Digital Tools for GHG Mapping and Environmental Impact Modeling in Shipping

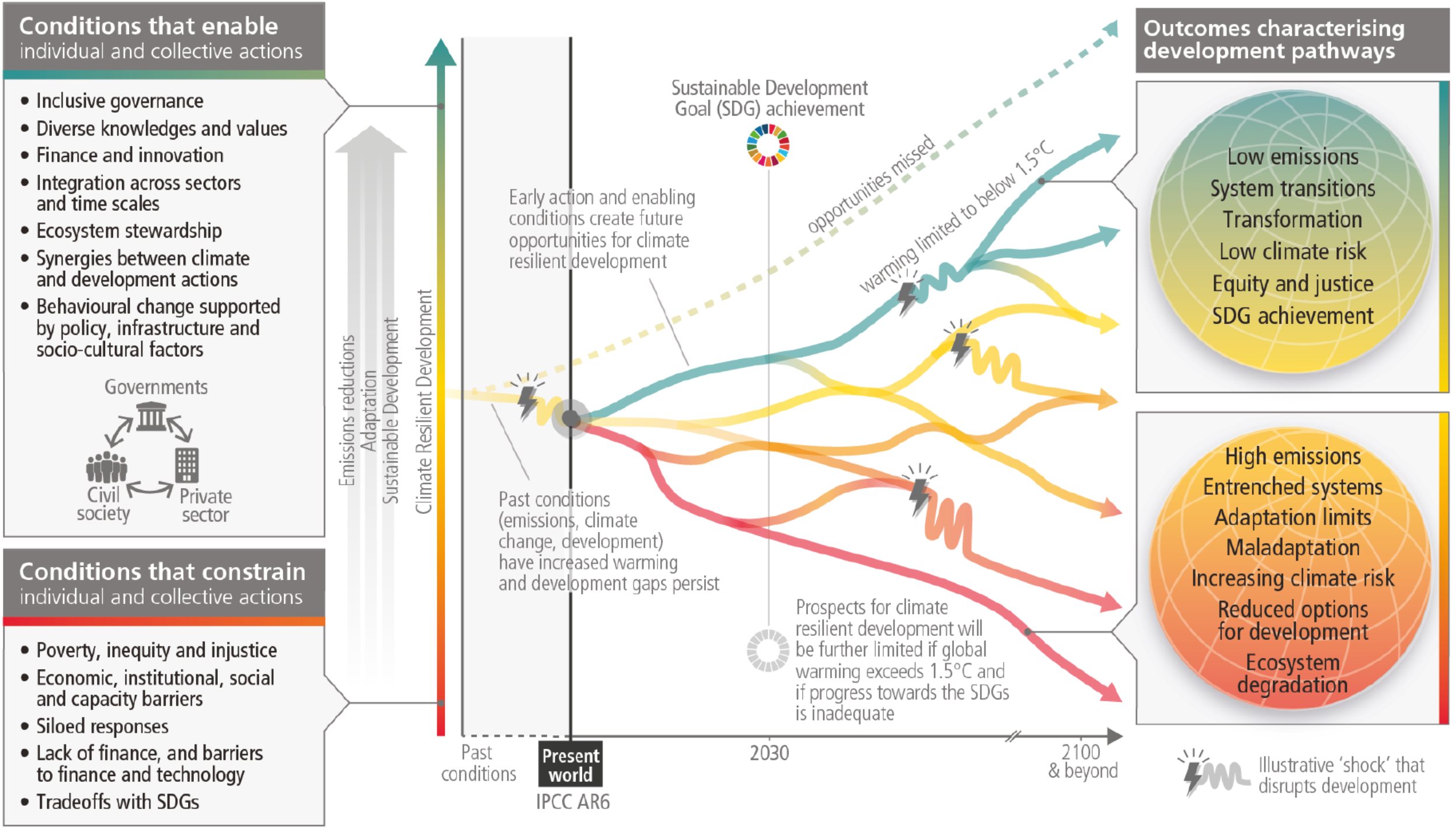
Jonne Kotta and many other contributors

Integrating knowledge and data for improved GHG emissions calculation: The Port of Tallinn case study

Sixth Assessment Report

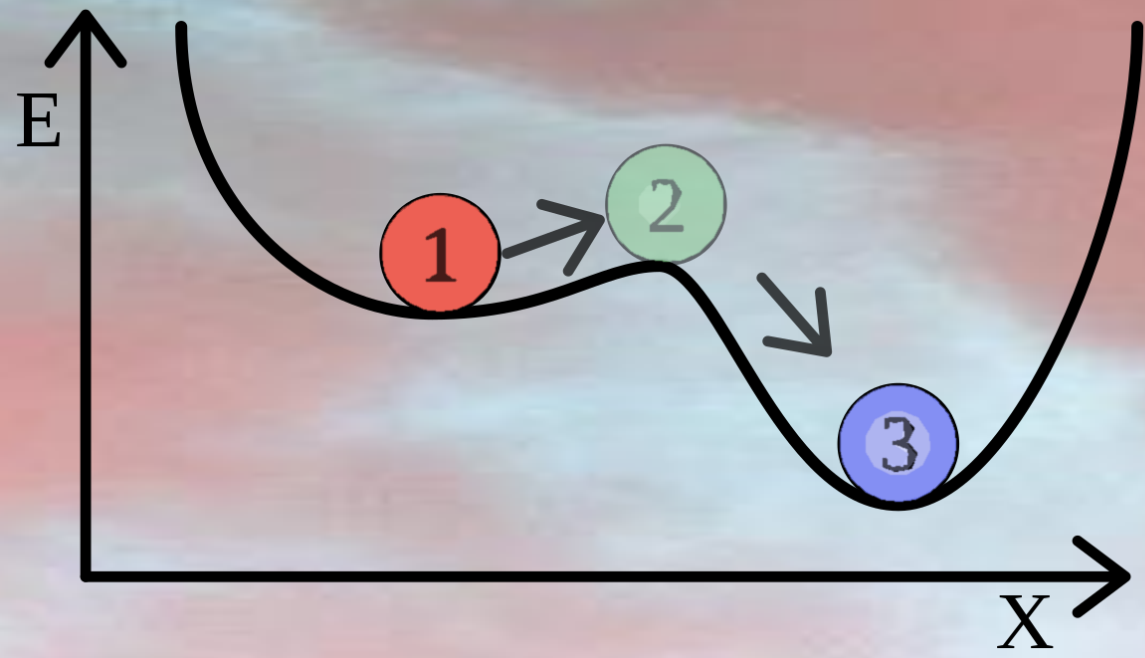
The Working Group I contribution was released on 9 August 2021. The Working Group II and III contributions were released on 28 February and 4 April 2022 respectively. The Synthesis Report was released on 20 March 2023.

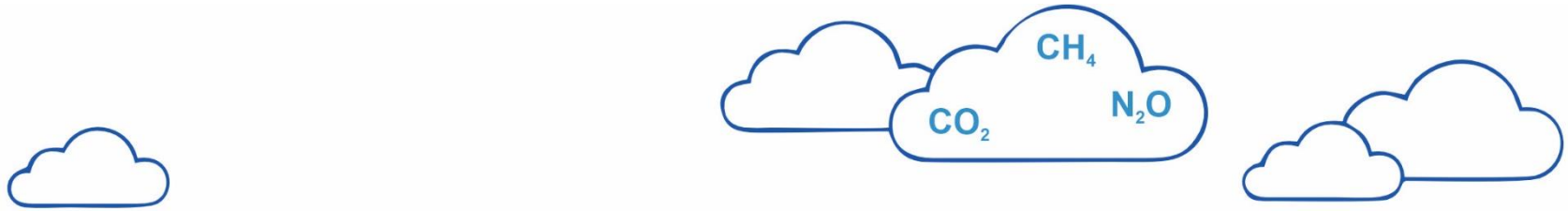
SYNTHESIS REPORT


Conditions that enable
individual and collective actions
• Inclusive governance
• Diverse knowledges and values
• Finance and innovation
• Integration across sectors and time scales
• Ecosystem stewardship
• Synergies between climate and development actions
• Behavioural change supported by policy, infrastructure and socio-cultural factors
Governments
Civil society
Private sector
Conditions that constrain
individual and collective actions
• Poverty, inequity and injustice
• Economic, institutional, social and capacity barriers
• Siloed responses
• Lack of finance, and barriers to finance and technology
• Tradeoffs with SDGs
Emissions reductions
Adaptation
Sustainable Development
Climate Resilient Development
Sustainable Development Goal (SDG) achievement
opportunities missed
warming limited to below 1.5°C
Early action and enabling conditions create future opportunities for climate resilient development
Past conditions (emissions, climate change, development) have increased warming and development gaps persist
Prospects for climate resilient development will be further limited if global warming exceeds 1.5°C and if progress towards the SDGs is inadequate
Past conditions
Present world
IPCC AR6
2030
2100 & beyond
Outcomes characterising development pathways
Low emissions
System transitions
Transformation
Low climate risk
Equity and justice
SDG achievement
High emissions
Entrenched systems
Adaptation limits
Maladaptation
Increasing climate risk
Reduced options for development
Ecosystem degradation
Illustrative 'shock' that disrupts development

CLIMATE CRISIS

Climate neutral solutions:
1. mapping
2. measures
3. good practices





Scope 1

Port direct

Port-owned fleet vehicles, buildings, stationary sources

Scope 2

Port indirect

Purchased electricity for port-owned buildings and operations

Scope 3

Port tenants and other sources

Ships, trucks, cargo handling equipment, rail, harbour craft, port employee vehicles, buildings, purchased electricity

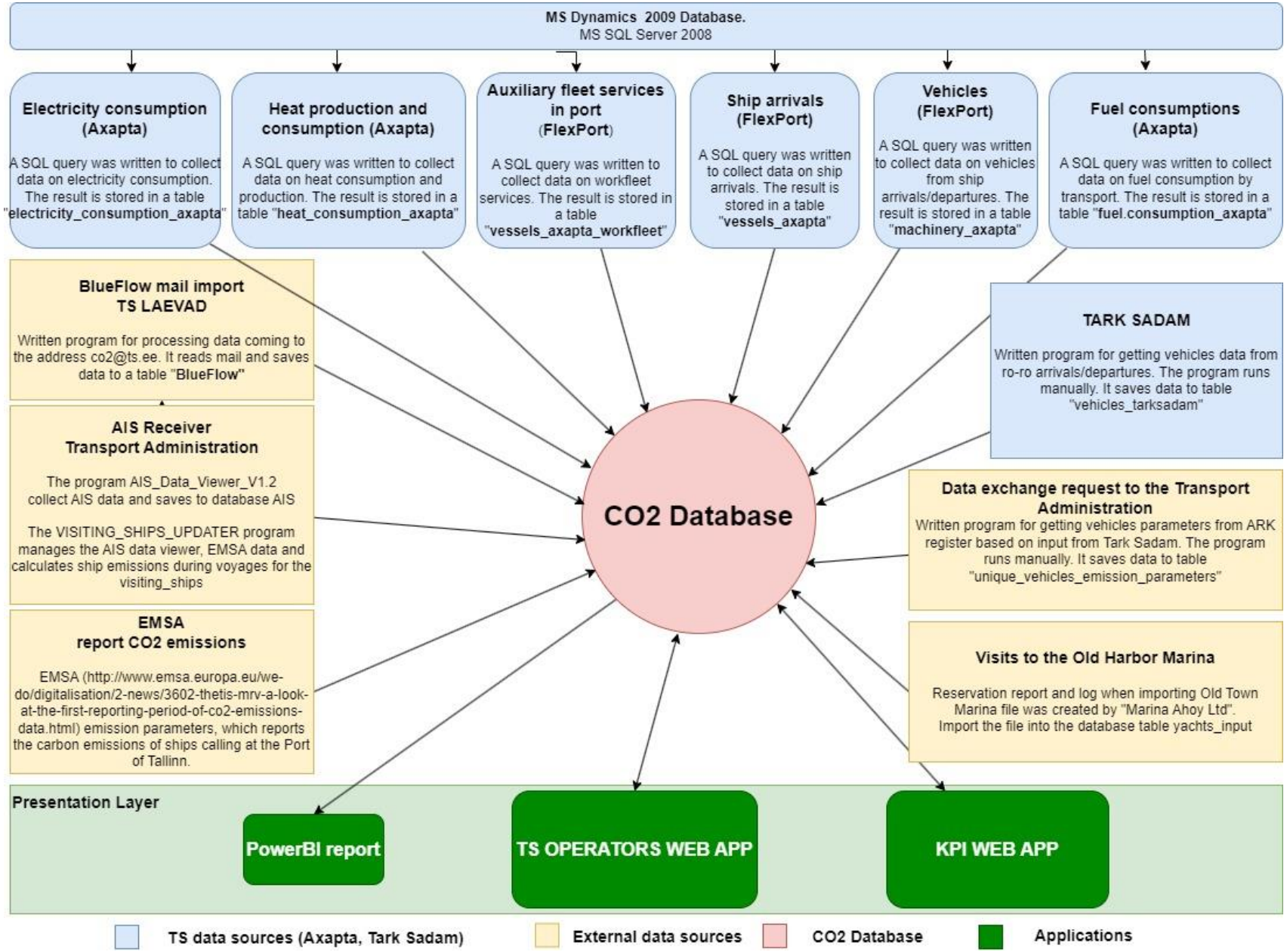
Organisatsioonide KHG jalajälg

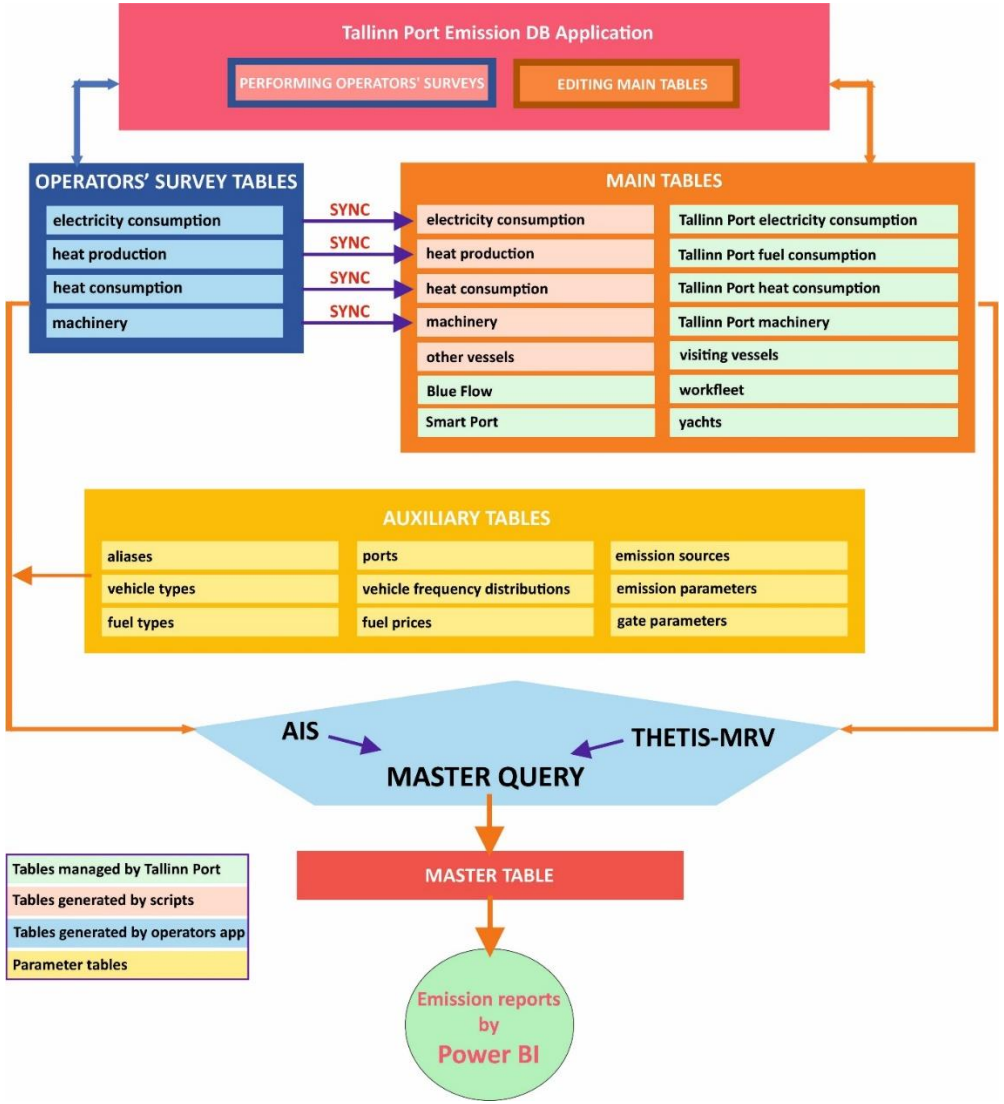
Selleks, et hinnata ettevõtte tegevuse mõju kliimale ning kavandada organisatsiooni tegevusi selle vähendamiseks, on oluline arvutada välja kasvuhoonegaaside (KHG) jalajälg. KHG jalajälg on üks osa organisatsiooni keskkonnamõjust.

Keskkonnaministeeriumi tellimusel koostatud suunised ja arvutusmudel toetavad Eesti ettevõtete ning organisatsioonide KHG jalajälje arvutuste ühtsetele alustele viimist.

Linking different technologies and databases:

Huge data and analysis challenge

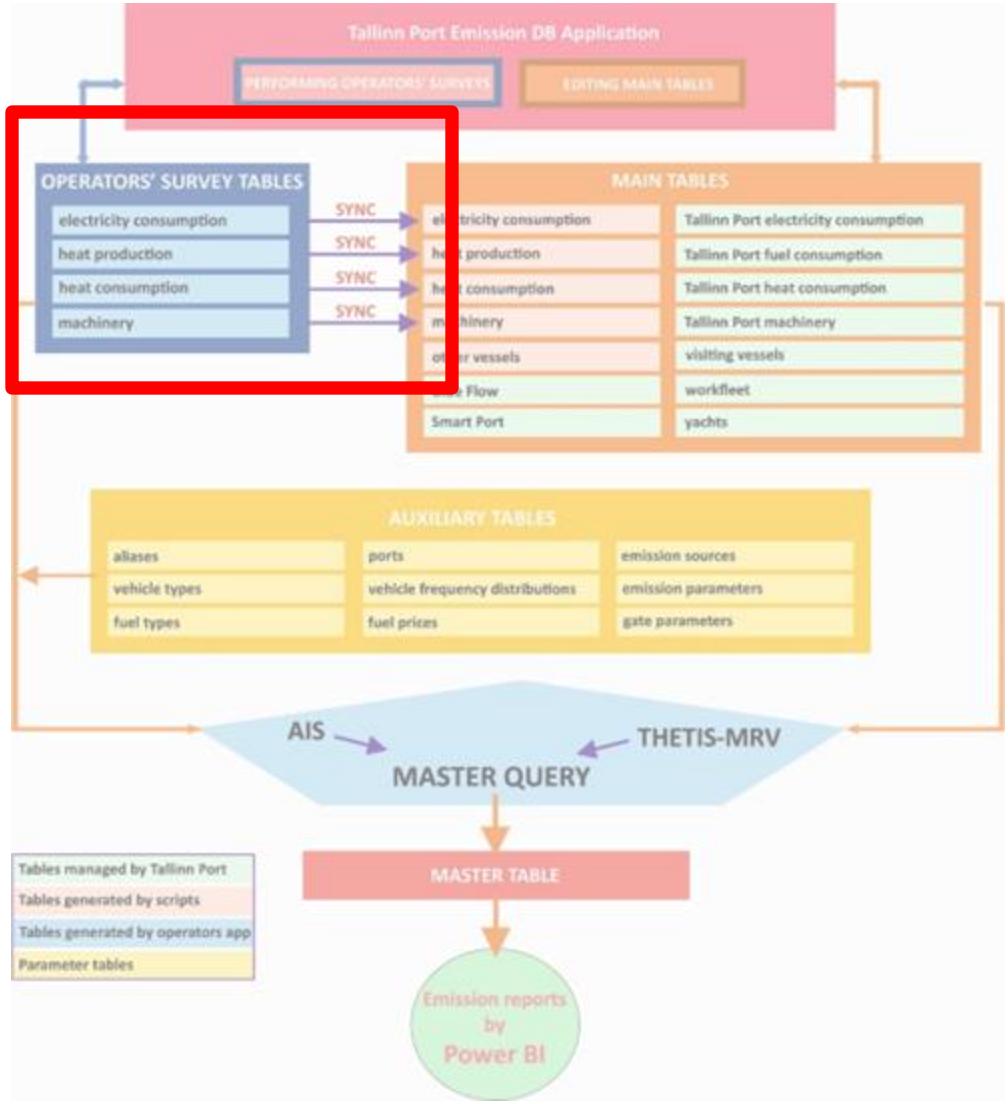

MS Dynamics 2009 Database.
MS SQL Server 2008
Electricity consumption (Axapta)
A SQL query was written to collect data on electricity consumption. The result is stored in a table "electricity_consumption_axapta"
Heat production and consumption (Axapta)
A SQL query was written to collect data on heat consumption and production. The result is stored in a table "heat_consumption_axapta"
Auxiliary fleet services in port (FlexPort)
A SQL query was written to collect data on workfleet services. The result is stored in a table "vessels_axapta_workfleet"
Ship arrivals (FlexPort)
A SQL query was written to collect data on ship arrivals. The result is stored in a table "vessels_axapta"
Vehicles (FlexPort)
A SQL query was written to collect data on vehicles from ship arrivals/departures. The result is stored in a table "machinery_axapta"
Fuel consumptions (Axapta)
A SQL query was written to collect data on fuel consumption by transport. The result is stored in a table "fuel.consumption_axapta"
BlueFlow mail import TS LAEVAD
Written program for processing data coming to the address co2@ts.ee. It reads mail and saves data to a table "BlueFlow"
AIS Receiver Transport Administration
The program AIS_Data_Viewer_V1.2 collect AIS data and saves to database AIS
The VISITING_SHIPS_UPDATER program manages the AIS data viewer, EMSA data and calculates ship emissions during voyages for the visiting_ships
EMSA report CO2 emissions
EMSA (http://www.emsa.europa.eu/we-do/digitalisation/2-news/3602-thetis-mrv-a-look-at-the-first-reporting-period-of-co2-emissions-data.html) emission parameters, which reports the carbon emissions of ships calling at the Port of Tallinn.
CO2 Database
TARK SADAM
Written program for getting vehicles data from ro-ro arrivals/departures. The program runs manually. It saves data to table "vehicles_tarksadam"
Data exchange request to the Transport Administration
Written program for getting vehicles parameters from ARK register based on input from Tark Sadam. The program runs manually. It saves data to table "unique_vehicles_emission_parameters"
Visits to the Old Harbor Marina
Reservation report and log when importing Old Town Marina file was created by "Marina Ahoy Ltd". Import the file into the database table yachts_input
Presentation Layer
PowerBI report
TS OPERATORS WEB APP
KPI WEB APP
TS data sources (Axapta, Tark Sadam)
External data sources
CO2 Database
Applications

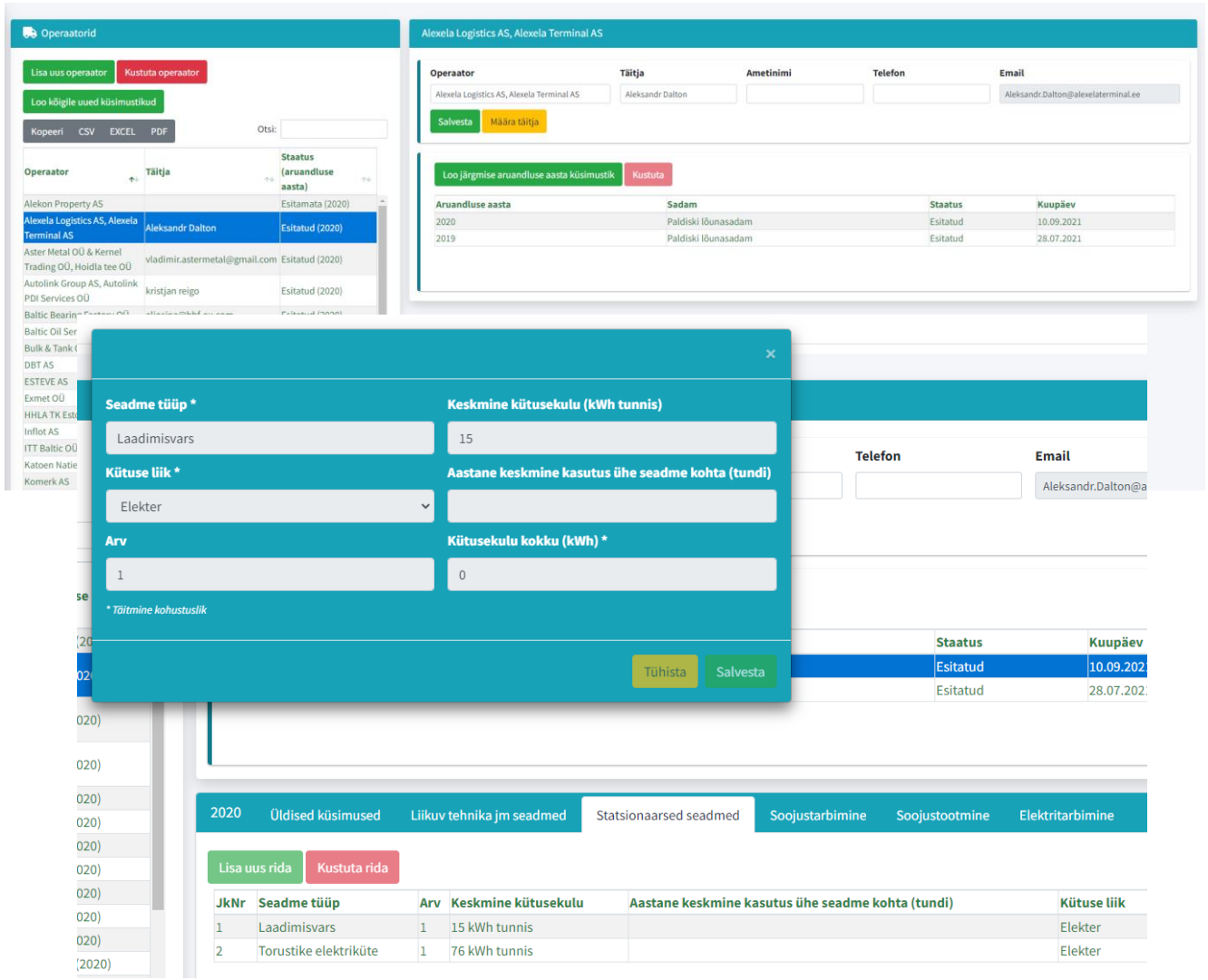


Key building blocks:

