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Livestock and Fish

More meat, milk and fish by and for the poor

Report of the ASARECA Workshop on Cage Aquaculture and the Environment Jinja, Uganda, 14-15 March 2013

Compiled by Malcolm Beveridge

www.livestockfish.cgiar.org

CGIAR is a global partnership that unites organizations engaged in research for a food secure future. The CGIAR Research Program on Livestock and Fish aims to increase the productivity of small-scale livestock and fish systems in sustainable ways, making meat, milk and fish more available and affordable across the developing world. The Program brings together four CGIAR Centers: the International Livestock Research Institute (ILRI) with a mandate on livestock; WorldFish with a mandate on aquaculture; the International Center for Tropical Agriculture (CIAT), which works on forages; and the International Center for Research in the Dry Areas (ICARDA), which works on small ruminants. http://livestockfish.cgiar.org

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Introduction

The following report provides a summary account of the workshop on Cage Aquaculture and the Environment, held at the National Fisheries Resources Research Institute (NaFIRRI), Jinja, Uganda, 14-15 March 2013. The work was instituted as part of the ASARECA project titled '**Building Public Private Sector Partnership to Enhance the Productivity and Competitiveness of Aquaculture in the ECA Region**'. The workshop also contributes to the targeting theme of the CGIAR Livestock and Fish Research Program.

The rearing of fish in cages[1] accounts for 10% of global farmed fish production. However, in some sectors, such as salmon farming, it is particularly important, accounting for more than 90% of production.

Cage aquaculture generally occurs in public waters - sheltered inshore coastal areas, lakes and reservoirs and rivers - and relies heavily on the supply of the ecosystem services that the water body provides, including:

- space in which the farm is located;
- water to support the fish, supply oxygen and disperse and assimilate potentially harmful wastes and metabolites;
- food (plankton), which supplements that supplied by the farmer.

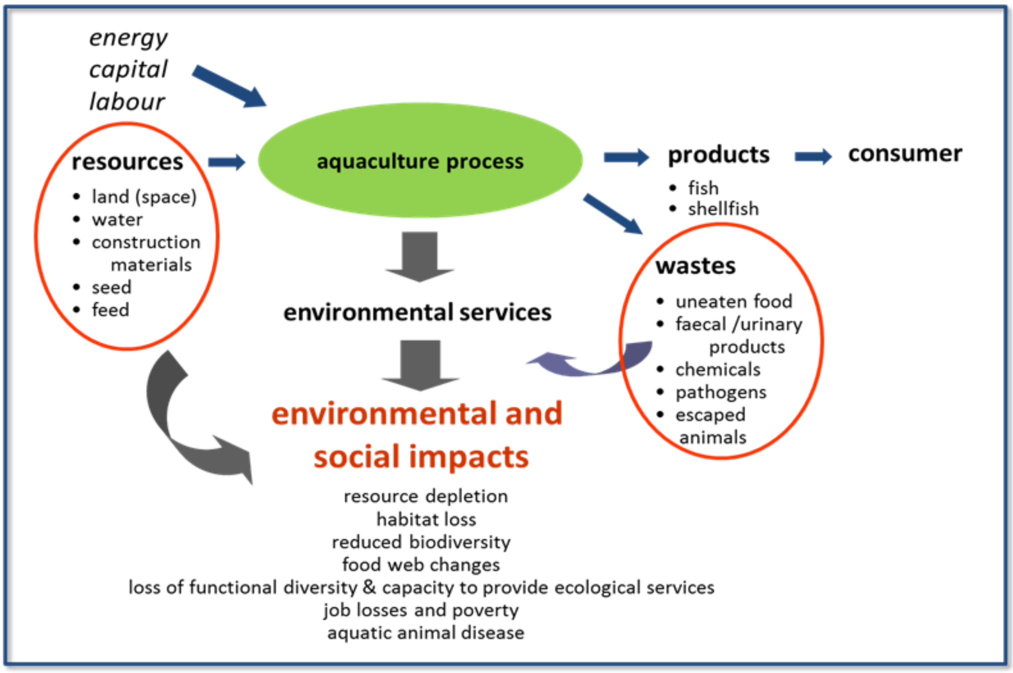


Figure 1: Relationships between cage aquaculture and the environment

[1] *'… rearing facilities in which all sides, including the bottom, are enclosed by wooden, mesh or net screens*; see Beveridge, M C M (2004). *Cage Aquaculture*. 3d Edition. Oxford, Blackwells.

There are many examples, particularly from Asia, that show that unless planned and implemented well cage aquaculture can be a socially and environmentally highly disruptive technology, eroding social and environmental capital and reducing biodiversity and the supply of ecosystem services (Figure 1). This not only undermines the sustainability of cage operations but also impacts on both livelihoods, especially of the poorest, who often have greatest dependency on aquatic natural resources, and on other sectors of the economy such as fishing and tourism.

Cage aquaculture provides opportunities to farm fish in areas where land is scarce, offering opportunities to landless poor to engage. Productivity of cage farming appears very high – up to 500 kg fish m^{-2} of cage y^{-1} (5000 t ha^{-1} y^{-1}). The figures, however, are misleading. First, cage farms are three-dimensional, cage nets often extending 5-10 m in depth. Moreover, a water body cannot be filled with cages; the proportion of water surface that can be sustainably occupied by cages in freshwaters is in the order of 0.1 – 0.5%.

Cage aquaculture has thrived in the coastal waters of Northern Europe, North and South America and in the inland waters of Asia, especially China, Philippines, Indonesia, Vietnam and more recently Bangladesh. However, cage farming has also appeared in Africa, where in addition to providing a source of much needed fish it is also causing concern around governance of common property resources and the exacerbation of anthropogenic pressures on some of the most biodiverse freshwater aquatic ecosystems in the world, which support the livelihoods of millions of poor people. Cage aquaculture currently occurs in Lake Victoria, Lake Tanganyika and Lake Malawi. On the Zambian side of Lake Kariba, there have been at least four applications for large scale cage aquaculture operations in the past 18 months.

The two day workshop was designed to explore these issues among a group of 22 research scientists and farmers from Kenya, Tanganyika and Uganda (Annex 2). The course was designed to raise awareness of environmental issues, the consequences of ignoring these, the tools available to incorporate cage aquaculture into more comprehensive lake management programs and how to mitigate impacts. The workshop consisted of lectures and discussions, visits to two cage farms on Lake Victoria and to the environmental laboratories at NaFIRRI research station (see Fig 2.).

Workshop structure

The workshop was hosted by NaFIRRI and Source of the Nile Fish Farm, both members of the ASARECA project. In addition to field visits, the discussions centered on:

- cage aquaculture technology;
- the origin and quantification of cage aquaculture wastes;
- modeling of waste impacts and environmental capacity;
- the design and implementation of monitoring programs;
- mitigation of impacts.

Copies of water quality manuals[2] were purchased in the UK and sent to Uganda and distributed among delegates, with one copy also being deposited in the NaFIRRI library.

