ODYSSEA

Creating products and knowledge for the Mediterranean

ΑΡΙΣΤΟΤΕΛΕΙΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΘΕΣΣΑΛΟΝΙΚΗΣ

ARISTOTLE UNIVERSITY OF THESSALONIKI

MARINE ECOSYSTEM MODELLING ECOPATH WITH ECOSIM

2nd ODYSSEA Summer School, Alonissos, 2-6/9/2019

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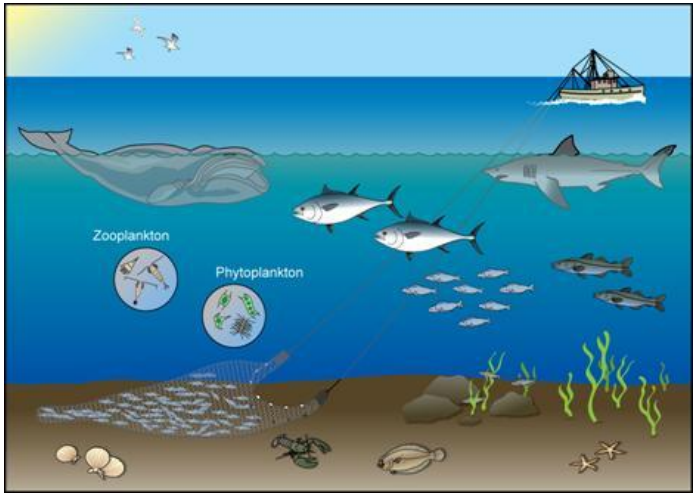
Ecosystem models

Ecological models

- the mathematical simulation of ecological processes



Ecosystem models

- the mathematical simulation/representation of a system (population/community/ecosystem)
- describe the structure and function of a system
- useful for the Ecosystem Approach to Fisheries / Ecosystem Based Fisheries Management
- usually complement single species models

Ecosystem models

ODYSSEA

synthesize existing data and knowledge

Ichthyology

Fisheries research

Marine biology

Oceanography

Ecology

Applied mathematics

+

Landings/discards estimates

Biodiversity

Productivity

$W=a*L^b$

Stock assessments

Age & growth

Feeding

Reproduction

Abundance estimates

Field data

++

Metabolism

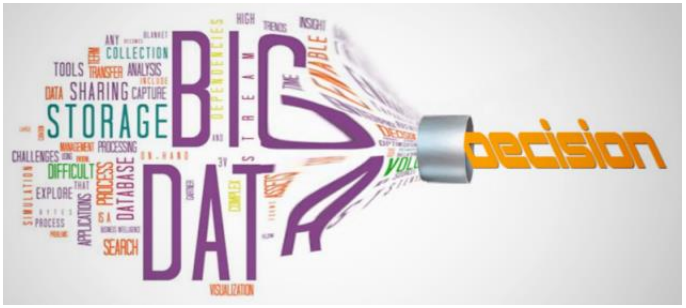
Fishing effort

Field experiments

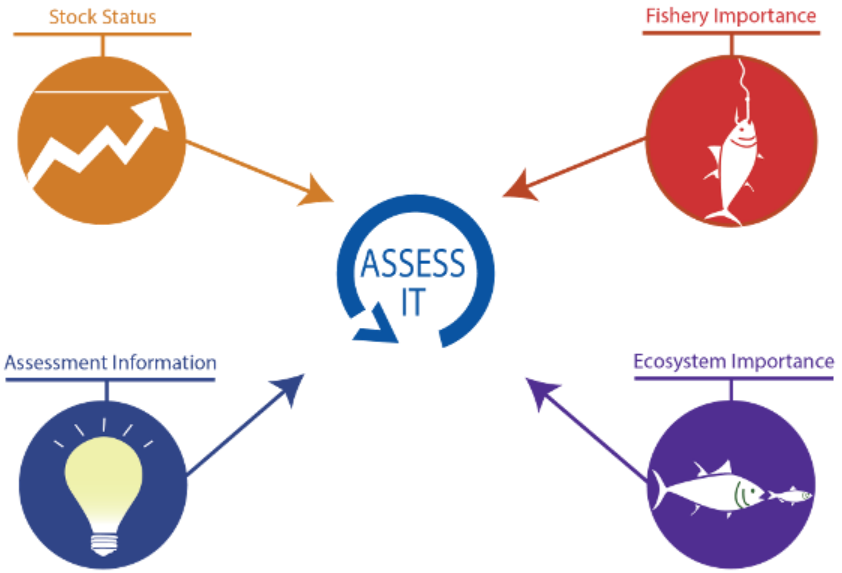
But … which model is the best? Which methodology? Which structure?

Ecosystem models

Choosing the most appropriate model has to do with …



- the research question
- the organisms we want to focus on
- the factors interacting with the target organisms (physical, biological, anthropogenic)
- the time period we want to focus on (short- or long-term)
- data availability
- its use (research or business)
- how flexible we want it to be
- user capabilities



Types of ecosystem models

- **Whole ecosystem models:** aim to include all the trophic levels of the studied ecosystem
- **Minimum Realistic Models (MRM):** they have a limited number of species/groups, mainly those that interact with the target species
- **Dynamic System Models (biophysical):** represent both bottom-up (natural) and top-down (biological) processes interacting in an ecosystem
- **Extensions of single-species assessment models (ESAM):** expand single-species assessment models taking into account some interactions among species

Plagányi, 2007

Types of ecosystem models

ODYSSEA

	1	2	3	4	5	6	7	8	9	10
RESEARCH QUESTION/ MODEL	**Ecopath with Ecosim and ECOSPACE**	**IGBEM**	**ATLANTIS**	**INVITRO**	ERSEM II	SSEM	KPFM*	MRM e.g. Punt and Butterworth (1995)	MSVPA and MSFOR	MSM
1a. Understanding - subset of ecosystem		■		■						
1b. Understanding - complete ecosystem	■		■							
2. Impact of target species	■		■	■						
3. Effect of top predators	■		■	■						
4. Competition: marine mammals - fisheries	■		■	■						
5. Rebuilding depleted fish stocks	■		■	■						
6. Biases in single-species assessment	■		■	■						
7. Ways to distribute fishing effort among fisheries	■		■	■						
8. Under-exploited species	■		■	■						
9. Change in ecosystem state	■	■	■	■						
10. Spatial concentration of fishing	■		■	■						
11. Environmental/physical effects	■	■	■	■						
12. Effects of habitat modification			■	■						
13. Effects of by-catch	■		■	■						
14. Introduction of non-native species	■		■	■						

Whole ecosystem models

* Still being developed

Plagányi, 2007

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Plankton models

* Still being developed

Plagányi, 2007

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Minimum realistic models

* Still being developed

Plagányi, 2007

Types of ecosystem models

ODYSSEA

	11	12	13	14	15	16	17	18	19	20
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Minimum realistic models

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Plagányi, 2007

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Dynamic system models

* Still being developed

Plagányi, 2007

Types of ecosystem models

ODYSSEA

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Antarctic models

* Still being developed

Plagányi, 2007

Types of ecosystem models

ODYSSEA

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Extended single-species models

* Still being developed

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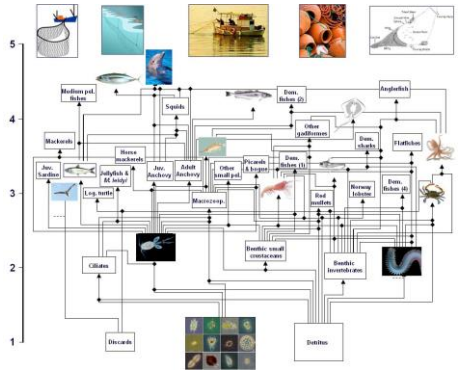
Ecopath with Ecosim

ODYSSEA

EwE

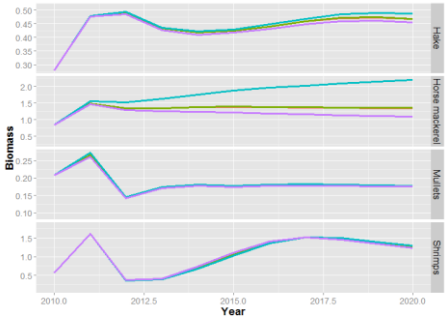
Ecopath

Snapshot of the food web



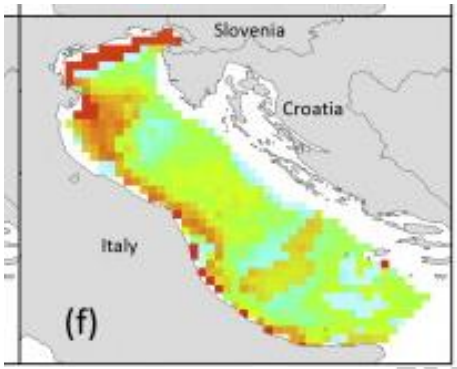
Ecosim

Time dynamic simulations

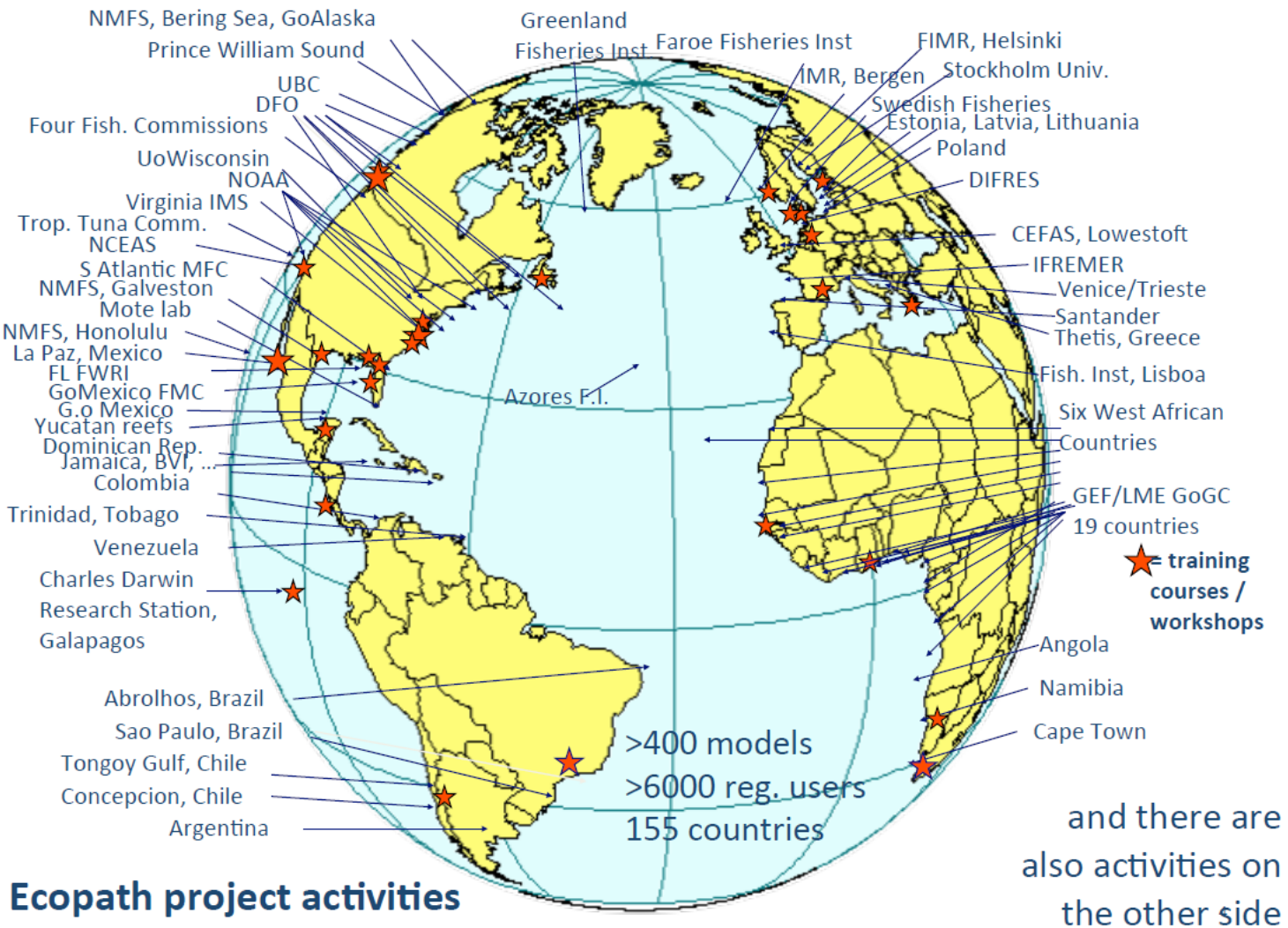


Ecospace

Spatio-temporal simulations



Ecopath with Ecosim

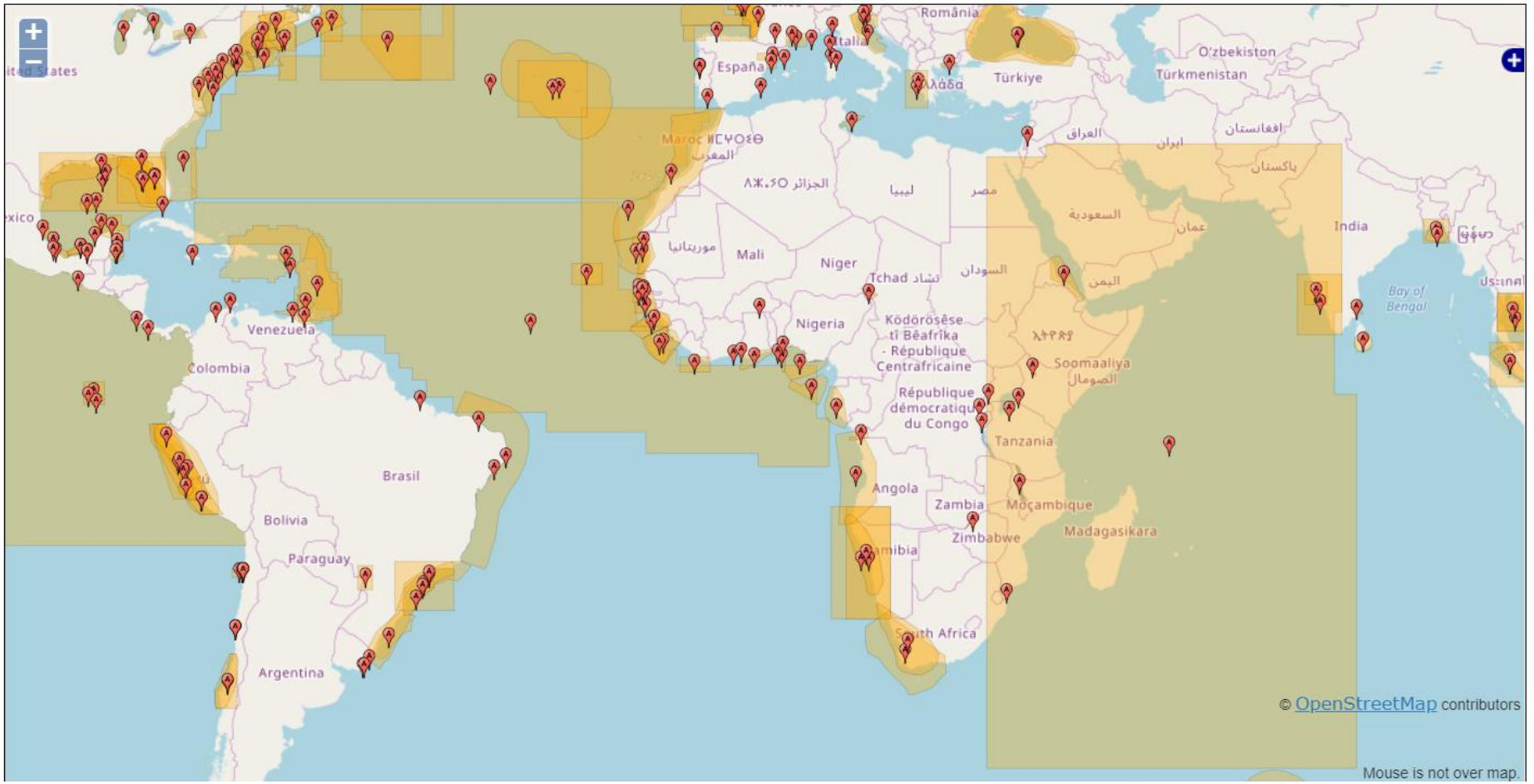


Ecopath project activities

Ecopath models around the world

>433 unique models globally

EcoBase repository



Ecopath models in the Mediterranean

ODYSSEA

>40 models in the Mediterranean

EcoBase repository

mostly in the **western** (e.g. Catalan Sea; Coll et al 2009) and **central** (e.g. Adriatic; Coll et al. 2007) part of the basin

eastern Med: *Israel* (Corrales et al. 2017; 2018), *Greece* (Piroddi et al. 2010; Tsagarakis et al. 2010; Moutopoulos et al. 2013)

Ecopath models in the Mediterranean

ODYSSEA

>40 models in the Mediterranean

EcoBase repository

Within the ODYSSEA project, Ecopath models are being built for the first time in:

