Stock assessment and management advice

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Main issues to cover:

- ➔Elementary population dynamics
- ➔Assessment methods
- ➔Computer programs
- ➔The management perspective

The course consists of:

- Lectures
- Exercises on spreadsheets
- Use of computer packages

Brief introduction to fisheries management in a scientific perspective

The management perspective

First question:
What do we want to achieve by managing a fish stock?
You may have to face a broad range of expectations,
that all may have some legitimacy, but not always are mutually compatible.

From a scientific perspective the bottom line is that a fish stock is a self-renewing resource, but only within limitations set by nature.

Science can assist by:

- Outline the limitations
- Outline the opportunities within those limitations
- Clarify realistic objectives
- Assist in designing management plans that reach the objectives in an optimal way.
- Provide information for year-to-year decisions on exploitation.

So, in brief, science can
Advice on a rational use of a self-renewing resource, within the limitations set by nature

That is what this course is about.

The limitations set by nature:

The stock can replace a loss, but only up to a certain point
If the loss exceeds the capacity for replacement, the stock will decline.

The loss that can be replaced varies from year to year,
and depends on the stock size.

Therefore, if the stock gets depleted, we may come into a vicious circle

To get out of that may require drastic measures and will at best take time.

Science can:

- Inform about the self renewing capacity, which is the limitations set by nature
- Within those limitations, science can advice on a rational use of the resource:
    - Management plans and harvest rules:
        - The overall perspective – strategic decisions
        - From year to year – tactical decisions

A management strategy has several elements:

- Objectives – what do we want to achieve?
- Data infrastructure (monitoring of fisheries, survey activities)
- Information base, incl. assessment
- Decision rules
- Fishery infrastructure
- Implementation and enforcement
- Simulation and evaluation
- Cooperation, governance, culture.

We shall come back to some of this towards the end of the course.
For the time being, a brief look at each.

The basics of fish population dynamics.

Fish stock (population)

A group of fish that is a closed entity:

- Members of the group belong to one species, and have common biological properties
- Enter by being born by parents in the stock
- Leave by death
- A stock reproduces itself

Typically a stock occupies an area, has specific spawning grounds and migrations,

But it is not the same as the fish in an area:
The fish in an area may be part of a stock or a mixture from several stocks,
with migrations into and out of the area.

Discrepancy between stock distribution and management units is a common problem.

For assessing the stock, the assumption that it is a closed entity is essential.

Stock dynamics.
How a stock evolves over time.

Each year a number of fish is born, which is a new year class.
Over the years, these individuals
- grow
- reproduce
- die.

The number and biomass of fish in the whole stock at any time is the sum of year classes

We shall describe, in mathematical terms, how fish recruit, grow, reproduce and die.
That gives us a complete model for the stock dynamic.

A year class is also a closed entity, you cannot change from one year class to another.
So, we can describe the population dynamics by following the year classes.

Alternatively, we can make a short-cut:
Describe directly how the biomass of the stock changes over time.

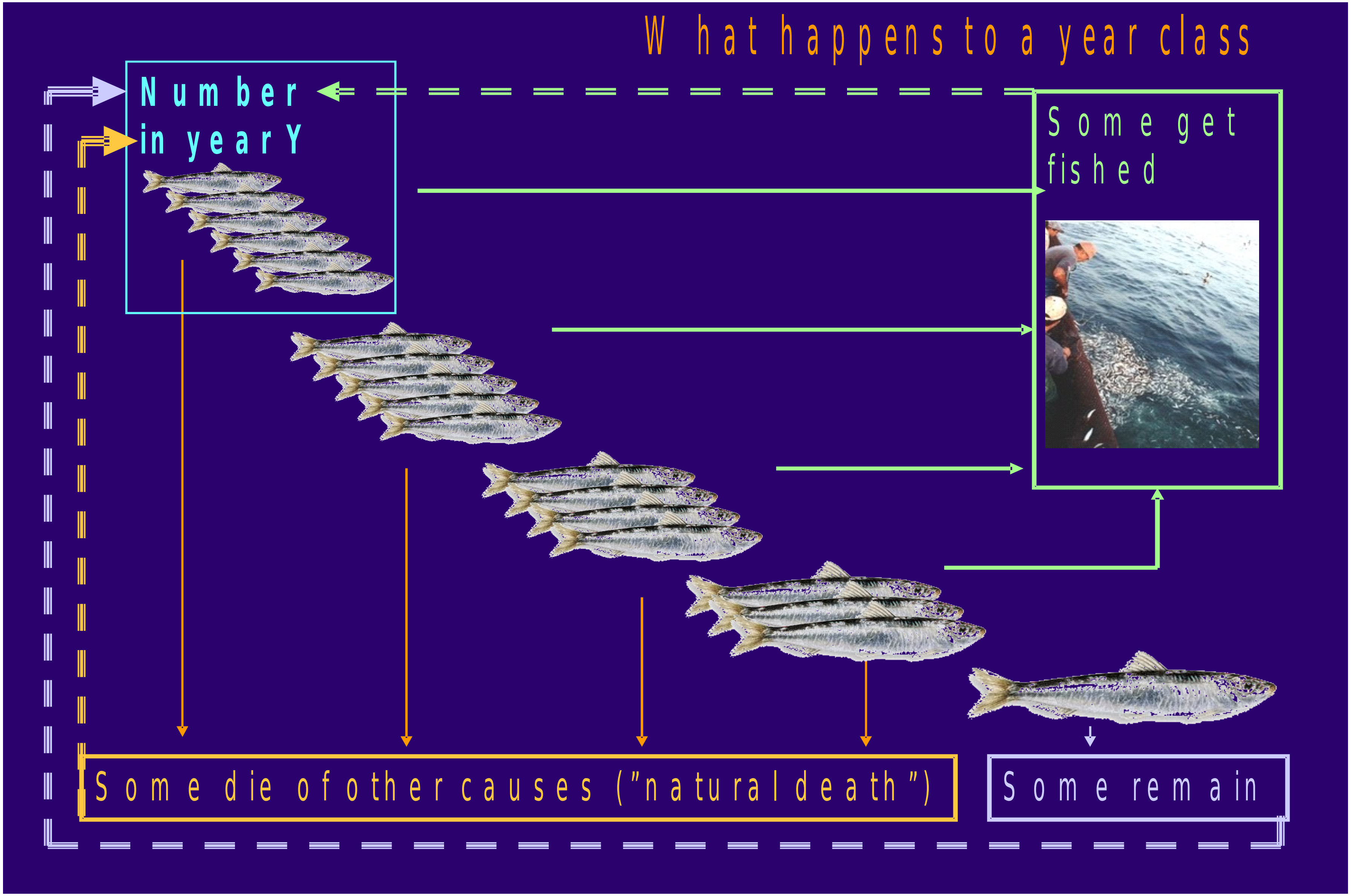
It is convenient to **follow a year class:**

- A year class is a closed entity, no other way of getting out than to die.
- A subset of a population that we can follow over time we call a cohort.
- A year class is one kind of cohort.

Key properties of a year class

- Born at a certain time (year)
- Later on, they all have the same age.
- Has a certain number of individuals initially
- These individuals grow
- Individuals die, depleting the year class

The biomass of the year class is the sum of the weights of all the individuals,
So it is the number of individuals times the individual weight
The biomass of the stock is the sum of the biomasses of all the year classes.


What happens to a year class
Number in year Y
Some get fished
Some die of other causes ("natural death")
Some remain

We usually describe the population by a table of Numbers of fish in the stock by year and age

Year

Age	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
0	436.0	1014.0	1313.7	1411.3	1081.6	582.5	911.5	836.9	1679.5	2556.5	1258.9	1931.3	526.7	574.0	1084.7	1635.7	1624.3	1045.2	1925.9	549.3
1	456.9	332.1	755.4	969.1	1027.3	738.8	361.4	548.1	502.7	939.7	1412.7	746.9	1176.6	336.8	395.9	770.5	1159.6	1185.3	716.8	1334.7
2	553.5	343.8	244.6	548.4	694.1	686.4	443.0	207.9	315.0	267.6	484.3	796.5	433.0	722.4	228.2	274.8	535.6	831.2	790.9	485.3
3	776.6	408.4	248.0	172.9	382.1	446.0	387.6	236.6	110.9	153.7	123.9	251.4	427.0	249.2	473.5	152.6	184.7	372.9	530.3	514.7
4	466.5	559.9	286.0	169.5	116.0	231.9	230.8	187.2	114.1	47.9	62.8	57.9	122.5	226.7	155.2	302.3	97.9	123.8	224.5	327.0
5	221.8	329.5	379.5	189.1	109.3	66.1	109.0	100.7	81.6	43.3	17.5	26.6	25.8	60.4	132.8	94.9	184.8	63.3	70.5	131.0
6	165.8	154.5	217.4	245.1	118.3	59.1	28.7	44.1	40.6	28.0	14.7	6.9	11.2	12.1	33.5	78.8	55.9	116.5	34.6	39.4
7	67.9	114.5	100.2	138.5	150.5	61.9	24.4	11.1	17.0	13.1	9.1	5.6	2.8	5.1	6.5	19.5	45.4	34.7	62.2	18.9
8	37.0	46.8	73.6	63.4	84.2	77.4	24.9	9.2	4.2	5.3	4.2	3.4	2.2	1.3	2.7	3.7	11.1	27.9	18.3	33.5
9	12.9	25.4	29.9	46.4	38.4	42.9	30.7	9.3	3.4	1.3	1.7	1.5	1.3	1.0	0.7	1.5	2.1	6.8	14.7	9.8
10	15.8	8.9	16.2	18.8	28.0	19.5	16.9	11.4	3.4	1.0	0.4	0.6	0.6	0.6	0.5	0.4	0.9	1.3	3.6	7.8
11+	10.0	17.7	16.9	20.9	23.9	26.3	18.0	12.9	9.0	3.7	1.5	0.7	0.5	0.5	0.6	0.6	0.6	0.9	1.1	2.5

Age

Year class

Plus-group

Notation (for reference):
Some standard notation

N for number of individuals. If nothing else is explicitly state, the convention is to use N in a year as the number at the start of the year
R for recruitment
F for fishing mortality
M for natural mortality
Z for total mortality
B for biomass
w for individual weight
L for length

a for age
t for time (general)
y for year

Start with looking at how the numbers in a year class evolve over time

Consider a year class which has age a in year y.

From year y to year y+1, some members of the year class die,
and by definition, no new members can enter it
So, the number N(a,y) in the year class is
reduced from

N(a,y) to N(a+1,y+1).

We want a measure of that reduction.

A convenient measure is the relative reduction of the stock number, on a log scale:

$Z(a,y) = \log\{N(a,y)/N(a+1,y+1)\}$

We call Z(a,y) the mortality at age a in year y

Could have used other measures, but this is practical.

