From cumulative activity to ecological risk: advancing cumulative effects assessment within strategic environmental assessment for marine spatial planning

Virginia Morejón
Virginia.morejon@ucdconnect.ie

PhD Researcher, University College Dublin, School of Geography, Ireland

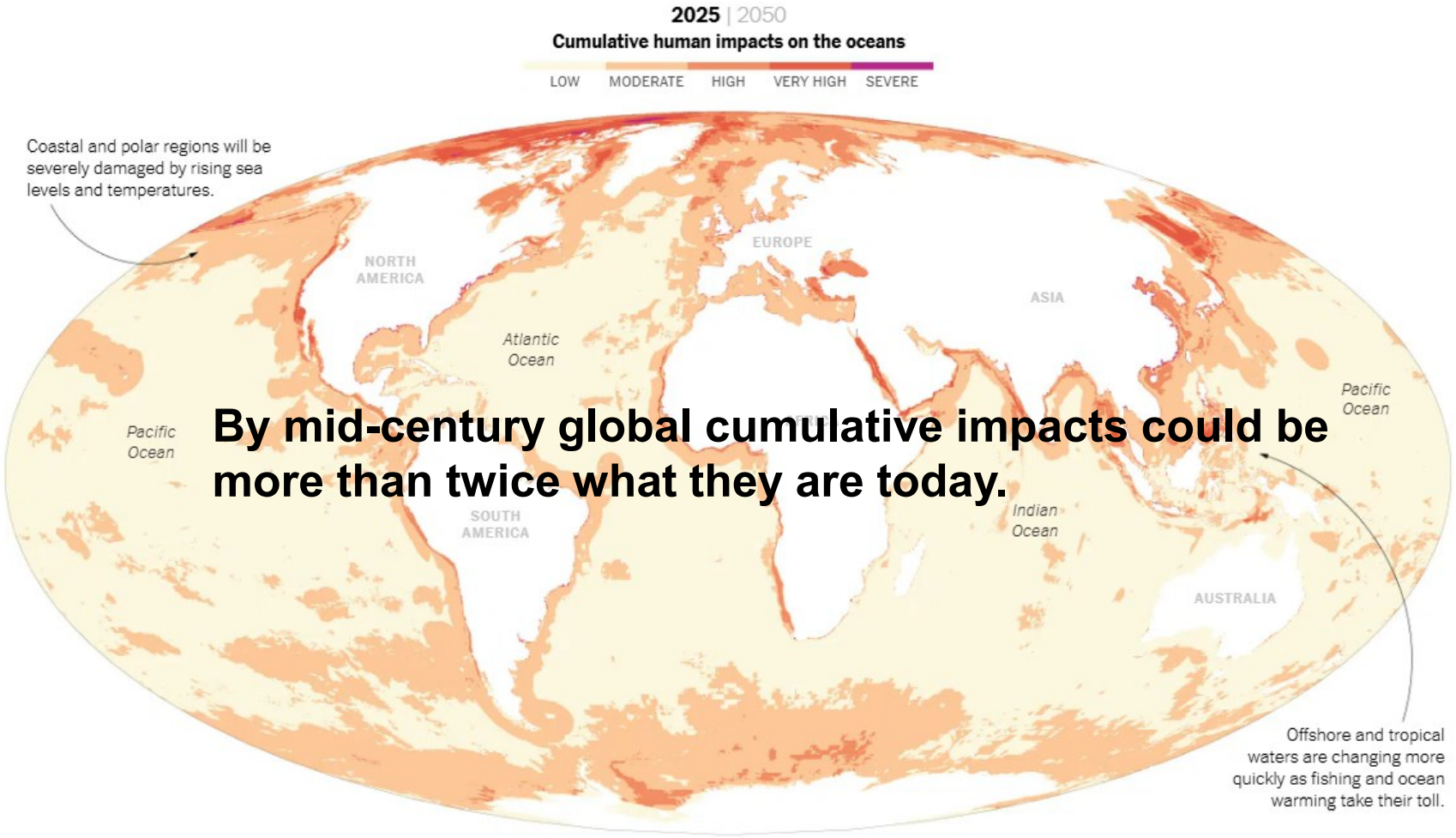
European Marine Board Science Webinar | November 19, 2026

UCD School of Geography
Scoil na Tíreolaíochta UCD

Marine Institute
Foras na Mara

Humans Are Altering the Seas. Here's What the Future Ocean Might Look Like.

Some marine ecosystems could soon be unrecognizable, according to new research.



By mid-century global cumulative impacts could be more than twice what they are today.

Source: Halpern, et. al., Science (2025)

Cumulative effects / cumulative impacts

- **effects = environmental changes**
- **impacts = often adds severity or significance**

In practice, both terms are often used around the same core idea: **combined consequences of multiple activities and pressures on ecosystem components**

*Cumulative effects assessment (CEA) is the process for systematically evaluating environmental changes resulting from the **additive, synergistic, or antagonistic** effects of multiple human actions and natural processes on ecosystem components—the species or habitats affected by different human activities and their pressures (Borja et al. 2016, 2024).*

Cumulative Effects Assessments (CEA) at heart of SEA and EIA processes

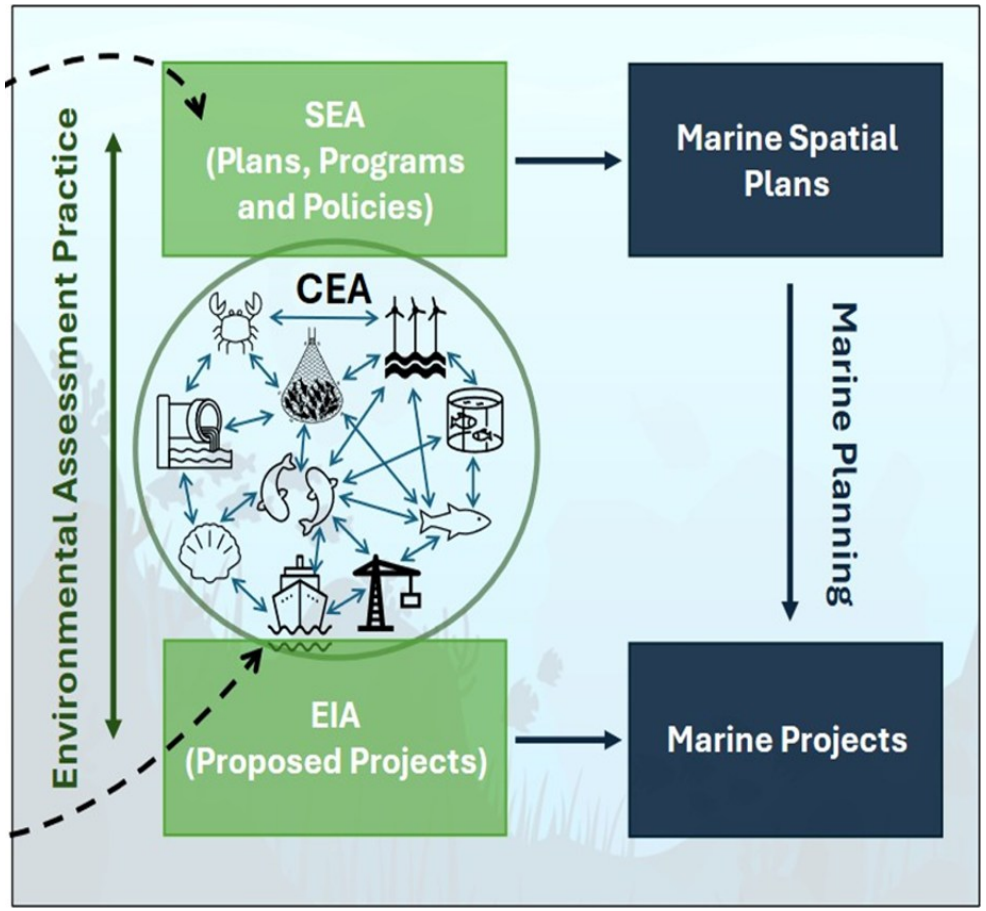
Strategic level

SEA
policies/plans/programmes
e.g. National ORE DMAP

Project level

EIA
individual projects
e.g. Offshore wind development

Strategic Environmental Assessment Directive (2001/42/EC)



Marine Strategy Framework Directive (2008/56/EC)

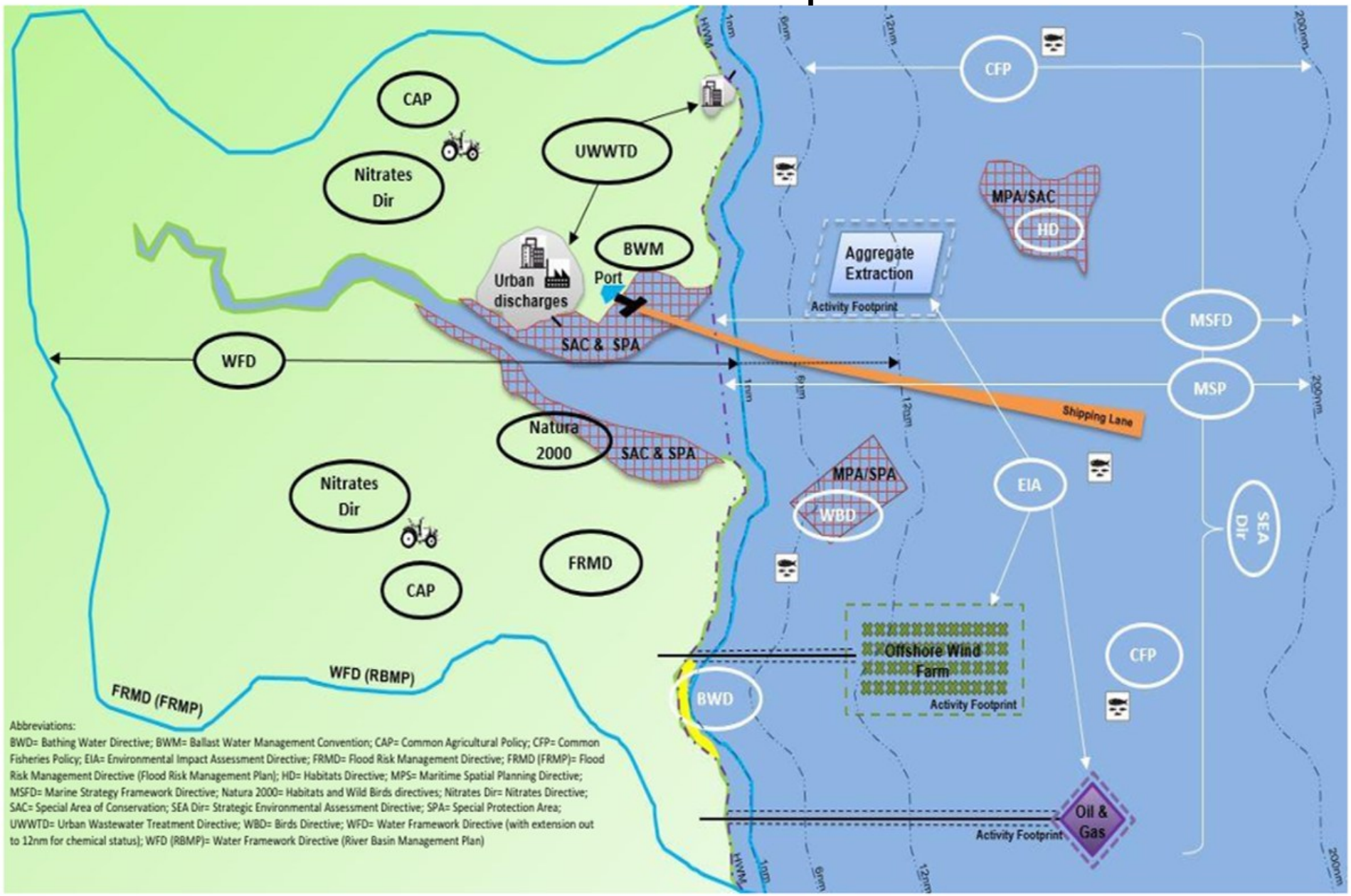
Maritime Spatial Planning Directive (2014/89/EU)

Environmental Impact Assessment Directive (2011/92/EU)

