GEM – Geochemical and Ecological Modelling

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Eutrophication and Aquaculture in Coastal Systems
Application of Screening Models for Assessment

Farm-scale screening models

International Symposium on Research and Management of Eutrophication in Coastal Ecosystems. Nyborg, Denmark

Session 12 – Eutrophication and Aquaculture

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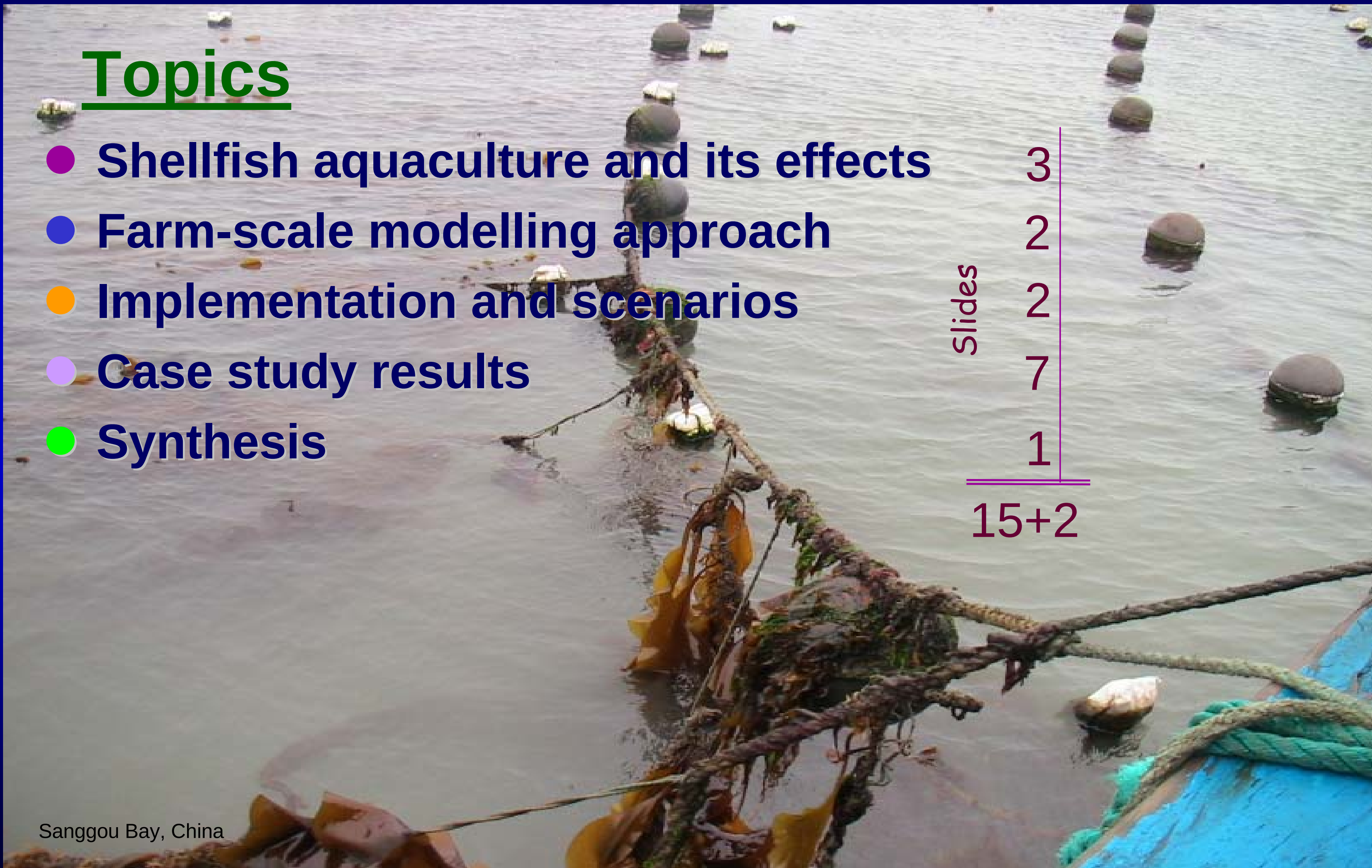
20th-23rd June 2006

Topics

- Shellfish aquaculture and its effects — 3
- Farm-scale modelling approach — 2
- Implementation and scenarios — 2
- Case study results — 7
- Synthesis — 1