Definition of mortality
Disappearance (in numbers) of individuals in a year class

	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910
0	436.0	1014.0	1313.7	1411.3	1081.6	582.5	911.5	836.9	1679.5	2556.5
1	456.9	332.1	755.4	969.1	1027.3	738.8	361.4	548.1	502.7	939.7
2	553.5	343.8	244.6	548.4	694.1	686.4	443.0	207.9	315.0	267.6
3	776.6	408.4	248.0	172.9	382.1	446.0	387.6	236.6	110.9	153.7
4	466.5	559.9	286.0	169.5	116.0	231.9	230.8	187.2	114.1	47.9
5	221.8	329.5	379.5	189.1	109.3	66.1	109.0	100.7	81.6	43.3
6	165.8	154.5	217.4	245.1	118.3	59.1	28.7	44.1	40.6	28.0
7	67.9	114.5	100.2	138.5	150.5	61.9	24.4	11.1	17.0	13.1
8	37.0	46.8	73.6	63.4	84.2	77.4	24.9	9.2	4.2	5.3
9	12.9	25.4	29.9	46.4	38.4	42.9	30.7	9.3	3.4	1.3
10	15.8	8.9	16.2	18.8	28.0	19.5	16.9	11.4	3.4	1.0
11+	10.0	17.7	16.9	20.9	23.9	26.3	18.0	12.9	9.0	3.7

We define the mortality from age a in year y to age a+1 in year y+1 as:

$Z = \log[(N(a,y)/N(a+1,y+1)]$

The logarithm is the natural Logarithm, with base e.

n this example:

$Z(a,y) = \log [230.8/100.7]$
$= \log [2.29] = 0.83$

It follows from the definition that
$N(a+1,y+1) = N(a,y)*\exp(-Z)$

and that the loss during the year is
$N(a,y)-N(a+1,y+1) = N(a,y)-N(a,y)*\exp(-Z) = N(a,y)*(1-\exp(-z))$

Alternatively, we can define the instantaneous disappearance rate z(t) at time t as:

$$z(t)=\frac{1}{N(t)}*\frac{dN(t)}{dt}$$

This definition often appears in the literature.

If we integrate that over a time interval (t, t+1) we get:

$$N(t) = N(0) * e^{\int_0^1 -z(\tau)d\tau}$$

Since $\int_0^1 -z(\tau)d\tau$ is the mean of z over the year, the mortality as we defined it previously is the mean over the year of an instantaneous mortality. So, the definitions are equivalent if we regard Z(t) as the mean of z(t). and we can write:

$$N(y+1) = N(y) * e^{-Z(y)}$$

when N(y) means N at the start of year y and Z(y) the mean Z over the year y.

But it also follows that

$$N(t+\Delta t) = N(t) * e^{\int_t^{t+\Delta t} -z(\tau) d\tau}$$

and if Z is constant as a mean z:

$$N(t+\Delta t) = N(t)* e^{Z*\Delta t}$$

The mean N over a time period Δt is

$$\bar{N} = \frac{1}{\Delta t} * \int_t^{t+\Delta t} N(\tau) d\tau = N(t) * \frac{1-e^{Z*\Delta t}}{Z*\Delta t}$$

Taken over the year y, and taking N(y) to represent the number at the start of year y, we get for the mean N:

$$\bar{N}(y) = N(y) * \frac{1-e^{Z(y)}}{Z(y)}$$

Why is Z a convenient measure for disappearance?

1. It is relatively stable over age and time. A year class of fish is depleted gradually - approximately the same fraction each year. Therefore, the Z-value will be **approximatel**y the same over time and age. So, it is a good descriptor of dynamics in that sense.

2. It has some nice properties (next slide)

3. It can be related to the intensity in the fishery - the effort in the fishery.

Less convenient:

Many people find it hard to understand. Sometimes, people prefer to describe the fraction

$$N(y+1,a+1)/N(a,y) = \exp(-Z)$$

that remains after a year rather than the logarithm of the fraction. But then we loose some nice properties.

This definition of mortality has **some nice mathematical properties:**

- It is additive over time:
  - The reduction in N over several years corresponds to the sum of the annual mortalities over those years.

  - If we can assume that the mortality is constant over the year, the mortality in a smaller time step of duration Δt is $Z(a,y)*\Delta t$

- It is additive over causes:
  - We can split the loss into loss of several causes, for example loss due to fishery and loss due to other, natural causes.
    The mortality can be split accordingly,

- We call
  - F: the part of the mortality due to fishery
  - M: the mortality from other (natural) causes

  So, Z = F + M
  Then, the loss due to the fishery is F/Z times the total loss.

- Total loss: N(a,y) - N(a+1,y+1) = N(a,y) - $N(a,y)*e^{-Z(a,y)}$

  = $N(a,y)*(1-e^{-Z(a,y)})$

  The fraction due to fishery is $\frac{F(a,y)}{Z(a,y)}*N(a,y)*(1-e^{-Z(a,y)})$

We have seen that the number lost from a year class during the year y is

$$N(a,y) * (1 - e^{-Z(a,y)})$$

and that the loss due to the fishery is the fraction F(a,y)/Z(a,y) of that loss. This is the catch in numbers from that year class in year y:

$$C(a,y) = \frac{F(a,y)}{Z(a,y)} * N(a,y) * (1 - e^{-Z(a,y)})$$

This is called **the catch equation**, and is fundamental to analytic assessments, because it describes the relation between stock abundance, fishing mortality and catch.

Popes equation - a simple approximation to the catch equation.

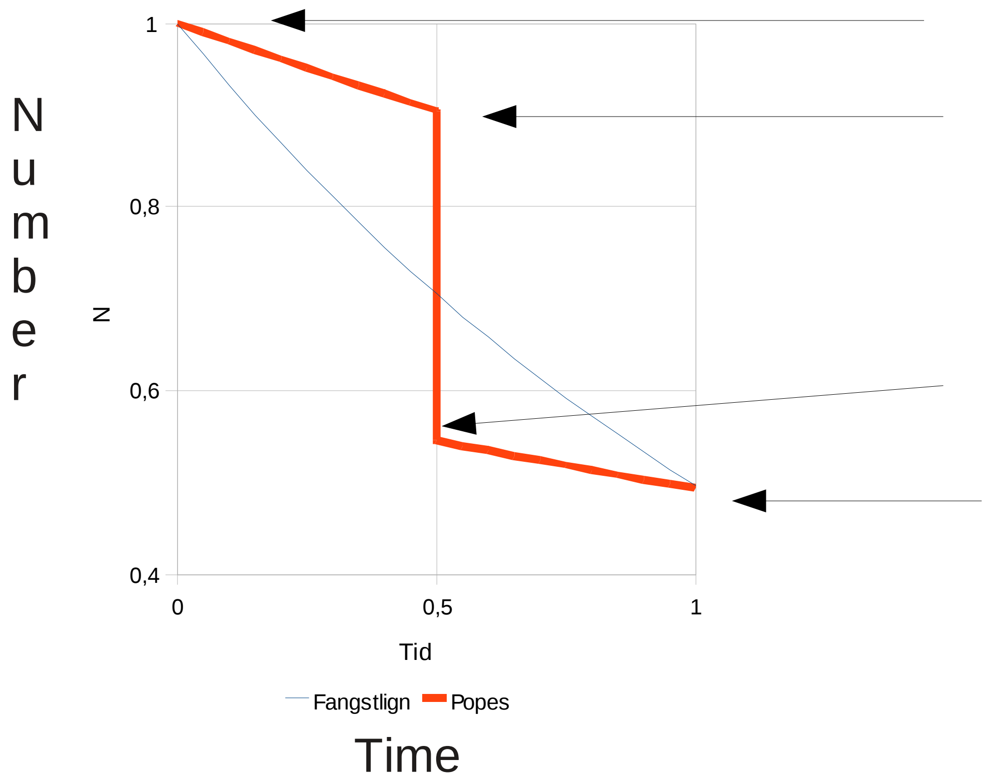
We often want to derive the number N that corresponds to a catch C
at a fishing mortality F.
The catch equation is cumbersome, because the relation between N, F and catch
cannot be expressed analytically, since there is a mix of plain and exponential terms.

We can find an approximate relation:

$$N(y+1) = N(y)*\exp(-M) - C(y)*\exp(-M/2)$$

This relation is correct if the whole fishery takes place exactly in the middle of the year,
but it is a very good approximation also when the fishery is spread over most of the year.
It is used very much in assessment work, as we shall do later on as well.

Popes equation



Start with N individuals (here =1)

Midway in the year that is reduced
by natural mortality to
N*exp(-M/2)

Subtract the catch, to get
N*exp(-M/2)-C

Reduce that further throughout
the rest of the year by natural mortality:
(N*exp(-M/2)-C)*exp(-M/2)

A little ordering gives
N(y+1) = N(y)*exp(-M) - C(y)*exp(-M/2)

You can use the same logic in the opposite direction and get
N(y) = N(y+1)*exp(M) + C(y)*exp(M/2).

A useful exercise is to nest Popes equation backwards in time:

Start with N(y)

N(y-1) = N(y)*exp(M) + C(y)*exp(M/2)
N(y-2) = N(y-1)*exp(M) + C(y-1)*exp(M/2)

and so forth.

Ordering these expressions (which involves some cumbersome algebra) will tell you that:

The stock number at one time y-i, say, is

A weighted sum of caches between year y-i and year y, where the weighting is due to cumulated natural mortality
\+ a sum with terms involving natural mortality only
\+ the remaining N(y) expanded by cumulated natural mortality

That means:
The stock number at some time in the past is what you need to account for the subsequent catches + what you need for the still remaining fish, both taking the extra loss due to natural mortality into account.

This is a very useful insight for understanding assessments.

If this is too much mathematics, this is the essence:

- $Z(a,y) = \log \dfrac{N(a,y)}{N(a+1,y+1)}$ is the definition of mortality

- N(y+1) = $N(y) * e^{-Z(y)}$ is what you are left with next year

- The mean N over the year is $\bar{N}(y) = N(y) * \dfrac{1-e^{Z(y)}}{Z(y)}$

- The catch equation C(a,y) = $\dfrac{F(a,y)}{Z(a,y)} * N(a,y) * \left(1-e^{-Z(a,y)}\right)$

  and
- Popes approximation: N(y+1) = N(y)*exp(-M) + C(y)*exp(-M/2)

describe the relation between catch, stock and fishing mortality.

It is strongly recommended to learn these formulas by heart, you will need them over and over again.

F and effort
It often is relevant to assume that the F-component is proportional to the effort in the fishery. Why?

It is a consequence of the additivity of mortalities due to different causes.

Example:
Suppose that the yearly effort in a fishery is 1000 hours trawling.
This effort leads to a fishing mortality of 0.2, for example
What happens if the effort is doubled?

That is the same as having an additional fleet, also with 1000 hours trawling, that also should generate a fishing mortality of 0.2.
Due to the additivity of the mortalities, the sum of fishing mortality by these two fleets becomes 0.2 + 0.2, so that is also doubled.

More generally, the fishing mortality is proportional to the effort, at least in principle.
The scaling factor generally has to be estimated.

We shall come back to effort and effort measures later on, but this is the basic idea.

CPUE
Following this further:

If it is relevant to assume that fishing mortality is proportional to effort, that is:

$F = q*E$

that can be substituted or F in the catch equation, so:

$C = N*q*E/(q*E + M)*(1-\exp(q*E + M))$

Then

$C/E = N*q*(1-\exp(q*E + M))/(q*E + M)) = q*\bar{N}$

Accordingly, C/E (Catch Per Unit of Effort) is a measure of stock abundance.

Separable model for fishing mortality:

When setting up a population model, we need to specify fishing mortatlities.

One way to do that is to is to assume a simple model for the fishing mortalities,
By assuming that the fishing mortality at age a in year y is a product of two factors:

- An age factor called selection at age: S(a) that is the same every year.
- A year factor $F_y(y)$ which varies from year to year but is common to all ages.

Thus: $F(a,y) = F_y(y) * S(a)$

We can think of the $F_y(y)$ as representing the intensity of the fishery that year,
and the S(a) representing the fleets preference for young vs. old fish.

We call this a separable model.

Reconstructing a year class from the catches - the VPA principle.

Rather than assuming a model for the fishing mortalities, we can reconstruct a year class using the catches.

Start with N(a,y) at the start of year y.
Use Popes approximation and the catches in year y-1 from that year class to get

$$N(a-1,y-1) = N(a,y)*\exp(M(a)) + C(a-1,y-1)*\exp(-M(a)/2)$$

and so forth backwards in time.