Morocco, **Egypt** and **Gökova Bay**

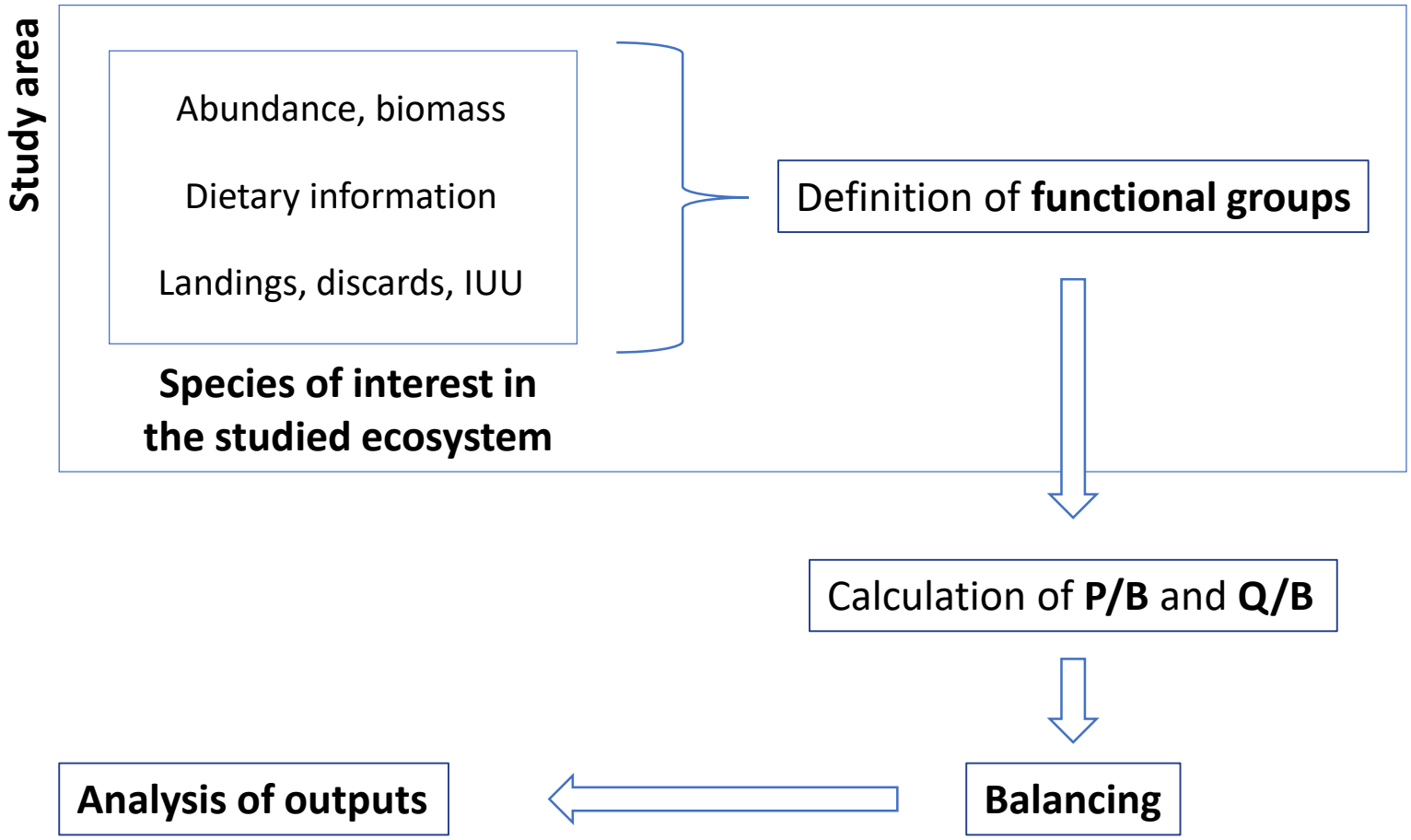
Why is it successful?

Ecopath with Ecosim

No fish is an island

- simple and understandable logic, relatively high realism
- advanced features (representation of the structure and function of the ecosystem, spatio-temporal management and environmental scenarios, evaluation of management strategies)
- friendly user interface, simple to use, user guide available
- extended user community
- evolving by developers as well as independent users (open-source code)
- ongoing workshops all over the world
- data meta-analysis

Steps in constructing an Ecopath base model (Thermaikos Gulf)



Ecopath master equations

Mass-balance model (whatever is consumed within the system cannot exceed what is produced in the system)

For every functional group of organisms:

Production = catches + predation mortality + biomass accumulation + net migration + other mortality

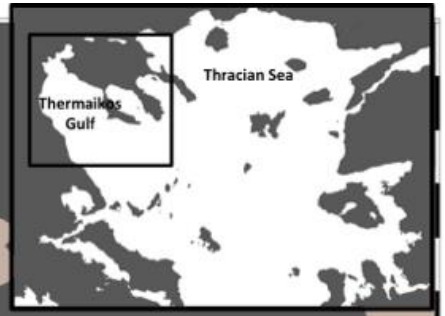
Consumption = production + respiration + unassimilated food

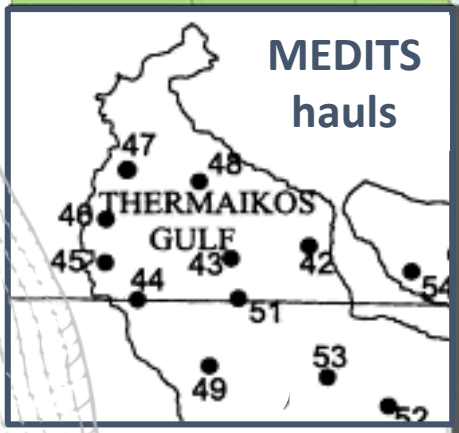
Study area - Thermaikos Gulf

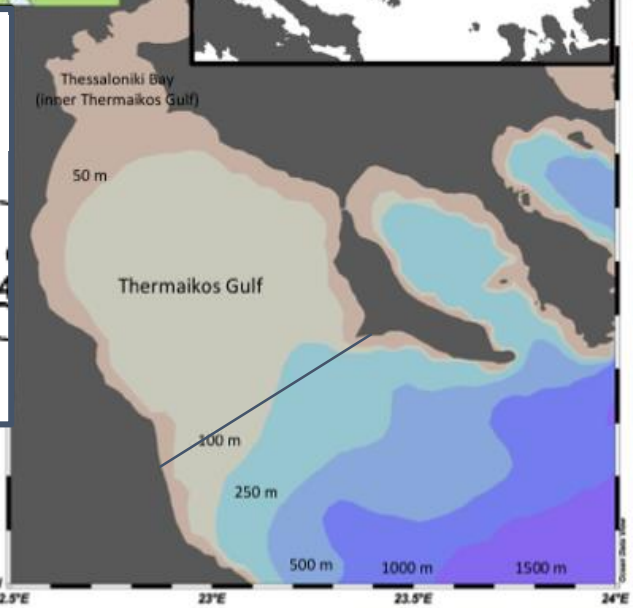
Modelled area: ~ **3200** km^2

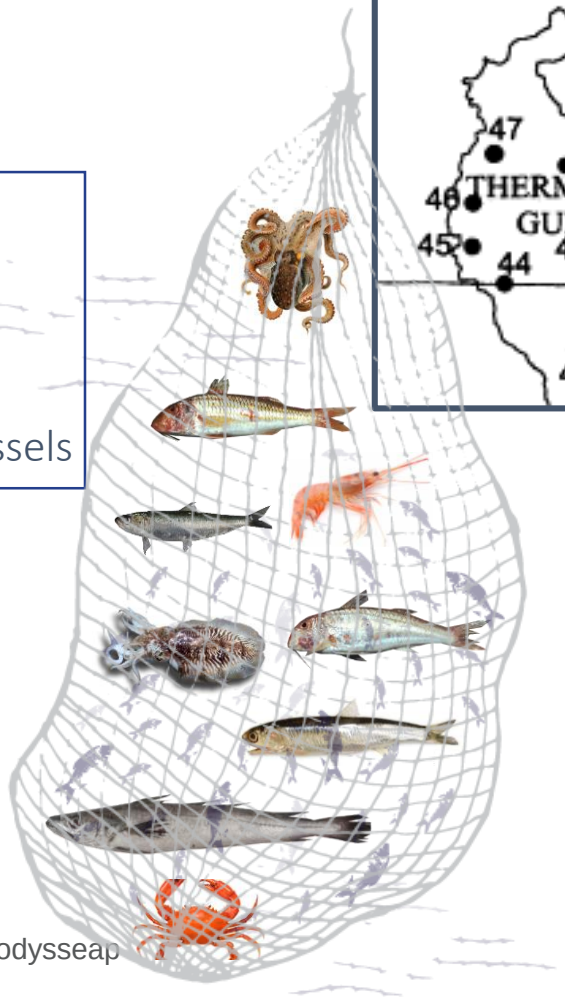
high **trawling** and **purse seining**

fishing effort









4 fishing fleets

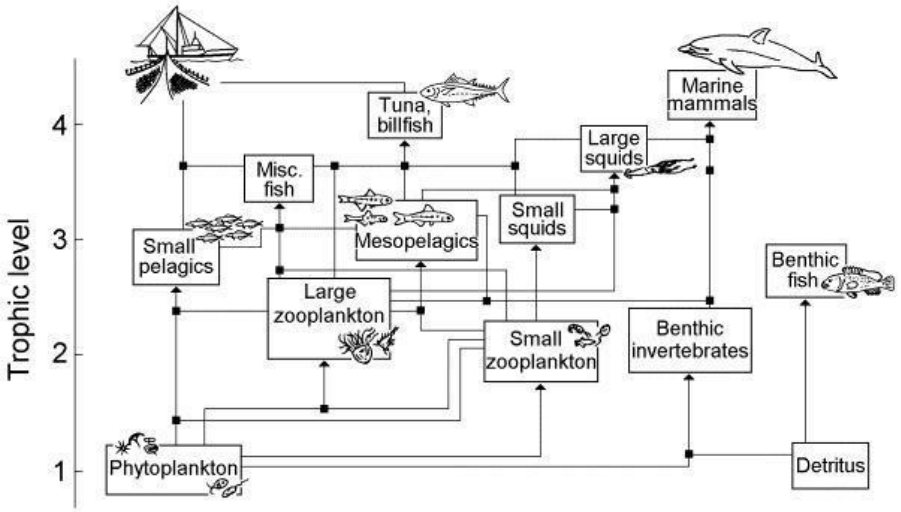
- trawlers
- purse-seiners
- beach-seiners
- small coastal vessels

Year of the model

- average of 1998-2000
- good data availability

Defining the functional groups

- the user defines the number and content of FGs
- focus on the groups we are most interested in, e.g. predators, commercial species
- multi-stanza groups can be defined (connected FGs of different life stages of the species)
- data availability
- it's better to include a group with no data (guesstimates) rather than exclude it
- ongoing workshops all over the world
- data meta-analysis



~ **108** taxa plus other invertebrates

33 functional groups (FGs)

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Low trophic level	Invertebrates	Fish	Other
Phytoplankton	Zooplankton	Red mullets	Sea turtle
Discards	Benthic small crustaceans	Anglerfish	Seabirds
Detritus	Polychaetes	Flatfishes	Dolphins
	Shrimps	Other gadiforms	
	Crabs	Hake	
	Benthic invertebrates	Demersal fishes 1	
	Octopuses & cuttlefish	Demersal fishes 2	
	Squids	Demersal fishes 3	
		Demersal fishes 4	
		Picarels and bogue	
		Sharks	
		Rays & skates	
		Anchovy	
		Sardine	
		Horse mackerels	
		Mackerels	
		Other small pelagics	
		Medium pelagics	
		Large pelagics	

Functional groups

ODYSSEA

Shrimps
Melicertus kerathurus
Parapenaeus longirostris

Red mullets
Mullus barbatus
Mullus surmuletus

Anglerfish
Lophius budegassa
Lophius piscatorius

Medium pelagics
Auxis thazard
Katsuwonus pelamis
Pomatomus saltatrix
Sarda sarda
Seriola dumerili

Large pelagics
Thunnus thynnus
Xiphias gladius

Picarels and bogue
Spicara smaris
Spicara maena
Spicara flexuosa
Boops boops

Rays and skates
Leucoraja naevus
Raja clavata
Raja radula
Torpedo marmorata
Rhinobatidae

Horse mackerels
Trachurus trachurus
Trachurus mediterraneus

Sharks
Mustelus spp.
Squalidae
Scyliorhinus canicula

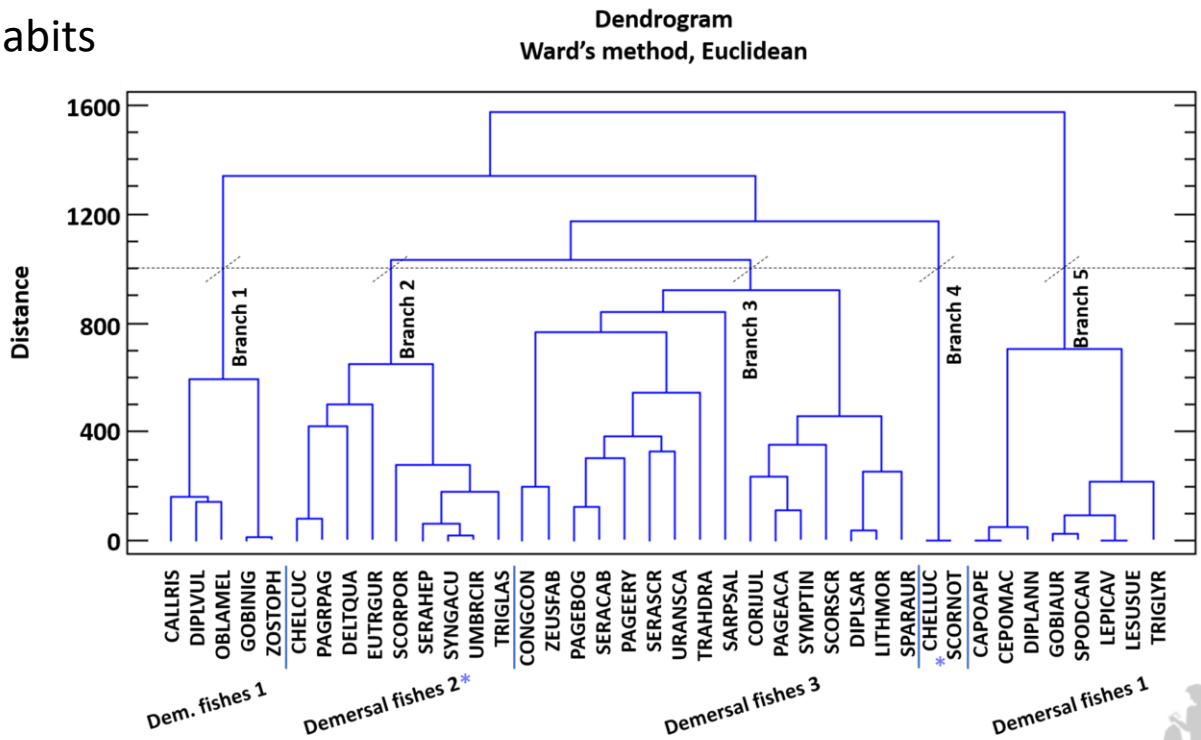
Mackerels
Scomber colias
Scomber scombrus

Other small pelagics
Mugilidae
Belone belone
Sardinella aurita

Defining the functional groups

Multi-species groups should be defined based on ecological feature rather than taxonomic

- habitat
- size (e.g. small/medium/large pelagics, small/medium/large demersal fish etc)
- diet composition, feeding habits
- multivariate analyses



Study area – Thermaikos Gulf

Biomass (t/km²)

- acoustic surveys
- trawling surveys

Diet composition

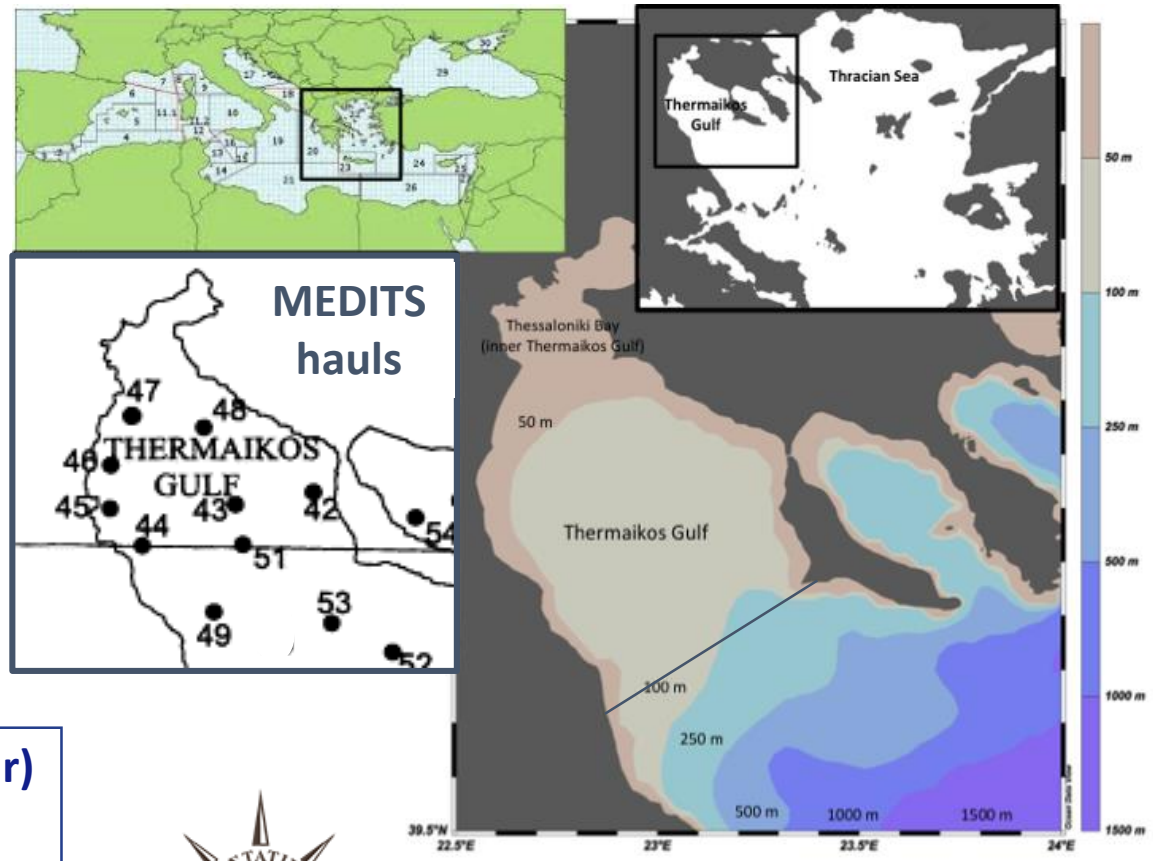
- literature reviews on feeding habits of Mediterranean fish

