Modeling aquaculture in common water bodies in Southeast Asia

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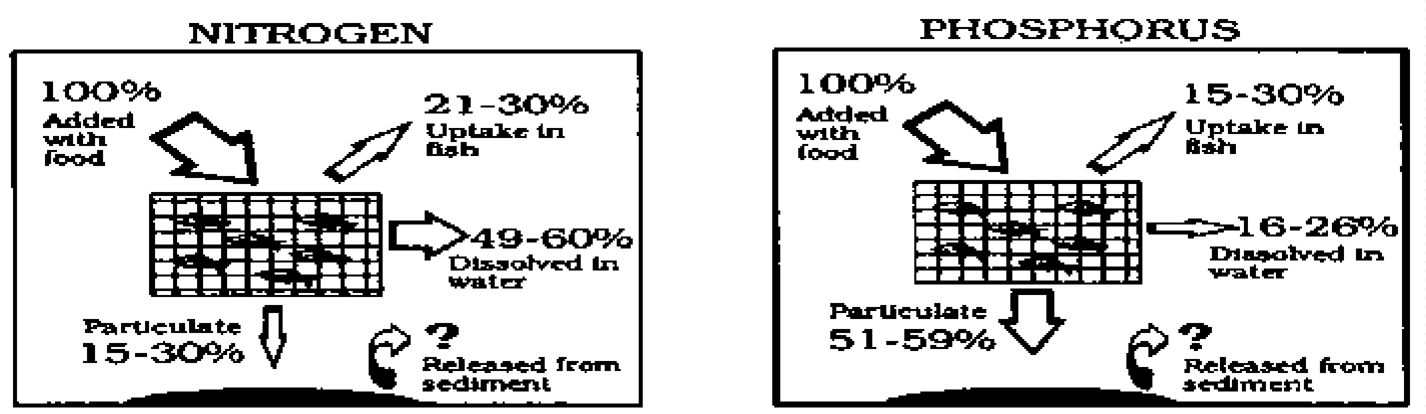
SOY-FED FISH
Farming the land to sustain the sea

The issue

- Fish in cages have environmental impacts:
  - Organic deposition of feces and uneaten feed
  - Ammonia production
  - Other (genetics, invasive species, drugs/chemicals, etc.)
  - Note: Only 25-30% of feed fed to fish ends up as harvested fish tissue – the rest ends up in the environment



Ecosystem services

- The ecosystem provides services if it is not overwhelmed:
  - Primary production
  - Nitrification (ammonia → nitrate)
  - Decomposition of organic matter

