Ecosystem Services and Societal Benefits

Assessment of goods and services provided by aquaculture to coastal systems. A modelling study of production, environmental effects, and biosecurity.

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Assessment of goods and services provided by aquaculture to coastal systems.

Outline of talk

- The FORWARD project – general approach
- Different questions, different models
- COEXIST: IMTA and environmental externalities
- Incorporation of disease aspects
- The other fifty percent
- Synthesis

Ria Formosa, Portugal
FORWARD study area – The Ria Formosa and its watershed
Framework for Ria Formosa Water Quality, Aquaculture, and Resource Development

Southeastern Portugal: 184 km², 1-3 m tidal range, 13-23 °C, 36 psu. Bivalve and finfish aquaculture, salt extraction, wild fisheries, MPA.
FORWARD modelling framework

Data analysis
- BarcaWin2000 database
- GIS
  - Spatial analysis
  - Statistics
  - Water quality

Drivers
- Individual growth models
  - AquaShell-AquaFish
- System scale ecological model
  - EcoWin2000
- Local scale models
  - FARM
- Hydrological model
  - SWAT
- Hydrodynamic model
  - Delft3D-FLOW

Different models for different questions. Scales are from minutes to decades.
Mass balance for gilthead cultivation

Weight: 350 g, AquaFish model

Anabolism: 1471 kcal
BMR: 277 kcal
SDA: 809 kcal
Swimming: 0.2 kcal

Food ingestion 449 g DW

Feed supplied 463 g DW

Respiration 0.78 kg O₂

Digestion in the gut

Faeces 126 g DW

Organic pollution 140 g DW

Inorganic pollution 7.4 g NH₄

Urine 7.4 g NH₄

Energy assimilated 385 kcal

Cultivation: 414 days
Current: 10 cm s⁻¹
Biomass: 350 g FW
Length: 29 cm
FCR: 1.3
ADC (N): 82%

Feed loss 14 g DW

Anabolism: 1471 kcal
BMR: 277 kcal
SDA: 809 kcal
Swimming: 0.2 kcal
Nutrient discharge from the watershed: 2007-2008 (SWAT)

More than half of the nitrogen and phosphorus load is from non-point sources.
Connectivity: Offshore- Ria Formosa (circulation model)

Tidal circulation in the Ria Formosa, Algarve. Water residence time of 1-2 days.
EcoWin2000 system-scale model – spatial framework

The system is divided into 34 boxes, two vertical layers. Boxes were defined using GIS based on uses, legislation, water quality, and hydrodynamics.
EcoWin2000 model – system-scale clam production

Declared harvest: 2000 t y⁻¹
Actual harvest: >5000 t y⁻¹
E2K model: 2300-6700 t y⁻¹
Revenue: 20-50 million € y⁻¹
Direct jobs: 4000-5000

System-scale carrying capacity is spatially variable, depends on ocean connections.
FARM model for pond culture of finfish
AquaFish model – gilthead bream (Sparus aurata)

Mass balance for gilthead pond culture - models are important for optimization
Gilthead bream culture – FARM model
Comparison of monoculture with polyculture (IMTA)

Culture practice
Cycle: 650 days
Area: 1 ha (4 ponds)
Water intake: 150 m³ d⁻¹ (3% of pond volume)
Culture density: 0.5 fish m⁻², 5 oysters m⁻²

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Monoculture (Gilthead)</th>
<th>Monoculture (oysters)</th>
<th>IMTA (Gilthead + oysters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual weight (g)</td>
<td>329</td>
<td>39</td>
<td>329 + 71</td>
</tr>
<tr>
<td>Production (kg cycle⁻¹)</td>
<td>1860</td>
<td>7</td>
<td>1860 + 1423.5</td>
</tr>
<tr>
<td>Average Physical Product (APP)</td>
<td>74</td>
<td>0.07</td>
<td>74 + 14</td>
</tr>
<tr>
<td>Primary production (kg N cycle⁻¹)</td>
<td>201</td>
<td></td>
<td>61</td>
</tr>
<tr>
<td>Ammonia emissions (kg cycle⁻¹)</td>
<td>97 (50%)</td>
<td>-</td>
<td>194</td>
</tr>
<tr>
<td>Chlorophyll emissions (kg cycle⁻¹)</td>
<td>6.9 (500%)</td>
<td>-</td>
<td>1.4</td>
</tr>
<tr>
<td>ASSETS (eutrophication)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population-equivalents removed</td>
<td>-</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Income (euros)</td>
<td>9303</td>
<td>155</td>
<td>9303 + 4224</td>
</tr>
</tbody>
</table>