Stergiou & Karpouzi 2002; Karachle & Stergiou 2017; Tsagarakis et al. 2010

Landings & discards (t/km²/year)

- Hellenic Statistical Authority
- discard ratio

Tsagarakis et al. 2014 "Mediterranean fishery discards"



P/B, Q/B (year⁻¹)

- FishBase
- empirical equations
- literature

Biomass (t/km^2)

Thermaikos Gulf - Ecopath with Ecosim 6.5.14040.0

File View Ecopath Ecosim Ecospace Tools Windows Help

Ecopath Ecosim Ecospace Ecotracer C:\Users\donna\Desktop\UNIVERSI

Navigator

- Ecopath
  - Input
    - Model parameters
    - Basic input
    - Diet composition
    - Detritus fate
    - Other production
    - Fishery
    - Tools
  - Output
    - Basic estimates
    - Key indices
    - Mortality rates
    - Consumption
    - Niche overlap
    - Electivity
    - Search rates
    - Fishery
    - Particle size distribution
    - Tools
- Ecosim
- Ecospace
- Tools

Start | Basic estimates | **Basic input**

Define groups... Edit multi-stanza...

	Group name	Habitat area (fraction)	Biomass in habitat area (t/k	Production / biomass	Consumption / biomass
1	Phytoplankton	1.000	7.866	117.3	
2	Zooplankton	1.000	6.100	62.47	186.4
3	Benthic small crustaceans	1.000	1.110	7.686	57.12
4	Polychaetes	1.000	4.808	1.712	13.08
5	Shrimps	1.000	0.306	3.339	7.896
6	Crabs	1.000	0.412	2.541	5.187
7	Benthic invertebrates	1.000	8.710	1.215	3.434
8	Octopuses and cuttlefish	1.000	0.392	2.900	5.807
9	Squids	1.000	0.363	2.600	26.47
10	Red mullets	1.000	0.196	1.908	7.192
11	Anglerfish	1.000	0.203	1.100	3.777
12	Flatfishes	1.000	0.107	1.820	8.741
13	Other gadiforms	1.000	0.580	1.450	6.493
14	Hake	1.000	0.400	0.587	3.700
15	Demersal fishes 1	1.000	0.150	2.400	9.306
16	Demersal fishes 2	1.000	0.246	1.600	7.739
17	Demersal fishes 3	1.000	0.322	1.400	4.592
18	Demersal fishes 4	1.000	0.237	1.900	11.10
19	Picarels and bogue	1.000	0.663	1.500	8.339
20	Sharks	1.000	0.0710	0.698	4.080
21	Rays and skates	1.000	0.141	1.000	3.394
22	Anchovy	1.000	2.250	1.753	6.693
23	Sardine	1.000	1.950	1.778	11.67
24	Horse mackerels	1.000	0.732	1.000	7.315
25	Mackerels	1.000	0.294	1.022	6.448
26	Other small pelagics	1.000	1.170	1.400	6.365
27	Medium pelagics	1.000	0.250	0.425	3.706
28	Large pelagics	1.000	0.0490	0.400	2.529
29	Loggerhead turtle	1.000	0.0200	0.160	2.680
30	Seabirds	1.000	0.00100	4.780	111.6
31	Dolphins	1.000	0.0200	0.0800	13.81
32	Discards	1.000			

Status | Remarks

1: Phytoplankton (Detritus import)

Catch per species /
Swept area (gear characteristics: wing opening * duration of the haul)

For each species **average biomass** from 3 years **(1998-2000)**

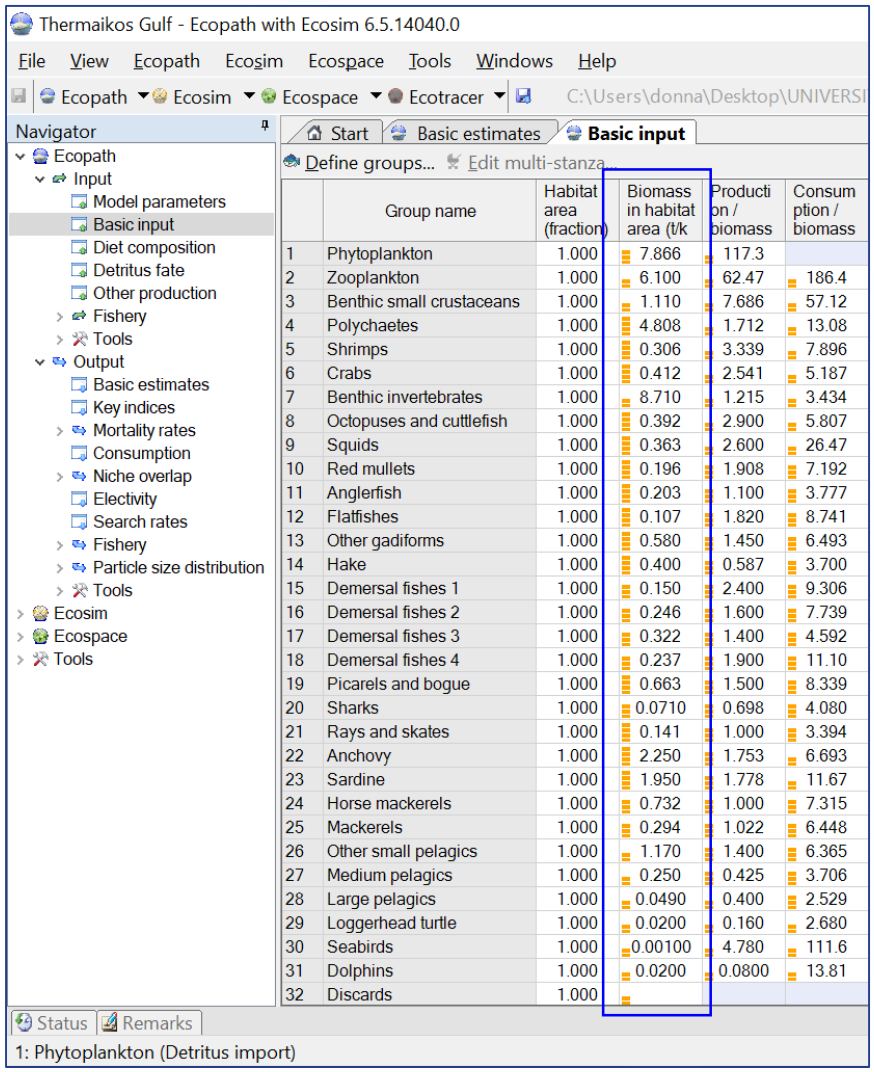
For the **FG**, **sum of the biomasses** of all species

For the final biomass value of the FG application of **catchability factor**

(Sánchez & Olaso 2014)

- 10% **demersal** species
- 15-20% **benthic** species

Biomass (t/km^2)



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21	Rays and skates	1.000	0.141	1.000	3.394
22	Anchovy	1.000	2.250	1.753	6.693
23	Sardine	1.000	1.950	1.778	11.67
24	Horse mackerels	1.000	0.732	1.000	7.315
25	Mackerels	1.000	0.294	1.022	6.448
26	Other small pelagics	1.000	1.170	1.400	6.365
27	Medium pelagics	1.000	0.250	0.425	3.706
28	Large pelagics	1.000	0.0490	0.400	2.529
29	Loggerhead turtle	1.000	0.0200	0.160	2.680
30	Seabirds	1.000	0.00100	4.780	111.6
31	Dolphins	1.000	0.0200	0.0800	13.81
32	Discards	1.000			

Catch per species /
Swept area (gear characteristics: wing opening * duration of the haul)

For each species **average biomass** from 3 years **(1998-2000)**

For the **FG**, **sum of the biomasses** of all species

For the final biomass value of the FG application of **catchability factor**

(Sánchez & Olaso 2014)

- 10% **demersal** species
- 15-20% **benthic** species

Biomass (t/km^2)

Method	+	-
Stock assessment models	• take many parameters into account • reliability	• assessments only for specific geographical areas probably different from our study area
Data onboard commercial boats (mainly trawlers)	• data frequency • good seasonal coverage	• not representative picture • specific fishing grounds • gear selectivity • uncertainty regarding gear catchability
bottom trawl surveys	• fixed gear • low selectivity • Targeted, stratified sampling • time-series	• lacks seasonality • uncertainty regarding gear catchability
acoustic surveys	• reliability • time-series	• only for a few pelagic species • lacks seasonality
Estimation from landings	• availability of fisheries data	• reliability of fisheries data? • assumes constant CPUE

Diet composition

Weighted averages for FGs
% weight

ODYSSEA

Thermaikos Gulf - Ecopath with Ecosim 6.5.14040.0

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Navigator

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Start | Basic estimates | Basic input | **Diet composition**

Sum diets to one — Set: Apply

	Prey \ predator	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	Phytoplankton	0.600	0.0200													0.0200	0.00900						0.131
2	Zooplankton	0.200	0.0970		0.103	0.00500		0.0900	0.175	0.140	0.0180	0.161	0.300	0.137	0.107	0.150	0.152	0.773	0.900	0.142	0.0350	1.000	0.849
3	Benthic small crustaceans		0.0300		0.230	0.0600		0.140	0.128	0.184	0.0300	0.121	0.305	0.0630	0.131	0.200	0.0780	0.100	0.0500		0.00600		0.0200
4	Polychaetes		0.0200	0.0300	0.200	0.410	0.0200	0.0600	0.0750	0.132	0.0600	0.0220			0.661	0.120	0.0950	0.0190	0.0450	0.0500	0.100		
5	Shrimps				0.0300	0.0200		0.01000	0.00500	0.0400	0.0200	0.0120	0.01000	0.0730	0.0180	0.0500	0.0840	0.0450	0.00500	0.01000	0.100		
6	Crabs				0.0260	0.0250		0.0500	0.0130	0.0800		0.0120	0.0320			0.0900	0.0380	0.0360		0.100	0.100		
7	Benthic invertebrates		0.0300	0.0600	0.280	0.310	0.0300	0.530	0.0200	0.0240	0.100	0.0400	0.00800	0.0200	0.0830	0.0200	0.145	0.0270		0.200	0.0350		
8	Octopuses and cuttlefish				0.0200			0.0500	0.0350		0.100	0.0400	0.00500	0.0400		0.0150	0.0480			0.0800	0.0120		
9	Squids								0.0450					0.115						0.0680	0.00800		
10	Red mullets								0.00900		0.0200		0.0310			0.0400					0.0550		
11	Anglerfish										0.0200									0.0200			
12	Flatfishes										0.0200	0.01000		0.0120						0.0540	0.00800		
13	Other gadiforms								0.0220		0.100	0.120	0.00600	0.0300		0.0800	0.0220			0.0480	0.0400		
14	Hake								0.00200		0.0360			0.0400						0.0460	0.0260		
15	Demersal fishes 1					0.00300			0.00100			0.0800	0.0300	0.0200		0.0150				0.0430	0.0800		
16	Demersal fishes 2							0.0200			0.0500	0.0400		0.0200			0.0500				0.0300		
17	Demersal fishes 3					0.00200		0.0400				0.120	0.01000	0.0400							0.0300		
18	Demersal fishes 4					0.00200			0.00100		0.0360	0.0700	0.0150	0.0400		0.0300	0.01000			0.0280	0.0600		
19	Picarels and bogue							0.01000	0.0230		0.0800		0.0320	0.0300		0.0750	0.0550				0.01000		
20	Sharks								0.00400											0.000100			
21	Rays and skates										0.0500	0.00800								0.0150			
22	Anchovy								0.156		0.0300	0.0400	0.184	0.160			0.114			0.0180	0.195		
23	Sardine								0.163		0.0500	0.00800	0.01000	0.110		0.0300	0.0500			0.0200	0.0500		
24	Horse mackerels								0.0300		0.130	0.0690								0.0480	0.01000		
25	Mackerels								0.00300		0.0500	0.0200				0.0300	0.0500						
26	Other small pelagics								0.0900					0.0500		0.0300							
27	Medium pelagics																						
28	Large pelagics																						
29	Loggerhead turtle																						
30	Seabirds																						
31	Dolphins																						
32	Discards		0.00300		0.0150	0.01000							0.0130							0.01000	0.01000		

Status | Remarks

1: Phytoplankton (Detritus import) — Thermaikos Gulf

Stergiou & Karpouzi 2002 "Feeding habits and trophic levels of Mediterranean fish"

Karachle & Stergiou 2017 "An update on the feeding habits of fish in the Mediterranean Sea (2002-2015)"

Diet composition

- high **plasticity** (important when balancing the model, usually it needs modifying)
- set a functional group to feed on **imported** material outside of the studied system if needed (e.g. migratory FGs, seabirds, preys not included in the model)
- a **weighted average** is needed for multi-species groups
- be careful with **cannibalism** (avoid it being more than 0.1. you don't want the consumption of a group to be higher than its production)

Landings / discards (t/km^2/year)

Thermaikos Gulf - Ecopath with Ecosim 6.5.14040.0

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- Ecosim
- Ecospace
- Tools

Start | Basic estimates | Basic input | Diet composition | Definition of f

	Group name	Trawlers (t/km²/year)	Purse seiners (t/km	Beach seiners (t/km²	Small scale (t/km²/year)	Total
1	Phytoplankton					0.000
2	Zooplankton					0.000
3	Benthic small crustaceans					0.000
4	Polychaetes					0.000
5	Shrimps	0.0320			0.0590	0.091
6	Crabs	0.00300			0.00600	0.009
7	Benthic invertebrates					0.000
8	Octopuses and cuttlefish	0.00824	0.000039	0.000105	0.191	0.200
9	Squids	0.01000		0.00100	0.00400	0.015
10	Red mullets	0.00800			0.0310	0.039
11	Anglerfish	0.0140			0.00500	0.019
12	Flatfishes	0.00200	0.00200		0.0920	0.096
13	Other gadiforms	0.0340			0.0170	0.051
14	Hake	0.0170			0.0540	0.071
15	Demersal fishes 1		0.00200		0.00800	0.010
16	Demersal fishes 2	0.0190	0.00500		0.0770	0.101
17	Demersal fishes 3	0.00200	0.00400	0.00100	0.0740	0.081
18	Demersal fishes 4	0.00100	0.00300	0.00100	0.0920	0.097
19	Picarels and bogue		0.0220	0.00200	0.0170	0.041
20	Sharks	0.00150	0.000500		0.00350	0.005
21	Rays and skates	0.00700			0.0380	0.045
22	Anchovy	0.00100	0.392	0.00300	0.199	0.595
23	Sardine	0.00100	0.341	0.0170	0.489	0.848
24	Horse mackerels	0.00600	0.0530	0.00200	0.105	0.166
25	Mackerels		0.0340	0.00100	0.0190	0.054
26	Other small pelagics		0.0860	0.00200	0.320	0.408
27	Medium pelagics		0.00200		0.0150	0.017
28	Large pelagics	0.000035	0.00100	0.000082	0.00883	0.010
29	Loggerhead turtle					0.000
30	Seabirds					0.000
31	Dolphins					0.000
32	Discards					0.000
33	Detritus					0.000

Status | Remarks

(derived value selected)

th Ecosim 6.5.14040.0

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Start | Basic estimates | Basic input | Diet composition | Definition of f

