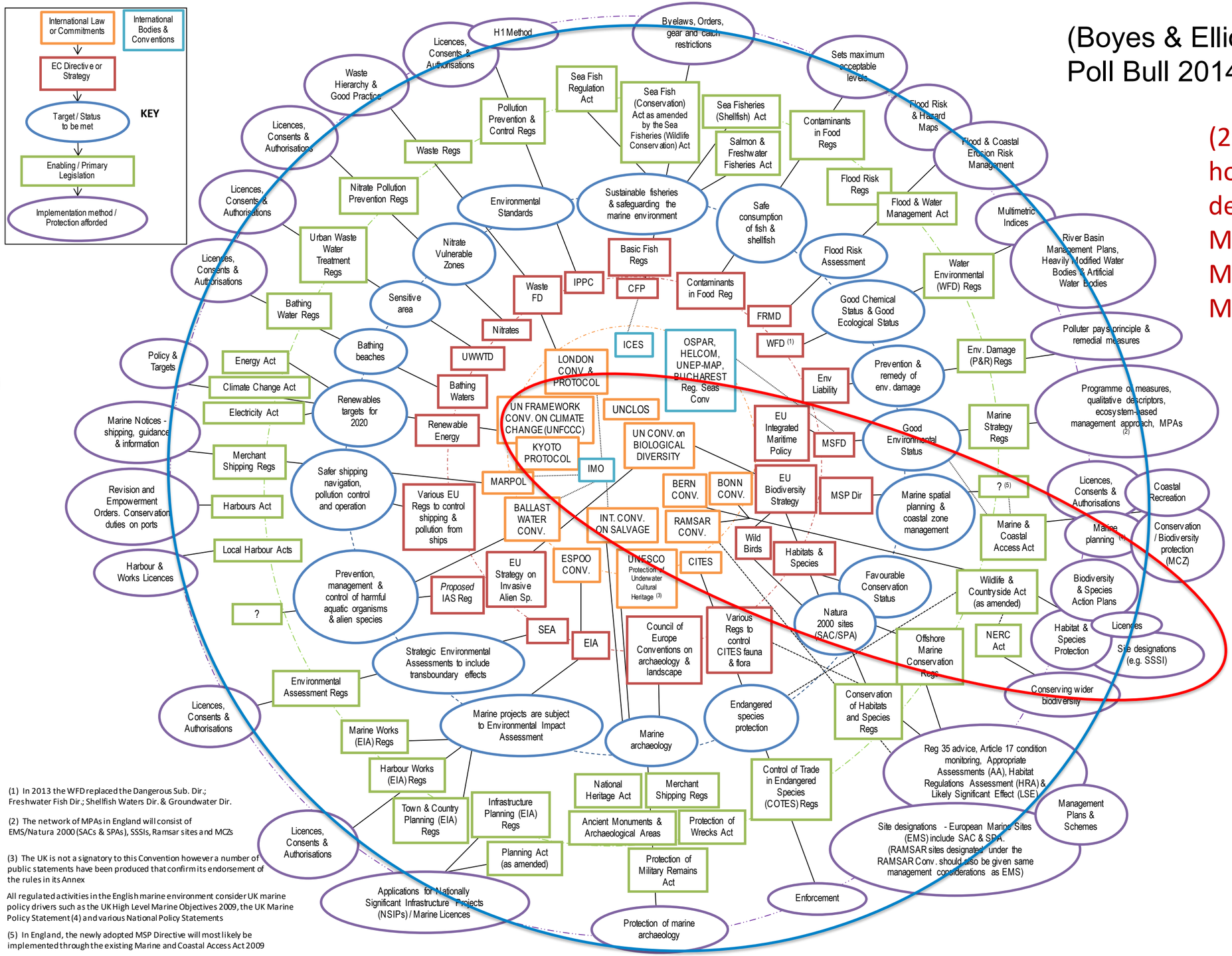
(Elliott 2013 Mar. Poll. Bull.; Elliott et al., OCMA 2025, + Cormier et al., in prep., and other papers)



Where are we managing?

- A small area (the activity footprint)
- A middle-sized area (pressures footprints)
- Middle to large areas (effects footprints)
- Whole estuaries
- Whole catchments/river basins
- Catchment-estuary-coastal areas
- Seas and sea regions
- Regional seas
- Areas Beyond National Jurisdictions
- The globe





(Boyes & Elliott, Mar Poll Bull 2014)

(29 geographical horrendograms developed in MarineSABRES, MarinePlan and MARBEFES)