Then you reconstruct the year class, but with some assumptions:

- N(y) has to be assumed
- M has to be known (here we have considered them age dependent but stable over time)
- The catches are known and correct, and the catch table has to be complete.

This method is often referred to as a VPA or SPA, and is the backbone of many assessment methods.
The challenge is to find adequate stock numbers N(y) at the end.

Then, time for practicing this: Make a model population.

Growth and growth models:

Fish grow in length throughout their whole life, but more slowly when they get old.

Most species follow quite closely the von Bertalanffy equation:

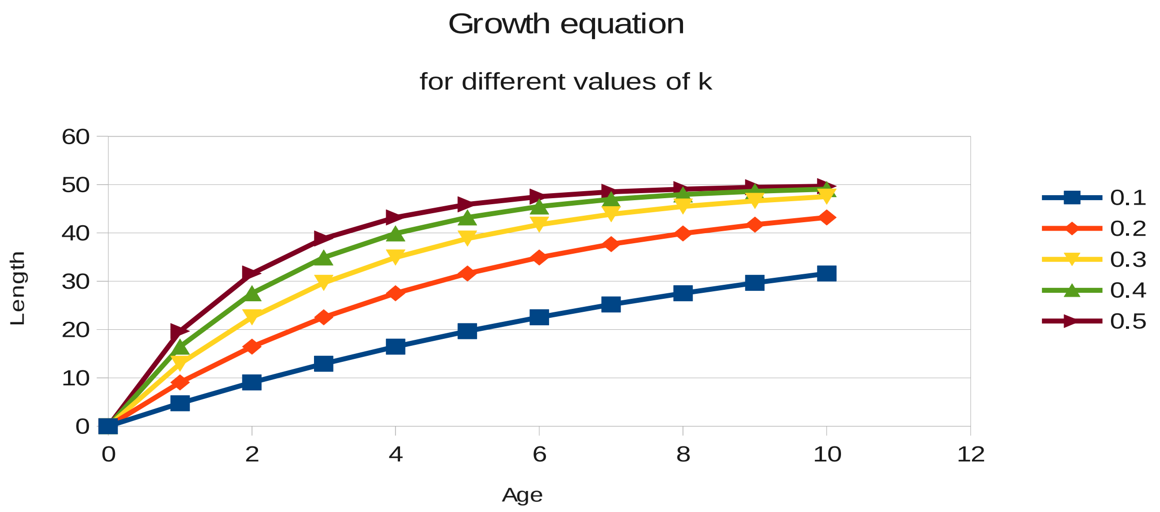
$L(t) = L_\infty *(1-\exp(-k(t-t0)))$

with the initial condition L(t0) = 0.

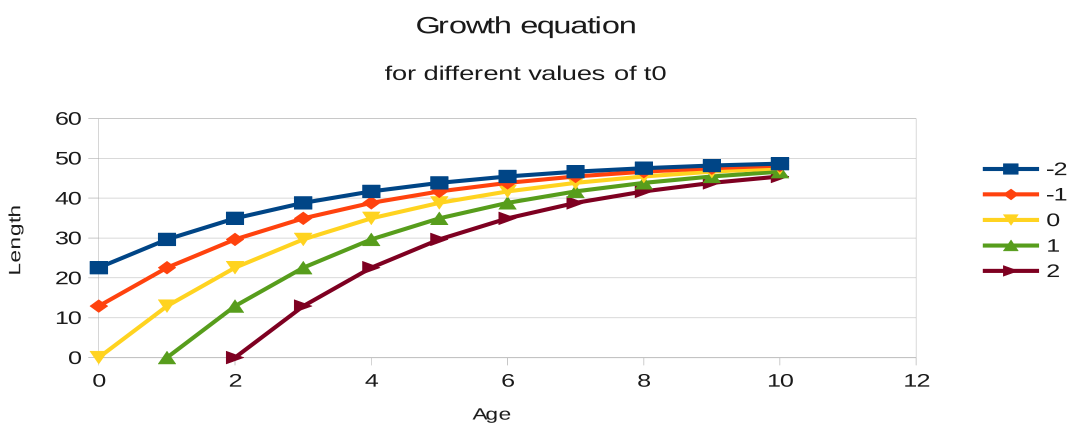
There are 3 parameters in this equation: L_∞ ,k and t0, that characterizes the growth of each species.

- L_∞ is the maximum length, this is the limiting value for the growth that in principle is never reached.
- k is the growth rate
- t0 is the age when the length is 0. It is not the same as the spawning time, but rather linked to get the length right at the age of the fish when it comes into the stock.

Examples of growth curves - length at age
Medium size, medium life span.



$L_\infty = 50$,
t0 = 0
k varies



$L_\infty = 50$,
t0 varies
k =0.3

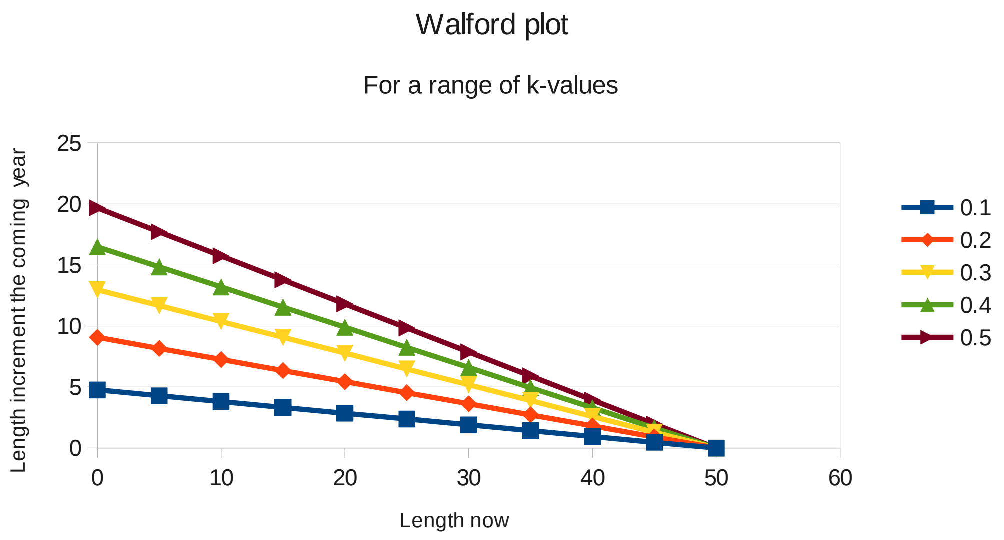
From the formulation

$L(t) = L_\infty *(1-exp(-k(t-t0)))$

it is easy to derive, with some manipulation, **the length increment ΔL in a time step Δt:**

$\mathbf{\Delta L} = L(t+\Delta t) - L(t) = \mathbf{(L_\infty - L(t)) * (1-exp(-k*\Delta t))}$

Obviously, that depends on L, and we note that since both L_∞ and k are constants, the length increment ΔL per time step is a *linear* function of the length L



We call this a Walford plot.

It is useful because the L_∞ and k can be read out of the plot, but to make it requires that we can measure the length at age
(or measure the fish twice)

Another useful relation, which can be derived by manipulating the von Bertalanffy equation, is for the time it takes to grow from L to L+ΔL. Obviously, that also depends on L.

$$\Delta t = \frac{1}{k} * \log \frac{L\infty - L}{L\infty - (L + \Delta L)}$$

These formulas are keys to some classical methods for analyzing catches at length.

For the mathematically interested:

The growth equation is the solution of a differential equation:

$dL(t)/dt = k^*(L_\infty - L(t))$

that is the original formulation by von Bertalanffy.
It says essentially that the growth rate at any time is proportional to how far the fish is from L_∞

It can be derived from physiological considerations, but we may just take it as a convenient form that most fish happen to follow.

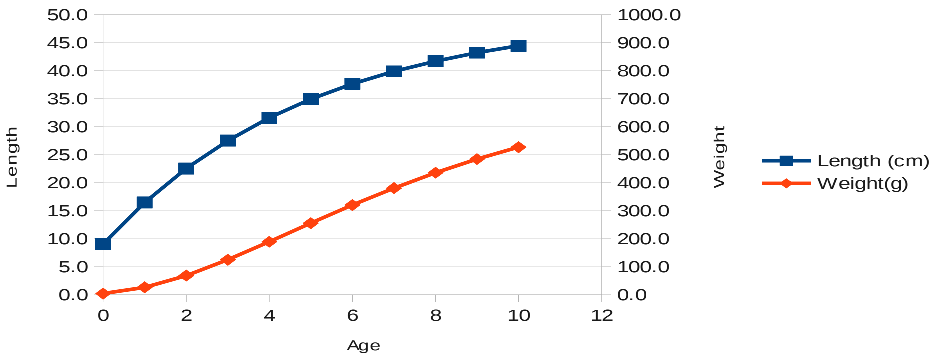
But it also illustrates the meaning of k:
It has the dimension of a rate, but relative to how far the fish is from L_∞.

A small k means a slow-growing species, a larger k means a fast growing species.

Weight and length

Weight (w) and length (L) follow each other.
The relation can often be described by the relation

$W = Cond*L^3$



- The coefficient Cond is called the condition factor.
  It varies between species, and also with the nutritional state.,
  but usually within a range that is characteristic of the species.
- The power term 3 is adequate for most species, but may deviate if the fish have a very strange shape.
- The power term and the condition factor are strongly confounded, which is another reason why the power of 3 usually is good enough

The equation can be derived by considering the energy balance:
Growth is the difference between energy supply and energy loss.
Supply is over surfaces (dimension 2),
Loss is by muscular activity (volumes of dimension 3)

Natural mortality (M) is the component of the total mortality that is not due to the fishery.

In assessment work, this covers all sources of loss that is not accounted for in the recorded catches, because the fishing mortality is estimated to fit to the catches.

In practice, to get a reliable estimate natural mortality in addition
to fishing mortality is not possible, with the kind of information that normally is available.

So the natural mortality is something that we just have to assume.
For management advice, the actual value of M does not always matter very much,
if it is reasonably realistic.

The value that we pick should be reasonable according to the life span of the species.

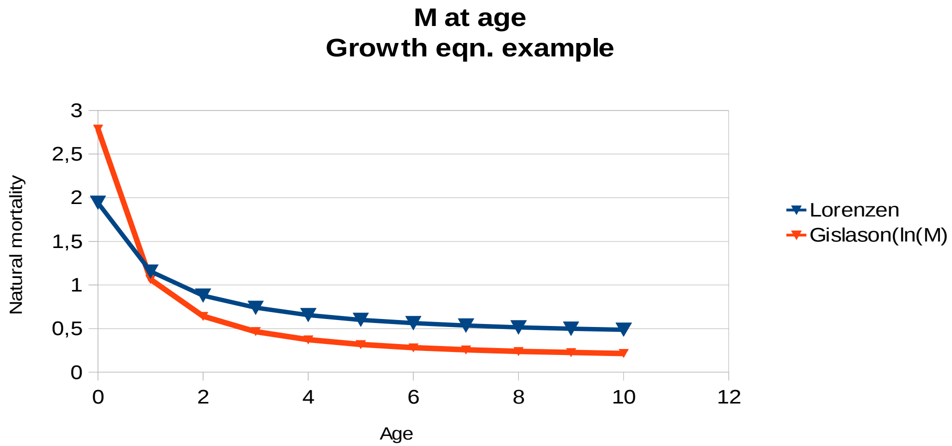
- For a species that can reach an age of 10-15 years, M=0.2 is a typical value.
- For a short lived species (life span 1-3 years),
  values around 1 - 1.5 can be adequate
- For very long lived species (life span 20-40 years) we often use 0.05 or 0.1

Many species are vulnerable to predation, in particular early in life.
Therefore, a higher M is often assumed at the youngest ages.