Slides: 15+2



Sanggou Bay, China

Farm-scale environmental changes

- Shellfish farming is extensive aquaculture, deployed e.g. in longlines, ropes or trestles
- Water properties are modified during flow across these structures
- Chl *a* and POM are food sources for shellfish, and are reduced by filtration
- TPM distribution is changed by pseudofaeces
- Shellfish provide top-down eutrophication control and increase water clarity, but also reduce O_2
- Polyculture with fish cages reduces environmental impacts of cage farming and enhances crop value
- Polyculture with seaweeds reduces secondary eutrophication symptoms (O_2) and enhances crop value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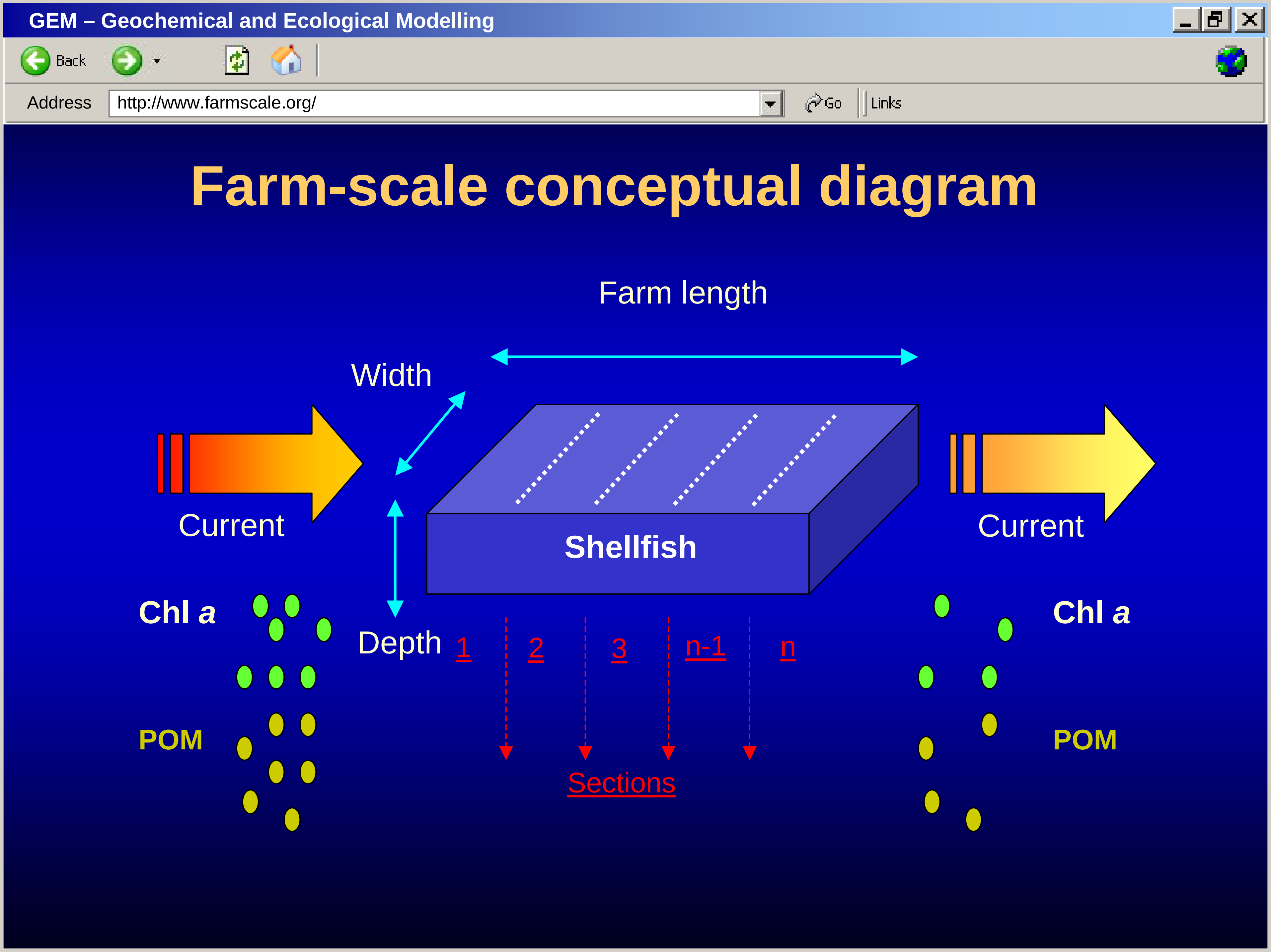
Shellfish
aquaculture effects
Farm
Inflow
Outflow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Farm-scale conceptual diagram
Farm length
Width
Current
Shellfish
Current
Chl a
Chl a
Depth
1
2
3
n-1
n
POM
POM
Sections