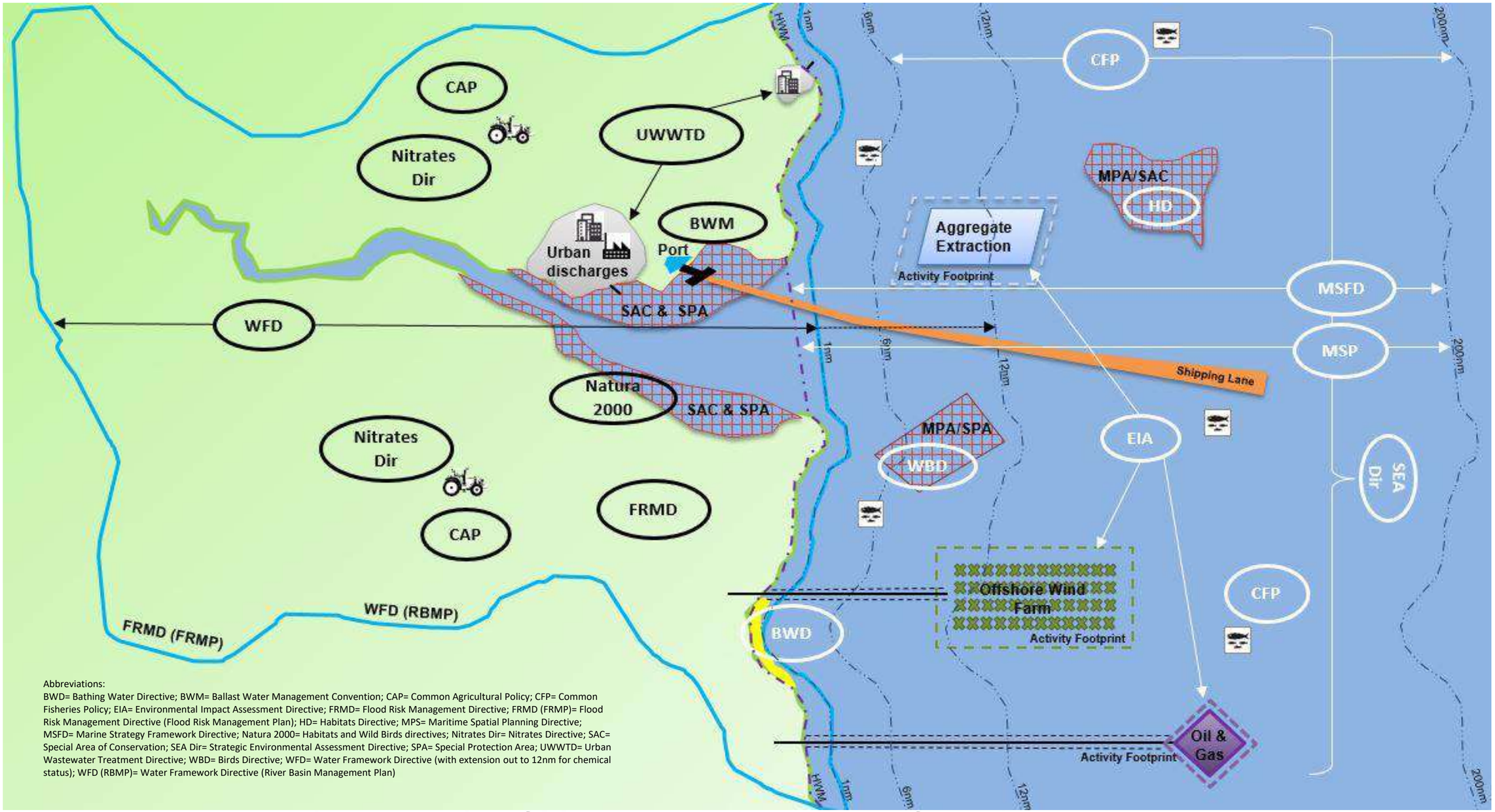
(1) In 2013 the WFD replaced the Dangerous Sub. Dir.; Freshwater Fish Dir.; Shellfish Waters Dir. & Groundwater Dir.

(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



An example of Management response-footprints – the geographical scope and competencies of EU legislation

How are we managing Emerald Growth/Economy? - Responses (using management Measures) (R(M)) (Programmes of Measures in WFD/MSFD/UKMS)

- By management action
- By developing programmes of measures
- By developing monitoring schemes
- By linking monitoring to SMART indicators
- By feedback to check if management is working
- By implementing laws
- By having lots of management bodies
- By making industry get their house in order
- By realizing the management footprint
- By having visions, objectives, policies
- By using good and fit for purpose science