Some species only can manage a limited number of spawnings. It may be adequate
to have a higher M at old age, but that is not often seen in practice.

We sometimes see attempts to relate natural mortality to fish length.
That is sensible, because smaller fish are more vulnerable to e.g. predation and may be less able to find food.

There are several formulas in the literature. Most relate natural mortality primarily to length or weight, often using the von Bertalanffy parameters K and Linf in the formula to get natural mortality at age.
They may be used as a a guidance, but with care, because the basis for them is not very firm (see next slides).



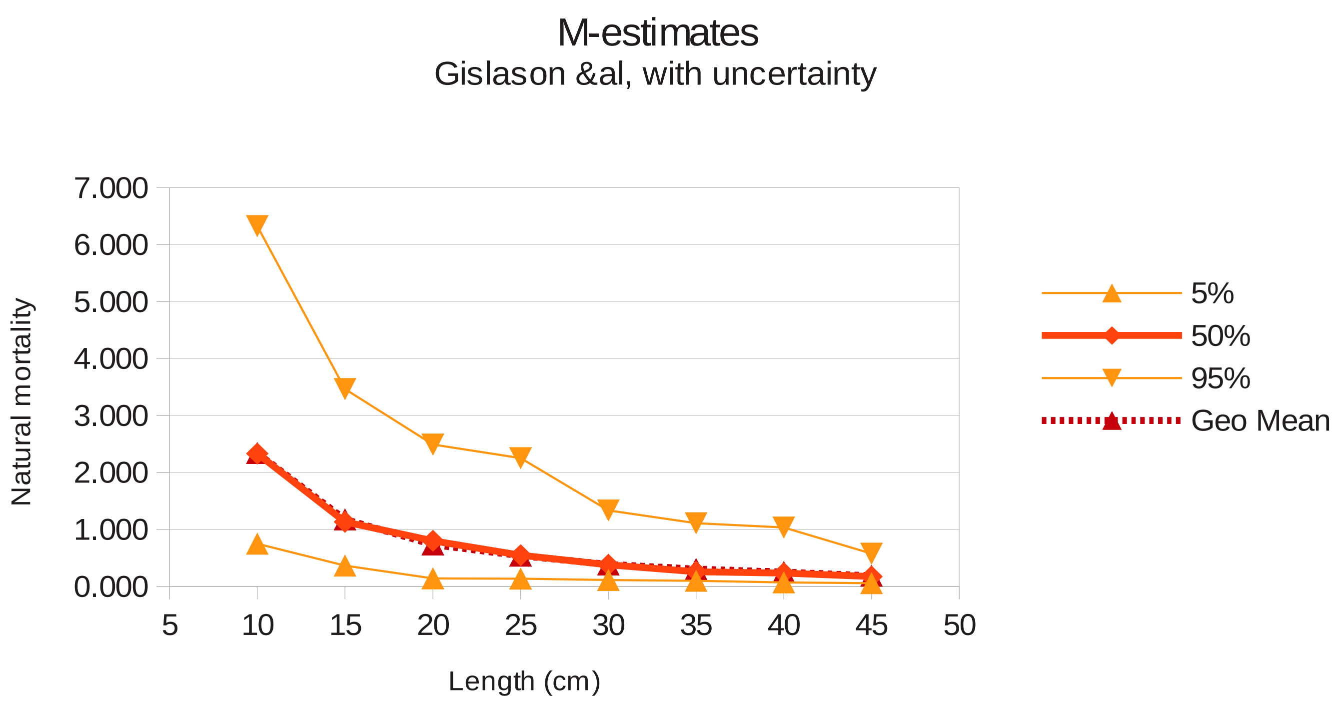
The graph shows

- The Lorenzen formula: $M = 3*W^{-0.29}$
- The Gislason &al formula: $ln(M) = 0.55 - 1.61ln(L) + 1.44ln(Linf) + ln(K)$

The paper by Gislason & al gives confidence intervals for the parameters.
Here is what that leads to in terms of uncertainty in M at length
obtained by a parametric bootstrap assuming log-normally distributed parameters
with the stated variances.

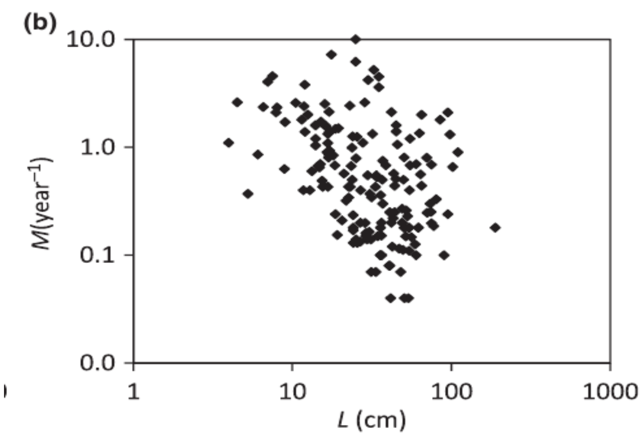
Such formulas may be a guidance, but not the final answer.
The mean values can often be sensible, but sometimes the actual
natural mortalities can be quite different.

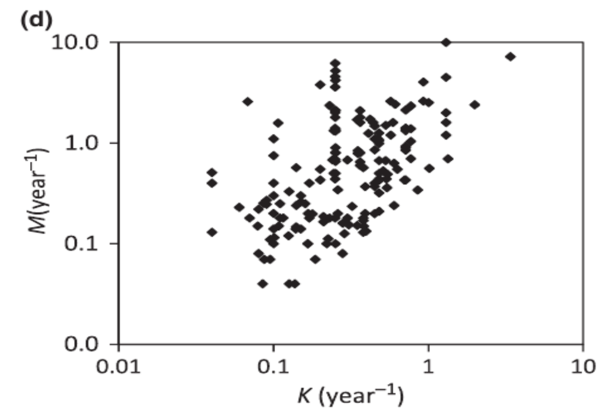
If there is direct information relating to your stock in question, use that.



The Gislason & al study was based on carefully selected M-estimates related to length and to k in the literature.
The actual data are shown here (Figure from Gislason & al)

Note the log scale on both axes





Even though the relations are clearly significant, there is a huge variation.
The relation to L_{inf} is less prominent.

Stock and recruitment

Intuitively, one might think that more parents means more offspring, i.e. that the recruitment would be proportional to the spawning stock biomass.

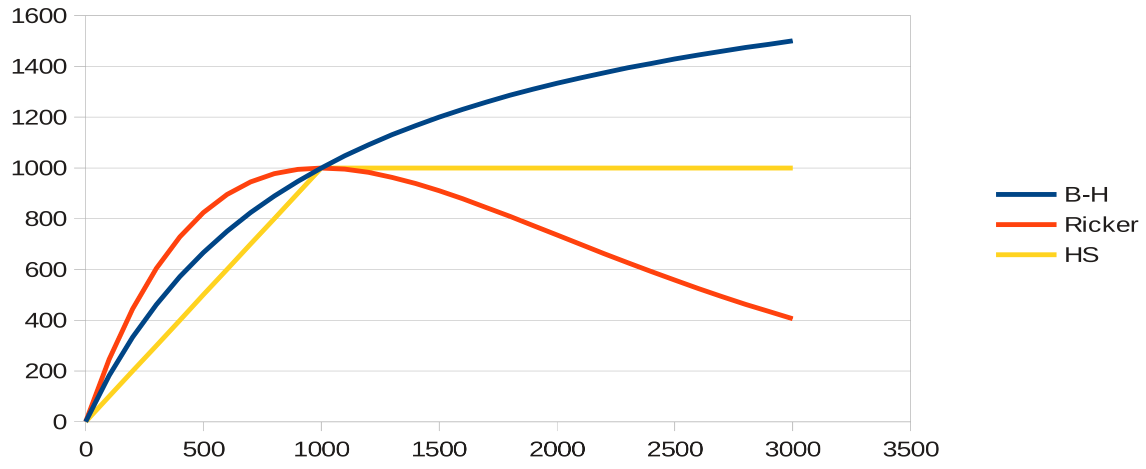
With fish, it is not quite that simple.

Clearly, if there is no parents, there will be no offspring. But if the SSB is big enough, the actual size of the spawning stock does not seem to matter much any more. This is also logical in an ecosystem setting, because if the recruitment were proportional to the SSB always, the stock would either grow infinitely or it would disappear.

The relation between stock (SSB) and recruitment is often described by simple functions, called stock-recruit (S-R) functions.

The most commonly used S-R functions all have two parameters, a and b

Beverton-Holt: R = a*SSB/(b+SSB)
Ricker: R = a*SSB/b*exp(1-SSB/b)
Hockey stick: R = MIN(a, a*SSB/b)



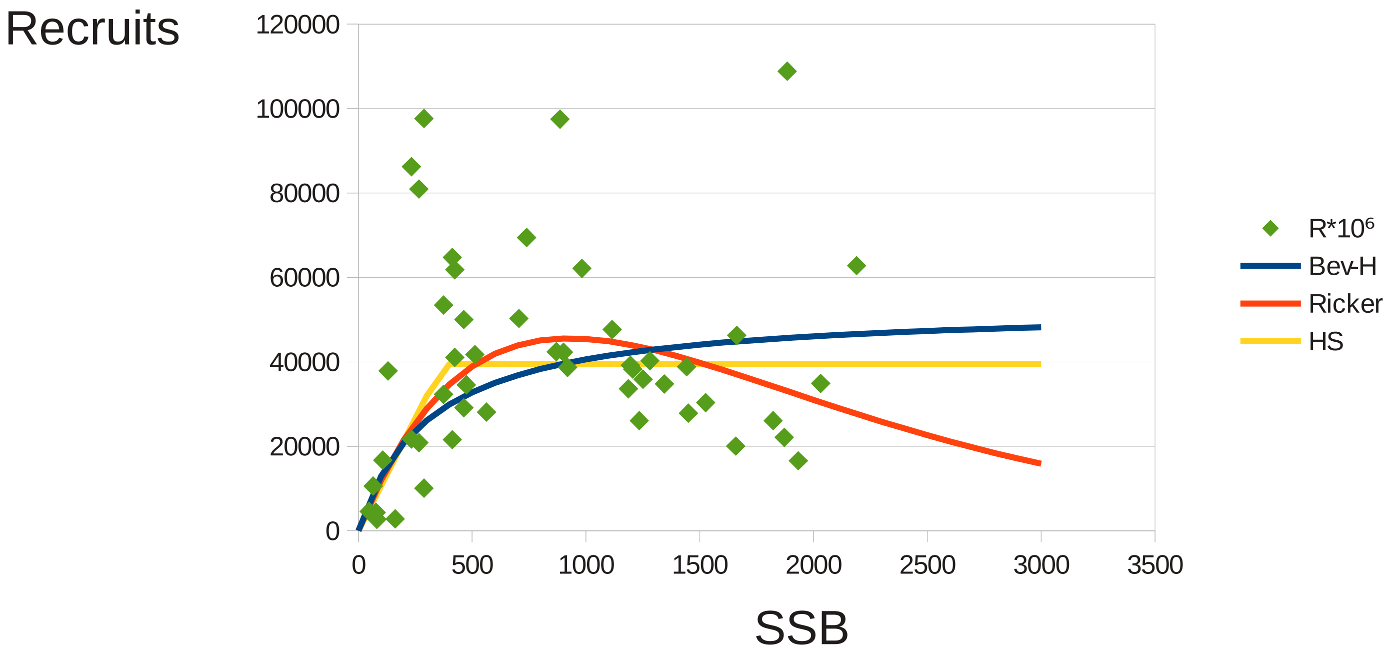
The a-parameter is the maximum recruitment,
the b-parameter defines the steepness:
At SSB=b, Bev-H: R=a/2, Ricker: R=a, Hockey: R=a.

