# Wild Salmon fishery

Anders Skonhoft
Dep. of Economics
NTNU

- Structure of the talk
  - The importance of the wild salmon fishery
  - Historical record
  - Threat factors…
- Age model perspective
- On optimal fishing
- Management issues

# 1. Introduction

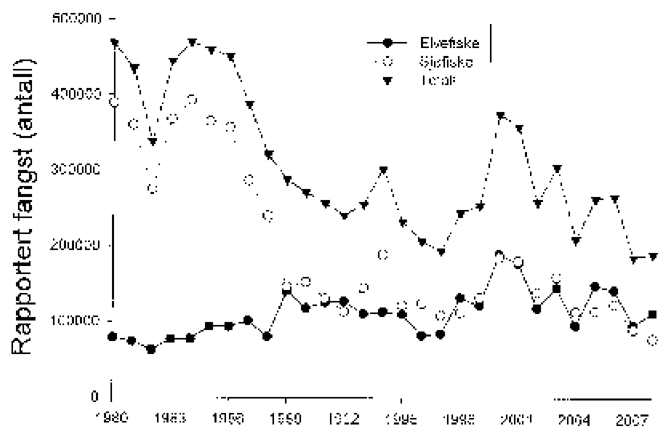
- Norwegian wild salmon fishery: Recreational as well as commercial
- Recreational in river and streams. Commercial in fjords
- Commercial today small also flavor of recreational..
- Recreational river far most important. Today more or less same amount of biomass catch. But the per kg. value much higher recreational
- Recreational river fishery: Separate sub-populations different rivers
- High profit local landowners. Various indirect effects local communities

# 2 STATUS FOR NORSK LAKS

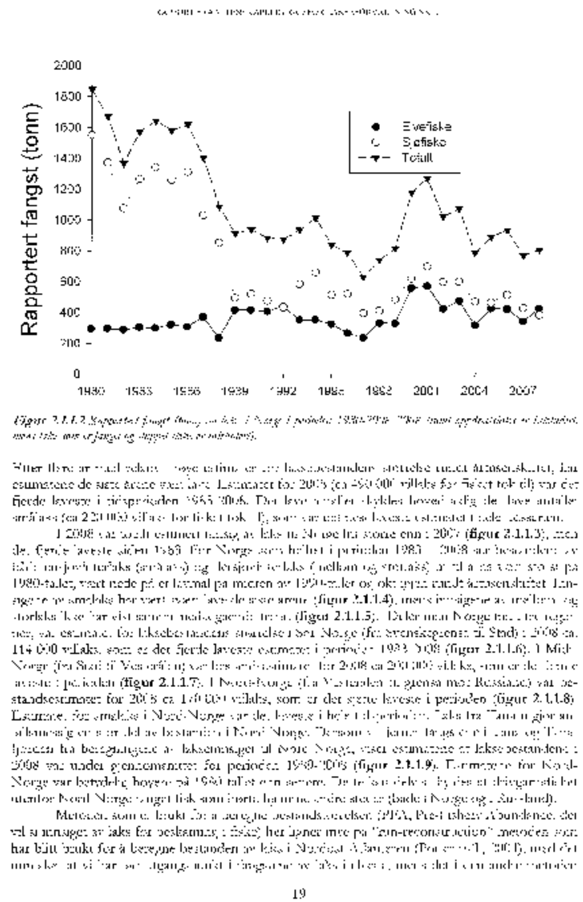
## 2.1 Utviklingstrekk

### 2.1.1 Fangst og innsig

I 2008 ble det rapportert fanget ca 192 000 laks i Norge (figur 2.1.1.1) som veide til sammen ca 807 tonn (figur 2.1.1.2). I tillegg ble det innrapportert at [illegible] laks ble sluppet ut igjen etter å ha blitt fanget. Anslått vekt på disse var ca 30 tonn slik at estimert totalfangst i Norge, fanget og sluppet laks blir på 837 tonn. Rapportert antall fanget og sluppet fisk er [illegible] siden rapporteringsrutinene for sluppet fisk ikke [illegible] 2009.




*Figur 2.1.1.1 Rapportert fangst (antall) av laks i Norge i perioden 1980-2008 [illegible]*


Rapportert fangst (tonn)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
Elvefiske
Sjøfiske
Totalt
19

- Threat factors against the wild salmon population
  - Escaped farmed salmon: Interbreeding and genetic ‘pollution’ (Hindar and Diserud 2007)
  - Salmon lice (transmitted from the farmed salmon industry)
  - *Gyrodactylus salaris* (parasit)
  - Acid rain
  - River water regulations
  - Overfishing

# 2. Age structured model

- In what follows present the basic structure of an age structured salmon model (Ongoing NFR Miljø 2015 project)

- Age structured model vs. biomass.
  - Biomass: ‘A fish is a fish’. A well formulated biomass model: Simple and illuminating analysis of driving forces (e.g., Clark 1990)

- But….often a feeling that ‘something is missing’. Ongoing discussion
  - Fishing ‘young’ or ‘old’ cod
  - Evolutionary drift due to selective fishing mortality
  - Trawlers versus coastal fleet, etc..
  - Recent paper Tahvonen (2009)