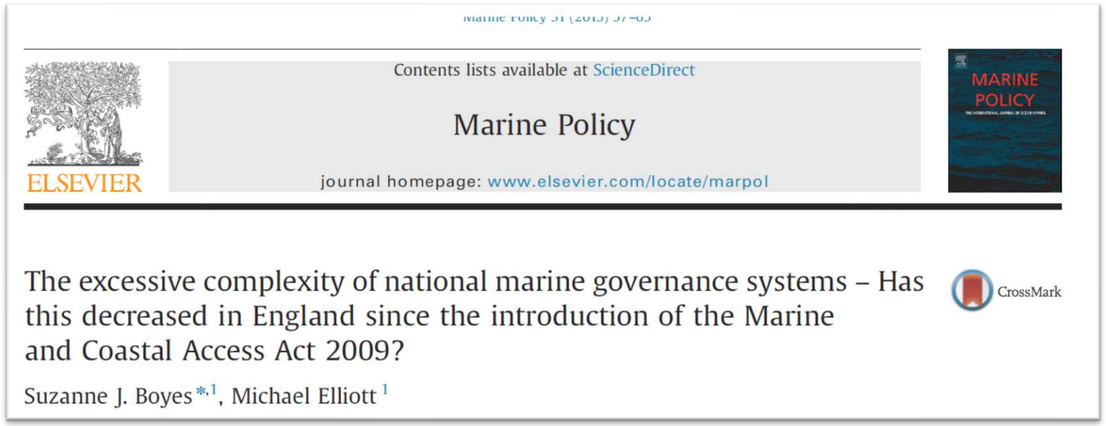
Cf.



Who is doing the managing?

- Environmental protection agencies
- Nature conservation bodies
- Fisheries departments
- Developers
- Municipal authorities
- Environmental health departments
- Port authorities
- Industries
- NGOs

(29 geographical organograms developed in MarineSABRES, MarinePlan and MARBEFES)