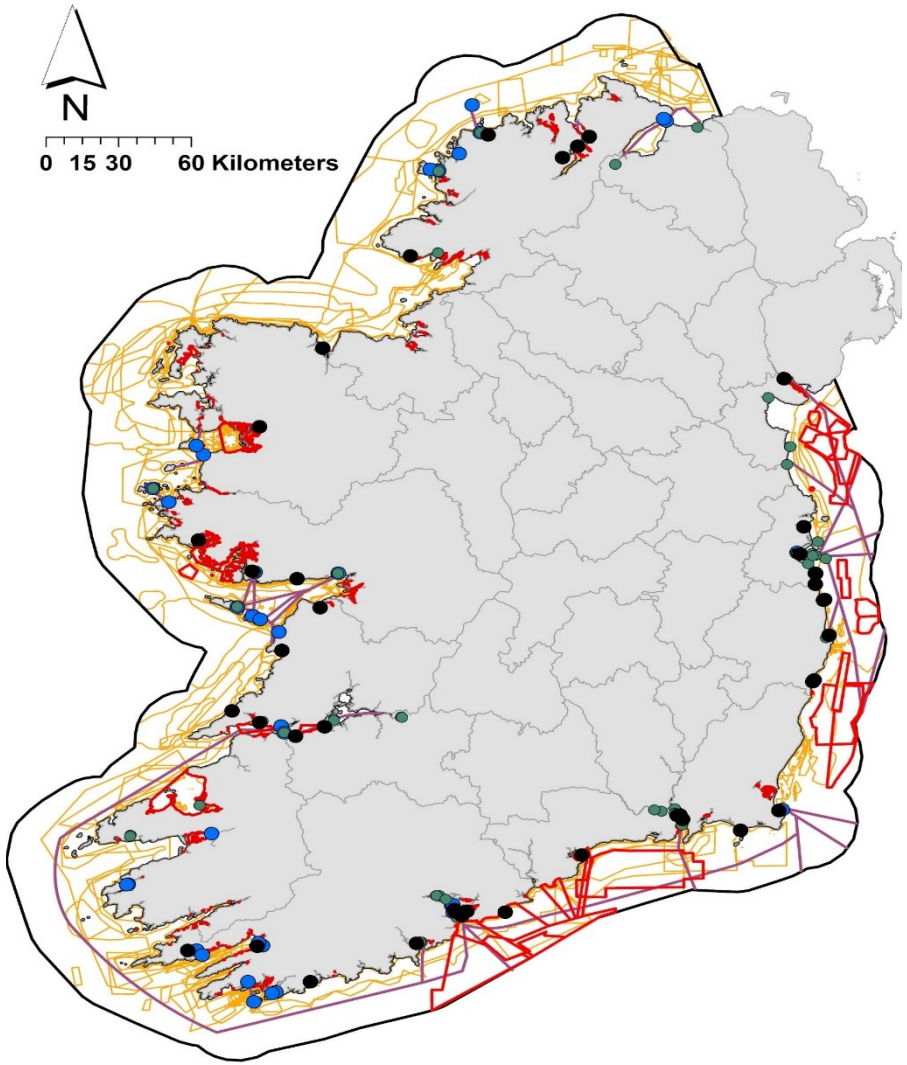
Water Framework Directive (2000/60/EC)

The marine policy context

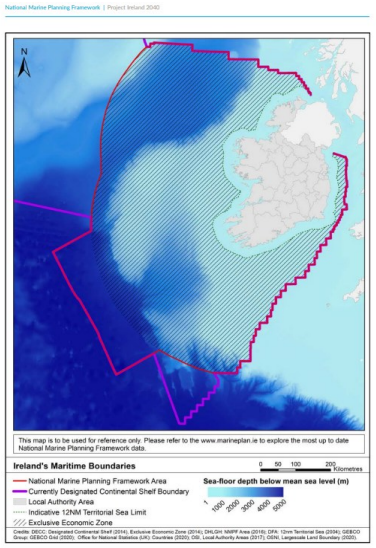
Source: Mike Elliott (2022), AZTI Summer School presentation

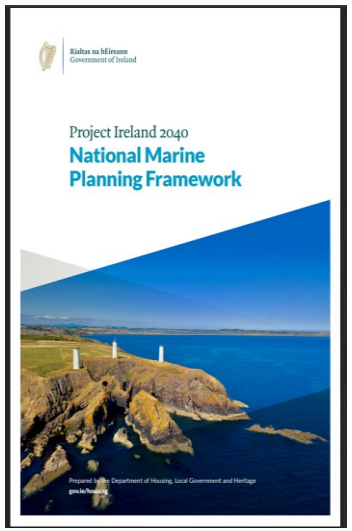


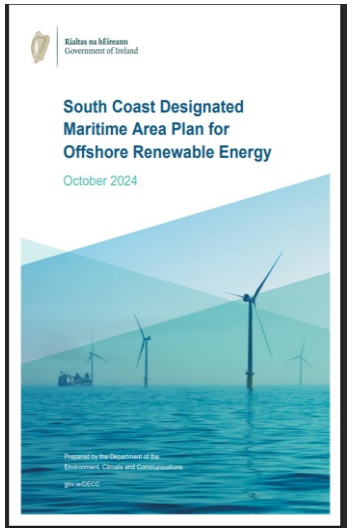
Marine spatial planning efforts are increasing in Ireland

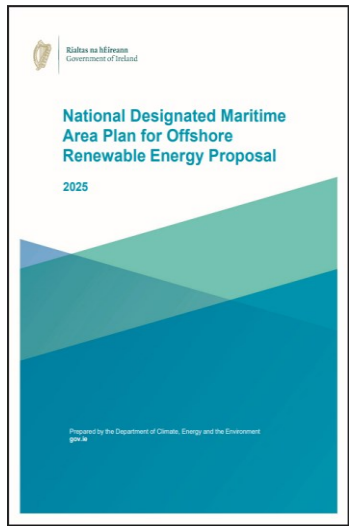


More offshore activity is expected, especially around offshore renewable energy.









5 GW by 2030 → 20 GW by 2040 → at least 37 GW by 2050.

Marine spatial planning is about deciding how marine space can be used while also protecting the ecosystems and services we depend on.

SEA
strategic view

→

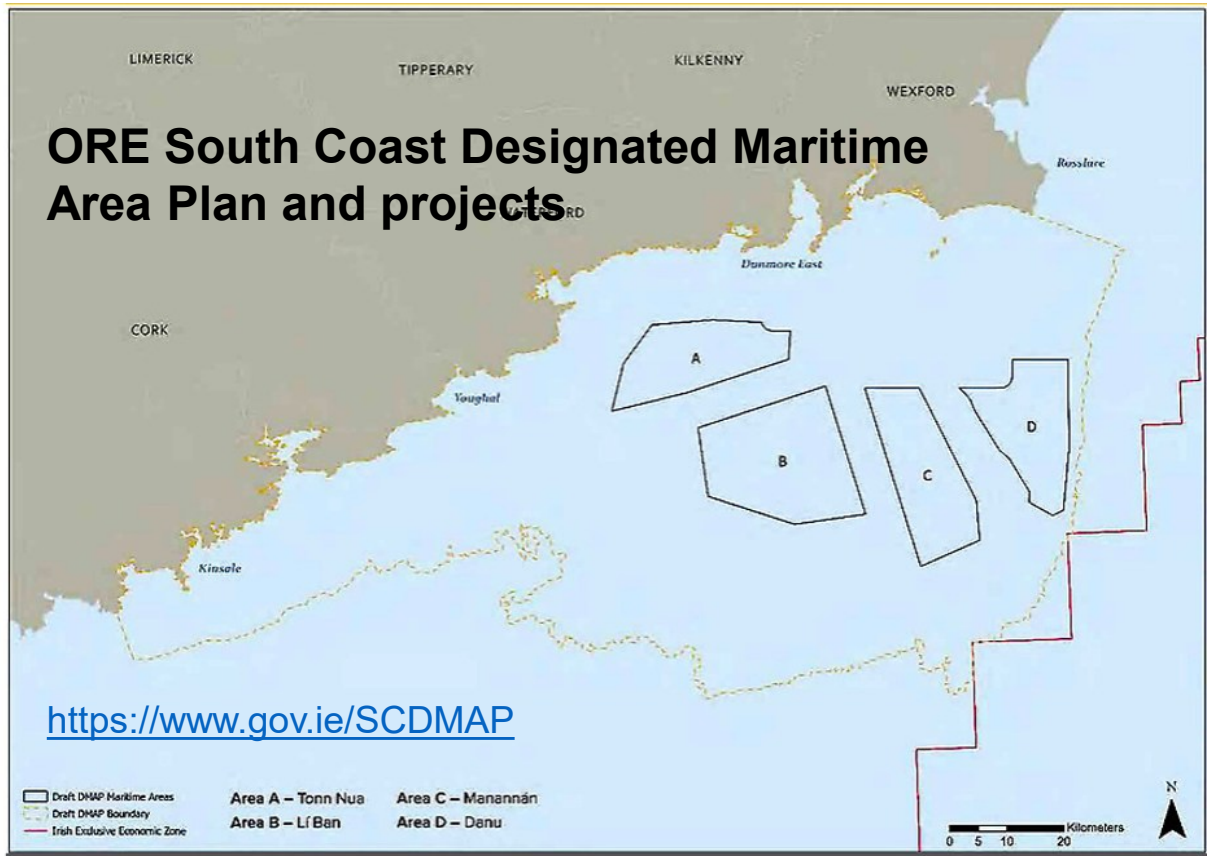
EIA
local detail

*offer better geographical scale for cumulative effects lose detail

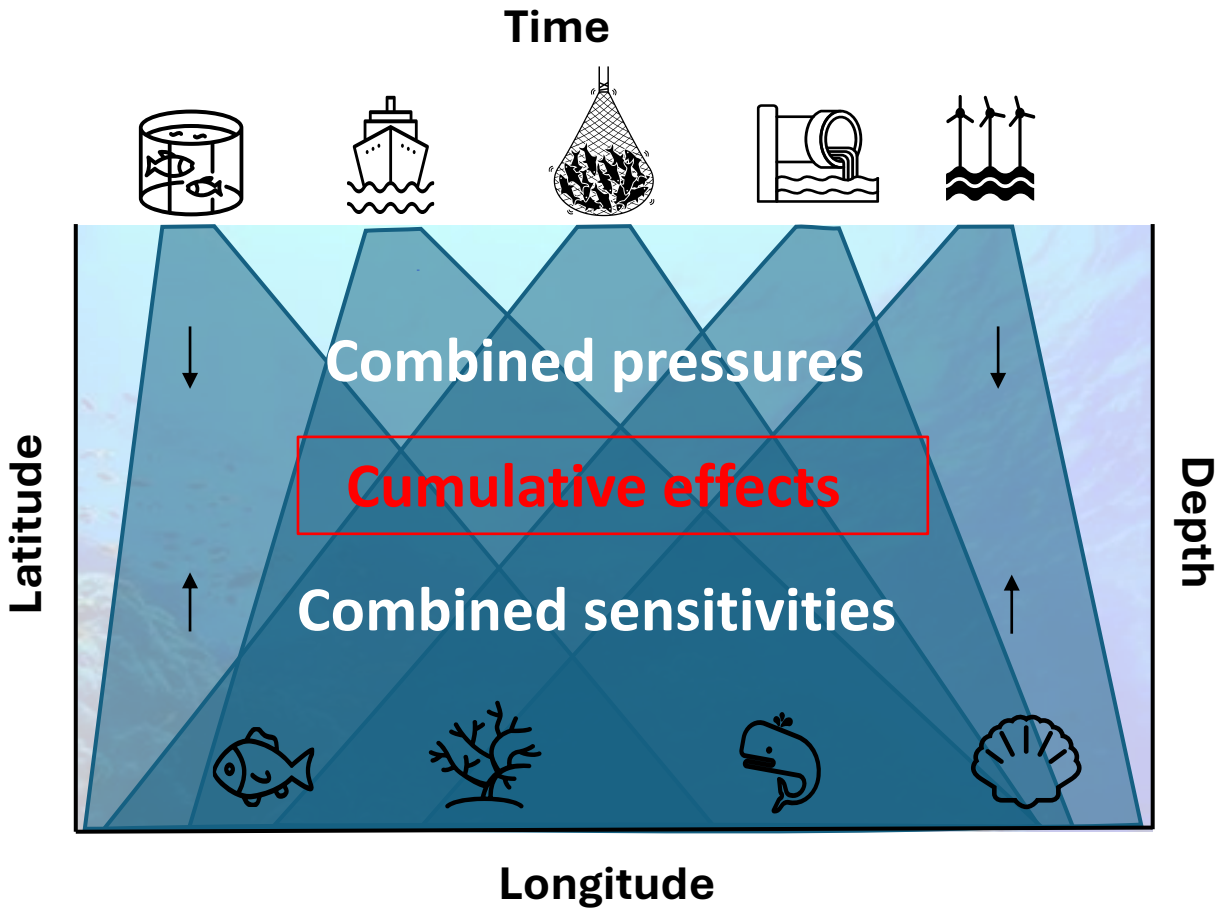
- project scale often has better detail

- strategic scale sees more
- pressures can disperse
- species move
- activities change over time
- effects can be transboundary

Zooming out helps, but it is not enough. Cumulative effects do not really respect plans/project boundaries.