The Ricker function is often stated as:
R = a*SSB*exp(-b*SSB)
The forms are equivalent, but the meaning of the parameters a and b is different.

Example with a real stock

SR functions fitted by minimizing sum of squared log residuals
The goodness of fit was almost equal for all three.

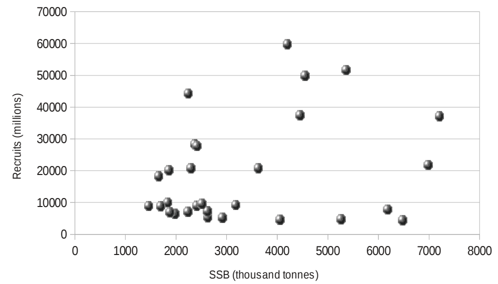
Note the spread in recruitment.
The functions explains very little of the variation,
but they predict very different recruitment at high SSB.



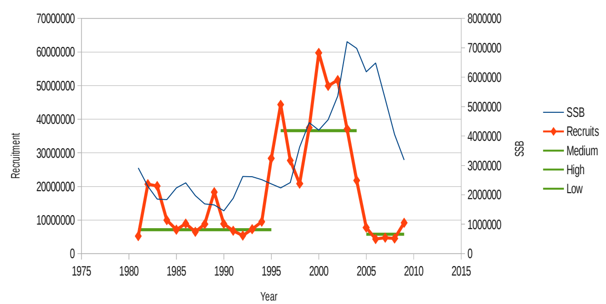
Another warning with S-R functions:

SSB and recruitment in a material from an assessment are not independent:
The SSBs depend on previous recruitments.
Mathematically, SSB is a weighted sum of previous recruitments, where
the weight are a combination of cumulated mortality and fish weight.

Therefore, if recruitment is strongly influenced by other factors, like fluctuation environment, strange patterns may occur.
Also, if the life span is short, the SSB in one year is closely linked to the recruitment the year before, and we look at a R-SSB relation rather than a SS_R relation.



Fitting S-R functions to these data would give almost straight lines.



But in reality, there were large fluctuations in recruitment, and the SSB followed 3-4 years after.

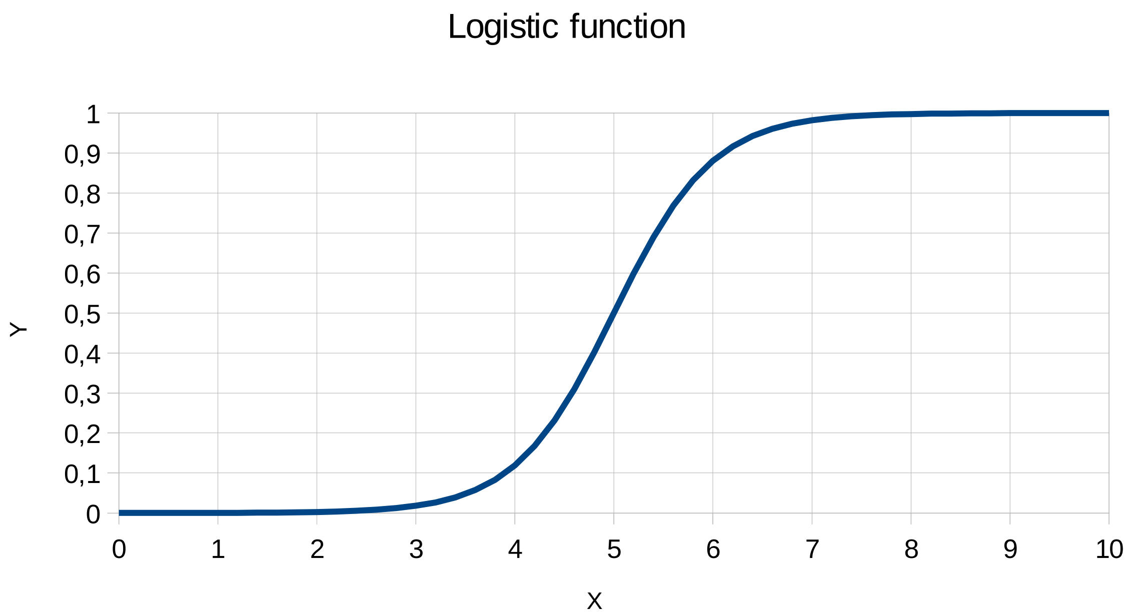
Another useful function – **the logistic function**

This is a general function of the form:

y = 1/(1+exp(-a*(x-x50)))

The parameter x50 is where y=1/2.
The parameter a determines the steepness of the curve.

It is often used when there is a need for a simple S-shaped function.



Stock assessment

We have seen how to generate a model population and to derive expected observations (for example catches and survey information) from that model.

This model has several parameters that we in principle can choose as we like. These parameters determine the properties and history of the model popualtion

To do an analytical assessment is to find a model for the population which is compatible with what we know from observations that we have.

To do so, we compare the expected observations with the real ones.
We need a way to measure how well they compare.
Such a measure is referred to as an objective function.

We the search for model parameters that make the model produce expected observations that are as similar as possible to the real observations.

Various methods to search for the best models parameters exist, some more sophisticated than others.

The population model will have:

- A structure (for example a matrix of numbers at age)
- Parameters that characterize the population in quantitative terms (for example mortalities and recruitments)

To **derive expected observations**, we need

- Parameters needed for the link between population and observations (for example catchabilities in surveys)
- A way to find the parameters that give the best fit

The basic structure and some of the parameters will have to be assumed. The rest we can find by comparing expected and real observations.

The main limitation is the information that actually can be extracted from the observation. That depends on:

- The type of observations
- The quality of the observations

Exercise:
Start with a separable age structured model fitted to catch and survey (or CPUE) data. This may not be the most relevant to your stocks, but it is a good way to learn the basic principles and see how things work.

Data:
- Catch numbers at age per year in some years
- One series of yearly survey indices at age

We can use the stock model that we already have. The parameters in that are
- Recruitment, each year
- Initital numbers the first year
- Selection at age
- Fishing mortality year factor by year

To generate expected data:
- Catches: Catch equation
- Survey indices: Catchability relation: I(a,y) = q/a)*N(a,y)

Model fit:
SSQ = $\sum(\ln Obs - \ln Model)^2$ summed over all years and all ages,
for both catches and survey indices.

Parameter estimation with Excel Solver

Some lessons learned:

- ➔Demonstrated the similarity between an assessment tool and a data generator
- ➔Got an impression of criteria for model fit
- ➔Seen some limitations as to which parameters we are able to estimate.
  - We did not have enough information fix all parameters. What to do?
    - Assume fixed values for some parameters
    - Assume models for some parameters (e.g. logistic selection curve)

    The further we have to go along this line,
    the more do the results reflect the assumptions

  - We already had some underlying assumptions
    - Separable fishing mortality (correct)
    - Flat selection at older ages (correct)
    - Constant survey catchability (correct)
    - Correct constant natural mortality

    How sensitive is the result to these assumptions?

- ➔ Noted that parameter estimates may go wrong.
- ➔ Noted that results may be driven by noise to quite some extent
- ➔ If the data are perfect, will we get the right result?

    With some methods yes, but not with all

Some alternatives:
If we can make a parametric population model that can generate the data that we have, we should in principle be able to fit the model to the data. The question is if there is sufficient information to fit a unique model.

Length based
If we had only data by length, should we do something similar?

- Catches at length
- Survey indices at length

can be generated by a model, if we introduce growth.
However, it is a challenge length at age is not unique, but has a distribution, and sometimes quite wide. There are some ways to approach that problem, none of them are quite satisfactory.

Biomass models:
From the model we had, we could derive catches in biomass and survey abundance in biomass. The information is such data is quite limited.

We might also make a simpler model and try to fit biomasses.

Aggregate models
We could also make something intermediate, have just two age classes, i.e. fit to juvenile biomass and adult biomass for example.

So, what is the right method?

Answer: There is no such thing.
They all have strengths and weaknesses.

A word of wisdom:

- If the data are good, the method does not matter.
- If the data are poor, the method does not matter either.
- If the data are variable, adapt the method to the best data.

But:
Select one or more methods that:

- Handles your data adequately, i.e. are adapted to the information in your data
- Makes realistic assumptions
- Where you understand its limitations

- Change method if the present ones has weaknesses that causes problems,
- But it is better to use a method that you are familiar with if it serves the purpose, rather than trying everything.
- If no method performs satisfactorily, the problem is usually the data. Sometimes, one may consider to develop methods (and management decision rules) that are adapted to the kind of data that can be trusted.
- Never select a method just because it gives you results that you would like to see.
- Results that are too good to be true are not true. Ask yourself: Where is the information that led to this result?

Some crucial questions:

- How much information is there in the data,
- How do we use the information?
- To what extent are the results determined by the assumptions, rather than by the data?
- When you have a result, ask yourself the question:
  Why did we get this result – who told that story?

Tracing the results back to the sources requires skill and insight in how the method you use actually works. It is a type of question that does not have a simple answer,

Usually, we use ready-made computer programs.
There is a large number of such assessment tools.

They differ in:
- Basic structure of the population
- Assumptions already made
- The kinds of data that they can reproduce
- The method for fitting the model
- The results that they can produce
- The lay-out and interface.

Some of these tools are very sophisticated and require a good deal skill to use.
- Leave many assumptions for the user to decide
- Quite sophisticated statistical background for the fitting process
- Sometimes a user-unfriendly interface

Others are 'simple'
- Sometimes simplistic population model structure
- Most assumptions are decided
- Processes are hidden (black box)
- 'User friendly' interface

These methods can sometimes be very useful, but have to be used with care.

So if the data are limited, meaning that the information in the data is sparse, doing analytic assessments may not be the best approach to management advice.

One approach may be to use the information in a more qualitative way.
Often, the real issue is:

Is this stock in a good shape?
If not,can we indicate how drastic measures are needed?

The answer to that does not necessarily come from applying some software, although that can sometimes be a rational way to analyze the data.

Data for assessments.

1. Catch data - what has been removed by the fishery
2. Relative measures of abundance (surveys and/or catch per unit of effort (CPUE)

Catch data can be:
- Total catch in biomass (tonnes)
- Catch in numbers disaggregated by length
- Catch in numbers disaggeregated by age.

Total catch requires some kind of registration system:
- Log books
- Landings registration - sales slips
- Small scale fisheries - difficult field, often from 'socioeconomic censuses' etc.

Correct catch statistics is a difficult field.
It is necessary, because that is the amount that we try to manage.
Some common problem areas:
- Under- (or over-) reporting.
- Discards.
  - It is the total amount removed that matters for the stock
  - Discarded fish is almost always dead.