Figure 2. ASARECA Workshop participants visiting cage facilities at SoN cage farm, lake Victoria

[2] Stirling, H. P. (ed.) (1985). *Chemical and Biological Methods of Water Analysis for Aquaculturists*. Bridge of Allan, UK. Pisces Press.

Report structure

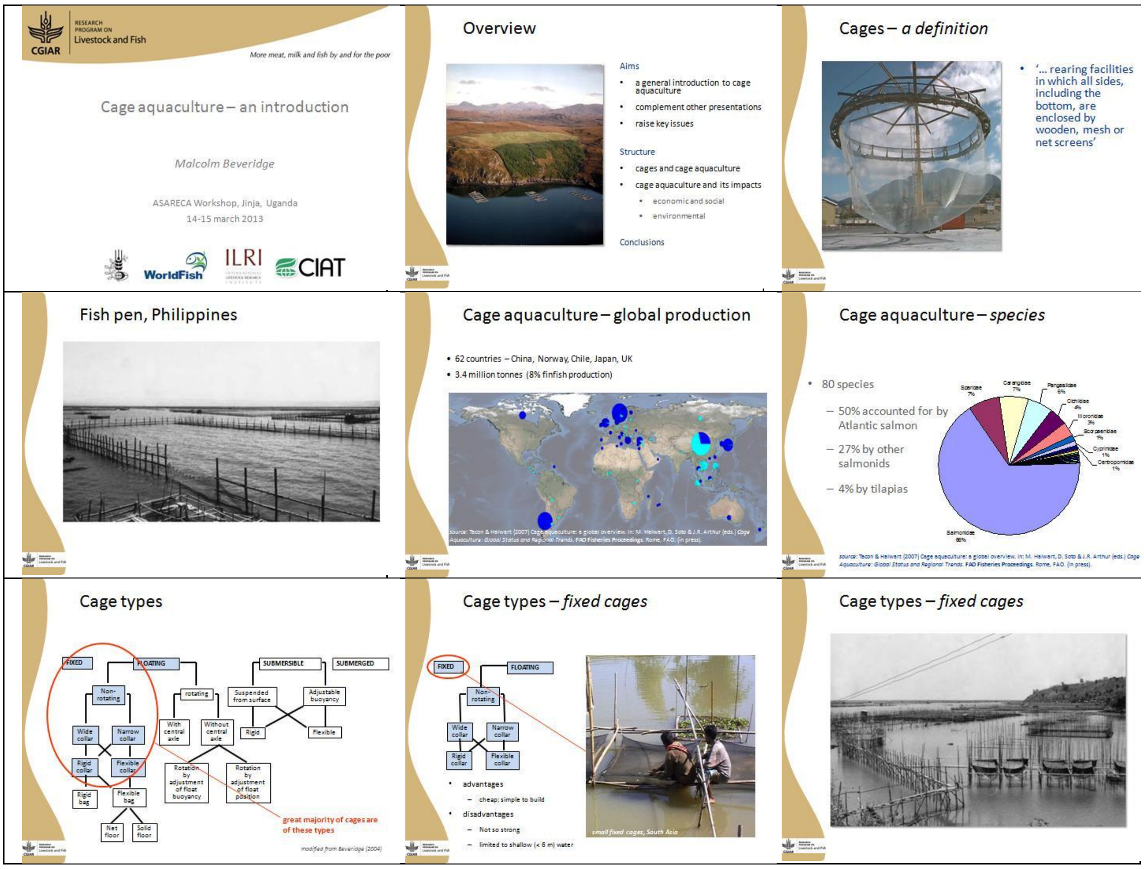
The report consists of the course PowerPoint presentations and a list of references. Annexes 1 and 2 provide the Agenda and list of attendees.

Powerpoint material

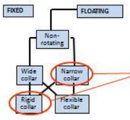
There are six Powerpoint presentations, beginning with an introductory set of slides designed to stimulate discussion on the advantages and disadvantages of cages over other water based and land based aquaculture systems, cage design, installation, management and problems. The five remaining presentations summarize key environmental issues and their management, especially in the context of the ASARECA research project and in development of cage aquaculture in African lakes.

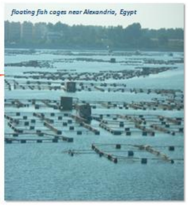
PDFs of all PowerPoint material were also circulated to workshop attendees.

Cage Aquaculture – an Introduction



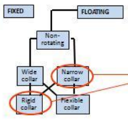
Cage types – *floating cages*

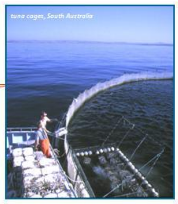




- advantages
  - cheap; simple to build
  - strong
- disadvantages
  - difficult to work from if big

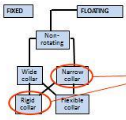
Cage types – *floating cages*





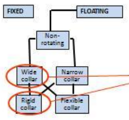
- advantages
  - cheap; simple to build
  - strong
- disadvantages
  - difficult to work from if big

Cage types – *floating cages*



- advantages
  - cheap; simple to build
  - strong
- disadvantages
  - difficult to work from if big

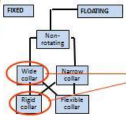
Cage types – *floating cages*

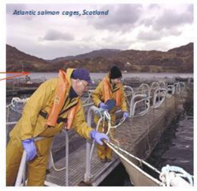


courtesy: M J Phillips

- advantages
  - cheap; simple to build
  - strong (depends on materials and construction)
- disadvantages
  - difficult to work from if big

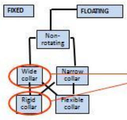
Cage types – *floating cages*





- advantages
  - strong
- disadvantages
  - expensive

Cage types – *floating cages*



- advantages
  - strong
- disadvantages
  - expensive

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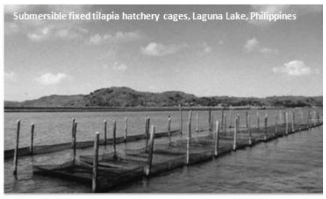
problems

Water hyacinth

- A problem that can affect cages
- Solutions
  - siting
  - cage design

Water hyacinth – *submersible fixed cages*



Predators

Table 7.1 Predators at cage fish farms. Latin names are given where possible (see also text).

