Ecopath
International
Initiative

Spatial ecosystem modelling using Ecopath with Ecosim

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Ecopath International Initiative, Spain

Webinar, 29 August 2016

Outline

Ecopath with Ecosim – brief overview

Recent developments in Ecospace

Work in progress

Other ways to use EwE

The EwE ecosystem

Ecopath with Ecosim

Ecopath with Ecosim

Ecological model that tracks the paths of energy through a food web

Functional groups

Requires relatively few input parameters

Data often readily available
(stock assessment, FishBase, literature, …)

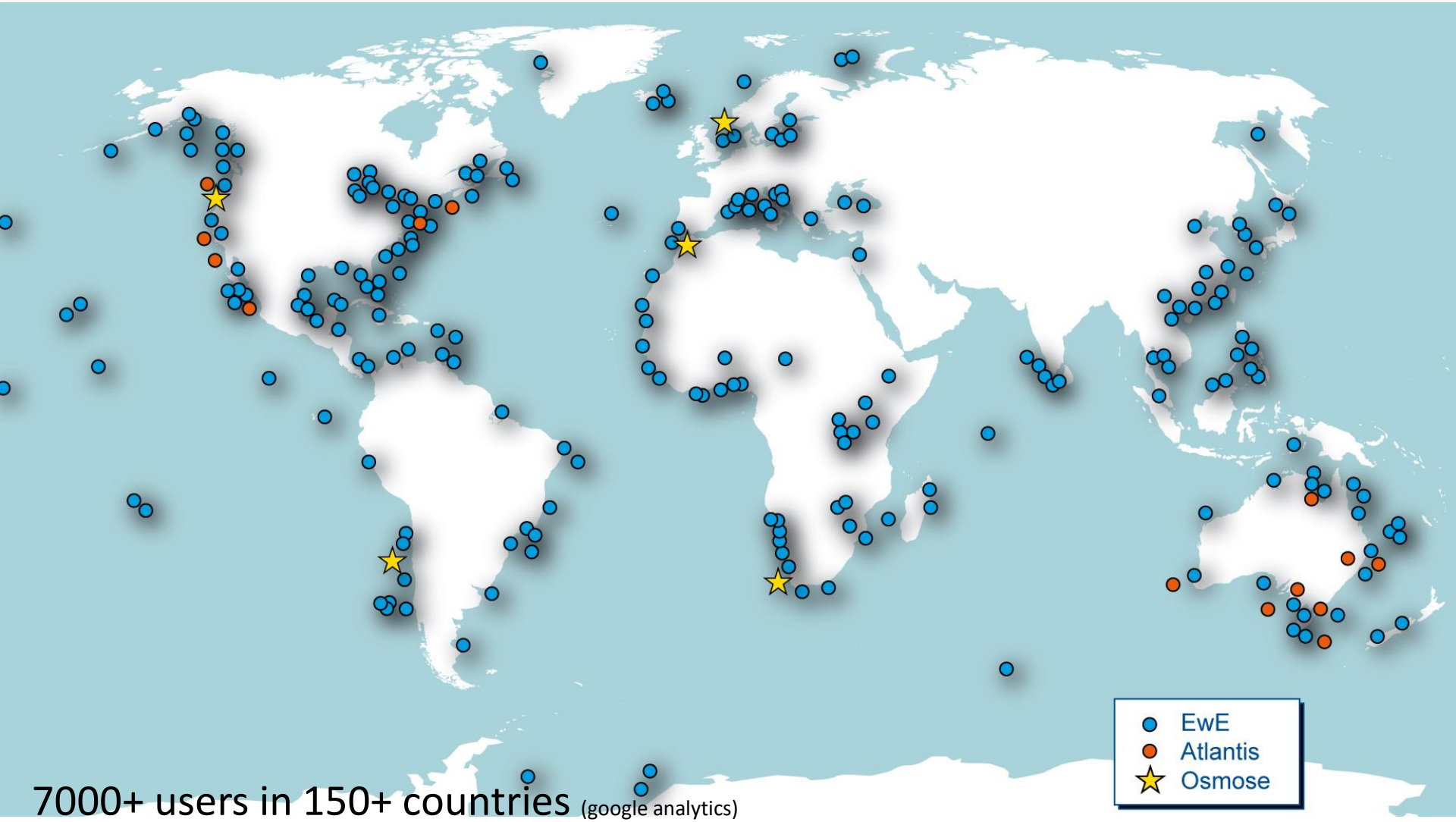
Includes environment and human activities

Ecopath with Ecosim

1984	Ecopath conceived (Polovina 1984)
1990	First desktop version released
1995	Ecosim introduced
1998	Ecospace introduced
2006	Re-engineered
2011	Supported by Ecopath R&D Consortium
2012	Open source, user support, co-development
2014	Thirty years anniversary

Freely available from http://www.ecopath.org

Ecopath with Ecosim



7000+ users in 150+ countries (google analytics)

800+ peer-reviewed publication (ISI Web of Knowledge)

Ecopath with Ecosim

Three major components

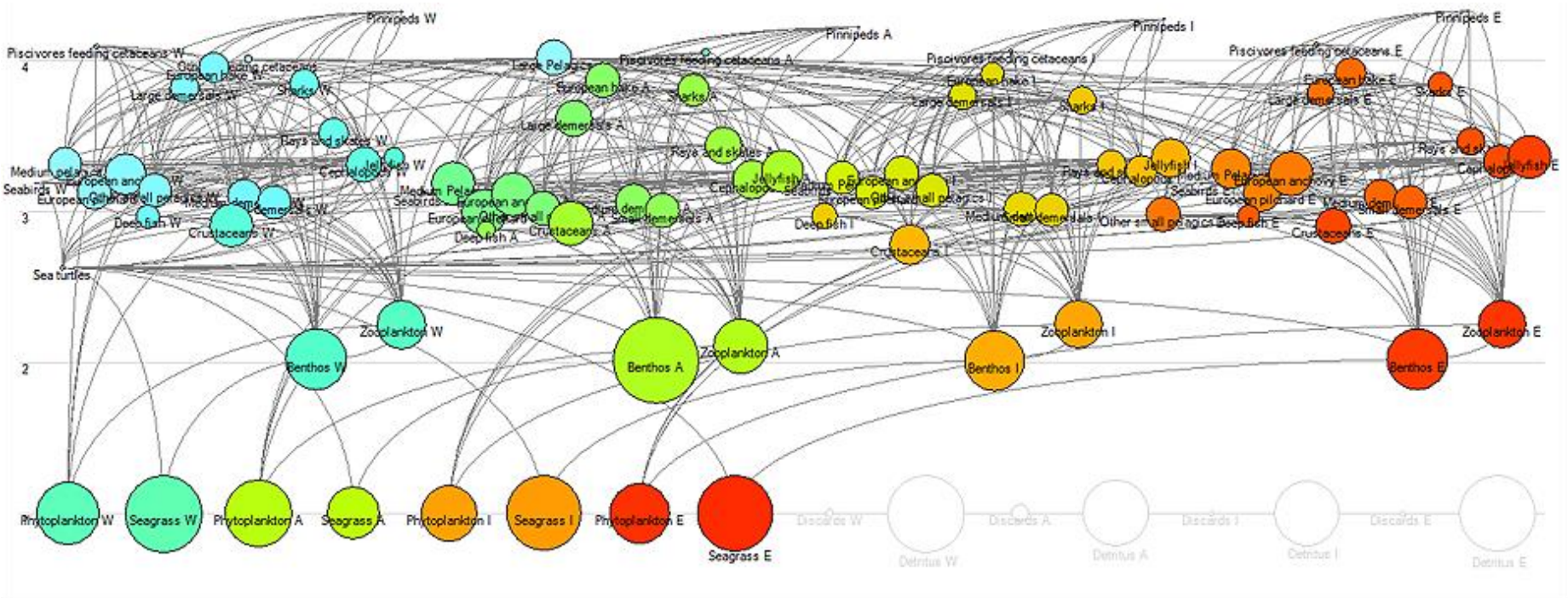
Ecopath	static mass-balanced model
Ecosim	temporal dynamics
Ecospace	spatial-temporal dynamics

Additional modules

Ecotracer	contaminant tracing
‘Searches’	Fishing Policy, MPA, Monte Carlo, MSE
Plug-ins	

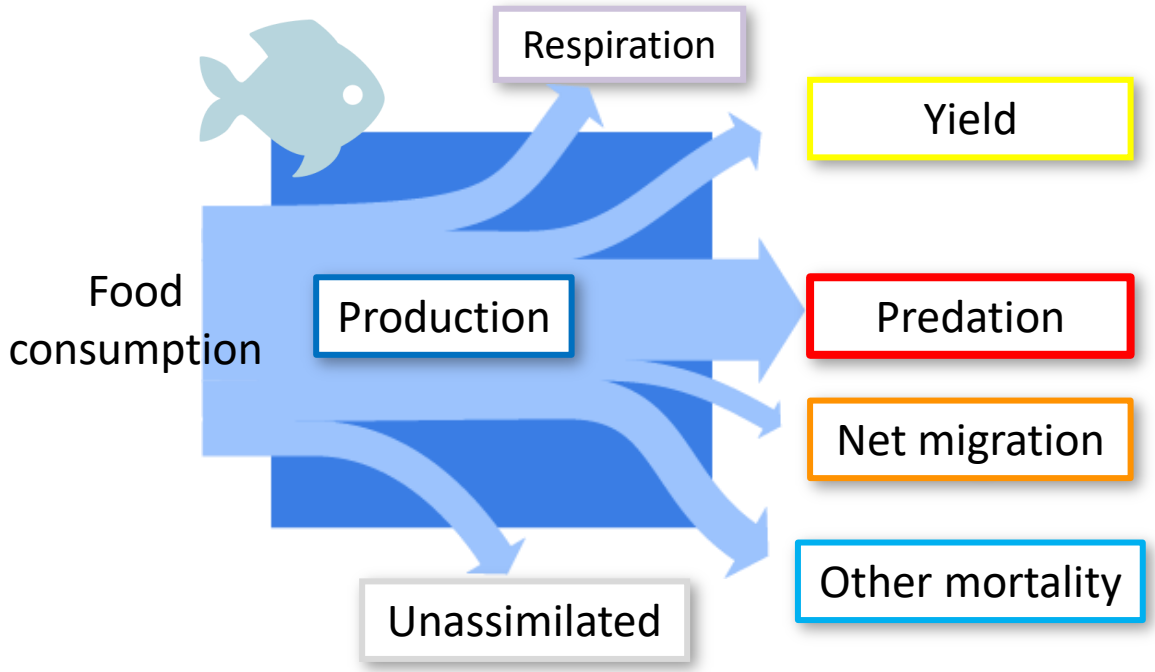
Ecopath

A snapshot of the state of an ecosystem,
its interactions, and exploitation



Model of entire Mediterranean basin, Piroddi et al. (2015)

Ecopath



B_i	Biomass
P_i/B_i	Production
Q_i/B_i	Specific consumption
DC_{ij}	Fraction of prey *i* in diet of predator *j*
B_iA_i	Biomass accumulation
EE_i	Production used in the system
1-EE_i	Unexplained mortality

1. $$\left(\frac{Q}{B}\right)_i \cdot B_i = \left(\frac{P}{B}\right)_i \cdot B_i + R_i + UN_i$$

2. $$\left(\frac{P}{B}\right)_i \cdot B_i = \sum_{Pred\_j=1}^{n} \left(\frac{Q}{B}\right)_j \cdot B_j \cdot DC_{ij} + E_i + Y_i + BA_i + \left(\frac{P}{B}\right)_i \cdot B_i \cdot (1 - EE_i)$$

Polovina, J.J. 1984. Coral Reefs, 3:1-11; Pauly et al. 2000. ICES J. Mar. Sci., 57: 697-706; Christensen and Walters. 2004. Ecol. Model., 172(2-4): 109-139

Ecosim

Temporal-dynamic module of EwE, initialized from Ecopath

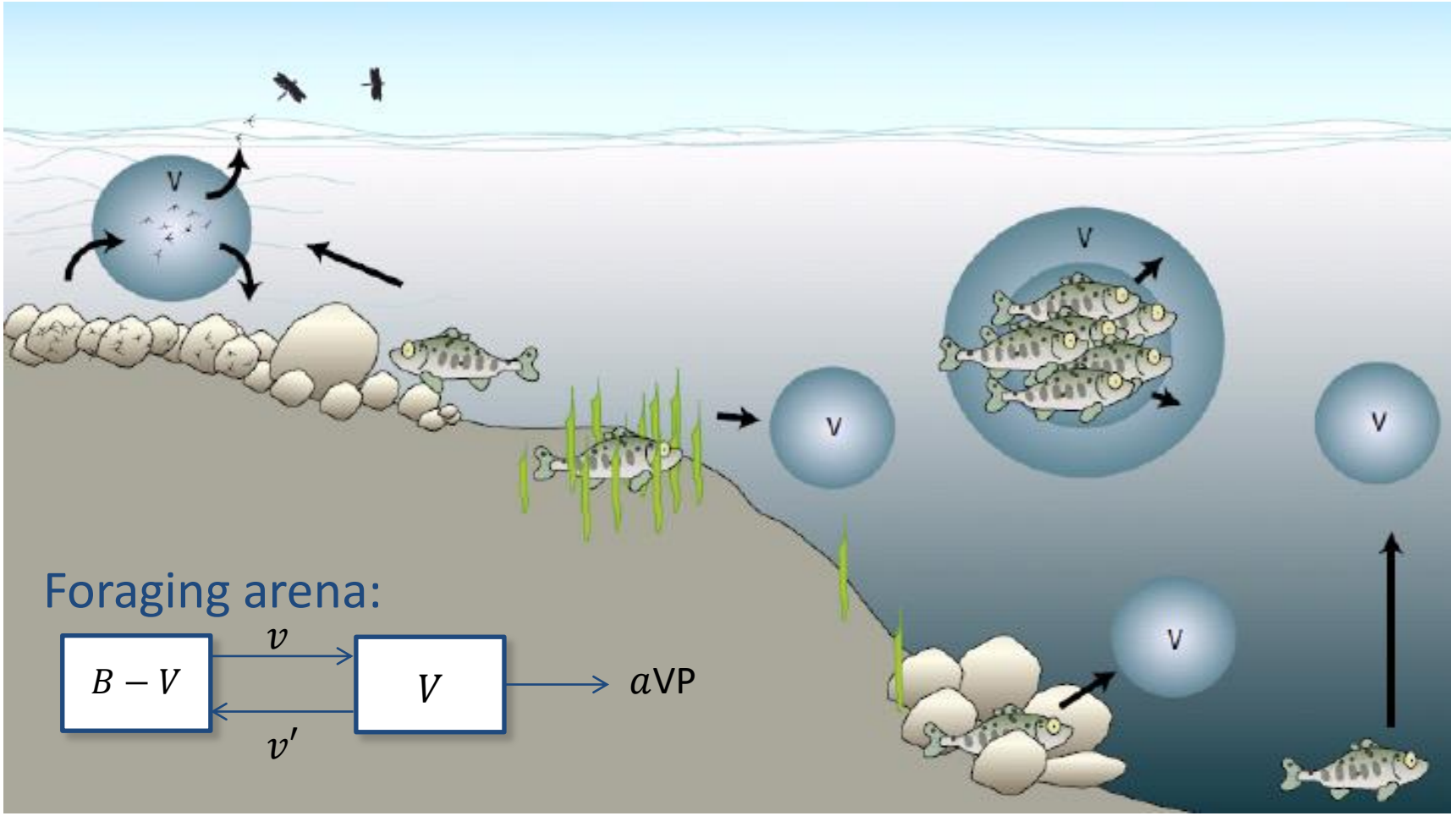
Includes biomass and size structure dynamics

Requires only a few extra parameters

Used, among others, to assess

- Quantify combined effect of species dynamics, fishing impacts, and environmental impacts on a food web over time
- Replicate past scenarios (time series fitting)
- Explore future scenarios
- Explore fishing policy alternatives
- Test model robustness

Ecosim



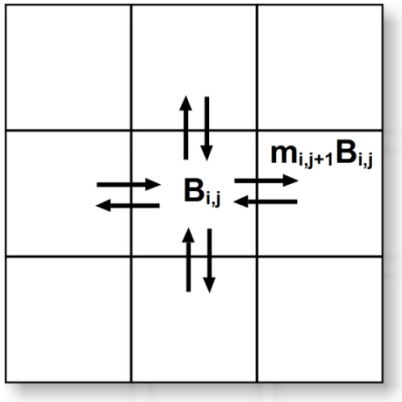
Walters et al 1997 RFBF, Ahrens et al 2012 Fish and Fisheries