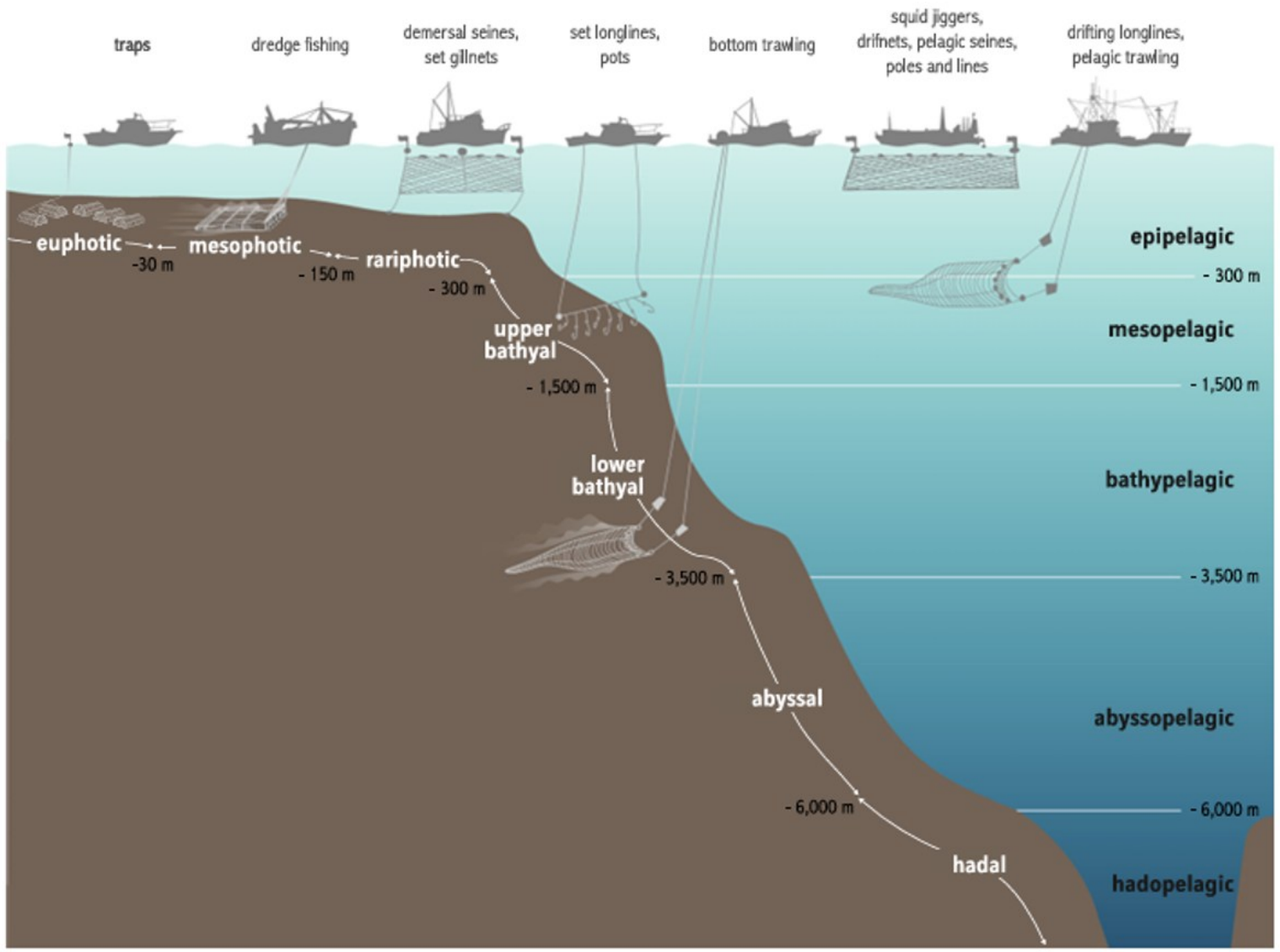


CEA is complex and offshore assessments can be harder



- Where are habitats?
- Where are species through the year?
- What happens at the seabed?
- How far might pressures travel?

The sea is not a flat map

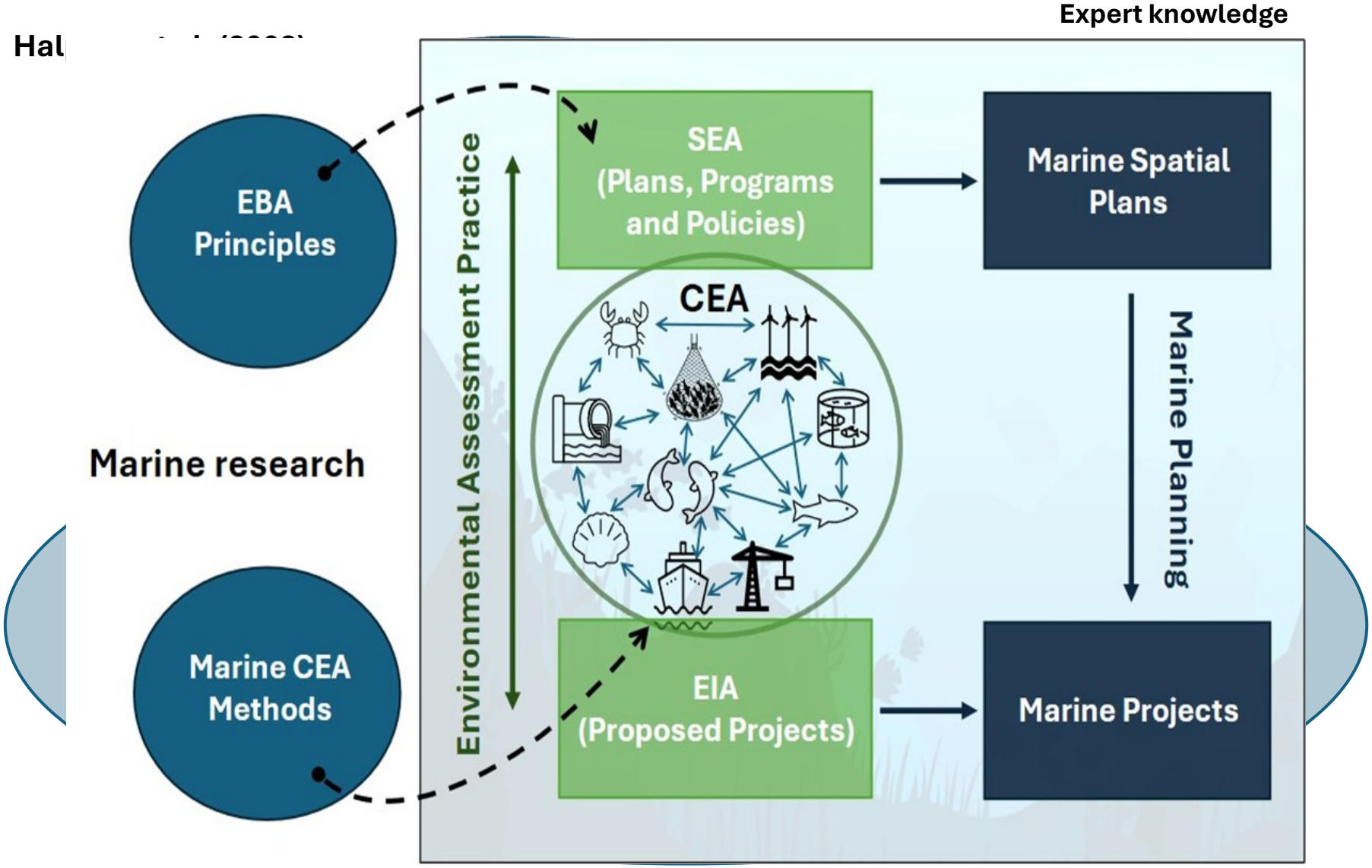


Jacquemont et al. (2024)

Most global mapping of activities and pressures remains predominantly two-dimensional (2D)

Planning often looks down from above. Below the surface, we rely heavily on data.

A variety of methods but Disconnection between the science and the practice



Morejón et al. (2025)

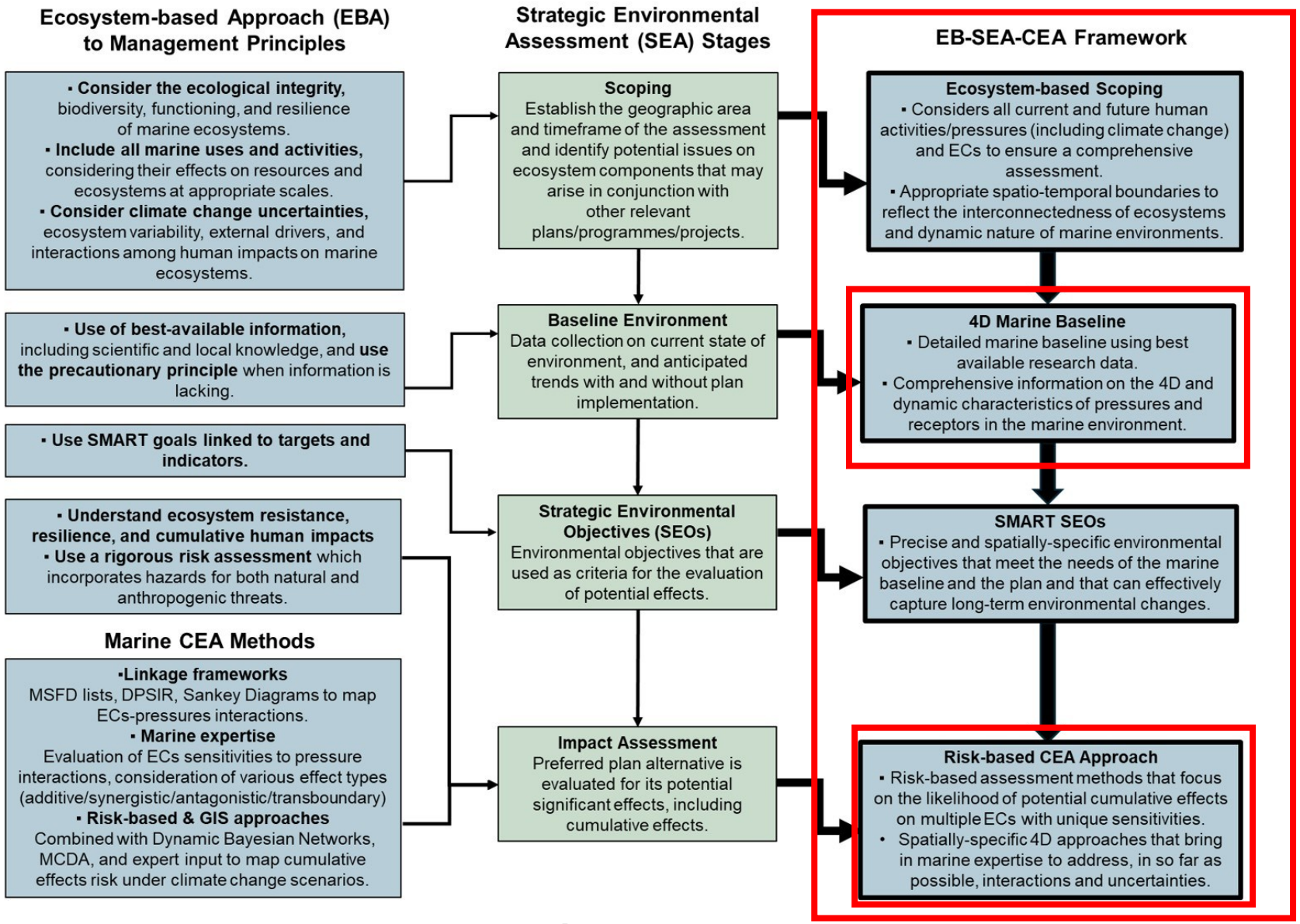
Where my PhD comes in

How can we use that existing science more effectively in practice, so that it can actually inform planning decisions at the strategic level?

How can CEA within SEA become more spatially explicit, ecosystem-based and better suited to marine planning?