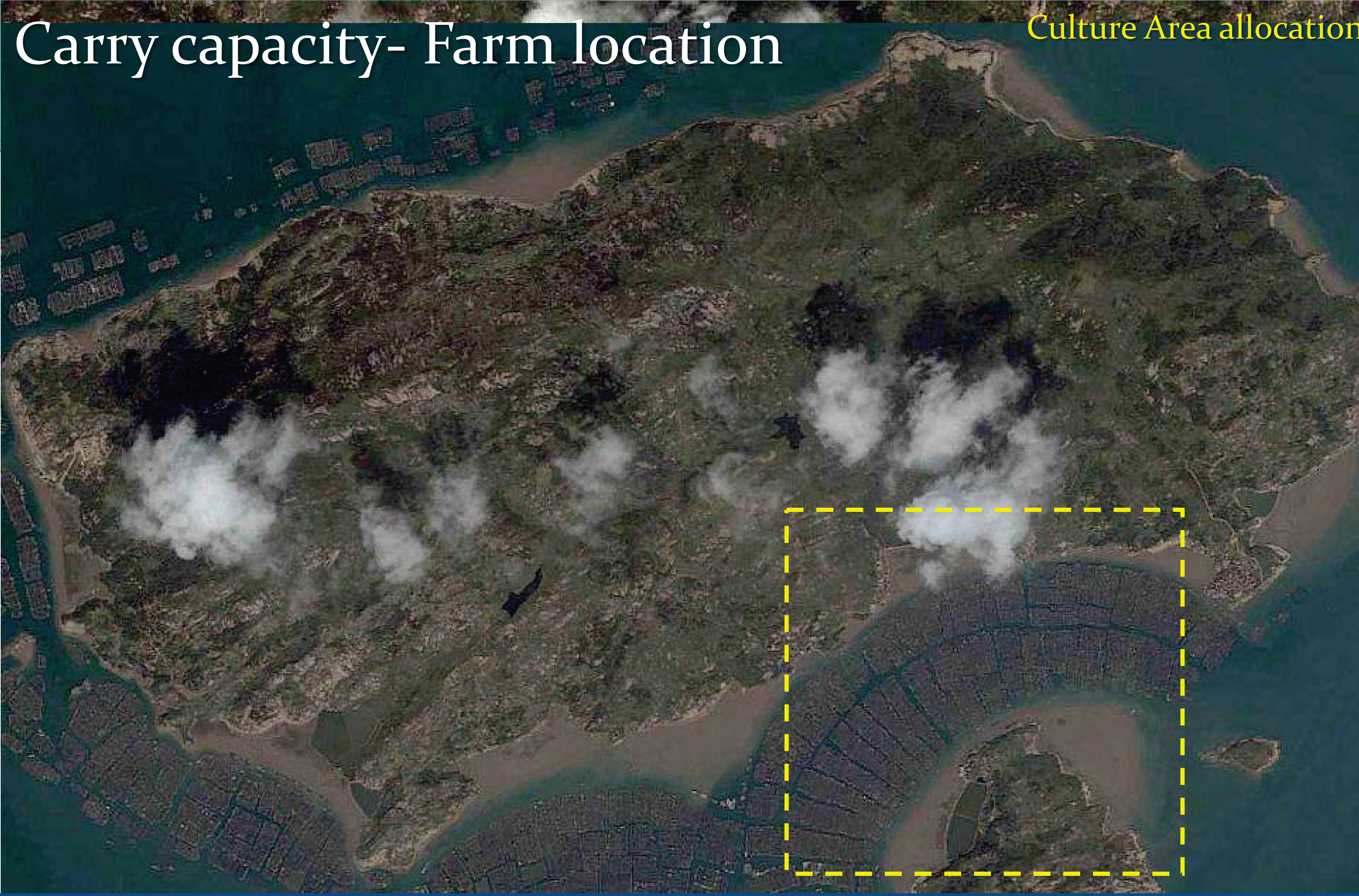
Open water bodies

- Lakes, reservoirs, estuaries, bays
- Fish in cages rely on ecosystem services outside the cages via water flow
  - Removal of feed and feces
  - Removal of ammonia
  - Removal of CO_2
  - Provision of O_2

How much fish production is too much?

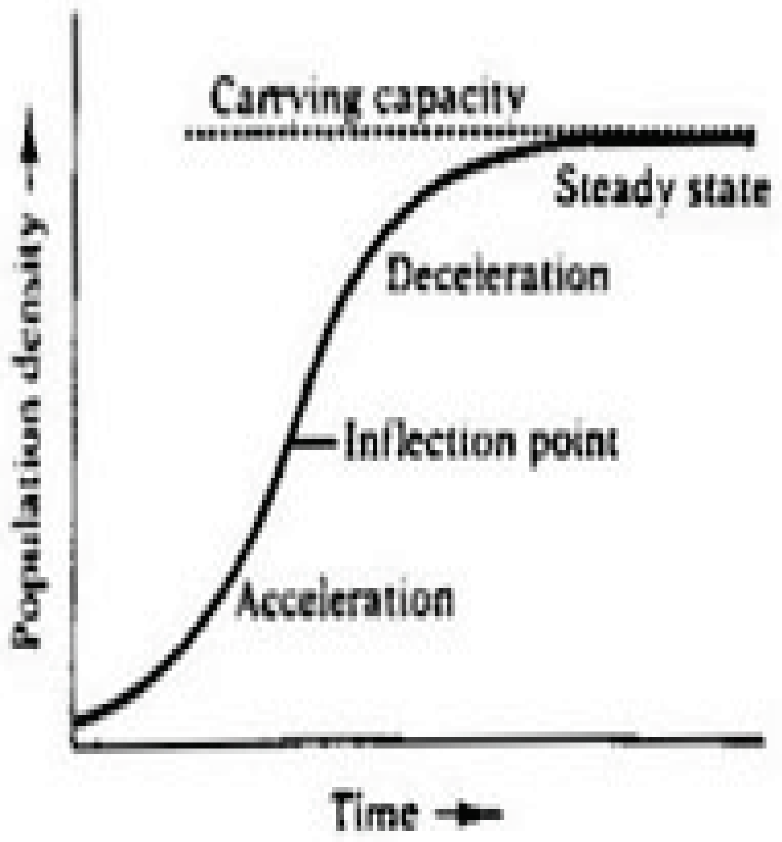
- Small-scale impact vs. ecosystem impact
  - One farm may have a small-scale, local impact (just in the vicinity of the farm) on a water body
  - Many farms together may have an ecosystem-level impact
    - Overwhelms the ecosystem services, not only for the farms, but for everything else
    - “Kills” the body of water