Ecospace

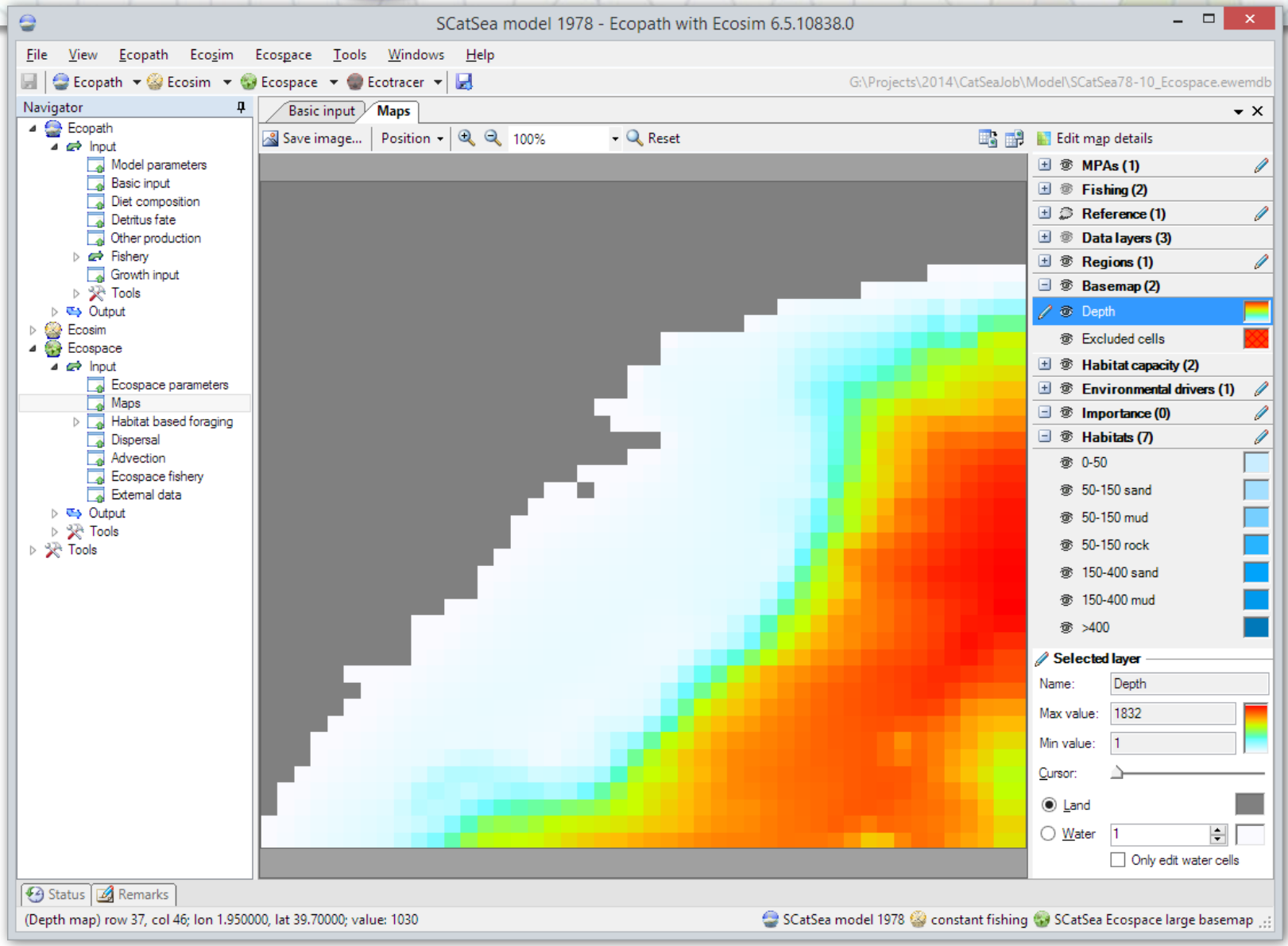
Spatial temporal component of EwE, executes Ecosim for every ‘water’ cell in a grid

Requires extra inputs, related to movement, habitat, fishing, environment

Groups and fleets try to move to nearby optimal conditions



Ecospace


SCatSea model 1978 - Ecopath with Ecosim 6.5.10838.0
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Ecopath Ecosim Ecospace Ecotracer
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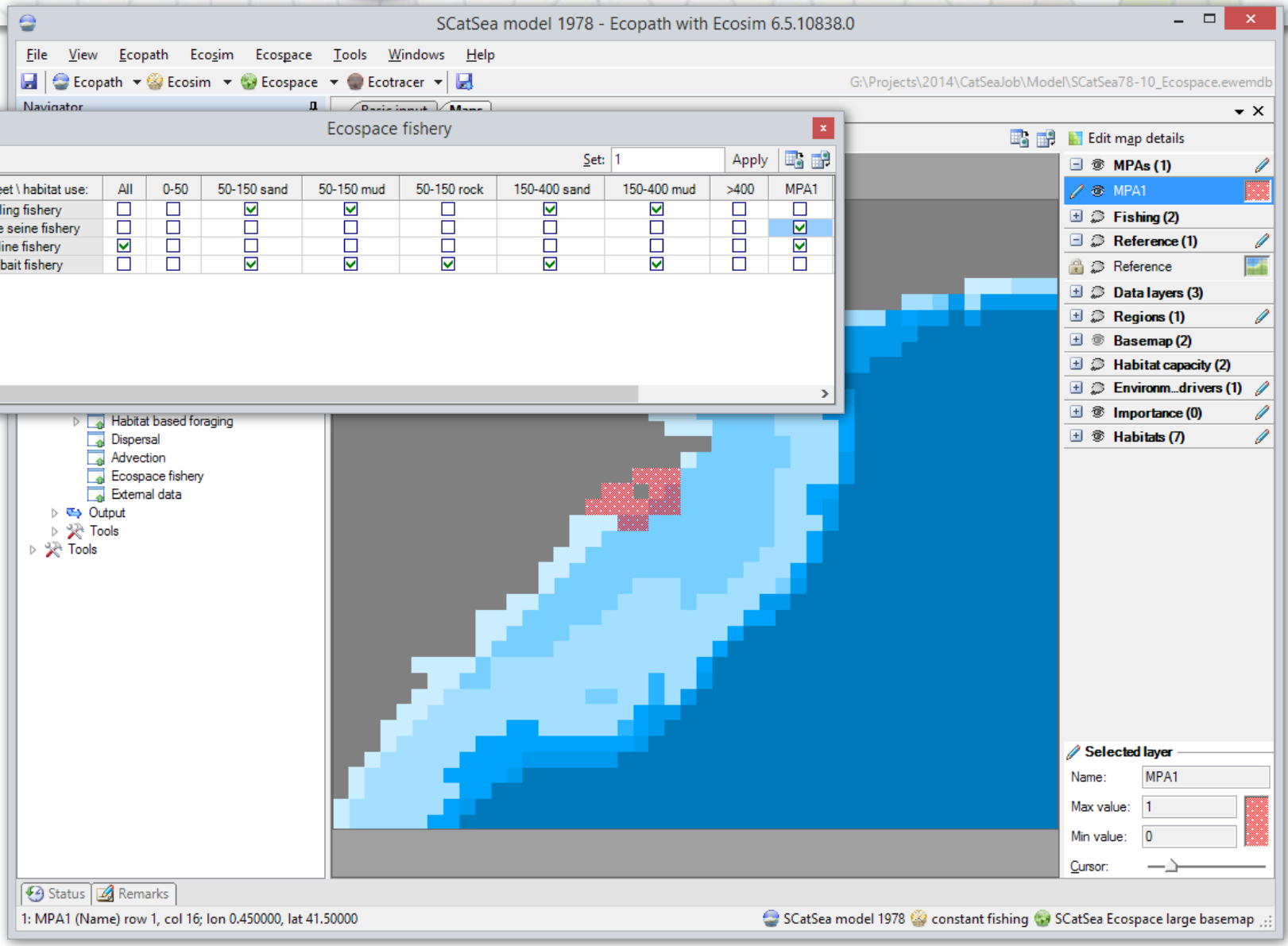
Navigator
Ecopath
Input
Model parameters
Basic input
Diet composition
Detritus fate
Other production
Fishery
Growth input
Tools
Output
Ecosim
Ecospace
Input
Ecospace parameters
Maps
Habitat based foraging
Dispersal
Advection
Ecospace fishery
External data
Output
Tools
Tools
Basic input
Maps
Save image...
Position
100%
Reset
Edit map details
MPAs (1)
Fishing (2)
Reference (1)
Data layers (3)
Regions (1)
Basemap (2)
Depth
Excluded cells
Habitat capacity (2)
Environmental drivers (1)
Importance (0)
Habitats (7)
0-50
50-150 sand
50-150 mud
50-150 rock
150-400 sand
150-400 mud
>400
Selected layer
Name: Depth
Max value: 1832
Min value: 1
Cursor:
Land
Water 1
Only edit water cells
Status
Remarks
(Depth map) row 37, col 46; lon 1.950000, lat 39.70000; value: 1030
SCatSea model 1978
constant fishing
SCatSea Ecospace large basemap

Ecospace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G:\Projects\2014\CatSeaJob\Model\SCatSea78-10_Ecospace.ewemdb
Navigator
Ecospace fishery
Set: 1 Apply
Fleet \ habitat use: All 0-50 50-150 sand 50-150 mud 50-150 rock 150-400 sand 150-400 mud >400 MPA1
1 Trawling fishery
2 Purse seine fishery
3 Longline fishery
4 Troll bait fishery
Habitat based foraging
Dispersal
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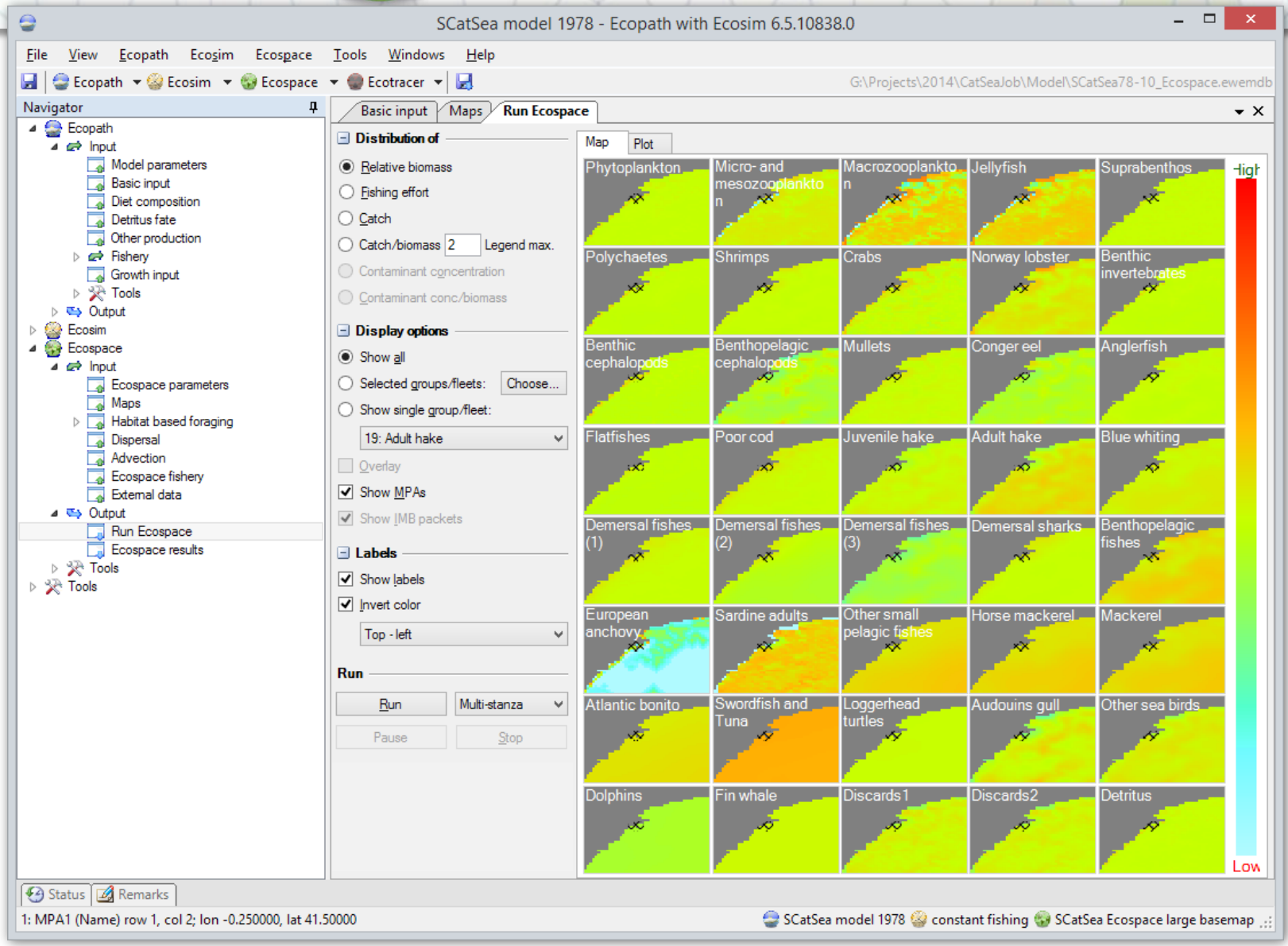
Environm...drivers (1)
Importance (0)
Habitats (7)
Selected layer
Name: MPA1
Max value: 1
Min value: 0
Cursor:
Status Remarks
1: MPA1 (Name) row 1, col 16; lon 0.450000, lat 41.50000
SCatSea model 1978 constant fishing SCatSea Ecospace large basemap

Ecospace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Advection
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External data
Output
Run Ecospace
Ecospace results
Tools
Tools
Basic input
Maps
Run Ecospace
Distribution of
Relative biomass
Fishing effort
Catch
Catch/biomass 2 Legend max.
Contaminant concentration
Contaminant conc/biomass
Display options
Show all
Selected groups/fleets: Choose...
Show single group/fleet:
19: Adult hake
Overlay
Show MPAs
Show IMB packets
Labels
Show labels
Invert color
Top - left
Run
Run
Multi-stanza
Pause
Stop
Map
Plot
Phytoplankton
Micro- and mesozooplankton
Macrozooplankton
Jellyfish
Suprabenthos
Polychaetes
Shrimps
Crabs
Norway lobster
Benthic invertebrates
Benthic cephalopods
Benthopelagic cephalopods
Mullets
Conger eel
Anglerfish
Flatfishes
Poor cod
Juvenile hake
Adult hake
Blue whiting
Demersal fishes (1)
Demersal fishes (2)
Demersal fishes (3)
Demersal sharks
Benthopelagic fishes
European anchovy
Sardine adults
Other small pelagic fishes
Horse mackerel
Mackerel
Atlantic bonito
Swordfish and Tuna
Loggerhead turtles
Audouins gull
Other sea birds
Dolphins
Fin whale
Discards1
Discards2
Detritus
High
Low
Status
Remarks
1: MPA1 (Name) row 1, col 2; lon -0.250000, lat 41.50000
SCatSea model 1978
constant fishing
SCatSea Ecospace large basemap

Ecospace

Used, among others, to assess

- Distribution of marine species and fishing effort
- Spatial impact of fishing
- Management options, e.g. impact of MPAs
- Impact of environmental change (EwE version 6.3+)

Running model has been linked to Marxan & Atlantis

Includes an IBM approach

Recent developments in Ecospace

2011 Ecospace had three major limitations

1. Unable to represent sub-cell features
2. Unable to explicitly incorporate environmental effects on species: “why are the species where they are?”
3. Limited facilities to exchange data with the outside world, thus unable to include environmental variability

1. Representing sub-cell features

Problem

Cells may contain small but important features that cannot be represented well, such as coral reefs

Old Ecospace accepted only one habitat type per cell, and yes/no habitat usage

Using ever smaller cells is no option: computationally demanding and wasteful, with risk of over-representing features and dynamics

Example: small but ecologically important coral reef

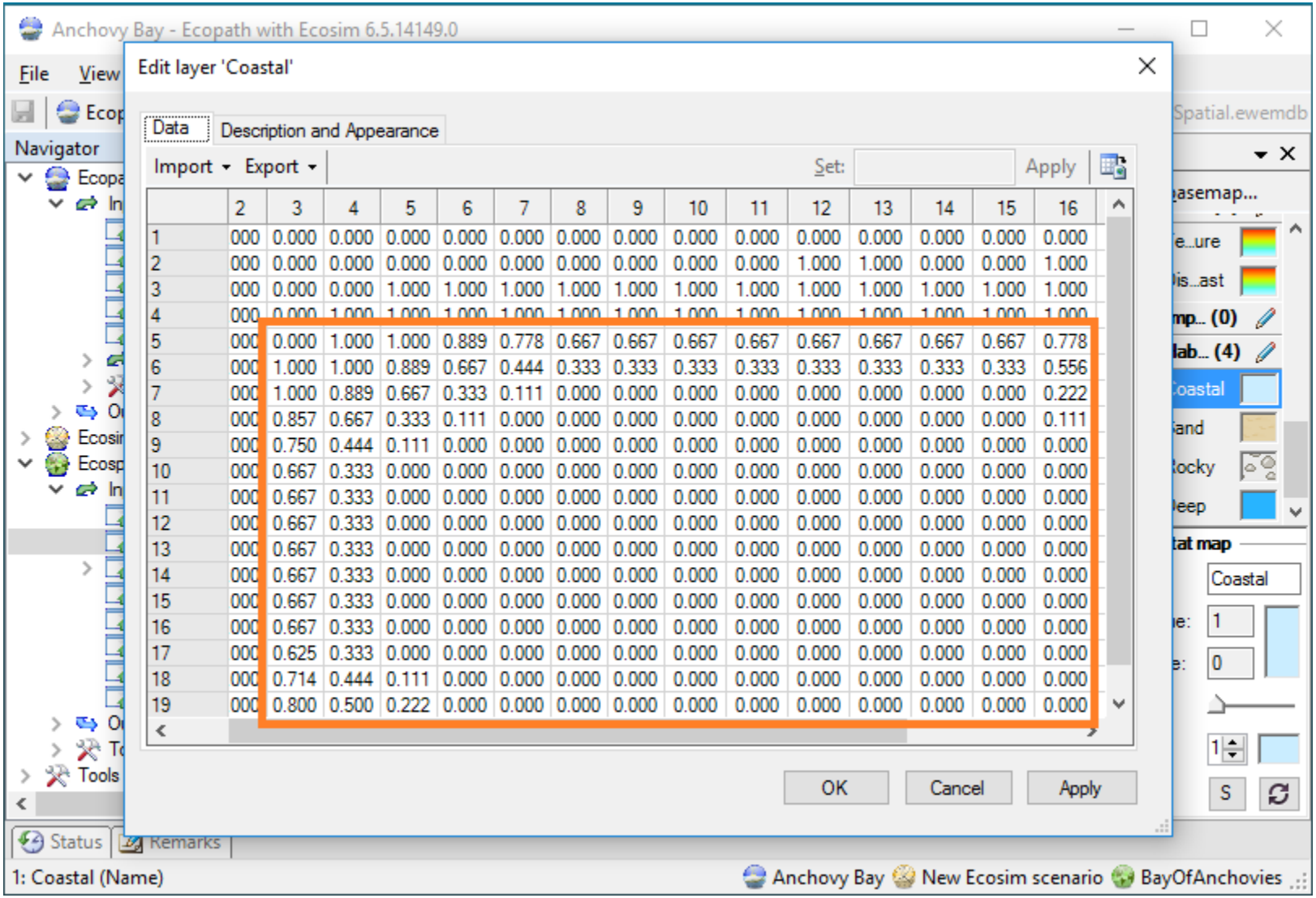
Solution

Ecospace (EwE version 6.3+) allows habitats to overlap, and habitats can occupy a fraction [0,1] of a cell