Country	Farmed species	Predator	Comments	References
United States				
Washington	Salmon	Dogfish[a]	Particular problems with larger mesh sizes	Mahnken 1975
Maine	Trout	Mink, otters	Metal mesh cages used	Lindbergh 1979
Canada				
New Brunswick	Salmon	Gulls[b], herons[c], cormorants[d]	Large numbers of unrecorded losses attributed to birds	Henderson 1980
British Columbia	Salmon	Seals[e], sealions[f], otters[g], mink[h], racoons[i], herons[c], kingfishers[j], gulls[b,k], cormorants[l], etc.	22 species of birds and 7 species of mammal involved	Rueggeberg & Booth 1989
UK				
Scotland	Salmon, trout	Seals, otters, cormorants, shags, mergansers[m], goosanders[n], guillemots, gannets[o], gulls[p]	List derived from many surveys	Mills 1979; Beveridge 1988; NCC 1989, 1990; Carss [illegible]
England	Trout	Gulls, grebes[q], cormorants	Damage to nets by diving birds	Beveridge 1988
Norway	Salmon	Herons, gulls, cormorants, seals	More than 50% losses at some farms attributed to predators	Möller 1979
Israel	Sparus sp.	Moray eels, squid	Lots of small fish also found in cages	Pitt et al. 1977
Malaysia	Marble goby	Snakeheads[r], water snakes	Damage to nets and mortalities in fresh water	Jee 1978
	Grouper	Otter[s], gulls, puffer fish[t]	Nets damaged by puffer fish. Dogs used to deter otters	Chua & Teng 1980
Australia				
Tasmania	Salmon	Seals	Up to 40% mortalities caused at one site	Pemberton & Shaughnessy [illegible]

[a] Squalus acanthias; [b] Larus argentatus, L. marinus; [c] Ardea herodias; [d] Phalacrocorax auritus; [e] Phoca vitulina; [f] Eumetopias jubatus, Zalophus [illegible]; [g] Lutra canadensis; [h] Mustela vison; [i] Procyon lotor; [j] Megaceryle alcyon; [k] Larus glaucescens, L. philadelphia; [l] Phalacrocorax auritus, P. penicillatus; [m] [illegible] serrator; [n] Mergus merganser; [o] Sula bassana; [p] Larus spp.; [q] Podiceps cristatus; [r] Ophiocephalus sp.; [s] Lutra sumatrana; [t] Sphaeroides sp.

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Cage Aquaculture and the Environment I. Resource Use and Wastes

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Cage Aquaculture and the Environment I: resource use and wastes

Malcolm Beveridge

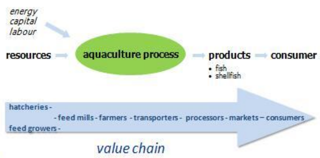
ASARECA workshop, Jinja, Uganda 14-15 March 2013

WorldFish ILRI CIAT

overview

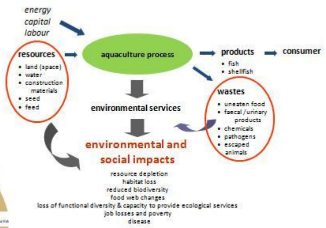
- The origin of environmental issues
- Resource consumption
  - space
  - water
  - seed
  - feed
- Wastes
  - definition
  - uneaten food, faecal and urinary wastes
  - medicines
  - parasites and other disease agents
  - escaped fish
- Quantifying wastes
  - mass balance equations
  - fate of wastes

Cage aquaculture



employment; livelihoods; economic development; food security

Cage aquaculture and the environment



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Resource use

What resources does cage aquaculture use?

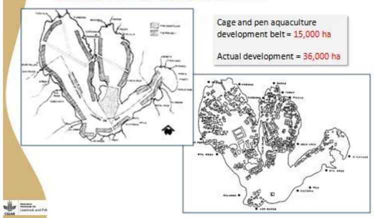
- Land
- Water
- Construction materials
- Seed
- Feed
- Labour (?)

Environmental resources - *space*

- cages usually sited in public water bodies
  - lakes and reservoirs
  - rivers and canals
- privatization of public resources
- can be socially divisive
  - promotes/consolidates power elites
  - excludes poor, who are often most dependent on environmental services
  - erodes environmental goods and services for others (e.g. fish and fishing (?); access to transport and fishing grounds)

Cage aquaculture – *space*

e.g. Laguna de Bay, Philippines, mid-1980s



Cage and pen aquaculture development belt = 15,000 ha

Actual development = 36,000 ha

Cage aquaculture – *water*

Reservoir drawdown and cages

Cage aquaculture – *seed*

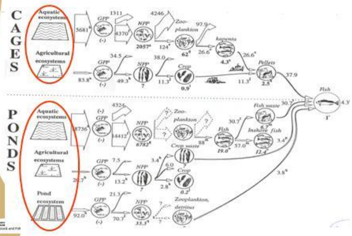
- Most freshwater fish seed is hatchery produced

source: http://ag.arizona.edu/azaqua/aquaculture_images/China/tilapiachina.htm

Cage aquaculture – *feed*

- Cage aquaculture is heavily reliant on feed
- FCR from cages is ~10% higher than in other aquaculture systems

Cage aquaculture – *feed*



Cage aquaculture – *feed*

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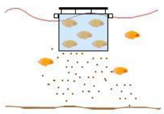
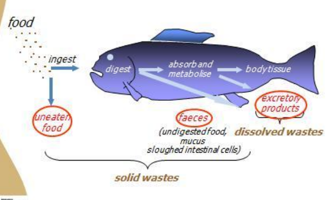
wastes

Origin of wastes

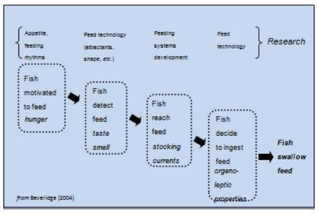
- uneaten food, fecal and urinary wastes
- escaped fish
- chemicals and medicines
- focus in this presentation is on uneaten food, fecal and urinary wastes



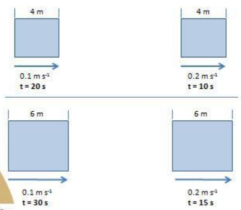
Food, faecal & urinary wastes - *origins*



Origin of wastes – *uneaten food*

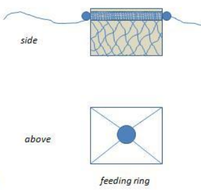


Feed losses – *cage size and currents*



In which cage and site are food losses likely to be higher?

Reducing cage feed losses



Feed

- Floating or slow sinking?
- Pellet stability
- Appetite

Wastes – *escaped farmed fish*

- causes

- Losses due to routine escapes - <0.01%; losses due to storm or predator attacks – 100%

Wastes – *escaped farmed fish*

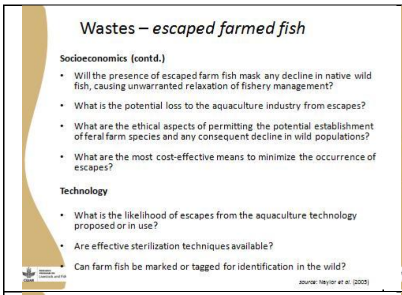
Ecology and genetics

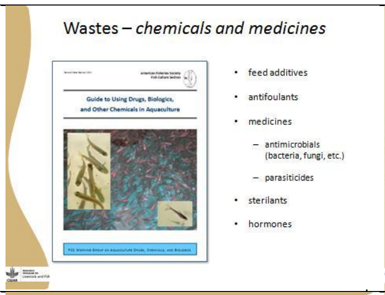
- What are the chances that escaped farm fish will establish feral populations?
- To what extent will escaped farm fish compete with wild fish for prey, space, and mates?
- What is the likelihood that escaped farm fish will interbreed with and alter the genetic characteristics of wild fish?
- Will escaped farm fish transmit pathogens to wild fish?