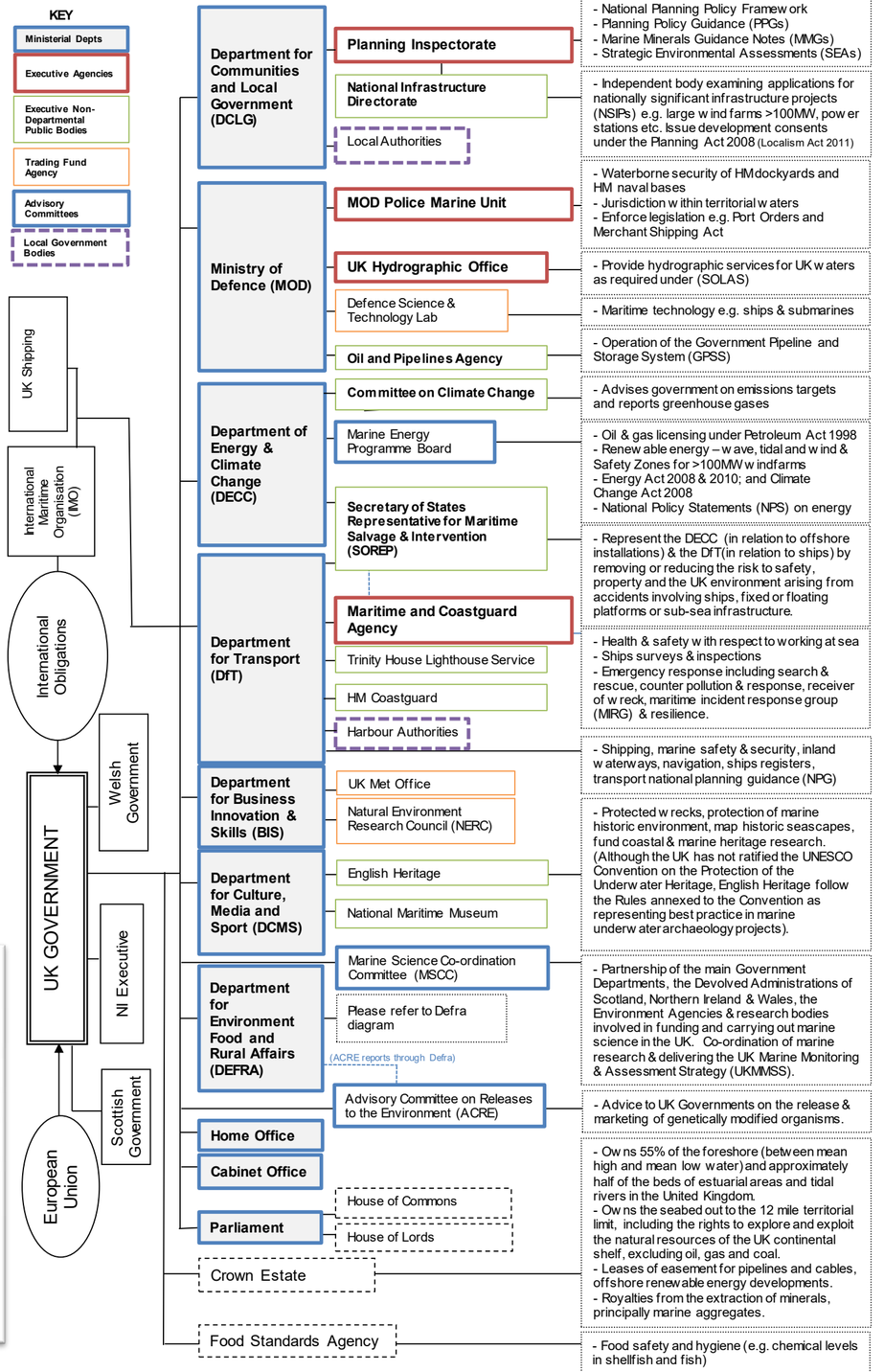

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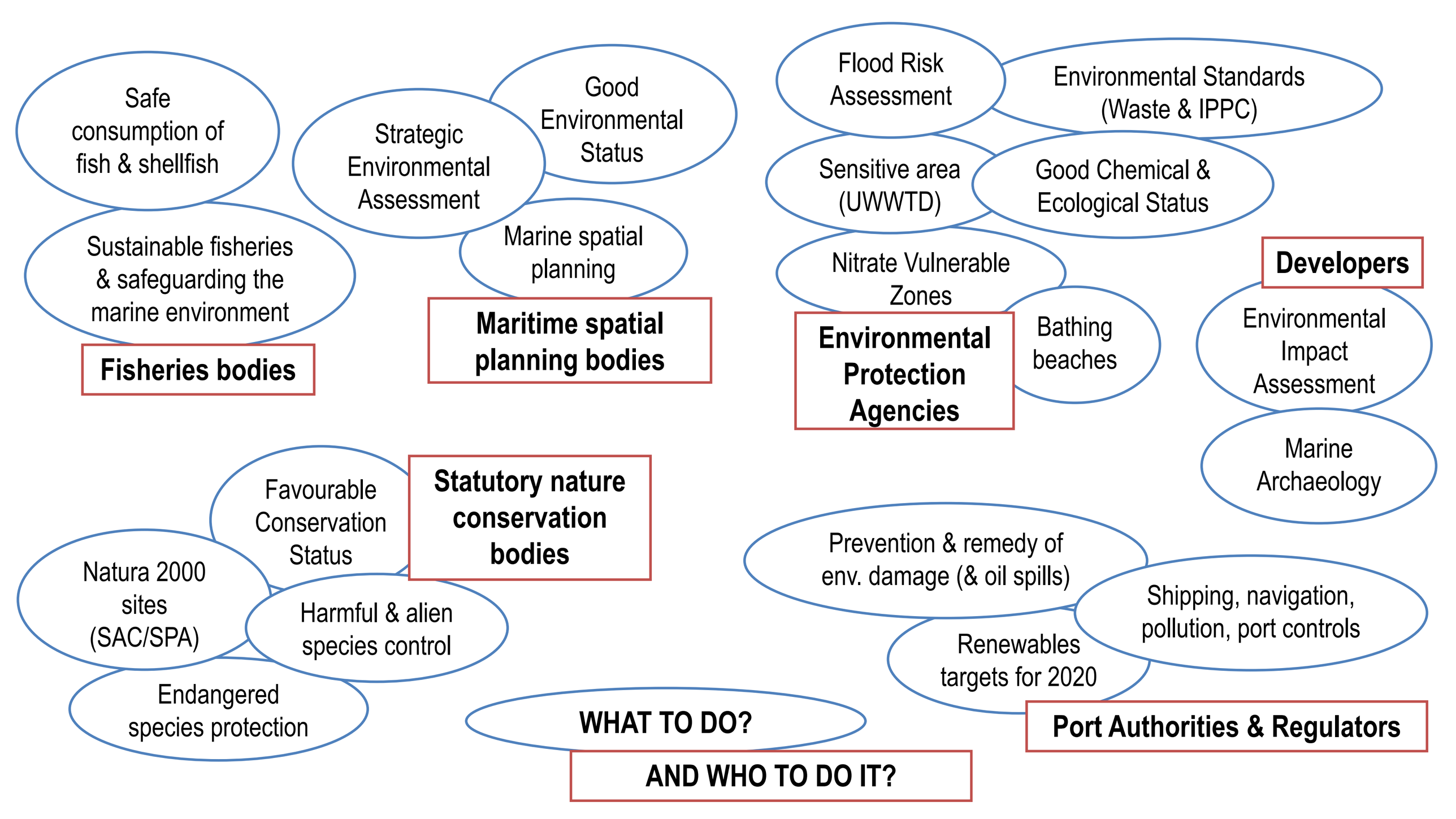
Marine Policy