	Group name	Trawlers (t/km²)	Purse seiners (t/km	Beach seiners (t/km²	Small scale (t/km²)	Total
1	Phytoplankton					0.000
2	Zooplankton					0.000
3	Benthic small crustaceans					0.000
4	Polychaetes					0.000
5	Shrimps	0.0140			0.00600	0.020
6	Crabs	0.00100			0.00100	0.002
7	Benthic invertebrates	0.00480			0.00350	0.008
8	Octopuses and cuttlefish	0.00900			0.0450	0.054
9	Squids	0.00400				0.004
10	Red mullets	0.00400			0.00300	0.007
11	Anglerfish	0.00600			0.00100	0.007
12	Flatfishes				0.00900	0.009
13	Other gadiforms	0.00800			0.00100	0.009
14	Hake	0.00700			0.00500	0.012
15	Demersal fishes 1				0.00600	0.006
16	Demersal fishes 2	0.00400			0.00800	0.012
17	Demersal fishes 3	0.00100			0.00800	0.009
18	Demersal fishes 4				0.01000	0.010
19	Picarels and bogue		0.00100		0.00200	0.003
20	Sharks	0.00100	0.00100		0.00300	0.005
21	Rays and skates	0.00400			0.00200	0.006
22	Anchovy		0.0180		0.0200	0.038
23	Sardine		0.0160	0.00200	0.0490	0.067
24	Horse mackerels	0.00400	0.00300		0.01000	0.017
25	Mackerels		0.00200		0.00200	0.004
26	Other small pelagics		0.00400		0.0310	0.035
27	Medium pelagics				0.00100	0.001
28	Large pelagics				0.00700	0.007
29	Loggerhead turtle				0.00250	0.002
30	Seabirds					0.000
31	Dolphins				0.000340	0.000
32	Discards					0.000
33	Detritus					0.000

P/B – production / biomass (year^{-1})

Turnover rate (high: phytoplankton; low: fish and marine mammals)

P/B = Z = F + M (total mortality rate – fishing plus natural)

F from stock assessment: **F = C/B**

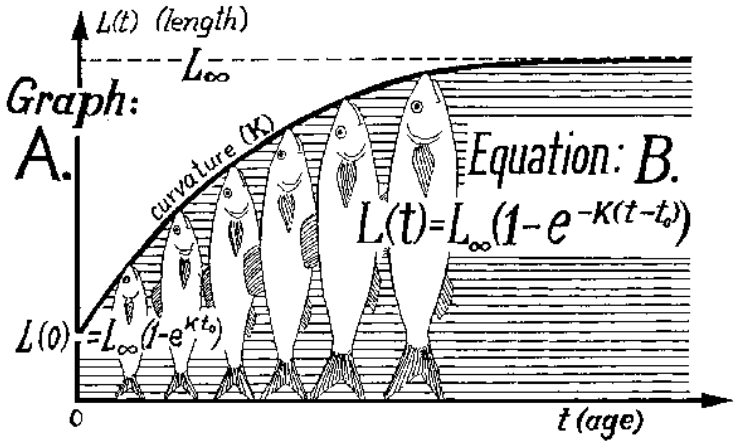
M from empirical equation (Pauly, 1980)

$$M = K^{0.65} \cdot L_{\infty}^{-0.279} \cdot T^{0.463}$$

K is the growth rate (/year)

L_{∞} is the asymptotic length (total length, cm)

Tc is the mean habitat (water) temperature, in °C



weighted averages for each FG

Non-fish FGs: values from other models with adjusted T, literature

Q/B – food consumption (year^{-1})

Q/B from **FishBase Life-history tool**

fishbase.se/popdyn/KeyfactsSummary_1.php?ID=1327&genusname=Mullus&speciesname=surmuletus&fc=332&vstockcode=1345

Values shown below are defaults. Please double-check, replace with better values as appropriate, and 'Recalculate'.

About this page...

Life History Data on *Mullus surmuletus*
Surmullet

Family:	Mullidae Goatfishes	
Trophic level:	3.5 +/- s.e. 0.29 Estimated from diet data. Diet	
Food consumption (Q/B):	6.6 times the body weight per year	Enter Winf, temperature, aspect ratio (A), and food type to estimate Q/B Winf = 450 g Temp. = 17.5 °C A = 1.9 Detrivore Herbivore Omnivore Carnivore
Estimate growth		

Recalculate

Note: The estimates are derived from default values taken from FishBase and will thus not be appropriate for every population. You can change these values and recalculate the life history parameters.

Back to Search Species summary

*Non-fish FGs: values from other models with adjusted T, literature

Pedigree

ODYSSEA

The **pedigree** of an Ecopath input categorizes the origin a given input (the **type of data** on which it is based), and specifies the likely **uncertainty** associated with the input, i.e. the **reliability** of the data.

Biomass

- Estimated by Ecopath
- From other model
- Guesstimate
- Approximate or indirect method
- Sampling/locally, low precision
- Sampling/locally, high precision

P/B, Q/B

- Estimated by Ecopath
- Guesstimate
- From other model
- Empirical relationship
- Similar species, similar system, low precision
- Similar species, same system, low precision
- Same species, similar system, high precision
- Same species, same system, high precision

Pedigree

ODYSSEA

The **pedigree** of an Ecopath input categorizes the origin a given input (the **type of data** on which it is based), and specifies the likely **uncertainty** associated with the input, i.e. the **reliability** of the data.

Diet composition

- General knowledge of related group/species
- From other model
- General knowledge for same group/species
- Qualitative diet composition study
- Quantitative but limited diet composition study
- Quantitative detailed diet composition study

Catch

- Guesstimate
- From other model
- FAO statistics
- National statistics
- Local study, low precision/incomplete
- Local study, high precision/complete

Pedigree

ODYSSEA

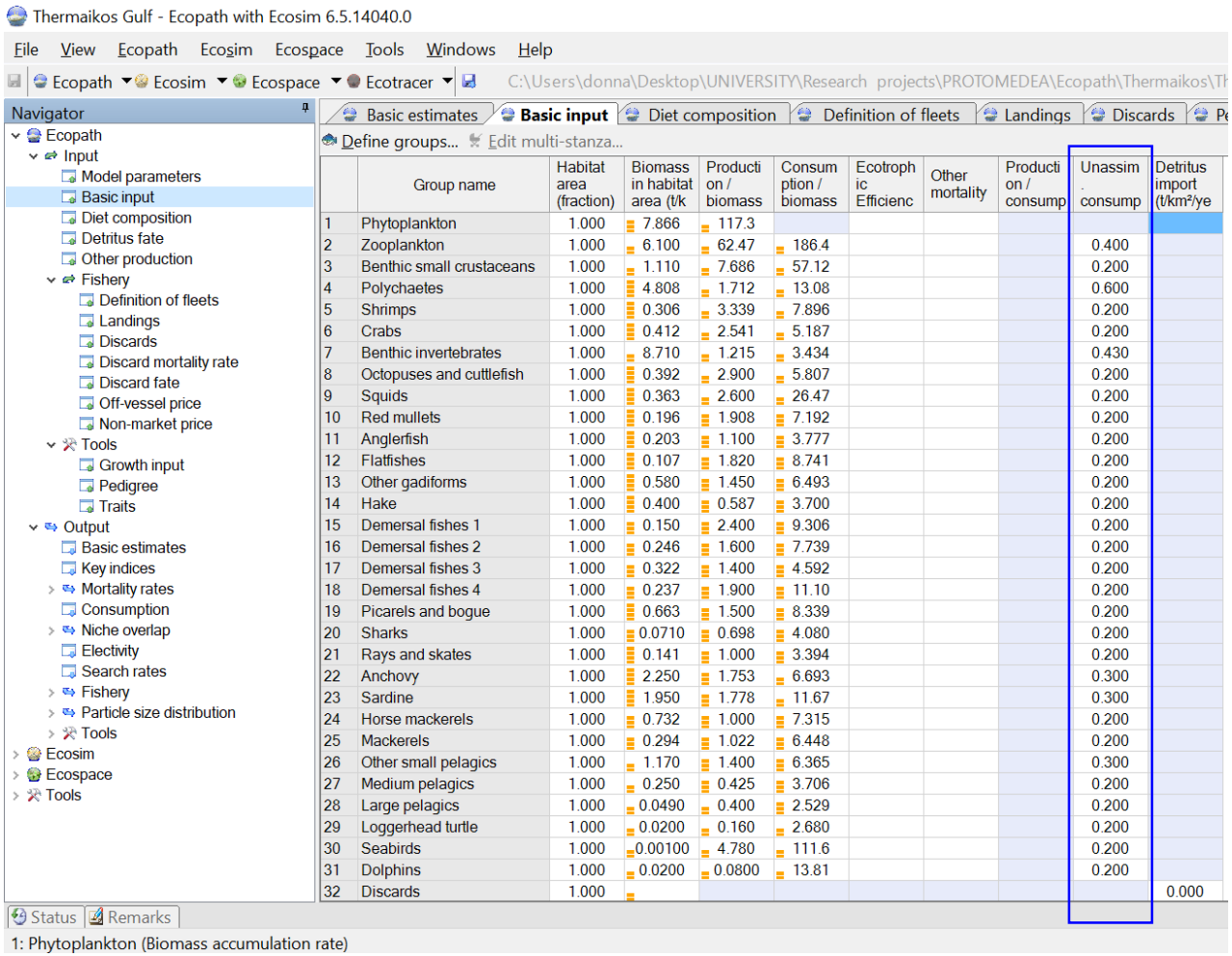
Diet composition | Definition of fleets | Landings | Discards | **Pedigree**

Set: Apply

Assignment

	Group name	Biomass in habitat area	Production / biomass	Consumption / biomass	Diet	Catch
1	Phytoplankton					
2	Zooplankton					
3	Benthic small crustaceans					
4	Polychaetes					
5	Shrimps					
6	Crabs					
7	Benthic invertebrates					
8	Octopuses and cuttlefish					
9	Squids					
10	Red mullets					
11	Anglerfish					
12	Flatfishes					
13	Other gadiforms					
14	Hake					
15	Demersal fishes 1					
16	Demersal fishes 2					
17	Demersal fishes 3					
18	Demersal fishes 4					
19	Picarels and bogue					
20	Sharks					
21	Rays and skates					
22	Anchovy					
23	Sardine					
24	Horse mackerels					
25	Mackerels					
26	Other small pelagics					
27	Medium pelagics					
28	Large pelagics					
29	Loggerhead turtle					
30	Seabirds					
31	Dolphins					
32	Discards					

Unassimilated consumption

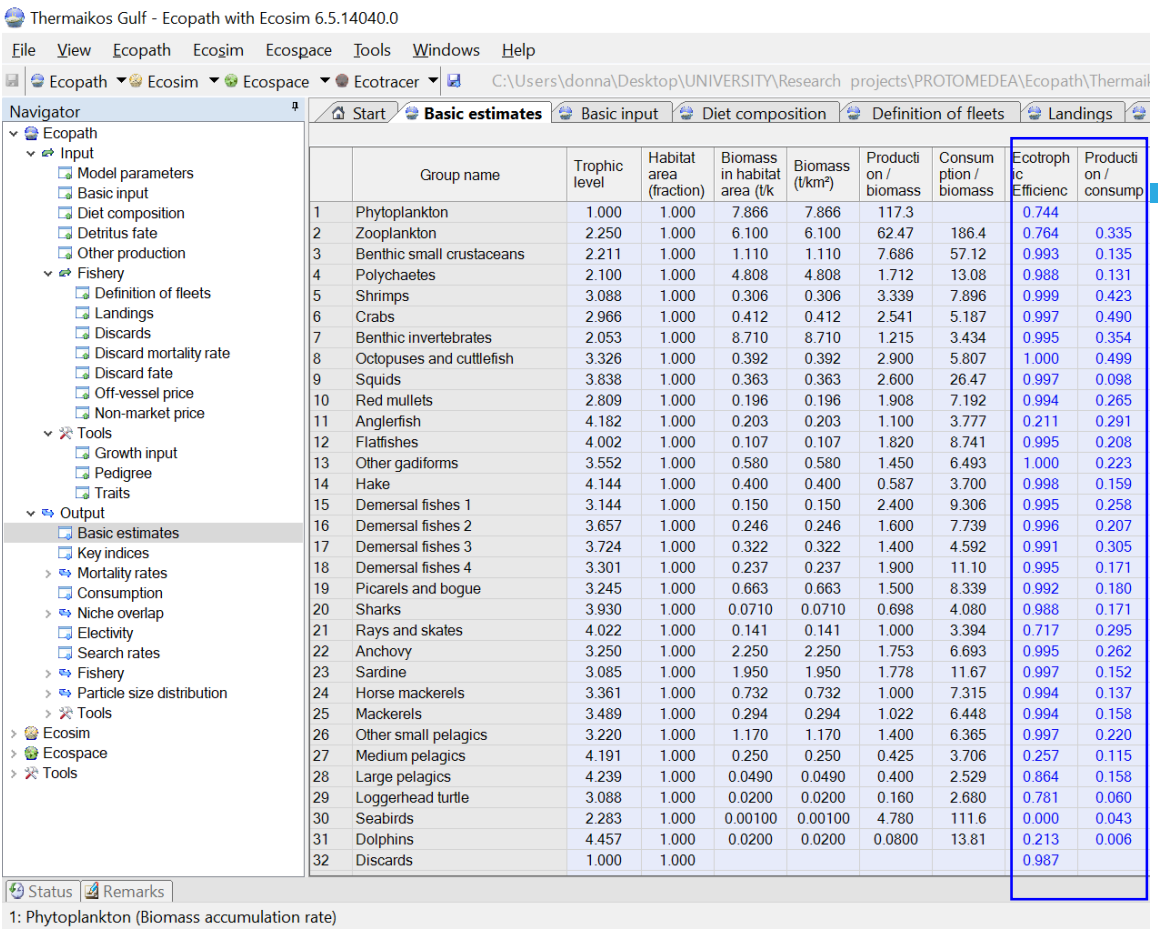


	Group name	Habitat area (fraction)	Biomass in habitat area (t/k	Production / biomass	Consumption / biomass	Ecotrophic Efficienc	Other mortality	Production / consump	Unassim. consump	Detritus import (t/km²/ye
1	Phytoplankton	1.000	7.866	117.3						
2	Zooplankton	1.000	6.100	62.47	186.4				0.400	
3	Benthic small crustaceans	1.000	1.110	7.686	57.12				0.200	
4	Polychaetes	1.000	4.808	1.712	13.08				0.600	
5	Shrimps	1.000	0.306	3.339	7.896				0.200	
6	Crabs	1.000	0.412	2.541	5.187				0.200	
7	Benthic invertebrates	1.000	8.710	1.215	3.434				0.430	
8	Octopuses and cuttlefish	1.000	0.392	2.900	5.807				0.200	
9	Squids	1.000	0.363	2.600	26.47				0.200	
10	Red mullets	1.000	0.196	1.908	7.192				0.200	
11	Anglerfish	1.000	0.203	1.100	3.777				0.200	
12	Flatfishes	1.000	0.107	1.820	8.741				0.200	
13	Other gadiforms	1.000	0.580	1.450	6.493				0.200	
14	Hake	1.000	0.400	0.587	3.700				0.200	
15	Demersal fishes 1	1.000	0.150	2.400	9.306				0.200	
16	Demersal fishes 2	1.000	0.246	1.600	7.739				0.200	
17	Demersal fishes 3	1.000	0.322	1.400	4.592				0.200	
18	Demersal fishes 4	1.000	0.237	1.900	11.10				0.200	
19	Picarels and bogue	1.000	0.663	1.500	8.339				0.200	
20	Sharks	1.000	0.0710	0.698	4.080				0.200	
21	Rays and skates	1.000	0.141	1.000	3.394				0.200	
22	Anchovy	1.000	2.250	1.753	6.693				0.300	
23	Sardine	1.000	1.950	1.778	11.67				0.300	
24	Horse mackerels	1.000	0.732	1.000	7.315				0.200	
25	Mackerels	1.000	0.294	1.022	6.448				0.200	
26	Other small pelagics	1.000	1.170	1.400	6.365				0.300	
27	Medium pelagics	1.000	0.250	0.425	3.706				0.200	
28	Large pelagics	1.000	0.0490	0.400	2.529				0.200	
29	Loggerhead turtle	1.000	0.0200	0.160	2.680				0.200	
30	Seabirds	1.000	0.00100	4.780	111.6				0.200	
31	Dolphins	1.000	0.0200	0.0800	13.81				0.200	
32	Discards	1.000								0.000

Default value of **0.2** for **carnivorous fish groups** if other estimates are not available (Winberg 1956)

For **herbivores**, the proportion not assimilated may be considerably higher, e.g. up to **0.4** in **zooplankton**

The **fraction of the food** that is not assimilated (it is **not physiologically useful**), consists of urine and feces and is directed to **detritus**.