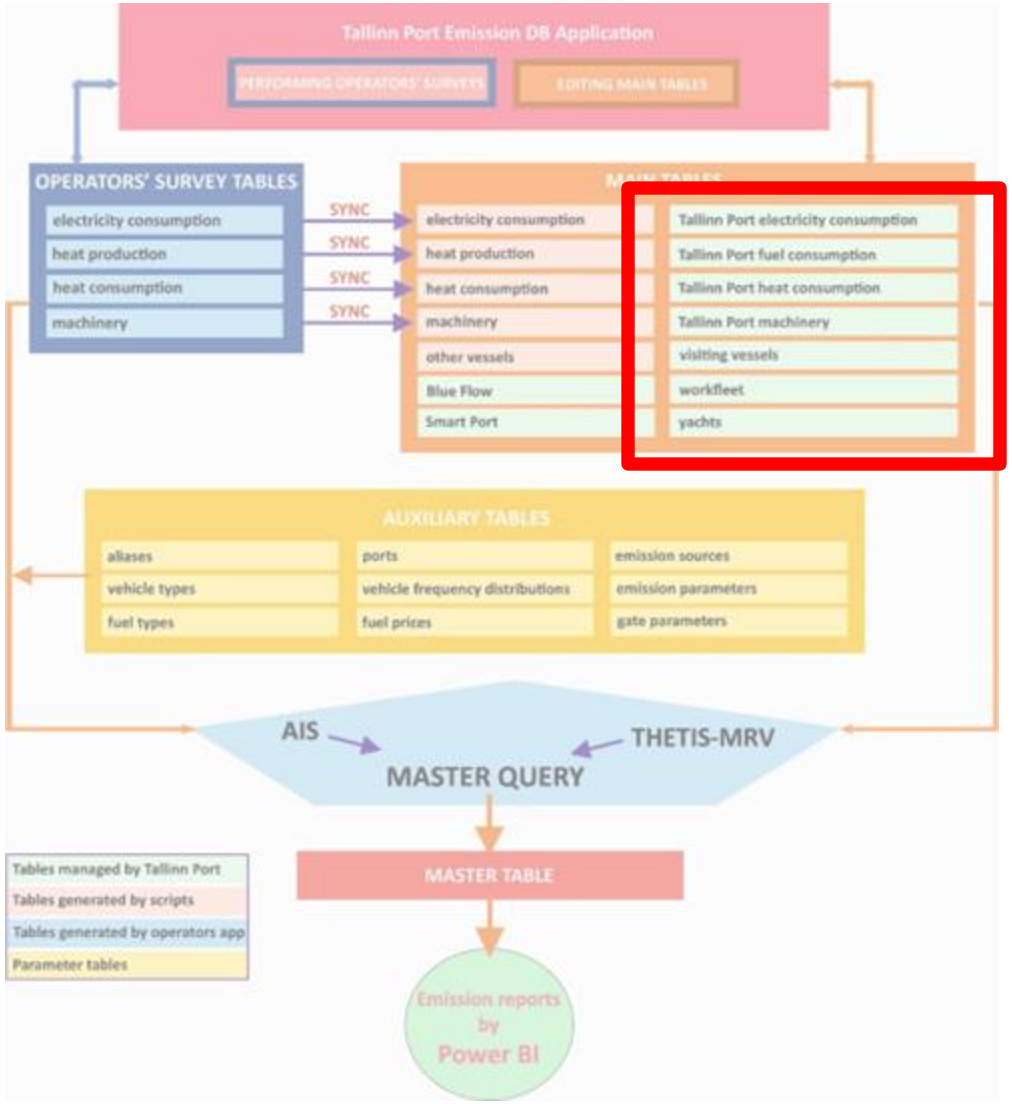
- central database
- supporting databases
- calculation scripts
- visualization tools

COLLECTING DATA FROM TENANTS & SIMPLER DATA HANDLING

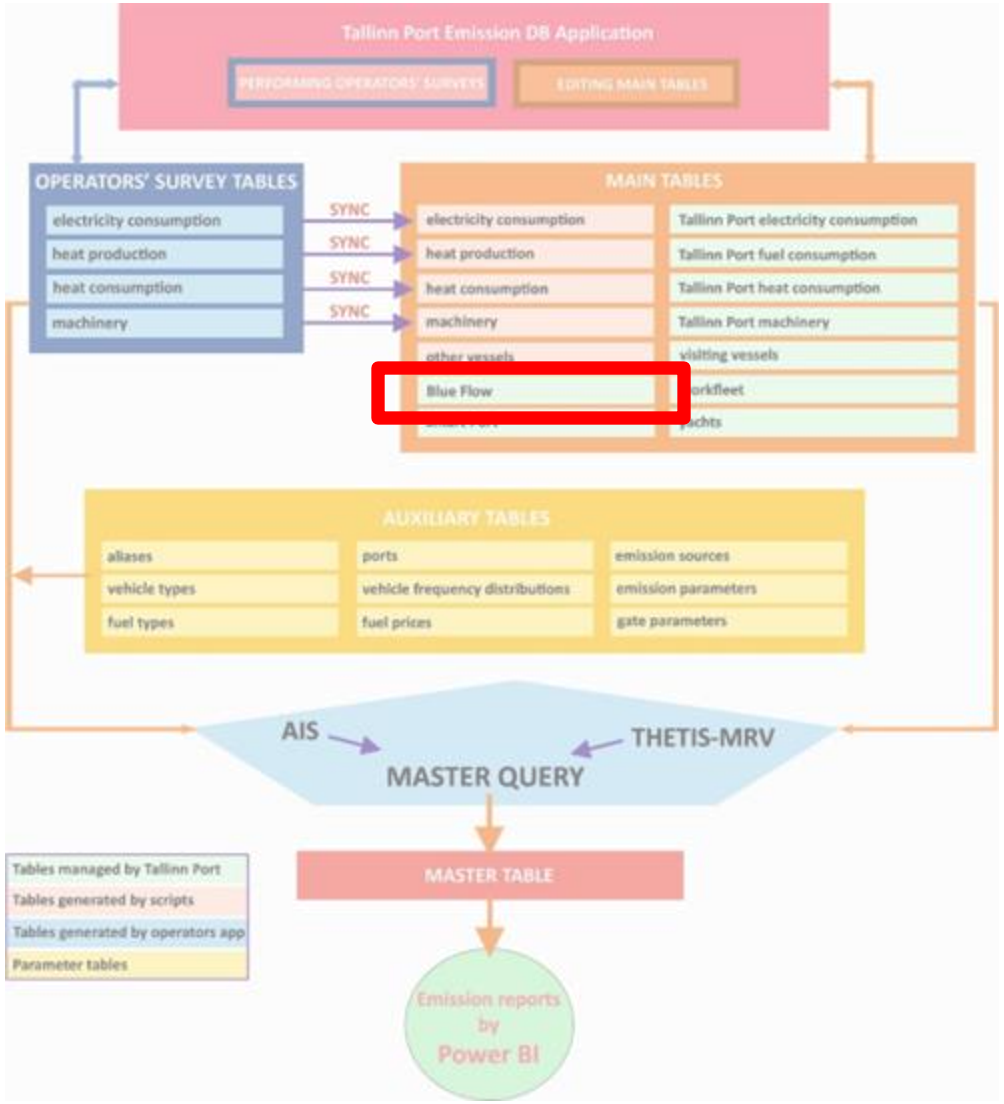




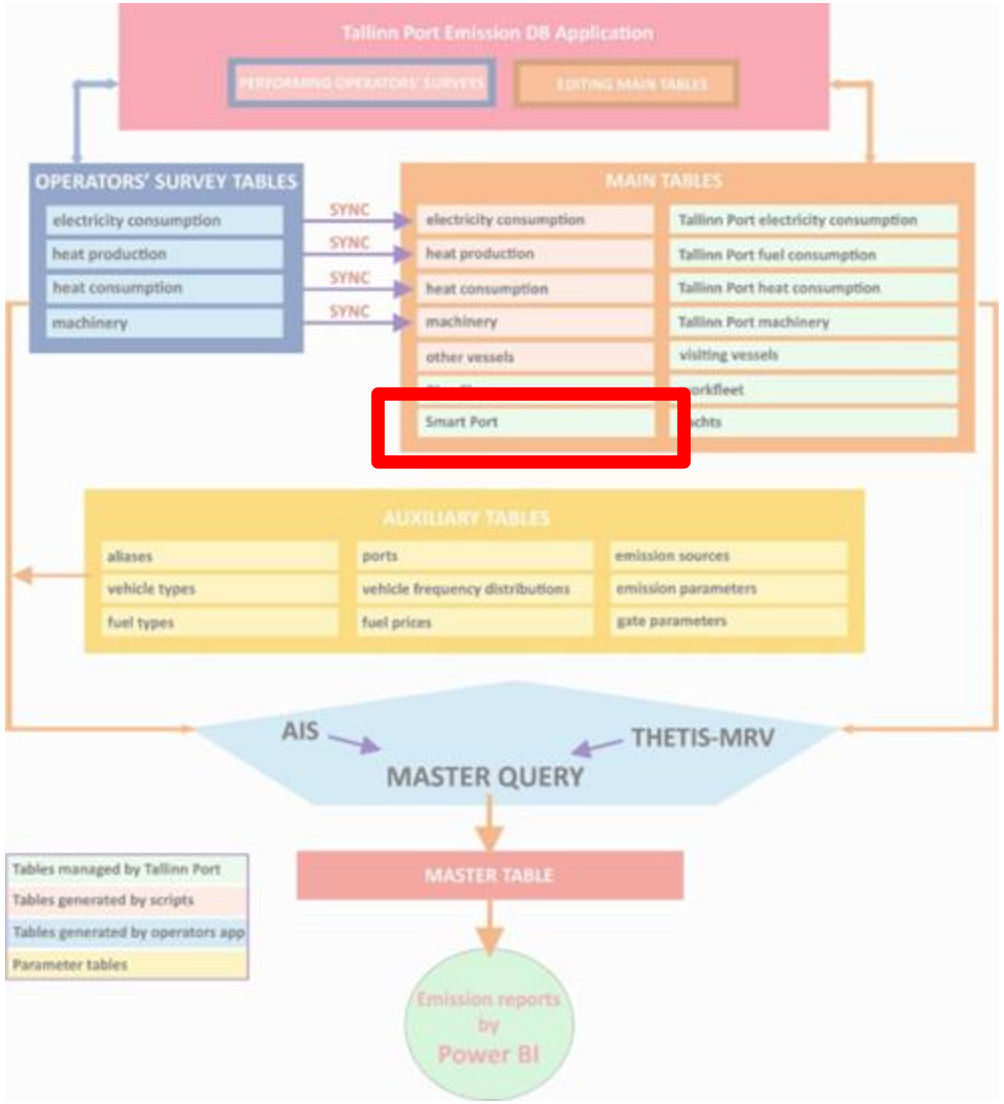
COLLECTING DATA FROM DBs MANAGED BY THE PORT OF TALLINN



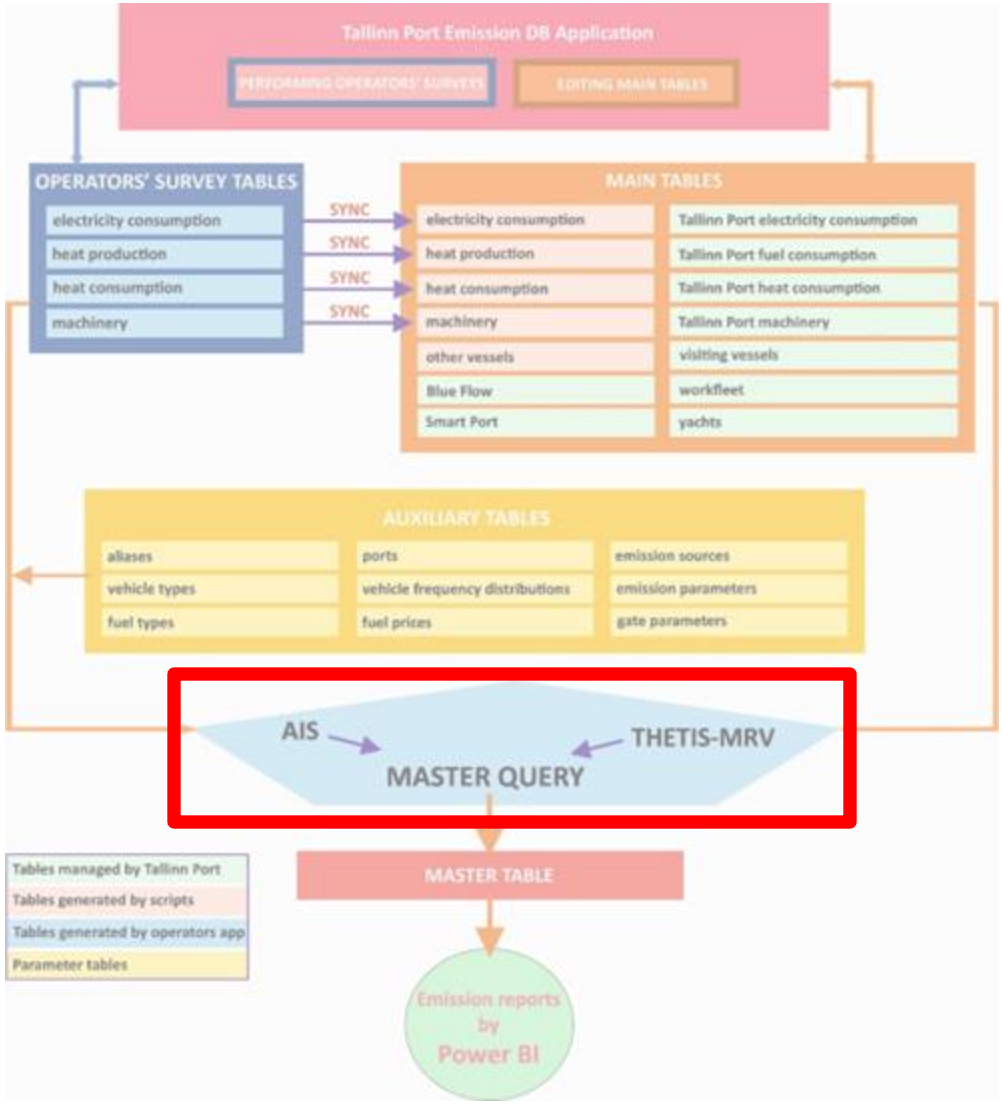
BLUE FLOW (TSL ship fuel and electricity)