- Wild salmon life history:
  - Anadromous species with a complex life cycle
  - Spawn in rivers where the juvenile salmon spend the first few (1-5) years
  - Migrate to the sea where they stay 2-4 years
  - Once mature, return to home, or parent, river to spawn
  - Dies (ex. about 5 %) after spawning

- Age structured model representation:
  - Restricted number of age classes
  - Three age classes immature plus recruitment
  - Two adult/mature and harvestable classes; ‘young’ (‘small’) and ‘old’ (‘large’)
  - These two harvestable classes are the spawning population
  - Higher fertility old than young
  - Spawning density dependent
  - Natural mortality fixed and density independent
  - Dies after spawning

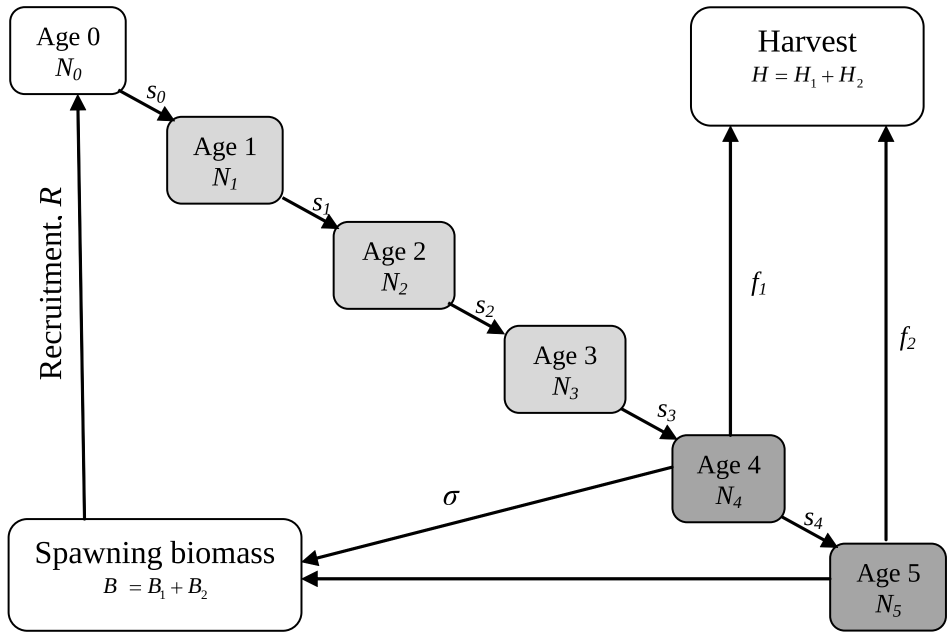



Figure 1. Schematic representation of the structure of a wild Atlantic salmon for a single cohort. Events shown are recruitment at age *0*, the following young salmon in freshwater habitats from age 1 to 3, and the returns of maturing parts of the stock and harvests at adult classes from age 4 to 5. $N$, age-specific salmon biomass in number of fish; $s$, age-specific survival rate; $f$, harvest rate; $H$, harvest; σ, the fraction of mature salmon at age class 4; R, recruitment; B, spawning biomass.

- Equations of motion:

$$N_{0,t} = R(B_t)$$

$$N_{a+1,t+1} = s_a N_{a,t} \qquad a = 0,1,2$$

$$N_{4,t+1} = s_3 N_{3,t} \sigma (1 - f_{4,t})$$

$$N_{5,t+1} = s_3 N_{3,t-1} (1 - \sigma) s_4 (1 - f_{5,t})$$

$$B_t = \gamma_4 N_{4,t} + \gamma_5 N_{5,t} = \gamma_4 s_3 N_{3,t-1} \sigma (1 - f_{4,t-1}) + \gamma_5 s_3 N_{3,t-2} (1 - \sigma) s_4 (1 - f_{5,t-1})$$

- Complex dynamic system . But straightforward to simulate effects of variations in fishing mortalities (stock growth, ‘sustainability’, etc.)
- However, difficult to optimize: Optimal fishing mortalities due to certain goals (e.g., costs and benefits)
- In what follows: Looking at a classical problem: What is the maximum sustainable yield of a salmon fishery?

- The maximum sustainable yield problem: What is the maximum harvestable biomass for a stable population?