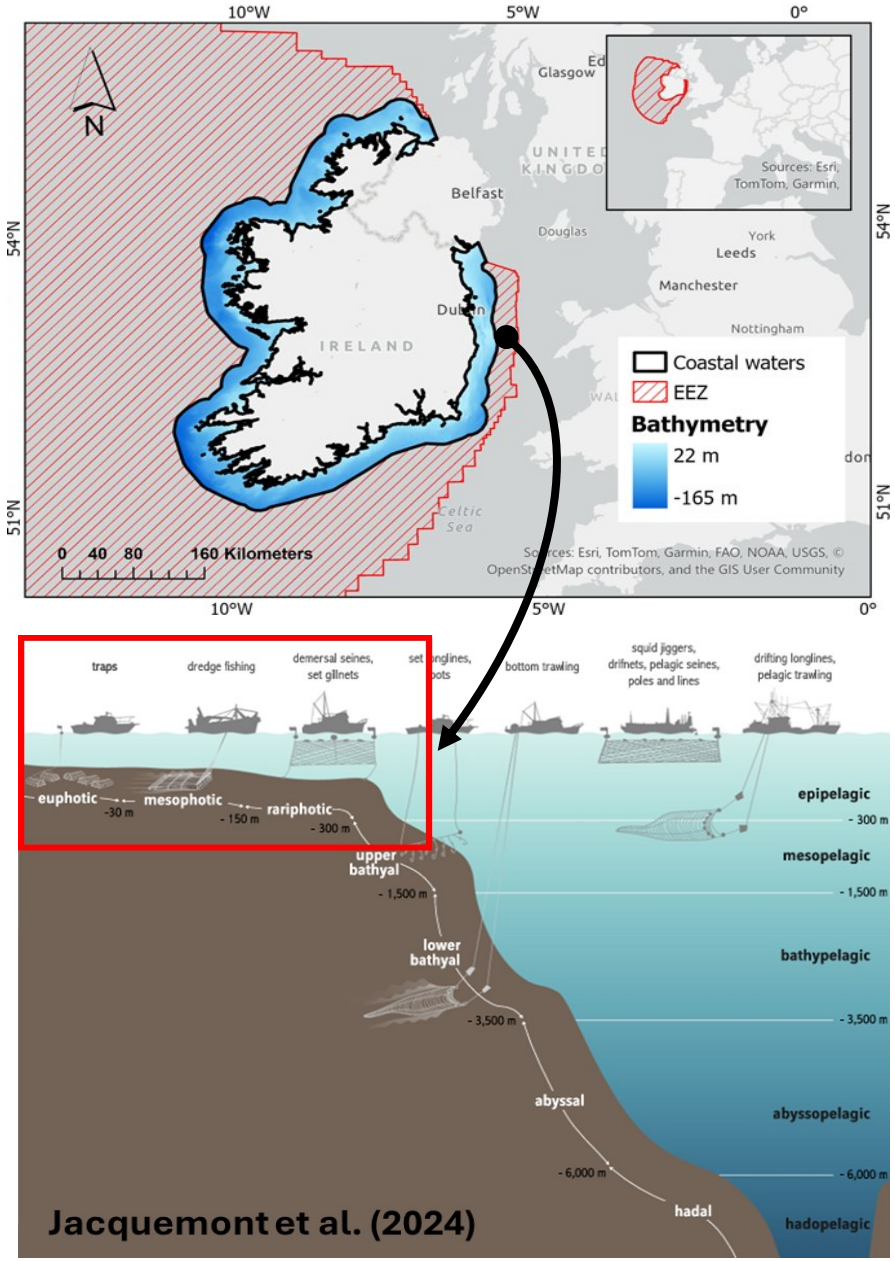
Step 1: connect research and environmental assessment practice

The Ecosystem-based-SEA-CEA Framework



Morejón et al. (2025)

Step 2: make the baseline more marine



Four-dimensional (4D) Marine Baseline: spatially-explicit maps of cumulative activity across seasons and depth

- Baseline = inventory of current environment
- Need to reflect how it changes
- Move beyond 2D view→ include:
  - **Horizontal space** (x,y)
  - **Time** (e.g., activity seasonal variations)
  - **Depth** (e.g., activity vertical footprint)

    euphotic (0-30m), **upper mesophotic** (30-60m), **lower mesophotic** (60-150m), **rariphotic** (150-165m)

Methodology/GIS Workflow

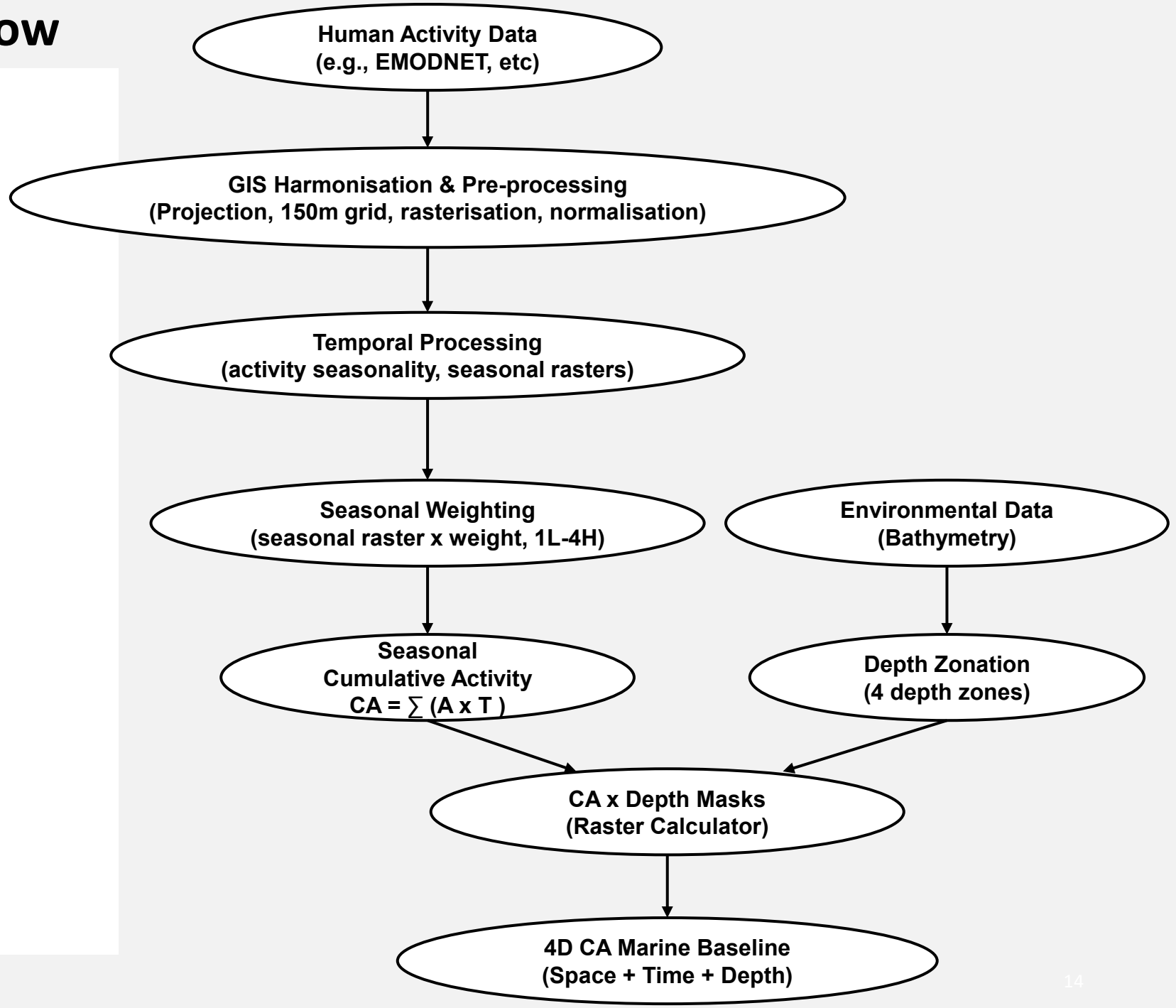
Sectors/Activities in Irish coastal waters (12 nm)

Mobile activities

1. **Fisheries (VMS raster)**
   - Beam trawling
   - Dredges
   - Static gears (gillnets, longlines)
   - Pots
   - Nephrops trawling
   - Bottom otter trawling
   - Pelagic trawling
2. **Shipping (AIS raster)**
   - Cargo vessels
   - Tanker vessels
3. **Tourism / Sports / Recreation (AIS raster)**
   - Pleasure vessels
   - Sailing vessels
   - Passenger vessels
4. **Defense and Security (AIS raster)**
   - Military vessels
5. **Mineral Exploration and Mining (AIS raster)**
   - Dredging vessels

Static activities

6. **Aquaculture (Polygon)**
   - Blue mussel farming
   - Pacific oyster farming
   - Atlantic salmon farming
7. **Wastewater Treatment and Disposal (Point)**
   - Wastewater discharges
8. **Energy – Offshore Renewable (Polygon)**
   - Offshore wind farm projects
   - Site investigations



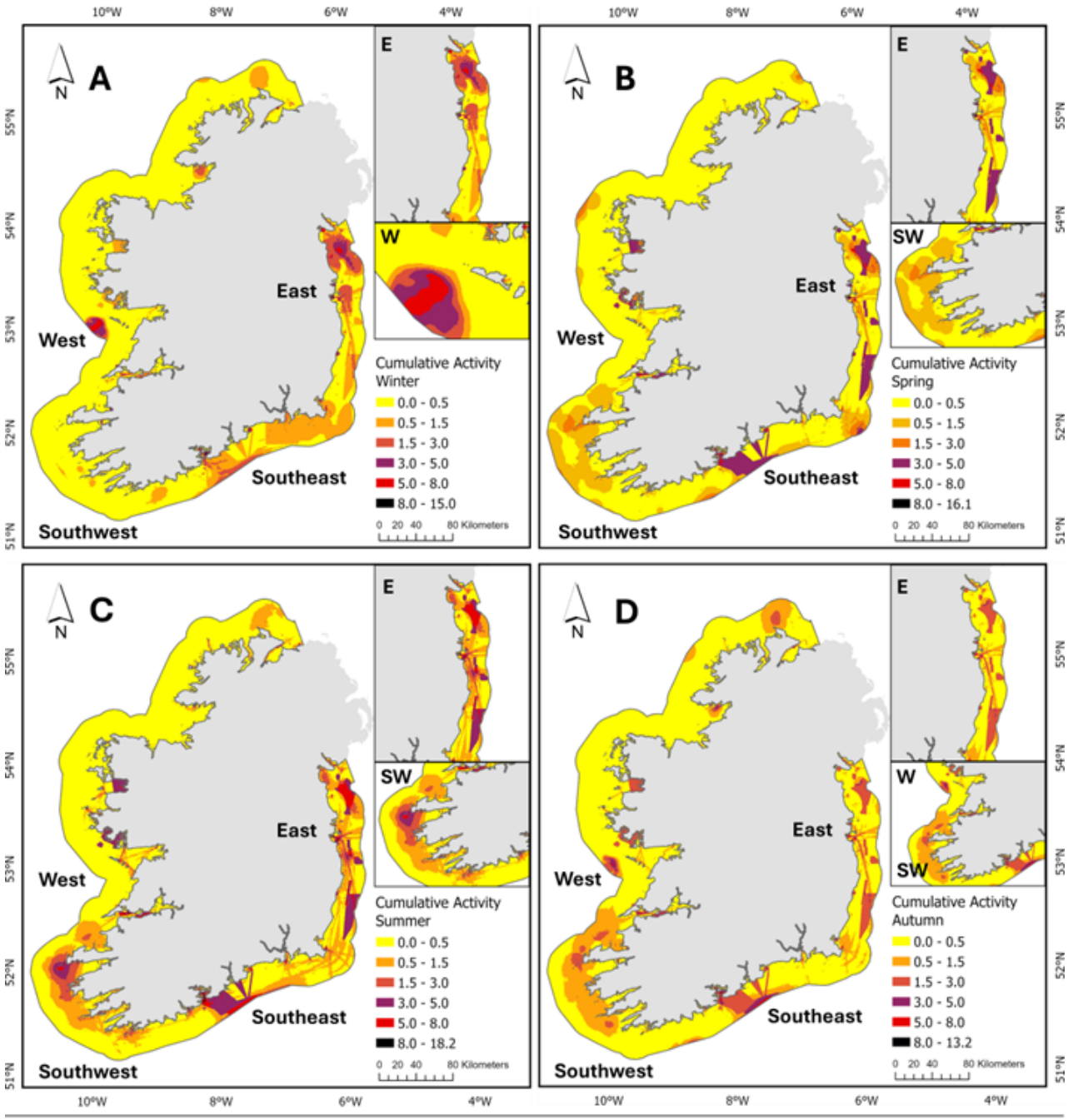
Variation of cumulative activity across seasons in 2023