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

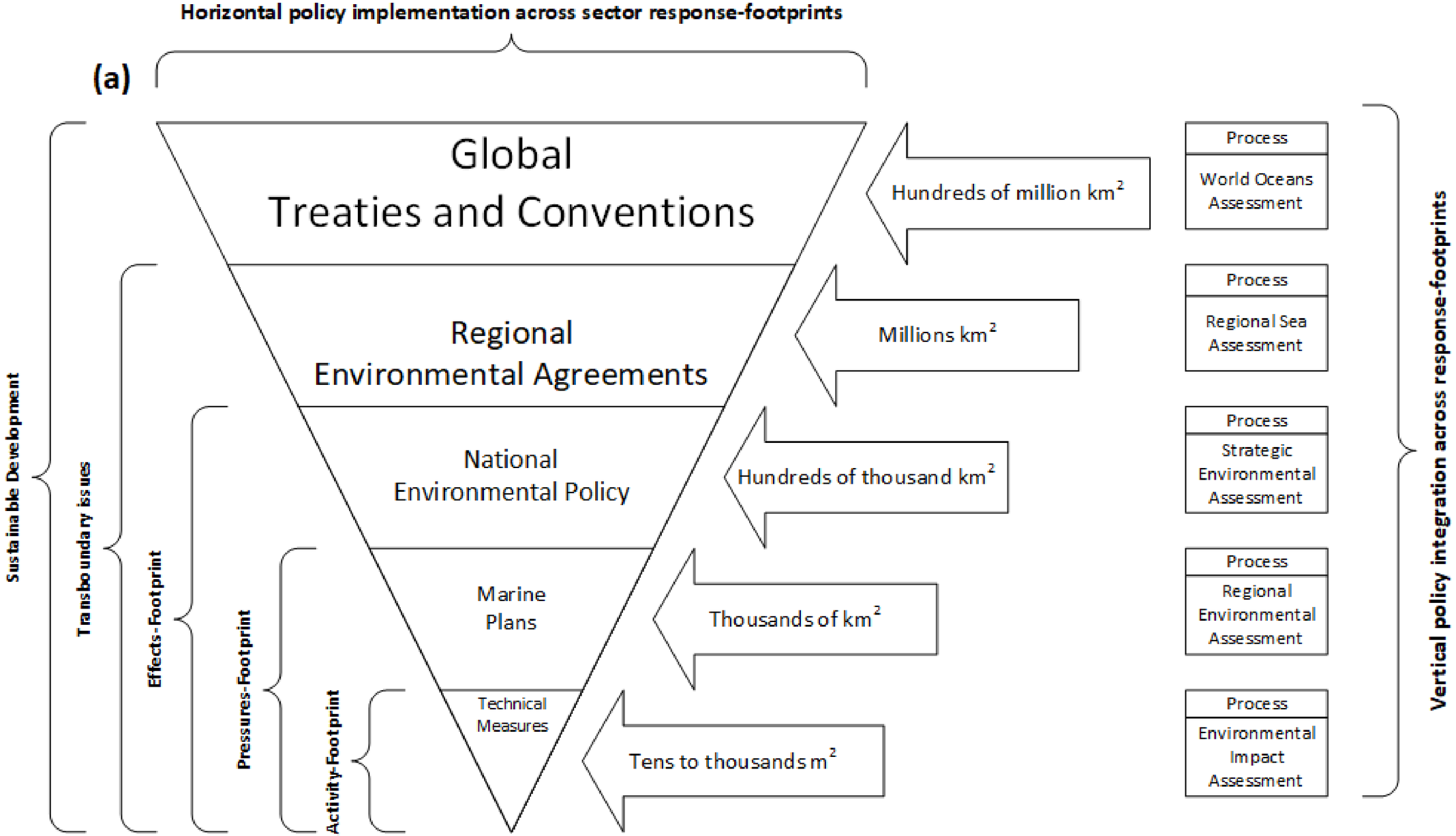
The excessive complexity of national marine governance systems – Has this decreased in England since the introduction of the Marine and Coastal Access Act 2009?

Suzanne J. Boyes*,[1], Michael Elliott [1]




Safe consumption of fish & shellfish
Sustainable fisheries & safeguarding the marine environment
Fisheries bodies
Strategic Environmental Assessment
Good Environmental Status
Marine spatial planning
Maritime spatial planning bodies
Flood Risk Assessment
Environmental Standards (Waste & IPPC)
Sensitive area (UWWTD)
Good Chemical & Ecological Status
Nitrate Vulnerable Zones
Bathing beaches
Environmental Protection Agencies
Developers
Environmental Impact Assessment
Marine Archaeology
Favourable Conservation Status
Statutory nature conservation bodies
Natura 2000 sites (SAC/SPA)
Harmful & alien species control
Endangered species protection
Prevention & remedy of env. damage (& oil spills)
Shipping, navigation, pollution, port controls
Renewables targets for 2020
Port Authorities & Regulators
WHAT TO DO?
AND WHO TO DO IT?