- Solved first time by Reed (1980) where several harvestable classes were considered. Result: Target only one or two age classes

- Combing the above dynamic system and considering the reduced form:

$$N_{3,t+3} = sR(B_t)$$

$$B_t = \gamma_4 N_{4,t} + \gamma_5 N_{5,t} = \gamma_4 s_3 N_{3,t-1}\sigma(1 - f_{4,t-1}) + \gamma_5 s_3 N_{3,t-2}(1-\sigma)s_4(1 - f_{5,t-1})$$

- Studying this system in biological equilibrium (stable population)
- Two stock variables and, and two fishing mortalities (control variables)
- The maximum sustainable yield problem is then to find fishing mortalities and stock stock sizes maximizing

$$Q = [w_4 s_3 \sigma f_4 + w_5 s_3 (1-\sigma) s_4 f_5] N_3$$

s.t. the biological constraints

- Using lagrange method, the first order control conditions read:

$$\partial L / \partial f_4 = w_4 - \mu\gamma_4 \begin{matrix} \geq \\ = \\ < \end{matrix} 0 \qquad 0 \leq f_4 \leq 1$$

$$\partial L / \partial f_5 = w_5 - \mu\gamma_5 \begin{matrix} \geq \\ = \\ < \end{matrix} 0 \qquad 0 \leq f_5 \leq 1$$

,

- Weight vs. fecundity

- In plain English these conditions say:
  - Harvest up the point where the marginal biomass gain equalizes (or larger, or smaller) the biomass loss, evaluated by the recruitment constraint shadow price

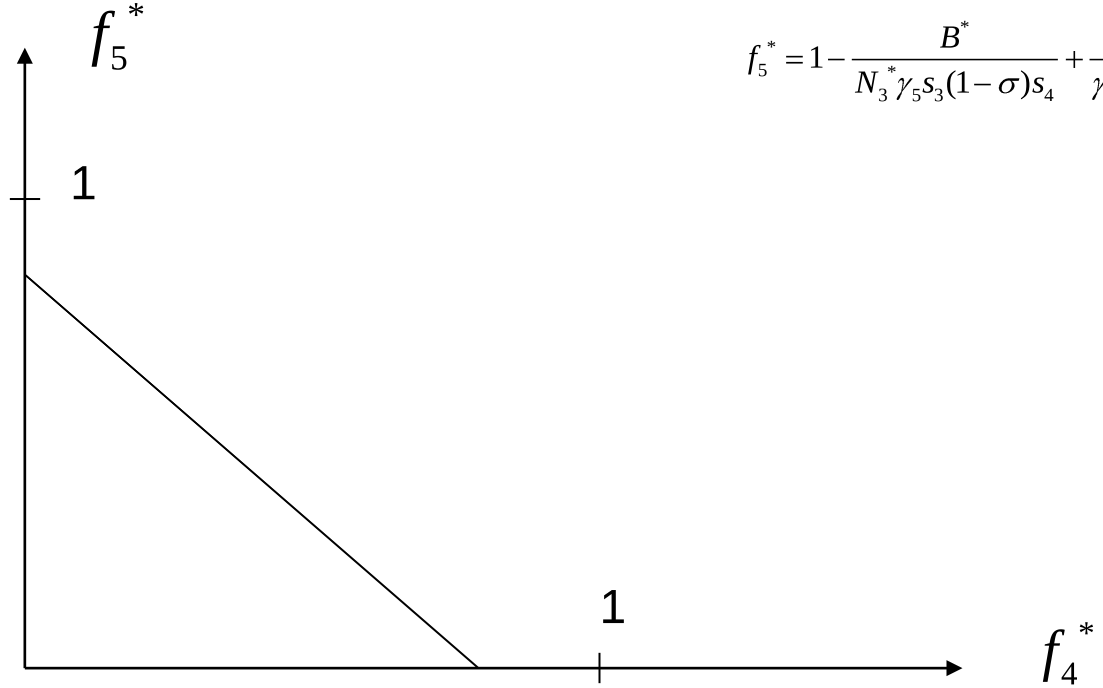
- Different possibilities. First assuming fertility being proportional to weight. Then Proposition:

- *If fecundity is approximated by weight, fishing both mature stages will represent the maximum sustainable yield policy. This optimal policy can be reached by an infinite number of combinations of fishing mortalities*.

- Why an infinite combinations? Intuition: Because the information content of the two control conditions are similar. Hence, one degree of freedom

- The sustainable yield frontier

$$f_5^* = 1 - \frac{B^*}{N_3^* \gamma_5 s_3 (1-\sigma) s_4} + \frac{\gamma_4 \sigma}{\gamma_5 (1-\sigma) s_4}(1 - f_4^*)$$



- The fishing mortality may be highest for the old mature class,… or the young mature class

- So what is the significance of this? One more year in the ocean: Higher weight (gain), higher fecundity (loss), but ‘discounted’ through natural mortality. But this discount rent plays no role in the harvest decision!

- If fecundity is not approximated by weight. Then several other possibilities. Proposition:

- *If the weight – fecundity ratio differs among the age classes, then fishing mortality should be highest for the age class with the highest ratio*

$$w_5 / \gamma_5 > w_4 / \gamma_4$$

- Then higher fishing mortality of the old age class. Intuition: Lower fertility

- Simple model, but different results compared to Red (1980)
  - Fertility plays a role
  - Natural mortality plays no role (no biological discounting)!
  - But as in Reed: Biomass gain (weight) plays a role
- Important biological difference: The salmon dies after spawning

# 3. Management

- As seen: Harvest also small salmon to obtain as much biomass as possible!
- Crucial for management: Possible to select between age classes in harvesting
- Due to seasonal variation in migration: Possible (to some extent) to target after size and age