Ecosystem models: Types and characteristics

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Reviews of ecosystem models/ing

- FAO: Plagányi 2007. Models for an Ecosystem Approach to Fisheries. FAO Fisheries Technical paper 477
- FAO: Report of Modelling Ecosystem Interactions for Informing an Ecosystem Approach to Fisheries: Best Practices in Ecosystem Modeling, Tivoli, Italy, 3-6 July 2007
- NMFS: National Ecosystem Modeling Workshop (NEMoW), Santa Cruz CA, 29-31 August 2007
- DFO's National Workshop on Modelling Tools for Ecosystem Approaches to Management, Victoria BC, 22-25 October 2007
- ICES WG(m)SAM 2007/RMC:08. 15-19 Oct, San Sebastian, Spain

Models and management

- **Conceptual**: describes the ecosystem, its form, function, and interactions. Sometimes part of the management process, but mainly serves to supply context
- **Strategic**: used with specified policy objectives; medium- to long-term; provides directions
- **Tactical**: used with operational objectives; short term; provides specific advice, e.g., on openings for fisheries

Types of ecosystem models

What are ecosystem models?

1. Extended single-species assessment models (ESAM)

Based on single-species assessment models incorporating additional inter-specific interactions

Model	Name
ESAM	Extended Single-Species Models e.g., Livingston and Method 1998, Hollowed et al. 2000, Tjelmeland and Lindstrøm 2005
SEASTAR	Stock Estimation with Adjustable Survey observation model and TAg-Return data

2. Dynamic System Models

With bottom-up (physical) and top-down (biological) forces interacting

SEAPODYM	Spatial Ecosystem and Population Dynamics Model
OSMOSE	Object-oriented Simulator of Marine ecOSystem Exploitation
SystMod	System Model for the Norwegian and Barents Sea

OSMOSE (Object-oriented Simulator of Marine ecOSystem Exploitation)

- Size-based Individual Based Model. Fish-focused, 2D
- Strengths:
  - Environmental effects
  - Age structure
  - Good fish coverage
  - Spatial species interaction
  - Some policy exploration
  - Well-described
  - Easy use
- Weaknesses:
  - No physical processes
  - No uncertainty
  - Fixed functional response
  - No habitat processes
  - No migration

3. Minimum Realistic Models (I)

Dynamics of assumed key species interacting with a target species of concern

Gadget	Globally applicable Area Disaggregated General Ecosystem Toolbox
BORMICON	BOReal Migration and CONsumption model
MULTSPEC	Multi-species model for the Barents Sea

3. Minimum Realistic Models (II)

MSVPA & MSFOR	Multi-species Virtual Population Analysis; Multi-species Forecasting Model
MSM	Multi-species Statistical Model
IBM, bioenergetic/ allometric	e.g., Koen-Alonso and Yodzis 2005

Multi Species Virtual Population Analysis (MSVPA)

- Fish stock assessment model
- Minimum Realistic Model
- Pred. mort. for single species
- Strengths:
    - Age structure
    - Some uncertainty considered
    - Some environment consideration possible
    - Policy evaluation
    - Good fish coverage possible
- Weaknesses:
    - Data demanding, notably for diets
    - Few species
    - Not spatial
    - No habitat considerations
    - No migration
    - No physical processes

3. Minimum Realistic Models (III, Antarctic)

FOOSA	Previously KPFM (Krill- Predator-Fishery Model)
SMOM	Spatial Multi-species Operating Model
EPOC	Ecosystem Productivity Ocean Climate model
Other CCAMLR	e.g., Mori and Butterworth 2005, 2006

4. Whole ecosystem models

Attempt to describe all trophic levels in the ecosystem

ERSEM	European Regional Seas Ecosystem Model (NPZ-fish)
Atlantis	Deterministic bio-geochemical with MSE
INVITRO	Agent based MSE framework
GEEM	General Equilibrium Ecosystem Model
EwE	Ecopath with Ecosim (UBC); time-space dyna mics with MSE
SSEM	Shallow Seas Ecosystem Model (NPZ-fish)

European Regional Seas Ecosystem Model (ERSEM II)

- Simulate C, N, P, Si. Focus on biogeochemistry and low TL
- Strengths:
  - Detailed link to T, light,
  - Uncertainty considered
  - Environmental processes
  - Habitat considerations
  - Good experience modeling the North Sea
- Can be linked to fish models (e.g., EwE)
- Weaknesses:
  - Mainly a plankton model
  - No age structure
  - Limited fish dynamics
  - No policy exploration
  - Data intensive

Atlantis: Physical transport biogeochemical process model

- Developed for multiple use management questions
- Strengths:
  - Links biogeochemical & ecological models
  - Considers environmental effects
  - Spatially explicit
  - Age structured
  - Policy exploration possible
  - Can consider many species
  - Migration can be included
  - Can be coupled to other models (e.g., Ecospace)
- Weaknesses:
  - Programming intensive
  - Data intensive
  - Not for data poor areas
  - Very long runtime