Species can utilize a fraction [0, 1] of each habitat type

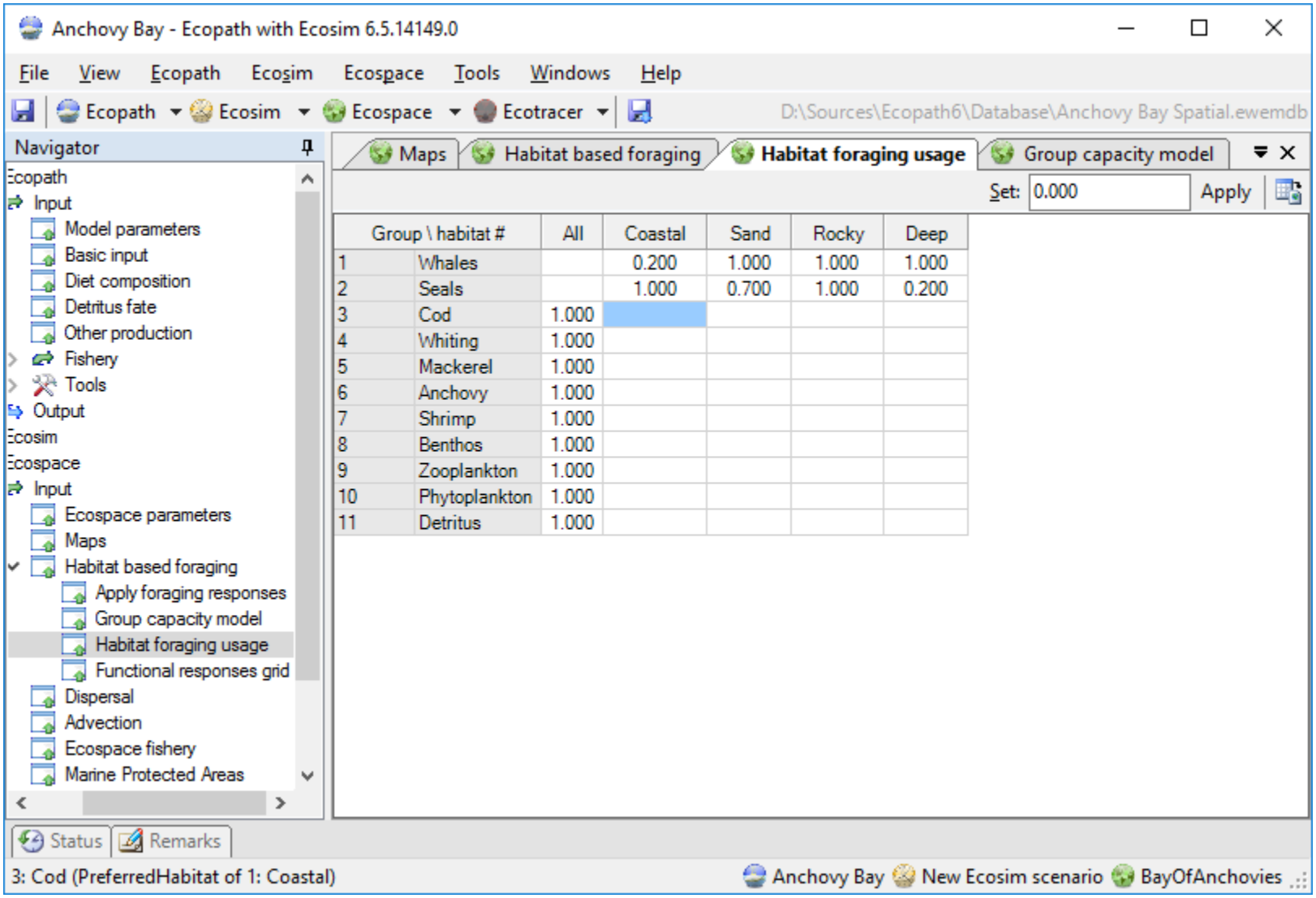
Old Ecospace models are directly translated to this structure, and work as expected

Habitats in fractions of a cell



	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	1.000	0.000	0.000	1.000
3	000	0.000	0.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
4	000	0.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
5	000	0.000	1.000	1.000	0.889	0.778	0.667	0.667	0.667	0.667	0.667	0.667	0.667	0.667	0.778
6	000	1.000	1.000	0.889	0.667	0.444	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.556
7	000	1.000	0.889	0.667	0.333	0.111	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.222
8	000	0.857	0.667	0.333	0.111	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.111
9	000	0.750	0.444	0.111	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	000	0.667	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	000	0.667	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	000	0.667	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	000	0.667	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	000	0.667	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	000	0.667	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	000	0.667	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	000	0.625	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	000	0.714	0.444	0.111	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	000	0.800	0.500	0.222	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Groups using fractions of habitats



2. Why are species where they are?

Habitat capacity model

Original Ecospace could not explain species distributions. Habitat usage was an aggregated assumption implying environmental preferences

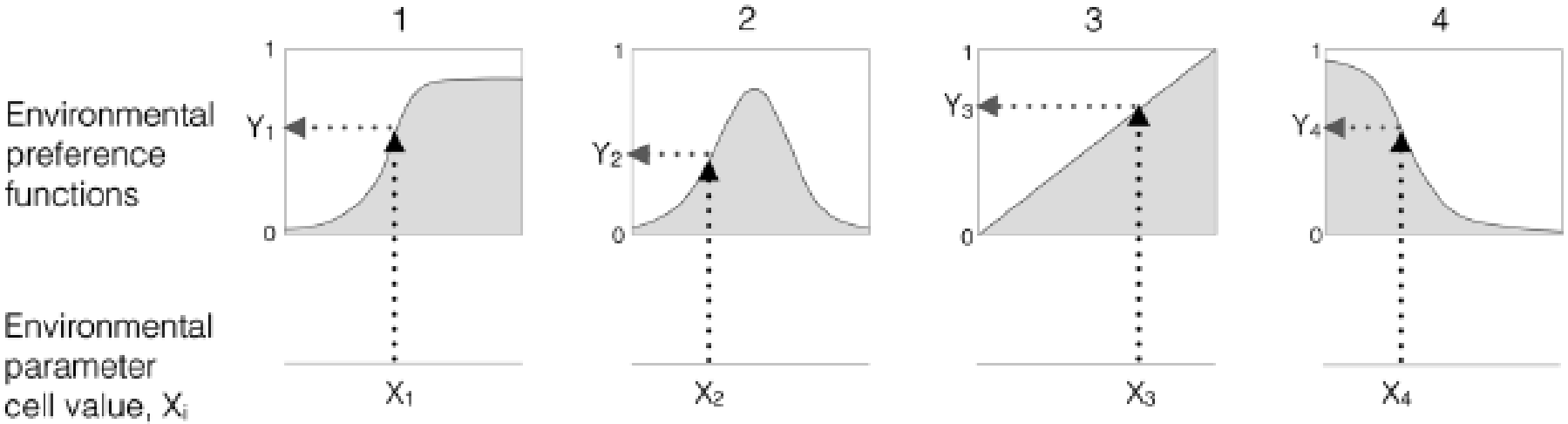
Ecospace (EwE version 6.3+) defines spatial foraging arena size from species' response to environmental conditions

Ecospace has become an integrated food-web / species envelope model

Christensen et al. 2014. Ecosystems, E17, 1397-1412.

Habitat capacity model

Dynamic habitat model predicts how productive individual cells are for each species, based on multiplicative effect of environmental responses

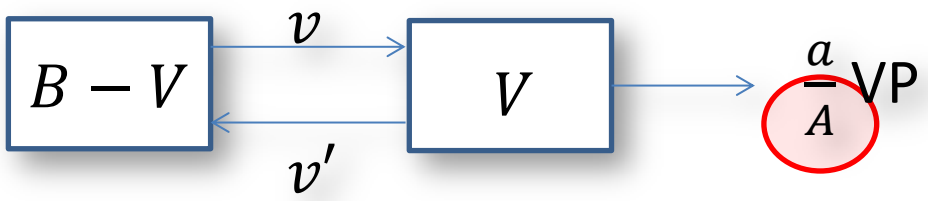


$$C = Y_1 * Y_2 * Y_3 * Y_4; \quad C \in [0,1]$$

Christensen et al. 2014. Ecosystems, E17, 1397-1412.

Habitat capacity model

Foraging capacity in a cell depends on the area to predate:



V	vulnerable prey density
B	prey biomass
P	predator abundance
v, v'	vulnerability exchange rates to and from arena
a	Search rate
A	Foraging arena size

Predation calculation is altered:

$$V = \frac{v\,B}{v + v' + a\,P/A}$$

Christensen et al. 2014. Ecosystems, E17, 1397-1412.

Habitat capacity model

Backward compatibility

For old Ecospace models, capacity is determine from existing habitat maps and habitat preferences

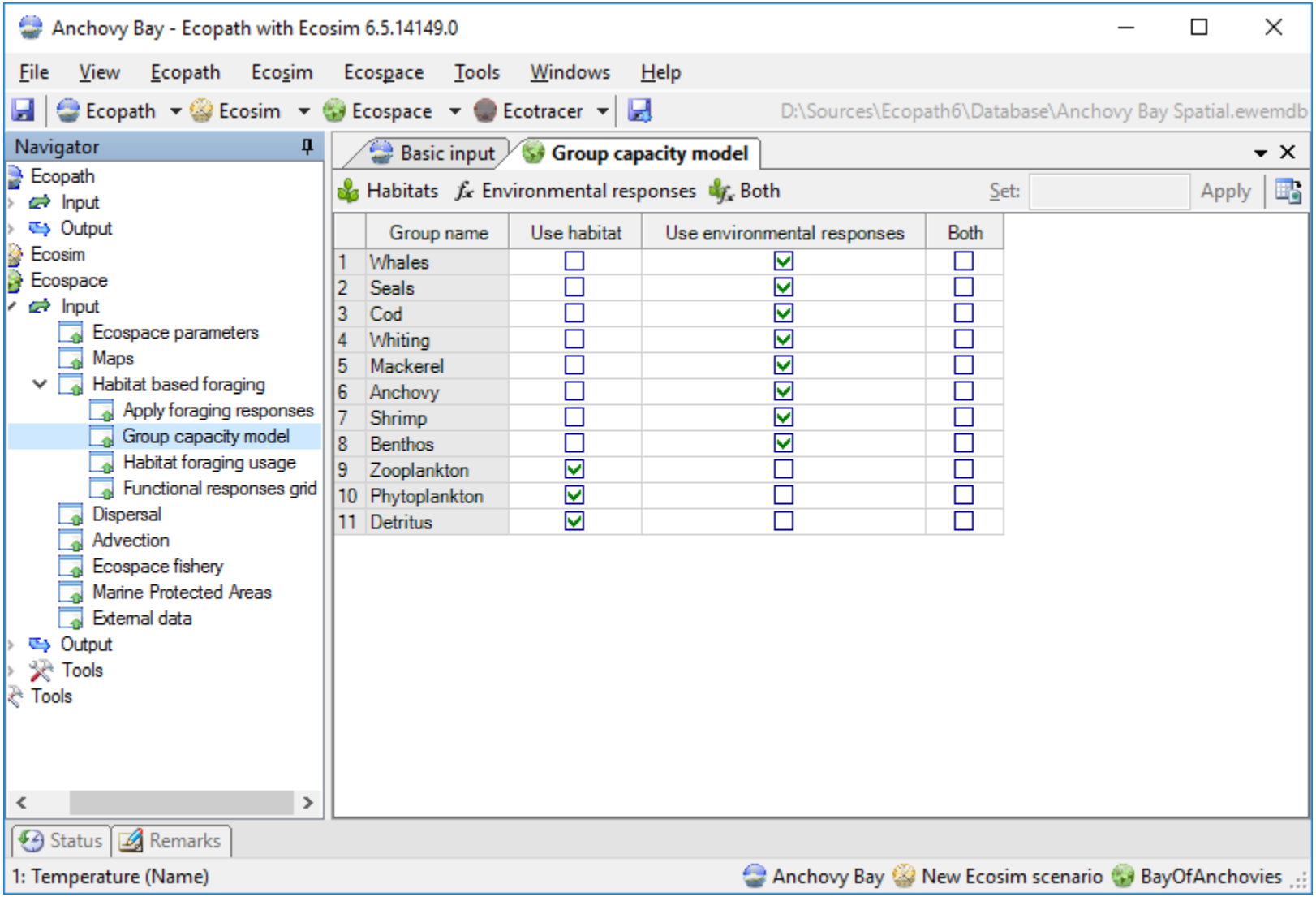
New Ecospace models (EwE version 6.5+) can derive capacity from habitat assumptions, from functional responses to of environmental conditions, or from both habitats and functional responses

This is a *per-group* setting (!)

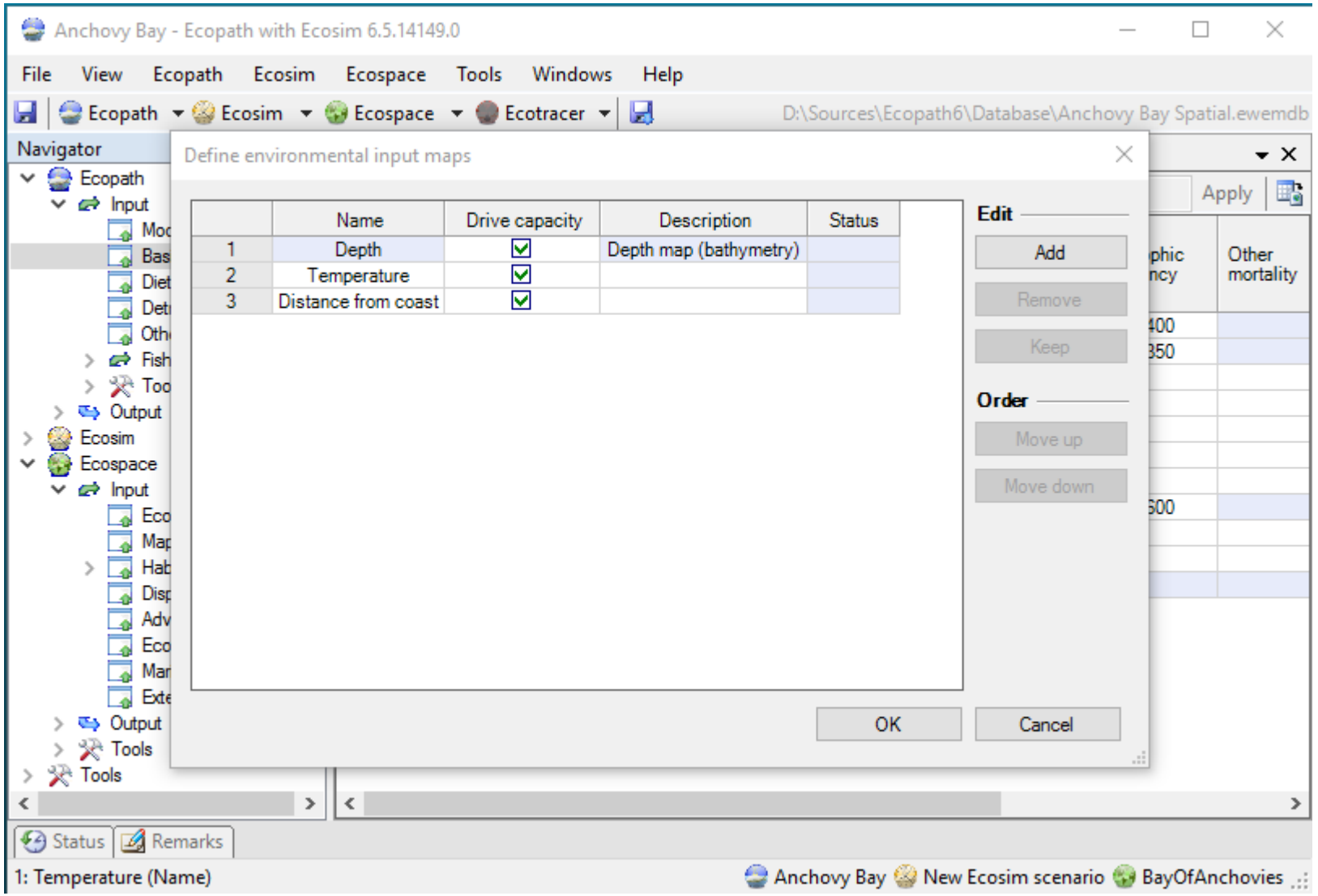
Christensen et al. 2014. Ecosystems, E17, 1397-1412.

