1. Supply of Animal Protein (and Fat)

2. AQUACULTURE PRODUCTION

   Introduction: Farming systems
   History
   Life cycle in nature
   Life cycle in an intensive production system
   FRESHWATER PHASE (Indoor): SALTWATER PHASE
   Some important management and feeding practices
   ON-GROWING “HOLDING” DEVICES (Cage/pen);
   FEEDS & FEEDING; DISEASE PREVENTION &
   CONTROL (Another time)

   Farming of several other example species

3. Issues ---- Sustainability

4. Selective Breeding Programs

* Lecture at Padova, Italy. April 1~3, 2003
Production

1. Introduction -- Farming Systems

   Of global production of farmed finfish and crustaceans,

   1) **Extensive** (lesser extent) and **semi-intensive** farming systems
      (~70%)

   Reared within earthen ponds, pen enclosures, rice fields, or small water bodies

   At low (extensive) to moderate (semi-intensive) stocking densities and farm inputs.

   Most commonly for freshwater staple-food species by small-scale farmers in developing countries

   Dietary nutrient supply may range from
      None at all (extensive system)
      Use of fertilizers for the controlled prod. of live food organisms
         Use of supplementary or nutritionally complete aquafeeds
      Common strategy is a combination of 2) and/or 3).

   Polyculture—mix species of different but complementary feeding habits:
      >25% global finfish prod. is from polyculture of the 2 filter-feeding species, silver and bighead carps, and use fertilizers.

2) **Intensive** farming system

   Reared in ponds, tanks, pens or cages at high stocking densities and fed on high-quality industrially manufactured complete diets or compound aquafeeds.

   >65% of finfish prod. in developed countries.
      Monoculture of high value diadromous/marine carnivores
<25% of total prod. in developing countries,
but rapid tendency of progressive intensification for both
lower value staple-food species for the domestic markets; and
high-value cash-crop species for export markets.

Here, use the farming of Atlantic salmon as a model to illustrate the intensive farming system,
Then a brief mentioning of farming of several other species
Emphasis: Farming system must be tailor-made for species, resources & environ. conditions.

Production
2. History

Chinese began fish farming before the birth of Christ.

The 1st book on fish farming by Fang Li on carp farming in earth ponds
and artificial fertilization.

Stephan Ludwig Jacoby (1709-1784), a Germany, inventor of artificial fertilization and hatching of trout.

1st hatcheries in Norway built around 1850 to produce salmon fry for release in rivers.

Farming for trout in fresh water experimented around 1900.

Farming for trout in sea before WW1, but picked up again 1950s. Succeeded in 1960s

Salmon farming started in 1970.

Many other species and shellfish species now.
3. Life Cycle in Nature - Atlantic salmon

Understand intensive farming of salmon, need to first understand its life cycle in the wild.

No salmon is better adapted to their river of origin than the offspring of this river.
   Its water quality, temperature, supply of nutrition, time the river freezes over, & spring flood.

In wild, a male fish in magnificent colors, powerful, w/ hooked jaw, muscular, aggressive. Ruthlessly claim the area where he was born, Relentlessly protective of his young.

His children are to take the trip back down to ocean confronting natural enemies. AND the laborious trip back up home, generation after generation.

**Spawning** takes place in late autumn.
   Immediately after fertilization, female covers eggs w/ clouds of sand & gravel on river bed.
   Here the fertilized eggs rest and protected but receive sufficient supplies of fresh water to survive hard winter.

As soon as temperature becomes suitable, eggs **hatch**.
   The 2~3 cm fish carrying a large yolk sac on their stomach began their journey for survival.
   Yolk provides food only for a few days. The little fish live in the river for 2~3 years, even 4~5 years
Finding shelters behind rocks and under eddies to 1) shelter from current, 2) shelter from enemies, 3) snatching food passing by with minimum movement.
Enemies abound. Insect larvae and fish when small. Larger fish, seagulls, smews and minks when bigger.
   Although in camouflage colors & pattern, a large proportion don't survive.
Production

3. Life Cycle in Nature - Atlantic salmon (continue)

When 10~15 cm long, urge to move to the open sea triggered. In fine silvery luster, now smolt.