Management response-footprint triangle (Cormier et al., Front. Mar. Sci. 2022)



Evidence Needs - Recipe Leading to Integrated Marine Management

- Need to understand how our activities lead to which pressures
- Need to understand which pressures are within and outside our control
- Need to understand ecological structure and functioning
- Need to understand what state changes on the natural system occur from those pressures (effects-footprints)
- Lead to describing the impact on human welfare as effects on Ecosystem services and Societal goods and benefits
- Lead to defining the appropriate responses as management measures
- Require implementation of governance (policies, politics, administration and legislation)
- Within a multiuser system requiring resolution of conflicts amongst users
- Communicate by working with stakeholders

Bringing it all together – Systems Analysis Approaches, Decision Support Systems, Estuarine Planning Support Systems

- A Systems Analysis Approach (SAA) is needed to bring all the elements together for a logical and structured approach to study, assessment and management
- A Decision Support System (DSS) is needed to enable managers to cost-effectively decide solutions and to check if solutions are effective
- An Estuarine Planning Support System (EPSS) is a framework that defines a clear planning or management process and the tools available to support the process
- These all take into account the different disciplines to ensure the management of a system is holistic and encompass all the relevant stakeholder views
- The approaches and tools should be applicable to all environmental systems

MARINE SABRES

Bringing it all together - Managing marine and estuarine resources sustainably: a proposed integrated systems analysis approach

A. Setting priorities, visions and issues: need for information for and from habitats, species, human activities ….



B. Getting and ensuring the provenance of the information: natural and social scientists need to obtain environmental information, using monitoring and laboratory methods