Setting up the habitat foraging capacity model

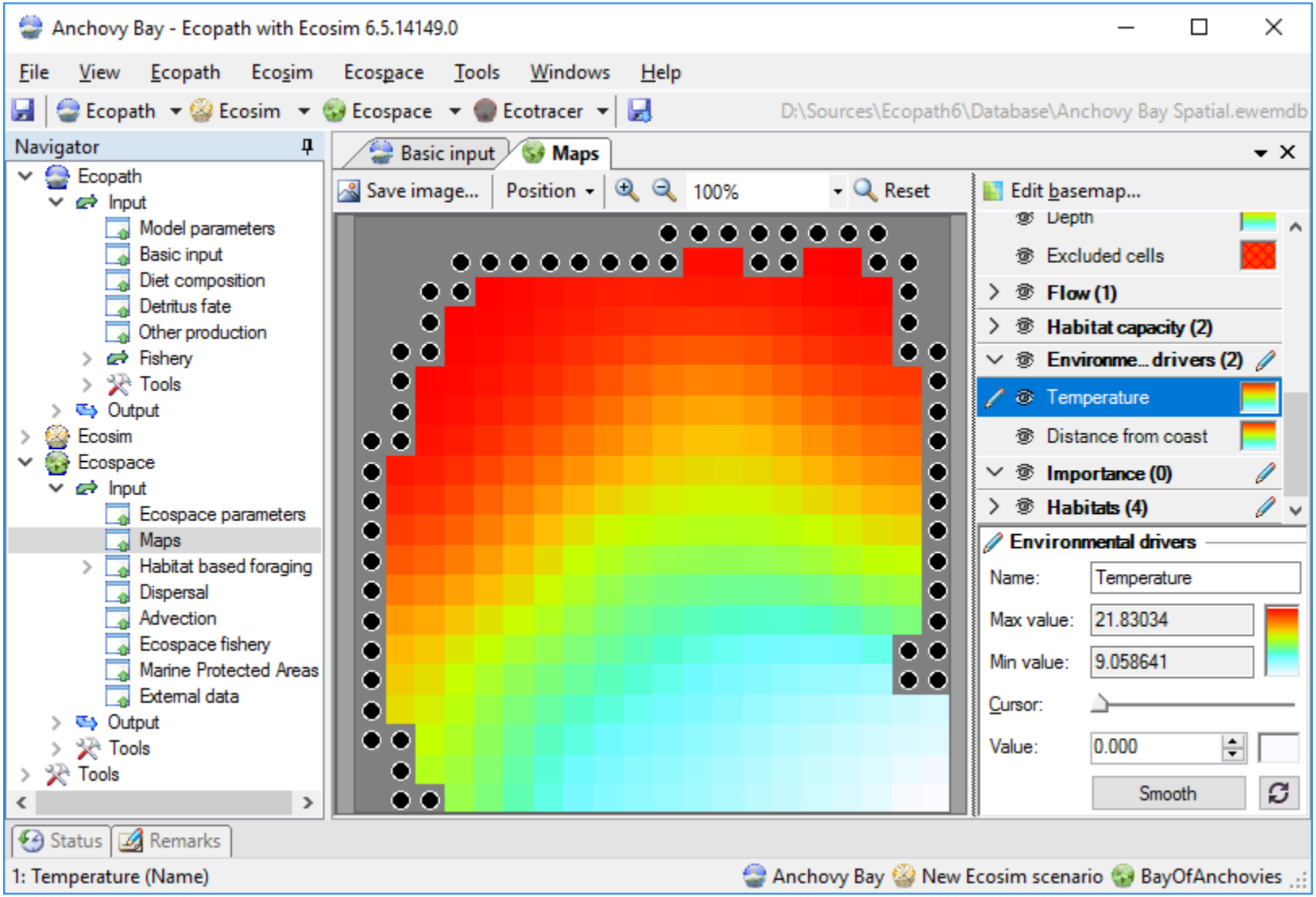
1. Select group capacity model



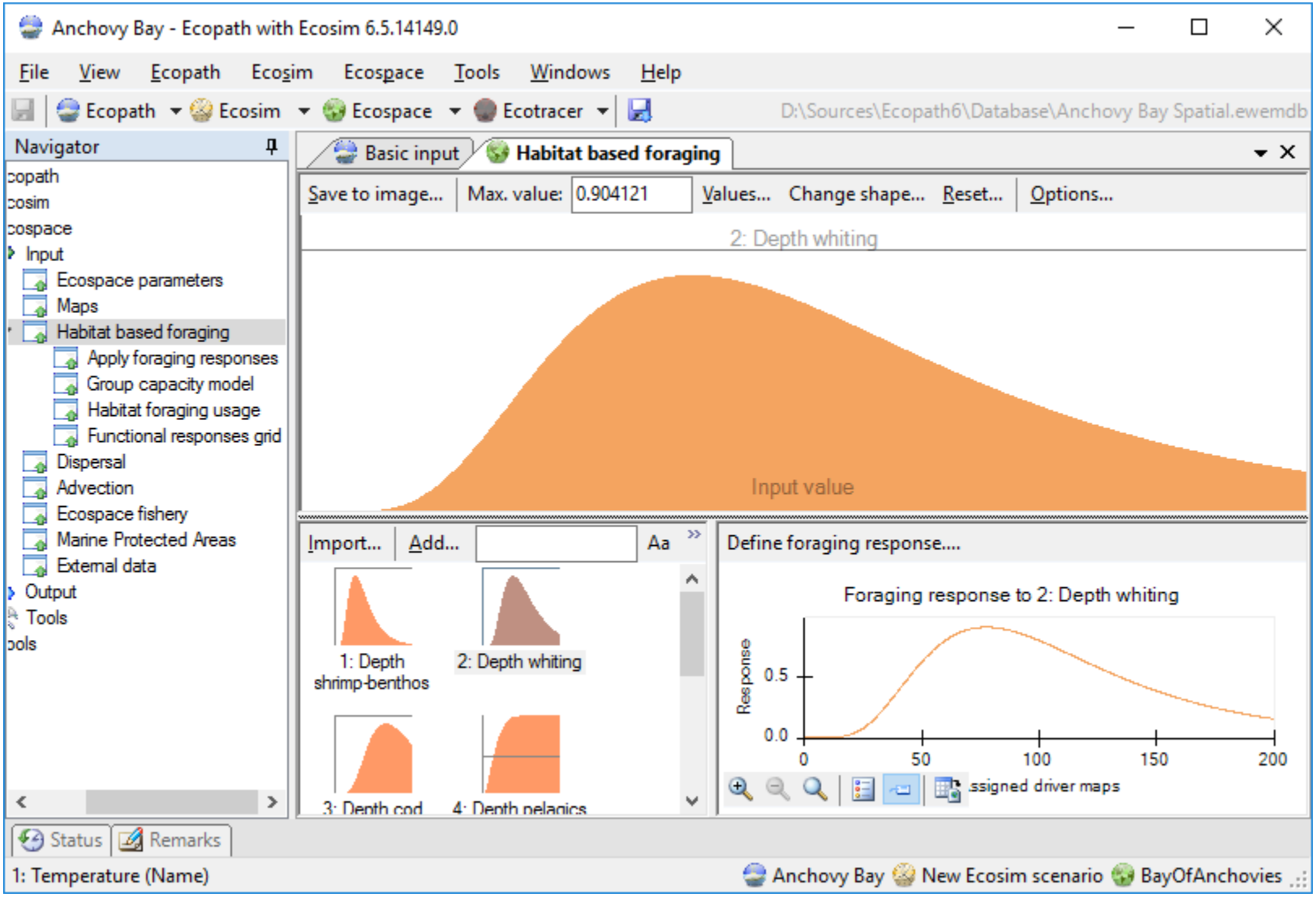
2. Define environmental drivers



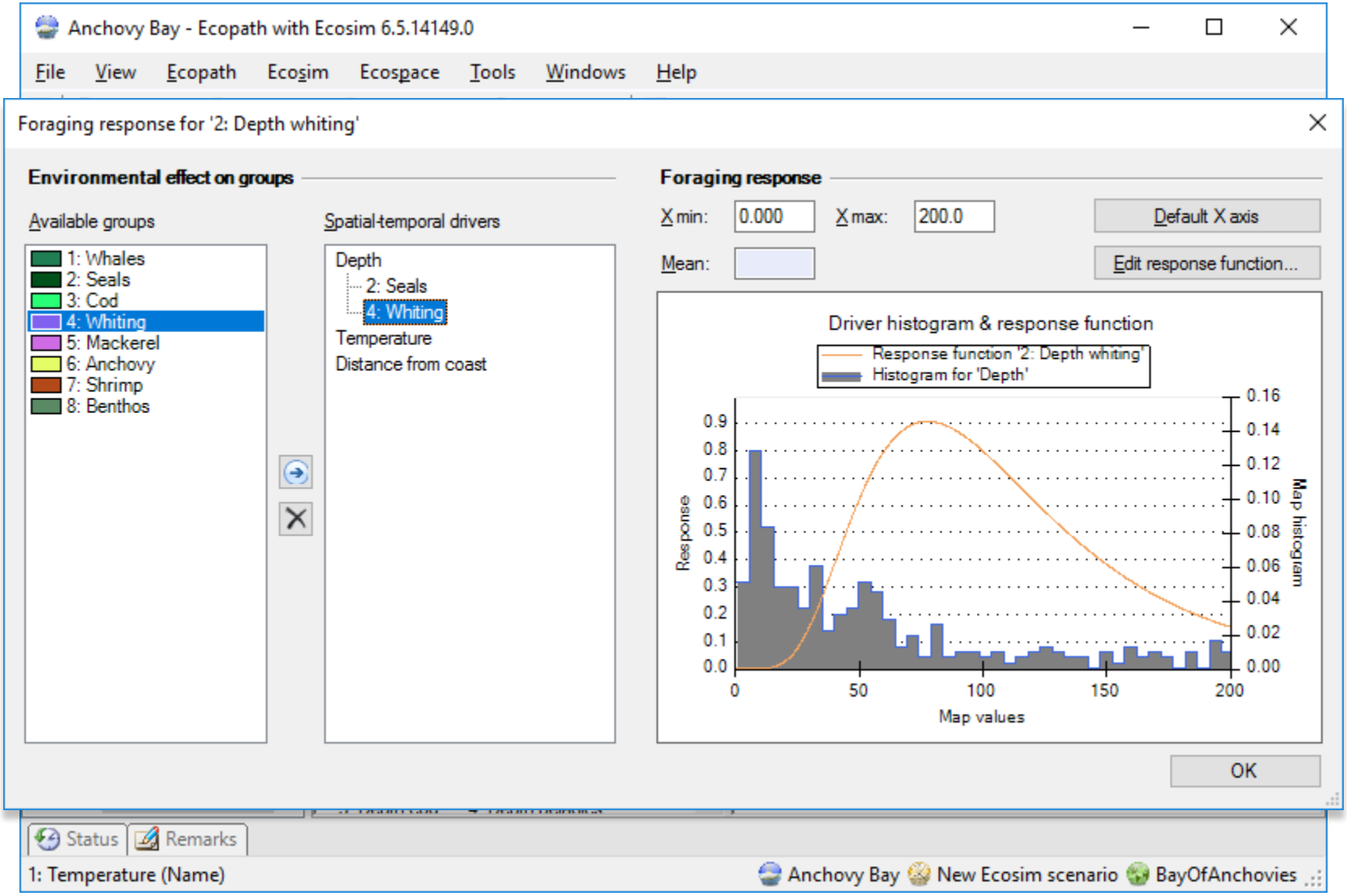
3. Populate env. driver maps



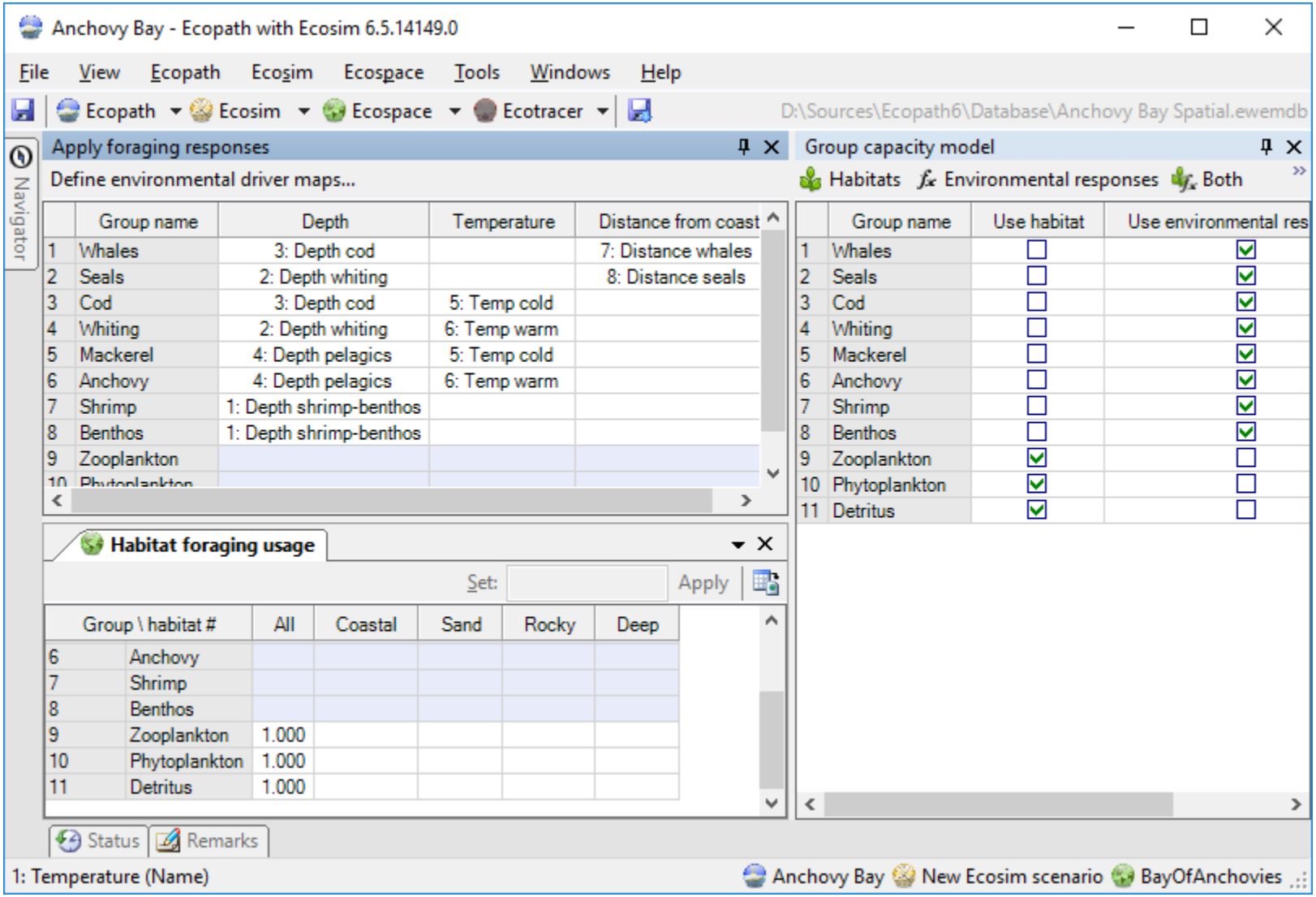
4. Define env. response curves



5. Connect groups, drivers and responses



6. Check set-up and run



Hab. Cap. case study

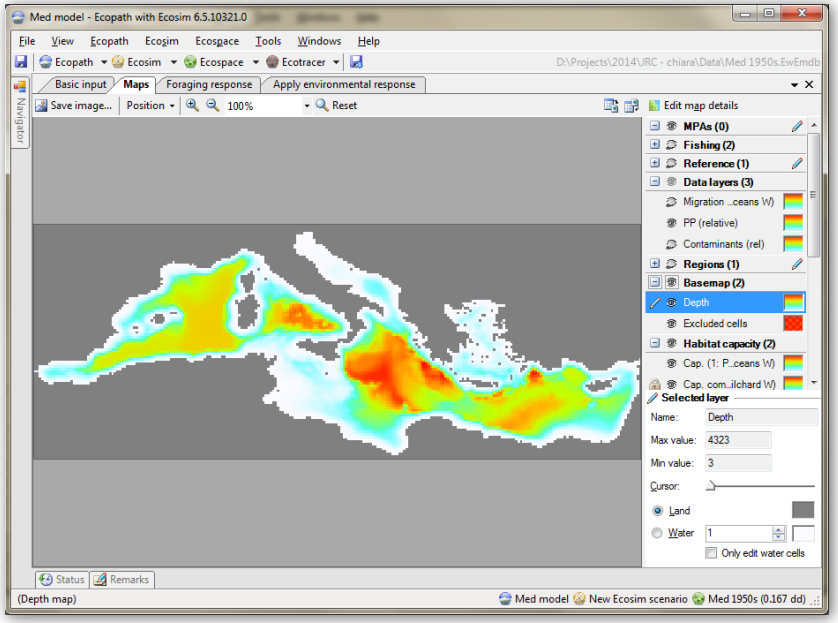
Foraging habitat capacity model case study

Full Mediterranean EwE model

90+ functional groups, assigned to 4 MSFD zones

Time frame 1950 – 2010

Entire basin at 0.167 dd grid



Piroddi et al (in progress)

EUROPEAN COMMISSION

Hab. Cap. case study

1. Define environmental drivers

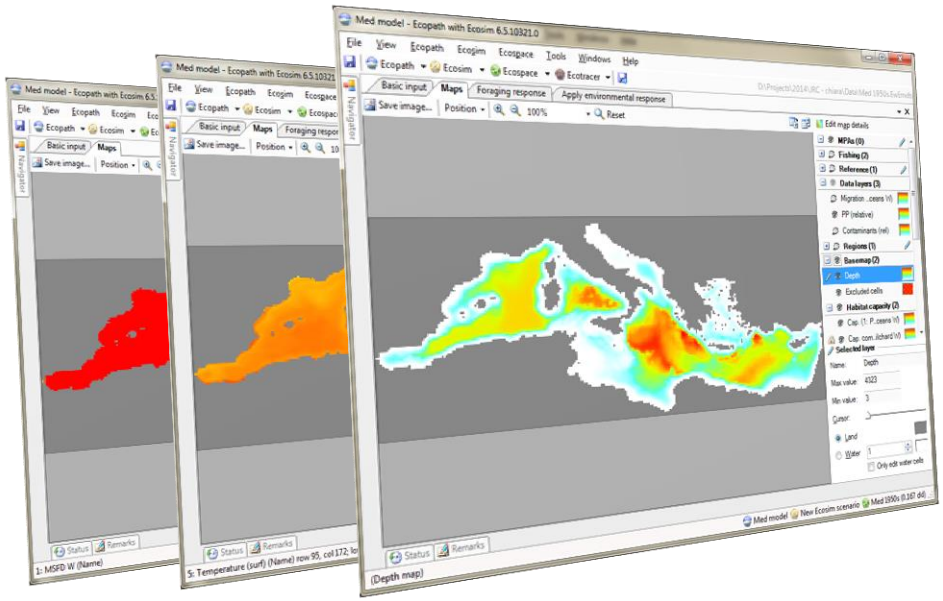
Primary production

Salinity (surface and bottom)

Temperature (surface and bottom)