Carry capacity- Farm location



A negative example from Fujian Province in China – maximum 30% survival and very poor water quality. This is NOT what we want to see in Southeast

Carrying capacity



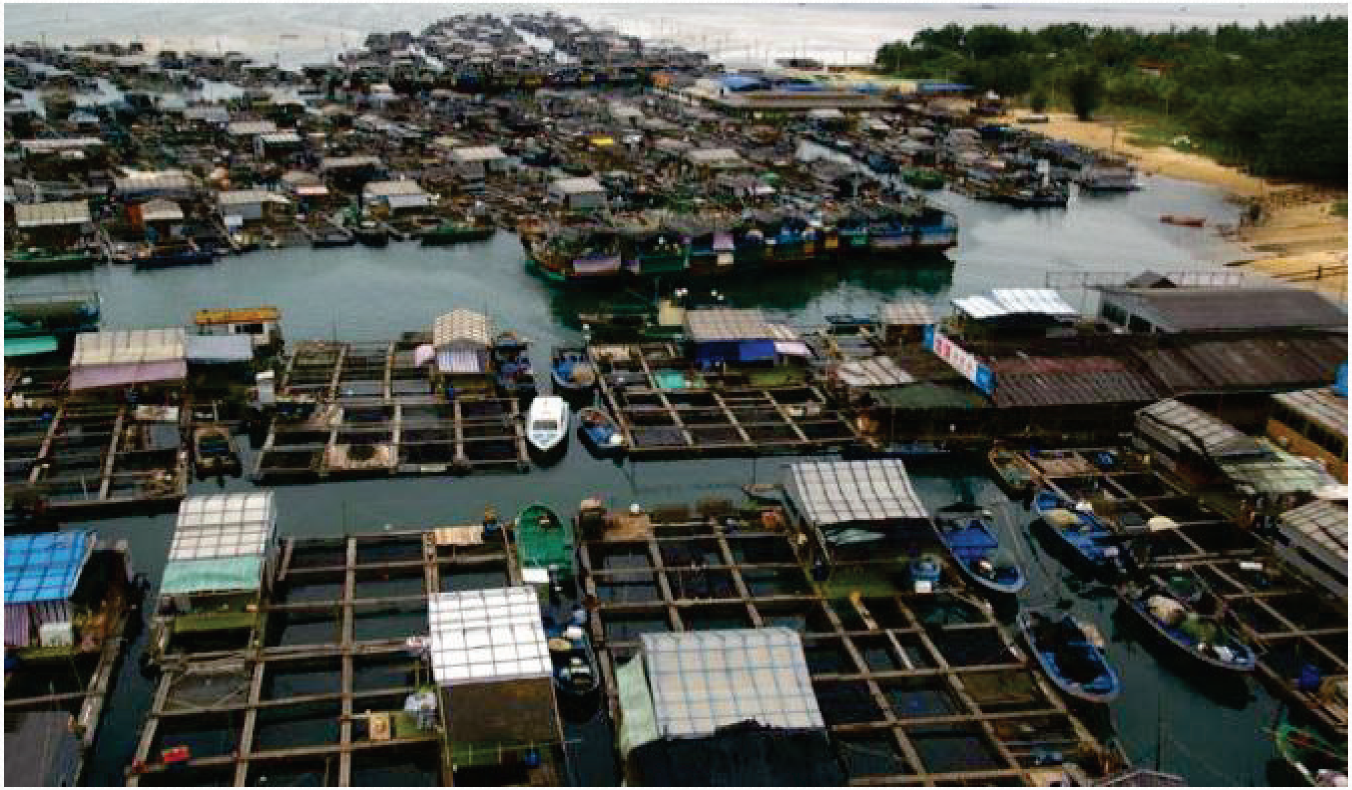
The logistic growth curve

Aquaculture carrying capacity

- Physical CC