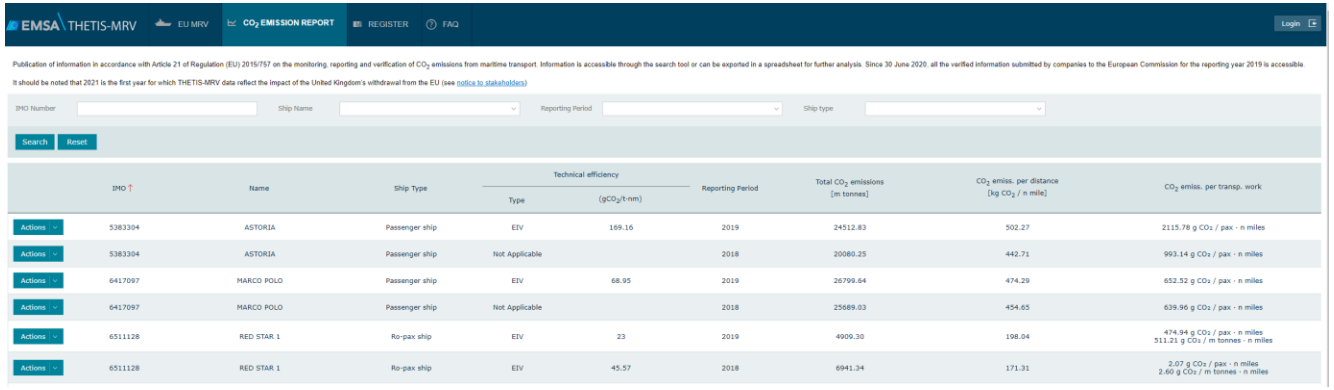


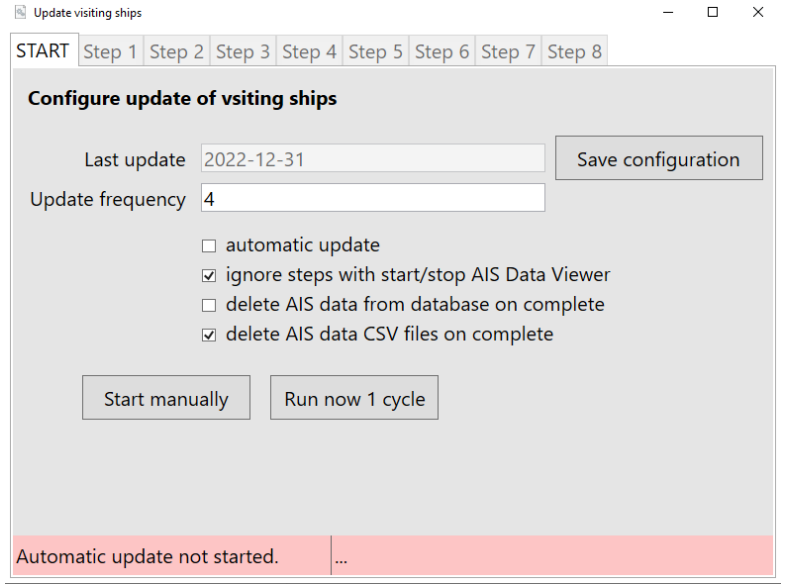
SMART PORT & TRANSPORT ADMINISTRATION

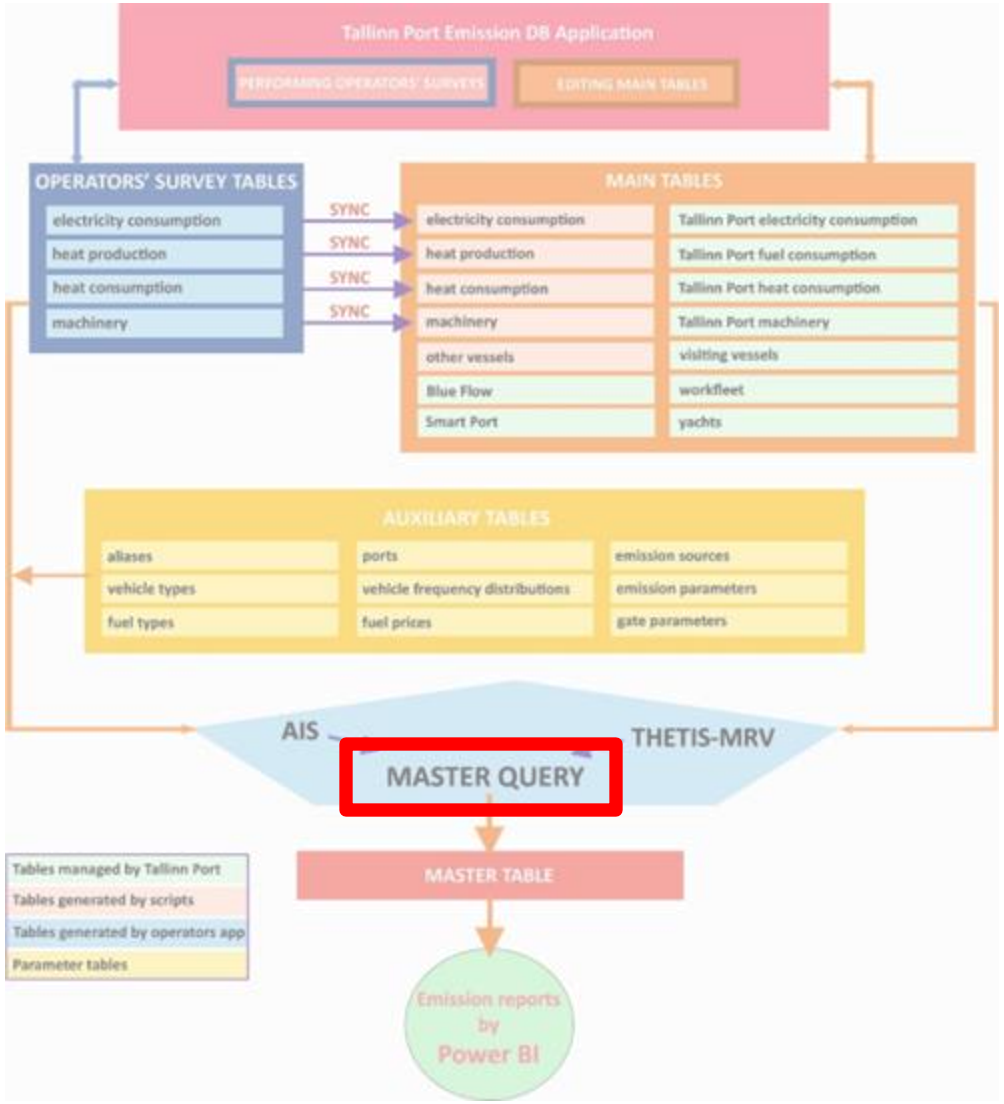


VISITING SHIPS



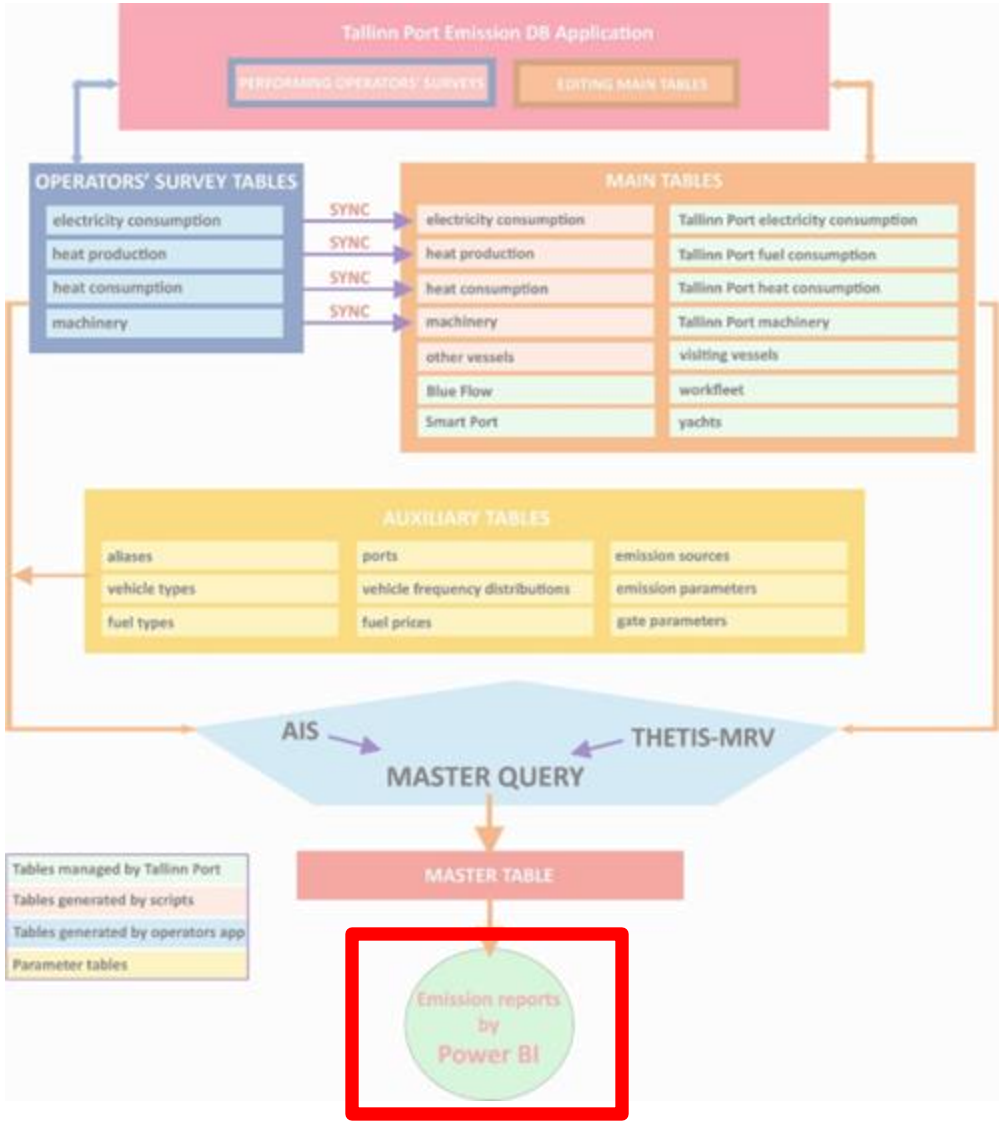




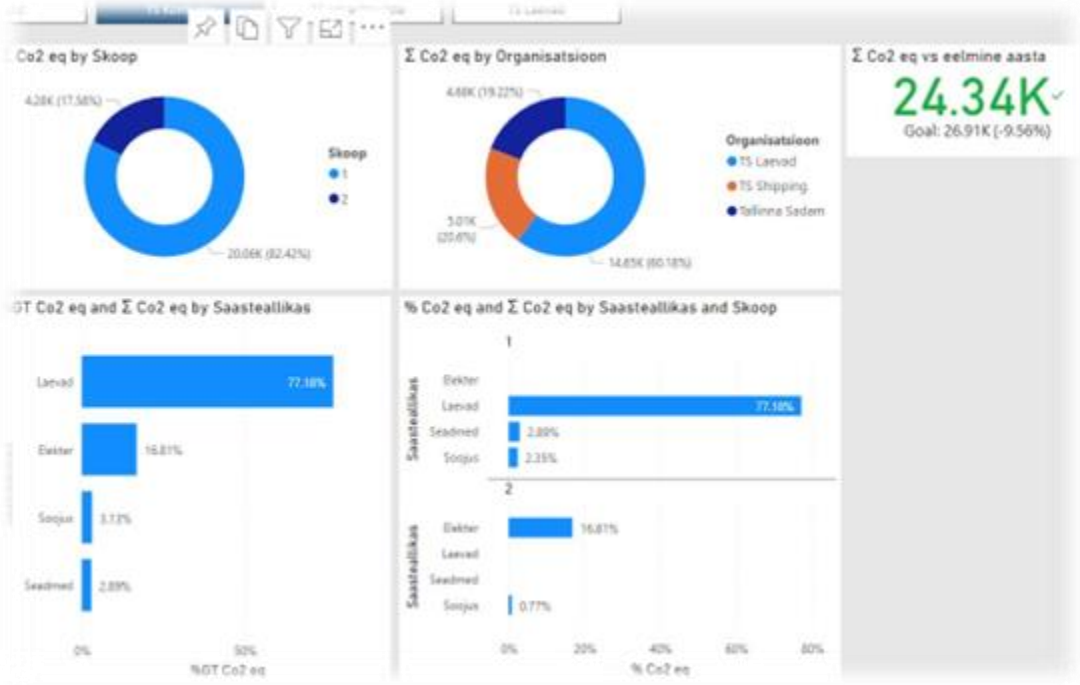


MASTER QUERY

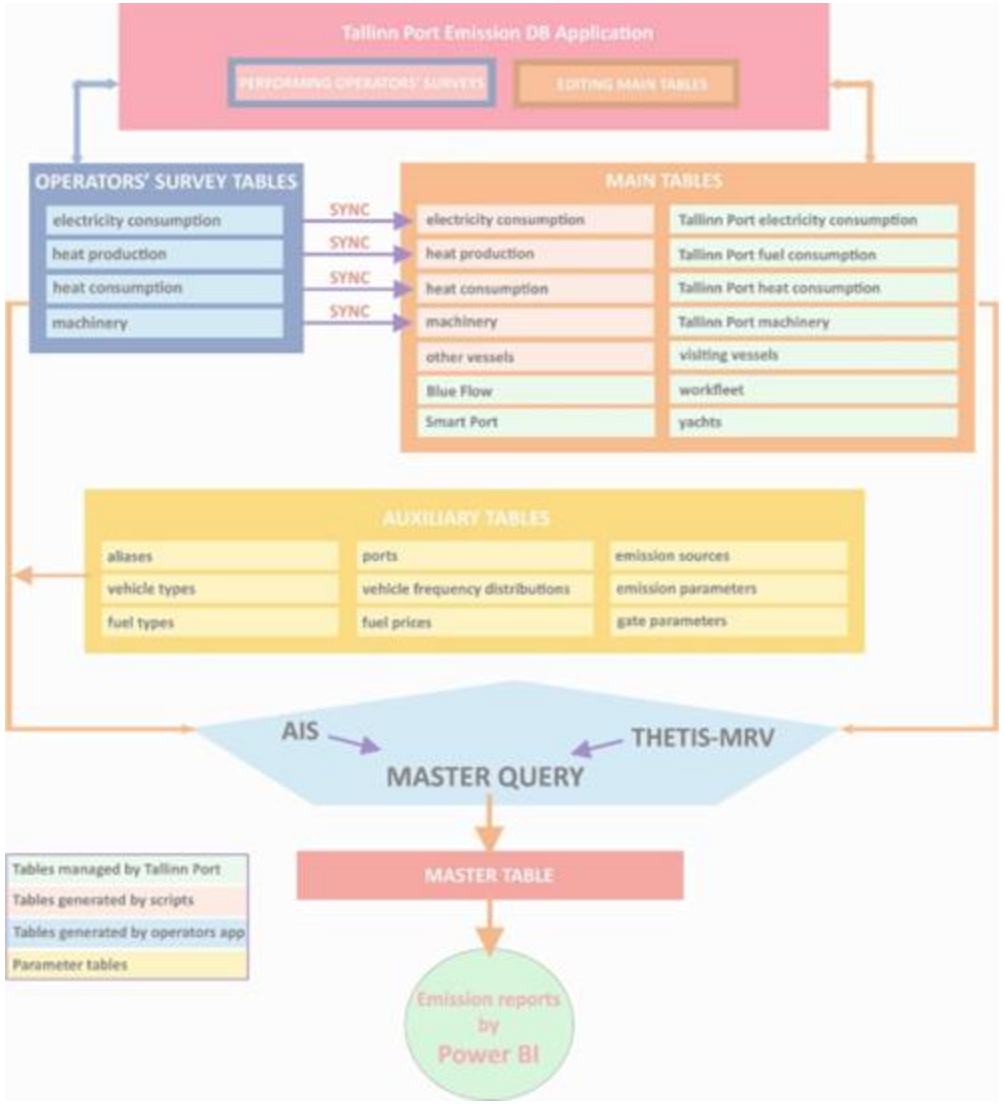
```
---- FUEL.CONSUMPTION_AXAPTA accountnum != 4211 - not aux fleet, other, marked as PC

SELECT
	1 as scope
	,mt.YEAR as year
		,mt.MONTH as month
		,'fuel.consumption_axapta - accountnum != 4211' as datasource
		,(select alias_name from aliases where field_name = 'machinery' and lang = @language) as source
		,'' as VesselID
		,(select alias_name from aliases where field_name = 'mobile_equipment' and lang = @language)  as
source_category_1
		,(select alias_name from aliases where field_name = 'PC' and lang = @language) as
source_category_2 --- ???
		,(CASE
				WHEN mt.SADAM = 'Sadamavalitsus'
				THEN (select alias_name from aliases where field_name = 'Vanasadam' and lang =
@language)

				ELSE (select alias_name from aliases where field_name = mt.SADAM and lang =
@language)
				END) as port
		,'' as terminal
		,(select alias_name from aliases where field_name = 'ts_group' and lang = @language) as
organization
		,'Tallinna Sadam' as organization_2 -- TS Sadam?
		,'Tallinna Sadam AS' as company -- TS Sadam?
		,'' as consumption_type
		,(select alias_name from aliases where field_name = lower(mt.FUEL) and lang = @language) as
fuel_type
	,mt.SUMMA/prices.price as energy_consumption
		,SUBSTRING([SEI_unit],CHARINDEX('/',[SEI_unit],0)+1,LEN([SEI_unit])-
CHARINDEX('/',[SEI_unit],0)+1) as consumption_unit
		,ft.SEI_unit as energy_consumption_unit
		,'' as oper_line
		,'' as vvv_count
	,0 as co2
		,(mt.SUMMA/prices.price) *
				ft.SEI_coefficient * 0.001 as co2eq
FROM [fuel.consumption_axapta] as mt
left outer join fuel_types_SEI as ft on
	lower(ft.fuel_type) = --lower(mt.FUEL)
```

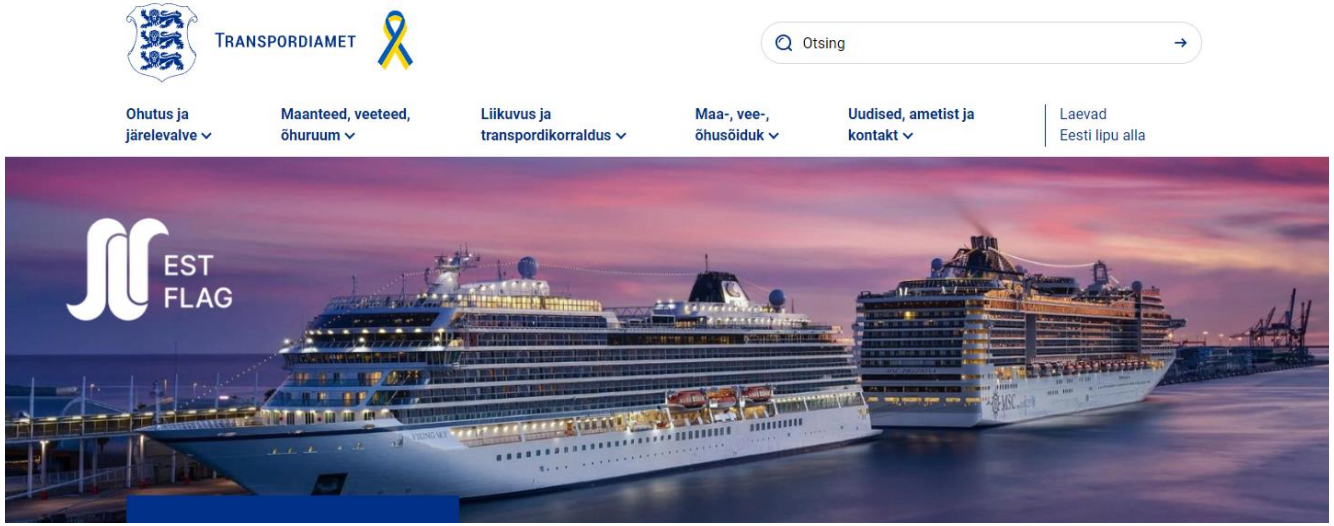

Tallinn Port Emission DB Application
PERFORMING OPERATORS' SURVEYS
EDITING MAIN TABLES
OPERATORS' SURVEY TABLES
electricity consumption
heat production
heat consumption
machinery
SYNC
SYNC
SYNC
SYNC
MAIN TABLES
electricity consumption
heat production
heat consumption
machinery
other vessels
Blue Flow
Smart Port
Tallinn Port electricity consumption
Tallinn Port fuel consumption
Tallinn Port heat consumption
Tallinn Port machinery
visiting vessels
workfleet
yachts
AUXILIARY TABLES
aliases
vehicle types
fuel types
ports
vehicle frequency distributions
fuel prices
emission sources
emission parameters
gate parameters
AIS
THETIS-MRV
MASTER QUERY
MASTER TABLE
Emission reports by Power BI
Tables managed by Tallinn Port
Tables generated by scripts
Tables generated by operators app
Parameter tables

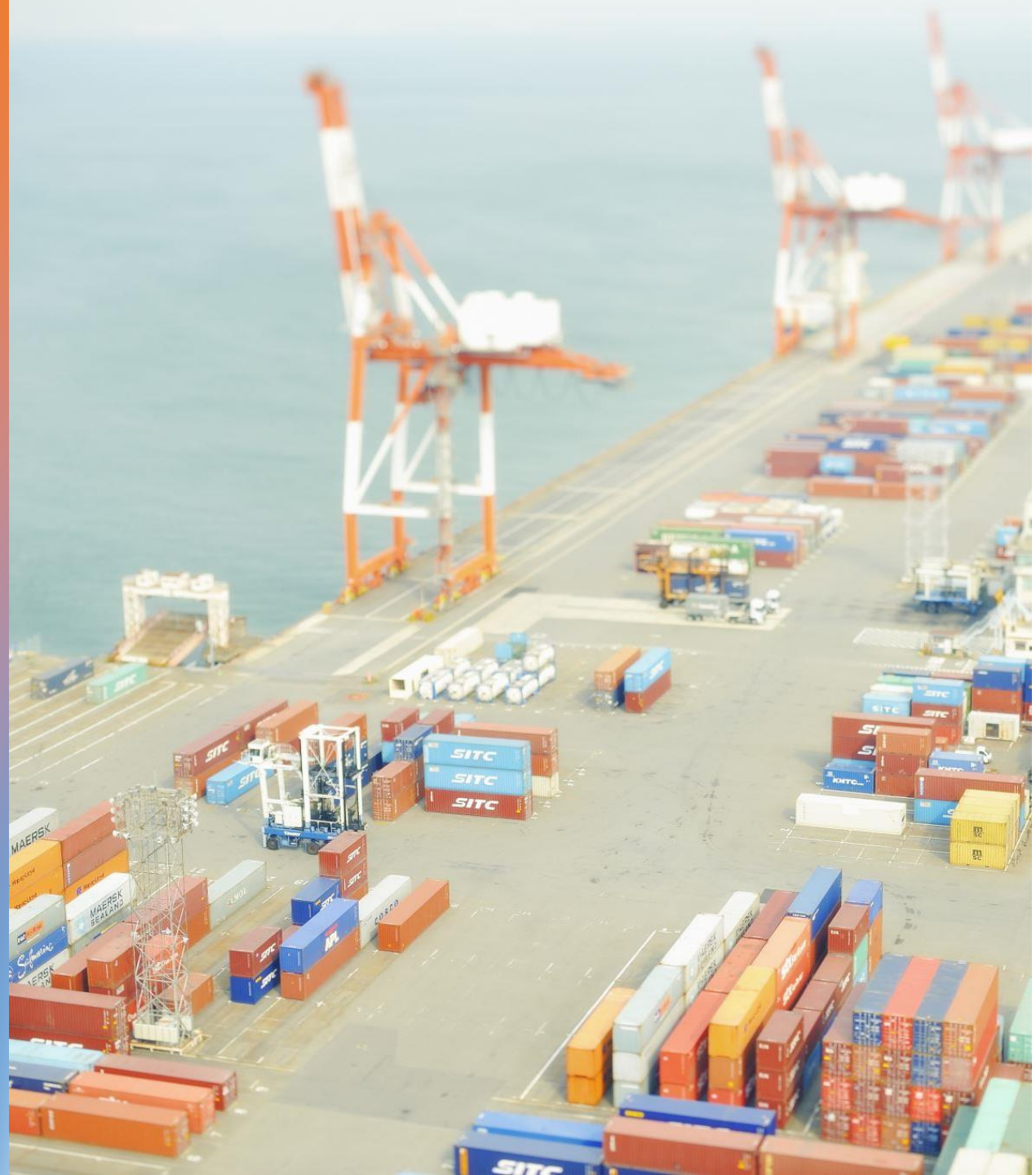
POWER BI


Co2 eq by Skoop
Skoop
1
2
Σ Co2 eq by Organisatsioon
Organisatsioon
TS Laevad
TS Shipping
Tallinna Sadam
Σ Co2 eq vs eelmine aasta
24.34K
Goal: 26.91K (-9.56%)
%GT Co2 eq and Σ Co2 eq by Saasteallikas
Laevad
77.18%
Elekter
16.81%
Sadamad
2.89%
%GT Co2 eq
% Co2 eq and Σ Co2 eq by Saasteallikas and Skoop
Saasteallikas
Elekter
Laevad
Sadamad
Sõidujõu
77.18%
2.89%
2.35%
16.81%
0.77%
% Co2 eq

GHG EMISSIONS CALCULATION SYSTEM FOR PORTS

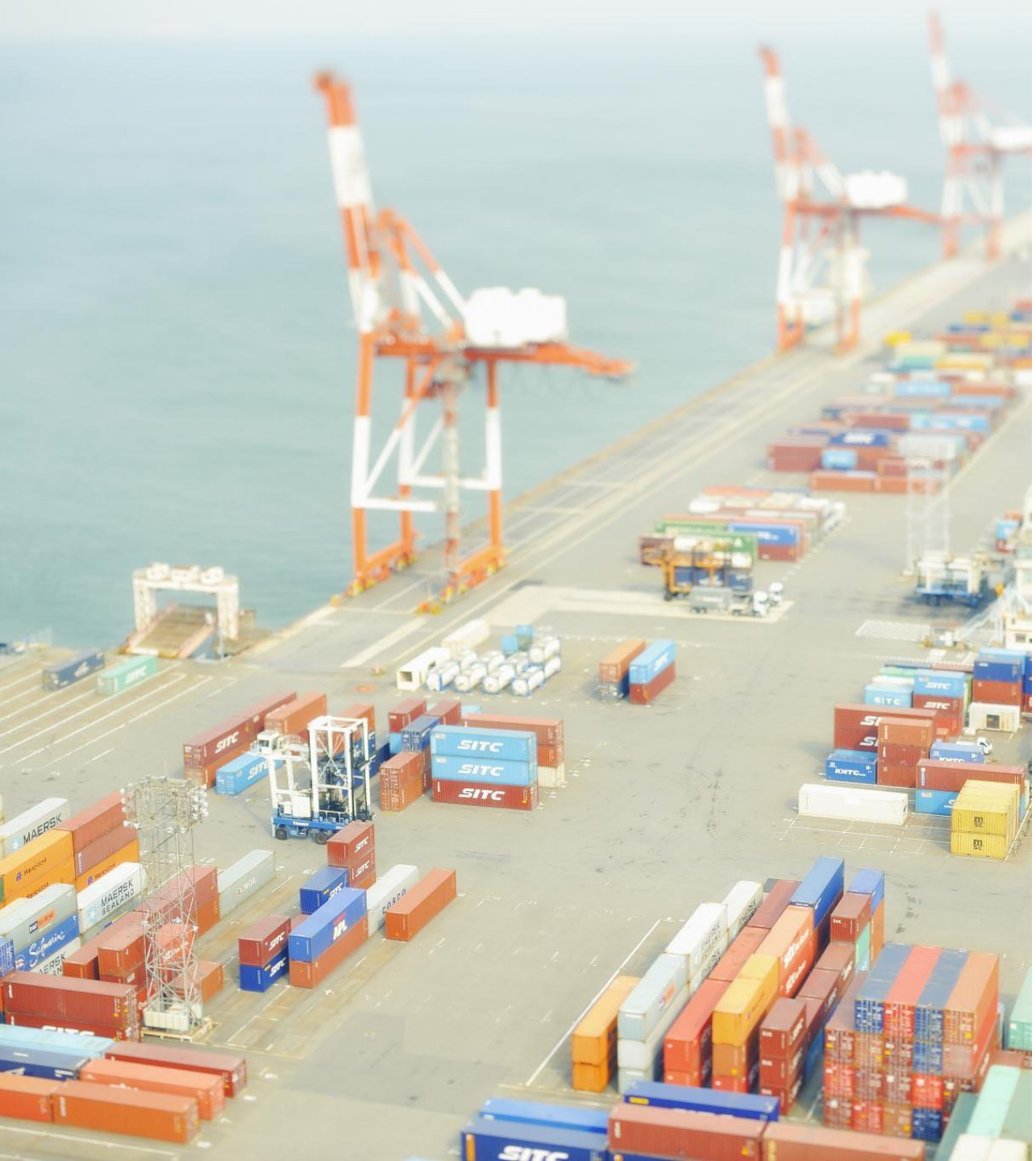






Key messages

- Hybrid approach combining existing methodologies
- Using direct inventories wherever possible
- Data collection and validation is the most time consuming phase → need to automate this process
- Strong focus on visiting ships as shipping is important source of GHG
- Efficient GHG emission assessment



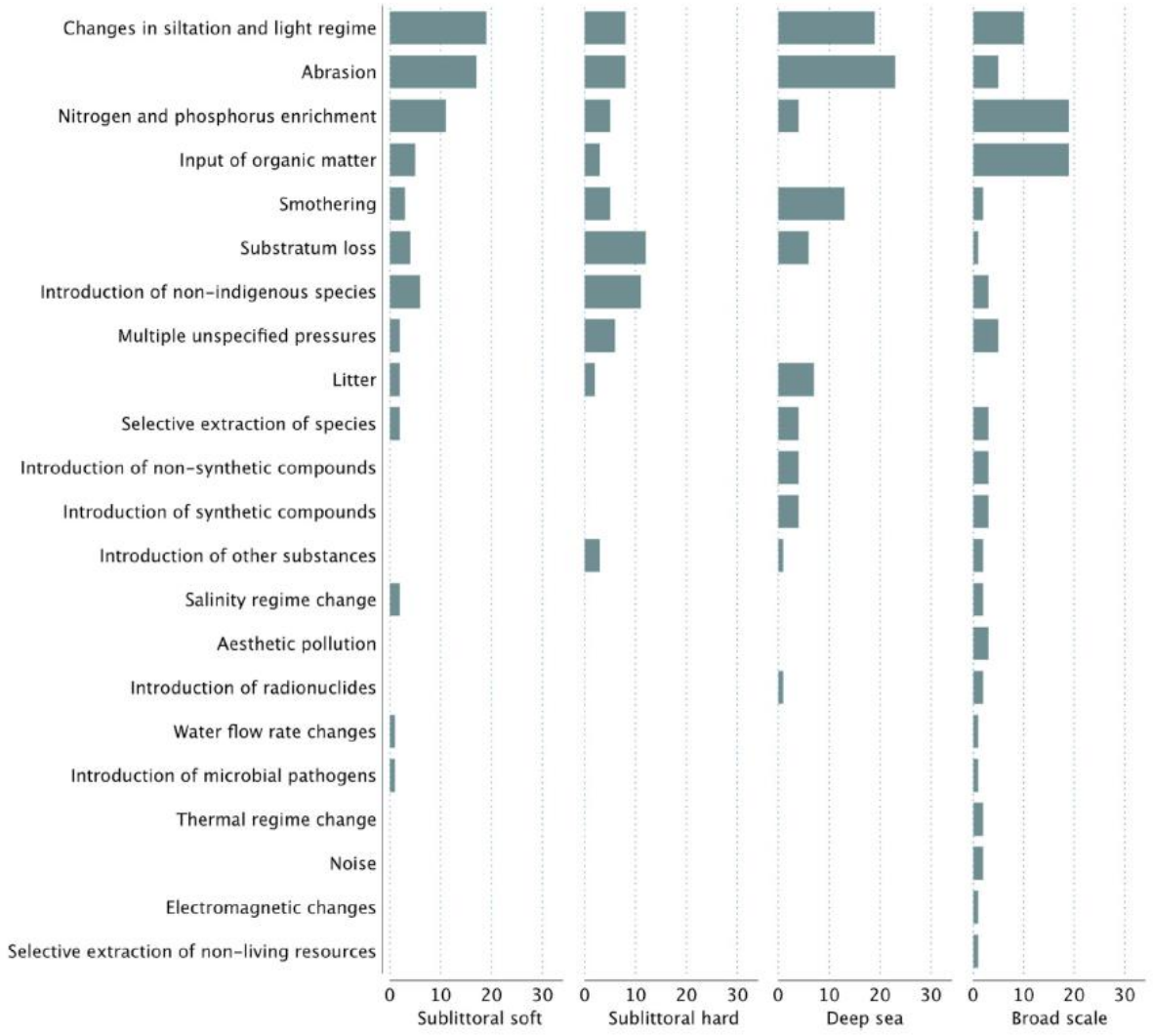
Future challenges

Ports must standardize their calculation methodologies for GHG emissions. This requires the development of IT tools that can integrate diverse databases, enabling meaningful comparisons of emissions across ports (Check out the results of the Sustainable Flow project).