Farm-scale modelling
Application to shellfish aquaculture

- **Define farm dimensions**
- **Define environmental parameters (e.g Chl *a*, POM, TPM, O_2)**
- **Select species and culture density**
- **Transport food across farm segments**
- **Calculate food depletion and oxygen consumption**
- **Output cultivation yield**
- **Assess eutrophication status**

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FARM™

Farm Aquaculture Resource Management Model

- Intended for screening purposes
- Uses inputs from field data and larger scale models
- Applies state-of-the-art models for individual shellfish growth
- Developed and tested in C++, FORTRAN, PowerSim™ and Stella™
- Implemented as a client-server application (runs on the web)
- Outputs shellfish yields and key ratios
- Applies ASSETS for eutrophication assessment

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Run the FARM model

Model run - screenshot

Farm layout			Shellfish cultivation			Environment		
Farm width	20	m	Species	Oysters		Water temperature	15	°C
Farm length	300	m	Cultivation period	20	days	Current speed	0.02	$m\ s^{-1}$
Farm depth	10	m	Density (first box)	370	ind. m^{-3}	Chlorophyll *a*	5	ug L^{-1}
N° sections	3		Density (middle box)	370	ind. m^{-3}	POM	5	mg L^{-1}
Section volume	20000	m^3	Density (last box)	370	ind. m^{-3}	TPM	25	mg L^{-1}
Total animals	22200000	ind	☑ Use shellfish			Dissolved oxygen	9.02	mg L^{-1}
☑ Bottom culture			☑ Use population			ASSETS score	High	

Harvestable biomass			Harvestable animals			Environment		
First box	-	tons	Adults (first box)	-	ind	Chl *a* (first box)	-	ug L^{-1}
Middle box	-	tons	Adults (middle box)	-	ind	Chl *a* (middle box)	-	ug L^{-1}
Last box	-	tons	Adults (last box)	-	ind	Chl *a* (last box)	-	ug L^{-1}
Total harvest (TPP)	-	tons	Adults (total)	-	ind	Chl *a* (average)	-	ug L^{-1}
Biomass ratio (APP)	-	%	Individuals (ratio)	-	%	Chl *a* reduction	-	%
						D.O. (minimum)	-	mg L^{-1}
						D.O. (reduction)	-	%
						ASSETS score		

Stop model...

Open a model: Please select...

Save model: MPP

model run: 72% done...

Internet

FARM
Example results

Five different types of simulations

- **Culture siting scenarios**
- **Culture distribution scenarios**
- **Culture density scenarios**
- **Economic analysis**
- **Environmental assessment (ASSETS)**

Average runtime for 180 day period: 1 minute

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Results – Different culture siting

Farm	Dimensions (m)	Species	Model
	300X20X10	*C. gigas*	PML
Cultivation period (d)	45	45	45
Food	Chl *a* (μg L^{-1})	POM (mg L^{-1})	TPM (mg L^{-1})
	10	5	25
Environment	Density (ind m^{-3})	T (º C)	O_2 (mg L^{-1})
Sections 1,2,3	500,500,500	15	8.7
Current speed	High	Medium	Slow
(m s^{-1})	0.5	0.1	0.02
Total seed (X10^3 ind)	30000	30000	30000
Total harvest (TFW)	727.1	692.4	323.9
Biomass ratio	485	462	216
Final mean Chl *a* (μg L^{-1})	7.9	4.7	2.1
Final min. O_2(mg L^{-1})	8.4	7.7	6.9
Income (k€)	3656	3462	1619

Results – Different culture distribution

Farm	Dimensions (m)	Species	Model
	300X20X10	*M. edulis*	PML
Cultivation period (d)	20	20	20