More on total catch data

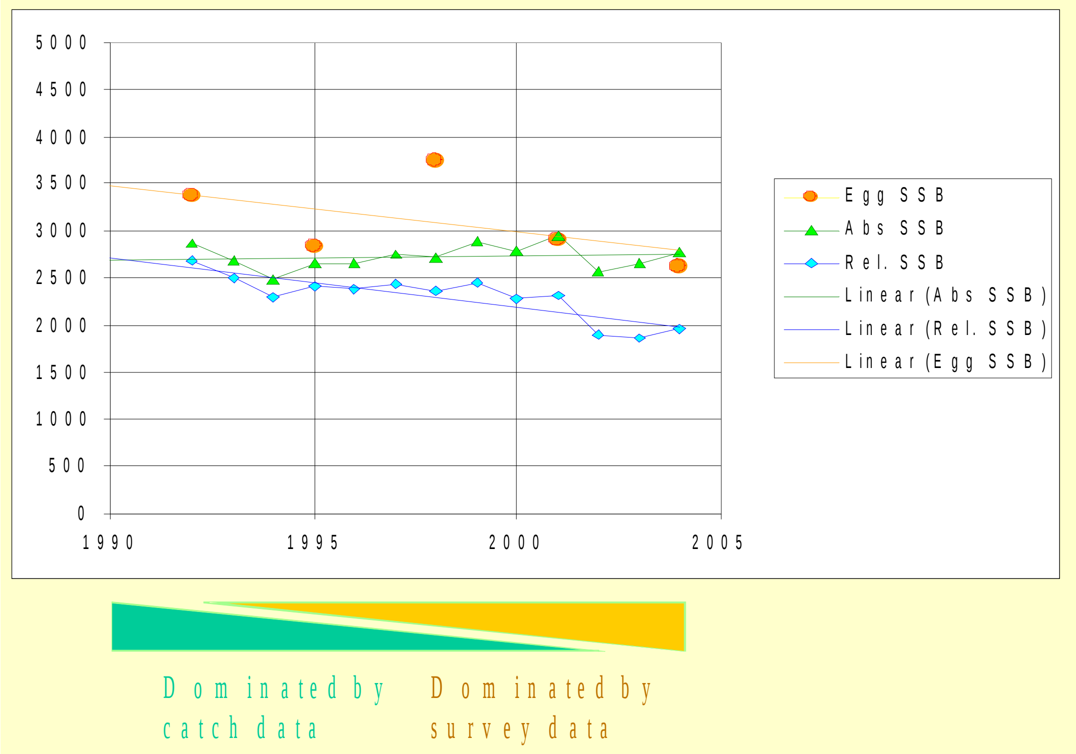
In an assessment, this is usually the only data that carries information about absolute amounts.
The assessment is scaled to the amount caught.
If catches are under-reported, the stock is under-estimated.
The advise is scaled as the catches.

If the catches are 50% higher than reported, can we then just expand the advice by 50%?
Basically yes, but if the reported catch equals the expanded catch,
then the real catch is 50% higher than we want it to be.
This is a very common problem that has caused many break-downs of management.

Advice consistent with the reported catches can be ok, if the percentage misreporting is constant. But it is always a problem area.

If we have other measures of abundance in absolute terms, there is **competing information.**
The consequence for assessment and advice is complex, because different sources influence different parts of the assessment.

Survey data mostly influence the estimates for the recent period
Catch data scale the whole time series, but the impact is strongest in the past.



The figure is an example for a real stock.

Two sources:

- Catch data
- A survey measuring spawning biomass

Green line: Survey absolute, the recent is scaled to that

Blue line: Used only trend in the survey, all scaled to the catch data.

Conclusion: Either the catches are underreported, or the survey overestimates the stock

Sampling for length, weight and/or age.

It is not practical to measure every fish in a fishery.
Normally, the numbers at length in the catch is derived from samples:

A suitable amount is sampled.

- The sample is weighed and the fish counted => mean weight of the fish in the sample
- Each fish is measured - and if possible weighed => gives a distribution of length
- The sample is regarded as representative for the catch by a fishery or for the catch in a survey haul.
- Then the Total numbers caught in that fishery is Total catch/mean weight of the fish
- The numbers caught at length is the Total numbers caught times the fraction at length in the sample
- The mean weight at length is the mean of the individual fish weights at that length.

If each fish in the sample is aged, the same procedure applies.

However, very often much fish is measured and only a few are aged.
Then, age-length keys apply.

Some words about sampling:

- It is essential (and self-evident) that the samples must represent what they are used for.
- If a sample is used to find the length distribution in a fishery, it must be representative for that fishery.
- Typically, fleet segments and fisheries are samples separately, and the numbers added at the end

Usually, many samples are combined. They can be used weighted or unweighted.
- Unweighted is the normal - the numbers (not the percentages!) in the samples are just added together.
- Weighting by the size of the underlying catch can be relevant if some samples are taken from very small catches and others from big catches, and the large catches constitute the bulk of the total fishery.

Random or stratified sampling.
- Random sampling means that the fish in the sample are picked randomly from the catch. Not always easy to get.
- Stratified samples are sometimes taken, typically a certain number of each length class. That is adequate for constructing age-length keys, but NOT for getting the length distribution in the catch.

Age-length keys.

Normally, only a few fish are aged, and a larger number is measured for length. An age length key is a table of the age distribution at each length.

```
************      MAKRELL            **************

 Data er hentet fra flg. filer:
                               mak2003
```

Lengths in centimeter

	Age																		
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15+	Number	Prosent	Middel
20.0		1															1	0.2	
21.0		7															7	1.4	
22.0		2															2	0.4	
23.0		2															2	0.4	
24.0																	0	0.0	
25.0		1	1														2	0.4	
26.0			11														11	2.2	
27.0			23														23	4.6	
28.0			37														37	7.5	
29.0			43														43	8.7	
30.0			22	1	6												29	5.9	
31.0			11	8	22	3											45	9.1	
32.0				6	28	4	1	1									40	8.1	
33.0			7	4	31	9	2	6									59	11.9	
34.0				3	20	14	5	7		1							50	10.1	
35.0				1	11	17	5	6		1	5						46	9.3	
36.0					6	5	6	6		2	2						27	5.5	
37.0					1	7	6	5	1	4	1						25	5.1	
38.0					1	4	7	3		1	2		1			1	20	4.0	
39.0						1				1	1		1				4	0.8	
40.0						1	1	2	3	1	2	1	1				12	2.4	
41.0									1				1	1			3	0.6	
42.0								1	2								3	0.6	
43.0									1				1	1	1		4	0.8	

To each length there is a distribution of ages:

Prob{a|L} =n(a,l)/Σn(a,L) summed over all ages a.

Then, when the number caught at length L is N(L),

N(a) = Σ N(L)*Prob{a|L}; summed over all lengths L

Final about catch sampling

A sampling program is a major task.
Critical points:

- Representative sampling
- Coverage of important fleet segments
- Adequate level to get reliable data
- Logistics
- Quality control

Best advice:

- Good planning
- Seek advice from experienced people
- Ensure that the resources are there
- Cost benefit thinking - concentrate the effort on what matters most.

Effort and catch per unit of effort (CPUE)

The simple logic is that the more you fish, the more dangerous it is for the fish out there. More formally, it is reasonable to assume that the fishing mortality is proportional to the effort in the fishery.

If so, we have:
$C = q*E$ and $C = F*N$ so $N = C/q*E$ or $C/E = q*N$
so the stock abundance is proportional to C/E - the Catch Per Unit of Effort

That requires that effort is measured in a way that reflects the risk to the fish, i.e. Effort is proportional to F.
In some cases, that is straight forward, in others not.
Some examples of effort measures:

- Number of licenses
- Number of days fishing or number of fishing trips.
- Numbers of hours trawled, sometimes hours*horse power, to account for difference in fishing capacity
- Number of hooks*days in line fisheries

All these effort measures are fine if the fishery is a random sampling of the fish out there, and that the fish is randomly distributed..

But:
- Fishermen know where to go, and fish where they expect to get fish.

- The fish tends to concentrate in certain places, and the concentration of fish there does not necessarily reflect the abundance of the whole stock.

- Fishermen try to improve. Over time, that gives better catches with the same effort from the same stock abundance. So, CPUE tends to improve without improvement in the stock, or worse:
  The effect of a stock decline can be compensated by getting more clever, or concentrating the effort on the best places.
  This is referred to as 'effort creeping'.
- Effort measures that relate to local fisheries may not reflect the state of the stock as a whole. But that is the way it is used in an assessment

Most scientists try to avoid using CPUE as a measure of stock abundance.
If better data, (well controlled surveys) are available, that is preferable.
Still, CPUE data may be better than nothing, but **if and only if they represent what they are supposed to represent.**

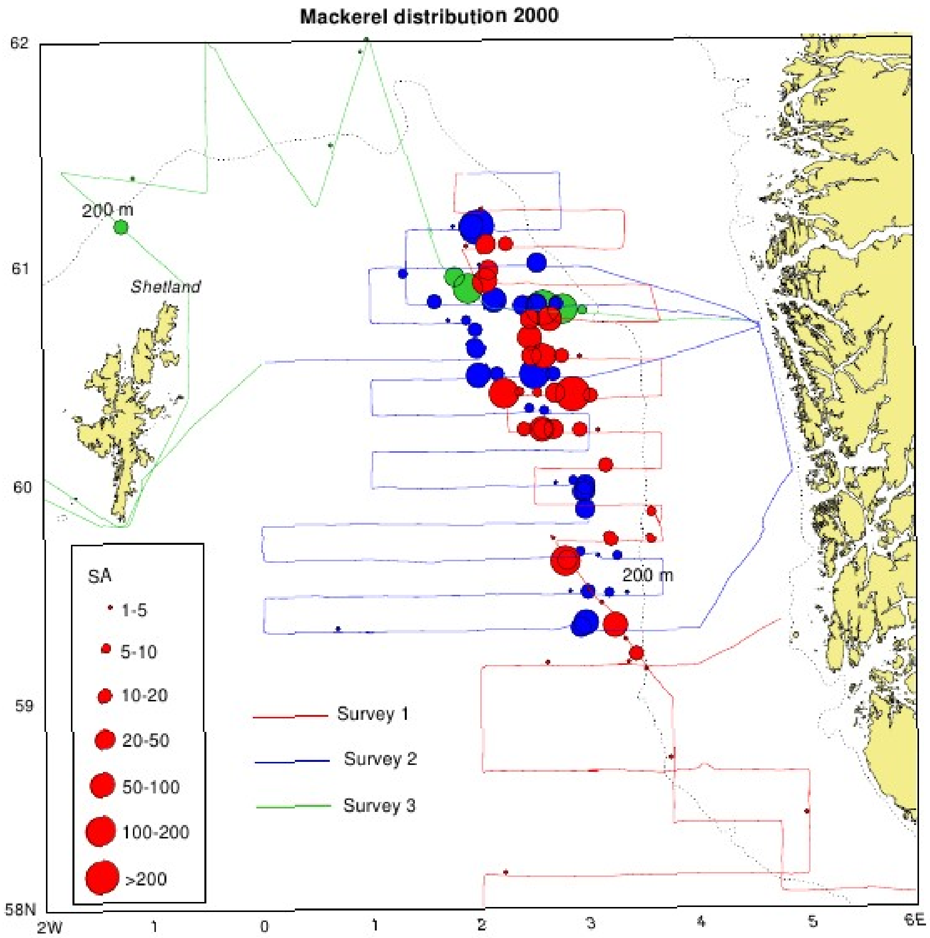
Survey data

Two main categories:

Bottom trawl surveys. Mostly on demersal fish
Trawl systematically, record the catches and use an average of the catches as a measure of abundance in the area.

Acoustic surveys. Mostly for schooling pelagic species
Go in systematic cruise lines and record the echo reflected from fish along the cruise line. The integrated echo can be translated into abundance, if the energy reflected from each fish (target strength) is known.
The target strength depends on the size of the fish, and both to get that and to get the species composition requires samples from the concentrations. Most often that is obtained by trawling. Some species can be identified in the acoustic tracings, but very often it is not that easy.

Example of an acoustic survey (mackerel in the North Sea).
Two full (red and blue) and one partial (green) coverages.
Bubbles indicate registrations



Notice that most of the fish
is concentrated in a narrow band.