	Group name	Trophic level	Habitat area (fraction)	Biomass in habitat area (t/k	Biomass (t/km²)	Production / biomass	Consumption / biomass	Ecotrophic Efficienc	Production / consump
1	Phytoplankton	1.000	1.000	7.866	7.866	117.3		0.744	
2	Zooplankton	2.250	1.000	6.100	6.100	62.47	186.4	0.764	0.335
3	Benthic small crustaceans	2.211	1.000	1.110	1.110	7.686	57.12	0.993	0.135
4	Polychaetes	2.100	1.000	4.808	4.808	1.712	13.08	0.988	0.131
5	Shrimps	3.088	1.000	0.306	0.306	3.339	7.896	0.999	0.423
6	Crabs	2.966	1.000	0.412	0.412	2.541	5.187	0.997	0.490
7	Benthic invertebrates	2.053	1.000	8.710	8.710	1.215	3.434	0.995	0.354
8	Octopuses and cuttlefish	3.326	1.000	0.392	0.392	2.900	5.807	1.000	0.499
9	Squids	3.838	1.000	0.363	0.363	2.600	26.47	0.997	0.098
10	Red mullets	2.809	1.000	0.196	0.196	1.908	7.192	0.994	0.265
11	Anglerfish	4.182	1.000	0.203	0.203	1.100	3.777	0.211	0.291
12	Flatfishes	4.002	1.000	0.107	0.107	1.820	8.741	0.995	0.208
13	Other gadiforms	3.552	1.000	0.580	0.580	1.450	6.493	1.000	0.223
14	Hake	4.144	1.000	0.400	0.400	0.587	3.700	0.998	0.159
15	Demersal fishes 1	3.144	1.000	0.150	0.150	2.400	9.306	0.995	0.258
16	Demersal fishes 2	3.657	1.000	0.246	0.246	1.600	7.739	0.996	0.207
17	Demersal fishes 3	3.724	1.000	0.322	0.322	1.400	4.592	0.991	0.305
18	Demersal fishes 4	3.301	1.000	0.237	0.237	1.900	11.10	0.995	0.171
19	Picarels and bogue	3.245	1.000	0.663	0.663	1.500	8.339	0.992	0.180
20	Sharks	3.930	1.000	0.0710	0.0710	0.698	4.080	0.988	0.171
21	Rays and skates	4.022	1.000	0.141	0.141	1.000	3.394	0.717	0.295
22	Anchovy	3.250	1.000	2.250	2.250	1.753	6.693	0.995	0.262
23	Sardine	3.085	1.000	1.950	1.950	1.778	11.67	0.997	0.152
24	Horse mackerels	3.361	1.000	0.732	0.732	1.000	7.315	0.994	0.137
25	Mackerels	3.489	1.000	0.294	0.294	1.022	6.448	0.994	0.158
26	Other small pelagics	3.220	1.000	1.170	1.170	1.400	6.365	0.997	0.220
27	Medium pelagics	4.191	1.000	0.250	0.250	0.425	3.706	0.257	0.115
28	Large pelagics	4.239	1.000	0.0490	0.0490	0.400	2.529	0.864	0.158
29	Loggerhead turtle	3.088	1.000	0.0200	0.0200	0.160	2.680	0.781	0.060
30	Seabirds	2.283	1.000	0.00100	0.00100	4.780	111.6	0.000	0.043
31	Dolphins	4.457	1.000	0.0200	0.0200	0.0800	13.81	0.213	0.006
32	Discards	1.000	1.000					0.987	

ECOPATH outputs

ODYSSEA

P/Q typically varies between **0.1 and 0.30**

Consumption of most groups is about 3-10 times higher than their production

May be lower for top predators and higher for very small organisms

It “travels well”

EE is the proportion of production that is used in the system (predation or fishing)

EE **close to 1** usually for preys and commercial species, except for

Phytoplankton in bloom (0.5)

Kelp and macro-algae (0.1)

Unexploited predators (~0)

1-EE is “other mortality”

Not mass-balanced model

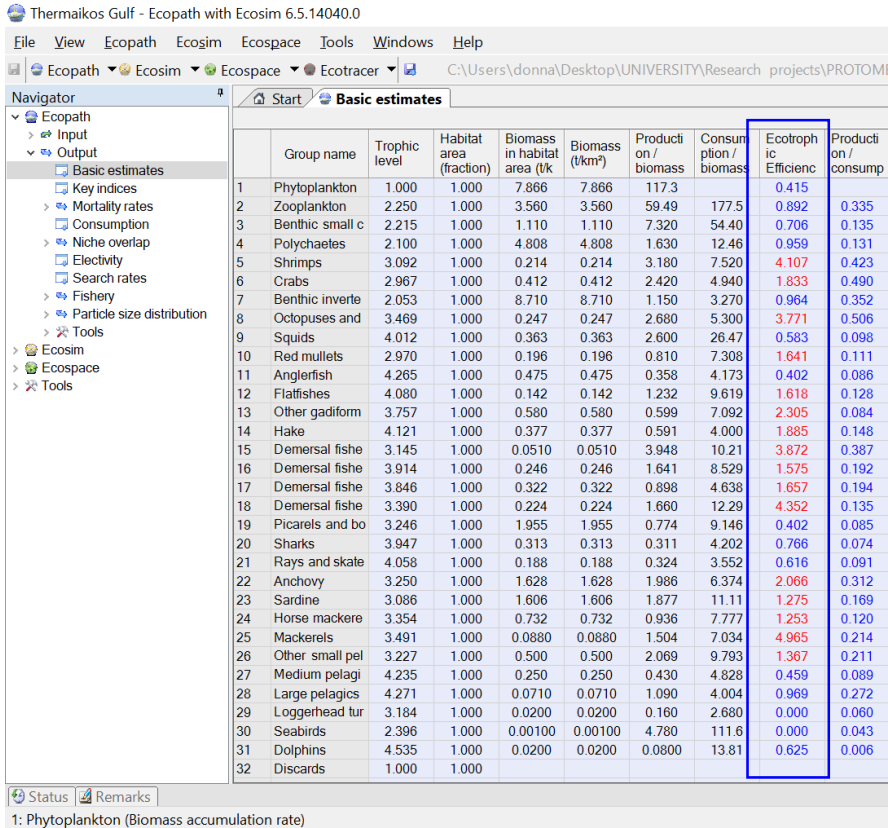
***EE* < 1.0:** The EE can never > 1

It is not possible for more biomass to be passed on to the next trophic level than was originally produced

- Maybe a FG has **too low biomass**
- Maybe the **conversion factors** used are wrong
- Maybe **too much predation** is exerted on a FG
- Maybe a FG is **fished too much**

Look for **big problems initially**, evaluate which parameters are **most uncertain**, change those

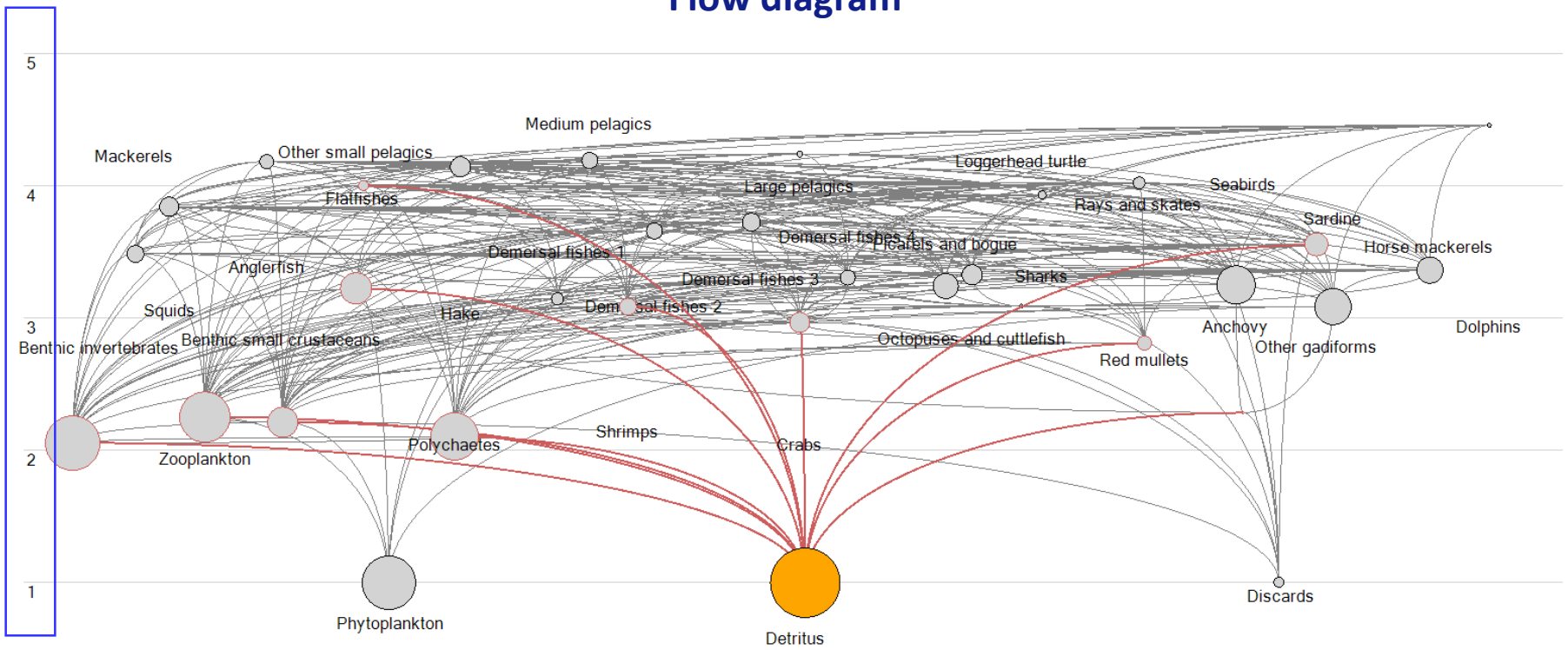
Modify the data that has **less quality** (use pedigree)



	Group name	Trophic level	Habitat area (fraction)	Biomass in habitat area (t/k	Biomass (t/km²)	Production / biomass	Consumption / biomass	Ecotrophic Efficienc	Production / consump
1	Phytoplankton	1.000	1.000	7.866	7.866	117.3		0.415	
2	Zooplankton	2.250	1.000	3.560	3.560	59.49	177.5	0.892	0.335
3	Benthic small c	2.215	1.000	1.110	1.110	7.320	54.40	0.706	0.135
4	Polychaetes	2.100	1.000	4.808	4.808	1.630	12.46	0.959	0.131
5	Shrimps	3.092	1.000	0.214	0.214	3.180	7.520	4.107	0.423
6	Crabs	2.967	1.000	0.412	0.412	2.420	4.940	1.833	0.490
7	Benthic inverte	2.053	1.000	8.710	8.710	1.150	3.270	0.964	0.352
8	Octopuses and	3.469	1.000	0.247	0.247	2.680	5.300	3.771	0.506
9	Squids	4.012	1.000	0.363	0.363	2.600	26.47	0.583	0.098
10	Red mullets	2.970	1.000	0.196	0.196	0.810	7.308	1.641	0.111
11	Anglerfish	4.265	1.000	0.475	0.475	0.358	4.173	0.402	0.086
12	Flatfishes	4.080	1.000	0.142	0.142	1.232	9.619	1.618	0.128
13	Other gadiform	3.757	1.000	0.580	0.580	0.599	7.092	2.305	0.084
14	Hake	4.121	1.000	0.377	0.377	0.591	4.000	1.885	0.148
15	Demersal fishe	3.145	1.000	0.0510	0.0510	3.948	10.21	3.872	0.387
16	Demersal fishe	3.914	1.000	0.246	0.246	1.641	8.529	1.575	0.192
17	Demersal fishe	3.846	1.000	0.322	0.322	0.898	4.638	1.657	0.194
18	Demersal fishe	3.390	1.000	0.224	0.224	1.660	12.29	4.352	0.135
19	Picarels and bo	3.246	1.000	1.955	1.955	0.774	9.146	0.402	0.085
20	Sharks	3.947	1.000	0.313	0.313	0.311	4.202	0.766	0.074
21	Rays and skate	4.058	1.000	0.188	0.188	0.324	3.552	0.616	0.091
22	Anchovy	3.250	1.000	1.628	1.628	1.986	6.374	2.066	0.312
23	Sardine	3.086	1.000	1.606	1.606	1.877	11.11	1.275	0.169
24	Horse mackere	3.354	1.000	0.732	0.732	0.936	7.777	1.253	0.120
25	Mackerels	3.491	1.000	0.0880	0.0880	1.504	7.034	4.965	0.214
26	Other small pel	3.227	1.000	0.500	0.500	2.069	9.793	1.367	0.211
27	Medium pelagi	4.235	1.000	0.250	0.250	0.430	4.828	0.459	0.089
28	Large pelagics	4.271	1.000	0.0710	0.0710	1.090	4.004	0.969	0.272
29	Loggerhead tur	3.184	1.000	0.0200	0.0200	0.160	2.680	0.000	0.060
30	Seabirds	2.396	1.000	0.00100	0.00100	4.780	111.6	0.000	0.043
31	Dolphins	4.535	1.000	0.0200	0.0200	0.0800	13.81	0.625	0.006
32	Discards	1.000	1.000						

ECOPATH outputs

Flow diagram



The **main trophic flows** among the functional groups are illustrated in the output flow diagram where all groups are organized based on their **TLs** and their **habitat** (pelagic or demersal).

ECOPATH outputs

ODYSSEA

Summary statistics and indicators

Parameter	Thermaikos	Units
Sum of all consumption	1386	t km^{-2} yr^{-1}
Sum of all exports	514	t km^{-2} yr^{-1}
Sum of all respiratory flows	417	t km^{-2} yr^{-1}
Sum of all flows into detritus	868	t km^{-2} yr^{-1}
Total system throughput	3184	t km^{-2} yr^{-1}
Sum of all production	1350	t km^{-2} yr^{-1}
Mean trophic level of the catch	3.314	
Calculated total net primary production	923	t km^{-2} yr^{-1}
Total primary production / total respiration	2.212	
Net system production	506	t km^{-2} yr^{-1}
Total primary production / total biomass	23	
Total biomass / total throughput	0.013	
Total biomass (excluding detritus)	40	t km^{-2}
System Omnivory Index	0.2	
Ecopath pedigree index	0.534	

ECOPATH outputs

ODYSSEA

Statistics

	Parameter	Thermaikos	Units
+	Sum of all consumption	**1386**	**t km^{-2} yr^{-1}**
+	Sum of all exports	**514**	**t km^{-2} yr^{-1}**
+	Sum of all respiratory flows	**417**	**t km^{-2} yr^{-1}**
+	Sum of all flows into detritus	**868**	**t km^{-2} yr^{-1}**
=	Total system throughput	**3184**	**t km^{-2} yr^{-1}**

The **total system throughput** is the **sum of all flows in a system**.

It is considered to be an indirect indicator of the size of the food web and is estimated as the sum of four flow components, i.e.

Total consumption + Total export + Total respiration + Total flows to detritus

(Export = commercial fishing)

Total system throughput represents the **'size of the entire system in terms of flow'** (Ulanowicz, 1986).

As such, it is an important parameter for **comparisons of flow networks**.

ECOPATH outputs

ODYSSEA

Statistics

Parameter	Thermaikos	Units
Total primary production / total respiration	**2.212**	
Net system production	**506**	**t km^{-2} yr^{-1}**
Total primary production / total biomass	**23**	
Total biomass / total throughput	**0.013**	

Total primary production / total respiration and biomass: important ratio for description of the **maturity of an ecosystem** (Odum 1971)

In **early developmental stages** of a system, production is expected to exceed respiration, **>1** and biomass accumulates over time, production to biomass **declines**

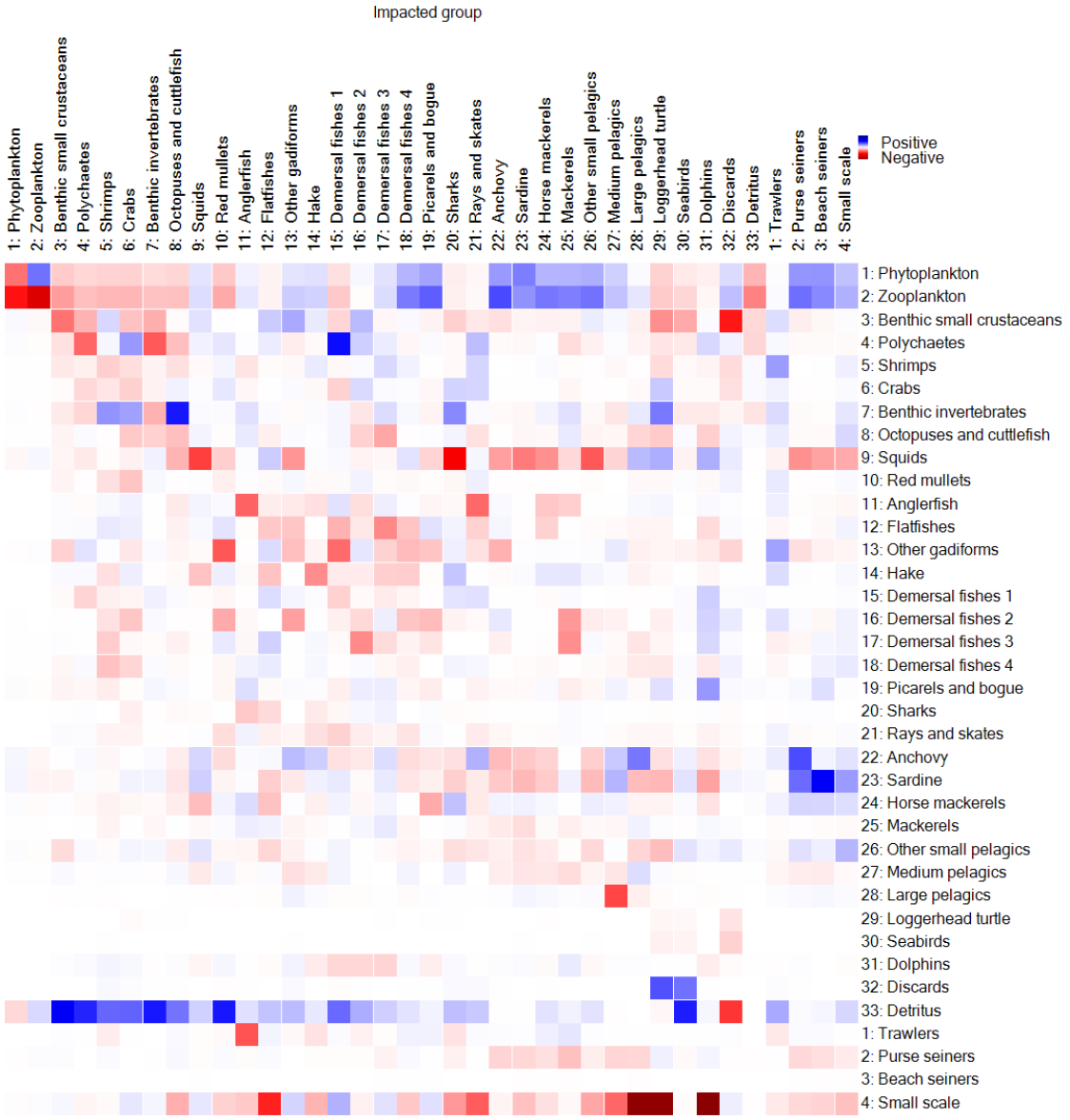
Fishing causes the bottom complexity as well as the benthos and fish species composition to change from mature to disturbed ecosystems (Watling and Norse, 1998)