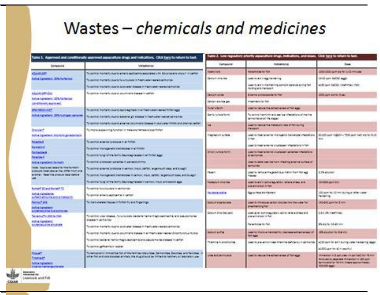
Socioeconomics

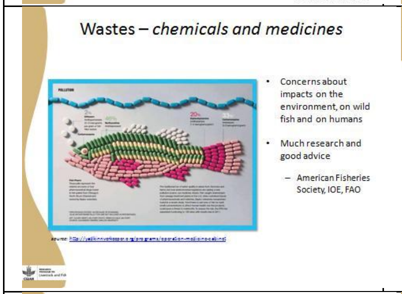
- What are the consequences to the fishing industry from the establishment of escaped farm fish?

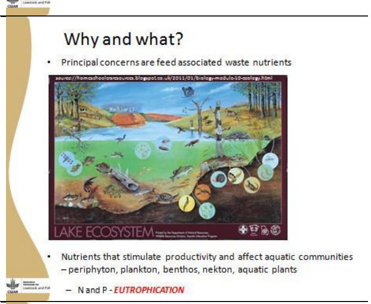
source: Naylor et al. (2005)