Tend to stay in family groups, they gain weight rapidly, 2 kg in a year. 5 kg in 2 years. 10~20 kg in 3 years.

Feed on smaller fish of herring and crustaceans.
But they themselves were feeds for seals, killer whales and porbeagle, & caught by fishermen

Survival rate from eggs to maturity only .12% (70% in intensive farming system)

After 1~3 years, urge to return to the river of origin, and returning in inconceivable precision.

Only a few make it back. The survivors will then spawn, etc. and carry on.
4. Life Cycle in Intensive Production System --- Atlantic salmon
4.1. FRESHWATER PHASE (Indoor)

4.1.1. Brood stock & “mating”

Brood stock (parental fish) -- giant of enormous strength.

Selected for desirable characteristics:
- Phenotypic (individual) selection for size, skin color, growth &
- Family selection for disease resistance, harvest quality such as meat color, etc. (tomorrow).

Removed from cages into brackish or fresh water tanks several months before stripping ----- (better gamete viability)

Stress due to transportation and handling also affect gamete viability and survival to eyed egg.
- Fed special diet rich with vitamins and minerals.
But Atlantic salmon stopped feeding months before spawning. Rainbow trout continues.

Check Ripeness: once a week. Lightly sedated when check

When collect eggs and milt, fish anesthetized (lasting only a few minutes)

Stripping (by compressed air), but now surgically, for easier faster and more eggs.
- Broodstock used for one generation anyways. In nature too. Greater G. progress.
- Male recover after stripping easy.

Stripping (harvesting eggs and milt)

Milt: a large male 20 ml per kg fish weight.

Roe: up to 1 dl.
4. Life Cycle in Intensive Production System --- Atlantic salmon

4.1. FRESHWATER PHASE (Indoor)

4.1.1. Brood stock & “mating” (continue)

Fertilization --- Mix (dry): First rinse the eggs with saline solution
1.5 ml milt per liter roe. Normally 20 ml to fertilize 2~3 liter eggs.

Mix and stir, and add water to activate sperm activity (wet), and to
initiate the swelling process.

Allow 2 minutes to fertilize (sperm movements end after 1 minute).

Add Buffodine solution, stand for 10 minutes before rinsed out.

Buckets fill up water to begin the swelling process. 3~4 hours at 5~10
°C (egg enlarge by 30-40%).


Then transfer to hatching trays.

Strict preventive and monitoring measures against BKD, furunculosis,
sometimes IPN, especially BKD:

Autopsy of all brookstock mortality and those after stripping. Bath
eggs in disinfectant.
4. Life Cycle in Intensive Production System --- Atlantic salmon
4.1. FRESHWATER PHASE (Indoors)

4.1.2. Hatchery

To hatch depend on degree-days -- At 8°C, takes 60 days.

Become eyed eggs after 25~30 days at 8°C (230 DGR).
Absolute still when 60-140 DGR.
Then, ready to be transported.

Dead white eggs. Shock.

After hatch, yolk-sac fry or alevins:
Water level, flow, pH all important. Require peace and quiet, stillness,
dim light.
On Astro-turf, must not be on flat smooth surface.

After 560 DGR (4~6 weeks at 15°C), alevins ready to commence startfeeding

4.1.3. First Feeding and Fry Development

Fry ? parr ? smoltification

From hatchery into fish tanks.

Feed particles coincide with fish size.
First feeds on surface to get parr surface to train to eat.
Then automatic dispense machine
2.5 cm length, weigh .15~.23 g. Grow 5~7% in weight per day.

Tank size 2~4 m² with water level up to 30 cm. Density high: up to 10,000 fish per m².
Temperature 10~14°C. Weak light.

After 6 weeks --- 1~3 months (4~12 weeks)
Sorted by size into larger tanks.
Production
4. Life Cycle in Intensive Production System --- Atlantic salmon
4.1. FRESHWATER PHASE (Indoor)

4.1.3. First Feeding and Fry Development

Fry ? parr ? smoltification

After 1st feeding: Large difference in size. Sorted regularly for best growth. As fish grow, adjust tank density and feed particle size, etc.

Large to large basins, may be outdoor pools.