Depth

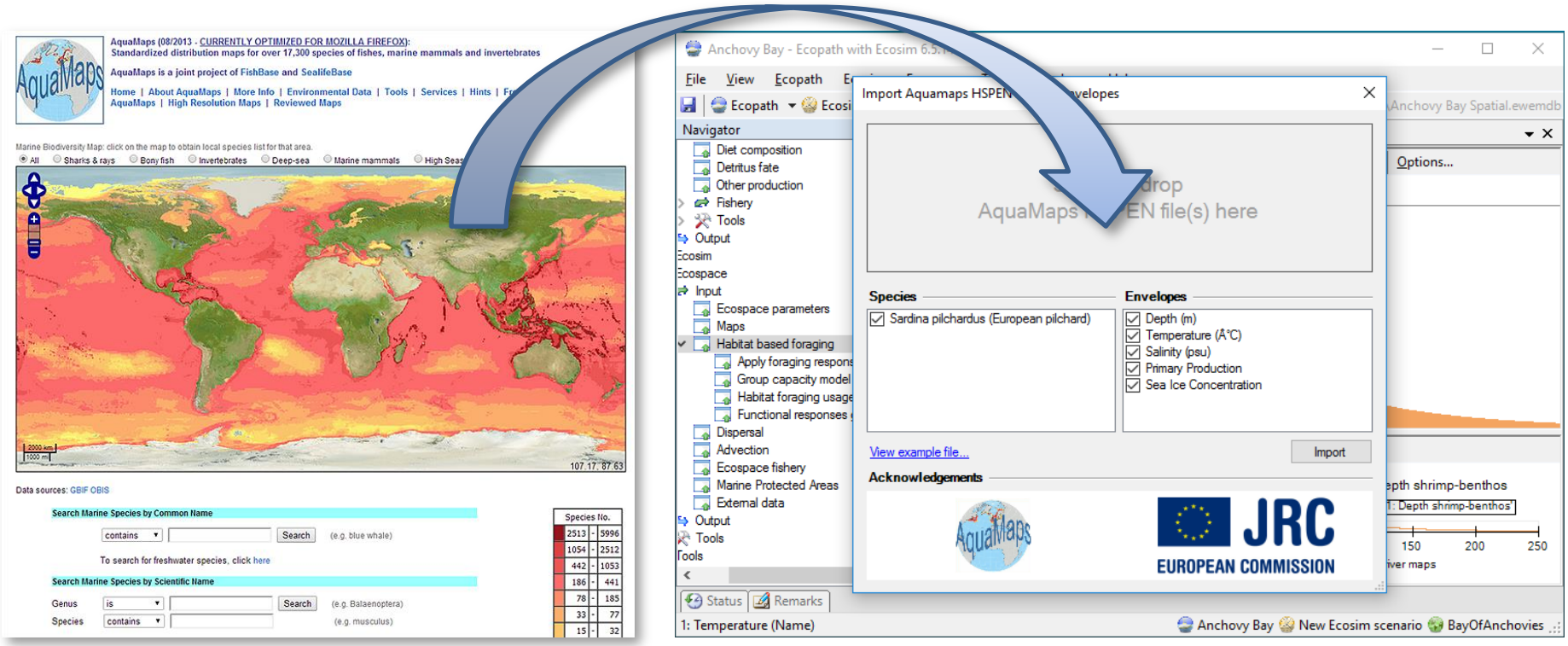
MSFD area restrictions



Hab. Cap. case study

2. Define environmental responses

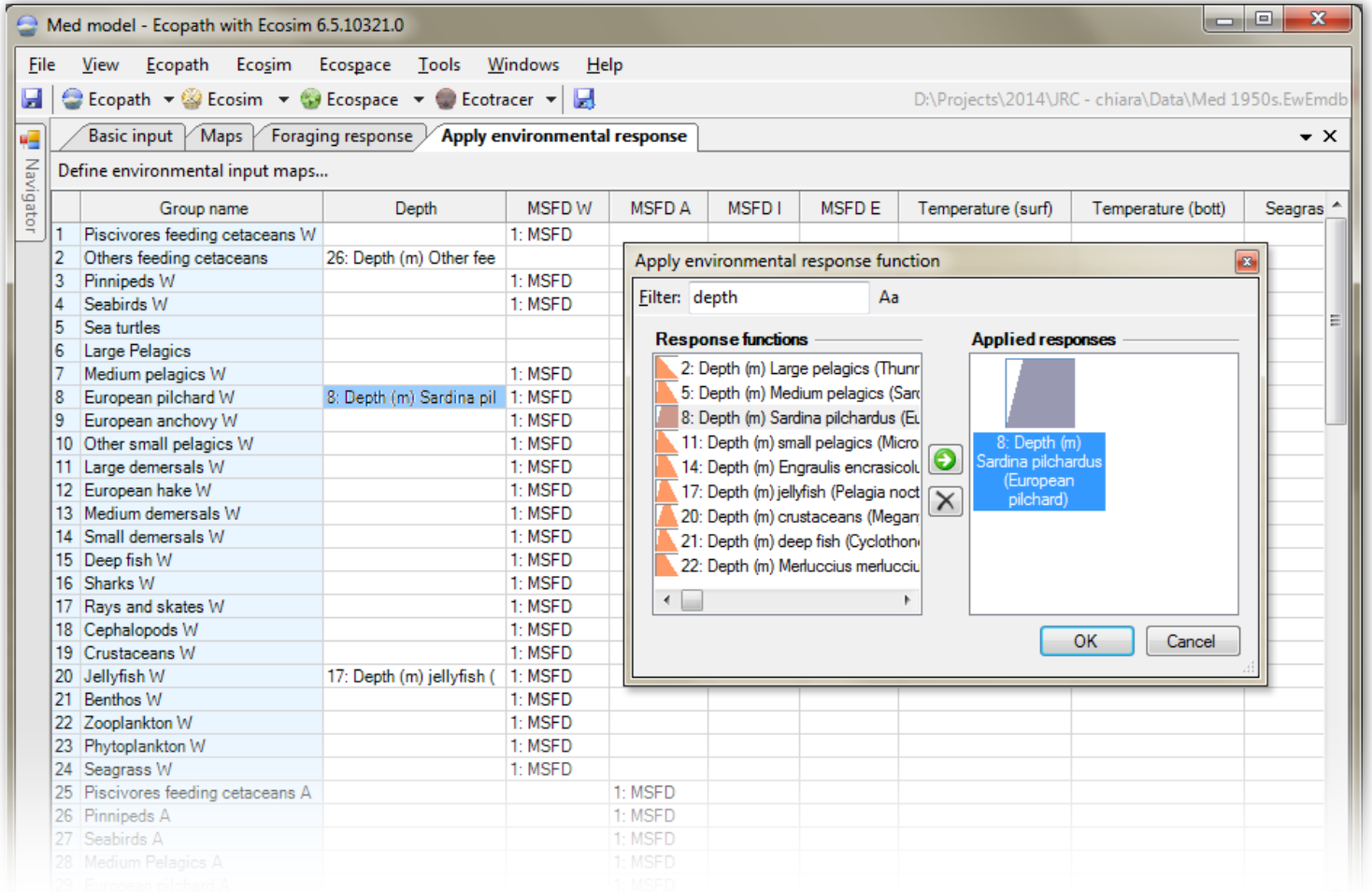
Here we are using a plug-in to import environmental responses from AquaMaps species envelopes



Piroddi et al (in progress)

Hab. Cap. case study

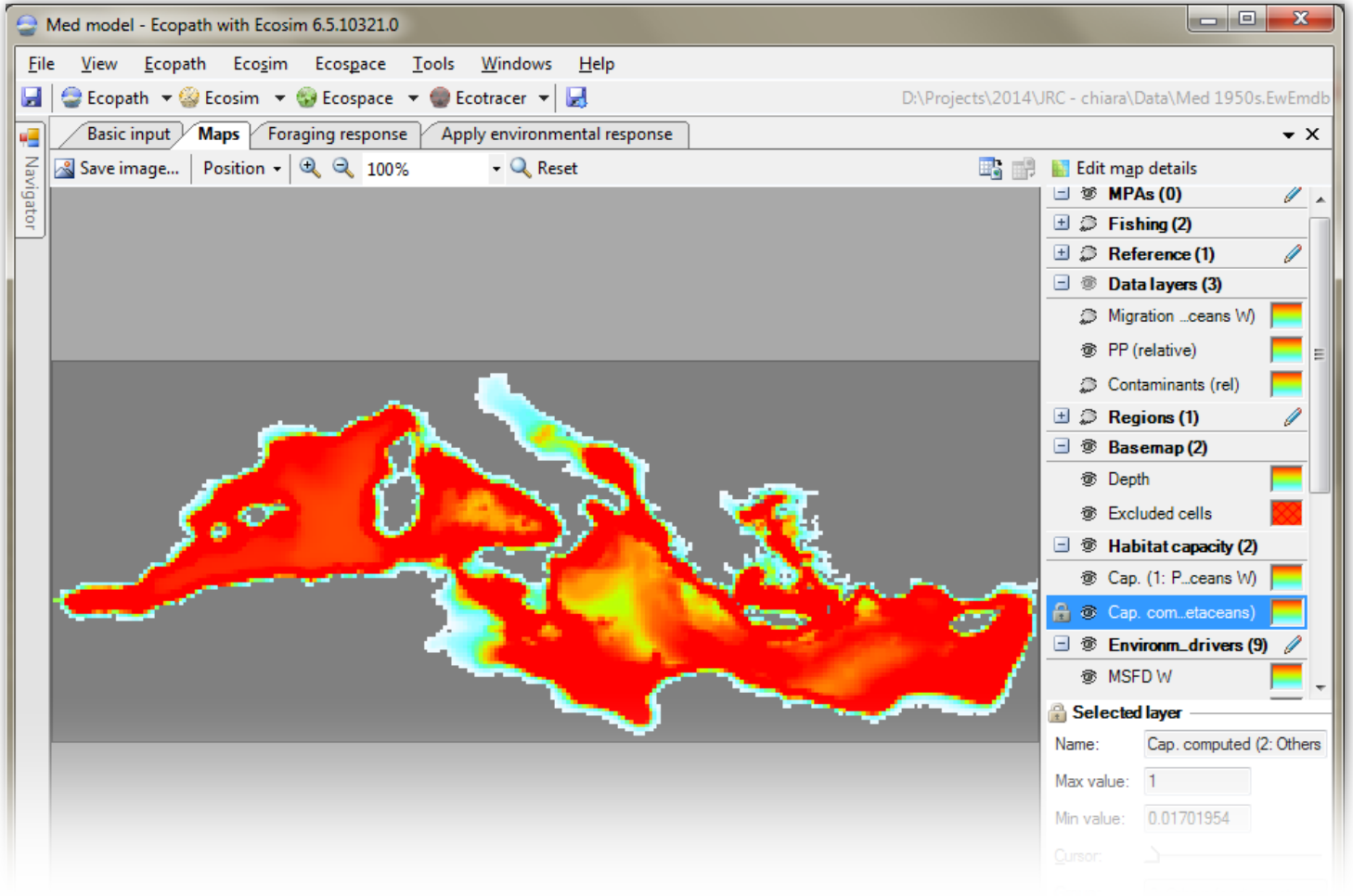
3. Apply drivers and responses



	Group name	Depth	MSFD W	MSFD A	MSFD I	MSFD E	Temperature (surf)	Temperature (bott)	Seagras
1	Piscivores feeding cetaceans W		1: MSFD						
2	Others feeding cetaceans	26: Depth (m) Other fee							
3	Pinnipeds W		1: MSFD						
4	Seabirds W		1: MSFD						
5	Sea turtles								
6	Large Pelagics								
7	Medium pelagics W		1: MSFD						
8	European pilchard W	8: Depth (m) Sardina pil	1: MSFD						
9	European anchovy W		1: MSFD						
10	Other small pelagics W		1: MSFD						
11	Large demersals W		1: MSFD						
12	European hake W		1: MSFD						
13	Medium demersals W		1: MSFD						
14	Small demersals W		1: MSFD						
15	Deep fish W		1: MSFD						
16	Sharks W		1: MSFD						
17	Rays and skates W		1: MSFD						
18	Cephalopods W		1: MSFD						
19	Crustaceans W		1: MSFD						
20	Jellyfish W	17: Depth (m) jellyfish (	1: MSFD						
21	Benthos W		1: MSFD						
22	Zooplankton W		1: MSFD						
23	Phytoplankton W		1: MSFD						
24	Seagrass W		1: MSFD						
25	Piscivores feeding cetaceans A			1: MSFD					
26	Pinnipeds A			1: MSFD					
27	Seabirds A			1: MSFD					
28	Medium Pelagics A			1: MSFD					

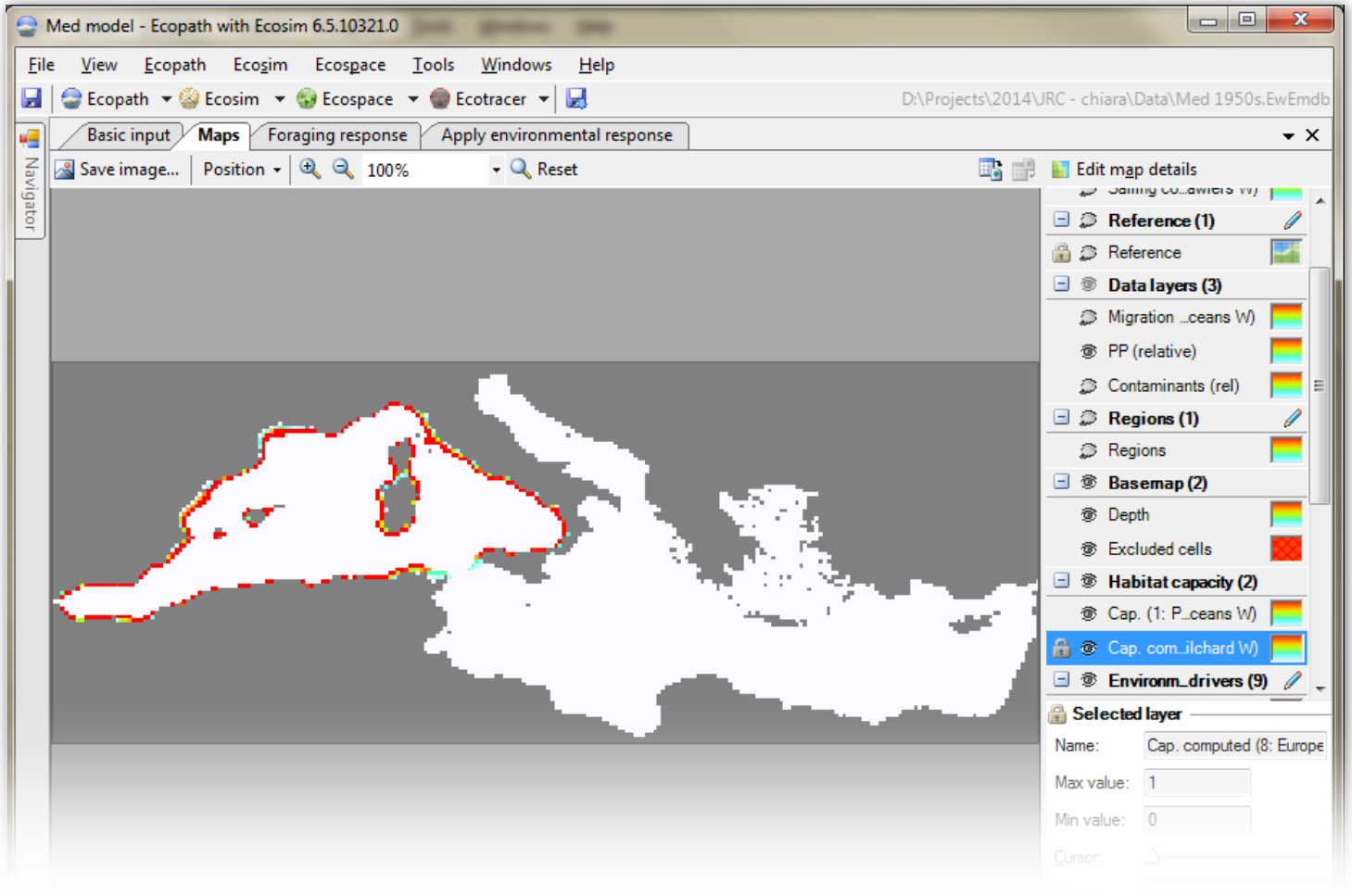
Hab. Cap. case study

4. **Ecospace computes capacity** (cetaceans - depth)



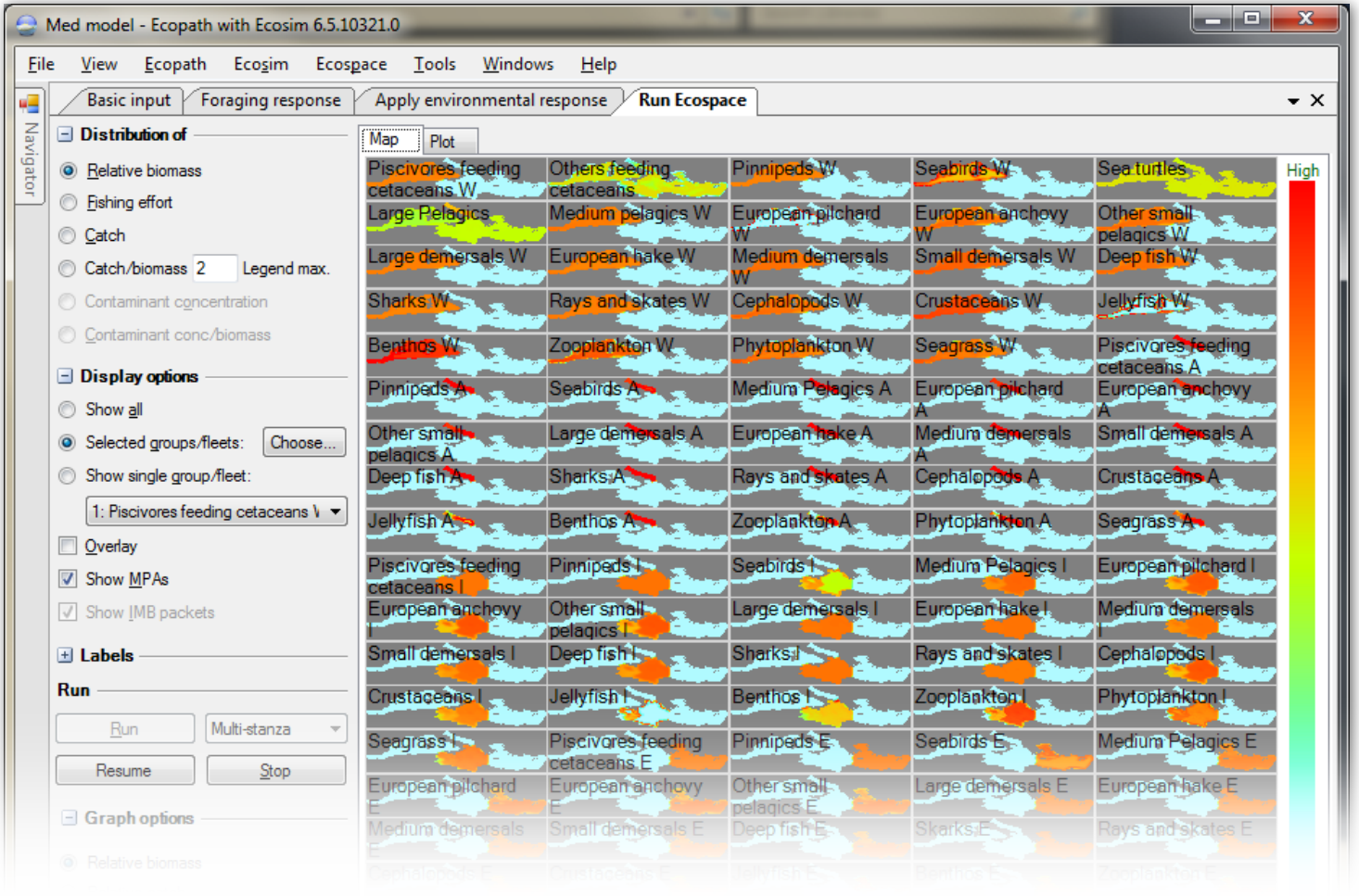
Hab. Cap. case study

4. More capacity (Western sardine - depth, MSFD W)



Hab. Cap. case study

4. Run



Ecospace spin-off

Functional responses are also available to Ecosim

- Previous Ecosim only supported two normal distributed response functions
- New Ecosim shares functional response curves with Ecospace
- Environmental drivers in Ecosim are functions; not maps
- Affects foraging arena size over time
- System is backwards compatible with older models