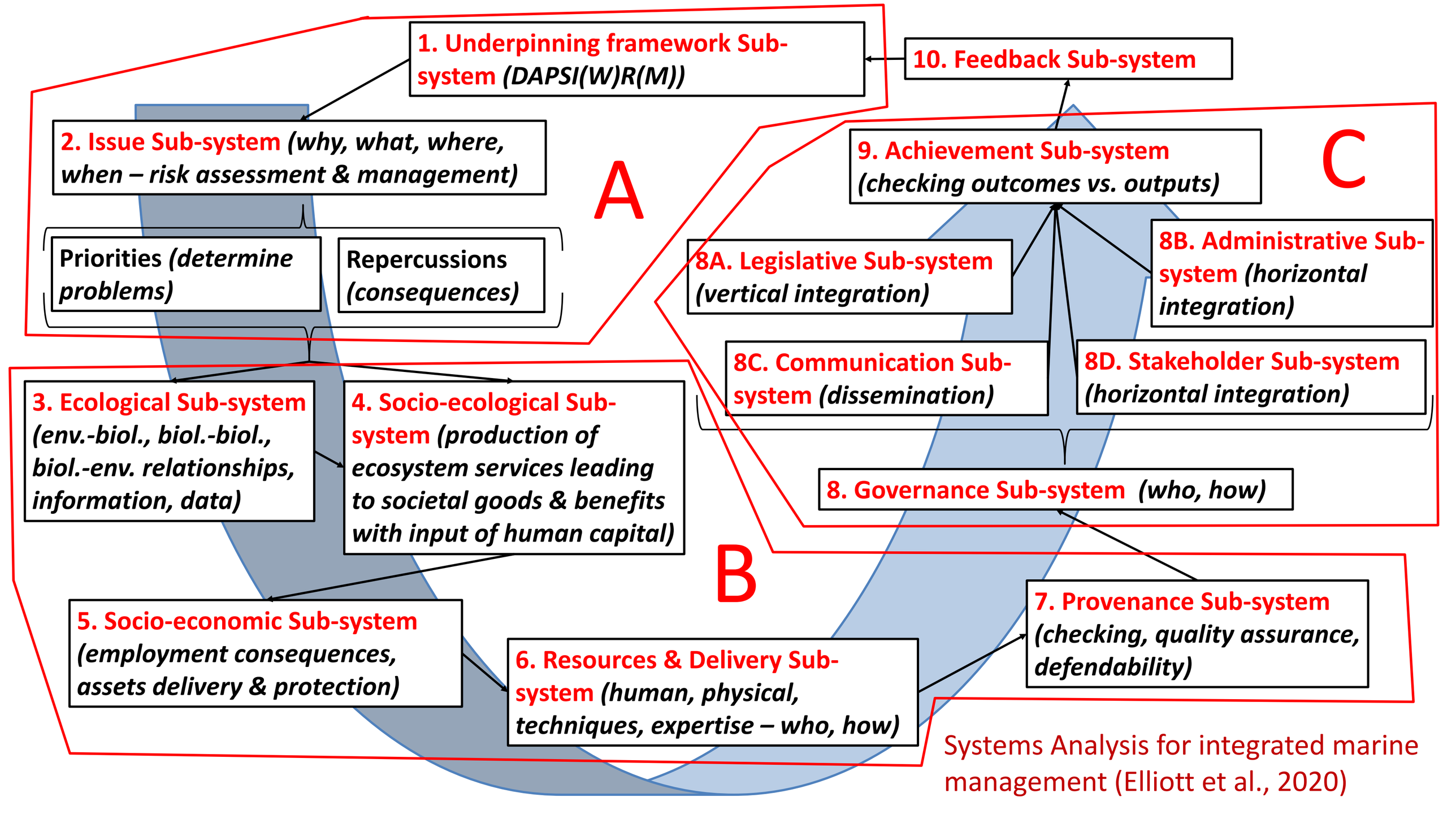


C. Using the information: governance and management imperatives, stakeholder meetings and consultation



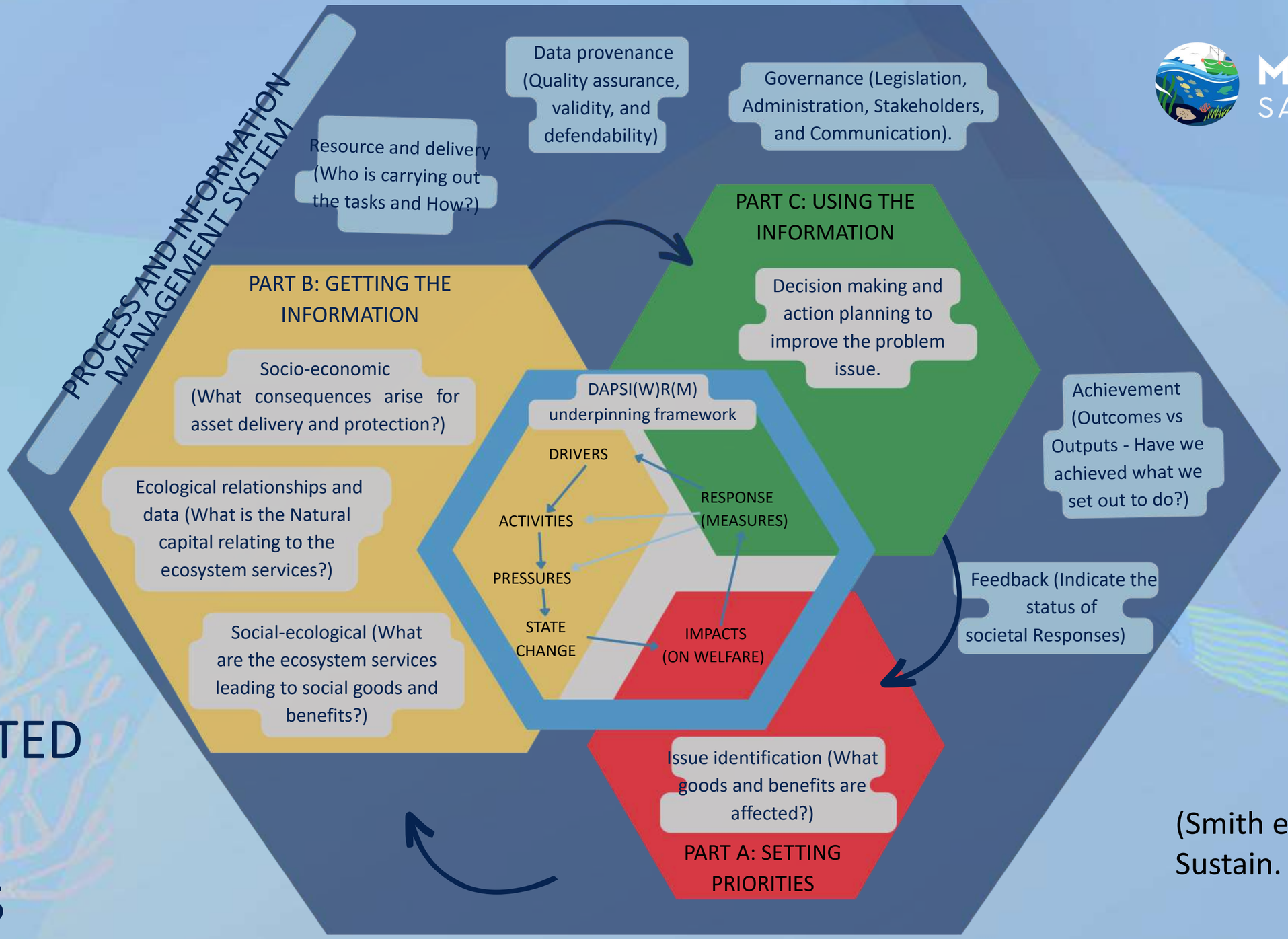


(Elliott, Borja & Cormier 2020 Ocean & Coastal Management; basis for Smith et al., 2025 Sustain. Futures)



Systems Analysis for integrated marine management (Elliott et al., 2020)

THE INTEGRATED SYSTEMS ANALYSIS



(Smith et al., 2025 Sustain. Futures)

Emerald Growth and Economy - Tackling the challenges:

- Emphasise that the system functions because of connectivity across all fields and domains
- Start off with SMART objectives (EBA-EBM-EBTM)
- Base management on good science
- Quantify the four footprints and ROAM framework
- Collect data to use and use data collected
- Have solid underpinning concepts and tools
- Use ecological, socio-ecological and socio-economic valuation
- Harmonise the governance (policies, politics, administration and legislation) with coherence and equivalence
- Use systems analysis and SES and know the measure of success in management



"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?"