Net system production: difference between total primary production and respiration, large in immature systems, close to 0 in mature

System biomass / throughput: decrease to a minimum for the most immature stages of a system, close to 0

Mixed Trophic Impact plot

ODYSSEA

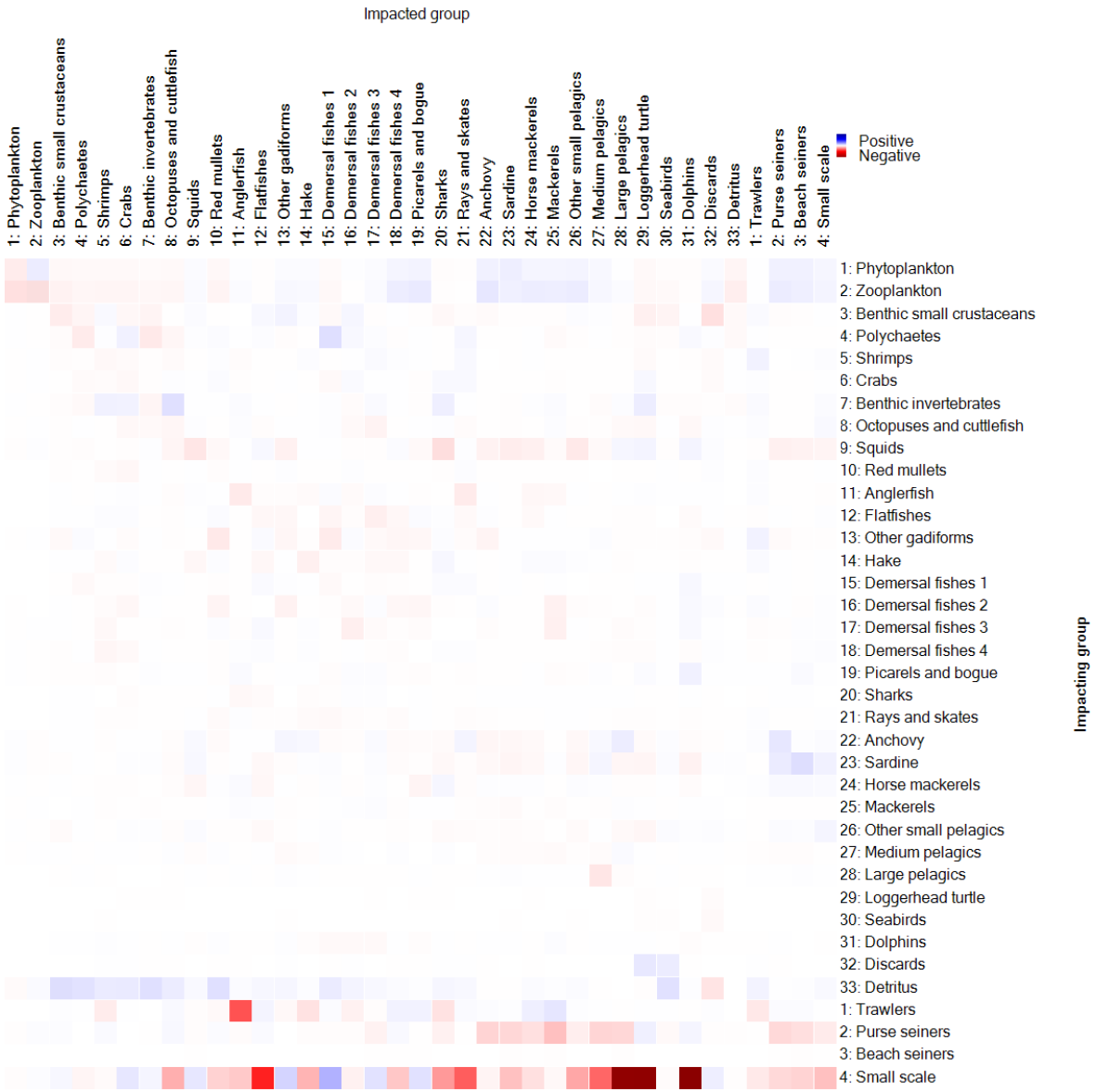


The **relative** direct and indirect **impact** that a hypothetical very **small increase of the biomass** of the impacting groups have on the biomass of the **impacted groups**.

Indirect cascade effects on a prey's prey or competitor can also be revealed.

Mixed Trophic Impact plot

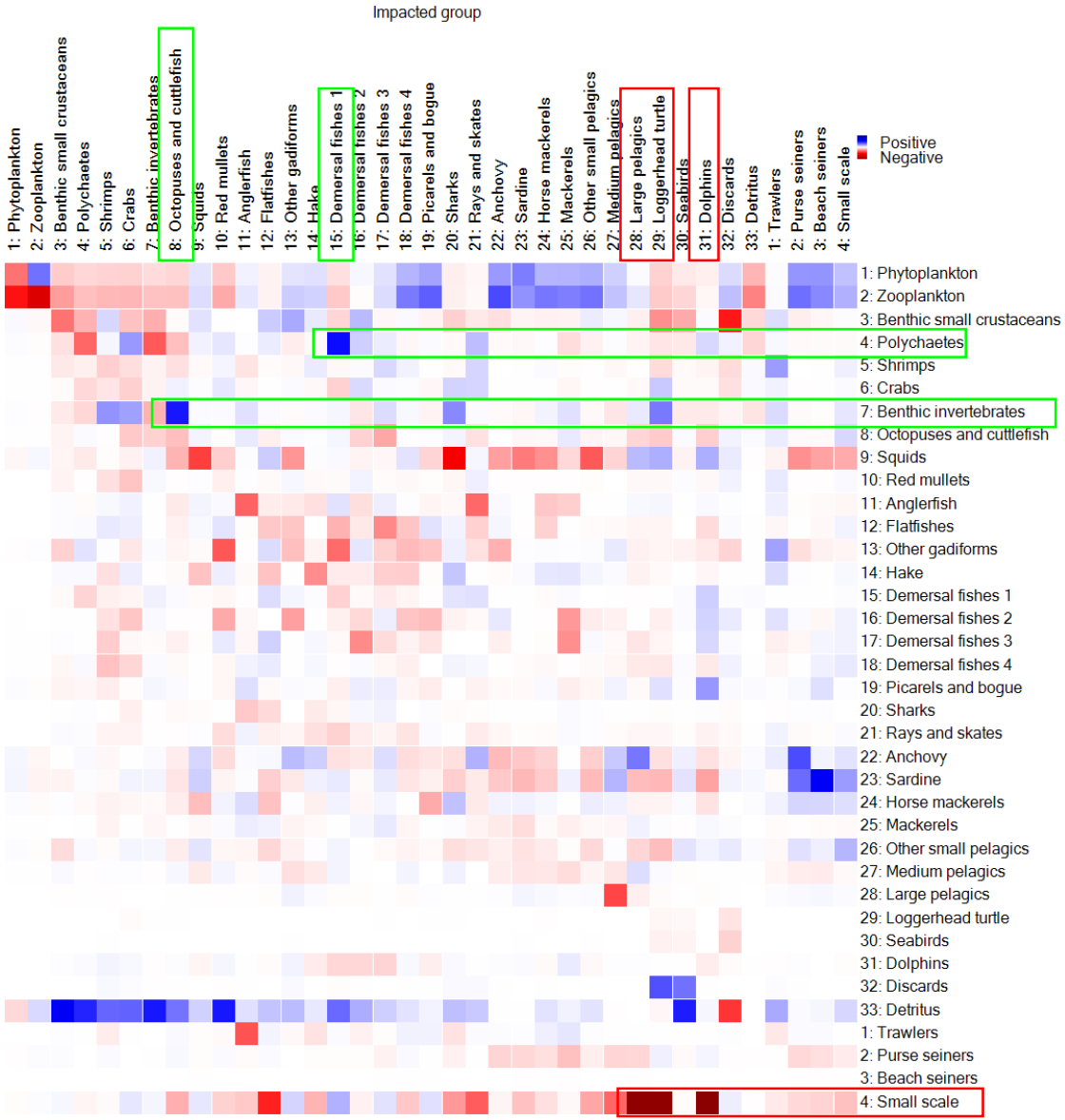
ODYSSEA



Impacts due to **fishing**

Mixed Trophic Impact plot

ODYSSEA



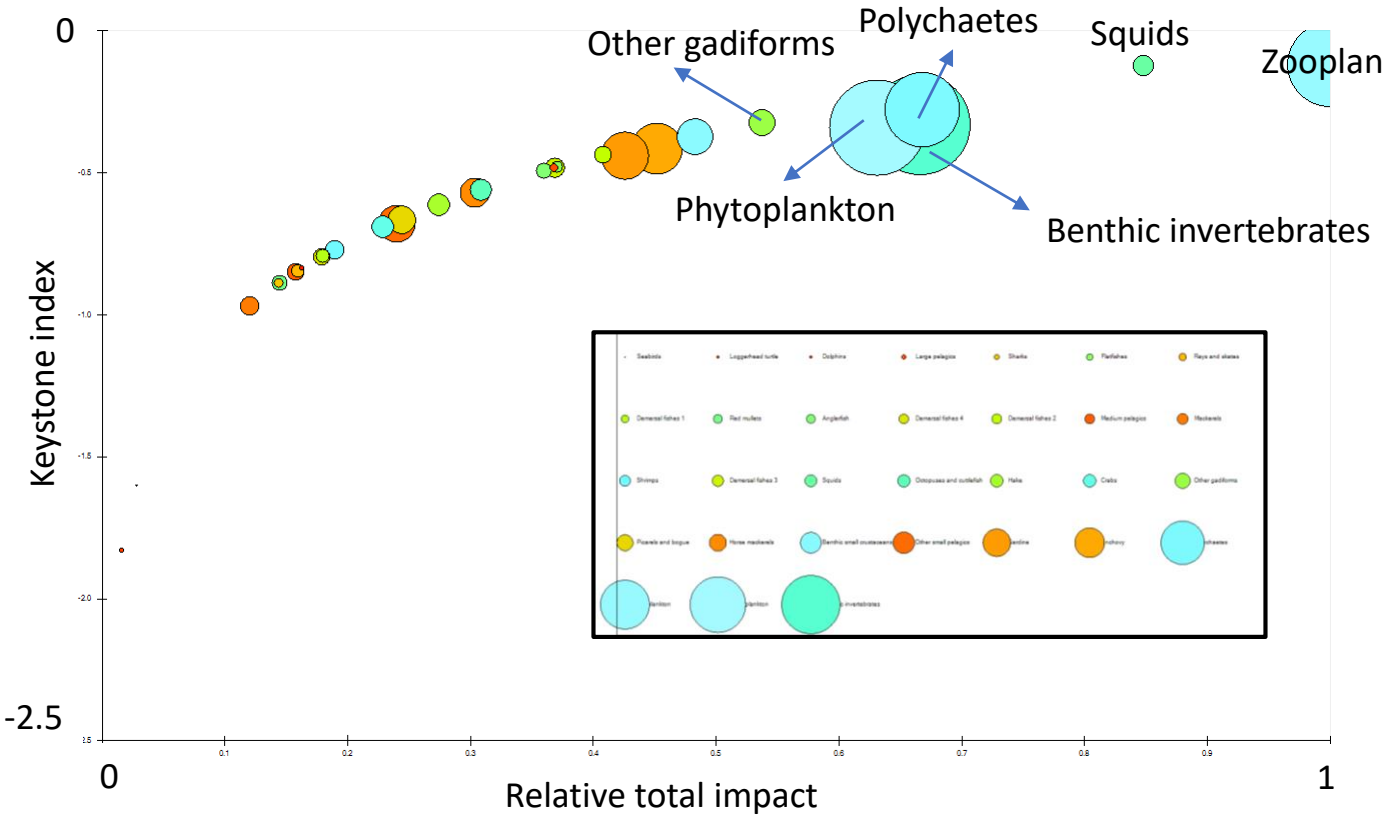
Octopuses & cuttlefish **eat a lot** of benthic invertebrates

Demersal fishes 1 **eat a lot** of polychaetes

Small scale vessels **discard** many large pelagics, turtles and dolphins

Most groups have a **negative impact on themselves**, interpreted here as reflecting increased **within-group competition for resources**.

Keystoneness graph



Squids and **other gadiforms**: high relative total **impact** and **keystoneness** with relatively low biomass

Zooplankton: the most important group (impact), but **not** keystone due to high abundance

Keystone groups >0: play an important role in the food-web with relatively low biomass

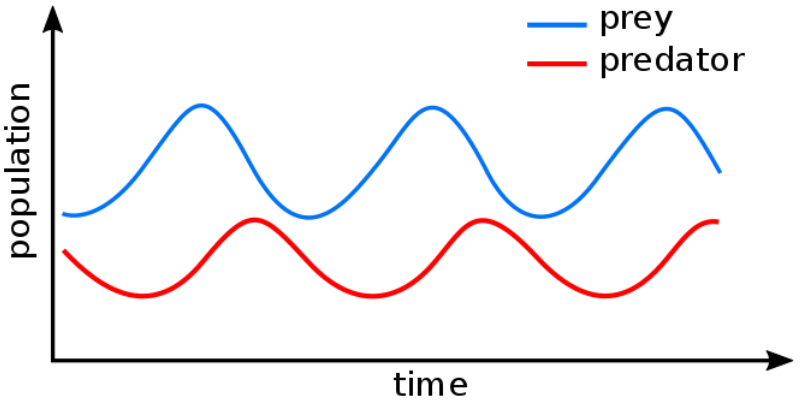
Dominant groups: play an important role and have a relative large biomass in the ecosystem

Ecosim

Ecopath with Ecosim

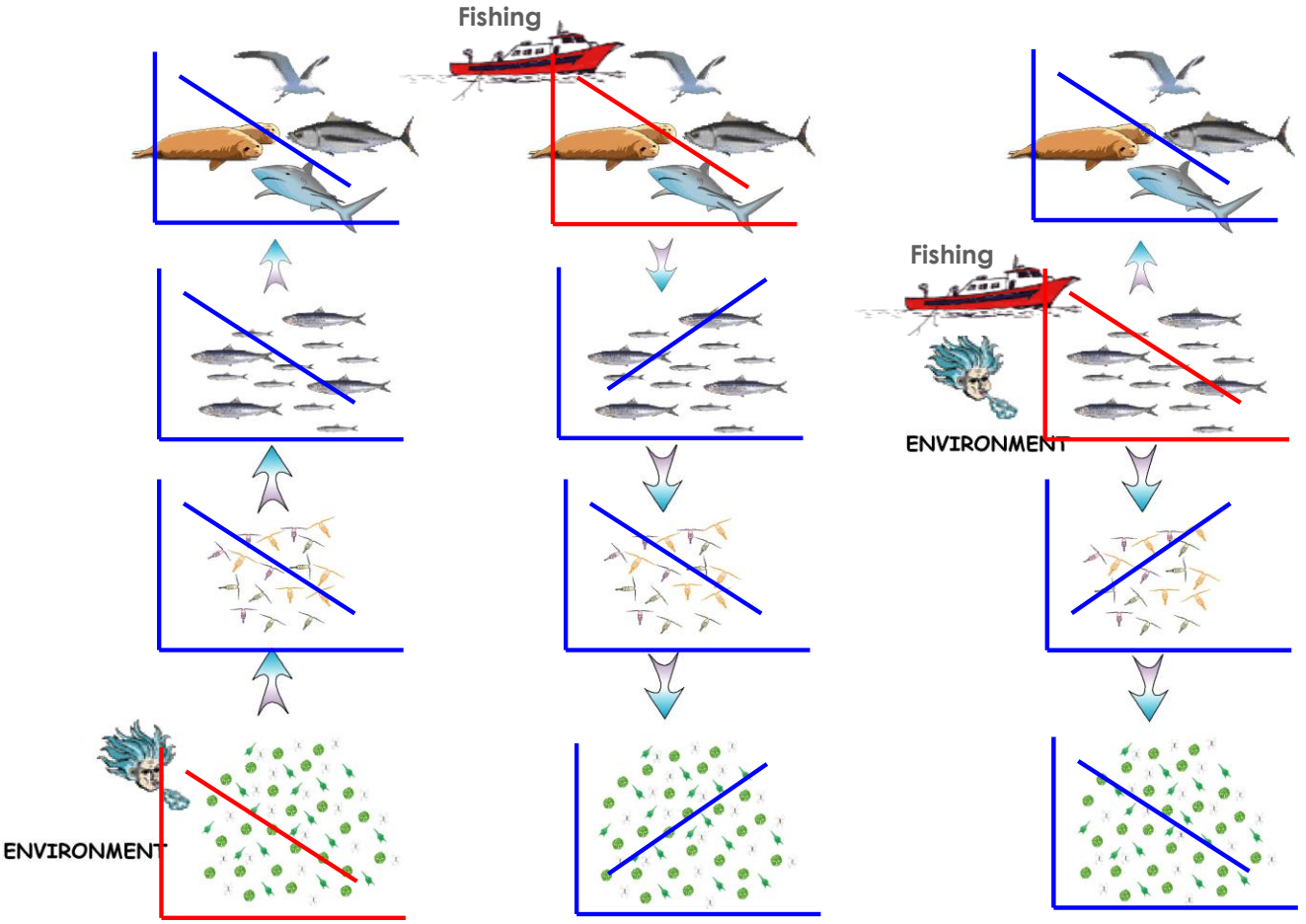
No fish is an island

- temporal simulations
- its purpose is not to replace single-species approaches, but to test strategic questions and interactions that can't otherwise be accounted for
- biomass dynamics expressed through a series of differential equations
- the consumption of each FG is expressed according to the "foraging arena" theory (not Lotka-Volterra) in which the prey is divided to available (vulnerable) and not available (invulnerable) to the predator through activities such as foraging and dispersal