Food	Chl *a* (μg L^{-1})	POM (mg L^{-1})	TPM (mg L^{-1})
	6	2	25

Environment	Current (m s^{-1})	T (º C)	O_2 (mg L^{-1})
	0.02	15	8.7

Distribution scenario	Increasing	Equal	Decreasing
Density (ind m^{-3})	200,300,400	300 (all)	400,300,200
(9) Sections 1-3,4-6,7-9			
Total seed (X10^3 ind)	18000	18000	18000
Total harvest (TFW)	42.9	42.8	42.2
Biomass ratio	48	48	47
Final mean Chl *a* (μg L^{-1})	3.3	3.0	2.9
Income (k€)	214.5	214	211

Results – Different culture densities

Farm	Dimensions (m)	Species	Model
	300X20X10	*C. gigas*	PML
Cultivation period (d)	180	180	180
Food	Chl *a* (µg L^{-1})	POM (mg L^{-1})	TPM (mg L^{-1})
	5	5	25
Environment	Current (m s^{-1})	T (° C)	O_2 (mg L^{-1})
	0.02	15	8.7
Cultivation scenario	Low	Medium	High
Density (ind m^{-3}) Sections 1,2,3	25 (all)	100 (all)	500 (all)
Total seed ($X10^3$ ind)	1500	6000	30000
Total harvest (TFW)	34.3	137.3	400.2
Biomass ratio	458	458	267
Final Chl *a* (µg L^{-1})	4.3	2.8	0.9
Income (k€)	171.5	686.5	2001

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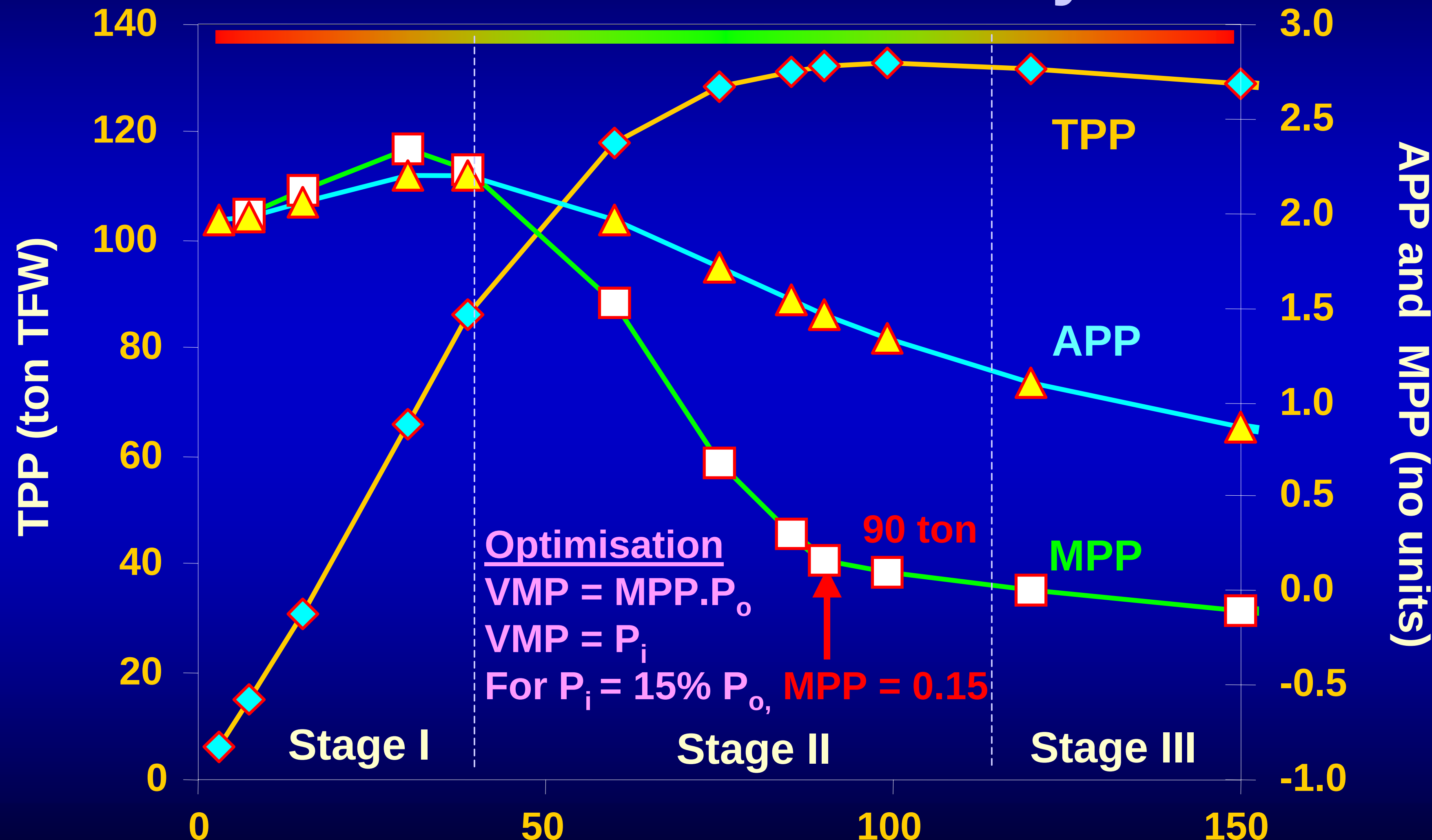
Results – Economic analysis I