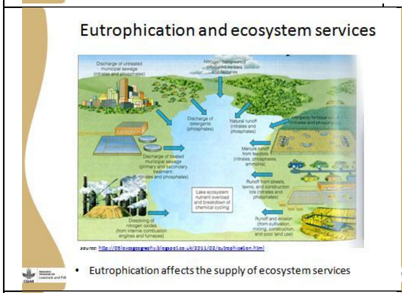


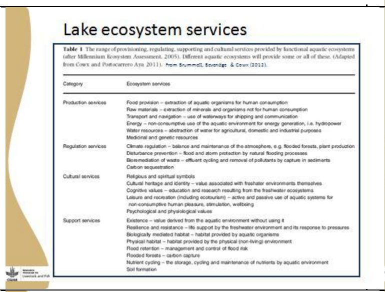


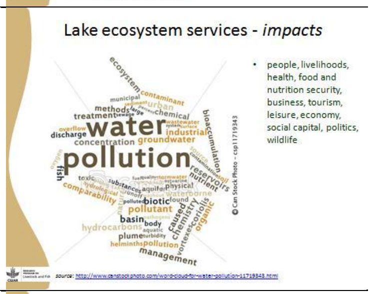


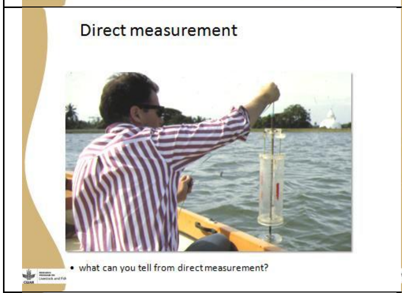


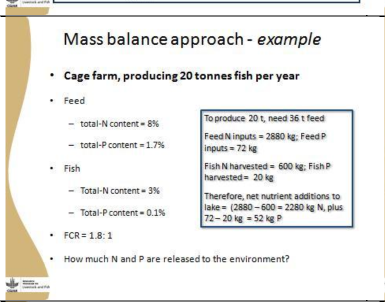


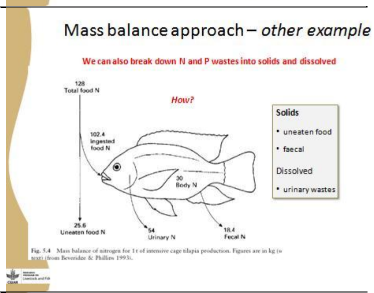


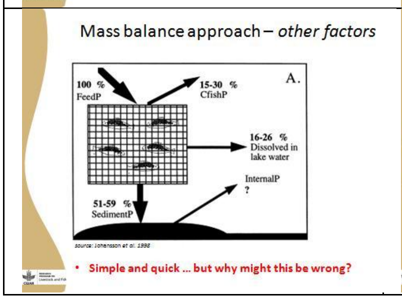


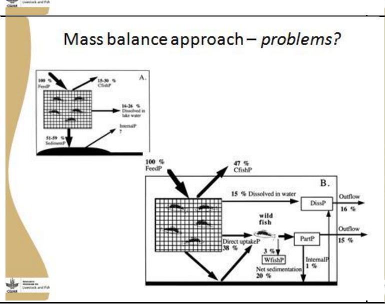




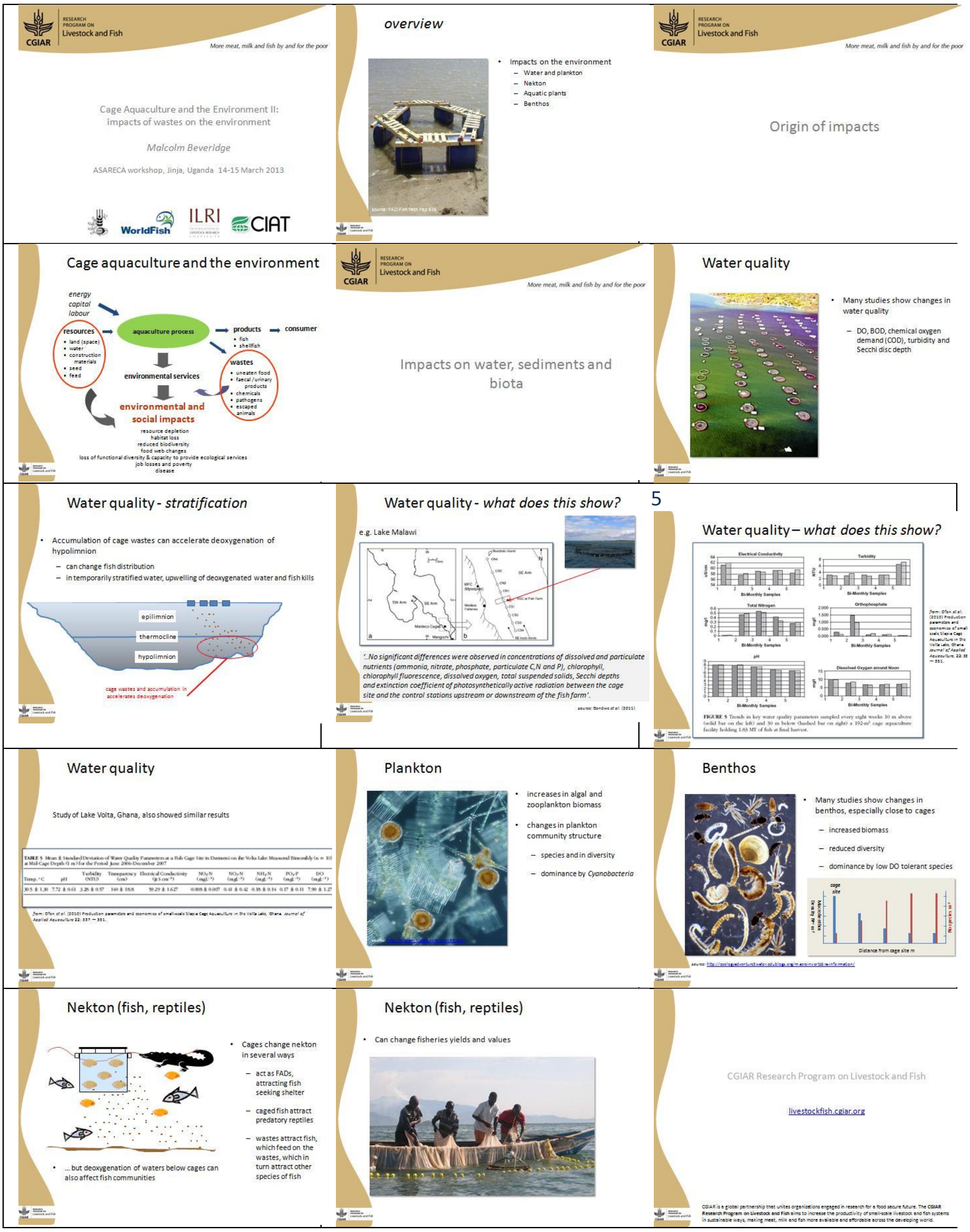








Cage Aquaculture and the Environment II. Impact of Wastes on the Environment



Cage Aquaculture and the Environment III. Modeling and Managing Impacts

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Cage Aquaculture and the Environment III: modeling and managing impacts

Malcolm Beveridge

ASARECA workshop, Jinja, Uganda 14-15 March 2013

WorldFish ILRI CIAT

overview


source: FAO Fish Tech Pap 498

- Why model cage wastes?
- Model types
- Modeling impacts of cage wastes on lakes and reservoirs

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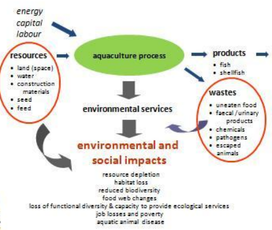
Why model cage wastes?

Cage aquaculture and the environment



Why?


Spraying yellow clay to tackle harmful algal bloom, South Korea.

- useful to be able to predict environmental impacts in order that cage development matches environmental capacity

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Model types

Models for different aquatic environments

- freshwaters lakes and reservoirs
  - dissolved nutrients (e.g. P) and trophic state
- rivers and canals
  - dissolved nutrients and sediment effects
- coastal marine environments
  - sediments
- ... but other aspects too
  - dissolved nutrients (marine)?
  - disease and wild fish?
  - alien species and wild fish?

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Modeling impacts of cage wastes on lakes and reservoirs

Principles

- Economic value of lakes and reservoirs determined by lake trophic status
- Lake trophic status determined by nutrients, especially P (total-P)
- Need to know how much total-P wastes cage farms produce and how this determines lake total-P
  - *What factors?*

Factors affecting total-P concentration

- Quantity of wastes
- Lake area
- Lake depth

Also ....

- But not all wastes end up in water column (consumed by fish; locked in sediments)
- Also, water flows in and out of the lake

Prediction of lake total-P

Two widely used models to predict total-P

(a) Dillon and Rigler (1972) $[P] = \frac{L(1-R)}{\bar{z}\rho}$

where [P] = total-P concentration (g m^{-3}); L = total-P areal loading (g m^{-2} y^{-1}); $\bar{z}$ = mean depth (m); R = fraction of total-P retained by the sediments; ρ = flushing rate (volumes y^{-1})

(b) OECD (1982) $[P] = \frac{[P]_j}{(1+T(w))}$

where $[P]_j$ = total P concentrations in the inflows (mg m^{-3}); T (w) = residence time (y)

Modeling impact of cage wastes on lake total-P

$$\text{cage production (t)} = \frac{\left(\frac{[\Delta P]\bar{z}\rho}{(1-R_{cage})}\right) \times SA}{P_{production}}$$

where:

[ΔP]	=	predicted increase in total P (μg l^{-1})
ρ	=	flushing rate (times per year)
R_{cage}	=	sedimentation coefficient = $1/(1+0.747\rho^{0.507})$
z	=	mean depth (m)
SA	=	lake surface area (m^2)
$P_{production}$	=	g P tonne caged fish production^{-1}

modified from Beveridge (1983, 2004)

Example – *cage tilapia farm in small lake*

Site

- Surface Area of lake, **A** = 100 ha
- Mean depth $\bar{z}$ = 10 m
- Flushing Coefficient, **ρ**, = 1 y^{-1}

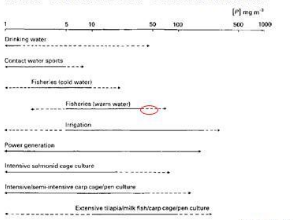
Step 1

- Determine mean total-P concentration $[P]_i$, prior to cage development (from monitoring) = 15 mg m^{-3}

Step 2

- Determine maximum acceptable total-P concentration $[P]_f$ = 60 mg m^{-3}
- $[\Delta P] = [P]_f - [P]_i = 60 - 15 = 45$ mg l^{-1}

Maximum acceptable (--) and ideal (–) fresh water total-P concentrations



from Beveridge (1984)

Example *(contd.)*

Step 3

since $P = \frac{L_{fish}(1-R_{fish})}{\bar{z}\rho}$

$L_{fish} = \frac{\Delta P \bar{z}\rho}{(1-R_{fish})}$

$R_{fish} = x + [(1-x)R]$; where R is calculated from Table 5.6, and x is assumed to be 0.5.

Thus, $L_{fish} = 45 \times 10 \times 1/0.23 = 1957$ mg m^{-2} per year = 1.957 g m^{-2} per year

Empirical models for determining

Table 5.6 Empirical models for calculating the sedimentation rate, δ, the retention coefficient, R(1/R), and the sedimentation coefficient, V of phosphorus for both general and specific categories of temperate water bodies (from Beveridge 1984a).

Model type	Size of database	Model	Correlation coefficient	Source
General; USEPA database and several European lakes and reservoirs	704	$\delta = 0.129(L/\bar{z})^{0.549}$	0.81	Canfield & Bachmann 1981
		$R = 1/(1+0.614\rho^{0.491})$	0.79[a]	Larsen & Mercier 1976
		$\delta = 0.94$	0.79[a]	Jones & Bachmann 1976
		$V = 2.99 + 1.7q_s^{b}$	0.73[a]	Reckhow 1983
		$V = 5.3$	0.71[a]	Chapra 1975
	73	$R = 1/(1+\rho^{0.5})$	0.79	Larsen & Mercier 1976
		$\delta = 0.65$	0.79	Jones & Bachmann 1976
		$R = 0.426\exp(-0.271q_s) + 0.574\exp(-0.00949q_s)$	0.71	Kirchner & Dillon 1975
		$V = 11.6 + 1.2q_s$	0.68	Reckhow 1983
		$\delta = 10/\bar{z}$	0.68	Vollenweider 1975
		$V = 12.4$	0.66	Chapra 1975
Reservoirs, North American	210	$\delta = 0.114(L/\bar{z})^{0.589}$	0.83	Canfield & Bachmann 1981
		$R = 1/(1+0.515\rho^{0.551})$	0.80[a]	Larsen & Mercier 1976
Natural lakes	151	$\delta = 0.129(L/\bar{z})^{0.549}$	0.83	Canfield & Bachmann 1981
		$R = 1/(1+0.747\rho^{0.507})$	0.80[a]	Larsen & Mercier 1976
Lakes with slow flushing rates	53	$R = 0.201\exp(-0.0425q_s) + 0.574\exp(-0.00949q_s)$	—	Ostrofsky 1978

[a] Coefficients recalculated by Canfield & Bachmann (1981) using their database.
[b] q_s = areal water loading (m y^{-1}).
[c] ρ = flushing rate (volumes per year).