- Production CC
- Ecological CC
- Social CC

Physical carrying capacity

- The amount of aquaculture that can physically fit into a body of water

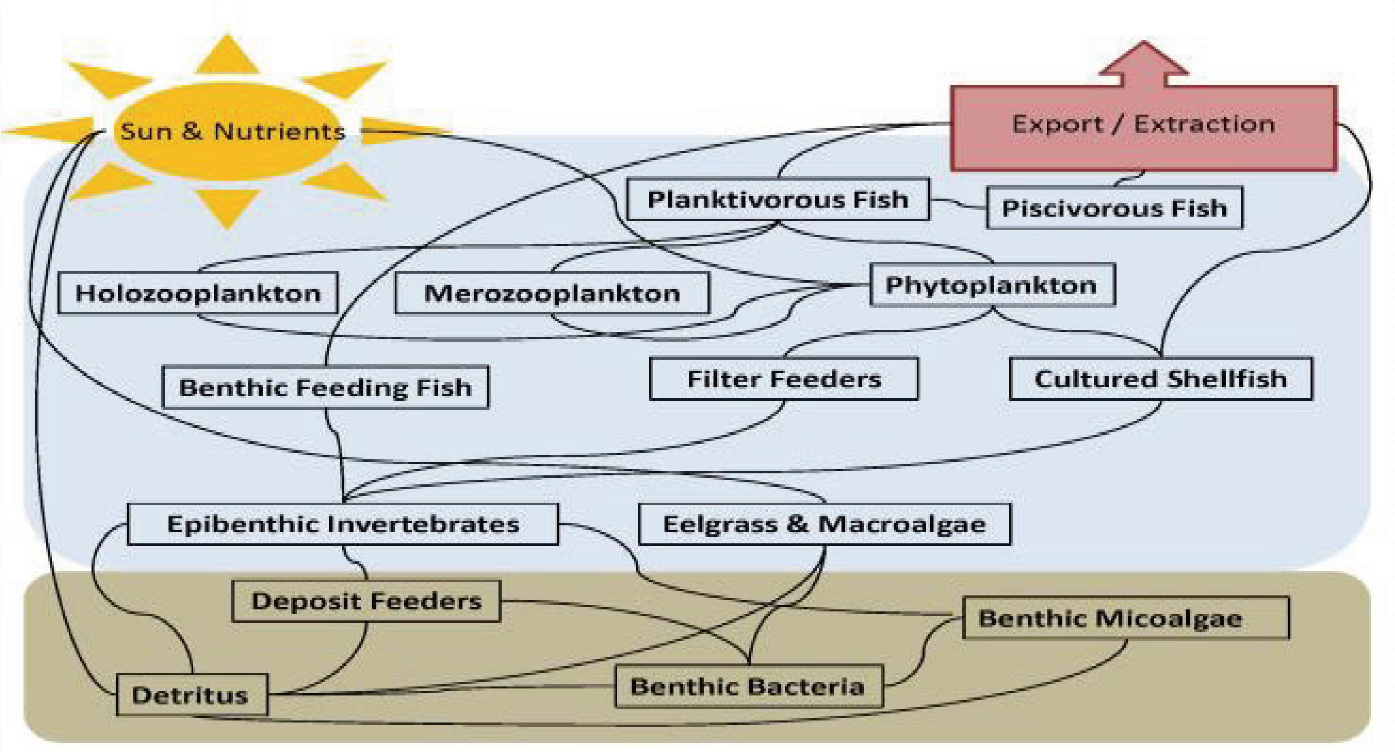


Production carrying capacity

- Maximum aquaculture production that does not have <u>unacceptable</u> impacts on the farm itself