Most of the biomass estimate
comes from a small number of
nautical miles.

Very common problem with
schooling fish.
No good solution,
makes the estimate uncertain.

Survey data are mostly regarded as **relative measures** of the stock abundance. Hence, to be useful, several years of observations are necessary, typically in the order of the life span of the species.

In an assessment model, the early (converged) years are used to calibrate the survey. Then the survey measurements in recent years can be translated into present stock abundance.

Surveys as absolute measures of abundance is possible in a few cases:

Bottom trawl: If you can assume that all fish that appears between the doors (or the wings) is caught, and none else, you can calculate the swept area and expand the catch in that area to the whole distribution area.
Requires:
- Fish that is well behaved - no escapement, no herding.
- The area swept is representative for the whole distribution area.

Acoustic: In principle, an acoustic survey measures abundance in absolute terms.
Requires:
- Target strength precisely known
- Fish is distributed such that the area is covered in a representative way.
- No ship avoidance or herding
- Proper calibration of the echo-sounder
- Good species identification

The concept of production

A stock produces biomass.
How and how much?

Two conditions are necessary for a stock (or species) to exist:

- The stock cannot be infinitely large -
  there is a limit to what the ecosystem can support
- When the stock is smaller than that limit, it will tend to grow,
  and more so (in relative terms) if it is far from the limit.

Since the stock tends to grow, there is a surplus production.
This surplus production can be harvested rather than being used for increasing the stock.

Good management is to ensure that the stock is harvested in a rational way.
That implies that in the long term, the loss does not exceed what the stock is able to replace.

So the key is to find out how much the stock can produce,
and what that amount depends on.

How does the stock produce biomass

A stock produces biomass because
- individuals grow
- new individuals enter the stock (recruits)

It looses biomass because
- individuals die
  - Removed by the fishery
  - Lost by other causes (natural mortality)

This is just as an accounting:

- ➔ If the production exceeds the loss, the stock grows in biomass.
- ➔ In equilibrium, the production balances the loss
- ➔ If the loss exceeds the production, the stock biomass declines.

How much biomass does the stock produce?

There is a balance between growth and mortality

- In the beginning of the life span of a stock, the growth is faster than the loss, and the year class grows in biomass.
- Later in life, growth slows down, and the loss exceeds the growth. The biomass of the year class goes down.
- At the end, there is nothing left of the year class

We can calculate this balance for a year class by setting up an accounting, year by year, of the gain due to growth and loss by mortality.

If we can assume that recruitment is stable, the sum over year classes equals the sum over the life span of one year class.

The total catch produced by a year class with recruitment = 1 is called **Yield per recruit,** and the biomass is **biomass per recruit.**
Both depend on the mortality. Although the natural mortality remains the same, the fishing mortality can vary, so we can construct a curve showing how Yield per recruit and Biomass per recruit depend on the fishing mortality.

We shall do that as an exercise.

Exercise:
Calculate yield per recruit and spawning biomass (SSB) per recruit

Consider a year class that starts out with N0 individuals.
We follow that throughout its lifetime

Each year (=age) it is exposed to a mortality - the natural mortality
and a fishing mortality.
The fishing mortality may depend on the age trough a selection at age.
The fish also grows, to get a weight w(a) at each age, and as it matures, it contributes to the SSB.

This can be easily set up on a spreadsheet

- Make one column with N-values, starting with something (e.g. 1) and reducing by Z
- Multiply each N with weight: Sum is TSB
- Multiply also with maturity: Sum is SSB
- Derive catches at age with catch equation
- Multiply by weights - sum is yield

You will need:

- Mortalites:
  - M at age
  - Selection at age
  - Yearly F-level
- Weights at age
- Maturities at age

You can make many such columns, with different F-levels. That gives you a curve showing how Yield per recruit and SSB per recruit depends on F-level.

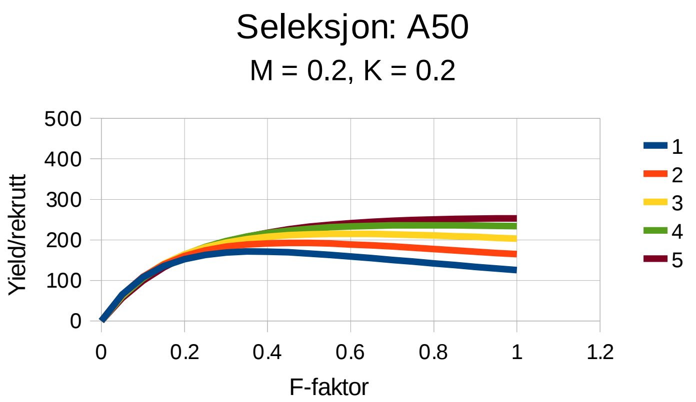
F-level=>		0.5
Selection		Numbers at ag
	0.1	1.000
	0.3	0.136
	0.5	0.037
	0.7	0.012
	0.9	0.004
	1	0.001
	1	0.000
	1	0.000
	1	0.000
	1	0.000
	1	0.000
		Spawning bion
		0.000
		0.000
		0.000
		0.000
		0.076
		0.170
		0.128
		0.058
		0.024
		0.010
		0.004
Sum		0.469
		Yield
		0.097
		0.307
		0.381
		0.319
		0.207
		0.103
		0.044
		0.018
		0.007
		0.003
		0.001
Sum		1.487
		Total biomass
		4.467
		3.660
		2.544
		1.495
		0.761
		0.340
		0.142
		0.058
		0.024
		0.010
		0.004
Sum		13.505

The shape of the yield per recruit varies, depending on natural mortality, growth and selection.
Sometimes there is a peak, like here.

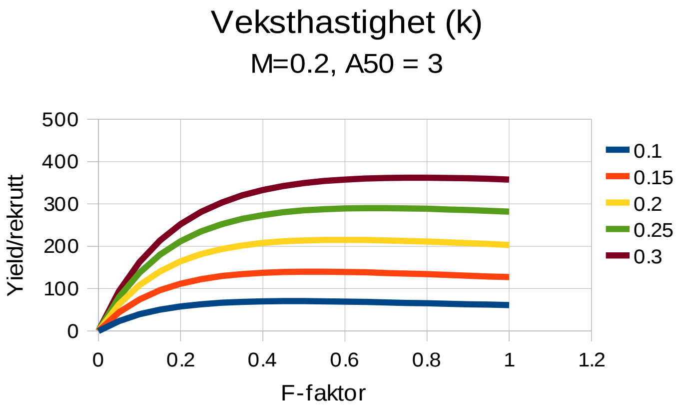
So far, we have assumed that recruitment is independent of SSB.

How the shape of the
Y/R curve is determined by
selection, growth rate
and natural mortality.

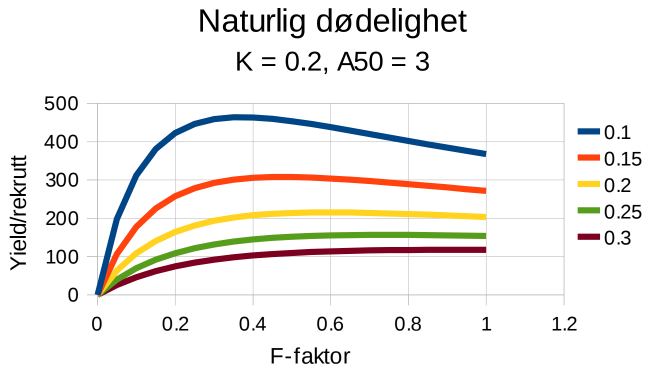
These are the factors that
go into this calculation.



Selection



Growth
rate



Natural
mortality

We may combine this curve with a stock recruit function.
The reduced SSB with a high fishing mortality will lead to reduced recruitment.
Therefore, the yield curve will have a peak where the yield/recruit is high and the recruitment still not much reduced.

For each F-level, there is an equilibrium, where the recruitment leads to an SSB that leads to the same recruitment. It can be calculated analytically from the SSB/R and the SR-function.

If the fishing mortality is too high, there is no such equilibrium.
This fishing mortality leads to stock collapse.
Here that happens a F-level around 0.8

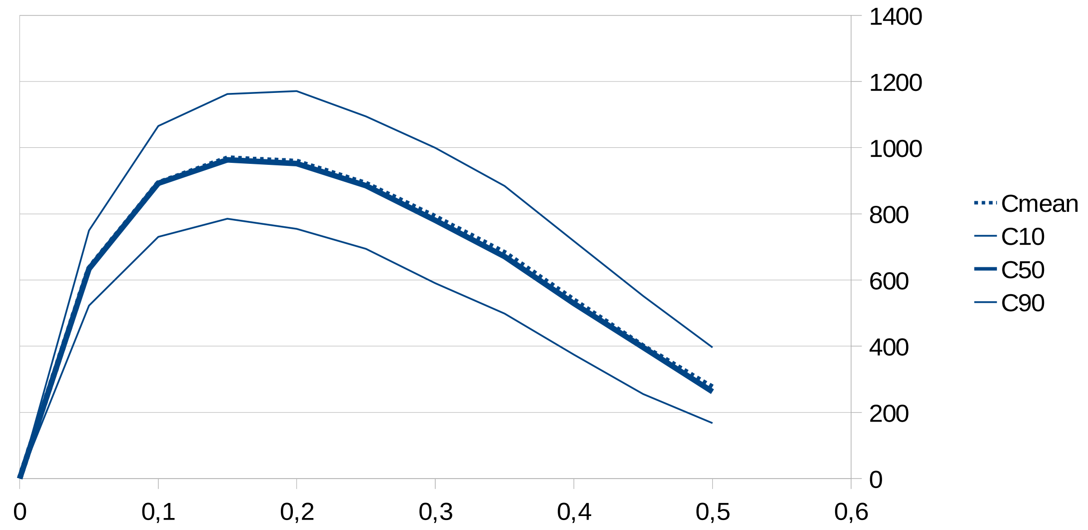
So far, we have looked at equilibria with constant recruitment, growth and maturation.

The real world is not quite that easy. From year to year, recruitment, growth and survival will vary. Therefore, with a fixed F at optimal level, we do not get the same catch every year.

It adds to the problem that if we try to have a constant F, it will in practice vary because the catches are decided based on an uncertain assessment.

Therefore, the actual catch will vary around a mean that typically is close to the equilibrium catch, but with a quite broad range.

The figure shows an example with a real stock, where we have simulated a management regime with fixed F at a range of levels, and assumed a stock-recruitment relationship.
These are the resulting catches after 100 years,
where we expect a stochastic equilibrium.



The mean is virtually equal to the 50 percentile (median)
The thin lines are the 10 and 90 percentiles, and note the broad range.
This is the year-to-year variation to be expected.

Yield and SSB per recruit by length.

We can make a similar calculation using length rather than age.

The key is the time it takes to grow from one length L to another length L+ΔL

$$\Delta t = \frac{1}{k} * \log \frac{L\infty - (L + \Delta L)}{L\infty - L}$$

which we have seen can be derived with some manipulation from
von Bertalanffys equation

Then, the numbers at L+ΔL is
N(L+ΔL) = N(L)*exp(-Z(L)*Δt)

Equivalently, we can show, again with some manipulation of the formulas, that:

$$N(L + \Delta L) = N(L) * \left(\log \frac{L\infty - (L + \Delta L)}{L\infty - L}\right)^{Z(L)/k}$$

This last formula also shows that what matters for the length profile in the stock is Z/k,
not each of them separately.
So, the length distribution informs about Z/k, while the age distribution
informs about Z directly.