C. gigas, 20 day cultivation period, 5 μg L^{-1} chl *a*

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Results – Economic analysis II

Seed (ton)	TPP (ton)	APP	MPP	VMP (€)	TR (TVP k€)	TC (k€)	Profit (k€)
0	0	0	0	0	0	0	0
7.5	15	1.98	1.98	9.9	74	6	69
15	31	2.05	2.12	10.6	154	11	143
30	66	2.20	**2.34**	11.7	329	23	307
39	86	**2.21**	2.23	11.2	430	29	401
60	118	1.97	1.53	7.7	591	45	546
75	128	1.71	0.68	3.4	642	56	586
90	132	1.47	**0.15**	0.8	661	68	**593**
111	**133**	1.19	-0.02	-0.1	**663**	83	580
120	132	1.10	-0.07	-0.3	660	90	570
150	129	0.86	-0.10	-0.5	645	113	532
180	125	0.70	-0.12	-0.6	627	135	492

Notes: Price of input (P_i) = 0.75 € kg^{-1}; Price of output P_o = 5 € kg^{-1}

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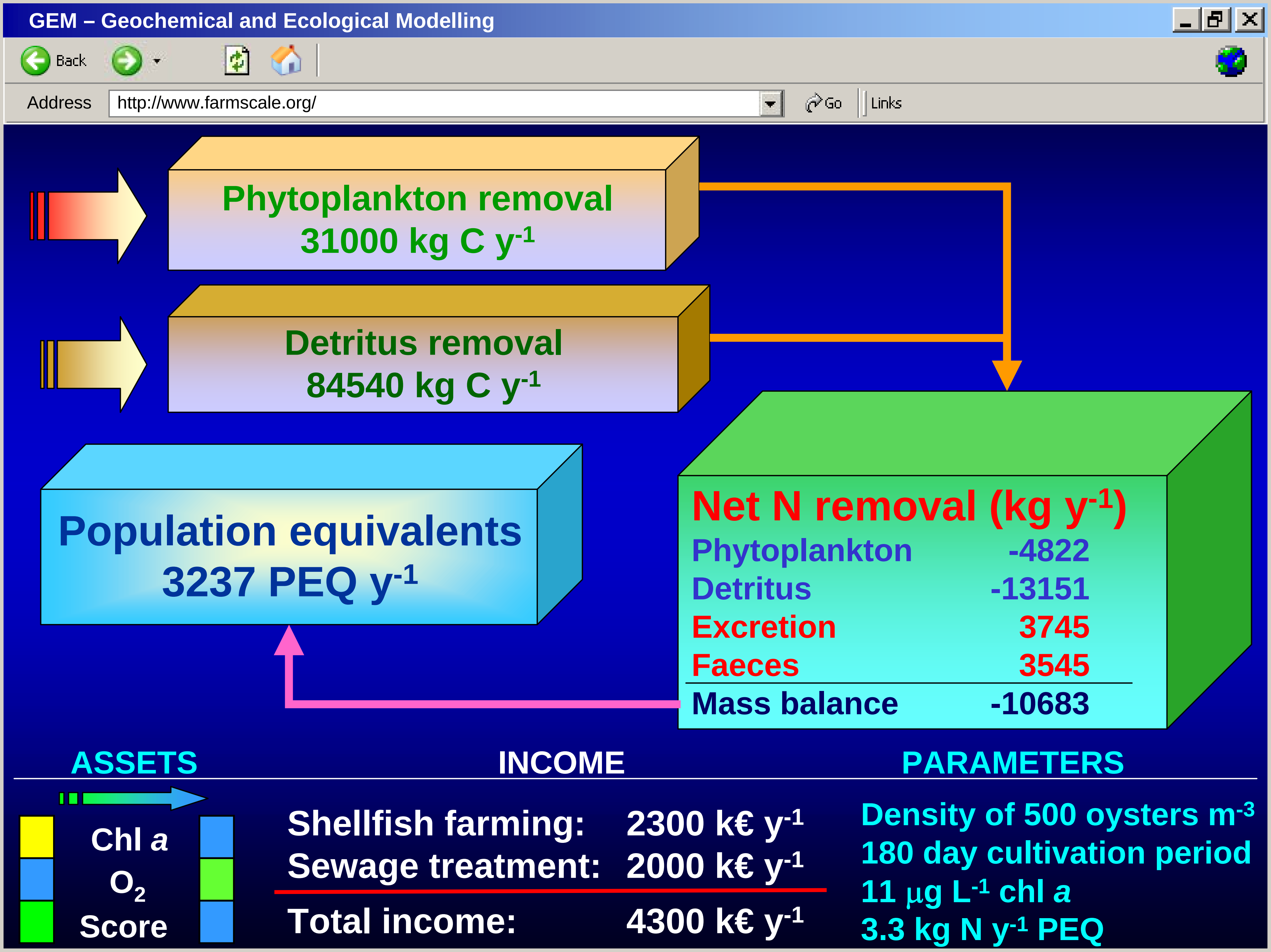
Results – ASSETS model