- Cumulative activity is dynamic:

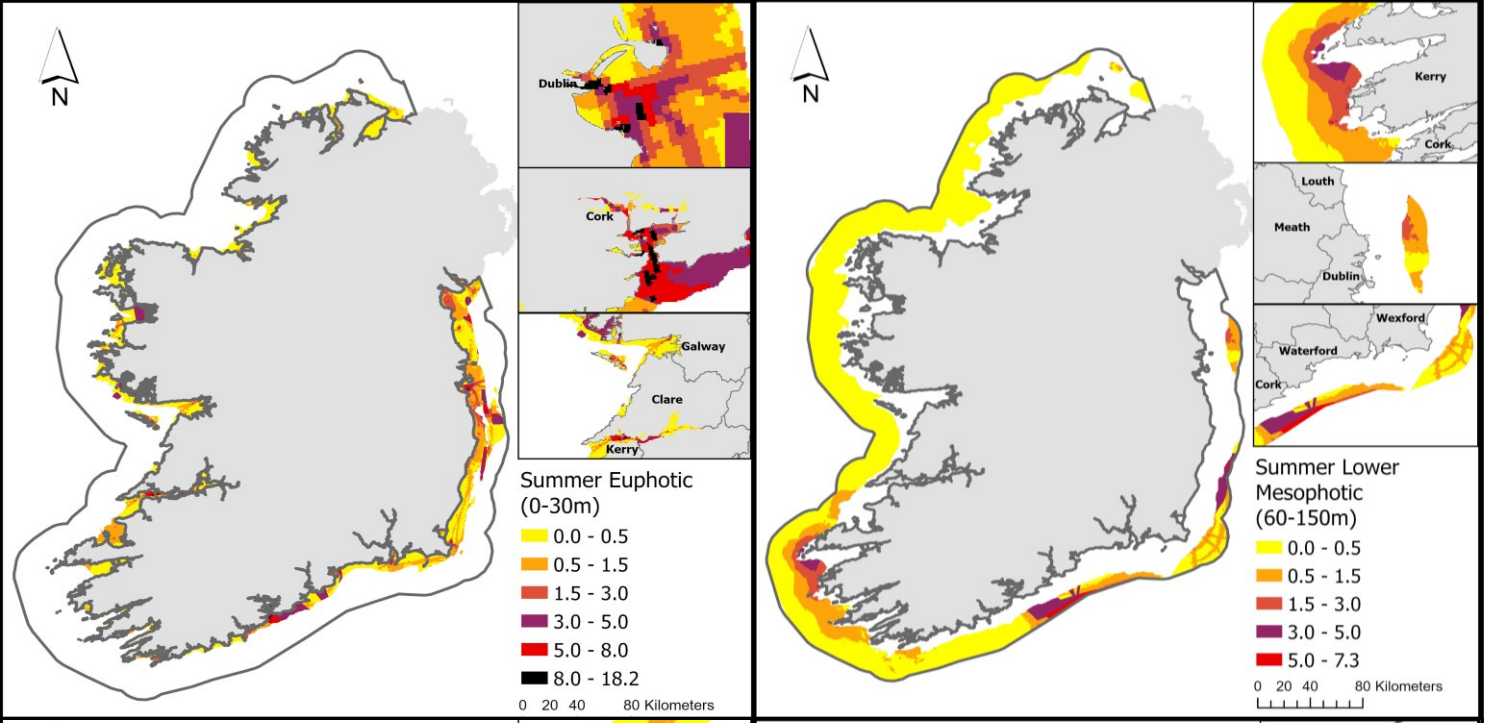
  C) Summer → highest CA intensity, widest spatial footprint

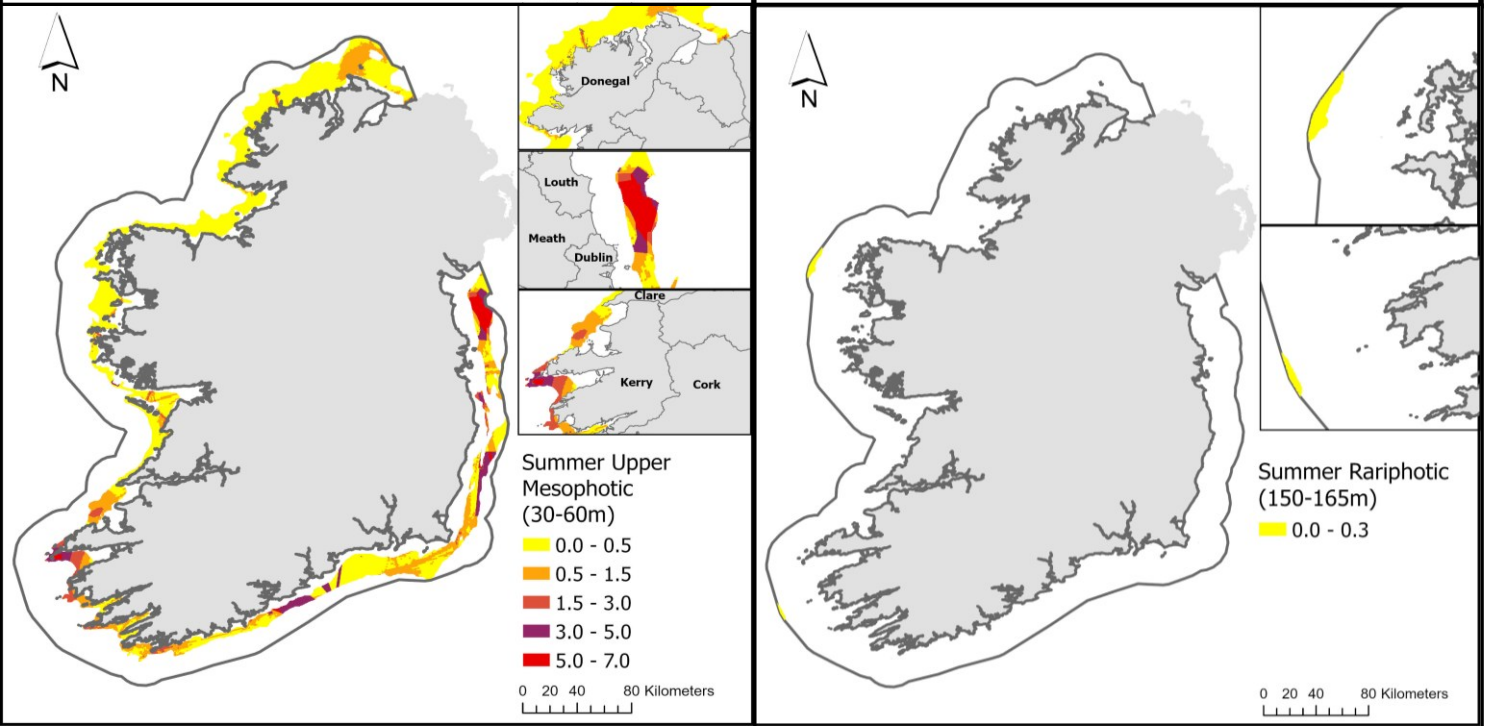
  A) Winter → lowest CA intensity, smaller footprint but localised hotspots (e.g., fisheries)

  B&D) Spring/Autumn → intermediate, distinct patterns



Morejón and González Del Campo (2026)

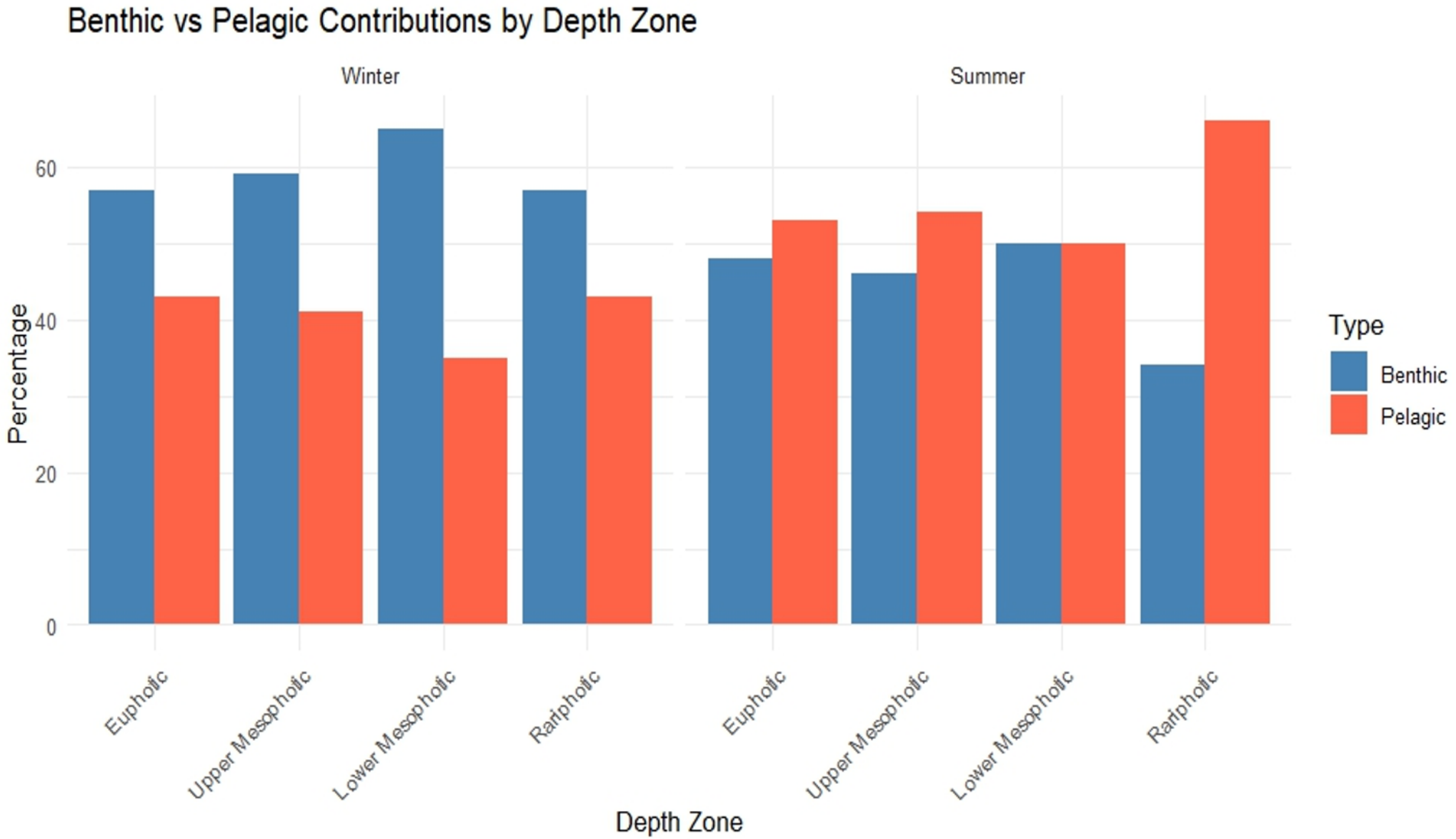




Variation of CA across 4 depth zones

- CA intensity decreases with depth:
  - Shallow (Euphotic, 0–30 m): multi-use, highest overlaps – most CA intense layer
  - Mid (UM, 30–60; LM, 60-150 m): transitional, localized activity (e.g., fisheries)
  - Deep (Rariphotic, 150-165 m): fewer, specialised activities

Morejón and González Del Campo (2026)



Morejón and González Del Campo (2026)