Vulnerabilities in Ecosim

- how is the biomass of each group in the ecosystem controlled



Bottom-Up
prey control

Top- Down
predator control

Wasp-Waist

Time series data in Ecosim

Forcing (no gaps allowed)

- fishing effort
- environmental (T, chla etc.)
- anomaly (estimated by the software based on the rest of the time series)

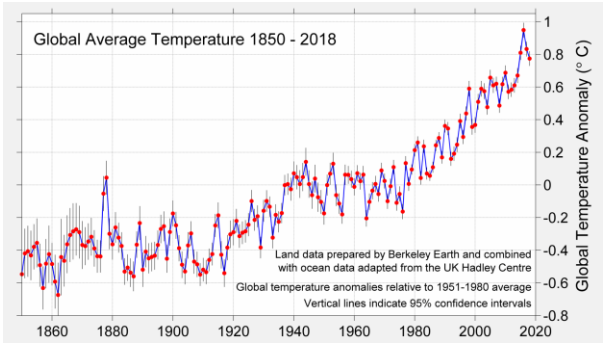
Forcing data

Fitting (gaps allowed)

- biomasses
- catches

Historical comparison data

Time series data in Ecosim



Forcing (no gaps allowed)

- fishing effort
- environmental (T, chla etc.)
- anomaly (estimated by the software based on the rest of the time series)

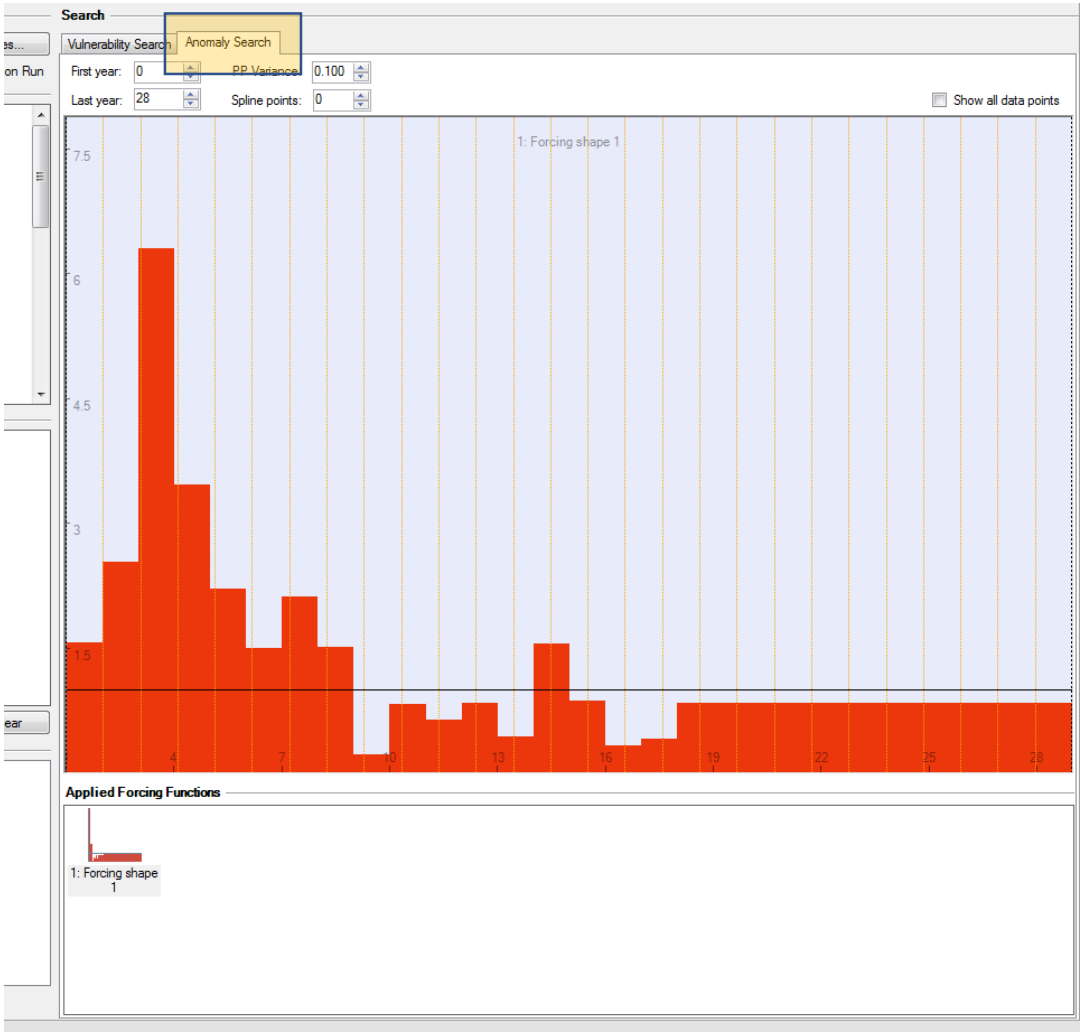
Fitting (gaps allowed)

- biomasses
- catches

Title	Shrimps	Benthic cephalopods	Anglerfish	Rays & skates	Anchovy	Fleet1	Fleet2	Fleet3	Fleet4	Fleet5	Shrimps	Crabs
Pool	8	13	16	28	29	1	2	3	4	5	8	9
Code	0	0	0	0	0	3	3	3	3	3	6	6
1	1	1	1	1	1	1	1	1	1	1	0.025036	0.003858
2		0.310601833	0.7686661	0.821828391		1.002961	1.011453	1.006749	1.006749	1.171353	0.034132	0.001927
3		0.947906737	1.5371966	1.229175358		0.979211	1.024337	1.020124	1.020124	1.310926	0.047167	0.004782
4	3.99754	0.667255227	0.8858707	1.472265217		1.007436	1.058968	1.008595	1.008595	1.888108	0.084283	0.008108
5	3.83744	0.411822512	0.7446751	1.021596572		0.945306	1.050856	1.077446	1.077446	2.094318	0.108242	0.002045
6	1.98804	0.332080708	0.3273468	0.722878687		0.89284	0.995023	1.098865	1.098865	2.082015	0.115333	0.001779
7	2.20083	0.260085738	0.271549	0.689867645		0.901452	1.067081	1.051024	1.051024	2.006737	0.112125	0.002088
8	3.55084	0.232328753	0.396056	0.664189054		0.918919	0.967822	1.032551	1.032551	2.21983	0.1268	0.007131
9	2.65607	0.278296231	0.133569	0.223133171		0.900953	0.996454	1.093854	1.093854	2.381371	0.126202	0.001358
10						0.924742	0.95573	1.075272	1.075272	2.910369	0.101171	0.00114
11	2.53895	0.845611636	0.3359912	0.377184984	1.642602	0.859365	1.040672	1.038407	1.038407	2.989602	0.148105	0.002031
12	1.68638	0.88735335	0.3506305	0.292742352	0.723162	0.785337	0.967087	1.008452	1.008452	2.646163	0.171776	0.001404
13	1.67488	0.589351589	0.5205981	0.443789969	1.259164	0.828922	1.095455	1.002928	1.002928	2.826303	0.211585	0.001894

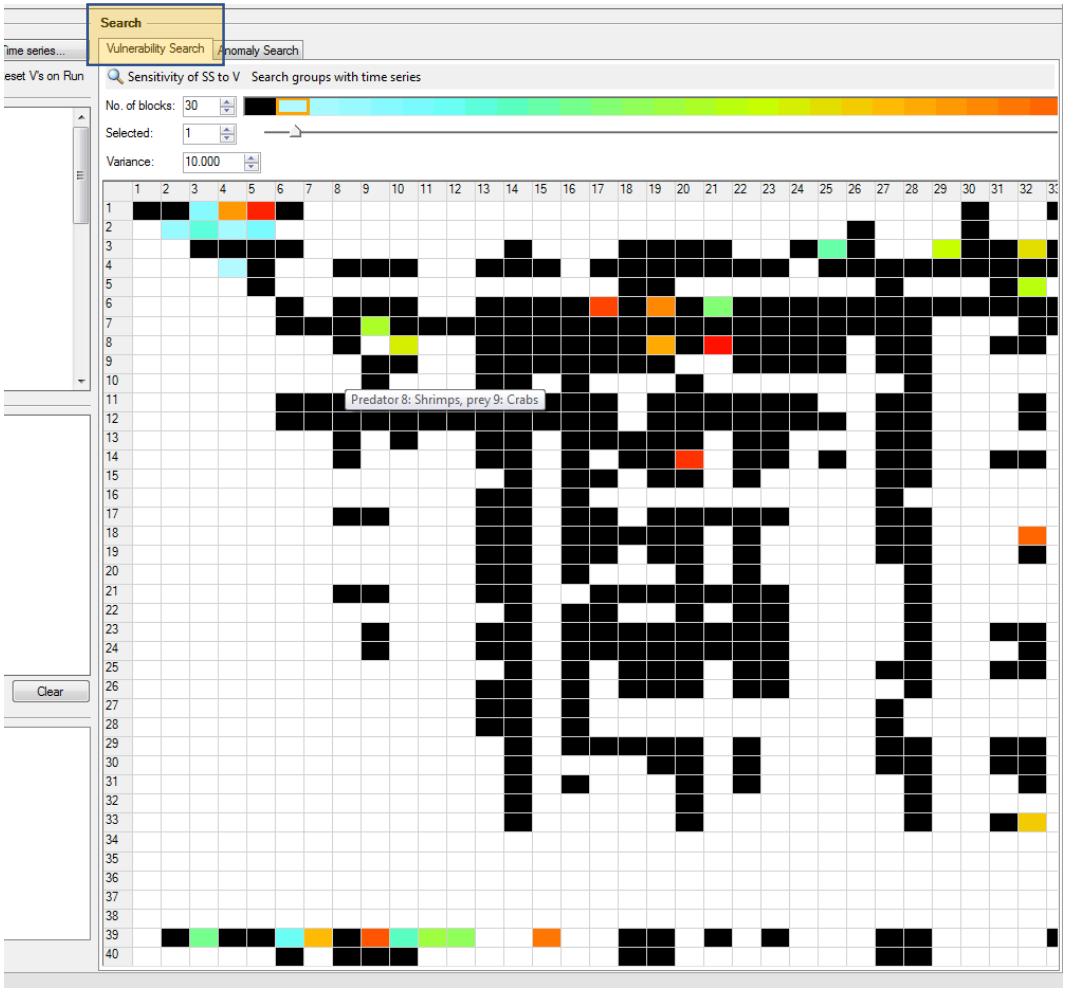
Ecosim fit to time series

Applying an environmental **anomaly** function (e.g. on the primary producers) that drives the model



Ecosim fit to time series

Search for the most **vulnerable** prey-predator interactions



Ecosim fit to time series

The most vulnerable interactions are modified. The software searches for the best solutions (with iterations)

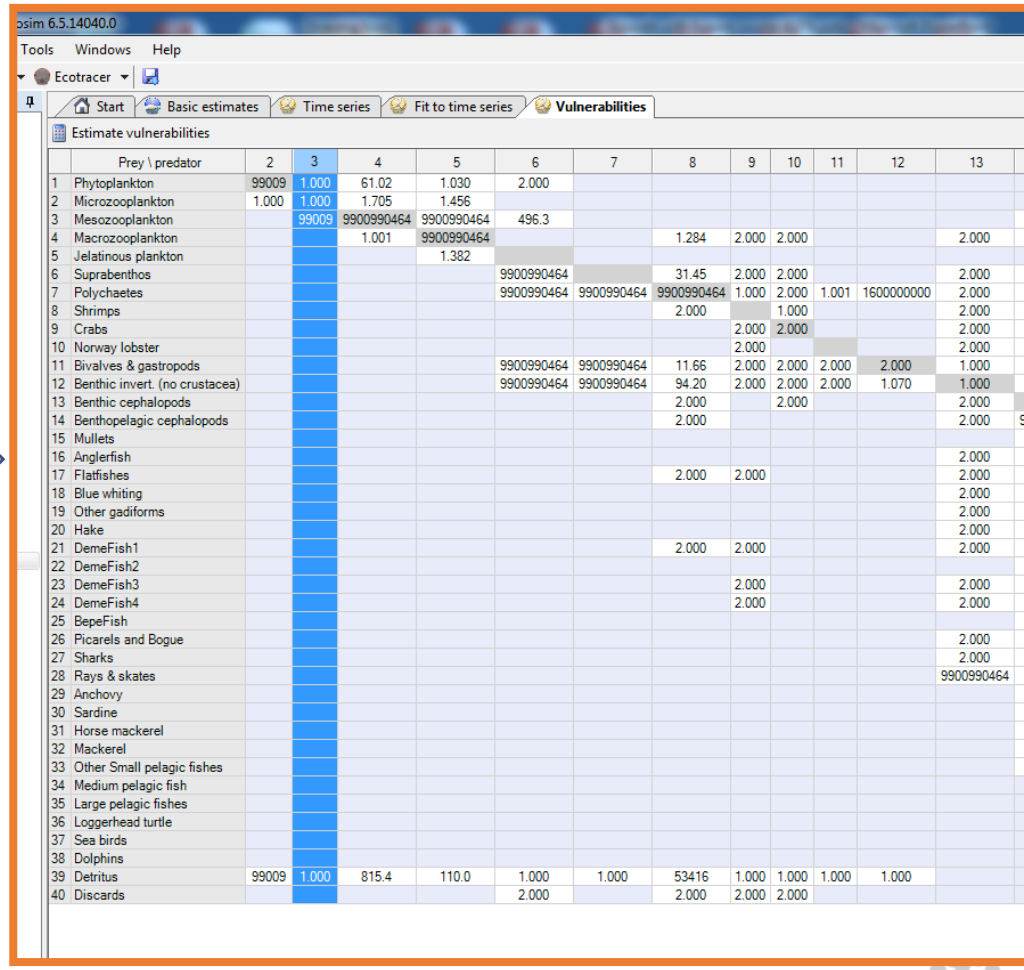
	Number of parameters	Number of AIC data points	Sum of squares	Akaike Information Criteria
1	30	688	384.2	-338.0