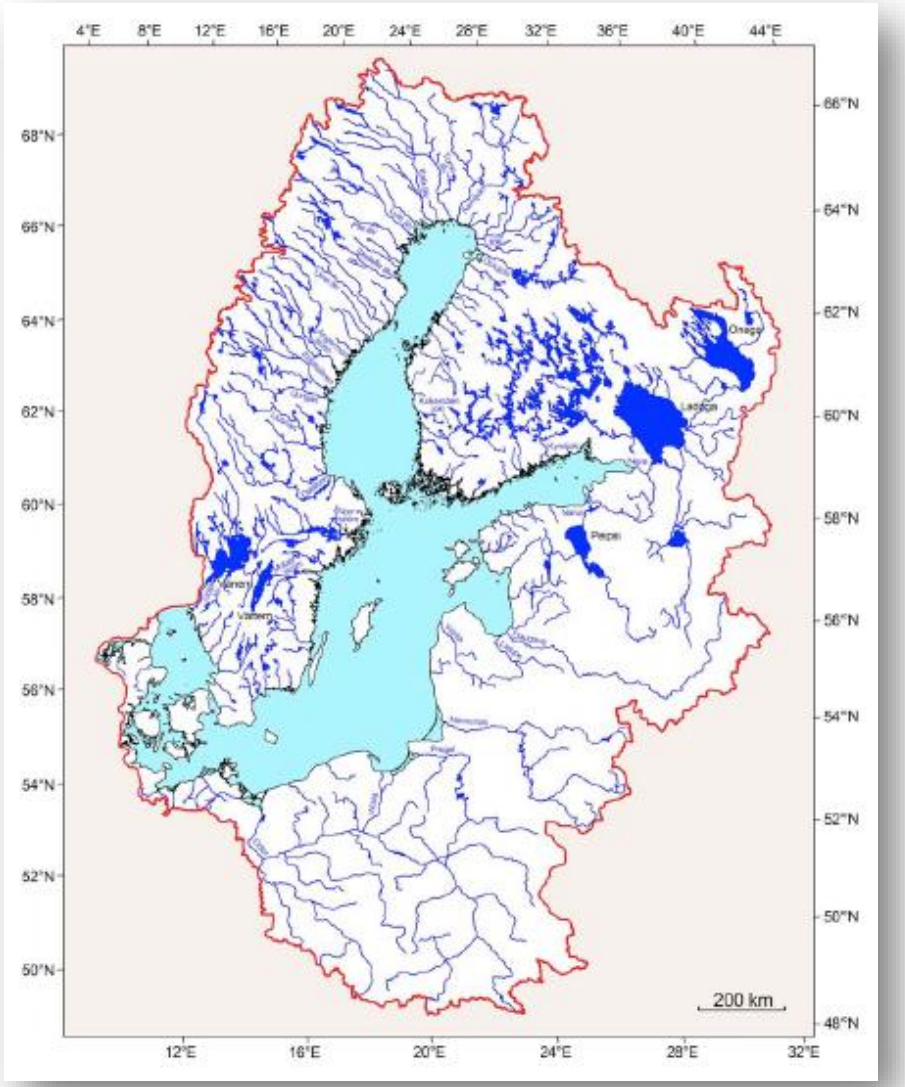

GHG emissions are only part of the broader environmental and climate impact of shipping

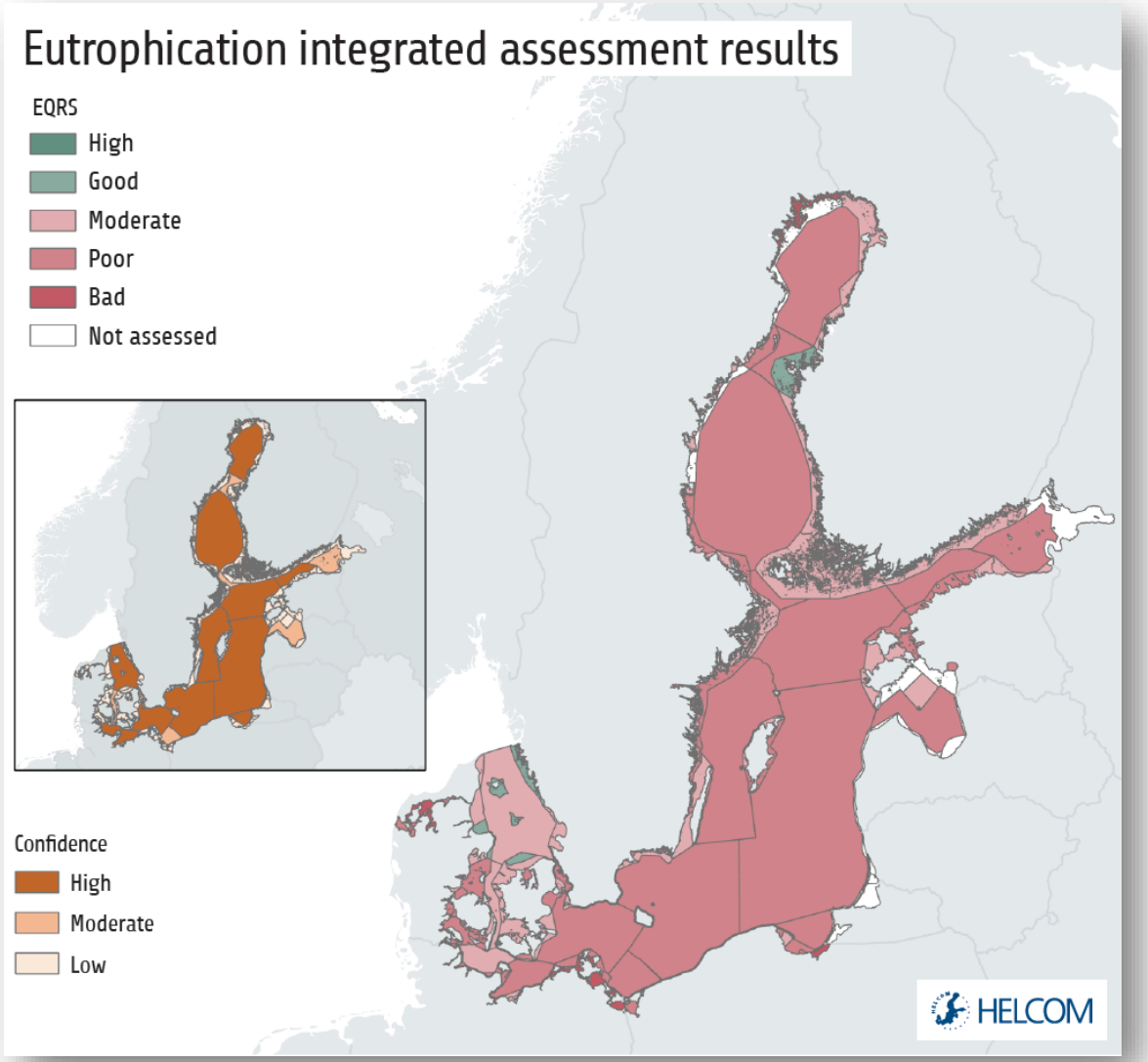
HUMAN ACTIVITIES HAVE IMPACTS

Human-induced pressures are intensifying and becoming more diverse, leading to habitat loss. These pressures stem from multiple causes operating across various scales.



Baltic Sea is a transboundary ecosystem with large watershed area





HELCOM Baltic Sea action plan (BSAP) environmental targets

Eutrophication

Baltic Sea unaffected by eutrophication

- Clear water
- Natural level of algal blooms
- Natural distribution and occurrence of plants and animals
- Natural oxygen levels

Biodiversity

Favourable status of Baltic Sea biodiversity

- Natural marine and coastal landscapes
- Thriving and balanced communities of plants and animals
- Viable populations of species

Hazardous substances

Baltic Sea undisturbed by hazardous substances

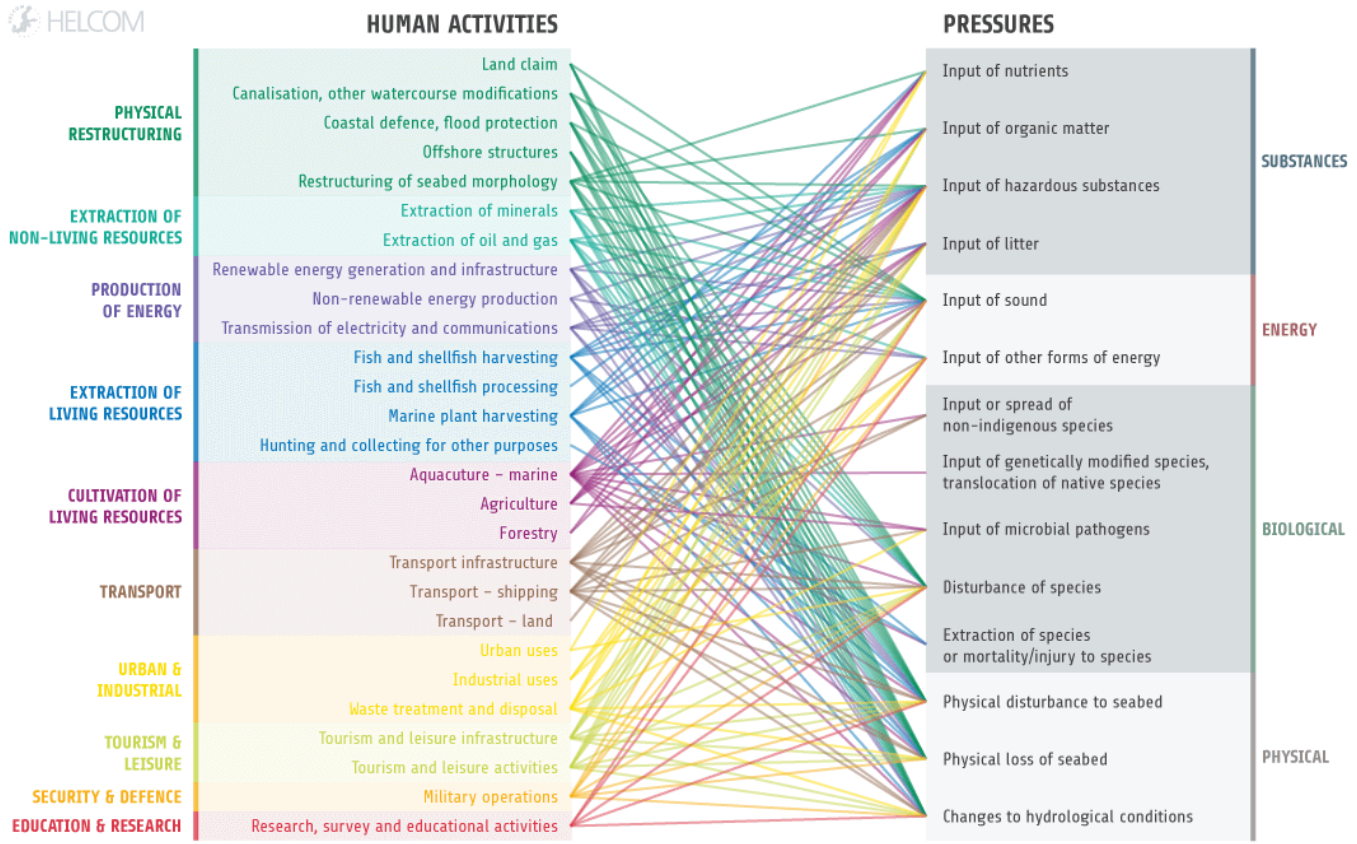
- Concentrations of hazardous substances close to natural levels
- All fish are safe to eat
- Healthy wildlife
- Radioactivity at the pre-Chernobyl level

Maritime activities

Enviromentally friendly maritime activities

- Enforcement of international regulations – no illegal discharges
- Safe maritime traffic without accidental pollution
- Efficient emergency and response capabilities
- Minimum sewage pollution from ships
- No introductions of alien species from ships
- Minimum air pollution from ships
- Zero discharges from offshore platforms
- Minimum threats from offshore installations

Complex system: human activities and related pressures in the Baltic Sea

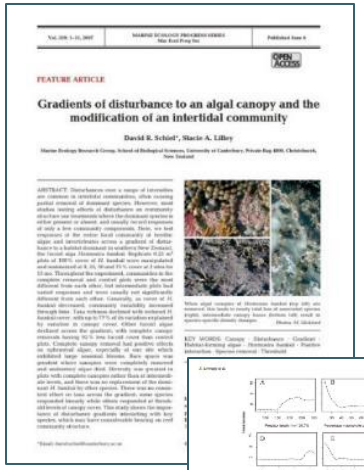


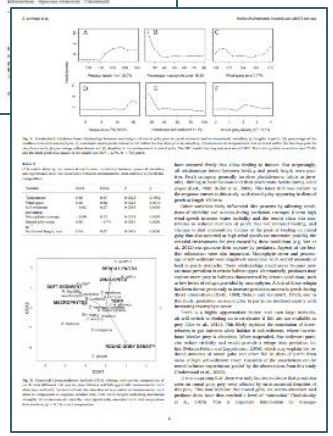
Complex ecosystems with multiple feedback loops


Creativity + Action
= Innovation

How to effectively bridge the gap between science and policy?

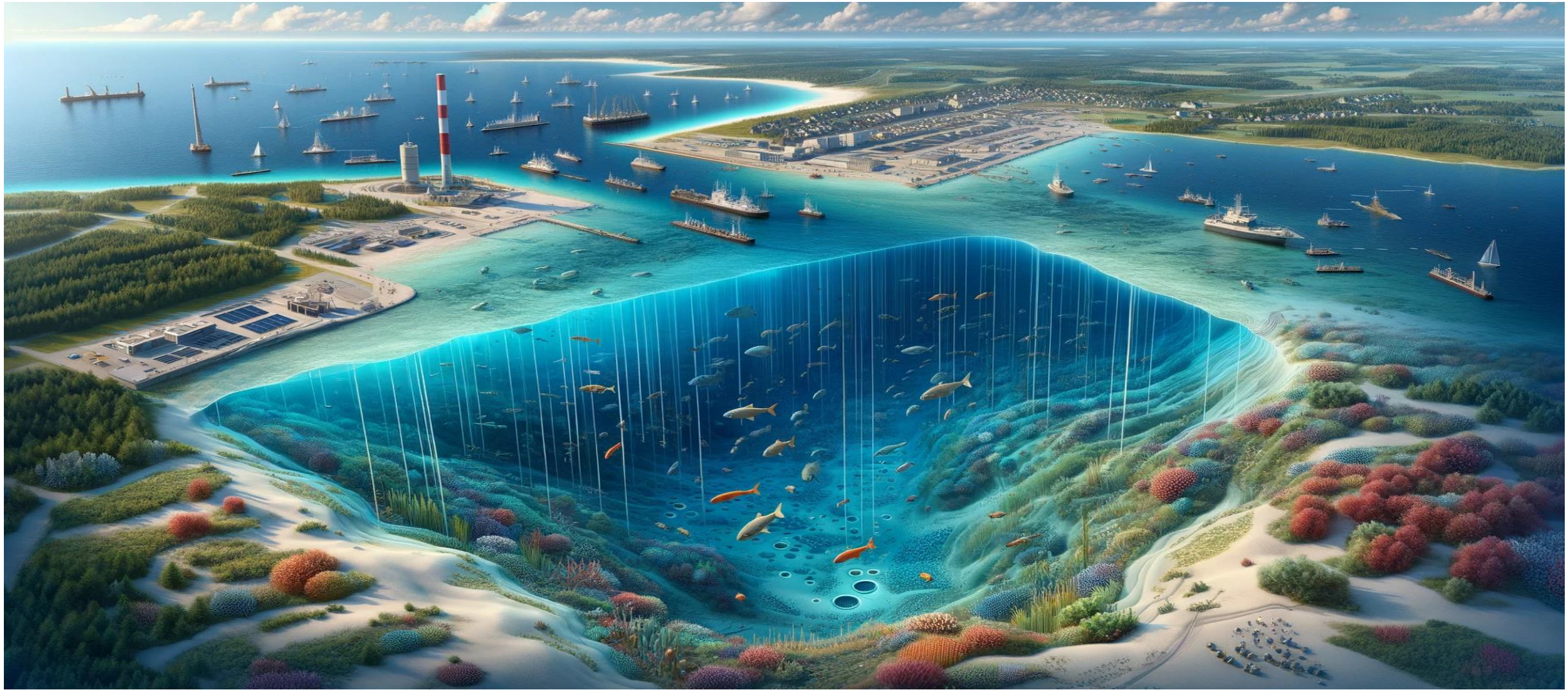
The structure and functioning of marine ecosystems is the result of myriads of components and processes acting simultaneously. Addressing this level of complexity ***requires data- and analysis-demanding schemes***.





Disconnection in the flow of knowledge between science (specific/technical) ***and policy*** (general/layman approach).