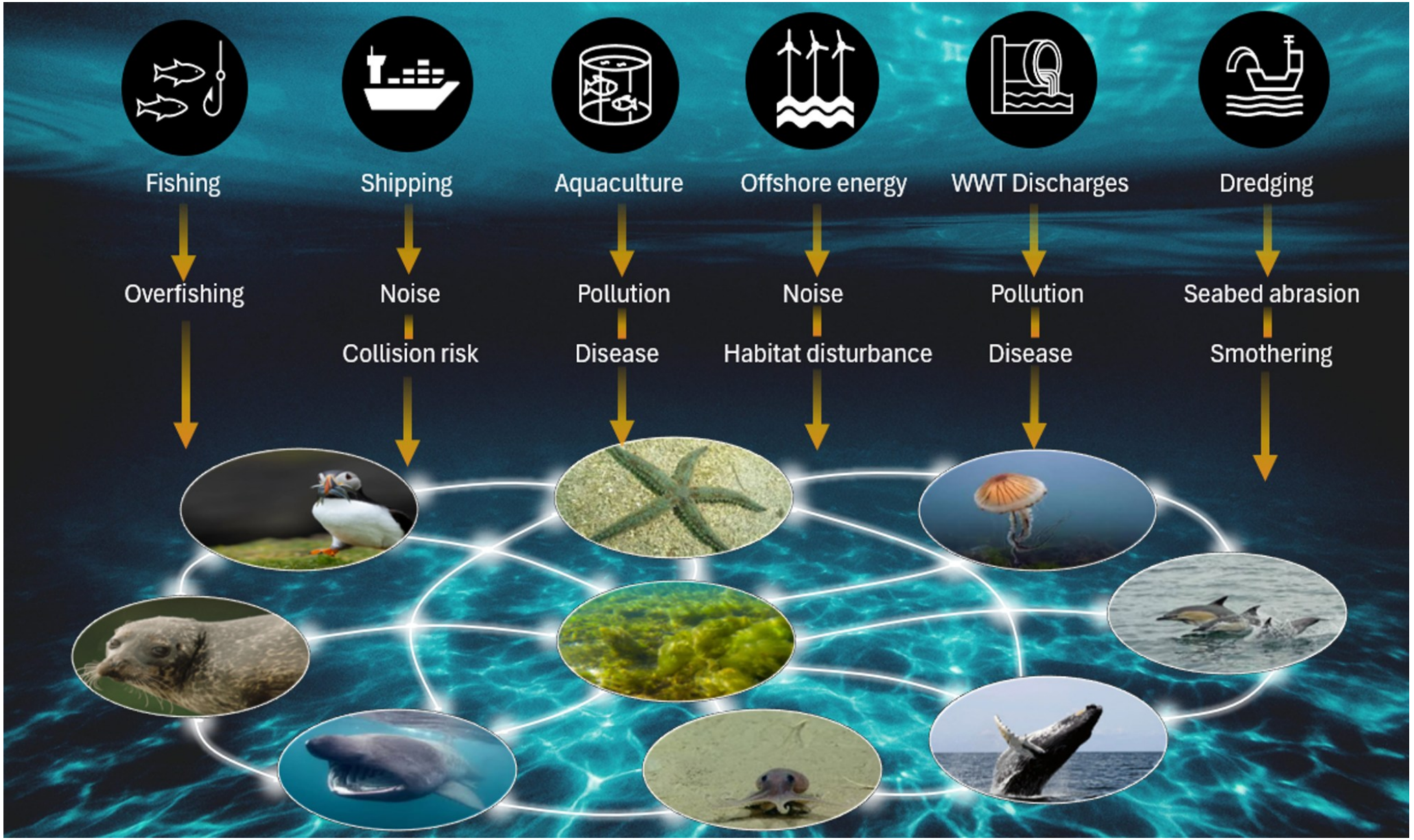
The 4D marine baseline shows where and when activities and potential pressure pathways may converge, but it only describes activity, not ecological risk

What happens when those activities are linked to the pressures that they generate and the ecosystem components that they may affect?

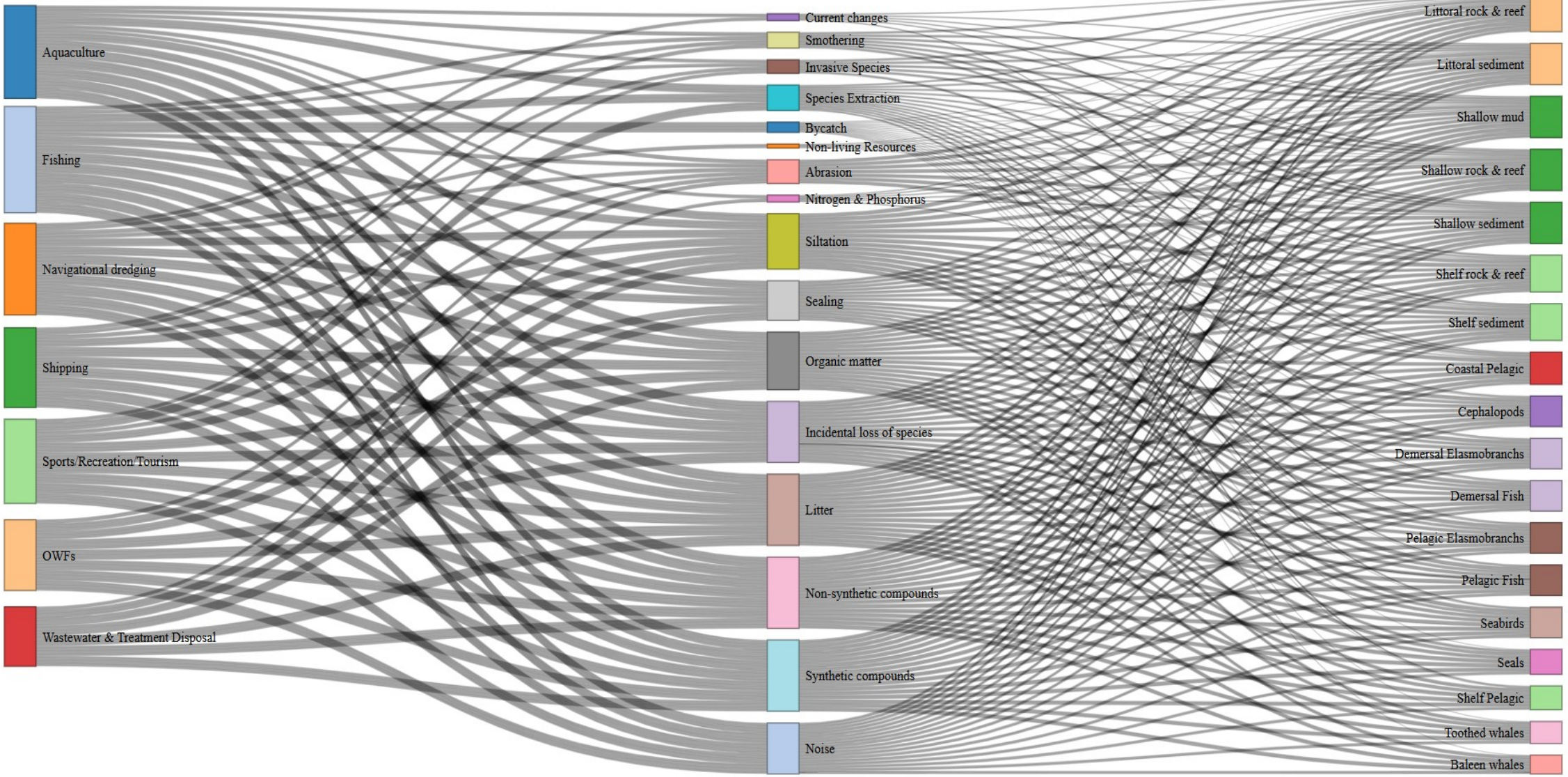
A

P

EC


Fishing
Shipping
Aquaculture
Offshore energy
WWT Discharges
Dredging
Overfishing
Noise
Collision risk
Pollution
Disease
Noise
Habitat disturbance
Pollution
Disease
Seabed abrasion
Smothering

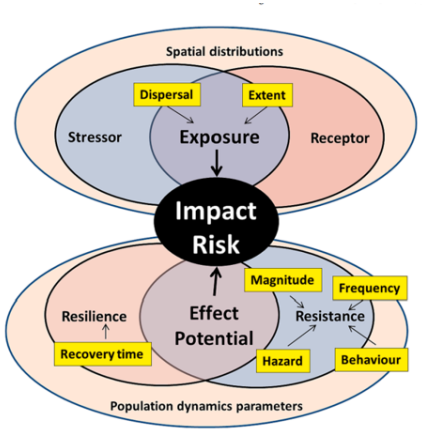
Horrendogram – aka linkage or impact chain framework



Step 3: From 4D activity to 4D ecological risk

SCAIRM: a Spatial Cumulative Assessment of Impact Risk for Management

SCAIRM (Piet et al. 2023)



SCAIRM links activities to ECs through impact chains

Activity (20) → **Pressure (18)** → **Ecosystem Component (17)**

Exposure x Effect Potential = Impact Risk

Exposure
Extent + Dispersal

Effect Potential
Resistance + Resilience

Resistance uses criteria such as **Hazard**, **Magnitude**, **Frequency** and **Behaviour**

Impact chains, scores, experts and spatial extent

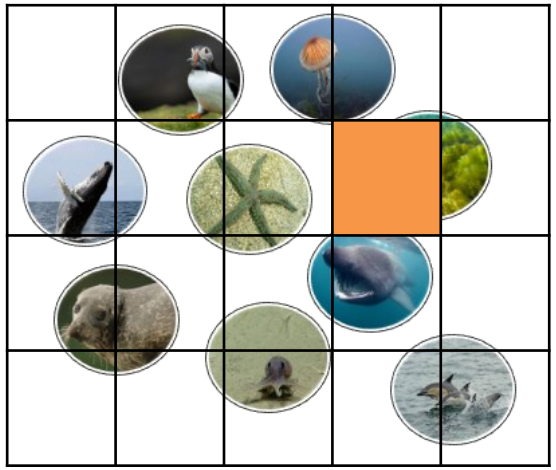
Existing Ireland SCAIRM scores from GES4SEAS provided a starting point

Existing impact chains and scores 9,462 → Refined impact chains 2,219 → Expert review workbook → Final impact chains and scores

Experts reviewed:
- **Dispersal**
- **Effect Potential-related criteria (hazard, magnitude, frequency, behaviour)**

e.g. Salmon farming→ Contamination compounds → Coastal pelagic

Extent is calculated spatially



One 150 m grid cell highlighted

Activity x EC overlap = spatial extent

Sector	Activity	Pressure	Ecosystem Componei	Ecosystem Group	Pressure mechanism	Dispersal	Hazard	Magnitude	Resilience	Frequency	Behaviour
Aquaculture	Atlantic salmon farming	Abrasion	Shallow Sediment	Habitat	Intermittent	N	LL	M	M	C	H
Aquaculture	Atlantic salmon farming	Abrasion	Shallow mud	Habitat	Intermittent	N	LL	M	M	R	H
Aquaculture	Atlantic salmon farming	Abrasion	Shallow Rock & Reef	Habitat	Intermittent	N	LL	M	M	R	H
Aquaculture	Atlantic salmon farming	Abrasion	Littoral Sediment	Habitat	Intermittent	N	LL	M	M	VF	H
Aquaculture	Atlantic salmon farming	Abrasion	Littoral Rock & Reef	Habitat	Intermittent	N	LL	M	M	R	H
Aquaculture	Atlantic salmon farming	Contaminating Compounds	Coastal Pelagic	Habitat	Continuous	H	SL	L	H	N/A	N/A
Aquaculture	Atlantic salmon farming	Contaminating Compounds	Shallow Mud	Habitat	Continuous	H	SH	M	M	N/A	N/A
Aquaculture	Atlantic salmon farming	Contaminating Compounds	Shallow Sediment	Habitat	Continuous	H	SL	L	M	N/A	N/A
Aquaculture	Atlantic salmon farming	Contaminating Compounds	Shallow Rock & Reef	Habitat	Continuous	H	SL	L	M	N/A	N/A
Aquaculture	Atlantic salmon farming	Contaminating Compounds	Littoral Sediment	Habitat	Continuous	H	SL	L	M	N/A	N/A
Aquaculture	Atlantic salmon farming	Contaminating Compounds	Littoral Rock & Reef	Habitat	Continuous	H	SL	L	M	N/A	N/A
Aquaculture	Atlantic salmon farming	Contaminating Compounds	Demersal Elasmo	Species	Continuous	H	SL	L	L	N/A	N/A
Aquaculture	Atlantic salmon farming	Contaminating Compounds	Cephalopods	Species	Continuous	H	SL	L	H	N/A	N/A
Aquaculture	Atlantic salmon farming	Contaminating Compounds	Demersal Fish	Species	Continuous	H	SL	L	M	N/A	N/A
Aquaculture	Atlantic salmon farming	Contaminating Compounds	Pelagic Elasmo	Species	Continuous	H	SL	L	L	N/A	N/A
Aquaculture	Atlantic salmon farming	Contaminating Compounds	Pelagic Fish	Species	Continuous	H	SL	L	M	N/A	N/A
Aquaculture	Atlantic salmon farming	Contaminating Compounds	Seabirds	Species	Continuous	H	SL	L	M	N/A	N/A
Aquaculture	Atlantic salmon farming	Contaminating Compounds	Seals	Species	Continuous	H	SL	L	M	N/A	N/A
Aquaculture	Atlantic salmon farming	Contaminating Compounds	Toothed Whales	Species	Continuous	H	SL	L	L	N/A	N/A
Aquaculture	Atlantic salmon farming	Contaminating Compounds	Baleen Whales	Species	Continuous	H	SL	L	L	N/A	N/A
Aquaculture	Atlantic salmon farming	Current Changes	Coastal Pelagic	Habitat	Continuous	M	SL	L	H	N/A	N/A
Aquaculture	Atlantic salmon farming	Current Changes	Shallow Mud	Habitat	Continuous	M	SL	L	M	N/A	N/A
Aquaculture	Atlantic salmon farming	Current Changes	Shallow Sediment	Habitat	Continuous	M	SL	L	M	N/A	N/A
Aquaculture	Atlantic salmon farming	Current Changes	Shallow Rock & Reef	Habitat	Continuous	M	SL	L	M	N/A	N/A
Aquaculture	Atlantic salmon farming	Incidental Loss	Shallow Mud	Habitat	Intermittent	N	LL	L	M	VF	H
Aquaculture	Atlantic salmon farming	Incidental Loss	Shallow Sediment	Habitat	Intermittent	N	LL	L	M	VF	H