No. AIC data points: 688

Iterations

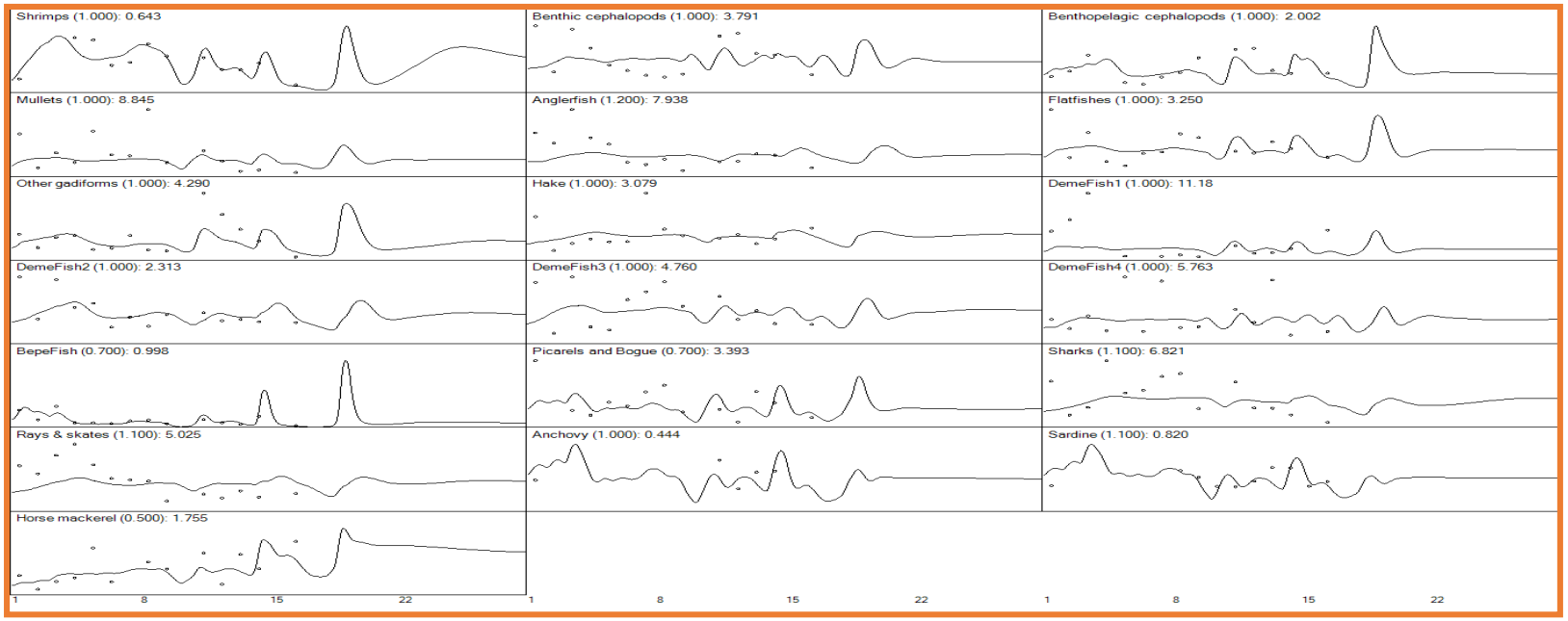
```
Run completed at 10:50 AM
Iteration 9,  SS =  384.1988
Iteration 9,  SS =  384.1989
Iteration 8,  SS =  384.1989
Iteration 7,  SS =  384.2612
Iteration 6,  SS =  384.2995
Iteration 5,  SS =  384.2996
Iteration 4,  SS =  384.2996
Iteration 3,  SS =  388.6408
Iteration 2,  SS =  391.0157
Iteration 1,  SS =  424.8379
Search started, base SS = 424.838
```

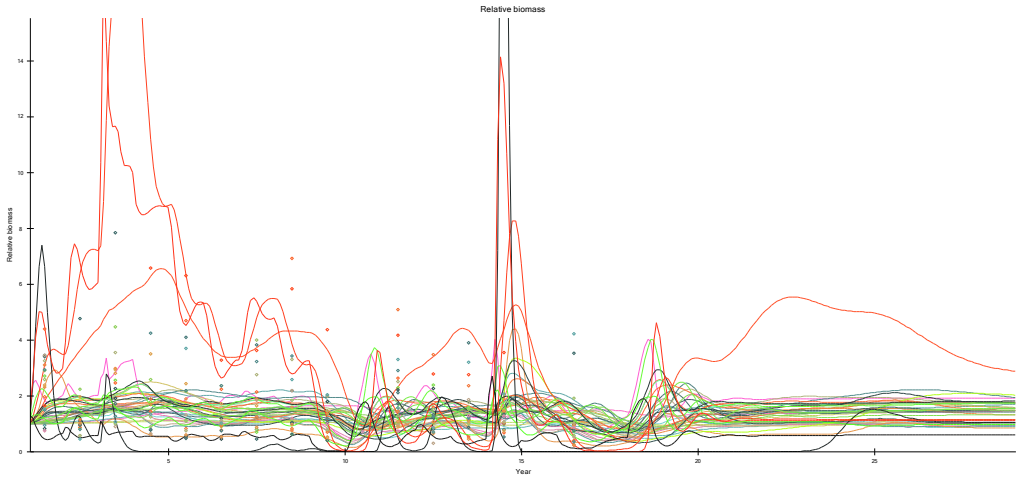
Stop | Search



	Prey \ predator	2	3	4	5	6	7	8	9	10	11	12	13
1	Phytoplankton	99009	1.000	61.02	1.030	2.000							
2	Microzooplankton	1.000	1.000	1.705	1.456								
3	Mesozooplankton		99009	9900990464	9900990464	496.3							
4	Macrozooplankton			1.001	9900990464			1.284	2.000	2.000			2.000
5	Jelatinous plankton				1.382								
6	Suprabenthos					9900990464		31.45	2.000	2.000			2.000
7	Polychaetes					9900990464	9900990464	9900990464	1.000	2.000	1.001	1600000000	2.000
8	Shrimps							2.000		1.000			2.000
9	Crabs								2.000	2.000			2.000
10	Norway lobster								2.000				2.000
11	Bivalves & gastropods					9900990464	9900990464	11.66	2.000	2.000	2.000	2.000	1.000
12	Benthic invert. (no crustacea)					9900990464	9900990464	94.20	2.000	2.000	2.000	1.070	1.000
13	Benthic cephalopods							2.000		2.000			2.000
14	Benthopelagic cephalopods							2.000					2.000
15	Mullets												
16	Anglerfish												2.000
17	Flatfishes							2.000	2.000				2.000
18	Blue whiting												2.000
19	Other gadiforms												2.000
20	Hake												2.000
21	DemeFish1							2.000	2.000				2.000
22	DemeFish2												
23	DemeFish3								2.000				2.000
24	DemeFish4								2.000				2.000
25	BepeFish												
26	Picarels and Bogue												2.000
27	Sharks												2.000
28	Rays & skates												9900990464
29	Anchovy												
30	Sardine												
31	Horse mackerel												
32	Mackerel												
33	Other Small pelagic fishes												
34	Medium pelagic fish												
35	Large pelagic fishes												
36	Loggerhead turtle												
37	Sea birds												
38	Dolphins												
39	Detritus	99009	1.000	815.4	110.0	1.000	1.000	53416	1.000	1.000	1.000	1.000	
40	Discards					2.000		2.000	2.000	2.000			

Running Ecosim





Ecosim scenarios

- fishing effort scenarios
- fishing practices, e.g. selectivity (indirect)
- application of management practices (e.g. landing obligation)
- scenarios of environmental changes (nutrients, temperature rise)
- biomass changes of specific groups (e.g. invasive species)

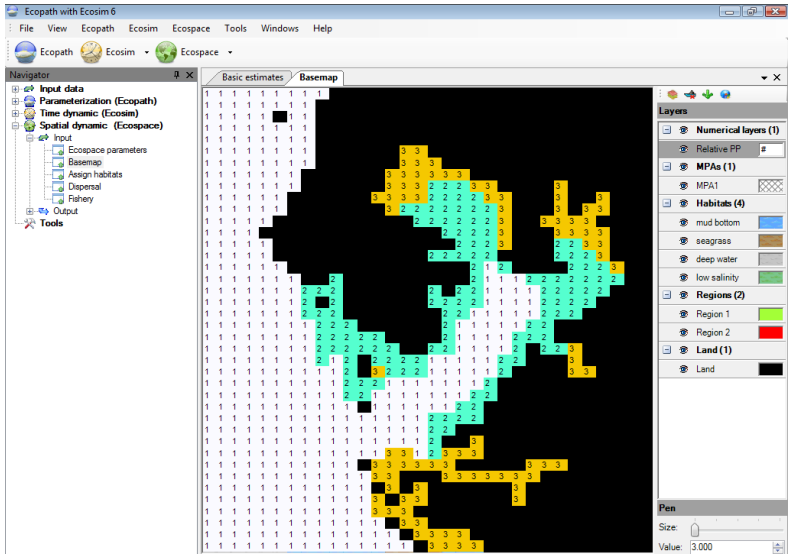
Ecospace

ODYSSEA

Ecopath with Ecosim

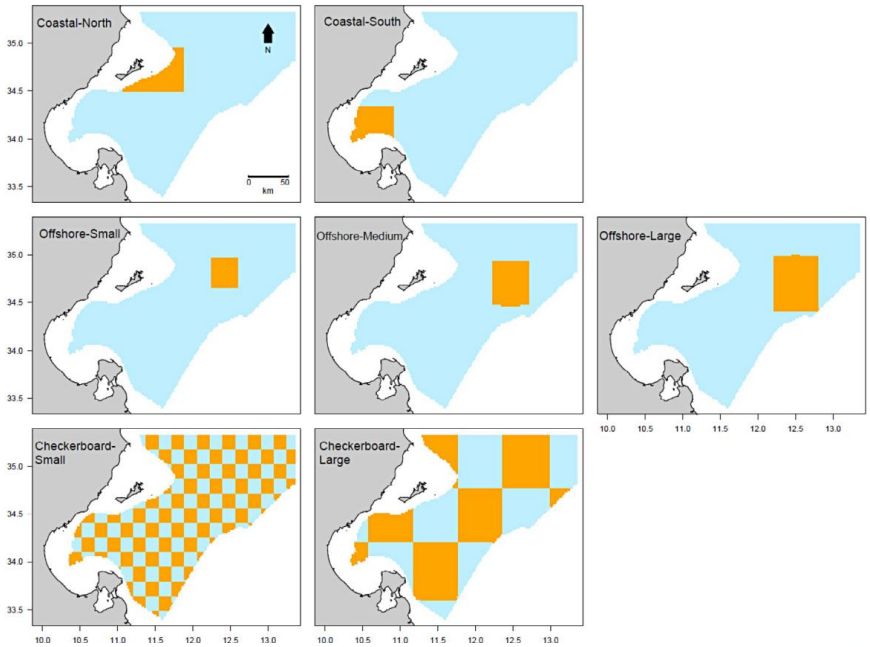
No fish is an island

- two-dimensional
- it employs the Ecosim model in a spatial grid of one size cells
- cells are connected through distribution/movements of populations and fishing effort
- the dispersal rate depends on the cell being a “preferred habitat” or not
- high predation risk and lower food intake in non preferred habitats
- fishing effort proportional to cell productivity



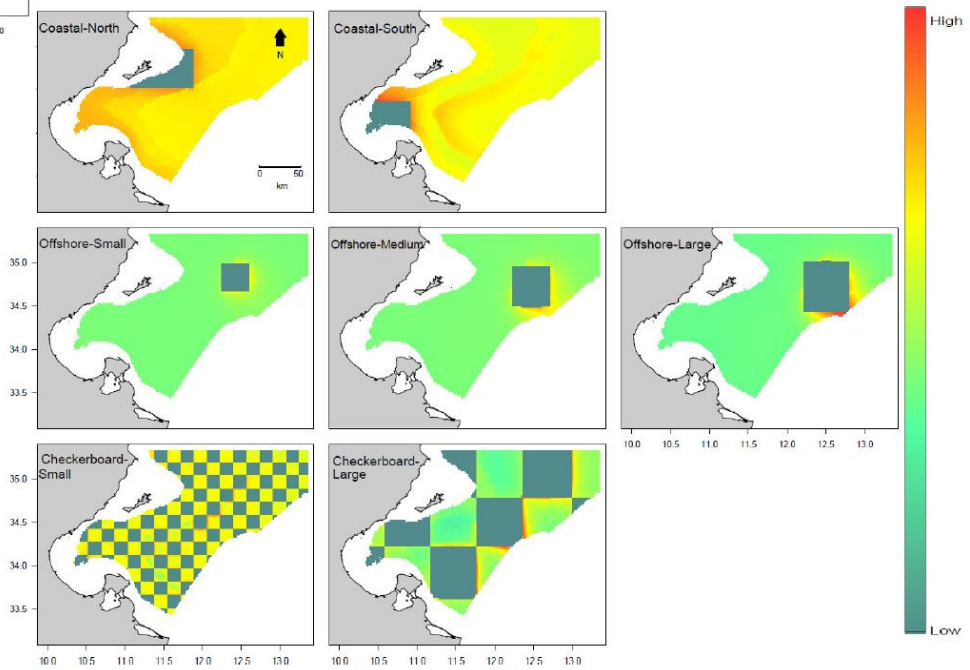
ODYSSEA

Defining and evaluating Marine Protected Areas



(Abdou et al. 2016)

Catches by the end of the simulation period

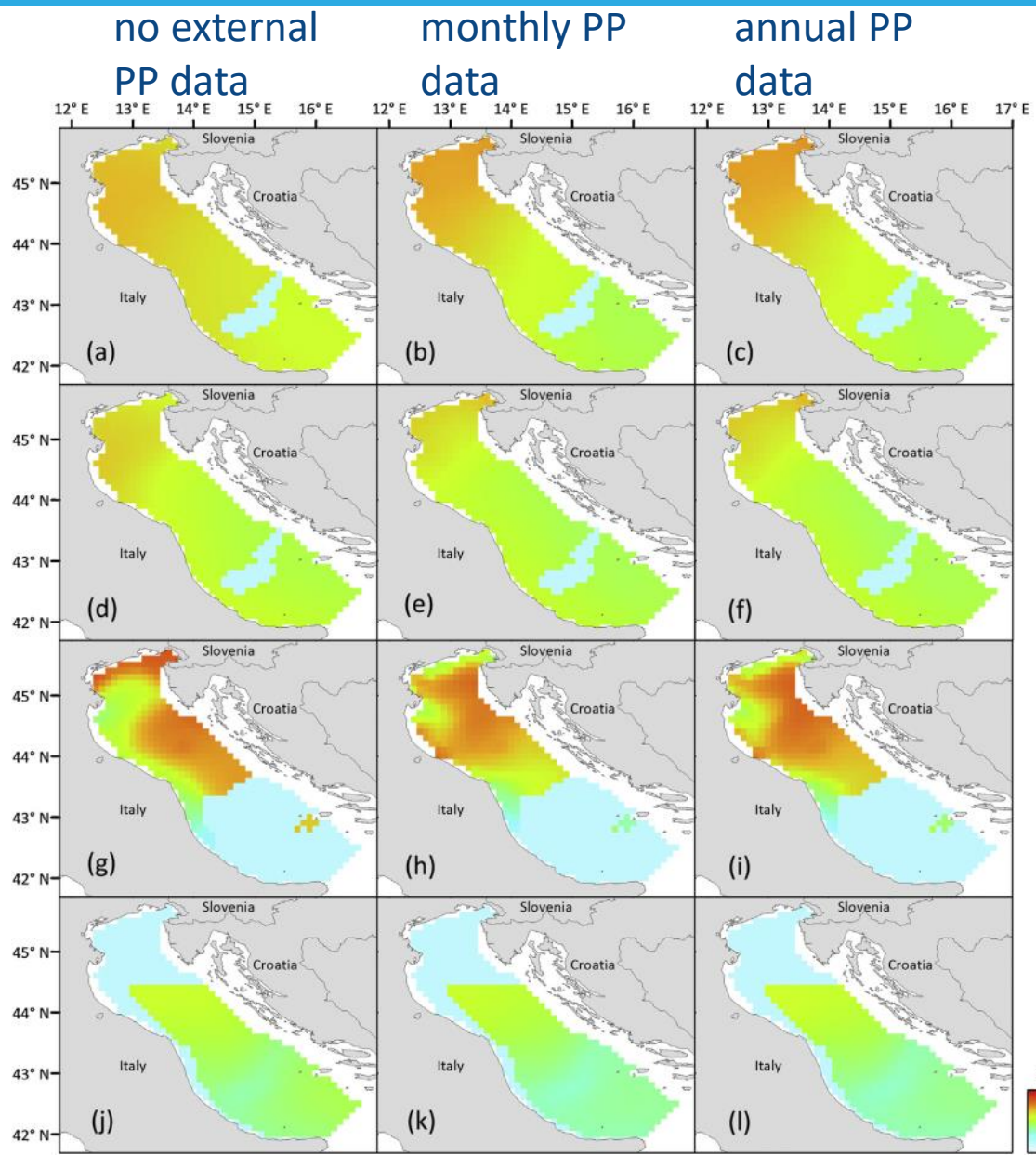


Ecospace

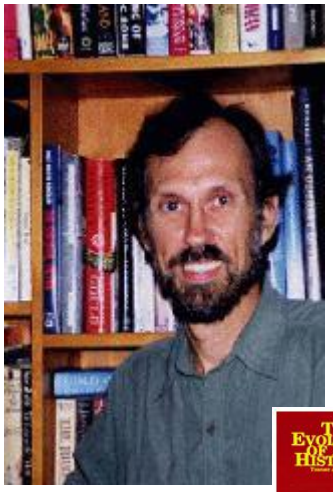
ODYSSEA

Species distribution

odysseaplatform.eu |@odysseaplatform



(Steenbeek et al. 2013)



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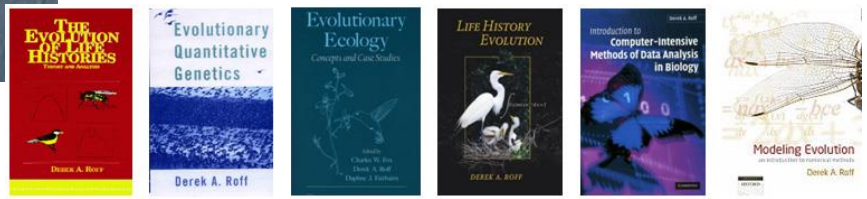

"No model is constructed to capture all the intricacies of the real world, for if it did so it would be as difficult to understand as the real world itself and little would be gained"

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THANK-YOU

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