Ecological digital twin for dynamic impact assessments and mitigation strategies

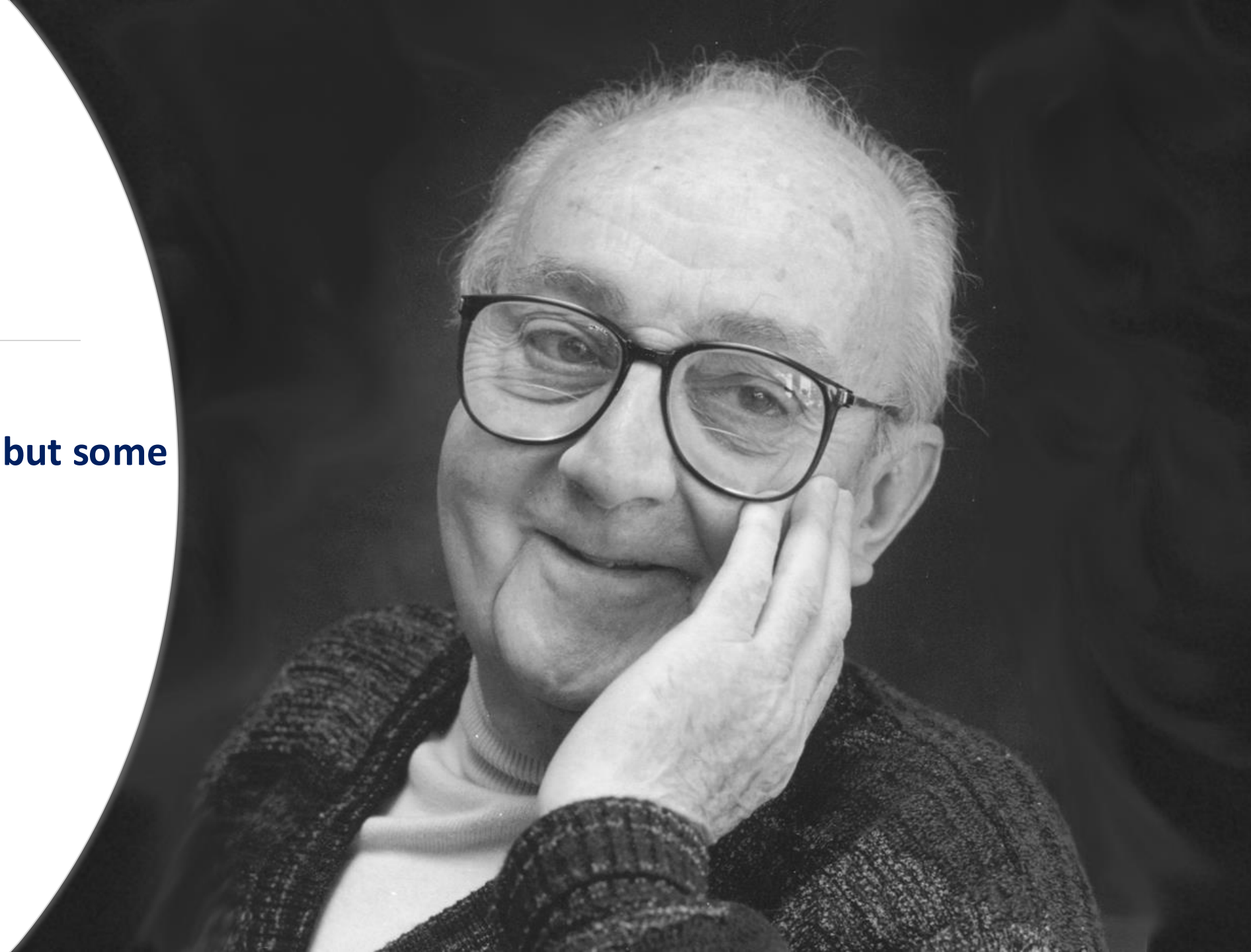


Ecological digital twin: New generation ecosystem models

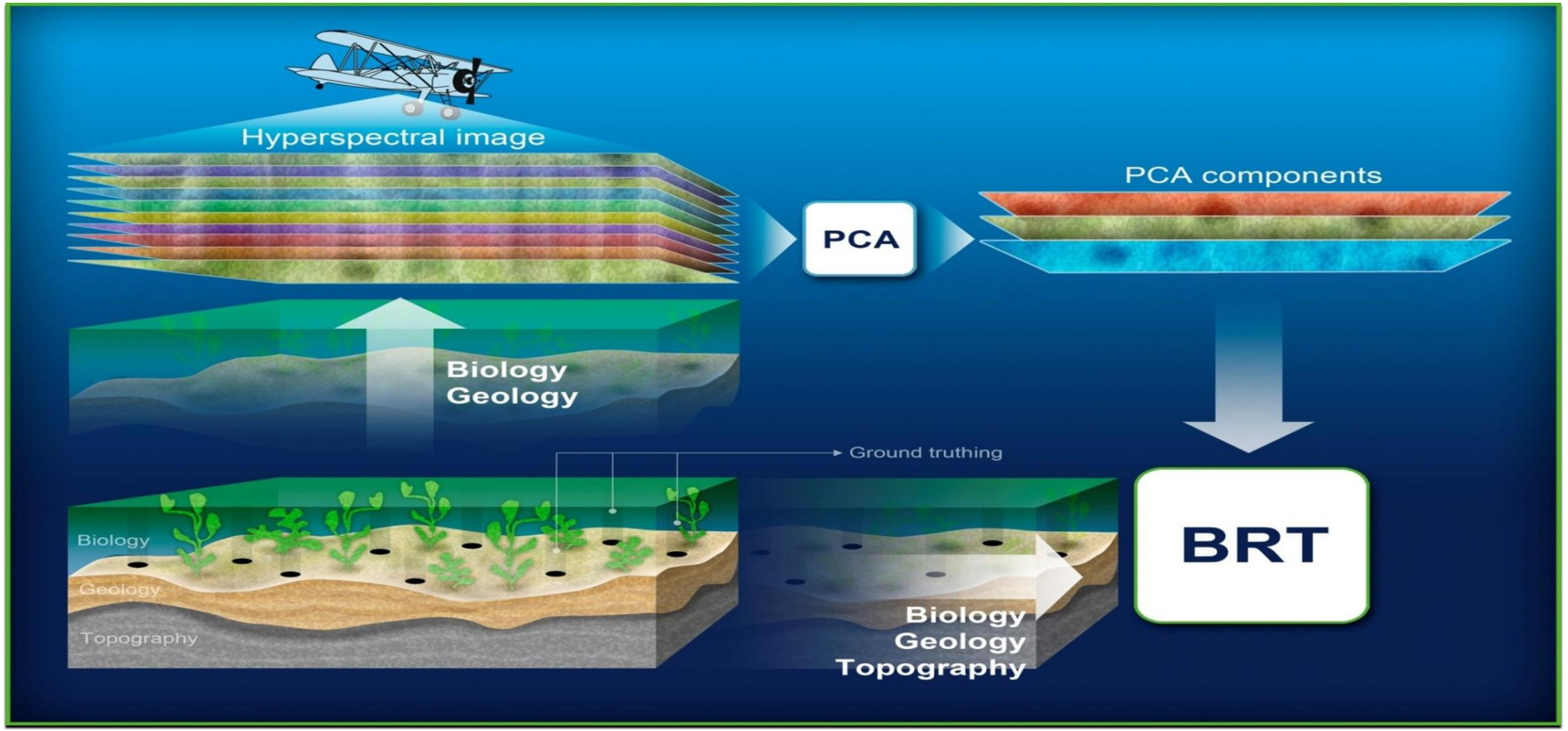
Modelling

All models are wrong, but some are very useful

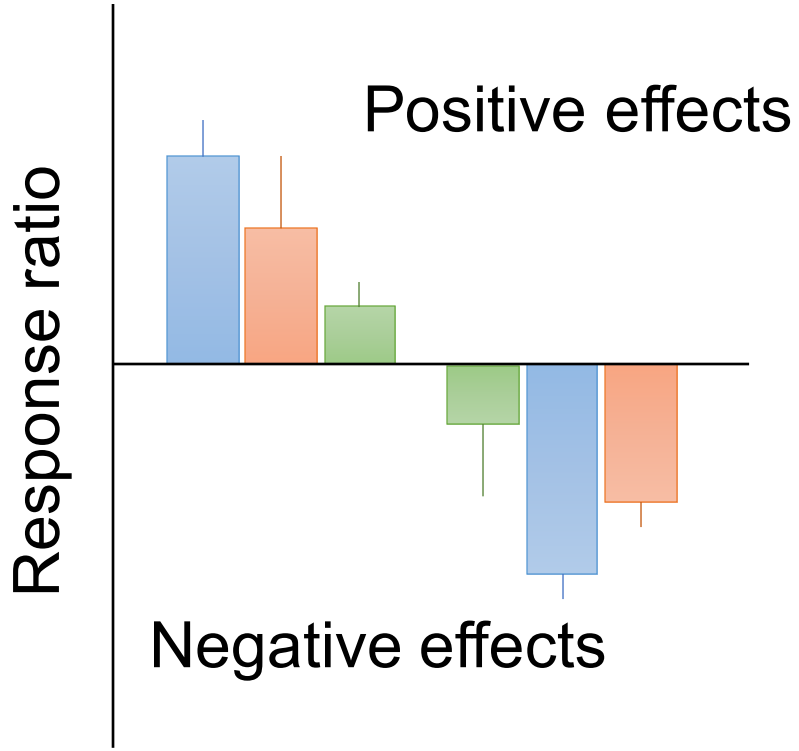
George E. P. Box



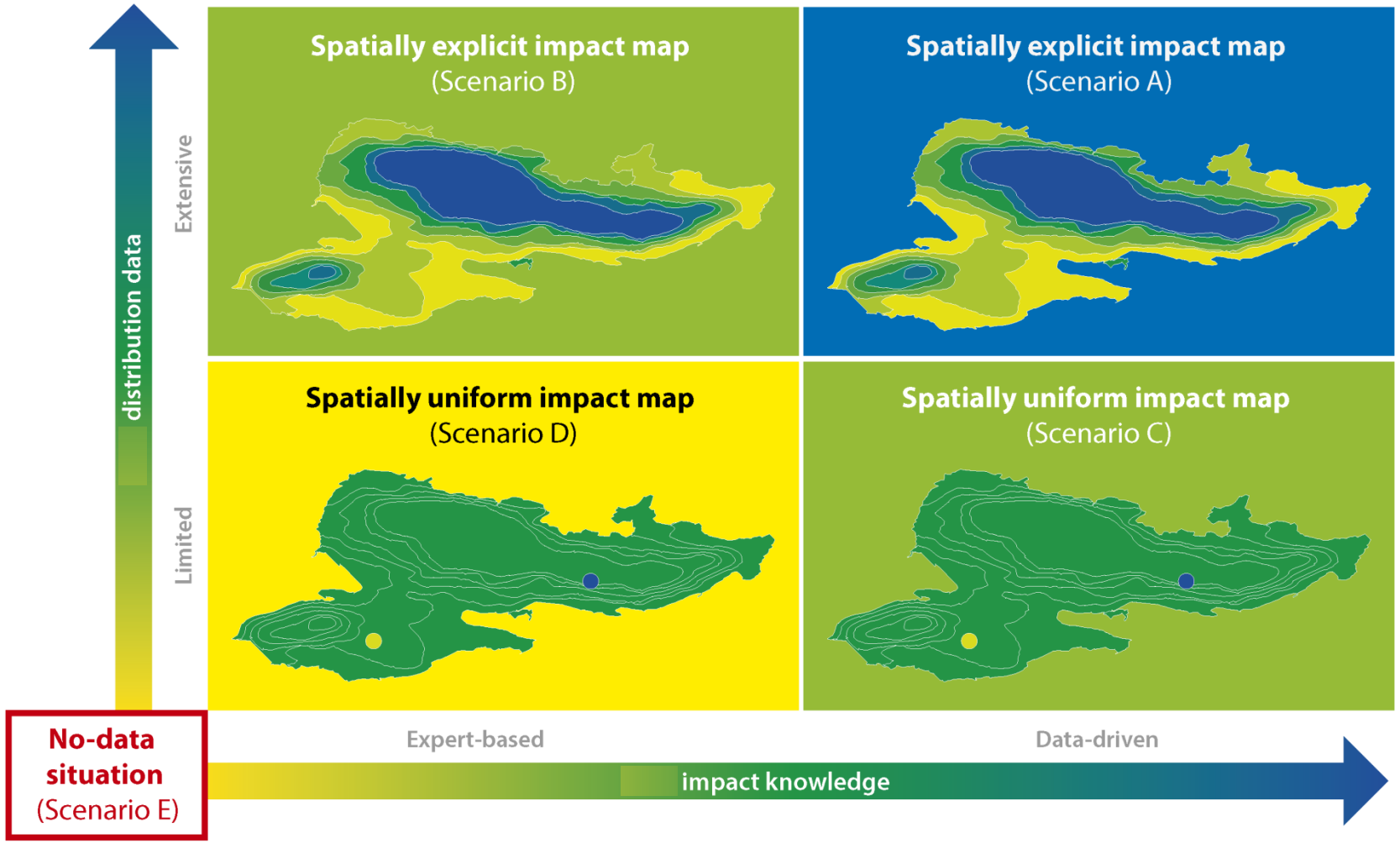
Ecological digital twin: Overcoming the challenges of data scarcity and quality

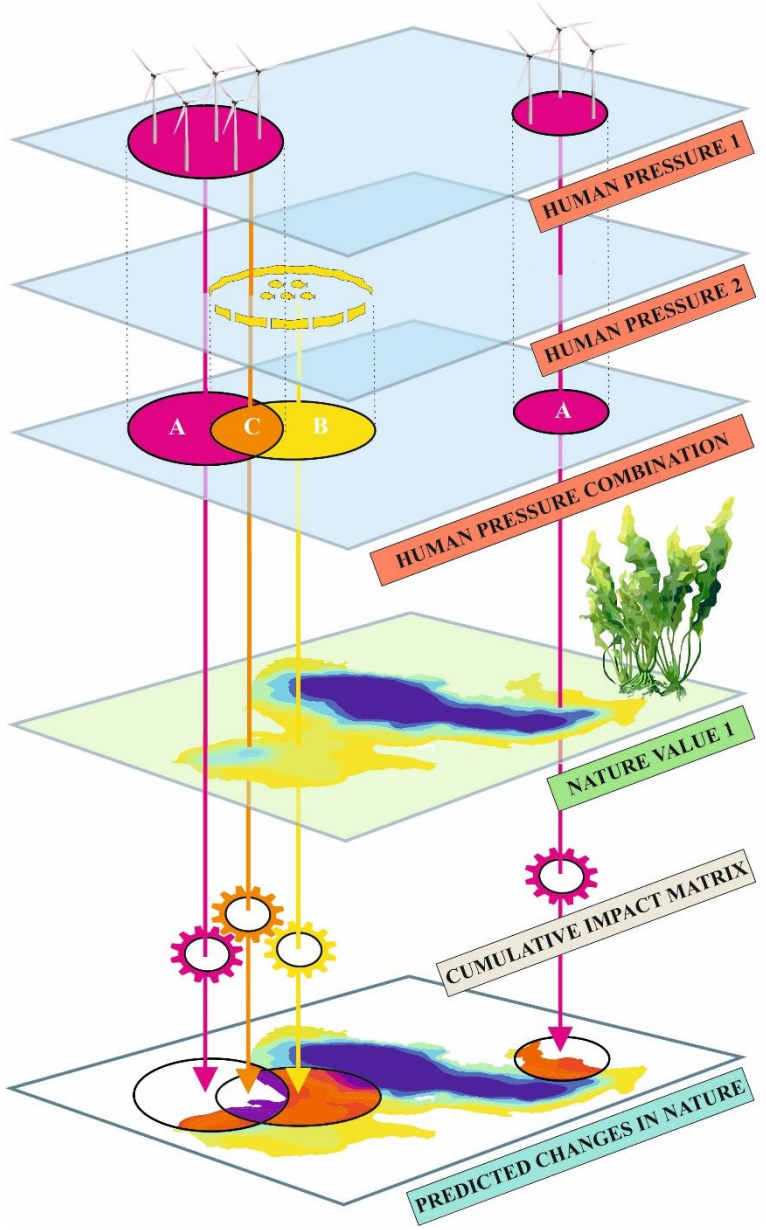


Ecological digital twin: limited knowledge and ensuring high-quality information



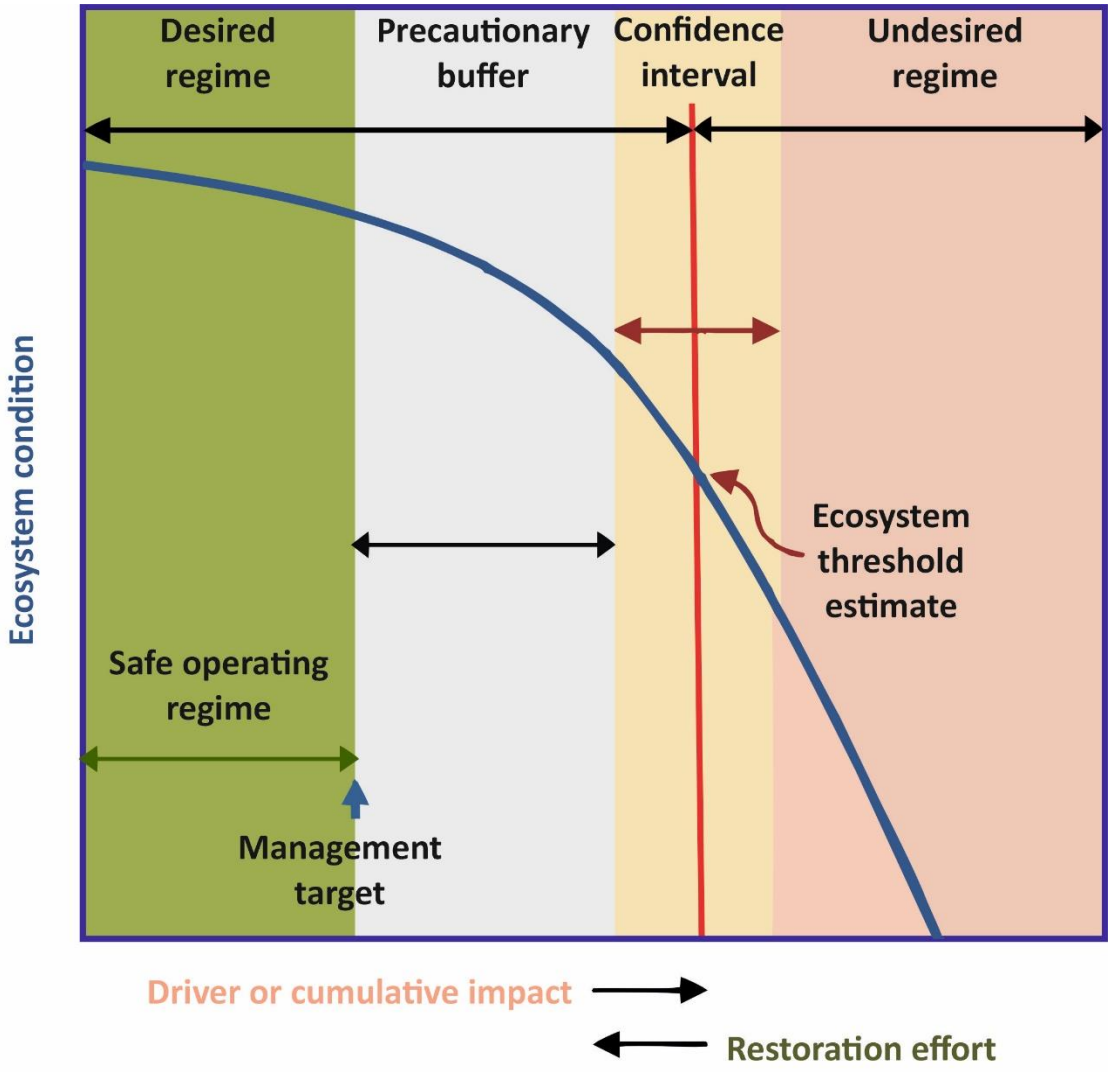
Calculating cumulative impacts

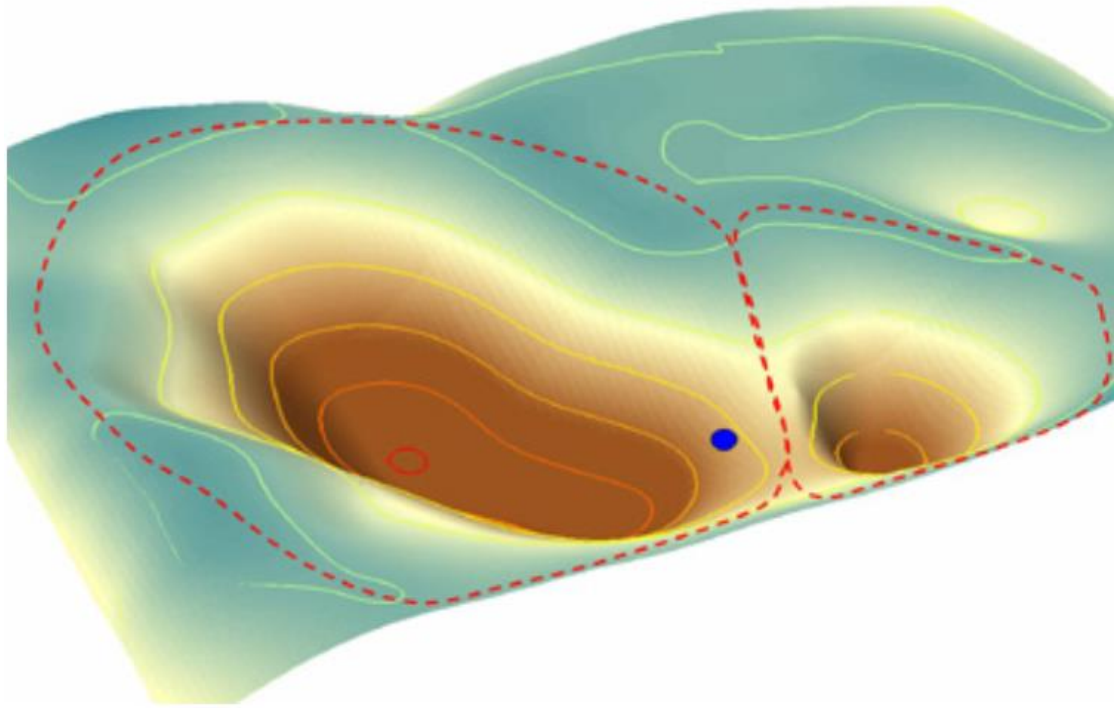




Presenting potential positive and negative outcomes of human impact scenarios and our restoration efforts

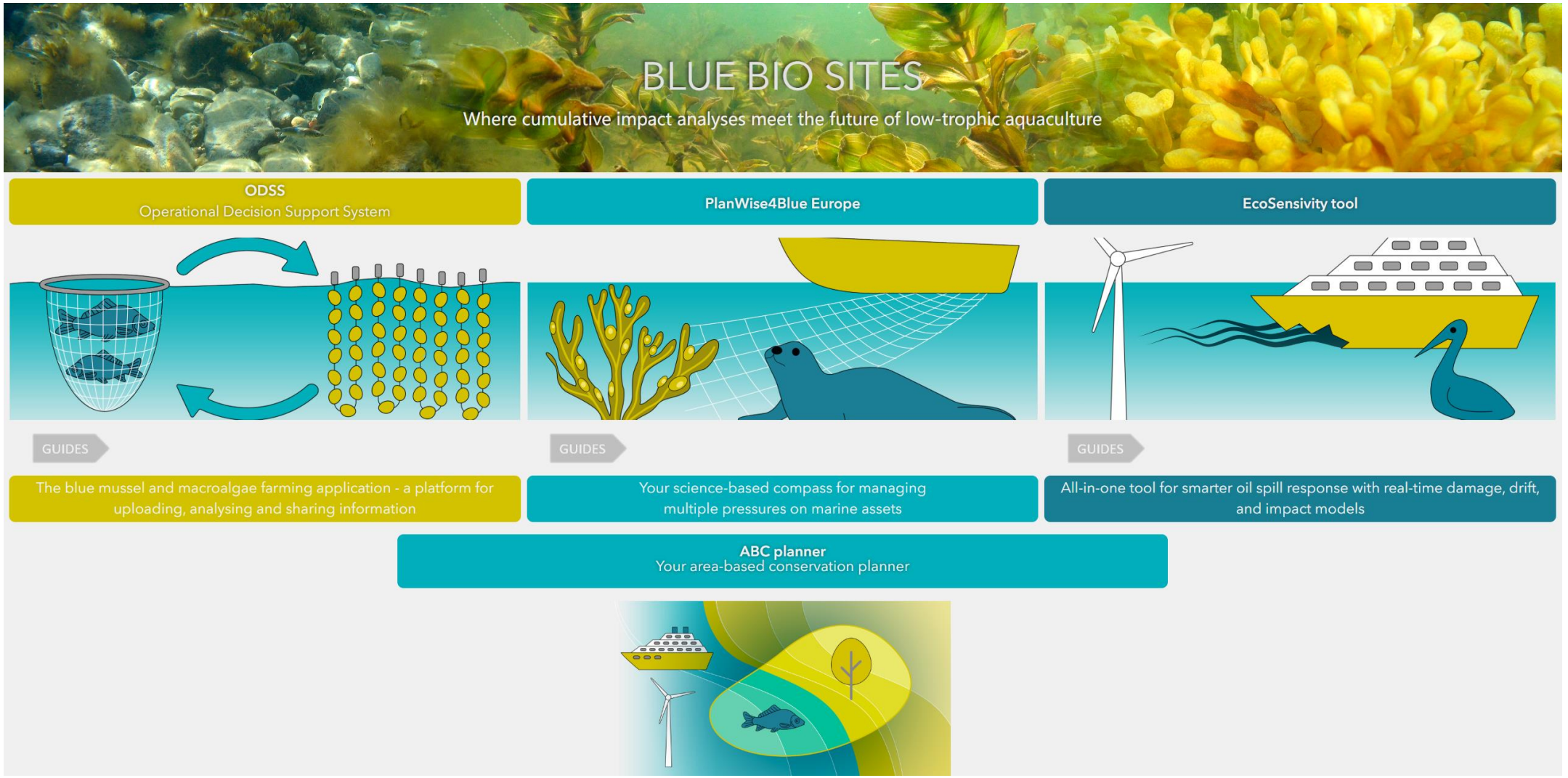
Ecological digital twin: Management model





A transition from current management to true ecosystem-based management

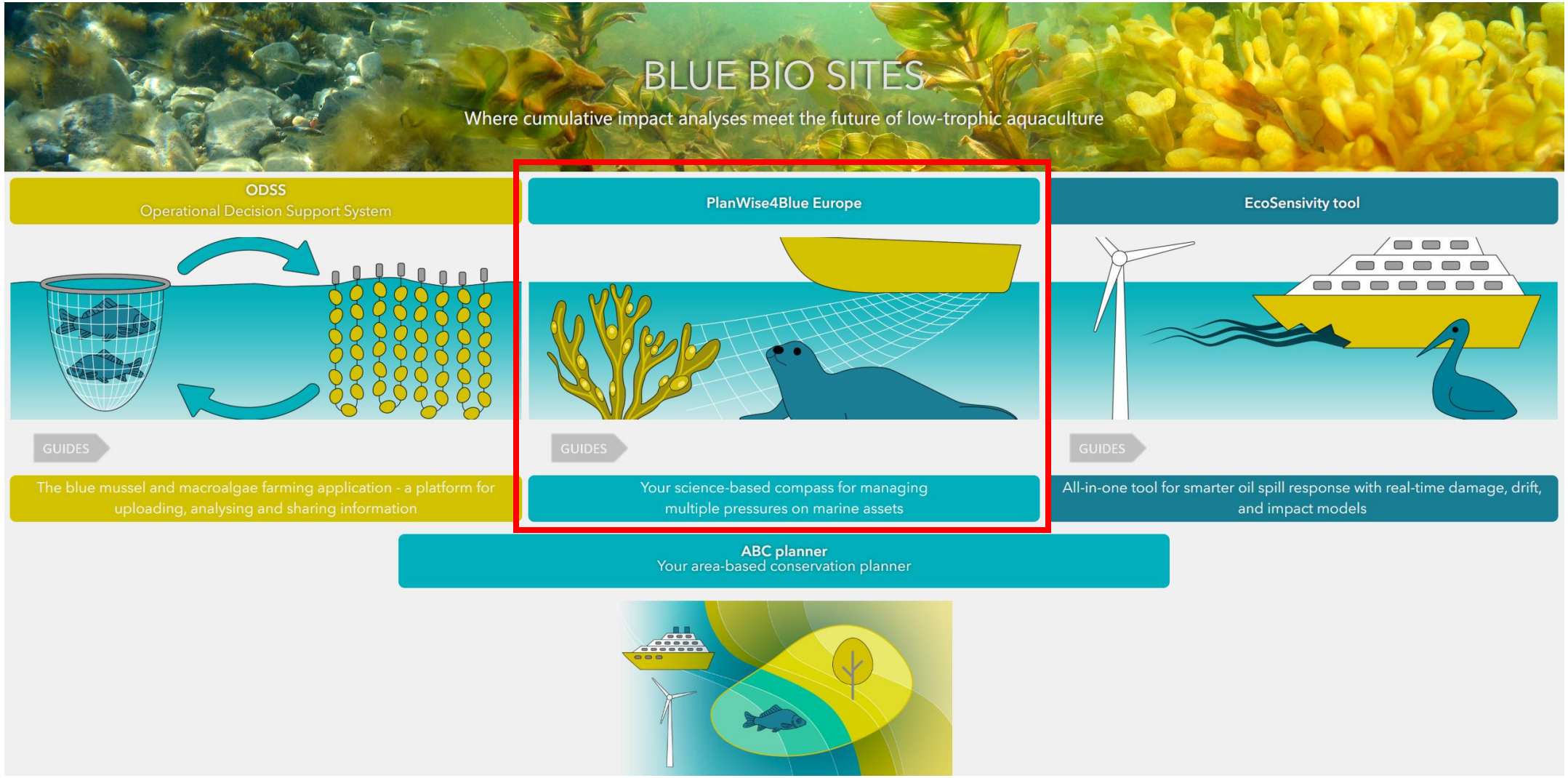
Ecological digital twin: Decision Support Tools



https://gis.sea.ee/bluebiosites/

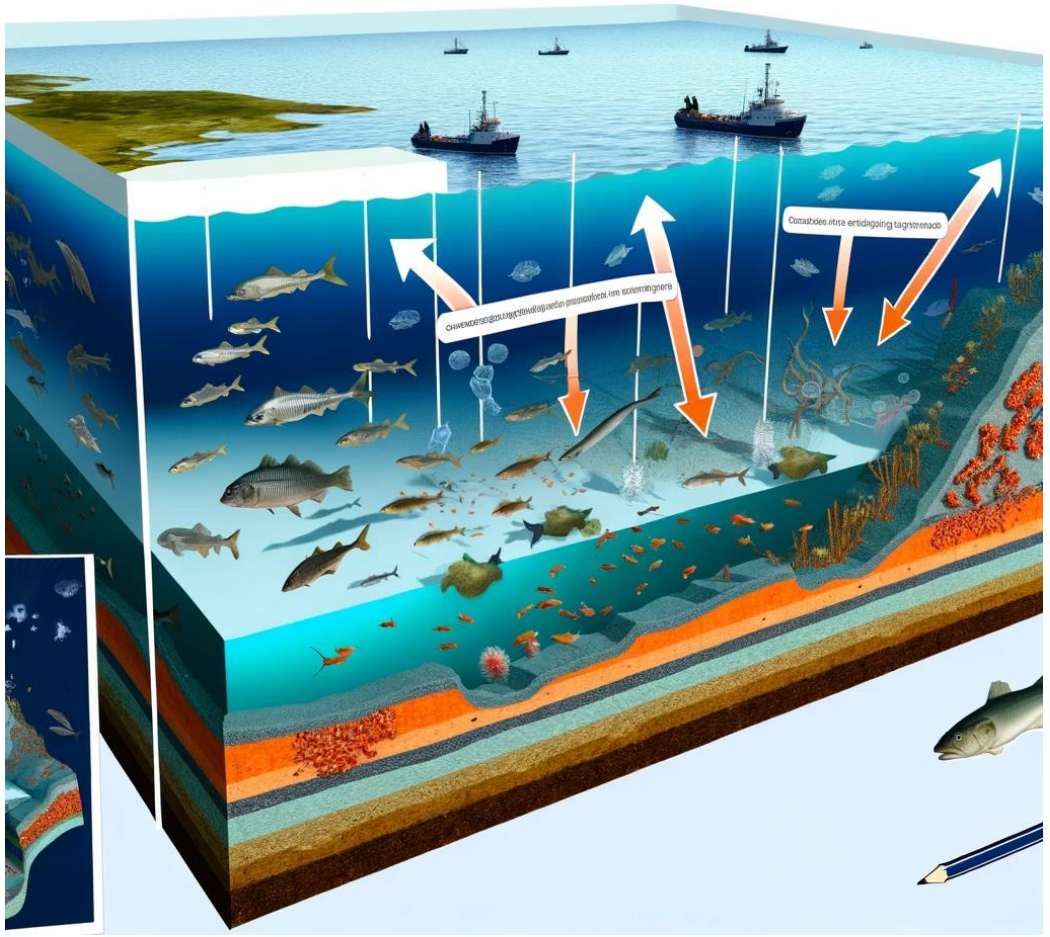
PW4B: Simple-to-use web tool

The PlanWise4Blue tool quantifies cumulative human impacts on key ecosystem elements at 1 km^2 spatial scale