But if operational strategy called for, parr are kept indoor to subject to light and temp manipulation

Before smolting, vaccination for ----

When ready to become smolt? Can be manipulated by water temp. and light. For fingerling producers, e.g., can manipulate as to when to deliver the smolt.

Production
4. Life Cycle in Intensive Production System --- Atlantic salmon
4.1. FRESHWATER PHASE (Indoor)

Water while indoor: Use water from springs, rivers and fjords. Mixed for salinity, filtered and treated (UV light, ozone, etc) for disinfections, add oxygen (may be), pH level monitored. Alternative and backup water sources.

Water circulation to carry away waste and current for fish to swim against.

High hygiene standard. All plastic.

Equipment disinfected after each use, not sharing between tanks.

Optimum environ. conditions re. Light, color, water flow, density, exercise.
### Egg and juvenile stage

<table>
<thead>
<tr>
<th>Months</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fertilized</td>
<td>Eyed eggs</td>
<td>Yolk-sac</td>
<td>Startfeeding</td>
<td>Fry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eggs</td>
<td>230 DGR</td>
<td>fry/alevins</td>
<td>1-3 months</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### $S_{\frac{1}{2}}$ (½-yr smolts)

<table>
<thead>
<tr>
<th>Egg</th>
<th>Juvenile</th>
<th>Smolt</th>
<th>After 1 yr in seawater</th>
</tr>
</thead>
<tbody>
<tr>
<td>60-110g</td>
<td>1-3 months</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### $S_1$ (1-yr smolts)

<table>
<thead>
<tr>
<th>Egg</th>
<th>Juvenile</th>
<th>Smolt</th>
<th>After 1 yr in seawater</th>
</tr>
</thead>
<tbody>
<tr>
<td>70-120g</td>
<td>1-3 months</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### $S_{1\frac{1}{2}}$ (1½-yr smolts)

<table>
<thead>
<tr>
<th>Egg</th>
<th>Juvenile</th>
<th>Smolt</th>
<th>After 1 yr in seawater</th>
</tr>
</thead>
<tbody>
<tr>
<td>150-200g</td>
<td>1-3 months</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### $S_2$ (2-yr smolts)

<table>
<thead>
<tr>
<th>Egg</th>
<th>Juvenile</th>
<th>Smolt</th>
<th>After 1 yr in seawater</th>
</tr>
</thead>
<tbody>
<tr>
<td>200-400g</td>
<td>1-3 months</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

Production

4. Life Cycle in Intensive Production System --- Atlantic salmon
Production

4. Life Cycle in Intensive Production System --- Atlantic salmon

4.1. FRESHWATER PHASE (Indoor)

4.1.4. Smoltification

**parr ? smolts**

From life in fresh water to life in sea water.

Parr's parrmark lost, stomach becomes silvery & back a bluish-green.
   Gills shape also change. Swim with current, etc.

In nature, impossible to forecast smoltification. Smolts found year round, with weights of 20~150 g. May take 1~4 years to become a smolt.

In culture, most important requirement to initiate smoltification is reaching a critical size (12 cm or 1½ finger-length).

When 6 months to go, grow rapidly from ~8 cm (1 finger length) to 12 cm, from October to March.

After these months, bimodal distributions in length
   --- lower ones remain parr to become S2, and the upper ones S1.

BUT, with control of temp., **photoperiod** and nutrition (growth regulating factors),
now possible to obtain known size and number of smolts at different time of year, to
1) allow max. use of hatchery, cage, the on-growing facilities, and
2) even production throughout the year, so no shortage or surplus on market.
   But there're advantages and disadvantages of S1, S2, etc. due to costs, length of freshwater phase and when, disease risks, etc.

[If missed the smoltification window and don't get to the sea, desmoltify and prepare life in freshwater]

During spring (longer days) after 1st feeding: Can use light to manipulate the length of smolting period.
Normally, 1-yr-old smolt. But many smolt and ongrowing producers want to place smolt in sea during the first autumn ----- called ½-yr-smolt.

Depending on operational strategies on farm and biological potential of fish, ½-yr to 2-yr smolts.

(in Norway, 160 mil. smolts produced, averaging 600,000 each unit).

(Rainbow trout similar process, but no distinct smoltification process.)

