Wild Salmon fishery

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- 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

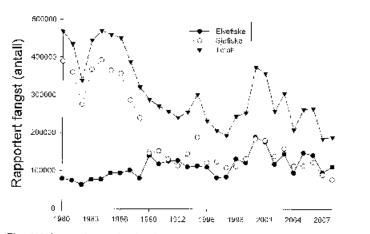
2 OF DRT 5NA VITEREN, OF OR DRD FOR THE CRUCH VALUE IN JANES

2 STATUS FOR NORSK LAKS

2.1 Utviklingstrekk

2.11 Fangst og innsig

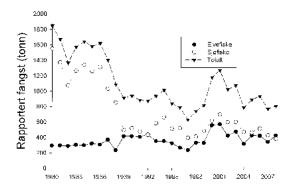
1 2006 ble det rappertent funget da 102 000 laks i Norej (figur 2.1.1.7) som verde af sammer en 807 ocn (figur 2.1.3.2). I fillege ble det lantapportent af 1500 bles the simpler ut gjen errer a ha ble finget. Audan voks på disse var es 20 ocm slik ar estanter nordrings i blebet, fanget og dispet bles blar på 8.57 ocm. Rappertent antolf forget og slupper fisk er undrites me er sliker rapportentingenderger fisk utke som markelide for avanger 2019



Flyrer 2.1.1.1 (lapparent fangel (minil) en link er brang i parasen 1730-1894 (enne optistatiskak, er utsånden, av ut John som er famge og stoppel dette er ledendorfj

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(Egent 3.1.1.2 Supported funget (many in 6.8.) Scarge I periodice 1980-2016. "Weit small approximate se locatedore more total new orfange og approximate og miljonders).

Hiter flore an trad velativ i roge infinite en div hassaarstandens stöttelse rundt åttäsenskultat, kan esimistase die sinte erane war have Lasianater for 2005 (en 450 000 villelse for Felet tiel di) van der fierde livewei i disprisieden 1565 3006. Die live interfere slyddes hoven in dig die have antalle anfrans for 220 005 village for tielet tiel. Egative an unteren beweit estimater take dasaren.

I 2008 car wordt estimert tansig av fills in No ise hit stone enn i 2007 (figur 2.1.1.3), men der Gerde faveste siden 1560. Für Norgs was haltet i preinden 1980 - 2008 aus beaurden owparticular and other thanks (and and) og the sport tertales (mellom og strettaks) at til a da væd stolst på 1980-failet, vertinede på er favmål på mieren av 1990-miler og oktiggen rundt årnsenshiftet. Junaggine to simplely her very even lace de sive areas (figur 2.1.1.4), mens intraigene as mellom, eq. storlele ikke har vist earrenn medsegeende trener, (ligen 2:1:1.5). Deler men Norge met streneger they was estimated for likelihestations stratelise a Sou Notice (for Sychologienes til Shid) i 2008 (a. 114.000 villaks, som er det fjerde laveste estimatet i perioder 1983 (5.08 (figur 2.1.1.6),) Mid-Norge (bu Sizi) fil Ves offen) vær lets and a sinnare i for 2008 ea 200 000 villeks, som er de forme aviste i palieden (figur 2.1.1.7). I Nord-Poorge (f.a Misterolen in grensa mor Ressiane) var bestandsestimatet for 20(6 ct 1/0/00) villabs, som er det sjene kweste i petioden (figur 2/1.1.8) Laurane, for anglelas i Nord-Norge car de, laveag i heix i diperiodor. Talas ira Tana u gior ansilemeasig en a mulei av bestandere i Norel Norge. Densone vil jærner brugs er relitigana og Terra-Ippenn ha beingungene as laksennisiger ul tonie. Noage, visti estimatere et likse bestindene i 2008 var under gjennomenittet for perioden 1950-2006 (figur 2.1.1.9). Donmetere for Nord-Norge van betydelig hovere på 1990 tallet einn senere. De te kon delvis fly des at dräugaristichet. utenfor Nord Norge suger fisk som hørta for mud stedre steder (bade i Norge og 1 Zussland).

Metecen som en brukt for a beregne bestonds vereken (PFA, Pre-) isher? Abundence der vil an nanger av lake for bestander, i foka? (het igner mer på "ton-reconstruction" metoden som har blitt brukt for å beregne bestanden av klast Nordeat Alameren (Poarer of 1, 1001), met det merske at så "tar ser lagga und i baggar er ve "ås i tilser anner sokat i ern ander rettraket

- 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

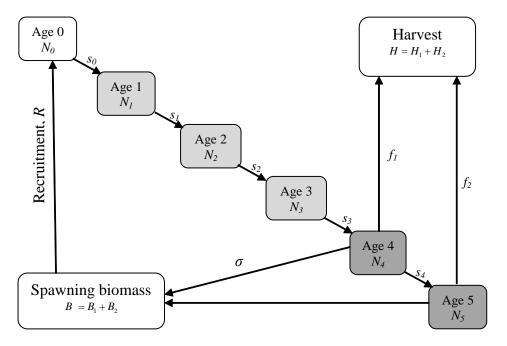


Figure 1. Schematic representation of the structure of a wild Atlantic salmon for a single cohort. Events shown are recruitment at age 0, the following young salmon in freshwater habitats from age 1 to 3, and the returns of maturing parts of the stock and harvests at adult classes from age 4 to 5. N, 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:

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

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

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

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

$$B_{t} = \gamma_{4}N_{4,t} + \gamma_{5}N_{5,t} = \gamma_{4}s_{3}N_{3,t-1}\sigma(1 - f_{4,t-1}) + \gamma_{5}s_{3}N_{3,t-2}(1 - \sigma)s_{4}(1 - f_{5,t-1})$$

Value creation... Esbjerg Oct 2009

- 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:

,

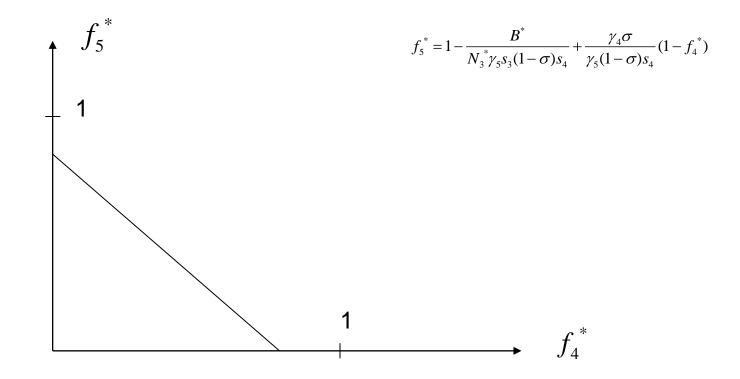
$$\partial L/\partial f_4 = w_4 - \mu \gamma_4 \stackrel{\geq}{<} 0 \qquad 0 \le f_4 \le 1$$

$$\partial L/\partial f_5 = w_5 - \mu \gamma_5 \stackrel{\geq}{=} 0 \qquad 0 \le f_5 \le 1$$

Value creation... Esbjerg Oct 2009

- 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



- 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