Not published yet, application in progress in PhD thesis

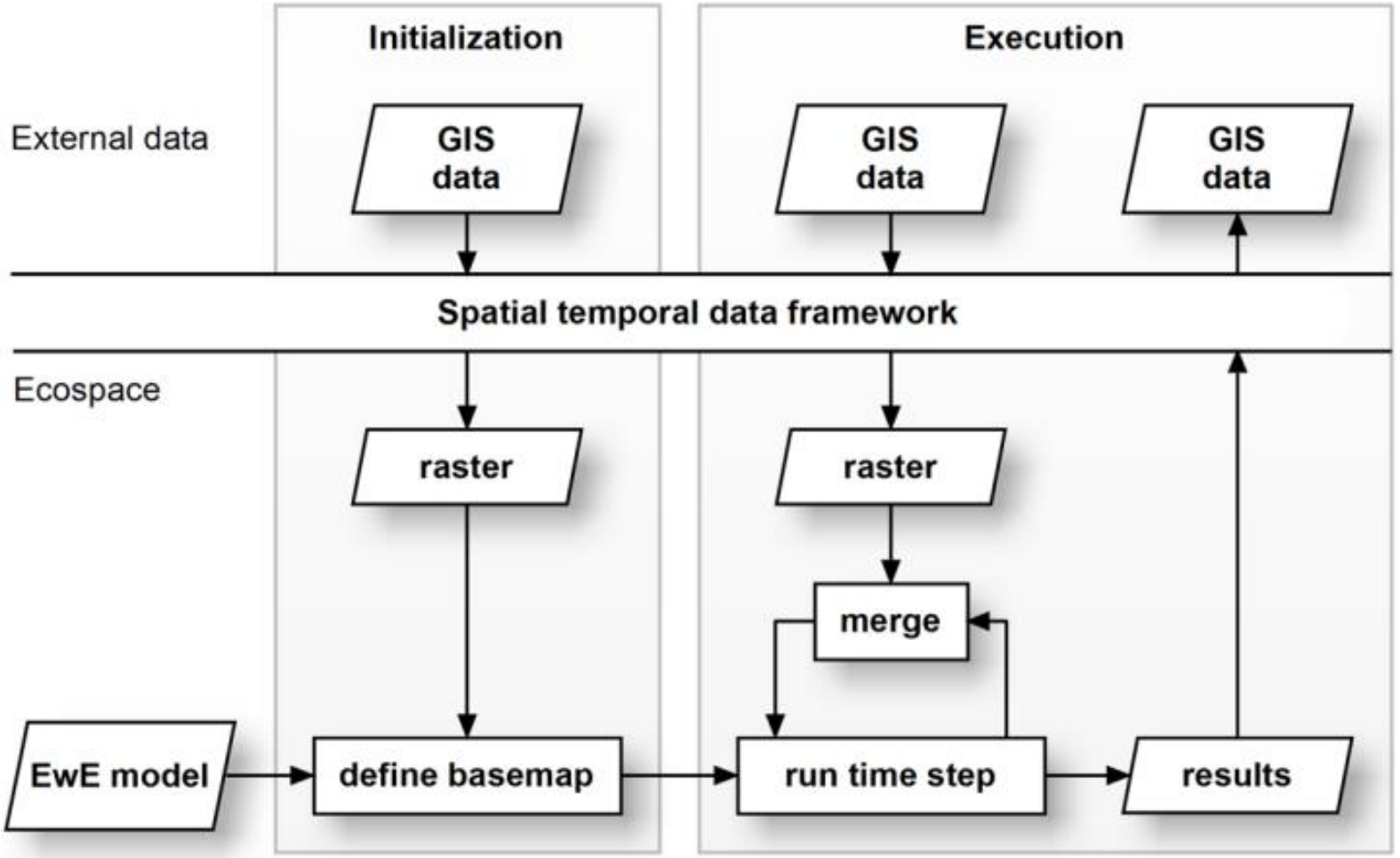
3. Exchanging data with the outside world

Ecospace shortcomings

Ecospace internal data model was hard to access

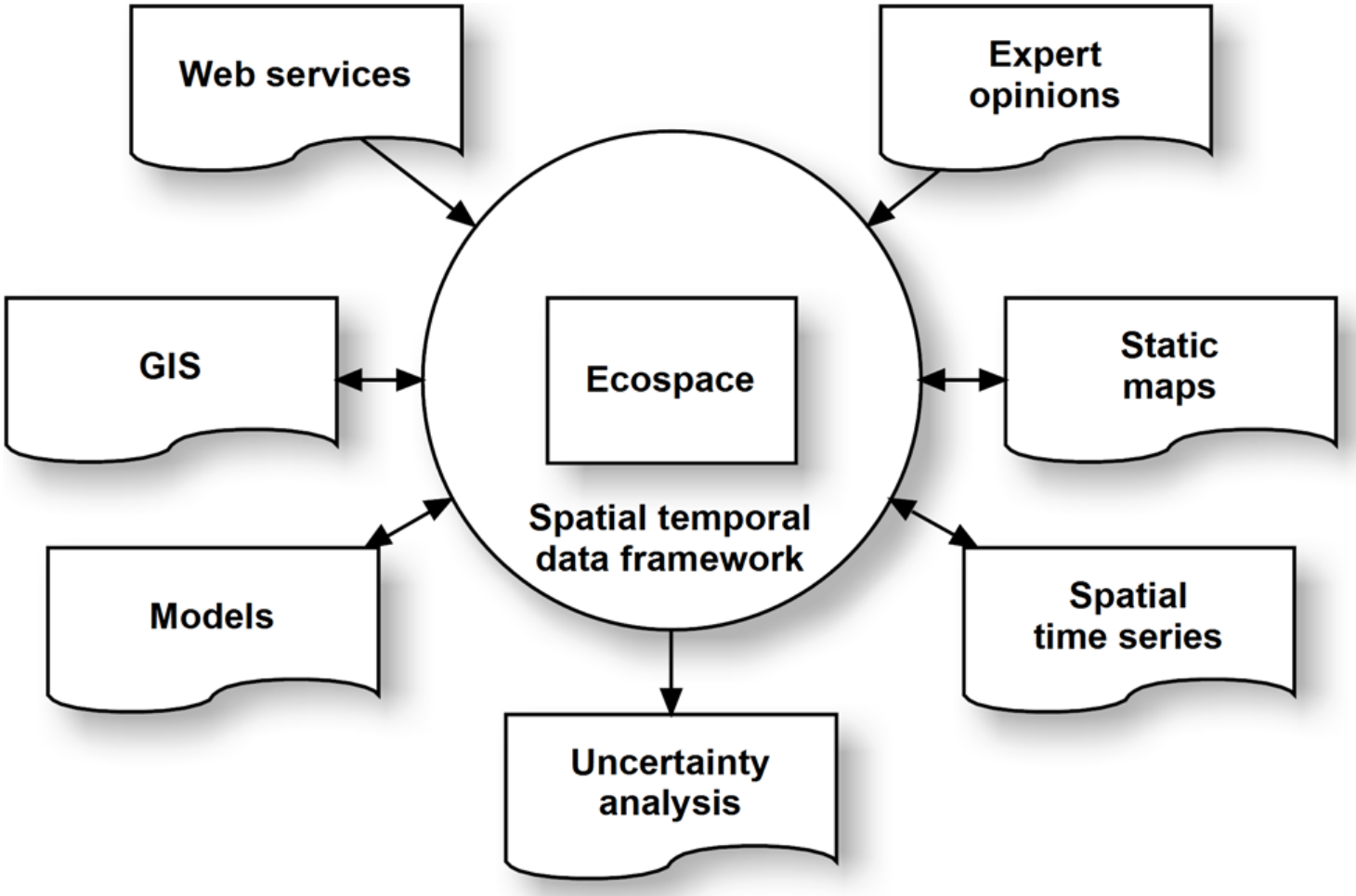
- Almost impossible to vary input maps over time
- Almost impossible to exchange data with other models
- Changing environmental conditions could not be included in spatial temporal analysis

Spatial temporal data framework

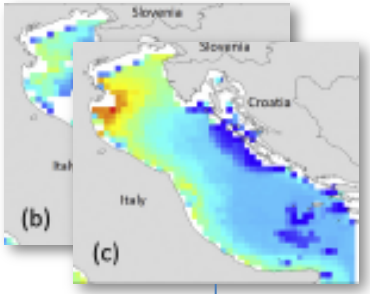


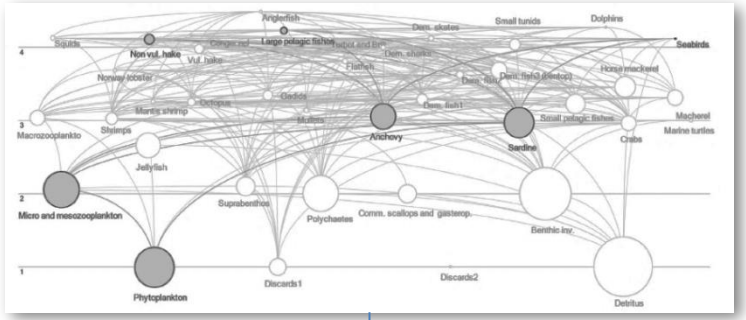
Steenbeek et al. 2013. Ecological Modelling 263, 139-151.

Spatial temporal data framework



Spatial Temporal data framework case study



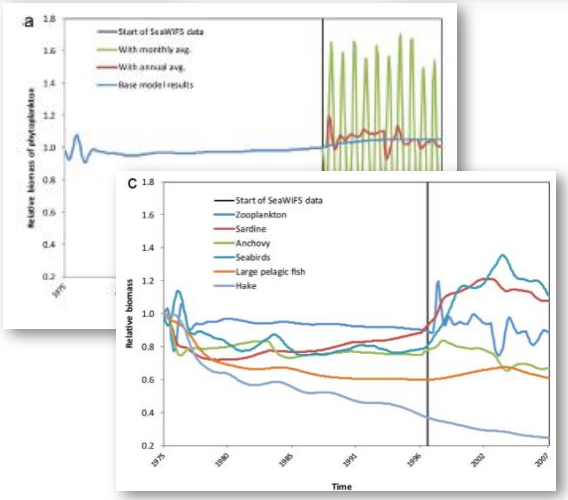


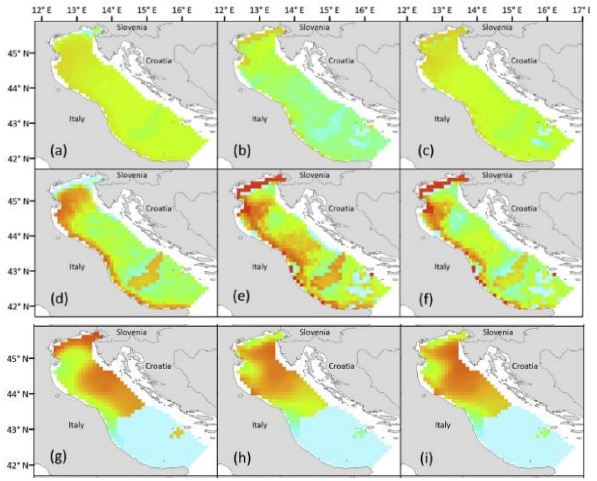
SeaWiFS PP (NetCDF, 10y)

Spatial-temporal data framework

Food web model (Adriatic)

Biomass (ESRI .ascii)





Steenbeek et al (2013) Ecological Modeling

Current status

Connected to most Ecospace layers

Reads and writes 20+ GIS data formats, both raster and vector

Designed upon EwE plug-in system. Easy to extend with new capabilities

Not (yet) publicly released: more R&D needed.

Can only be applied by directly involving EwE team

Needs better support for projections

Needs integration of new data types

Needs user testing to streamline workflow

GIS data for many Ecospace layers

Connected to existing Ecospace driver layers

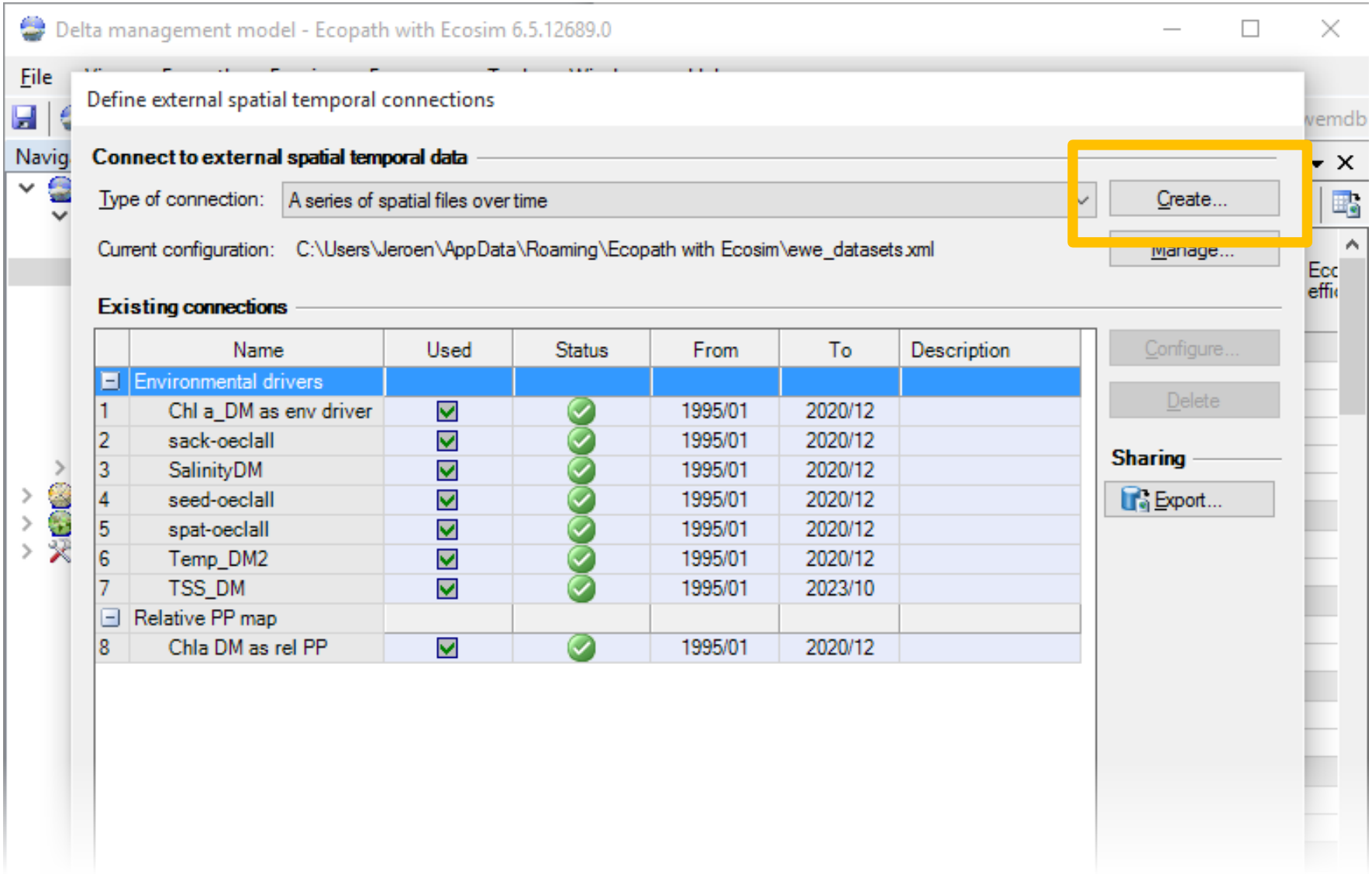
- Primary production
- Environmental drivers
- Habitats
- Fishing cost
- MPA layouts
- Contaminants
- Migration
- Computed foraging capacity