When smolts large enough, transferred to outside in large tanks exposing to natural daylight. Salinity tolerance tests waiting to be transported to sea.

Production

4. Life Cycle in Intensive Production System --- Atlantic salmon

4.2. SALTWATER PHASE

4.2.1. Place smolts into sea

In April in south Norway, June in north.

Transport by trucks and boats.

Stress affect smolt survival.

4.2.2. Grow in sea

Fed in pens/cages till slaughter size. 3~5 kg after 1 year at sea.

Growth can be controlled by feeding and light (add light in winter and spring)

Need to harvest before fish reaches sexual maturity.

So harvest after 1~2 years in sea when 3~5 kg depending on markets.

Sexual maturity: Especially for males, darker brown color, lengthened head and kype --- signs ready for life in freshwater.

Early sexual maturity is not desirable: Strain differences, but regardless,
mature after 18 months in sea is too early. <1-yr is a definite no (gresile).
Genetic selection and diet to control to prevent early maturity.

4.2.2. Grow in sea

As fish grow, sorting needed
Vaccinate (not covered) at sorting, but at early stage of growth.

Reproductive strategies possible, and may be advantageous under certain circumstances: All female fish. Sterile fish (triploidy). Off-season eggs

Much causes and consequences w.r.t. social behaviors, verticle distribution, swimming patterns. (Not covered)

4.2.3. Harvest

As short as after 10 months ----- to slaughterhouse
(Monday at crack of dawn, in fish market in Japan on Wednesday morning)

Process and cooking not covered.
5. Some Important Management and Feeding Practices

5.1. On-Growing “Holding” (And Other) Devices

For holding, many systems: Cage/bag types, land-based system (ponds, raceways, etc.), and recirculation systems with controlled environment (eel, catfish, bass, sturgeon).

All kinds of equipments and facilities to go with each, e.g., monitoring, feeding and cleaning devices; video, biomass and fish counting devices; hydacoustics; remote operating devices; devices for grading and splitting fish stocks; transportation systems by pumping, boats, trucks, and air; light manipulation system.

**Cage/pen**

A cage is a large net (nylon cords) bag that hangs free in the sea connected to floatation unit, above which, a fence. Weights at bottom.

Varity of shapes, sizes, and material, but *floating net ring cage* most common.

Must be easy to maintain, well moored, and easily moved from one location to another.

Single cage/pen or multiple units.

Interlocking cages with secure mooring, especially in exposed conditions.

Density: Recommended <2kg fish, 15 kg/m³ >2kg fish, 25~30kg/m³ (but all exceed in practice)

Fish appear to prefer large pens with depth of 15~20 m, placed far apart—choose suitable salinity and water temp.

50m circumference X 20m deep = 4000m³ for 80,000 kg (say 20kg/m³)
90m×20m=129,000 m³ for 260,000 kg

Large ones of 120m×25m=28,600 m³ are being produced.

Many environmental factors to cope.

Tendency is larger and deeper and in more exposed localities --- towards open sea.

Ocean-cages in more open sea, the better quantity and quality of water, but stronger units are required.

Land-based farms using pumped up seawater.

5.2. FEEDS AND FEEDING

Feeds:

Fish meal is the most important part

   using capelin, blue whiting, mackerel, herring, sandeel.

Alternative sources important: e.g., natural gas for single cell protein.

Efficient energy converter: <1 kg for 1kg fish, 2kg for chicken, 3 for pigs.

Feeding:

Age, size, temp., season, time of day determines intake (amount and content) and feeding frequency.

During 1st period, stay deep in sea pens. Hand feed to see if they come up for feeds.

Then, mostly automation with computerized control.
6. Farming of several other example species.

Rainbow trout

Shell fish, mussels, scallops, oysters

Shrimp (P, Monodon, and P. Vanamei)

Halibut

Cod

Turbot

Wolffish
supports the aquaculture organisms. Broadly, aquaculture structures include ponds, tanks, raceways, cages and pens. (B) Water exchange. Water exchange describes the amount of water exchanged or the control over water flow to the system. Broadly, the levels of water exchange are static, open, semi-closed and recirculating (closed). (C) Intensity of culture. The type of system used for aquaculture production is a combination of the above criteria.