Ecological carrying capacity

- Maximum aquaculture production that does not cause <u>unacceptable</u> impacts to the ecosystem



Social carrying capacity

- Maximum aquaculture production that does not cause <u>unacceptable</u> impacts to the social system (e.g., fishermen, tourism)

Models

- A model is a representation of the relationships among variables
- Can be very simple
- Can be very complex

A simple model

- $dC/dt = (N/U) - FC$, where C = nutrient concentration, N = nutrient input, U = volume, and F = flushing rate

A complex model

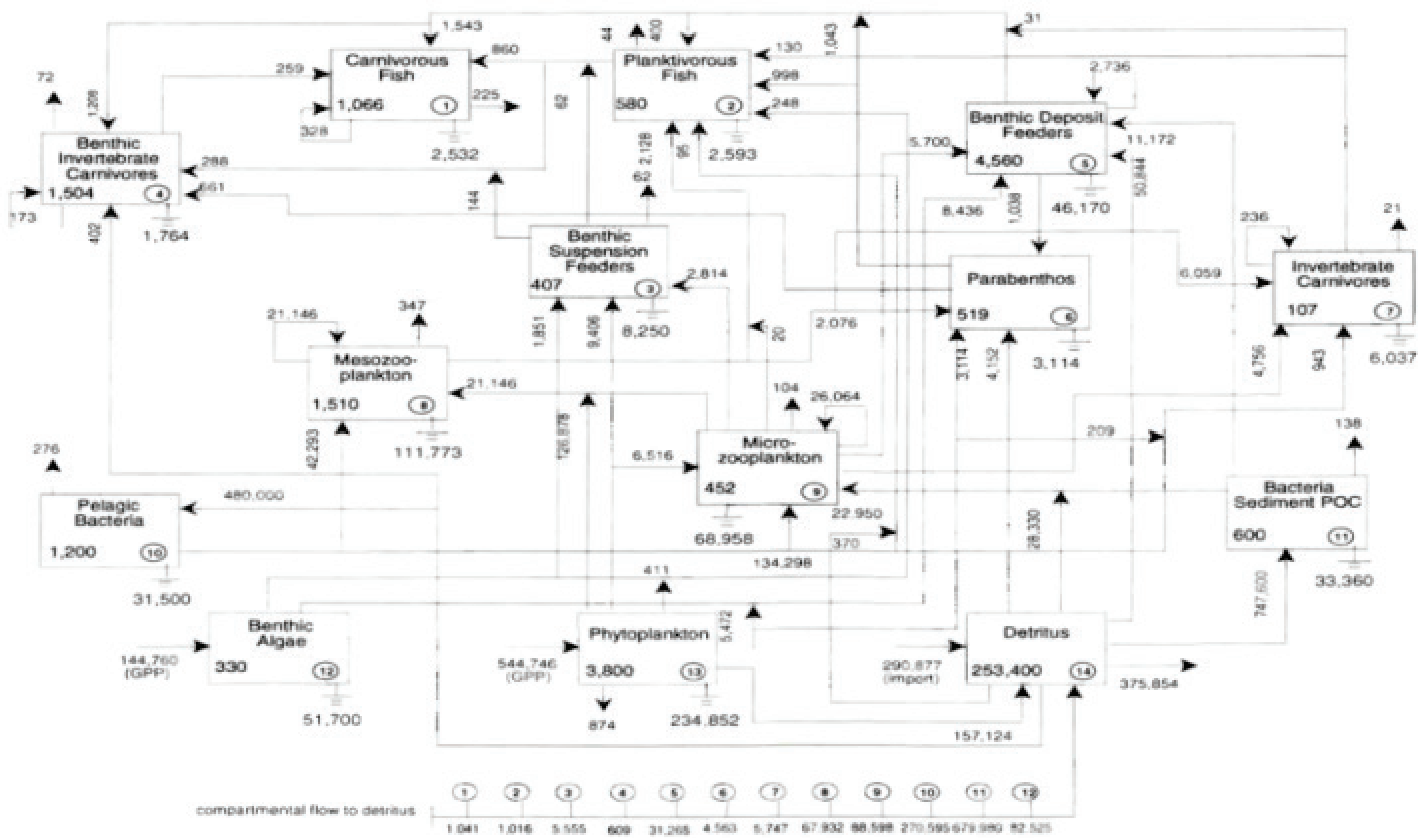


Fig. 2. Average annual energy flow (mg C m⁻² yr⁻¹) and compartmental biomass (mg C m⁻²) in Narragansett Bay

Utility of models

- To be useful, a model should be:
  - Complex enough to realistically describe the system under consideration
  - Not so complex that regulators refuse to use it

Continuous spectrum of models (Holling)

Empirical ⟵--------------------⟶ Abstract
(practical use) (general insights)