R

Example *(contd.)*

Step 4

- Since the lake has a surface area of 10^6 m^2, the total acceptable loading = 1.957 x 10^6 g y^{-1}

- Thus, the tonnage of fish that can be produced, assuming a total-P loading of 17.7 kg t^{-1} = 1.957 x 10^6/17,700 g

= 111 t y^{-1}

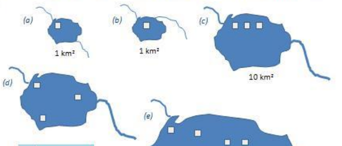
- ***In other words, the model predicts that 111 tonnes can be produced per annum, without serious adverse effects to water quality or provision of ecosystem services***

But ....

Do you believe it?

Problems occur are not only with complexity of estimating effects of P discharges on lake-P concentrations but also lake responses, especially of ecologically complex and poorly understood African lakes

Rank the accuracy of modeling impacts



Lake	
1	
2	
3	
4	
5	

Effects of morphometry on model output

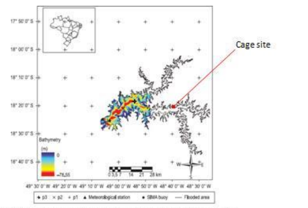


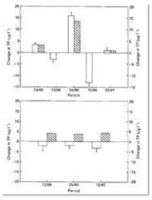
Figure 1. The Itumbiara hydroelectric reservoir and their bathymetry shows the location of SIMA buoy, meteorological station and the samples of water surface temperature time series (p1, p2 and p3).

source: de Alcantara *et al.* (2012). http://www.scielo.br/scielo.php?pid=S2179-975X2011000500004&script=sci_arttext

e.g. watershed developments

- One problem is modeling cage impacts when many other developments may be taking place in the watershed

e.g. watershed developments



- In which lake does the model predict well?
- In which lake does the model not predict well?
- What might be the reasons?

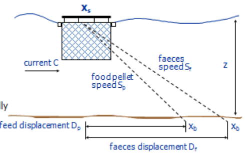
modeled

observed

Modeling solid wastes dispersal

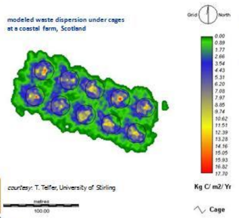
based on the principles that

- faecal pellets and uneaten food particles fall at a rate *s* through a depth *z* take a time $t = z/s$ to reach the bottom
- during time *t*, current velocity *v* will displace the particle horizontally by a distance $x = v/t = v/s$ from the cage



from Beveridge (2004)

Solid wastes dispersal model outputs



courtesy: T. Telfer, University of Stirling

- collected over production cycle for feed and faeces
- values summed and stored in spreadsheet
- values printed out and interpolated using software (e.g. SURFER®; GIS)

Modeling - *conclusions*

- In which type of lake does the model predict well?
- In which lake does the model not predict well?
- What are the reasons?
- How should the model be used, for what and by whom?

Other questions

- How to divide up the environmental capacity of a lake or reservoir
  - One large concession?
  - Several medium sized concessions?
  - Many small concessions?
  - A mixture?

Adaptive management

Other questions

- Set conservative [P] , and production limits
- Monitor impacts of cage development on total-P for at least 2 years
- If mean total-P concentration after cage development (i.e. [P] ,) is less than expected, then licensed production tonnages may be increased
- If mean total-P concentration after cage development is more than expected, then the licensed production tonnage may have to be reduced

Adaptive management

TABLE 2

Overview of selected notable or innovative features

a) Africa

Country	Selected notable or innovative features
Egypt	• Very long tradition of regulation and management of scarce water resources, closely allied with irrigation management rather than EIA legislation. • Particularly strong with respect to the allocation of *rights to competing users*, and social impact issues more generally.
Madagascar	• Legal framework explicitly recognizes the need for a *balance* between investment and environmental quality. • Specific law on responsible and sustainable aquaculture development. • *Shrimp industry has been very pro-active* in establishing environmental standards, and has been successful in maintaining low levels of disease, high quality product and associated price premium.
Nigeria	Quality of the environment enshrined in the federal constitution.
South Africa	• Right to a healthy environment and sustainable development are both *enshrined in the constitution*. • *Hierarchy of requirements* for SEA, EIA, ERA, EMPs. • Problem of alien species is addressed through provision for *liability* in the Biodiversity Act: • *"Should an alien species establish itself in nature as an invasive species because of the actions of a specific person, a competent authority may hold that person liable for any costs incurred in the control and eradication of that species".*
Uganda	• Area environmental officers and *environmental liaison units* have been established *within* sectoral departments/agencies to promote *integration*. • *Standards* for sourcing and certification of aquaculture inputs, import of live fish and GMO.
United Republic of Tanzania	• High level of *environmental awareness*. • Introduction of Nile perch offers an excellent case study on the issue of *alien species*. • An innovative mechanism is provided for *out of court settlements of environmental disputes*, through specially trained environmental mediators. • Strong regulatory guidance on *public participation*.

from: FAO (2009). *Environmental Impact Assessment and Monitoring in Aquaculture*. Rome, FAO.

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Cage Aquaculture and the Environment IV. Environmental Monitoring

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Cage Aquaculture and the Environment IV: environmental monitoring

Malcolm Beveridge

ASARECA workshop, Jinja, Uganda 14-15 March 2013

WorldFish ILRI CIAT

overview

- Who should monitor cage farm sites and why?
- Sample design
- Sampling
- Analysis
- This part of the workshop is meant to complement '**Chemical and Biological Methods of Water Analysis for Aquaculturists**' (Stirling *et al.*, 1985)*

** Now out of print*

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Who should monitor cage sites?

Who and why?

Who	Why
Farmers	To ensure that conditions remain suitable to farm fish and to provide warning of any actions required to reduce risk to stock To support any insurance claim To ensure compliance with regulatory requirements To counter any accusations of impacts of farm on incomes or livelihoods of other stakeholders
State	To ensure that environmental quality remains within acceptable/required limits
Researchers	To ensure that environmental conditions do not influence outcomes of production trials, testing, say effects of stocking density, cage size, feeds
Others (e.g. power companies, resort operators, irrigation managers, environmental consultants)	To ensure that environmental quality of water and other environmental services (e.g. fisheries) is not unacceptably compromised.