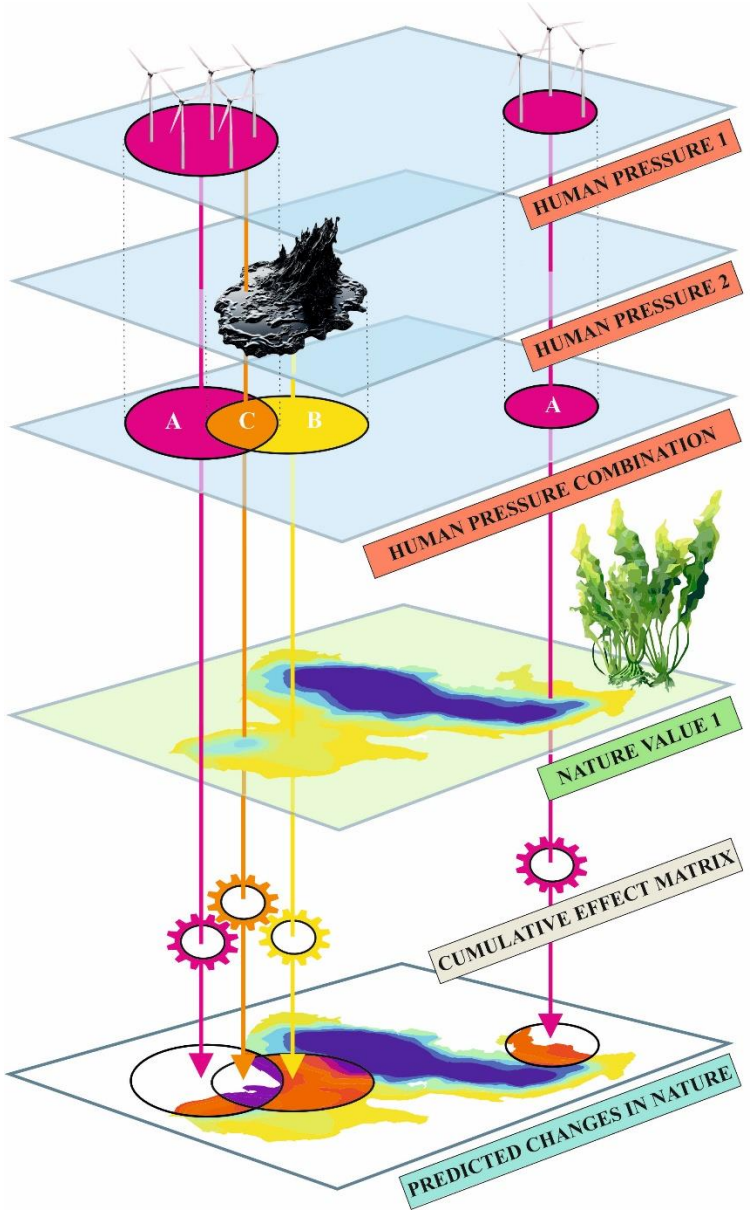


Key building blocks of the tool

- Updated maps of nature assets
- Any scenario involving a combination of human activities
- Innovative algorithm predicting environmental impacts



Innovative algorithm: GIS perspective



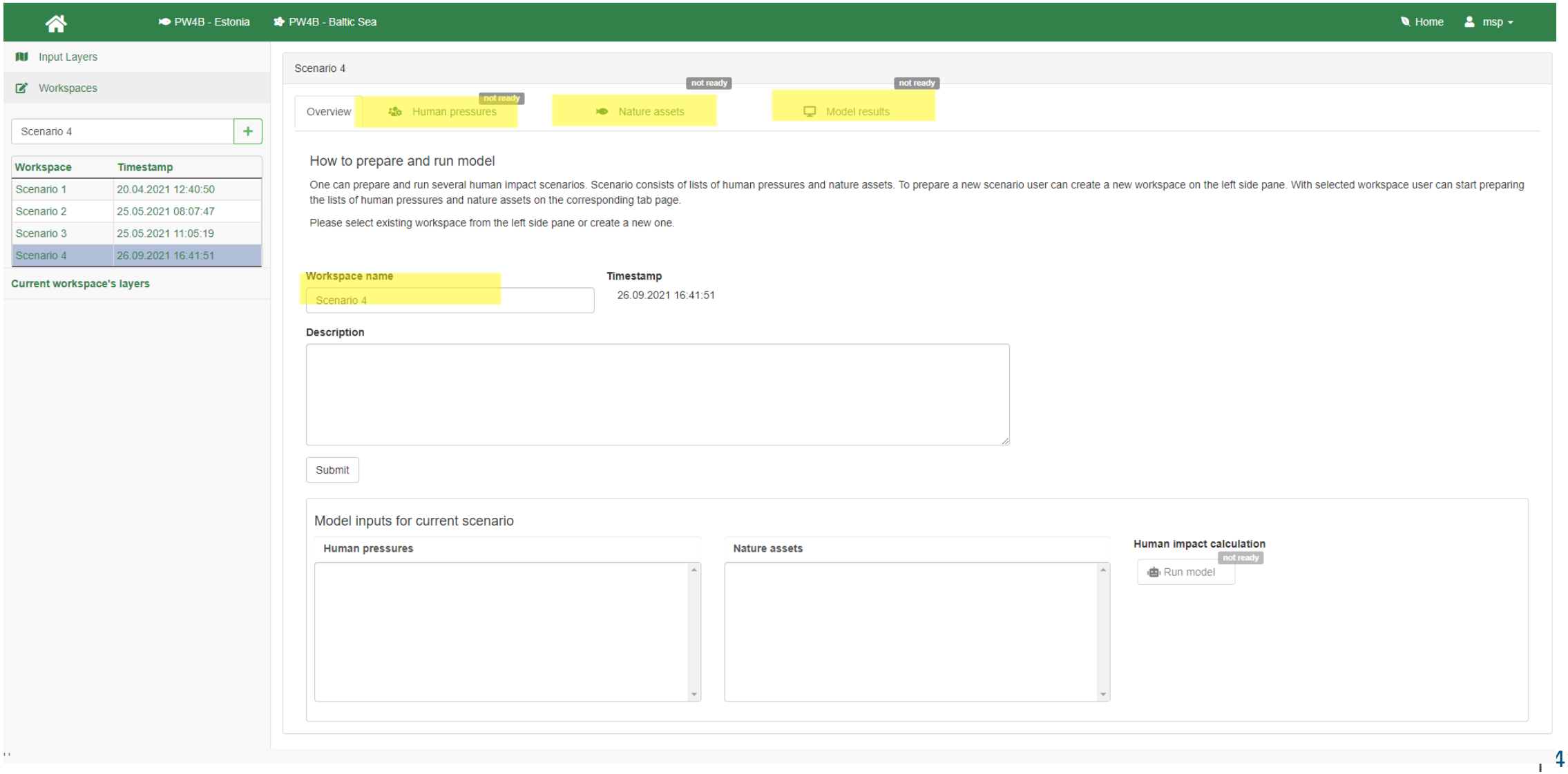
Reading scenario (spatial distribution of pressures)

Reading nature values

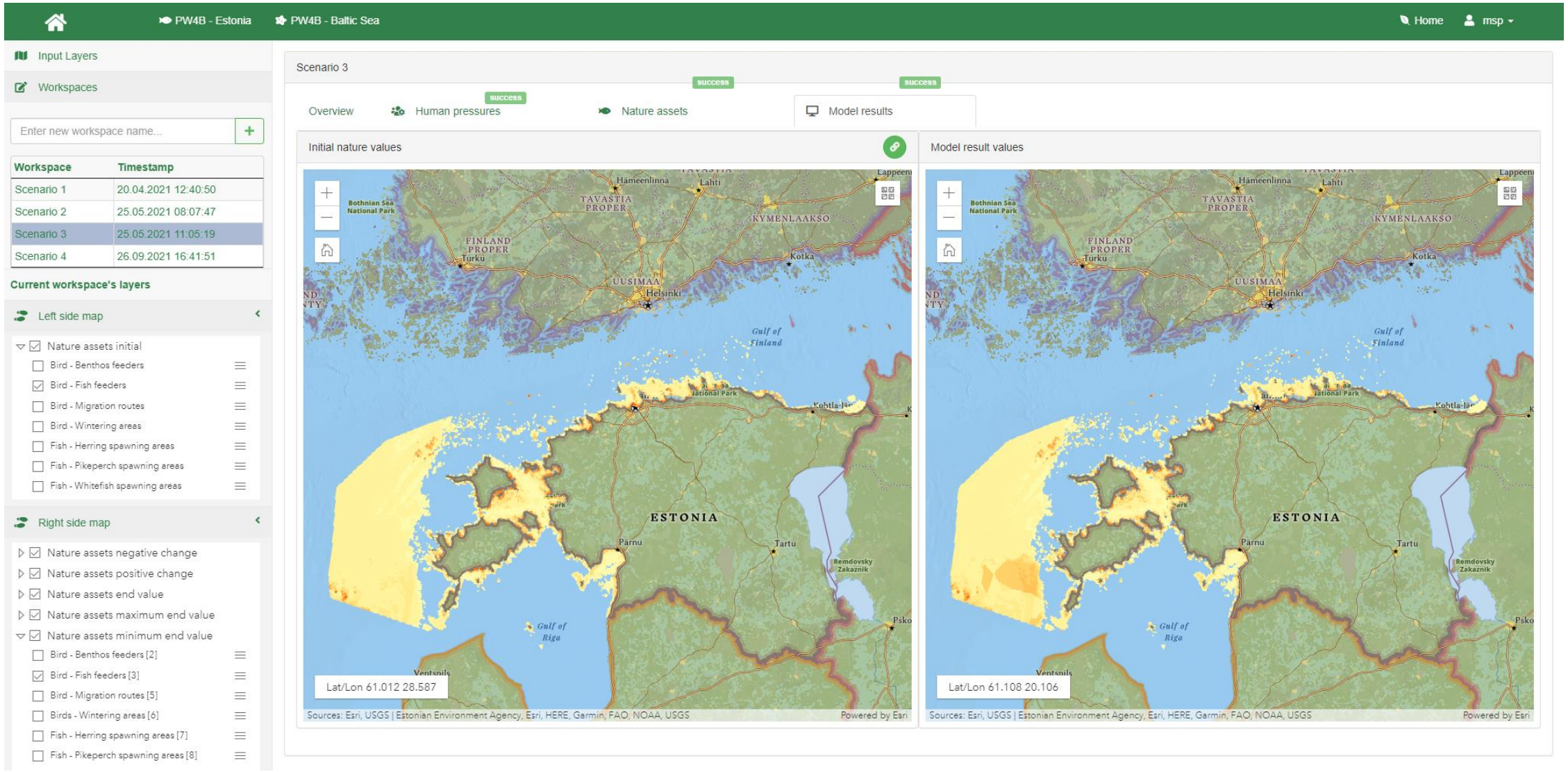
Running GIS modelling

Publishing maps on impacts

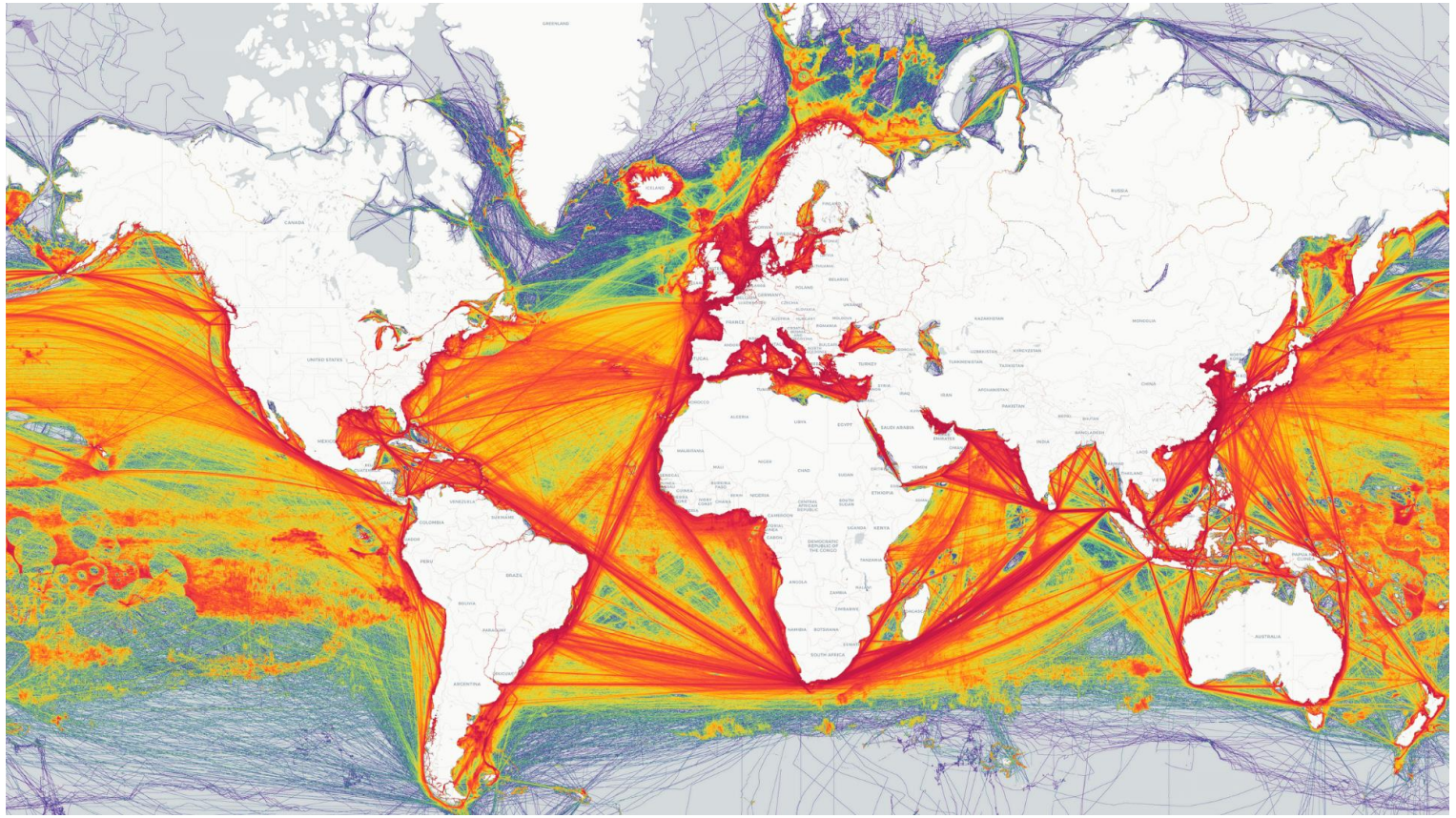
Workspace view (defining workspace)



Workspace view (results)



Oil spills



Addressing the Complexity of Oil Spill Impacts

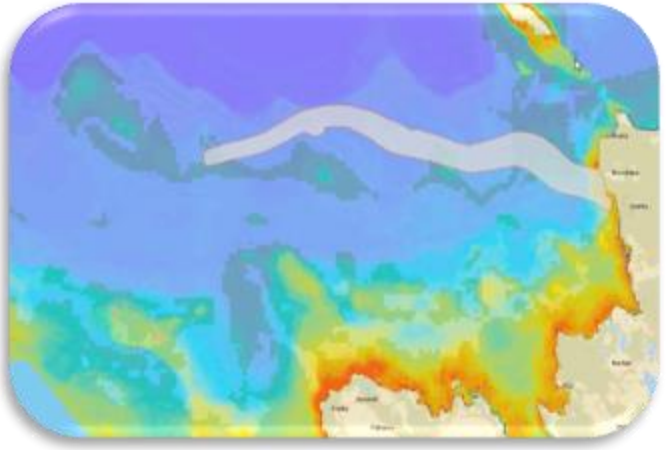
Oil Spills Are Highly Specific Events:

- Vary by location, oil type, spill volume, and environmental conditions.
- Require real-time response to minimize immediate damage.
- Have long-term cumulative effects on marine ecosystems.

EcoSensitivity – A New Web Tool:

- Combines oil spill dynamics with cumulative impact assessments.
- Integrates real-time spill data, drift modeling, and ecosystem vulnerability.
- Helps authorities prioritize response actions and long-term restoration.

Seatrack Web

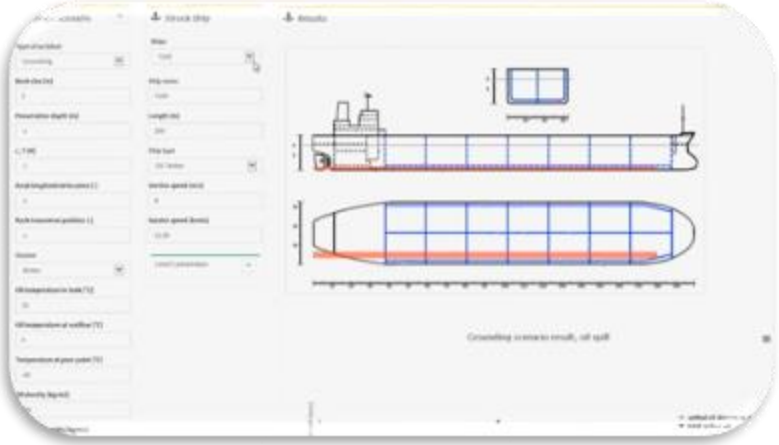


PlanWise4Blue: human pressures (oil spill)

Selection of nature assets

PW4B: Calculating impacts (Environmental Sensitivity Index)

ADSAM module



BlueBioSites

Shared Tools

Accidental Damage and Spill Assessment Model (ADSAM)

Menu

- Vessels
- Scenario

All input fields in Single scenario must be filled. If input value is not known then -1 should be entered (for temperatures it is -1000).

Accident type	Grounding
Rock size [m]	3
Penetration depth [m]	4.5
c_T [N]	-1
Rock longitudinal location [-]	-1
Rock transverse location [-]	-1
Struck Ship length [m]	274
Struck Ship velocity [m/s]	8
Struck Ship breadth [m]	48
Struck Ship draft [m]	9.6
Season [-]	Winter
Oil temperature in tank [°C]	10
Oil (seawater temp.)temperature at outflow [°C]	0
Temperature at pour point [°C]	-40
Oil density at tank temperature [kg/m3]	764
Seawater density [kg/m3]	1005
Ice cover thickness [m]	0.1
Relative actual contact length [-]	-1
Reference contact length in [m]	-1
Smallest load width [mm]	-1
Flexural strength of ice [kPa]	-1
Elastic modulus of ice [GPa]	-1
Ice-hull friction [-]	-1
Ice density [kg/m3]	-1
Scale factor [-]	-1

Scenario settings | Ice conditions | Struck ship

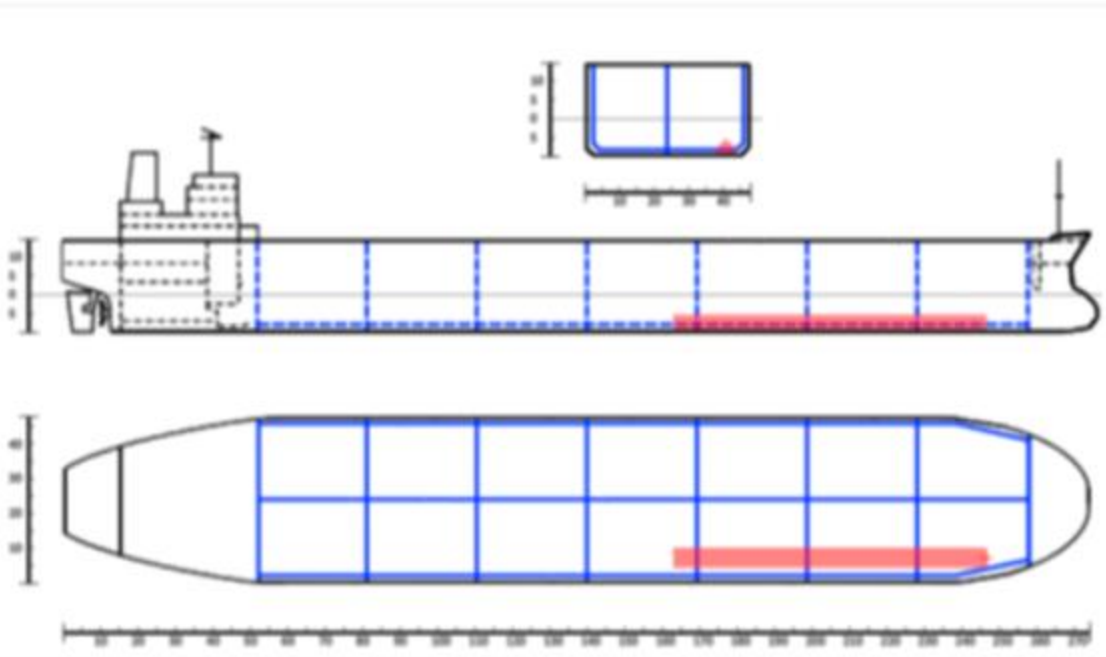
Vessels

Oil Tanker 2

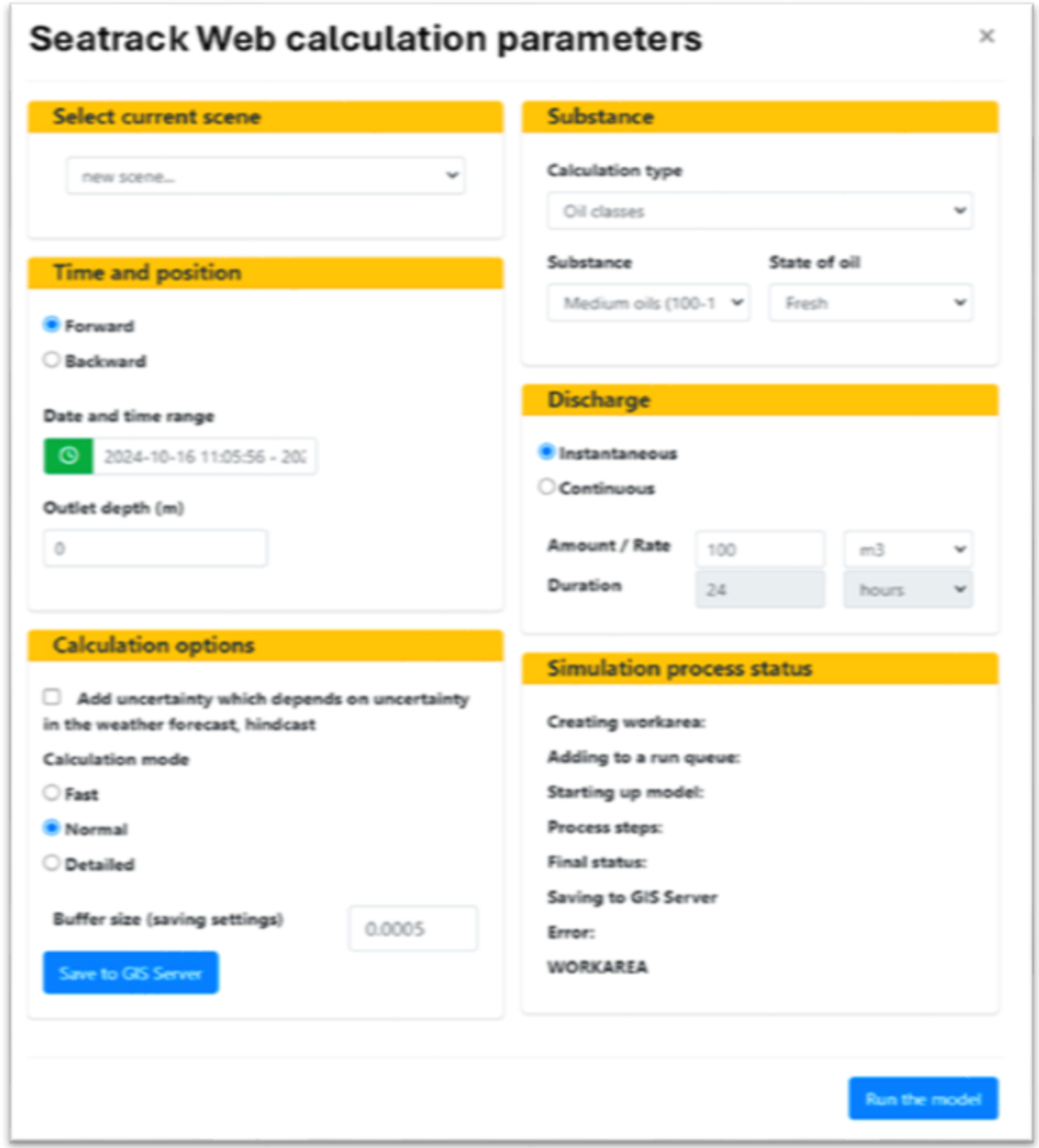
Ship name	**Depth**	**Total number of tanks**
Oil Tanker 2	24.22	14
Ship type	**Deadweight [t]**	**Hull type**
Choose...	150842	double hull
Service speed [m/s]	**Block coefficient [-]**	**Double-bottom height [m]**
8	0.83	2
Service speed [knots]	**Mass (displacement) [t]**	**Double side thickness [m]**
15.55	104795	9.65
Length [m]	**Number of tanks in longitudinal direction**	**Ship slope angle [deg]**
274	7	-1
Breadth [m]	**Number of tanks in transverse direction**	**Cargo type**
48	2	Oil
Draft (fully loaded) [m]		
9.6		