Realism, precision, generality

Aquaculture models

- Lots of uses for modeling in aquaculture, esp. at the “empirical” end of the spectrum
  - 1. Pond management (modeling pond dynamics, e.g., to predict DO levels)
  - 2. Recirculation system performance
  - 3. Genetic interactions (cultured vs. wild)
  - 4. Bioenergetics (e.g., fish production as a function of feeding rates, DO levels, temp)
  - 5. Effects of aquaculture operations on the environment (organic enrichment, drugs/chemicals)

Aquaculture effects models – what level of complexity?

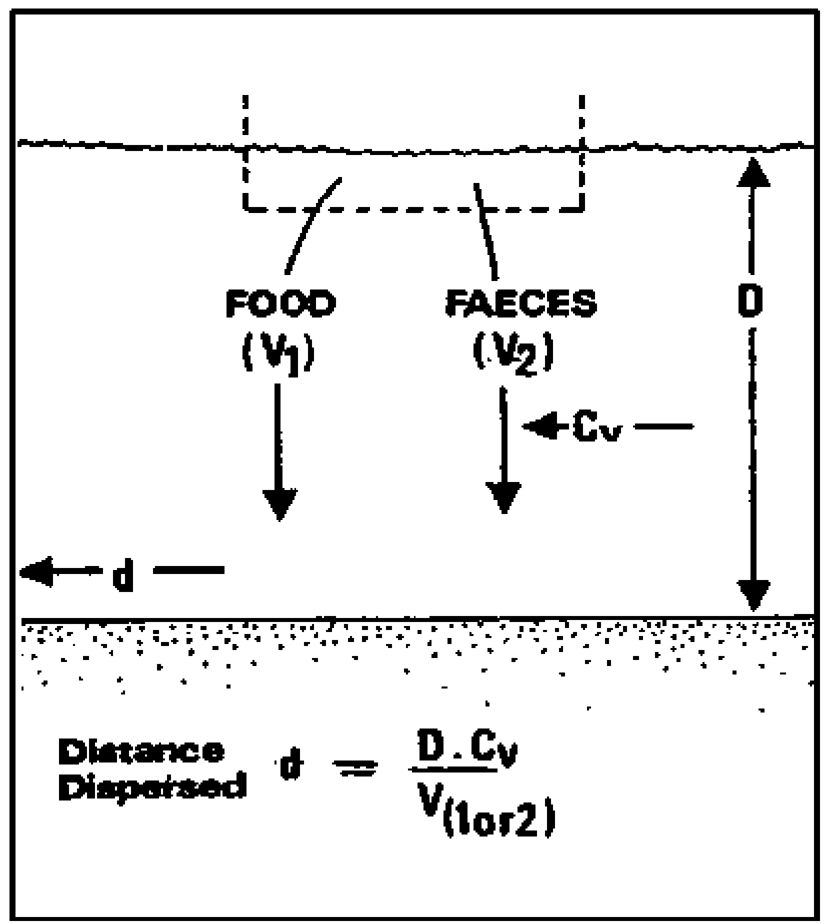
- Generally require knowledge of:
  - Hydrodynamics – currents, tides, river inflows, bottom topography
    - 2-D or 3-D?
    - Do we assume that all fjords in Norway are the same or should we have a separate model for each?
  - Rate of input of a material to the system
    - Seasonal/temperature effects?
  - Performance of the material in the system
    - Settling rates, solubility