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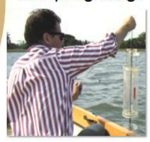
Sample design

Sampling design



Step 1

- Be clear on the purpose

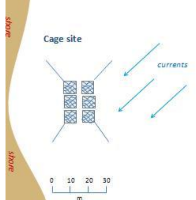
Step 2

- Design your sampling program - what, where, how?
  - temptation to include too many variables
  - how do you choose controls?
  - Are there any license conditions that influence sampling design?

Step 3

- Write down plan, involve all who are involved in planning
- Ensure you have sampling equipment, reagents, fridges, lab equipment
- Implement

Sampling design – *example 1*



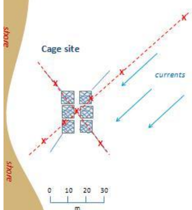
Purpose

- To ensure water quality is not affecting growth and production

Program

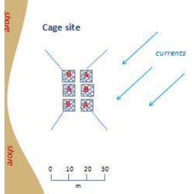
- what water quality issues do you anticipate?
  - self-pollution?
  - pollution from agricultural run-off, domestic wastes?
- If pollution from other human activities
  - how many sample stations?
  - when would you take water samples?
  - how often would you take water samples?

Sampling design – *example 1 (contd.)*



What	
Sites	8(?) in transects; samples taken at surface or integrated samples
What?	**T °C** and **DO** daily (early morning); surface and at depth (if stratified) **Secchi** depth (weekly) **Water quality** (total-P; total-N; $NH_3 + H^+$; pH) weekly/monthly **Plankton** (perhaps during blooms; looking for Cyanobacteria)

Sampling design – *example 2*



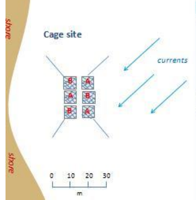
Purpose

- To ensure water quality is not influencing results from cage production trials

Trials

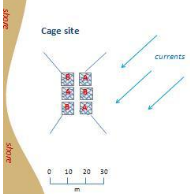
- Assess two feeds, A (control) and B (new feed)
  - what water quality issues do you anticipate?
  - ***where*** would you take water samples; ***when*** and ***how often*** would you take water samples; in order to adequately address these

Sampling design – *example 2 (contd.)*



What	
Sites	Environmental sampling in all cages; (mid-depth); however, preliminary trials should indicate whether, say, the current direction means that outer cages have consistently and much better water quality; if so, then maybe re-think design
What and when?	*Important to set sample times consistently at the same time of day* **T °C** and **DO** daily (early morning); surface and at depth (if stratified) **Secchi** depth (weekly) **Water quality** (total-P; total-N; $NH_3 + H^+$; pH) weekly/monthly **Plankton** (perhaps during blooms; looking for *Cyanobacteria*)

Sampling design – *example 3*



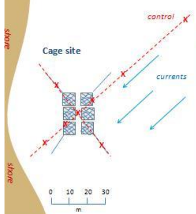
Purpose

- To ensure cage site is not adversely affecting lake water quality, especially outside consent terms

Design

- Need to measure cage and control site, before and after introduction of cages
  - If not, how do you prove it was not the cage farm that was causing the problem?

Sampling design – *example 3 (contd.)*



What	
Sites	8(?) in transects; samples taken at surface or integrated samples' must have a control site at a similar depth
What and when?	*Sample consistently at the same times; best to do 1 h or so after feeding* **T °C** and **DO** daily (early morning); surface and at depth (if stratified) **Secchi** depth (weekly) **Water quality** (total-P; total-N; NH_4-N; pH) weekly/monthly

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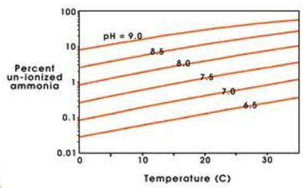
sampling

Environmental monitoring parameters

Parameter	Why?
DO	Essential to support good growth and health
T °C	Ideal range for growth; + / – affects feeding and growth, stress and disease
pH	Should be ~ pH 7; as pH increases, free ammonia levels increase exponentially $NH_4 - N \rightleftharpoons NH_3 + H^+$
Total-N	Indicative of pollution and of potential problems with blooms and free ammonia (together with DO, T °C and pH data)
Total-P	Indicative of pollution and
$NH_4 - N$	Toxic to fish in its unionized form , which is determined by T °C and pH
Secchi disc	Indicates turbidity levels, comprising suspended detritus, silt and plankton; chlorophyll-a determination would indicate how much of the turbidity is algal

Unionized ammonia and pH



source: http://echo2.epfl.ch/VICAIRE/mod_2/chapt_6/main.htm

Solubility of oxygen in water and temperature

Temperature-Oxygen Solubility Relationship	
Temperature (°C)	Oxygen Solubility (mg/L)
0	14.6
5	12.8
10	11.3
15	10.2
20	9.2
25	8.6
100	0

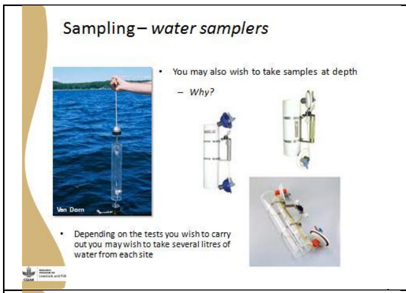
Sampling – *field measurements*

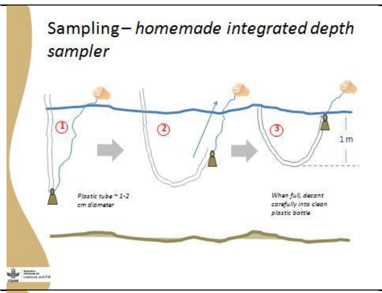
- DO and Secchi depth are determined in field
- Buy the best DO meter you can afford and learn how to service it (especially the anode and membrane

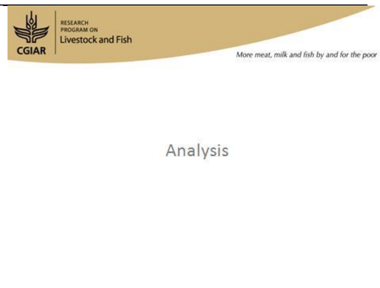
Sampling – *water sampling*

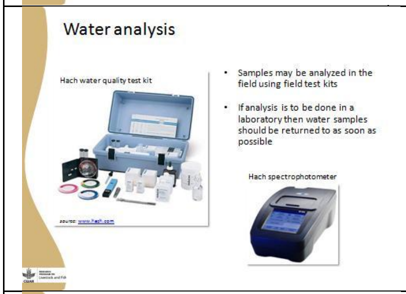
source: http://www.sks-science.com/Water-Testing-Supplies-and-Containers-c-54.html