Coming soon

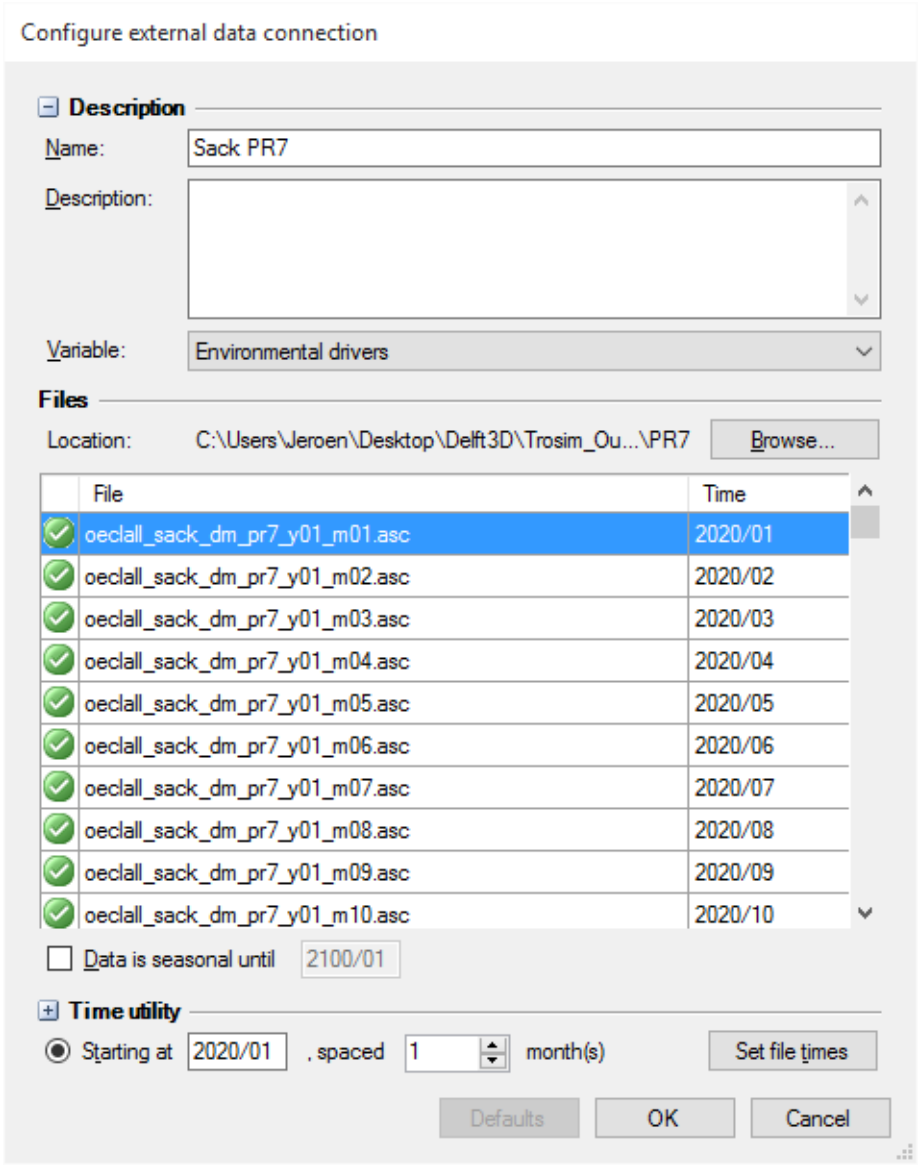
- Advection

Setting up the spatial temporal data framework

1. Define external data



2. Define external data



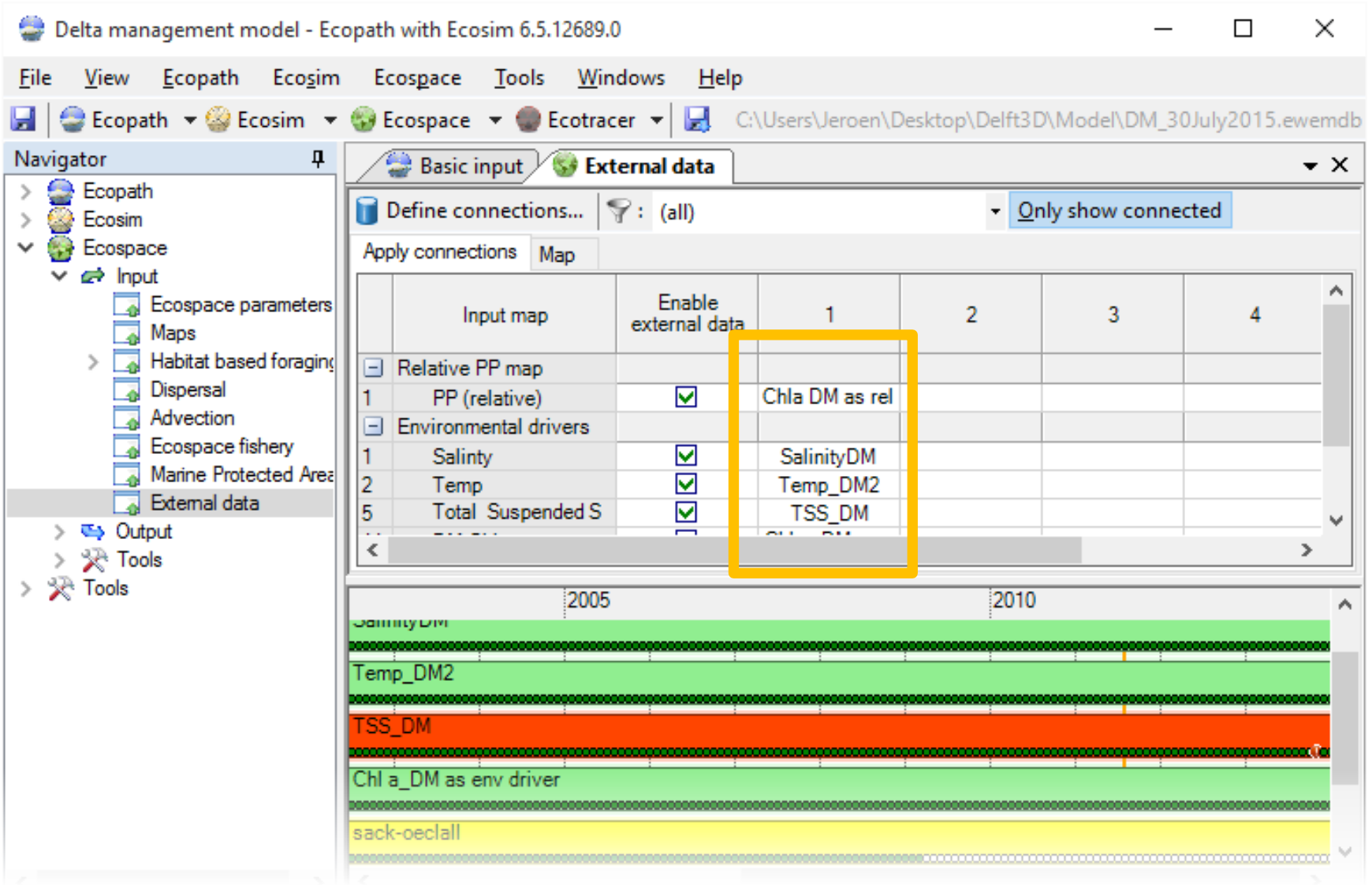
Name and description to help a user applying this data

Optional filter limits where this data can be applied to

Maps that define the patters of this data connection over time. Each map represents data at a given moment in time

Utility to time stamp the maps

3. Connect external data to maps



Other recently changes to Ecospace

- Automatic saving of outputs
  - Various map formats (.asc, .csv, …)
  - Various image formats (.png, .jpg, .bmp, …)
  - Averages by region
- Cell exclusion layer
  - Exclude cells from analysis without turning them to land
- Overlapping Marine Protected Areas
  - Allow different fisheries regulations in a single cell
- Migration
  - Use migration weight maps instead of centroid + spread

Work in progress

Advection

Current Advection model in EwE, which computes advection flow fields from wind, mixed layer depth, and upwelling, does not work

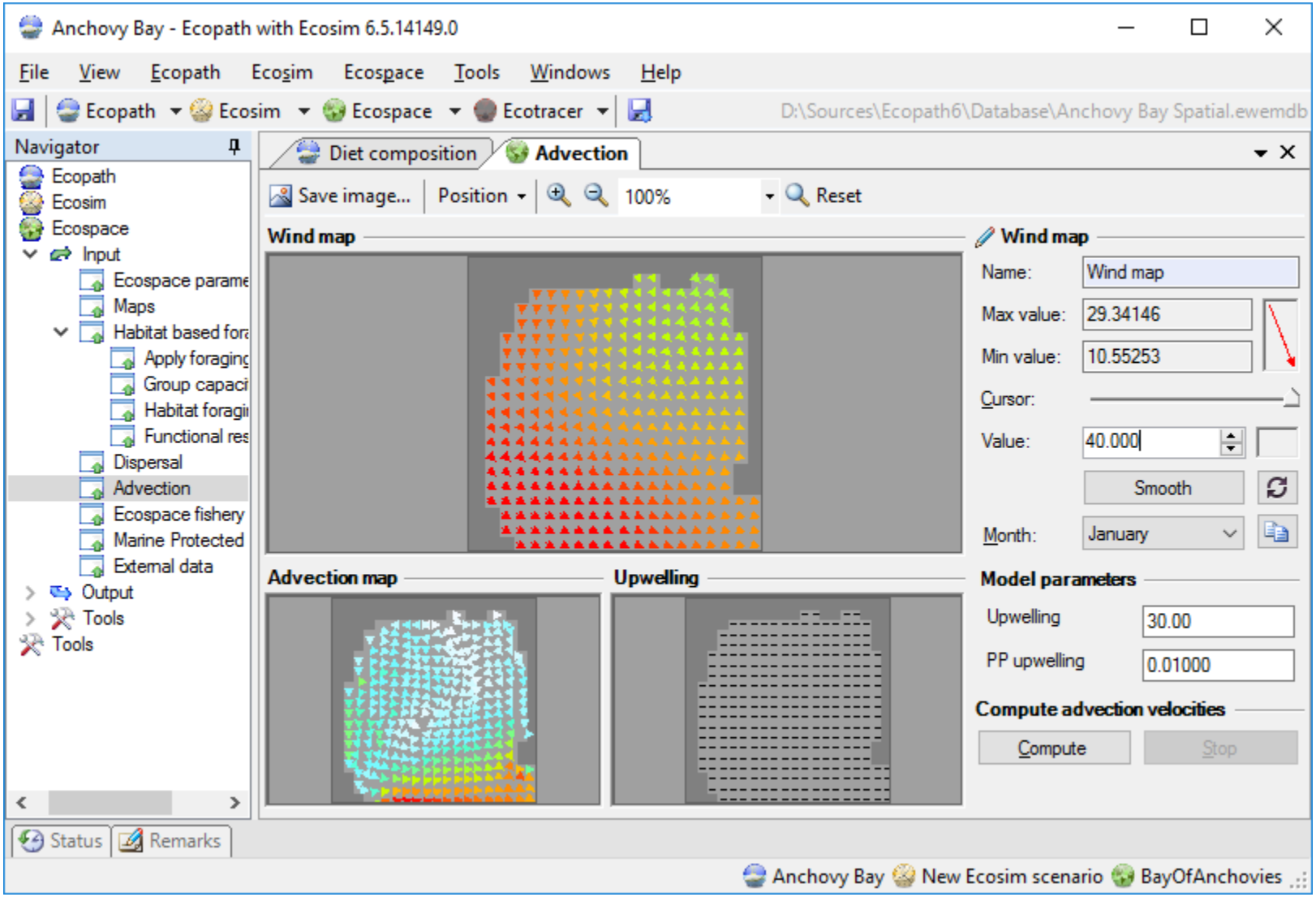
Work-around (EwE version 6.5+)

Applying advection flow fields does work: flow layer content can be entered or driven by spatial temporal framework

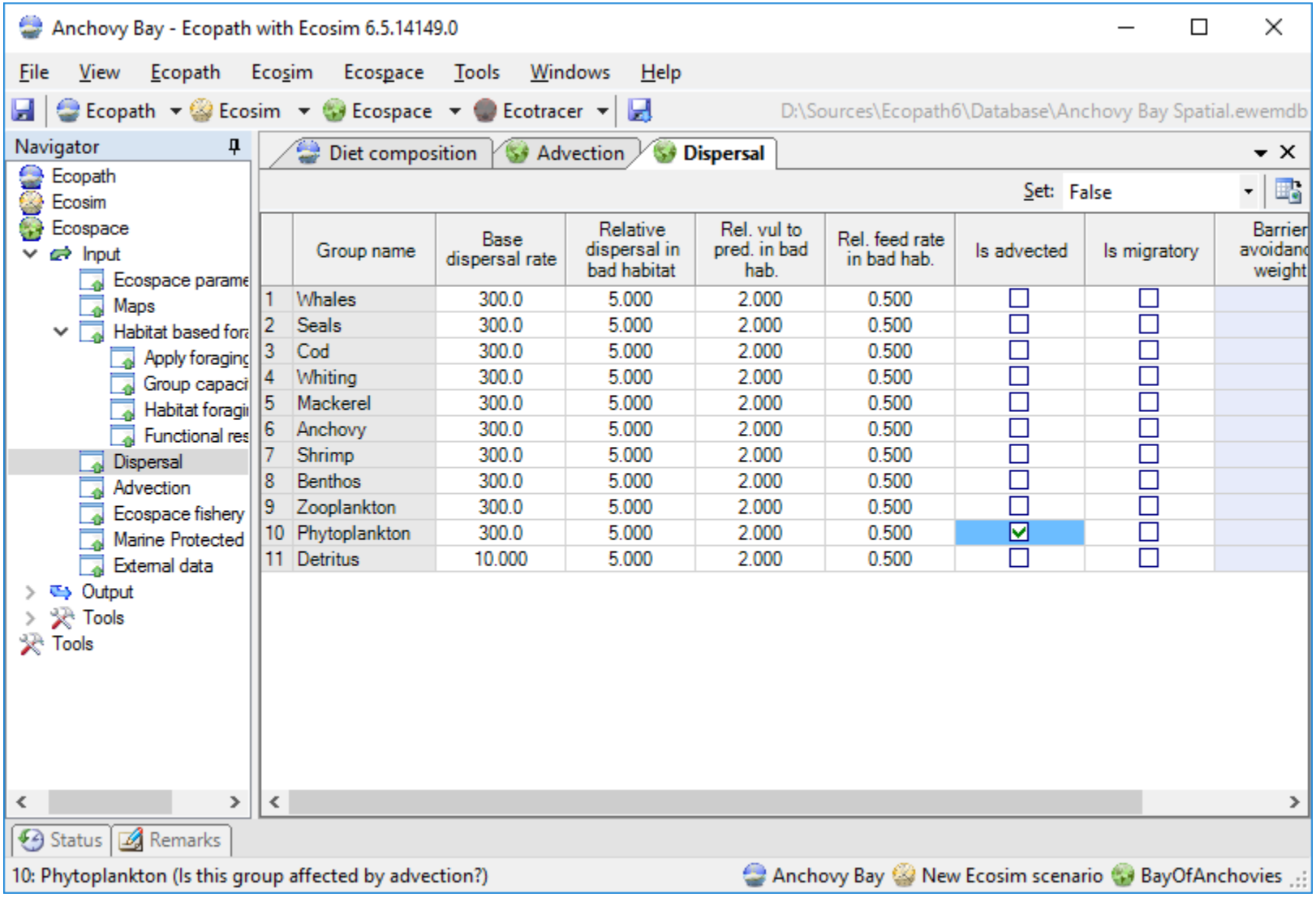
Ongoing developments

New Advection model only requires depth and wind input to calculate advection and upwelling

1. Calculate advection



2. Choose advected groups



Advection

Computed advection, per month, is stored with the EwE model

Advection patterns can be overwritten with external hydrological model output via the spatial temporal data framework

Will be made available in a next EwE version, but development version can be applied by involving the EwE development team

Publication is in progress

Ecotracer

Modelling the propagation of pollutants through the food web (Ecosim, Ecospace)

Existing Ecotracer module is being debugged, sped up, and made ready for application in large spatial temporal case study

Ecotracer model is driven by a contaminants forcing function (Ecosim) or contaminants map (Ecospace)

Publication is in progress

Measure Ecospace fit

Use spatial-temporal reference time series to report how well Ecospace reproduces observations

Prototype version uses point (x,y,z) time series

Future version should use the spatial-temporal data framework

Needs further R&D, funding

Ecosim forcing in Ecospace

Allow non-spatial forcing (Ecosim) to be applied to Ecospace

Prototype only applies biomass forcing time series

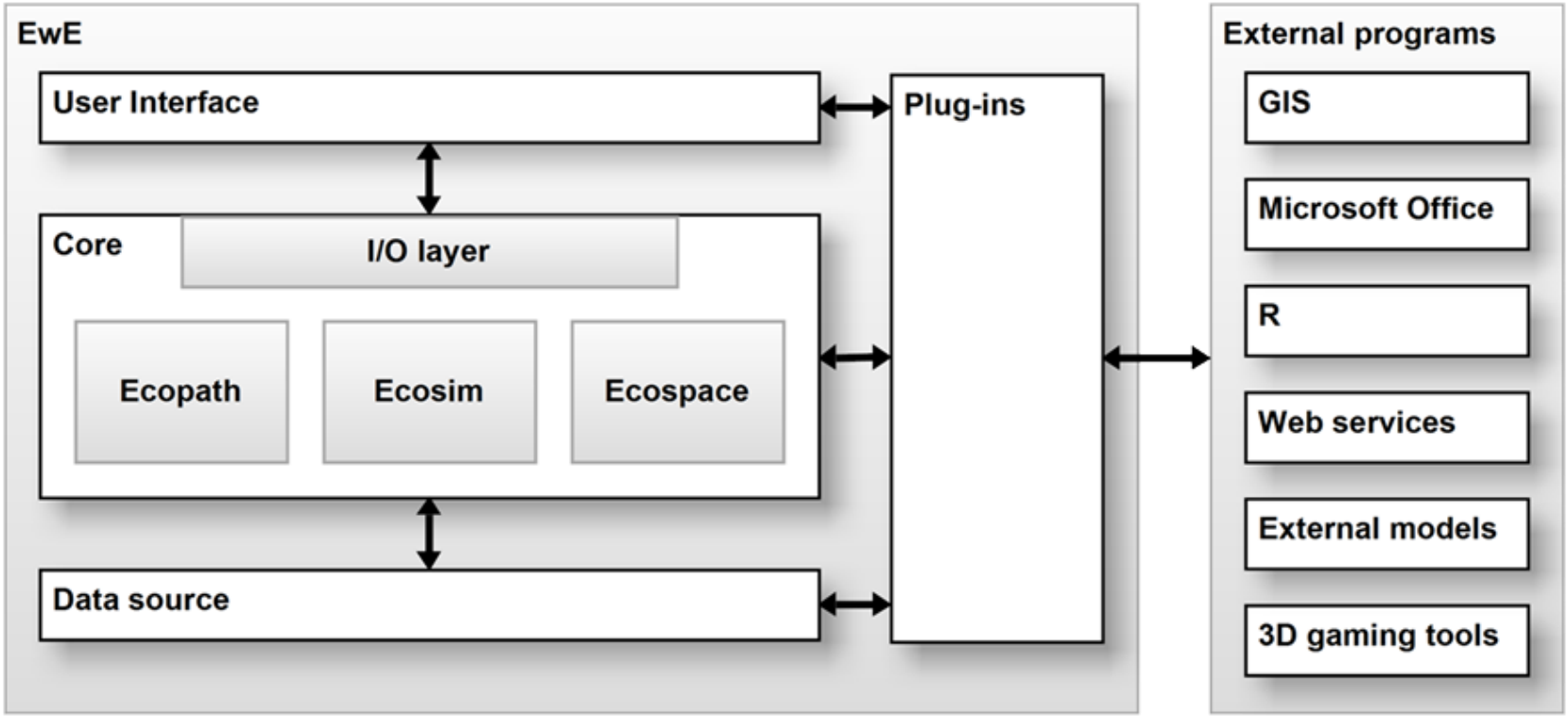
Can be extended to include any type of forcing