Ecopath with Ecosim (EwE)

- Food web model, time- and spatial dynamics, widely used
- Strengths:
  - Age structure
  - Environmental and physical effects can be considered
  - Spatially explicit
  - Uncertainty considerations
  - Management Strategy Evaluation integrated
  - Policy exploration modules
  - Can consider many species
  - Coupling to other models
  - Support and training;
  - Ease of use
- Weaknesses:
  - Data needs for diets
  - Migratory species handling
  - Limited physical processes
  - Ease of use

Let questions guide model choice

- How will fishing a predator impacts its prey and competitors?
- How will fishing a prey species impact its predators?
- How important is the competition between fisheries and endangered, threatened, or vulnerable (ETV) species?
- How will by-catch of, e.g., juveniles of a commercial species impact the species when its competitors and predators also are impacted?
- What are the ecological, economic, and social trade-offs?
- What is the relative impact of the environment, food web, and fishing?

	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	■		■	■						

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	11	12	13	14	15	16	17	18	19	20
	MULTSPEC	**GADGET**	**Bioenergetic/ allometric models**	**OSMOSE**	**SEAPODYM**	**CCAMLR models**	**EPOC***	**SMOM***	**ESAM**	**SEASTAR**
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				■						

* Still being developed

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Data requirements and model suitability for data poor areas (I)

EwE	Less than BGC, but difficult: diet composition, abundance
IGBEM	Only suitable for very intensively studied systems
Atlantis	Data intensive, not suitable
InVitro	Mixed, depends on agent type selected
ERSEM II	Data intensive, not suitable
SSEM	Data intensive, but lumped components, so not as bad as other BGC
KPFM	Can be adapted to match data level
MRM	Fairly data intensive
MSVPA/F	Unsuitable for most regions

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Data requirements and model suitability for data poor areas (II)

MSM	Some potential, focus on few species which often have data
MULTSPEC	Unsuitable for most; requires detailed stomach data
GADGET	Good, can be tailored to available data
Bioenerg.	Not suitable
OSMOSE	Based on fairly general parameters, could be applied, some difficulties
SEAPODYM	Not suitable
CCAMLR	Min: relative abundance data; can be tailored
EPOC	Data intensive
SMOM	Can be adapted
ESAM/SStr	Detailed data only required for target species

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User level, programming & math capabilities

Low	Fair	High
EwE (entry: none, advanced: benefit) OSMOSE (graphic interface)	IGBEM, Atlantis, InVitro, ERSEM II, Multspec, Gadget, EPOC	MRM (very high), MSVPA/MSFOR MSM, Bioenergetic/allometric, SEAPODYM, CCAMLR, ESAM, SEASTAR

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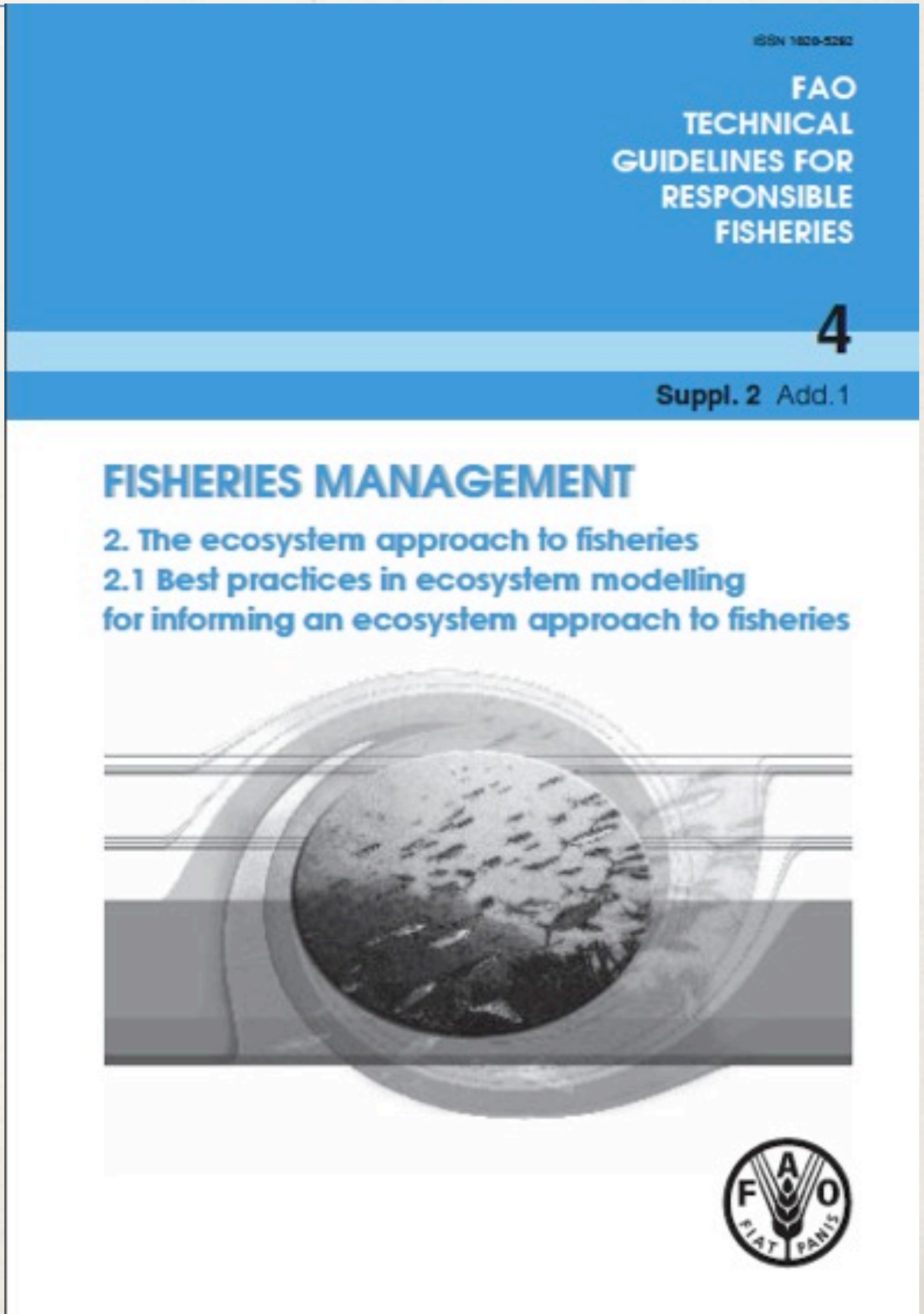
Conclusions (EwE), Plagányi