Types of models for aquaculture impacts on environment

- Benthic deposition
- Water quality
- Ecosystem
- Decision support systems

Benthic deposition models

- Gowen et al. (1989)
- Hevia et al. (1996)
- Silvert (1994)
- Findlay & Watling (1997)
- Panchang et al. (1997)
- Dudley et al. (2000)
- Cromey et al. (2002)
- Corner et al. (2006)
- DEPOMOD
- TROPOMOD (milkfish)



Water quality models

- Kishi et al. 1994 – Japan. Four components
  - Current simulation model
  - COD diffusion model
  - DO diffusion model
  - Accumulation model
  - Many grid points in bay to give spatial distribution
  - System-wide, includes COD loading from rivers
  - Can identify the best placement of cages in the bay

Water quality models (cont.)

- Kishi and Uchiyama (1995) – 3-D numerical model for N in Shizugawa Bay, Japan. Calculation of:
  - Spatial distribution of PON
  - Spatial distribution of DO
  - Spatial distribution of DON
  - Spatial distribution of DIN
  - Horizontal distribution of accumulated deposits from mariculture

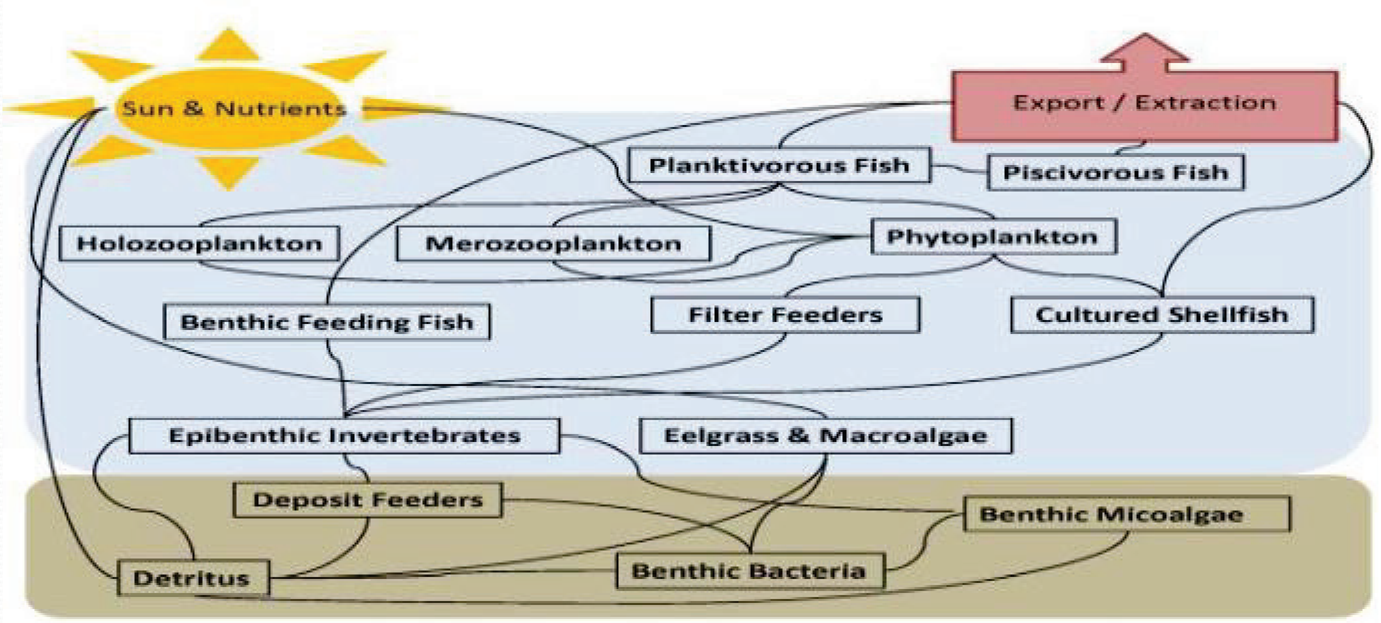
  (Included DIN loading from rivers)

Water quality models (cont.)