Needs further R&D, funding

Other ways to use EwE

Other ways to use EwE

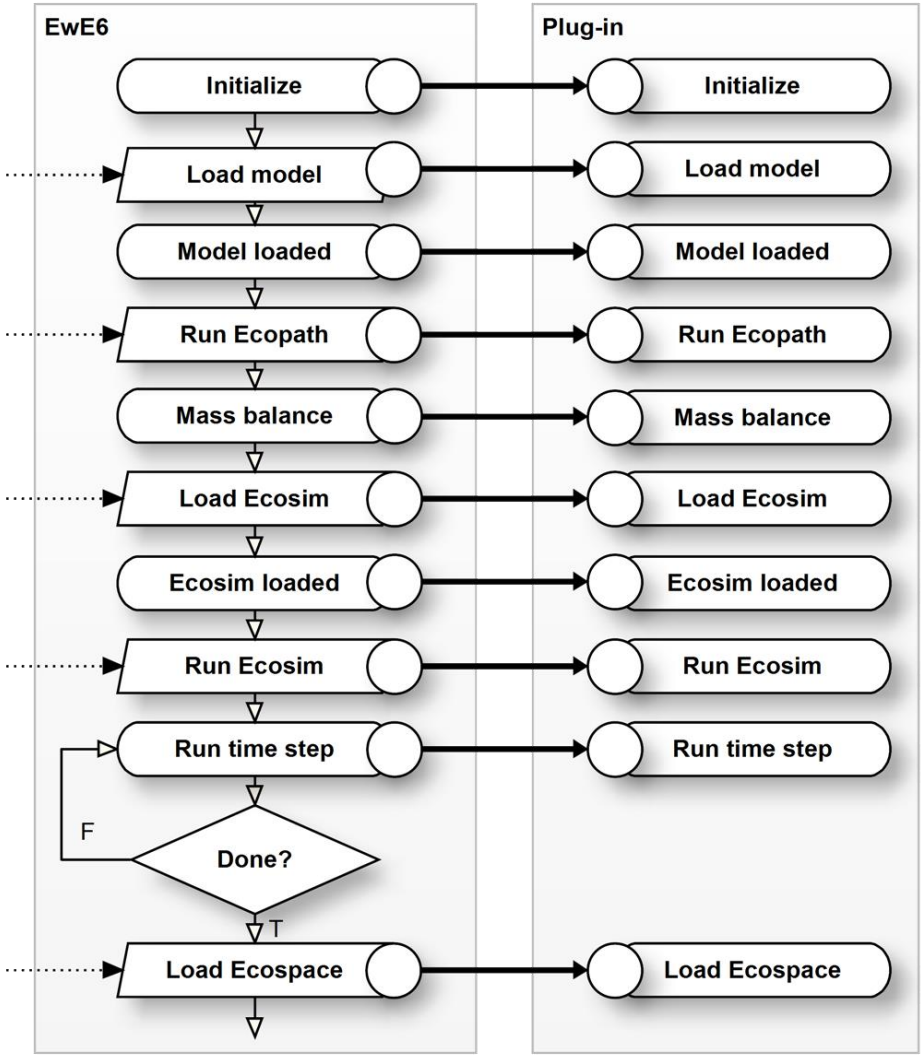
Modular structure of EwE



Other ways to use EwE

Plug-ins

- Independently of EwE
- Auto-loaded on start-up
- Included in program flow
- Replace or extend computations and user interface
- Perform external analysis and do other really neat things!



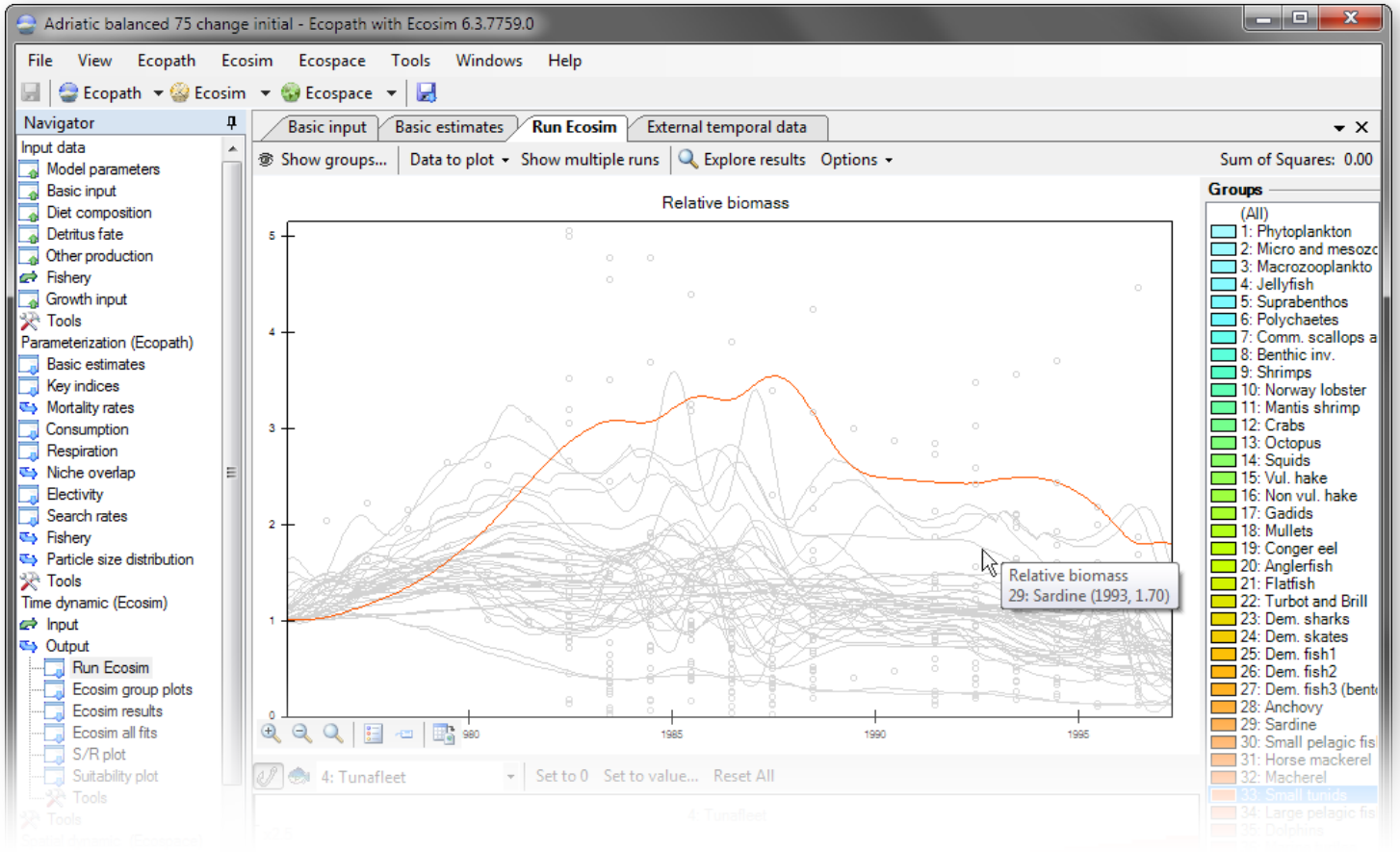
Other ways to use EwE

A few plug-ins

Aquamaps importer	EII
Biodiversity indicators	IRD, in progress
Ecotroph analysis	Agrocampus Ouest
WoRMS taxon search	EII
Multi-Sim	DFO
Network analysis	SAMS
Result extractor	CEFAS
Value Chain	UBC
Your plug-in?	

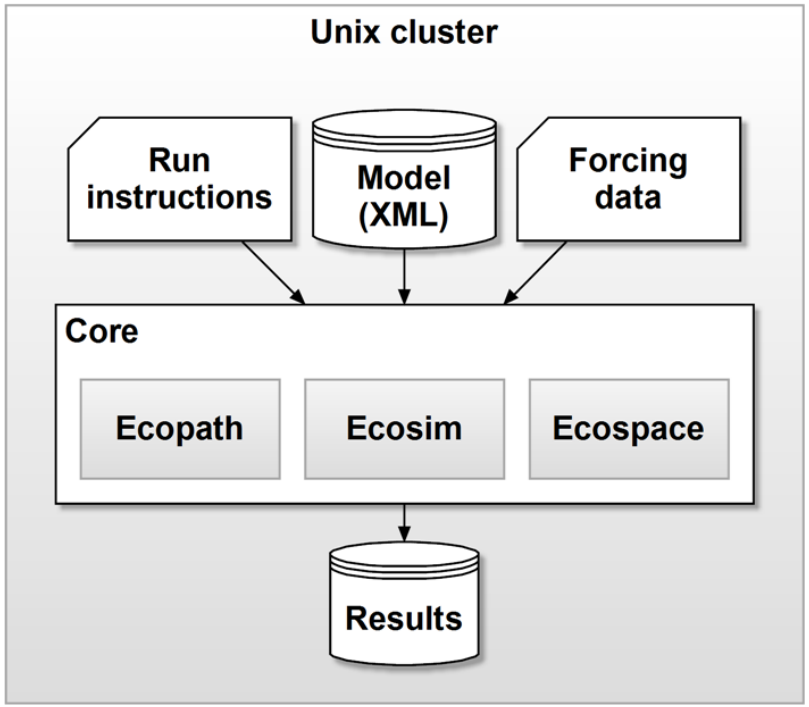
Other ways to use EwE

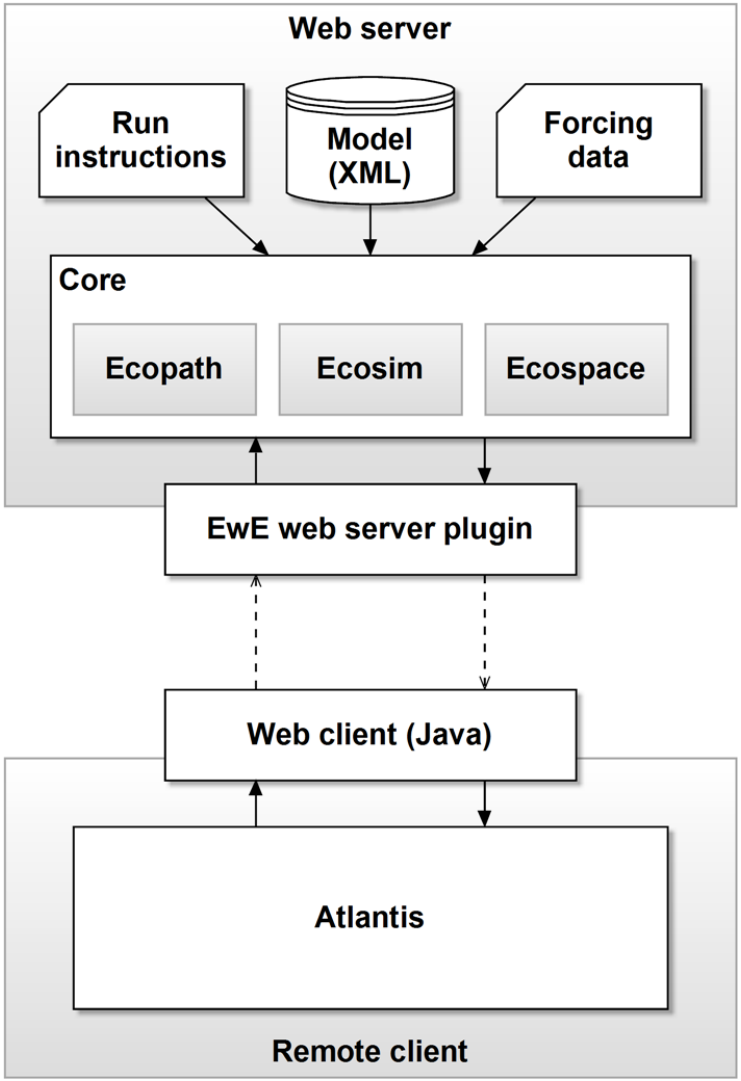
Standard use: EwE6 Scientific Interface



Other ways to use EwE

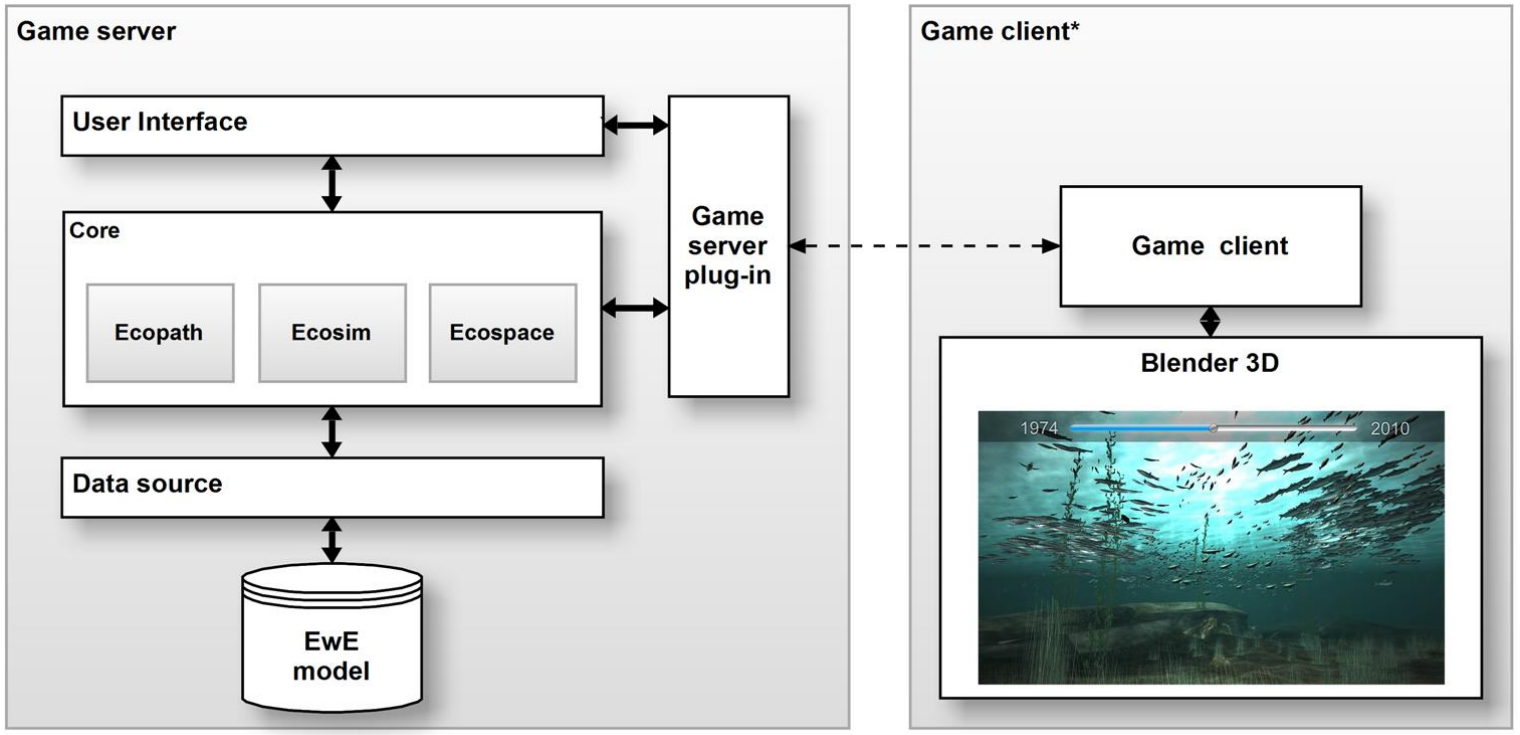
Distributed computing, model interoperability





Other ways to use EwE

OceanViz



The EwE ecosystem

Ecopath

Research and
Development
Consortium

The EwE ecosystem

EwE is free and open-source, and has no core funding

- Funding brought by user community via R&D and projects
- Overhead used for R&D and maintenance

Ecopath R&D Consortium: improving and applying EwE

- High quality training courses
- Pursuing and executing projects
- Release new versions of EwE
- Organizing development, user support, co-development
- Open for any institute to join, voluntary participation

The EwE ecosystem

EwE needs active users to continue

- Get a support contract for projects that need EwE
- Participate in user community (forums, Facebook)
- Improve functionality through co-development
- Organize training courses with the Consortium
- Join the Consortium

http://ecopath.org/consortium

http://facebook.com/eweconsortium

Thank you

jeroen@ecopathinternational.org

Ecopath
International
Initiative

Selected references

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