- ***Focus on the global primary activity footprint for causes to climate change and the response activity footprint for the consequences***

Thank you!

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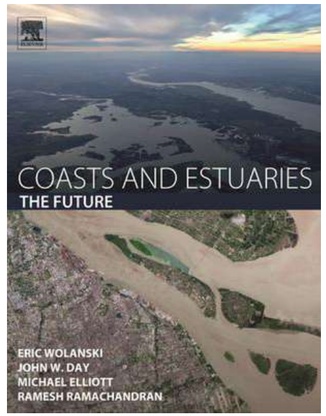
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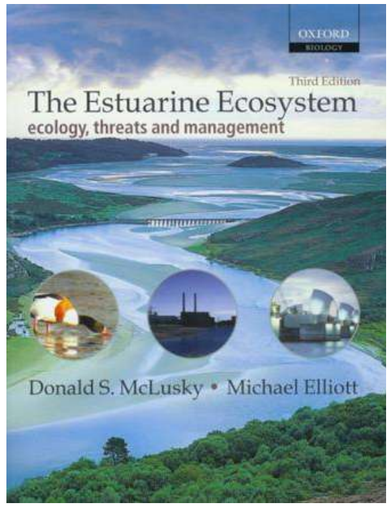
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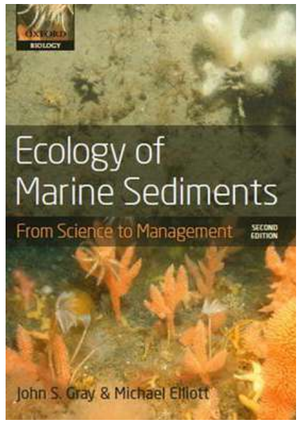
MarineSABRES (led by UCC, Ireland)

MARBEFES (led by IOPAN, Poland)

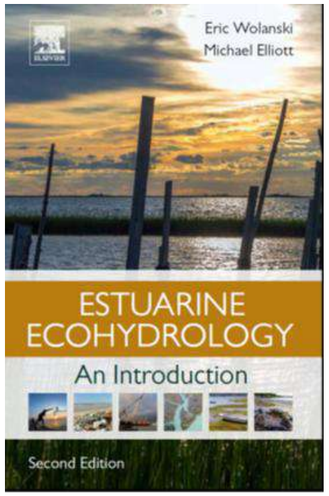
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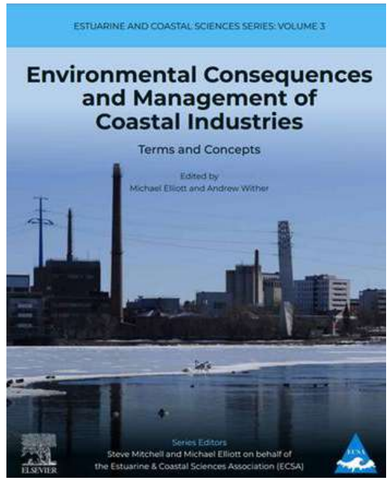


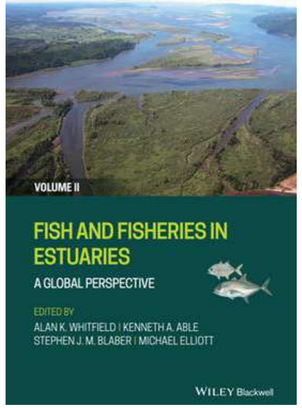


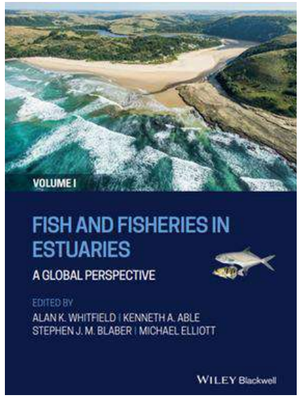


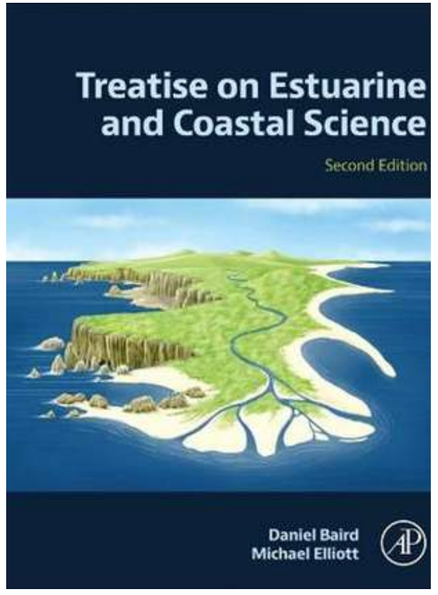












7 volumes – (March 2024)