**IMTA: greater production, less environmental impact, more profit**
COEXIST - Goods and services from bivalves

• Removal of organic waste from finfish aquaculture
• Detrital organic material enhances shellfish growth
• Bivalves may act as firewall to prevent disease spread

Up to 70% finfish
At least 30% bivalves

Several large areas in the Algarve are currently designated for offshore aquaculture
AquaFish model analysis
Offshore current speed effects on finfish growth

Four current speed classes were identified; class B optimises cultivation period and Feed Conversion Ratio (FCR)
Offshore aquaculture Pilot in the offshore area – APPAA (Armona)

- 480 ha cultivated area
- 60 leases (400 x 200m)
- 70% for fish production
- 30% for bivalve culture
EcoWin2000 - Simulated change in clam harvest due to offshore aquaculture of mussels

An annual loss of 120 t of clams (1.2 million €) is offset by 13,000 t of mussels
Within Site Epidemics

Diagram showing the life cycle of a pathogen, with stages labeled 1 to 5. The diagram also includes a flowchart with boxes labeled S, I, Tr, R, Th, C, and To, indicating the spread and recovery of the disease.
This type of probabilistic approach to disease simulation can be implemented in both system- and farm-scale models.
Disease modelling approach

Integrated Multi-Trophic Aquaculture (IMTA)

Anthropogenic stock movements
Finfish escapes/migrations
Hydrodynamic connectivity

Shellfish aquaculture

Relaying

Offshore
Inshore

Wild stocks
Wild fish reservoirs

Farmed
Fish
Shellfish
Animal welfare – network models
Three levels

Example for three oyster leases

INDEX CASE

Relaying by producers
Finfish: escapes and migrations
Hydrodynamic connectivity

Example for three oyster leases
Virus Particle tracking:
Ratio between concentrations at XYZ and emission concentration

- Disease source: APPAA
- Virus concentration: Up to $2 \times 10^6 \text{ ml}^{-1}$
- Forcing functions wind and tide
- No decay
- 6 day model run
- Release in mid-water layer

Background virus release the first 2 days, high release on days 3, 4 and 5, then a reduction by a factor of a hundred on the last day.
Number of hours of exposure to 0.5% of the shedding concentration as a measure of potential infection.
The FORWARD Project - Carrying capacity
Social aspects and governance - The other 50%…

- Even if you solve 50% of the problem, you still need to resolve the other half
- **Social aspects and governance** cannot be modelled, but are very important
- Examples: moving animals among regions can spread disease; small leases can conflict with each other; governance issues over the use of machines; obstacles to certification
- Lots of plans, no practical results – respecting multiple uses (third principle of EAA): the Paper Park syndrome
- Good governance is a major element of success

Mathematical models can address part of the issues, but that still leaves the rest…
The four orders of coastal governance outcomes

First order: Enabling conditions
- Formalized mandate with implementing authority
- Management plans adopted
- Funding secured
- Constituencies present at local and national levels

Second order: Changes in behaviour
- Changes in behaviour of institutions and stakeholder groups
- Changes in behaviours directly affecting resources of concern
- Investments in infrastructure

Third order: The harvest
- Some social and/or environmental qualities maintained, restored, or improved

Fourth order: Sustainable coastal development
- A desirable and dynamic balance between social and environmental conditions is achieved

Avoiding the ‘paper park’ syndrome...

Olsen, 2003
Synthesis

- A set of models that address different issues, at different time and space scales, can be very valuable for coastal management;
- Disease prediction is a key aspect of aquaculture, but it cannot be modelled deterministically;
- Risk-based approaches and stochastic simulations can be combined with growth models to address disease;
- We cannot model the vagaries of the human mind—but for sustainable development, we need to factor them in;
- Sound governance, and stakeholder-driven participation, are key factors in making the public understand that aquaculture can and should be a positive sum game;
- Integrated Coastal Zone Management is not just about the environment—it is also about jobs and food.

http://ecowin.org/forward/  http://coexistproject.eu