WFD

Farm	**Dimensions (m)**	**Species**	**Cultivation (d)**
	300X20X10	Generic	45
Food	**Chl *a* (µg L^{-1})**	**POM (mg L^{-1})**	**TPM (mg L^{-1})**
	11	5	25
Environment	**Current (m s^{-1})**	**T (° C)**	**O_2 (mg L^{-1})**
	0.02	15	7.0
Cultivation scenario	**Low**	**Medium**	**High**
Density (ind m^{-3})	25 (all)	100 (all)	500 (all)
Total seed ($X10^3$ ind)	1500	6000	30000
Total harvest (TFW)	13.1	36.8	39.1
Final mean Chl *a* (µg L^{-1})	9.5	6.0	1.3
Final min. O_2(mg L^{-1})	5.9	3.8	1.8
ASSETS grade	Good	Moderate	Poor
Income (k€)	65.5	184	195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Phytoplankton removal
31000 kg C y-1
Detritus removal
84540 kg C y-1
Population equivalents
3237 PEQ y-1
Net N removal (kg y-1)
Phytoplankton -4822
Detritus -13151
Excretion 3745
Faeces 3545
Mass balance -10683
ASSETS
Chl a
O2
Score
INCOME
Shellfish farming: 2300 k€ y-1
Sewage treatment: 2000 k€ y-1
Total income: 4300 k€ y-1
PARAMETERS
Density of 500 oysters m-3
180 day cultivation period
11 µg L-1 chl a
3.3 kg N y-1 PEQ

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Synthesis

- FARM is a screening model directed both at the farmer and the regulator;
- FARM has three uses: (i) Prospective analysis for siting or distribution; (ii) Ecological and economic optimisation of existing farms; (iii) Assessment of farm-related eutrophication effects (including mitigation);
- The seamless integration of ASSETS™, allowing eutrophication assessment, means that FARM is effectively a screening model both for shellfish productivity and water quality;
- The model's simple interface hides complex internal processing, including transport equations, shellfish individual growth, population dynamics, dissolved oxygen balance and the calculation of ASSETS™;
- The FARM model will go live in the Fall of 2006, and will include the possibility of adding fish cages and seaweeds to explore polyculture effects. Different combinations of shellfish polyculture will be implemented in 2007;
- The FARM model is at the forefront of the latest generation of client-server models, part of the rapidly emerging paradigm of *Software as a Service* (SaaS).

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