- EwE is capable of addressing the widest range of topical EAF questions
- The most widely used approach is undoubtedly Ecopath with Ecosim (EwE), which is likely to remain a frontrunner given the user friendly interface and on-going improvements to the software
- However, faced with incomplete knowledge of ecosystem functioning, there has been increasing recognition that definitive conclusions cannot be drawn from a single model structure
- There has thus been a parallel increase in efforts to modularize models so that different components can be easily substituted
- Spatial considerations are similarly playing an increasingly important role in the development of ecosystem modeling approaches

FAO Best Practices for Ecosystem Modeling

- "Careful design and application, raises the stakes for and capabilities of the modeling programs"

- "It is necessary ... to carefully examine assumptions and requirements, and to investigate how different parameterizations and implementations impact model findings."



Model considerations: FAO best practices (key words)

# groups	Age, size, stage structure?	Details in pred-prey relations
Functional response	Spatial structure	Seasonal, temporal structure
System boundaries	Stock structures	Fishing fleets
Prim. prod & nutrient cycling	Environmental forcing	Model recruitment?
Movement	Process & observation errors	Anthropogenic forcing

Model considerations: FAO best practices (key words)

Alternative stable states	Fleet dynamics	Technical interactions
Non-trophic interactions	Fitting to data	Parameter uncertainty
Model structure uncertainty	Management strategy evaluation	Implementation uncertainty
Open source code	Social and economic	Modularization

Notes from WGSAM 2007

- It is important to note that EwE and MSVPA (or other assessment type models such as Gadget) were not created for the same purposes; ... The models should be thought of as complimentary rather than being in competition,
- ... aspirations for comparative work, ... : (1) detailed comparisons using identical input data, and highlighting mechanical differences in the way each model works; (2) simple comparisons of model outputs – when applied to the same fisheries question ...

Table 6.1. Planned model runs for the North Sea EwE, 4M, SMS comparisons.

Model Run	Diet Data 4M/SMS	Diet Data ECOPATH	Period	F
Hindcast 1	1991	1991	1973–2003	F at age from 2005 keyrun
Hindcast 2	1981, 1985–1987, 1991	1991	1973–2003	F at age from 2005 keyrun
Forecast 1	1991	1991	2004–2020	Fpa at group pattern from 4M/SMS
Forecast 2	1981, 1985–1987, 1991	1991	2004–2020	Fpa at group pattern from 4M/SMS
Mesh Size 1	1991	1991	2004–2020	0.50* F_{2004} age 2+ ??
Mesh Size 2	1981, 1985–1987, 1991	1991	2004–2020	0.50* F_{2004} age 2+ ??
Nursery 1	1991	1991	2004–2020	0.25* F_{2004} age 0and1
Nursery 2	1981, 1985–1987, 1991	1991	2004–2020	0.25* F_{2004} age 0and1

My suggestions

- Specify model questions; why are you making a model?
- Get the data organized; that is a necessary and big part of the work
- Start with the simplest model that can address your questions, (1) conceptual, (2) quantify state variables and flows, (3) explore dynamics, (4) gradually add functionality
- Bear in mind: model complexity (as in # of parameters) correlates inversely with predictability

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