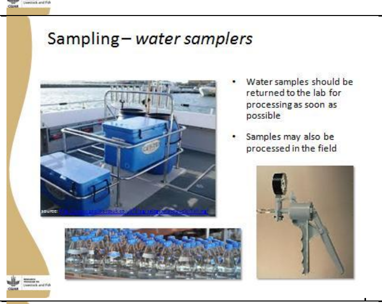
- You can take surface samples using clean (acid rinsed) plastic bottles
  - fill just below the surface
  - fill 5-10% full, shake, pour out over cap
  - repeat
  - fill to overflowing, avoiding air bubbles
  - place in cool, dark box and return to lab as soon as possible
  - process and use asap

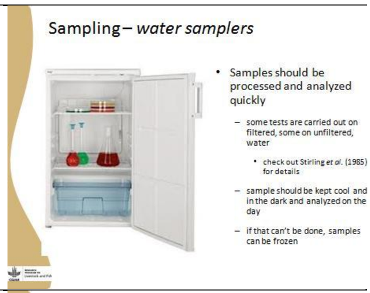


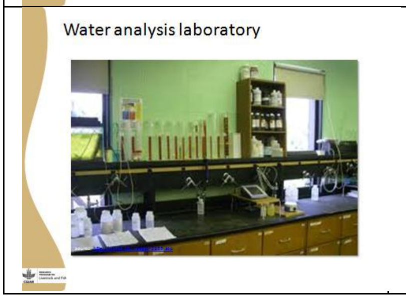


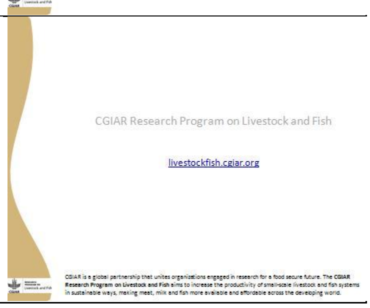




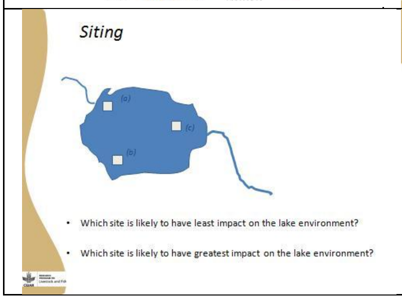




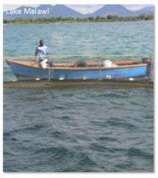




Cage Aquaculture and the Environment V. Mitigation of Impacts



Feeding



- Huge improvements can be generated through studying and applying better feeding methods

Feeding strategies

- e.g. contrast two 1000 t farms
- *farm a*
  - low pollution feeds (P-content 0.8%)
  - careful feeding; FCR 1.1:1
- *farm b*
  - standard feed (1.3%)
  - careless feeding; FCR 1.5:1
- ***Calculate the P-wastes from each farm***

Feeding strategies

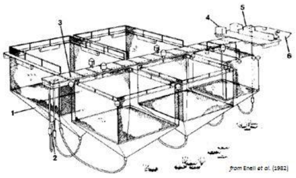
farm a

- low pollution feeds (P-content 0.8%)
- careful feeding; FCR 1.1:1
- (1000 x 0.08 x 1.1) - (1000 x 0.048) = 40 t P wastes per annum

farm b

- standard feed (1.3%)
- careless feeding; FCR 1.5:1
- (1000 x 0.13 x 1.5) - (1000 x 0.048) = 147 t P wastes per annum

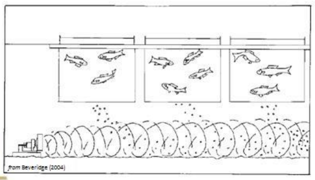
Cage waste recovery systems



- This design didn't work; other, simpler designs can, such as those that are designed to remove mortalities

Waste dispersal systems

Not a good idea … !



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escapes

Losses

- Losses can be substantial
- Work with staff to carry out a HACCP-type analysis to identify where losses occur and how much
- Introduce cost-effective measures to reduce losses

Anti-predator initiatives

- Tidy away spilled feed and feed bags
- Use anti-predator nets
- Have staff around the farm as often as you can
- Keep a dog

Theft and vandalism

- Fishers and their dependents may fear impacts of farm on their livelihoods
- They may resent no-fishing zones
- Farms may have to work hard to reduce tensions and losses

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disease

Disease

- Disease largely caused by introductions of fish from outside the farm
- Poor conditions on the farm
  - dead fish, open feed bags and spilled feed that attracts birds and vermin
  - poor hygiene (nets; etc.)
- Other stressors
  - heat; low DO; birds; bad handling
- Tidy away spilled feed and feed bags
- Use anti-predator nets

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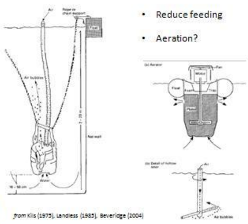
Water quality problems

Stock management and aeration

- Reduce feeding
- Aeration?



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The following key references were used to prepare the above material and should serve as sources of further information.

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Annex 1. ASARECA Cage Workshop Agenda

Aims: To develop a shared understanding among project partners of cage fish farming and environment interactions and the economic and social consequences.

Outcome*:* improved environmental management of cage fish farms

Time	Activity	Who
DAY 1: 14 March		
09.00	**Welcome and introductions** • Introductions • Workshop overview	
0915	**Cage aquaculture – an introduction** • What are cages • Why cages - alternatives? • Global importance • Cage design, construction and installation • Siting • Production - stocking, feeding, management, harvesting • Problems (predation, storms, water hyacinth, vandalism) • Social aspects	
10.00	*Coffee*	
10.30	**SoN farm visit*** • Travel to farm • Meeting with staff • Introduction to SON • Visit to cages and discussion	Allen and co
14.00	*Lunch*	
14.30	**Cage aquaculture and the environment I : resource consumption and wastes** • Environmental issues and their origins • Resource consumption • Wastes o Definition o Uneaten food, faecal and urinary wastes o Medicines o Parasites and other disease agents o Escaped fish • Quantifying wastes o Mass balance equations • Fate of wastes o Solids o Dissolved faction	
15.30	*Tea*	
	• Visit to NaFIRRI cages, Jinja	
1600	**Cage aquaculture and the environment II: impacts** • Water and plankton • Sediments and benthic community • Fish communities and fisheries	
17.00	*Workshop close*	

DAY 2: 15 March		
09.00	**Cage aquaculture - general discussion**	
09.45	**Cage aquaculture and the environment III: modeling and managing impacts** • Environmental capacity • Models and modeling • Lake scenarios (small, simple; large; large, dendritic) • Use of model outputs – adaptive management • Use of solids waste dispersal models	
10.30	*Coffee*	
11.00	**Cage aquaculture and the environment IV: environmental monitoring** • Who and why? • Sampling design • Sampling • Analysis	
12.00	**Visit to environmental laboratories, NaFIRRI, Jinja**	
13.00	*Lunch*	
14.00	**Cage aquaculture and the environment V: mitigating impacts** • Reducing wastes o Feeds, feeding and FCRs o Reducing escapes o Reducing disease issues o Waste dispersion and collection • Mitigation through siting and site management • Aeration **Final discussion**	
15.00	*Tea*	
15.30	***Workshop close***	

Annex 2: Workshop Attendees

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