Read Me | Review this tab | All impact chains | Lookups | Pressure_Mechanism

From impact chains to a spatial risk dataset

2,219 impact chains → **~1.45 billion impact risk records**

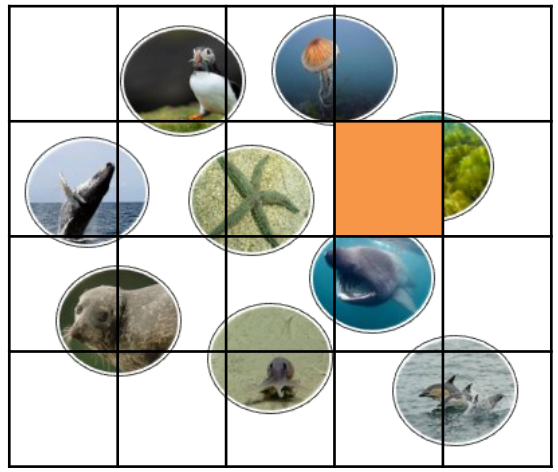
starting linkage framework

spatialised across cells + seasons

Impact risk x seasonal activity intensity from the 4D = seasonal impact risk

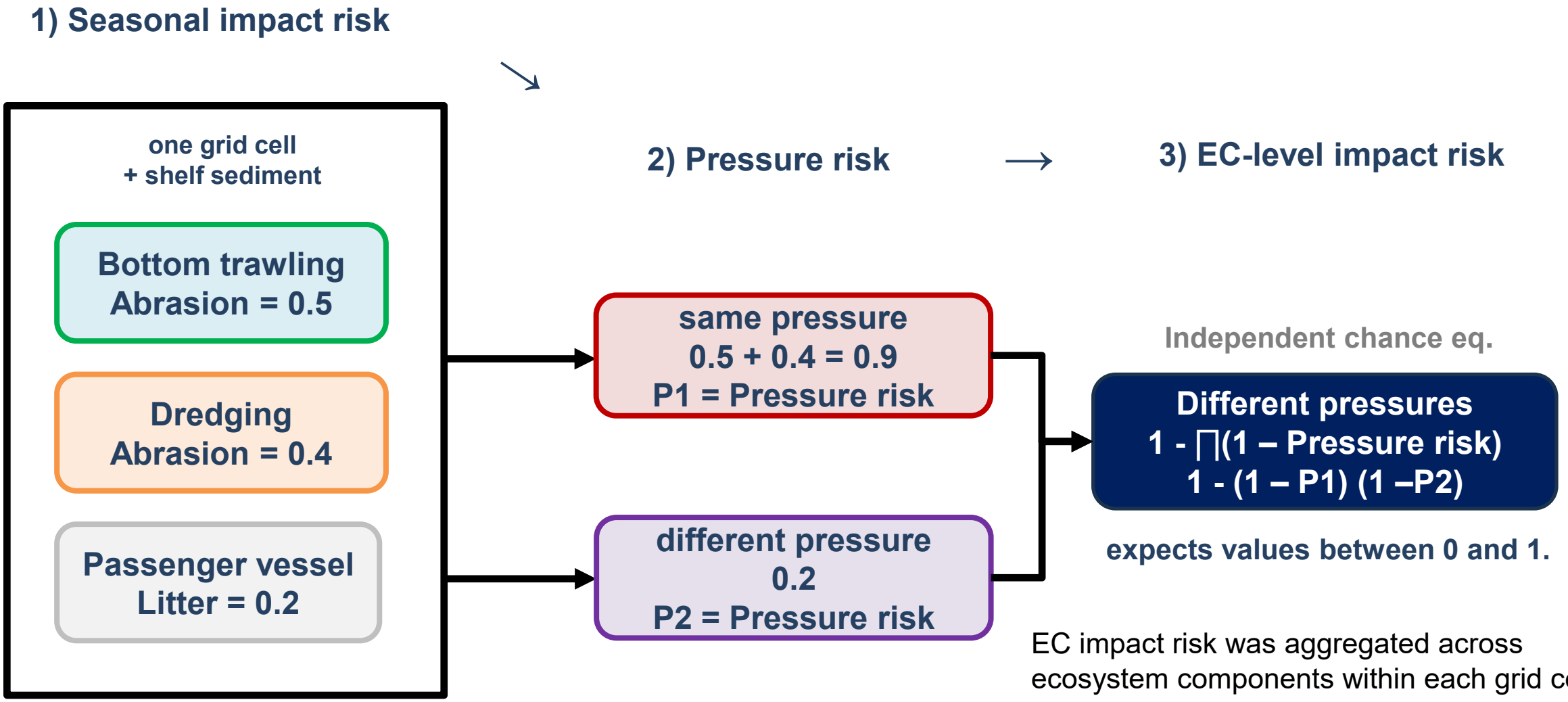
The big dataset is the same impact-chain logic repeated across space and season

Winter/spring/summer/autumn

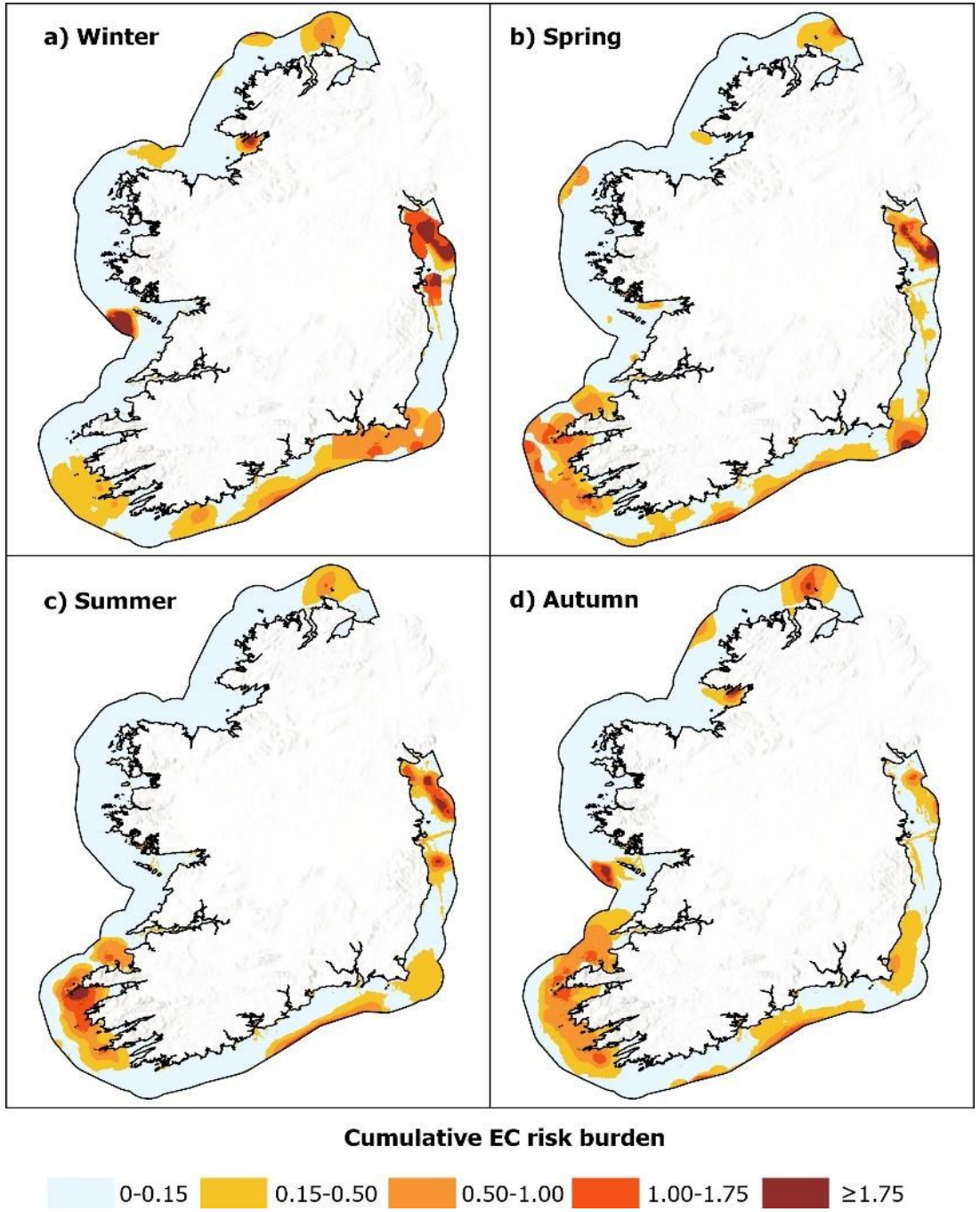


One 150 m cell highlighted

Seasonal impact risk aggregation



EC impact risk was aggregated across ecosystem components within each grid cell and season. The summed value was termed the **cumulative ecological risk.**

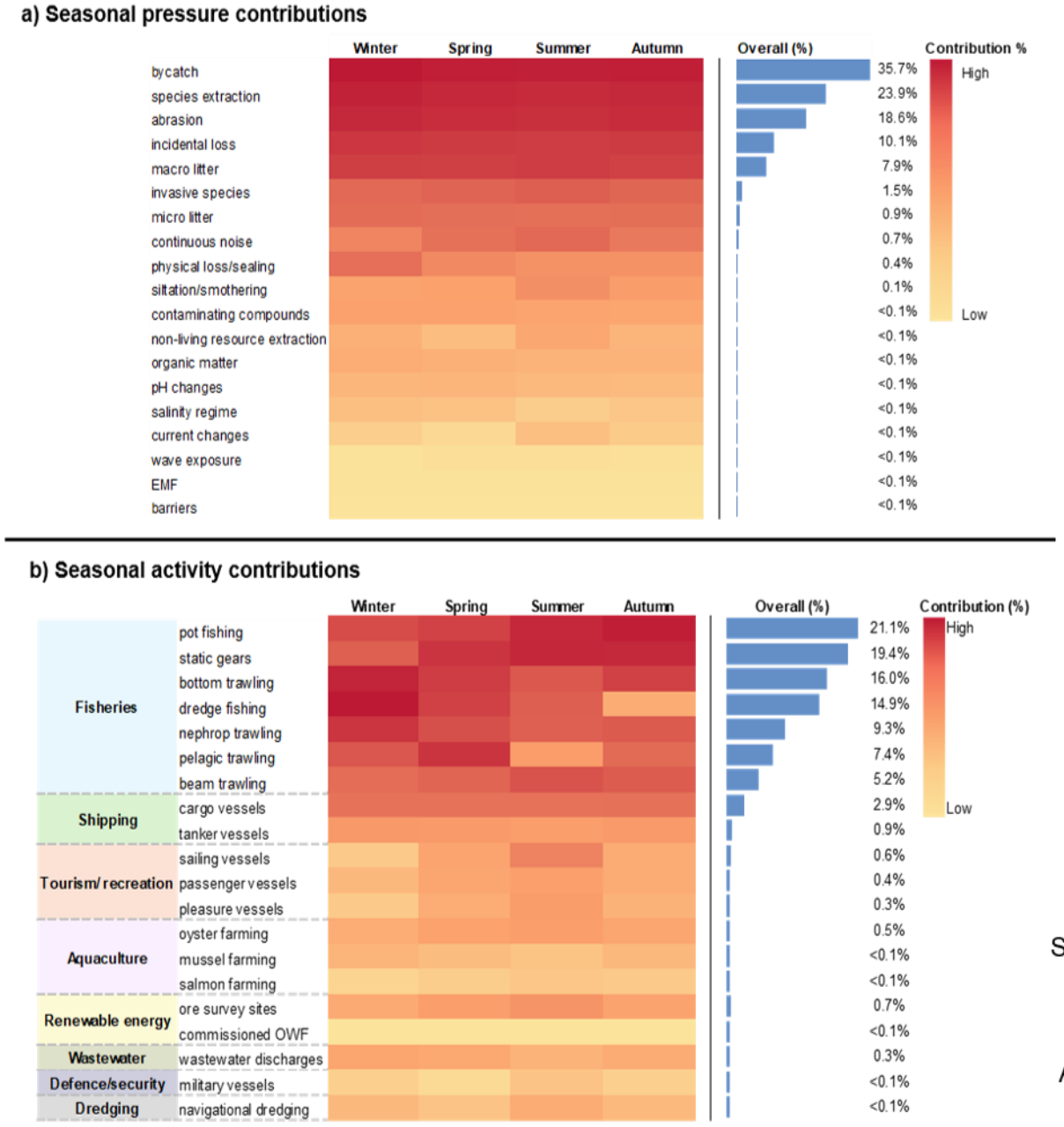


Morejón et al. (in preparation)