- Beveridge (1996) – Mass-balance modeling for cage culture impacts
- Hanafi et al. (2006) – CC of Kaping Bay, Bali
- Akvaplan-Niva work – Philippines; Gecek and Legovic (2010)
  - Taal Lake – Volume of lake plus water input/output; nutrients introduced via fish farms; calculation of productivity
  - Bolinao Bay – ditto
  - Too much fish production in both places

Ecosystem trophic-web models

- Allows calculation of ecological CC
- Based on a balanced ecosystem
- Add aquaculture production in increments until system becomes unbalanced



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No fish
is an
island

Ecopath with Ecosim (EwE) is a free ecological/ecosystem modeling software suite. EwE has three main components: *Ecopath* – a static, mass-balanced snapshot of the system; *Ecosim* – a time dynamic simulation module for policy exploration; and *Ecospace* – a spatial and temporal dynamic module primarily designed for exploring impact and placement of protected areas. The Ecopath software package can be used to

- Address ecological questions;
- Evaluate ecosystem effects of fishing;
- Explore management policy options;
- Analyze impact and placement of marine protected areas;
- Predict movement and accumulation of contaminants and tracers (Ecotracer);
- Model effect of environmental changes.

Created by UBC Fisheries Center

EcoWin2000 – Ecosystem model

- Originally developed by Ferreira (1995)
- Incorporates trophic levels, nutrients, transport, inflows
- Used primarily for shellfish culture

Decision Support Systems

- Van der Wulp et al. (2010) DSS for Bali coastal aquaculture
- Halide et al. (2009)
  - Site classification
  - Site selection
  - Holding capacity determination
  - Economic appraisal of a farm at a given site
  - CADS_TOOL (ACIAR)

National programs - Norway

- LENKA (began 1987)
  - Efficient and standardized tool for coastal planning
  - Model developed for estimating the production capacity of an area
- M-O-M (began 1997)
  - (Modelling – Ongrowing fish farms – Monitoring)
  - Level of monitoring for environmental impacts depends on the level of exploitation of the site
  - Modified for application to grouper, barramundi, and rabbitfish in Asia

General observations from my survey last year

- Thailand, Vietnam, Philippines, Indonesia
- I was talking to national regulators, but local governments control permits
- Industry could be much more efficient
- Strategic plans emphasize increases in production, not sustainability

General observations from my survey last year – issues for modeling

- Models wanted for multiple systems (bays, ponds, lakes/reservoirs, rivers
- Uncertainty (or different opinions) about what to protect – farms or whole ecosystems?
- Very limited data available
- Universities or research institutes have some modeling ability

Industry inefficiency

- A lot of fish feed is wasted by sinking feeds falling through the cages
- Poor water quality causes increased disease
- Disease leads to mortality; loss of money
- Really poor water quality leads to fish kills; loss of money and bad publicity
- Industry could be made much more profitable with better practices
- Thus, we can "sell" the idea of carrying capacity on an economic basis, not just ecological

Modeling recommendations

- Do what we can with the data available
  - Mass-balance models (water volume, inflow, outflow, nutrients added by aquaculture)
  - Water quality models (using existing hydrodynamic data for coastal areas)
- Gather more data to use more complex models in the future
  - Ecosystem models

Similar problems everywhere

- In all the countries I've visited, the issues are very similar
- Little modeling of aquaculture carrying capacity
- Much interest in the subject
- Many issues to resolve
- If SE Asia countries join together in a regional approach, they may have an easier time

Regional meeting

- USSEC Common Water Body Modeling Conference
- Objectives:
  - Acquaint participants with issues of aquaculture carrying capacity (ACC) in the SE Asia region
  - Introduce participants to modeling and spatial planning tools for ACC
  - Identify and prioritize aspects of ACC that can be addressed on a regional basis
  - Develop recommendations for specific activities to address ACC as a regional initiative

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