

Spatial ecosystem modelling using Ecopath with Ecosim

Jeroen Steenbeek 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



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

- 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



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

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	



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



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

Ecopath



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



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





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



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



Ecospace

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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

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Groups using fractions of habitats

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2. Why are species where they are?

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

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



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

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
 - Search rate

а

Α

Foraging arena size

Predation calculation is altered:

$$V = \frac{v B}{v + v' + a P (A)}$$

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



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3. Populate env. driver maps



4. Define env. response curves

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5. Connect groups, drivers and responses

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6. Check set-up and run

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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)

Hab. Cap. case study

1. Define environmental drivers

Primary production

Salinity (surface and bottom)

Temperature (surface and bottom)

Depth

MSFD area restrictions


2. Define environmental responses

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



Piroddi et al (in progress)

3. Apply drivers and responses

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gat										
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4	Seabirds W		1: MSFD	<u>F</u> ilter: d	epth	Aa				
	Sea turtles								=	
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8	8 European pilchard W 8: Depth (m) Sardina pil 1: MSFD 5: Depth (m) Medium pelagics (Sard									
9	European anchovy W		1: MSFD	8: 0	Depth (m) Sard	lina pilchardus	(EL			
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•	2 European hake W		1: MSFD	17:	Depth (m) jelly	- /fish (Pelagia n	oct (Europea	n		
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ŀ	4 Small demersals W		1: MSFD	21.	Depth (m) dee	en fish (Cycloth	ioni			
ŀ	5 Deep fish W		1: MSFD	22	Depth (m) Me	duccius meduc	rciu			
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ŀ	7 Rays and skates W		1: MSFD	-			P			
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ŀ	9 Crustaceans W		1: MSFD					UK Cancel		
2	0 Jellyfish W	17: Depth (m) jellyfish (1: MSFD							
2	1 Benthos W		1: MSFD						_	
1	2 Zooplankton W		1: MSFD							
1	23 Phytoplankton W 1: MSFD									
1	4 Seagrass W		1: MSFD							
2	25 Piscivores feeding cetaceans A			1: MSFD						
1	Pinnipeds A			1: MSFD						
1	7 Seabirds A			1: MSFD						

4. Ecospace computes capacity (cetaceans - depth)



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



4. Run

led model - Ecopath with Ecosim 6.5.10	0321.0		-			x			
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© <u>C</u> atch	Large demonsals W	European bake W	W Medium demorsals	W Small demorsals W	pelagics W				
Catch/biomass 2 Legend max.			W						
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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



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

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	7	TSS_DM		Ø	1995/01	2023/10			
	-	Relative PP map							
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2. Define external data

Configure external data connection

Description	I							
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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

🈂 D	Delta management model - Ecopath with Ecosim 6.5.12689.0									
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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

🚭 Anchovy Bay - Ecopath	with Ecosim 6.5.14149.0		– 🗆 X
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2. Choose advected groups

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Ecospace		Group name	Base dispersal rate	Relative dispersal in bad habitat	Rel. vul to pred. in bad hab.	Rel. feed rate in bad hab.	Is advected	ls migratory	Barrier avoidand weight	
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✓ → Habitat based for	2	Seals	300.0	5.000	2.000	0.500				
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🔚 Habitat foragiı	5	Mackerel	300.0	5.000	2.000	0.500				
🗔 Functional res	6	Anchovy	300.0	5.000	2.000	0.500				
🗔 Dispersal	7	Shrimp	300.0	5.000	2.000	0.500				
Advection	8	Benthos	300.0	5.000	2.000	0.500				
Ecospace fishery	9	Zooplankton	300.0	5.000	2.000	0.500				
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10: Phytoplankton (Is this group affected by advection?) 🥏 Anchow Bay 🤗 New Ecosim scenario 🚳 BayOfAnchovies 👉										

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



Modular structure of 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!



A few plug-ins

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

EII IRD, in progress Agrocampus Ouest EII DFO SAMS CEFAS

Standard use: EwE6 Scientific Interface



Distributed computing, model interoperability





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

> <u>http://ecopath.org/consortium</u> <u>http://facebook.com/eweconsortium</u>
Thank you

jeroen@ecopathinternational.org



Ecopath International Initiative

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