The ecological risk story is different

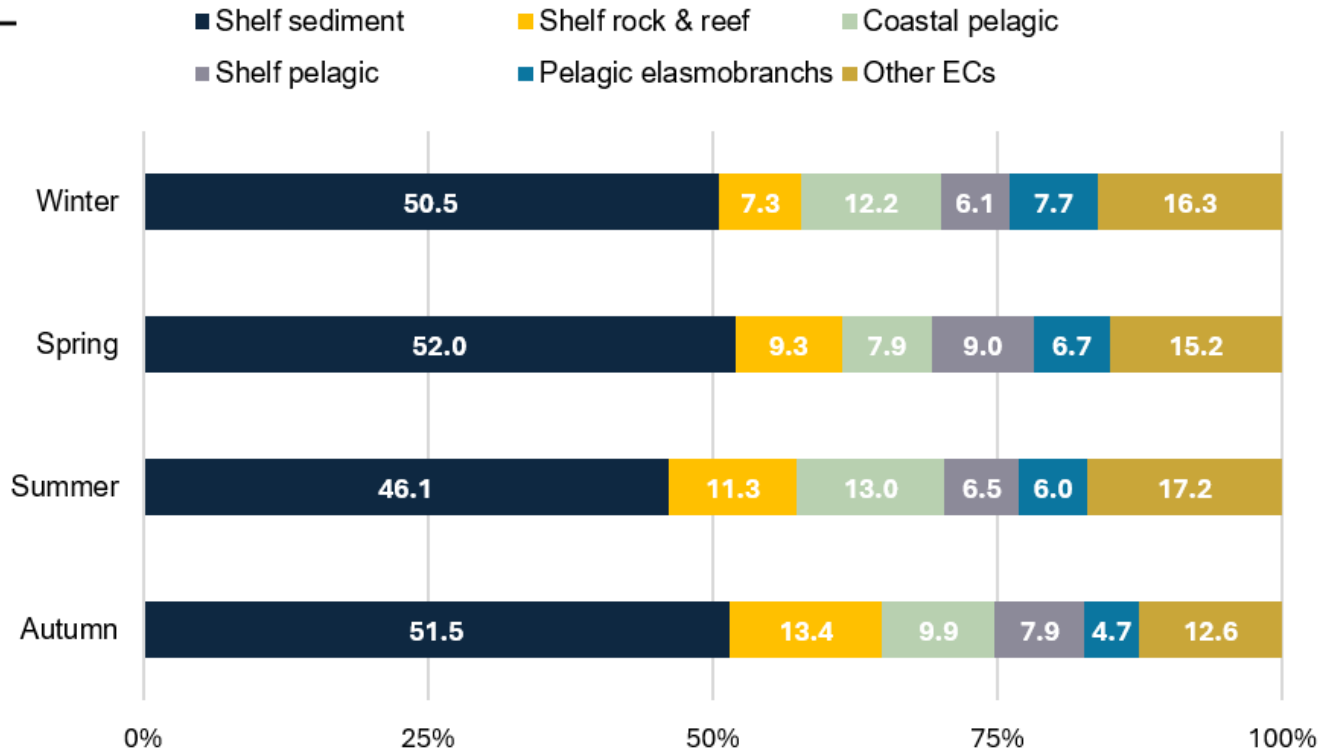
- **Activity baseline:** highest in summer, followed by spring
- **Ecological risk burden:** highest in winter
- Adding **ecological pathways changed the spatial footprint** of higher-risk areas

Cumulative activity tells us where to look; ecological pathways help explain what may be at risk and why.



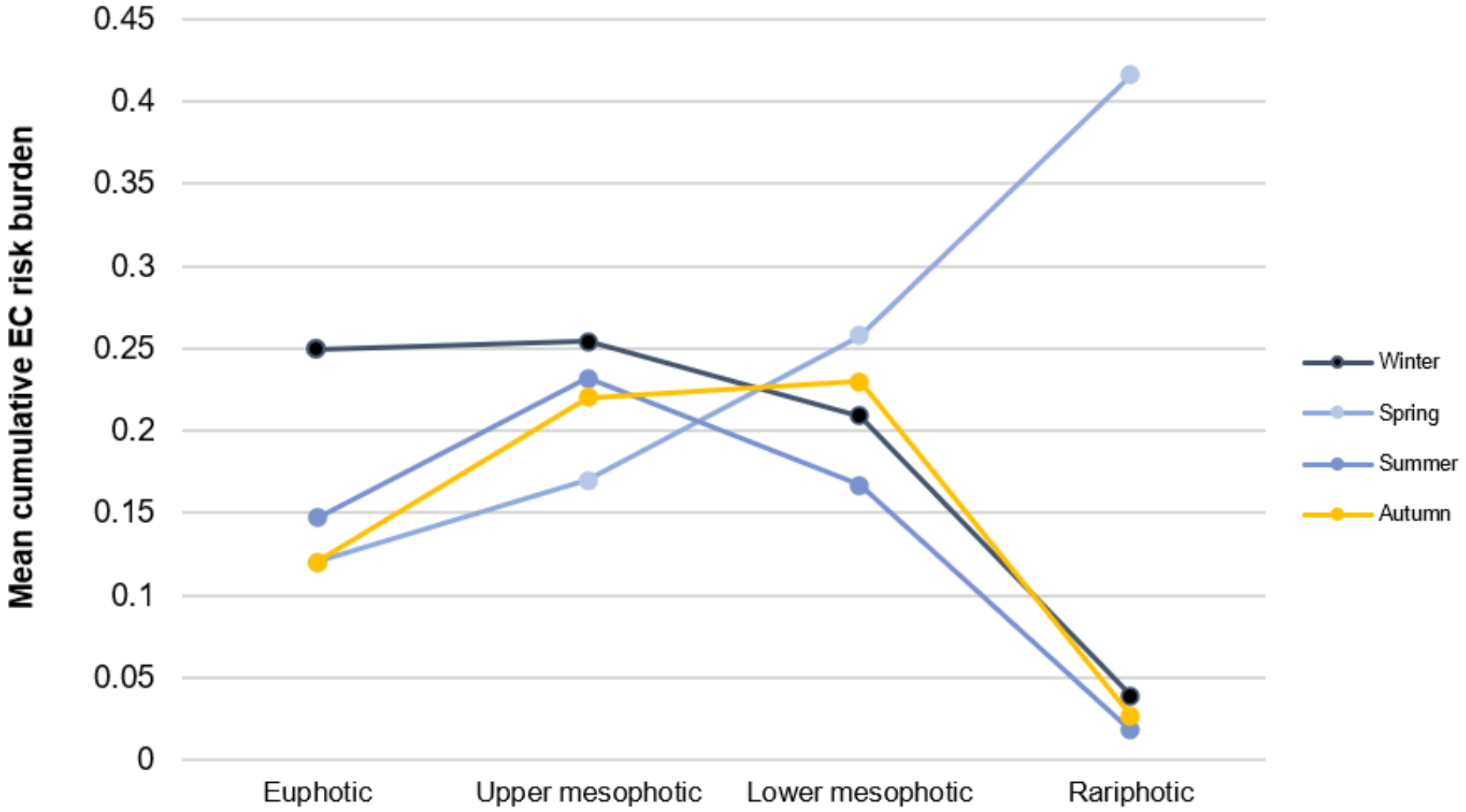
The ecological pathways

- Risk depended on which activities were present, which pressures they generated, and which ecosystem components were exposed
- Pressure contributions were relatively stable, but the activities driving them changed seasonally
- Shelf sediment dominated EC risk burden in every season (~46-52%), while other EC contributions shifted seasonally
- The ecosystem components driving risk also changed seasonally



Morejón et al. (in preparation)

Cumulative risk across depth and seasons



Morejón et al. (in preparation)

- Unlike cumulative activity, ecological risk did not consistently decrease with depth
- No single depth zone had the highest risk burden across all seasons

What this contributes to CEA within SEA for MSP

- **Connect marine CEA research more directly with SEA practice**
- **A stronger marine baseline:** where, when and at what depth activities occur
- **A traceable ecological pathway:** activity → pressure → ecosystem component → potential risk
- **Enhancing the ecological evidence for SEA decisions**
- **From mapping cumulative activity to understanding where ecological risk may matter and why.**

Thank you!
Questions?

✉ Virginia.morejon@ucdconnect.ie

With thanks to my supervisors: Prof. Ainhoa González Del Campo (UCD), Dr Fiona Culhane (MI), and Dr Christie O'Donnell (MI)

Selected sources

- Borja et al. (2024). Addressing the cumulative impacts of multiple human pressures in marine systems, for the sustainable use of the seas. *Frontiers in Ocean Sustainability*, *1*, 1308125. https://doi.org/10.3389/focsu.2023.1308125
- Borja et al. (2016). Overview of integrative assessment of marine systems: the ecosystem approach in practice. *Frontiers in Marine Science*, *3*, 20. https://doi.org/10.3389/fmars.2016.00020
- Boyes, S.J. and Elliott, M., 2014. Marine legislation–The ultimate 'horrendogram': International law, European directives & national implementation. *Marine pollution bulletin*, *86*(1-2), pp.39-47. https://doi.org/10.1016/j.marpolbul.2014.06.055
- Côté et al. (2016). Interactions among ecosystem stressors and their importance in conservation. *Proceedings of the Royal Society B: Biological Sciences*, *283*(1824), p.20152592. https://doi.org/10.1098/rspb.2015.2592
- Elliott et al. (2014). A typology of marine and estuarine hazards and risks as vectors of change: a review for vulnerable coasts and their management. *Ocean & Coastal Management*, *93*, pp.88-99. https://doi.org/10.1016/j.ocecoaman.2014.03.014
- Halpern et al. (2025). Cumulative impacts to global marine ecosystems projected to more than double by mid-century. Science. https://doi.org/10.1126/science.adv2906
- Heinatz et al. (2023). A first estimate of the effect of offshore wind farms on sedimentary organic carbon stocks in the Southern North Sea. *Frontiers in Marine Science*, *9*, p.1068967. https://doi.org/10.3389/fmars.2022.1068967
- Morejón et al. (2025). A new ecosystem-based cumulative effects assessment framework to enhance SEA of marine spatial plans. Environmental Management. https://doi.org/10.1007/s00267-025-02231-0
- Morejón & González Del Campo (2026). Toward ecosystem-based strategic environmental assessments for marine spatial planning. Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2026.181611
- Piet et al. (2023). SCAIRM: A spatial cumulative assessment of impact risk for management. Ecological Indicators. https://doi.org/10.1016/j.ecolind.2023.111157
- Przeslawski et al. (2025). Environmental considerations related to floating offshore wind farms: a case study from waters around New South Wales, Australia. *Marine and Freshwater Research*, *76*(16), p.MF24279. https://doi.org/10.1071/MF24279
- Selkoe et al. (2015). Principles for managing marine ecosystems prone to tipping points. *Ecosystem Health and Sustainability*, *1*(5), pp.1-18. https://doi.org/10.1890/EHS14-0024.1
- Jacquemont et al. (2024) 3D ocean / depth-layer assessment of fishing pressure and conservation coverage. https://doi.org/10.1038/s41467-024-47975-1