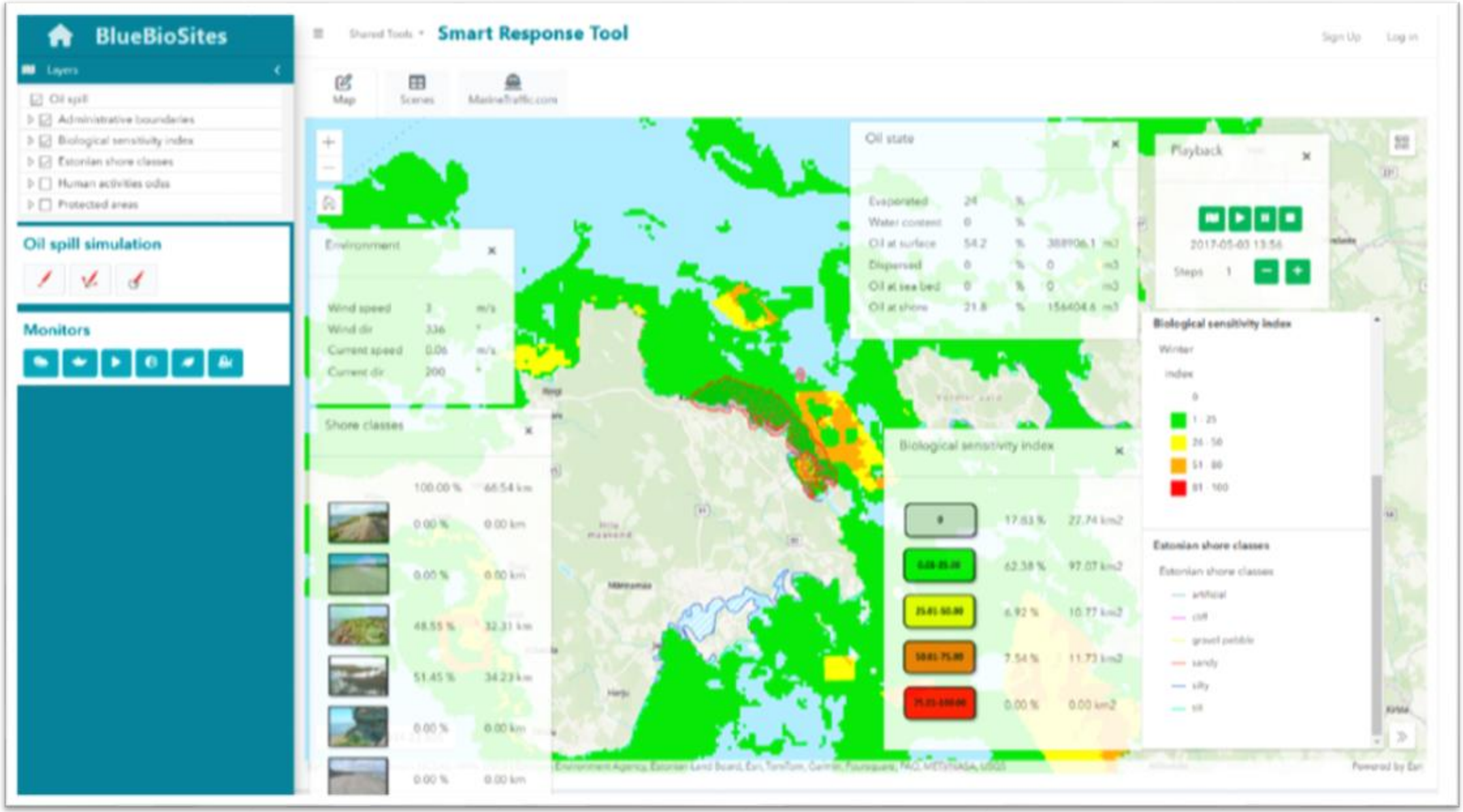
Run model

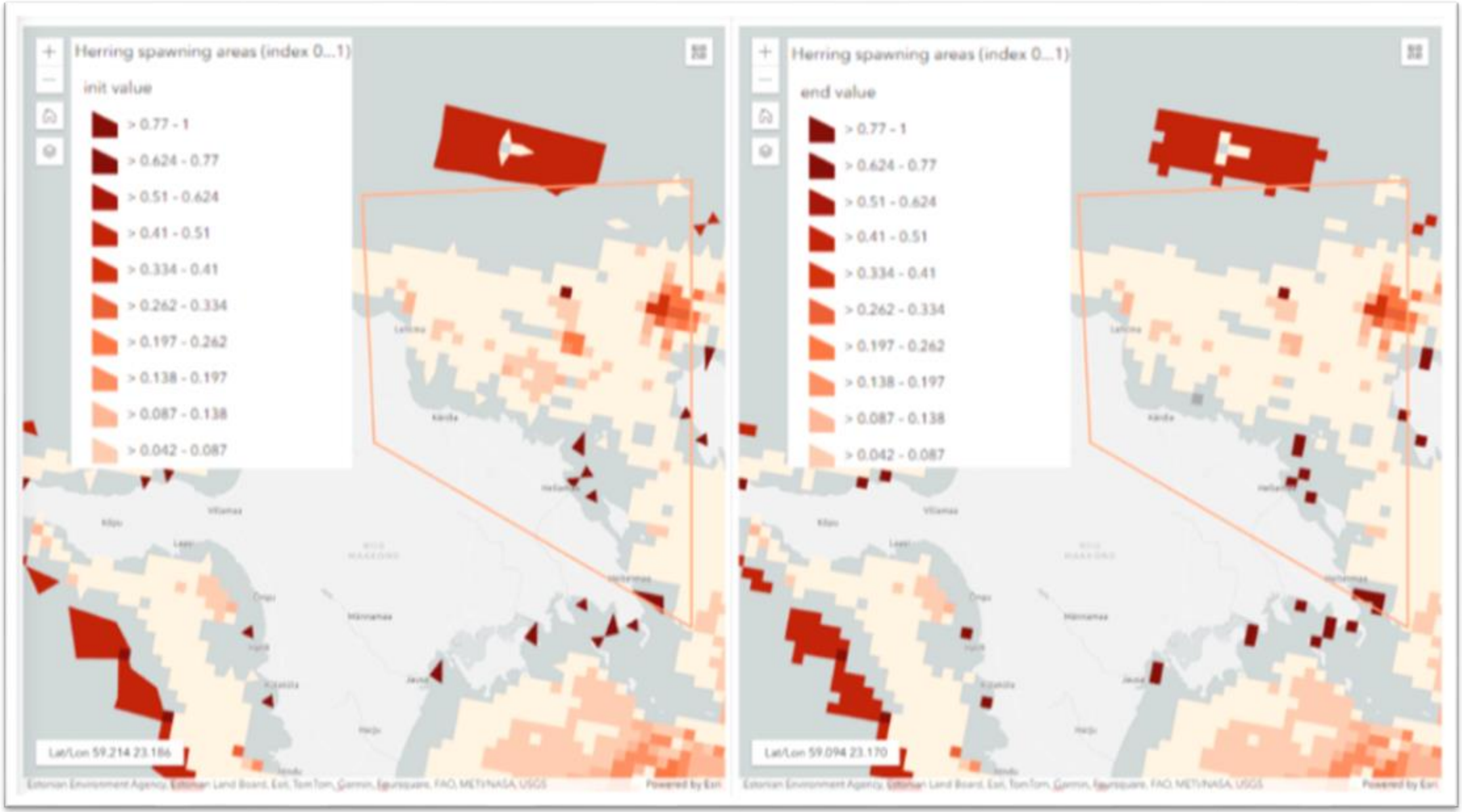
Results



Damage length [m]	83.72
Damage width in inner hull [m]	4.8
Damage width in outer hull [m]	5.88
Grounding force [N]	
Oil spilled directly to the sea [tons]	19413
Oil spilled through the double bottom [tons]	1920
Total oil spilled [tons]	21333
Time	

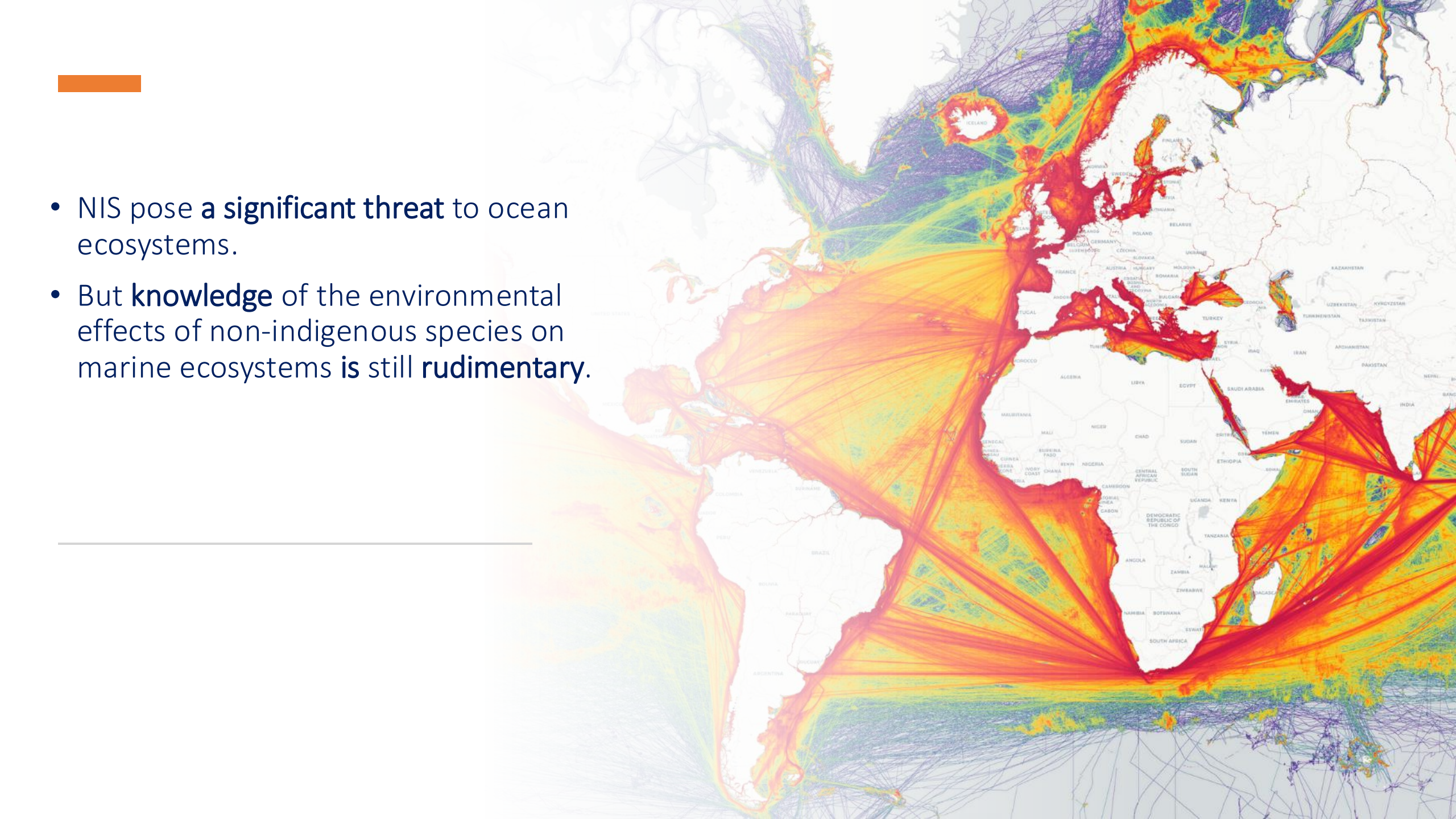

Seatrack Web calculation parameters
Select current scene
new scene...
Time and position
Forward
Backward
Date and time range
2024-10-16 11:05:56 - 20
Outlet depth (m)
0
Calculation options
Add uncertainty which depends on uncertainty in the weather forecast, hindcast
Calculation mode
Fast
Normal
Detailed
Buffer size (saving settings)
0.0005
Save to GIS Server
Substance
Calculation type
Oil classes
Substance
Medium oils (100-1
State of oil
Fresh
Discharge
Instantaneous
Continuous
Amount / Rate
100
m3
Duration
24
hours
Simulation process status
Creating workarea:
Adding to a run queue:
Starting up model:
Process steps:
Final status:
Saving to GIS Server
Error:
WORKAREA
Run the model


BlueBioSites
Layers
Oil spill
Administrative boundaries
Biological sensitivity index
Estonian shore classes
Human activities odbs
Protected areas
Oil spill simulation
Monitors
Shared Tools
Smart Response Tool
Sign Up
Log in
Map
Scenes
MarineTraffic.com
Environment
Wind speed 3 m/s
Wind dir 336 °
Current speed 0.06 m/s
Current dir 200 °
Oil state
Evaporated 24 %
Water content 0 %
Oil at surface 54.2 % 388906.1 m3
Dispersed 0 % 0 m3
Oil at sea bed 0 % 0 m3
Oil at shore 21.8 % 156404.6 m3
Playback
2017-05-03 13:56
Steps 1
Shore classes
100.00 % 66.54 km
0.00 % 0.00 km
0.05 % 0.00 km
48.55 % 32.31 km
51.45 % 34.23 km
0.00 % 0.00 km
0.00 % 0.00 km
Biological sensitivity index
17.03 % 27.74 km2
62.38 % 97.07 km2
6.92 % 10.77 km2
7.54 % 11.73 km2
0.00 % 0.00 km2
Biological sensitivity index
Winter
index
0
1 - 25
26 - 50
51 - 80
81 - 100
Estonian shore classes
Estonian shore classes
artificial
cliff
gravel pebble
sandy
silty
till
Powered by Esri

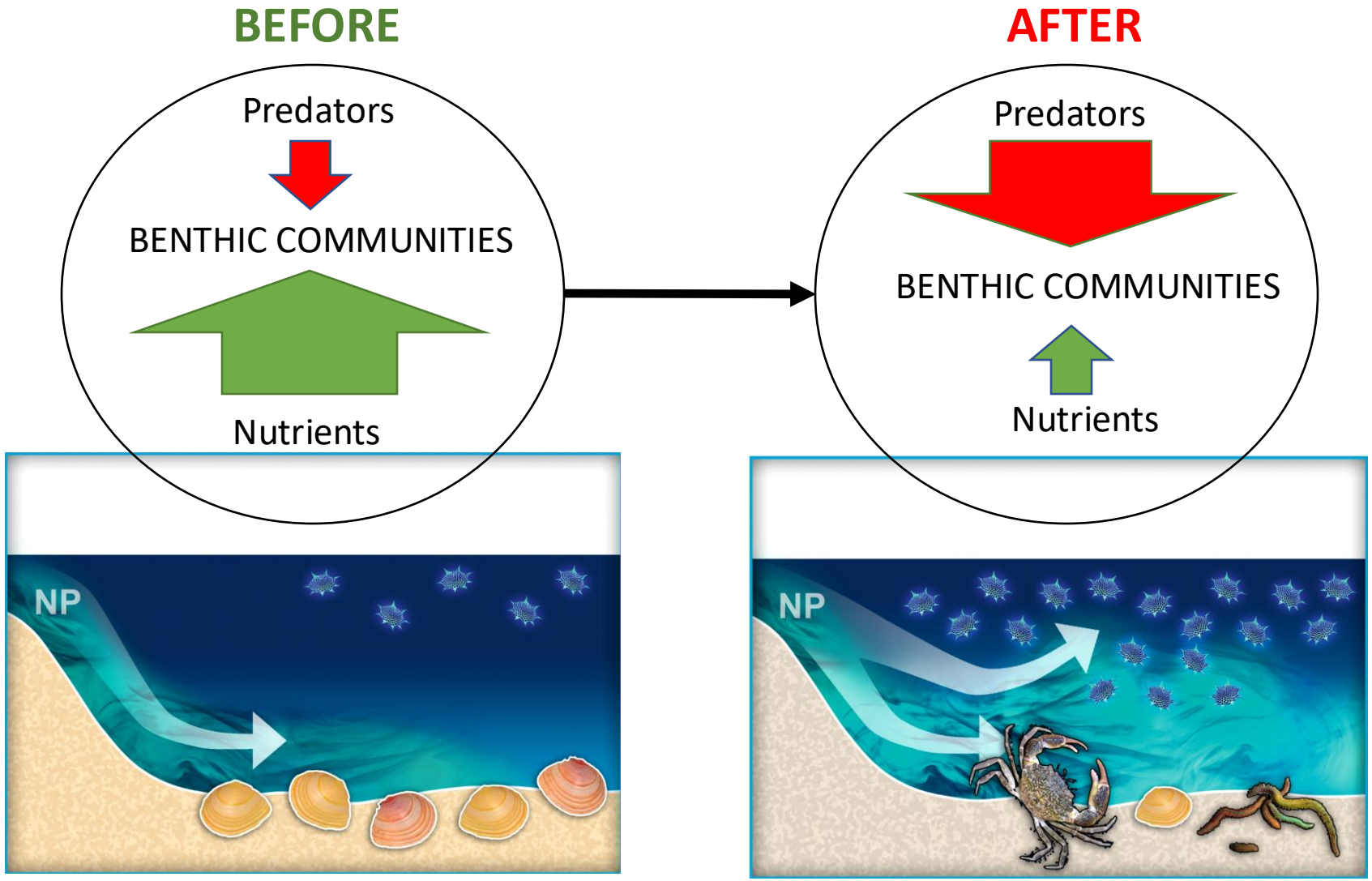

Herring spawning areas (index 0...1)
init value
> 0.77 - 1
> 0.624 - 0.77
> 0.51 - 0.624
> 0.41 - 0.51
> 0.334 - 0.41
> 0.262 - 0.334
> 0.197 - 0.262
> 0.138 - 0.197
> 0.087 - 0.138
> 0.042 - 0.087
Lat/Lon 59.214 23.186
Herring spawning areas (index 0...1)
end value
> 0.77 - 1
> 0.624 - 0.77
> 0.51 - 0.624
> 0.41 - 0.51
> 0.334 - 0.41
> 0.262 - 0.334
> 0.197 - 0.262
> 0.138 - 0.197
> 0.087 - 0.138
> 0.042 - 0.087
Lat/Lon 59.094 23.170

alien species

- NIS pose **a significant threat** to ocean ecosystems.
- But **knowledge** of the environmental effects of non-indigenous species on marine ecosystems **is** still **rudimentary**.

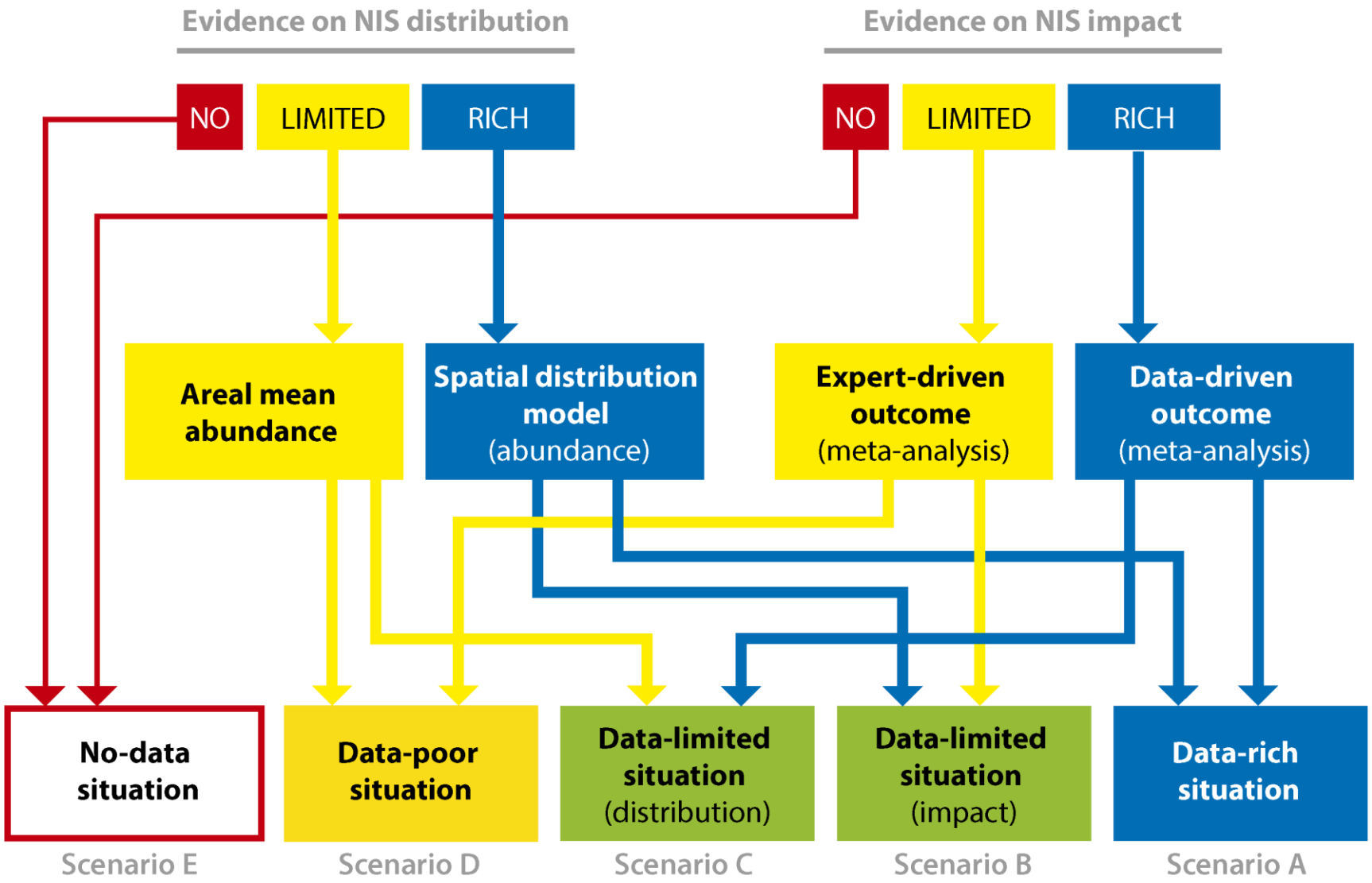


mud crab

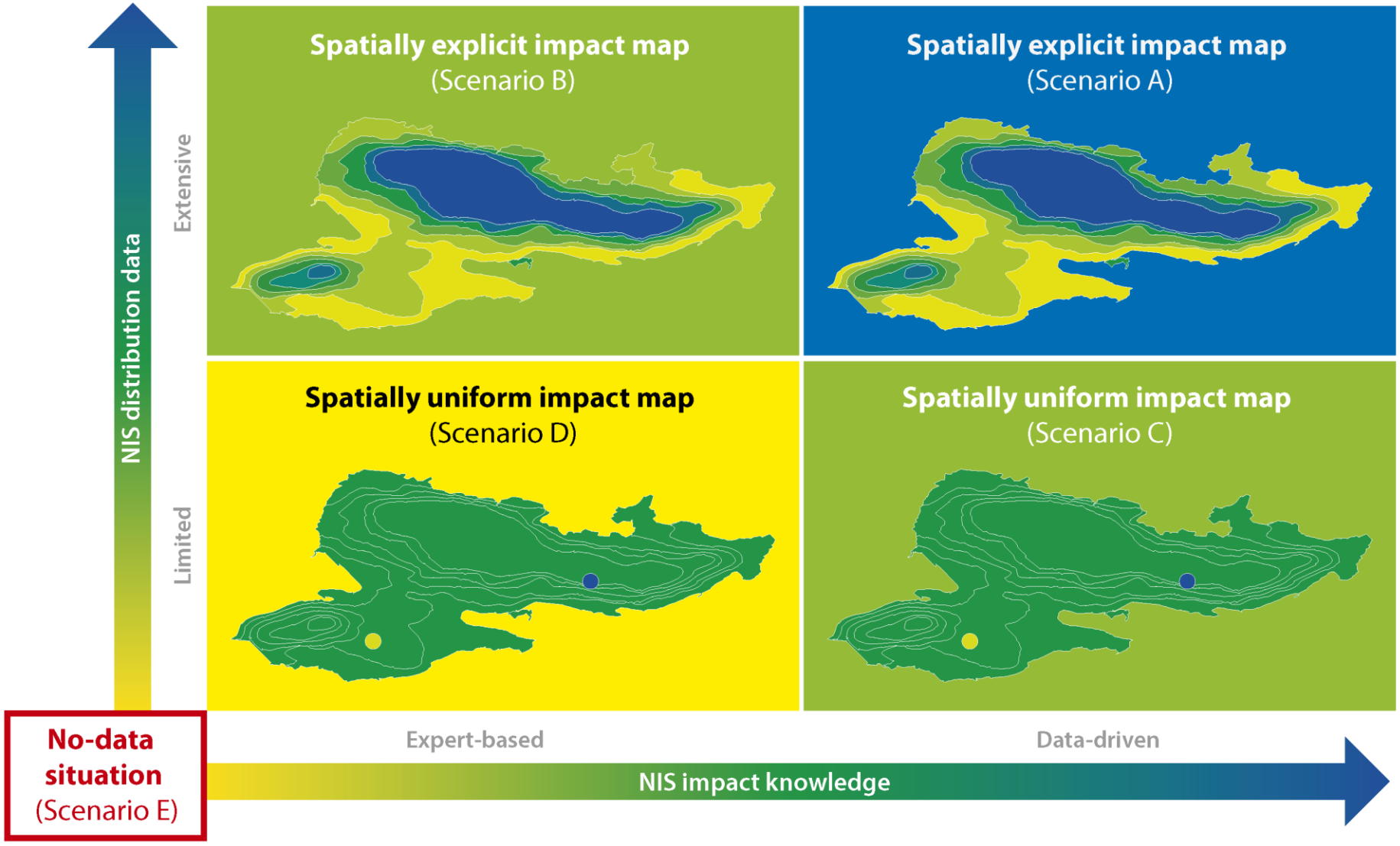

BEFORE
Predators
BENTHIC COMMUNITIES
Nutrients
NP
AFTER
Predators
BENTHIC COMMUNITIES
Nutrients
NP

The **increasing amount of data** on NIS impacts and **new analytical techniques** require **a shift** from expert judgement **to data-driven analysis**

Assessment of NIS impacts in the marine environment



Assessment of NIS impacts in the marine environment



A

$Impact = distribution \times abundance \times individual\ effect$

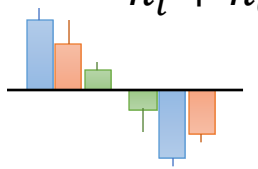
a) The impacts of NIS on the environment are known.
b) There is sufficient data to model the spread of NIS.

Meta-analysis

$$Per\ capita\ Hedges'g = \frac{(\overline{Y_i} - \bar{Y}_C)/ai}{SDpooled}\ J$$

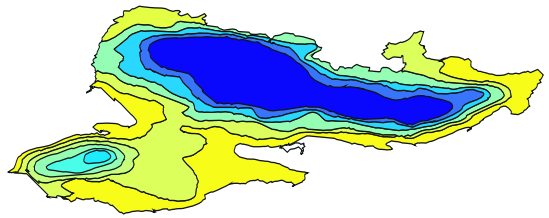
$$J = 1 - \frac{3}{4(n_i + n_c - 2) - 1}$$

$$SDpooled = \sqrt{\frac{(n_i - 1)SD_i^2 + (n_C - 1)SD_c^2}{n_i + n_C - 2}}$$



Spatial modeling

$$Abundance = f(spatial\ prediction\ algorithm)$$



Impact assessment

$$Impact = Per\ capita\ Hedges'g\ \times Abundance$$

$$SE_{pooled} = \sqrt{p^2\ SE_{effect}^2 + effect^2\ SE_p^2}$$

$Impact = distribution \times abundance \times individual\ effect$

Murchisonella

a) The impacts of NIS on the environment are not known.
b) There is no data to model the spread of NIS.

D

Meta-analysis

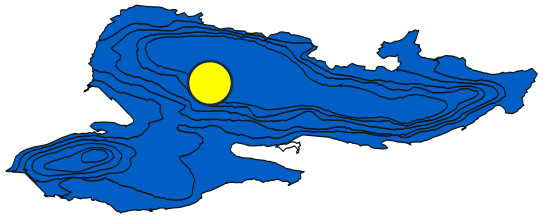
$Individual\ effect = \text{mean of expert opinion}$

$SE = variability\ of\ expert\ opinion$

Spatial modeling

$Abundance = mean\ of\ monitoring\ station(s)$

$SE = variability\ of\ monitoring\ station(s)$



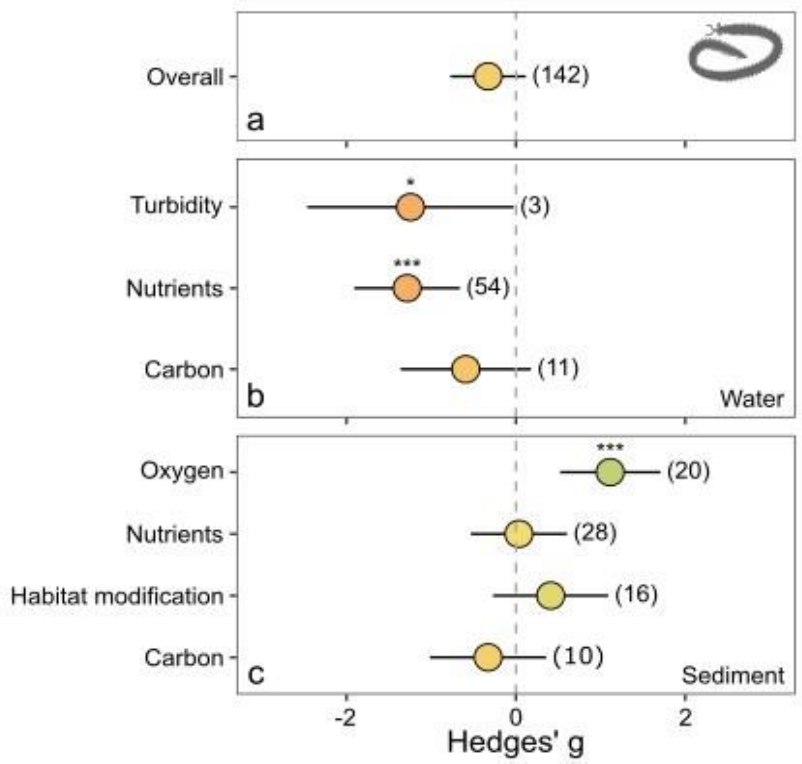
Impact assessment

$Impact = Individual\ effect \times Abundance$

$SE_{pooled} = \sqrt{p^2\ SE_{effect}^2 + effect^2\ SE_p^2}$

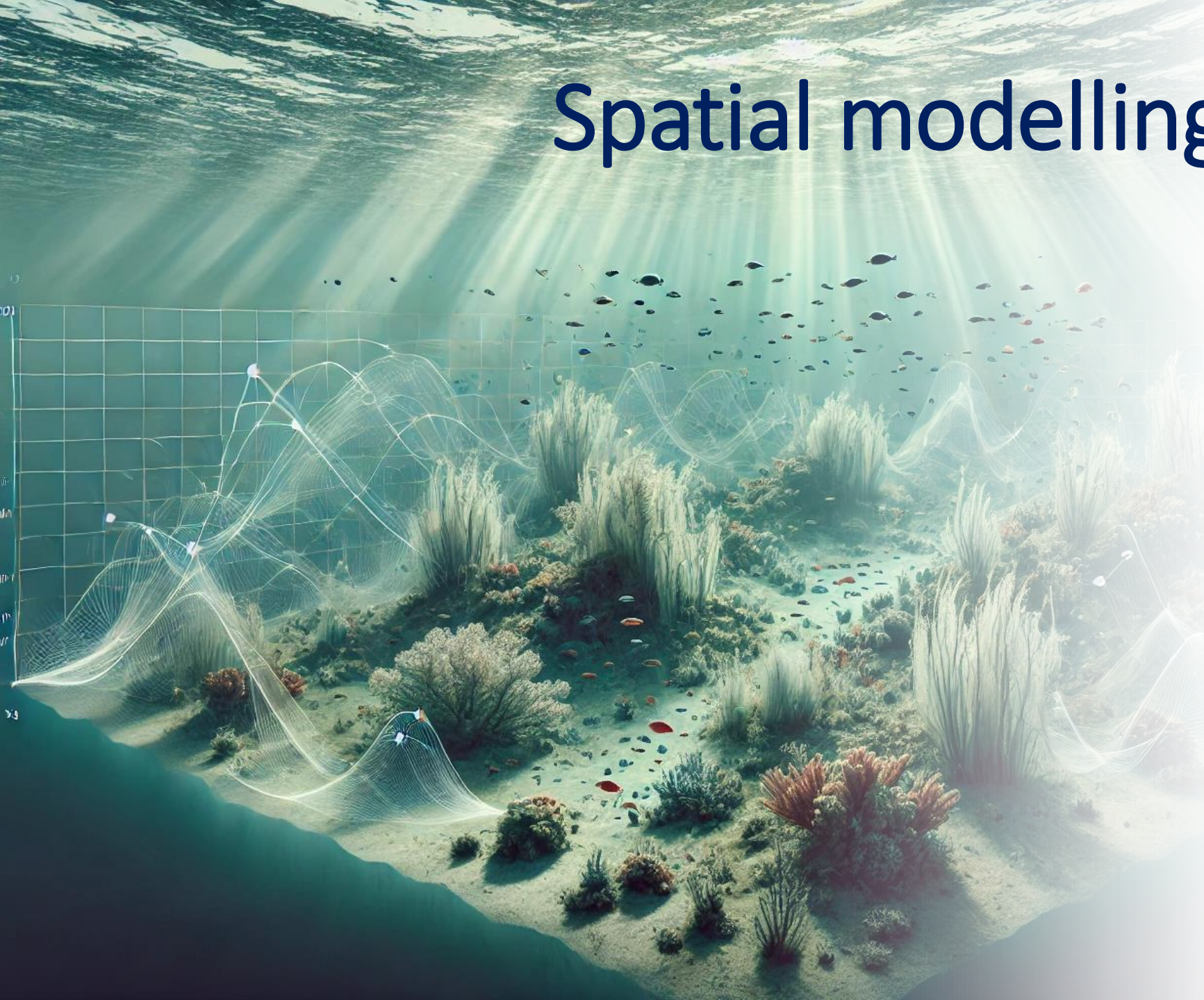
Metaanalysis

An example of a knowledge inventory on *Marenzelleria* spp., focusing on the impacts of NIS on various abiotic properties of ecosystems.



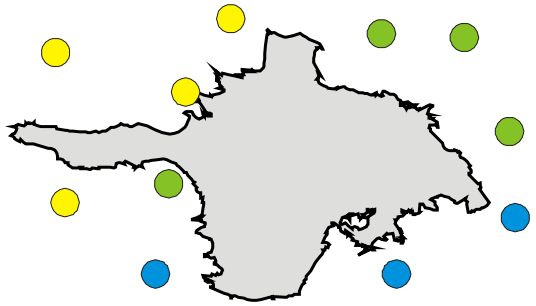
An inventory of cause-and-effect relationships

Spatial modelling

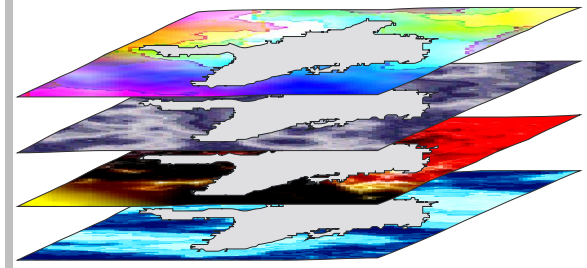


Spatial modeling of species and habitats is not a theoretical prediction but a reconstruction of distribution patterns based on actual mapping data.

Response variable:
point data of substrate or species

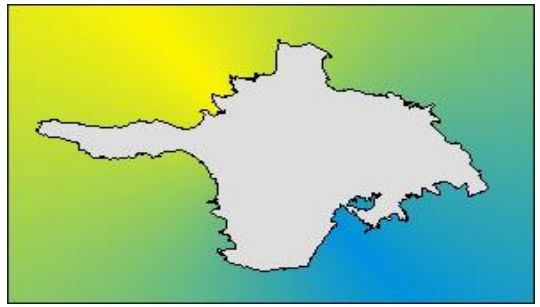


Predictor variables:
GIS-layers of environmental data



Mathematical model

Prediction:
occurrence of substrate or species



Model assessment

- importance of predictors
- relationships between predictors and response
- model validation

BlueBioSites

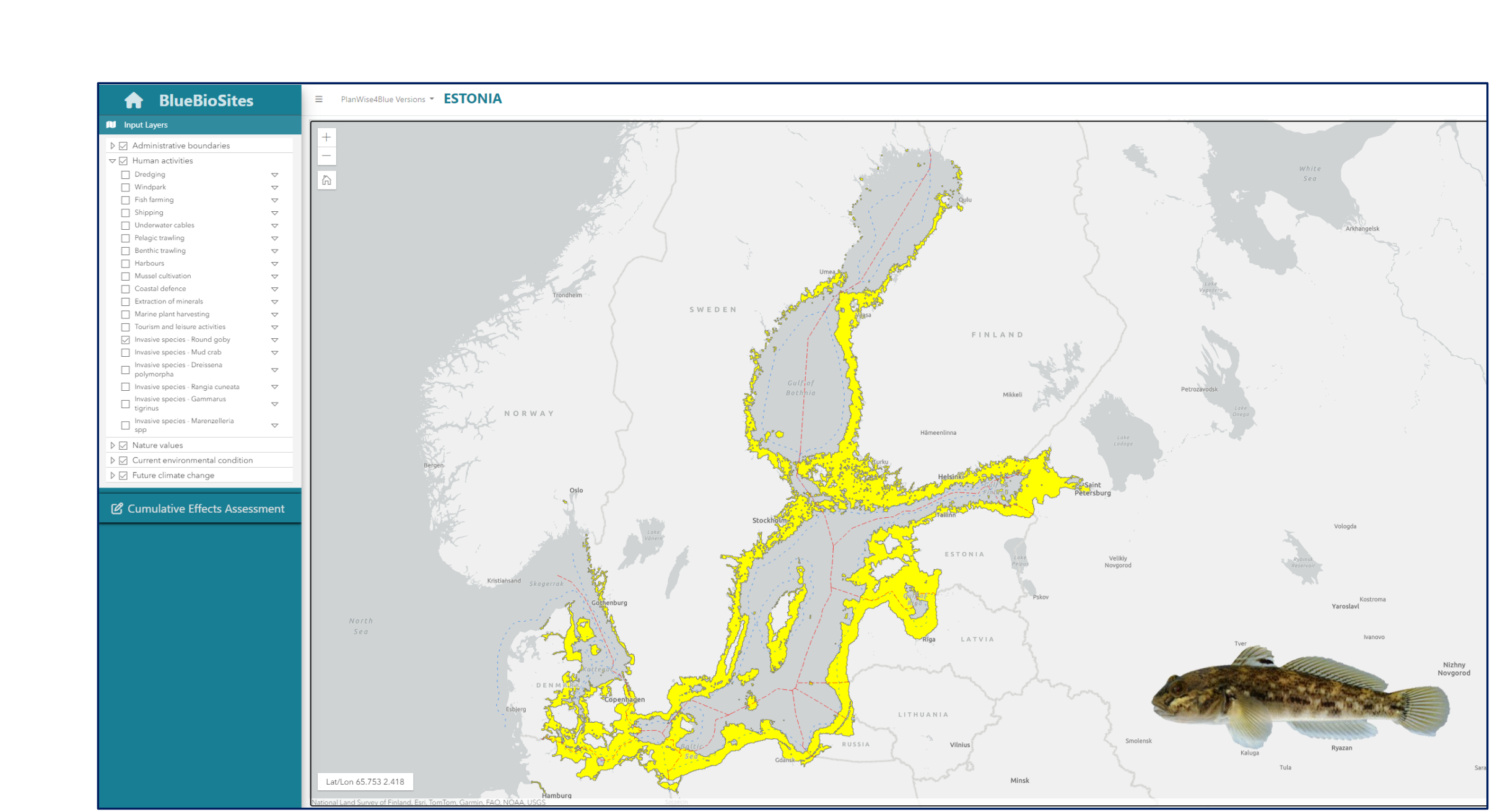
PlanWise4Blue Versions

ESTONIA

Input Layers

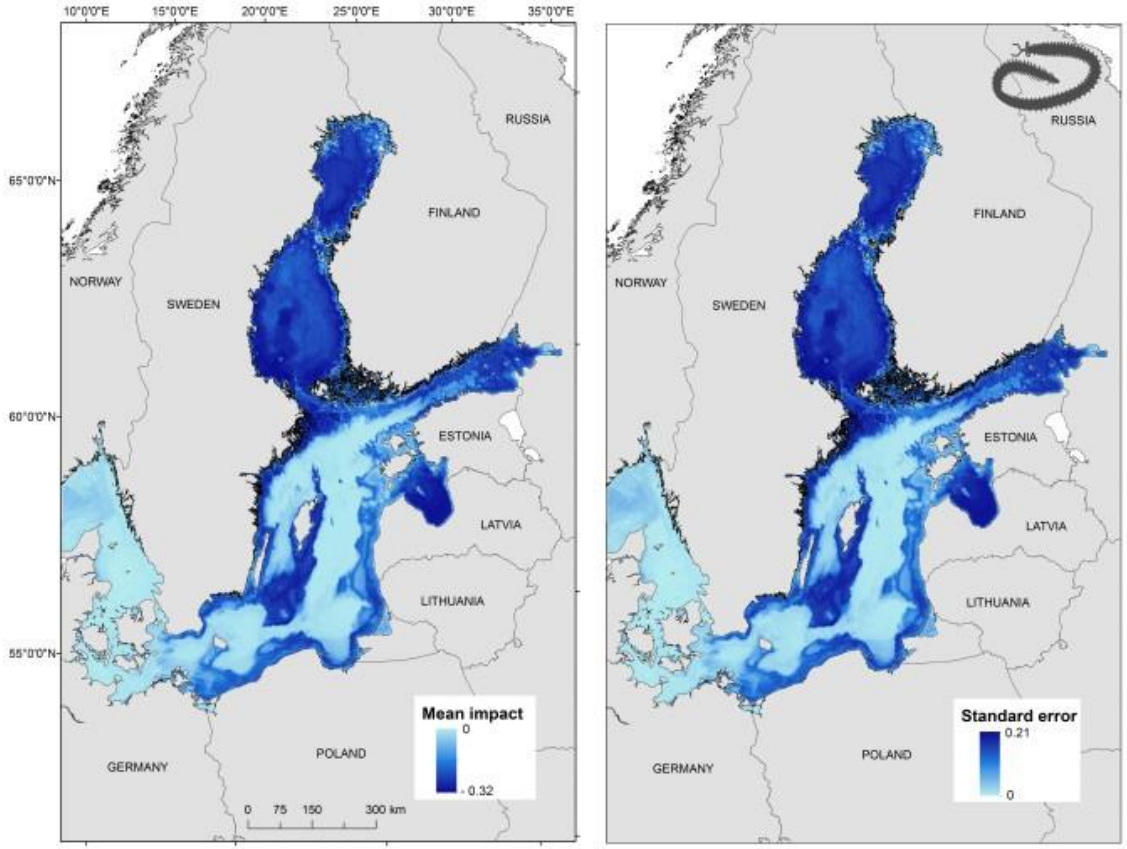
- Administrative boundaries
- Human activities
  - Dredging
  - Windpark
  - Fish farming
  - Shipping
  - Underwater cables
  - Pelagic trawling
  - Benthic trawling
  - Harbours
  - Mussel cultivation
  - Coastal defence
  - Extraction of minerals
  - Marine plant harvesting
  - Tourism and leisure activities
  - Invasive species - Round goby
  - Invasive species - Mud crab
  - Invasive species - Dreissena polymorpha
  - Invasive species - Rangia cuneata
  - Invasive species - Gammarus tigrinus
  - Invasive species - Marenzelleria spp
- Nature values
- Current environmental condition
- Future climate change

Cumulative Effects Assessment



Lat/Lon 65.753 2.418

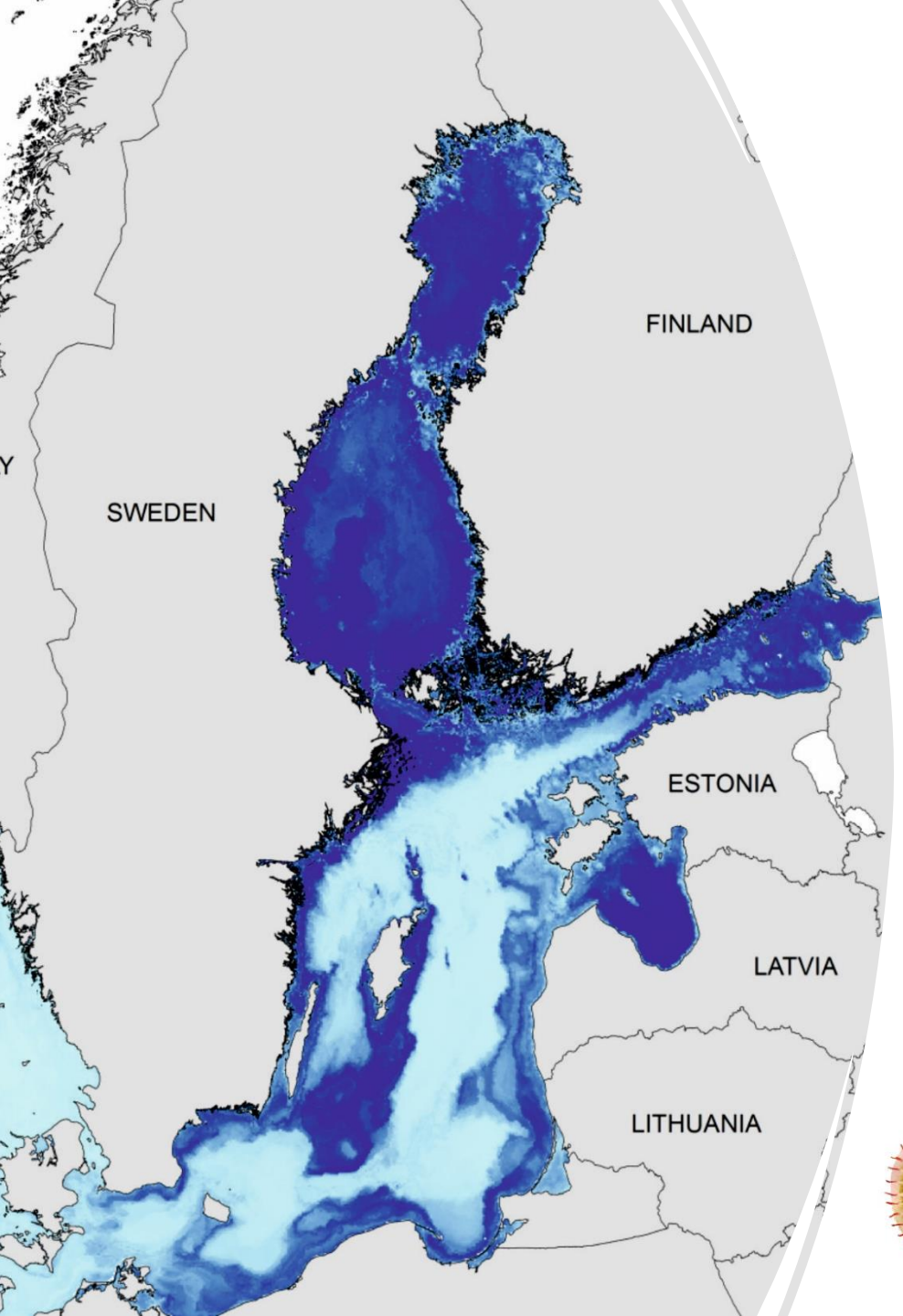
Impact calculation



$$Impact = Per\ capita\ Hedges'g\ \times Abundance$$

$$SE_{pooled} = \sqrt{p^2\ SE_{effect}^2 + effect^2\ SE_p^2}$$

Assessing the environmental impact of a NIS



Assessment of environmental status on non-indigenous species (D2) under the EU Marine Strategy Framework Directive

- Number of new non-indigenous species
- Abundance and spatial distribution of invasive non-indigenous species
- Spatially explicit assessment of NIS environmental impacts: from sub-basins to assessments made on a 1 km² scale.

NEAT

NEAT: Tool for assessing and mapping the impact of invasive species

Ecological digital twin: Facilitating the creation of a shared vision