In the yield per recruit curve itself, which does not take into account
how recruitment depends on spawning biomass, there may be a maximum, if
the growth is slow and the fish comes early into the fishery.
Then, if the F is higher than that, the fish cannot realize its growth potential,
it is caught too early, so by reducing the F one would gain catch in the long run.

This is referred to as **growth overfishing**, and the F with a maximum in the
yield per recruit curve is called Fmax.
In our example, this does happen at F-levels at approximately 0.4

However, a high F will reduce the SSB, and that may reduce the recruitment.
If the fishing mortality is high enough, there is a loss of catch because the
recruitment gets poorer. Here, that happens at F around 0.3
This is referred to as **recruitment overfishing.**

Traditionally, preventing growth overfishing has been a guideline for management
in many parts of the world.
We see that recruitment overfishing may be a much more severe problem.

The fishing mortality that will lead to the biggest average catch, taking both
growth and recruitment into account, should be the optimum,
and is one way of defining an FMSY.

Surplus production

The change in biomass from one year to the next: $B(y+1) - B(y)$
is the net production.

The surplus production is the change in biomass that would have taken place without a fishery. That is the net production plus what we have taken out:

$$SP(y) = B(y+1)-B(y)+C(y)$$

It tells us the new biomass that the stock actually has produced from year y to year y+1. Some of it was used for catch, the remainder is used to increase the stock (or decrease it if the catch exceeds the SP)

In equilibrium, the surplus production equals the catch, we remove the surplus each year leaving the stock biomass unchanged.

The surplus production can vary considerably from year to year, depending on growth, recruitment and natural death.

If the catch just equals the surplus production, the biomass remains stable.
The level of the stable biomass depends on the exploitation.

We already have calculated the relation between the equilibrium biomass and catch or between equilibrium catch and fishing mortality, by just combining Yield and biomass per recruit and a stock-recruit relationship. That can inform us about the level of exploitation that allows the highest equilibrium catches.

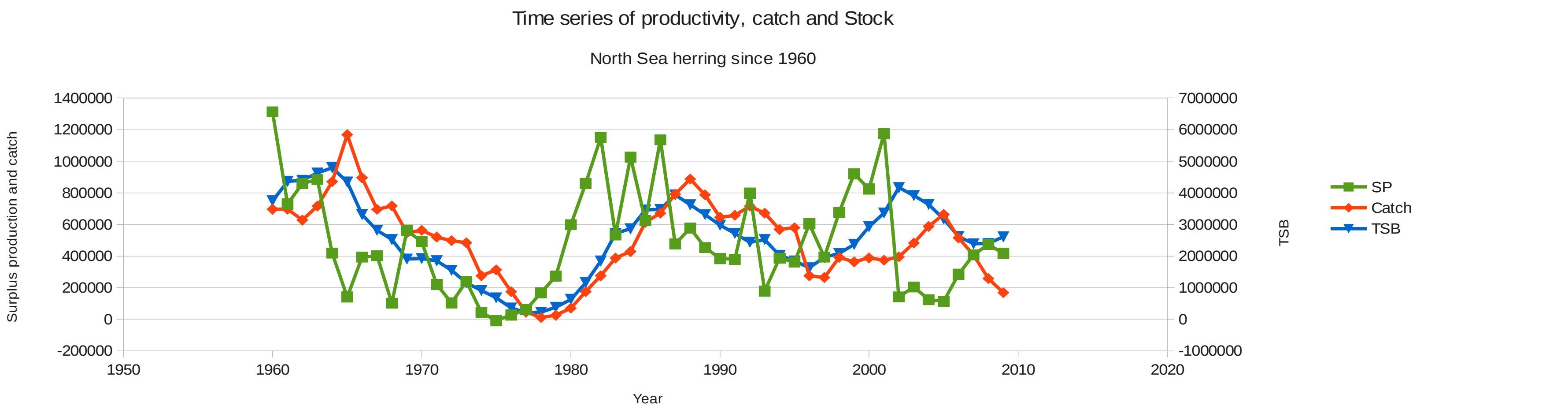
To get an impression of the dynamics of the surplus production,
we can extend the exercise spreadsheet to include the production.
Simply make some extra lines:

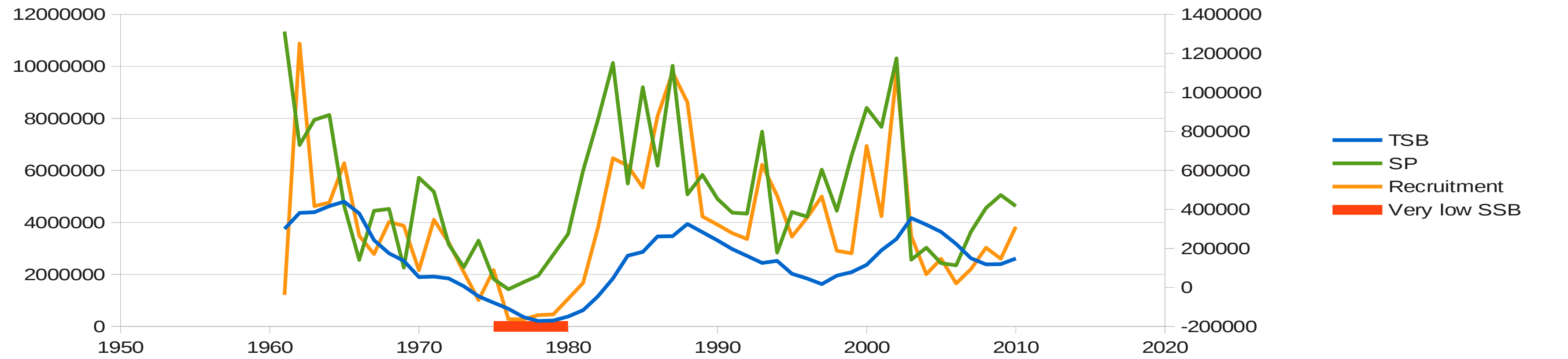
1. The year
2. The difference TSB(year+1) - TSB(year)
3. Add the catch (in biomass) to that - that is the surplus production

You now can make a graph of how the surplus production fluctuates over time,
and another showing the relation between surplus production and biomass.

What you see no is not the equilibrium biomass, but the surplus production
from year to year.
You can play with changing recruitments, natural mortalities,. fishing mortalities etc,
and get used to seeing what happens.

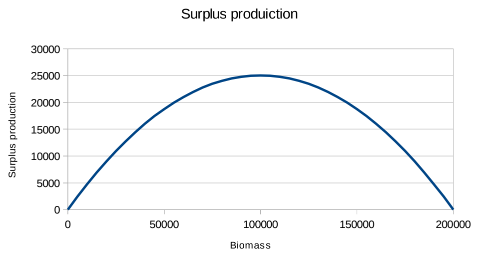
This is an example from the real world, where the data come from an analytic assessment. This stock had a collapse in the 1970ies, but recovered.





Production models:
Reminder:
We defined the surplus production SP = B(y+1) -By + Catch
Accordingly, the change in biomass is the surplus production minus the catch:
B(y+1) -By = SP - Catch

We now assume that SP is a function of the biomass:



$$B(y+1) = B(y) + r*B(y)*(1-B(y)/K) - C(y)$$

Biomass next year | Biomass this year | + Surplus production | - Catch

The model essentially says that the surplus production depends directly on the biomass, and the dependence can be described by a simple function with two parameters r and K.

- K represents the largest stock that the ecosystem can support, and is called the carrying capacity.
  Note that this is not the same k as in the von Bertalanffy growth equation!
- r is the intrinsic growth rate.

The fundamental idea is that a stock will tend to grow, but that there is a limitation to how large it can become.
The equation is the simplest thinkable formulation of that principle, saying that the relative growth is proportional to the distance to the maximum abundance, i.e. the carrying capacity.

If there is biomass and catch data, one may attempt to estimate the parameters r and K.

If we lack measurements of the biomass, but have catch and effort (E) data we may introduce

$B = q*C/E$, where q is the catchability.

We shall use the CEDA package to analyze catch, effort and abundance data to find current stock size, unexploited stock size and population dynamics parameters like fishing mortality and catchability (= F/E equivalent to C/CPUE)

The CEDA package can do that either by considering how CPUE declines over time (depletion methods) or by fitting a production model.

Fitting production models to data means to find values of r and K that 'explain' the data. Some possibilities:

Equilibrium fit

If you have a measure of the biomass (for example from CPUE data) and you have the catches, you may try to fit the the catch biomass data to a parabola:

$$C = r*B*(1-B/K)$$

But this is not right. This relation refers to an equilibrium, and we apply it to year-to-year data. Don't do that!

Time series fit

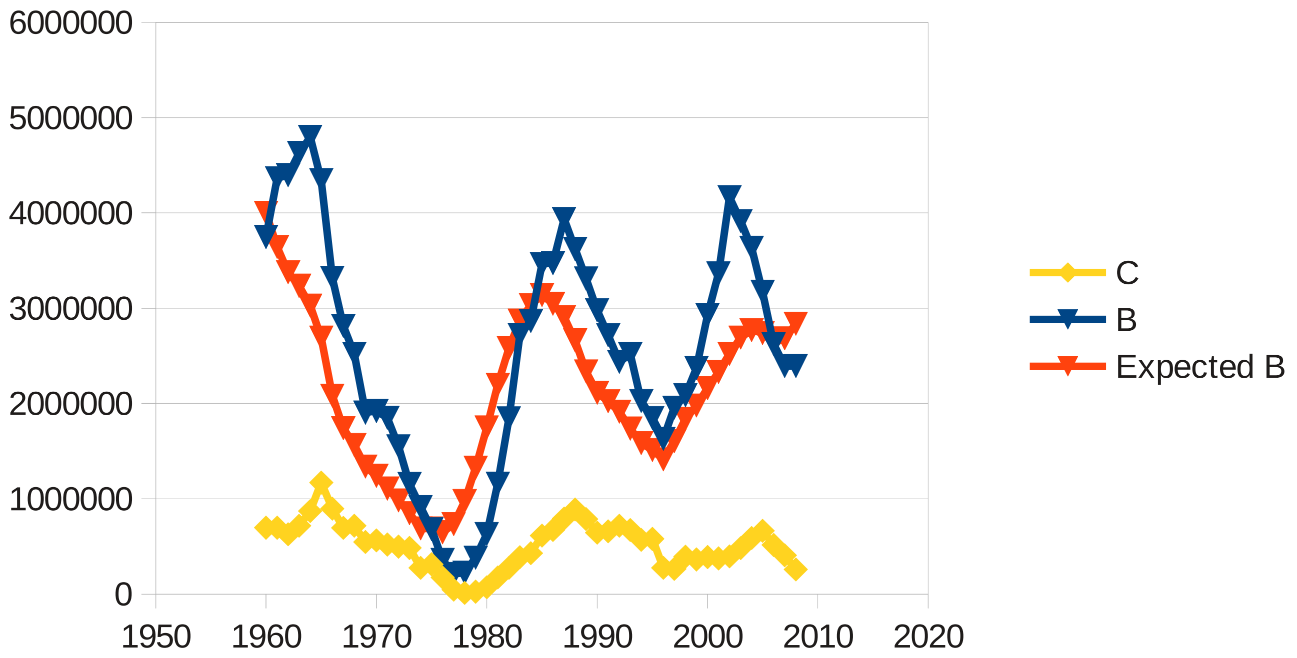
A more relevant alternative is to explain next years biomass by this years biomass and the catch:

$$B(y+1) = B(y) + r*B(y)*(1-B(y)/K) - C(y)$$

Then, one may try to create a time series of B, with the underlying hypothesis that the change in biomass is due to surplus production (which depends on the biomass) and the catch, and try to fit that to the data. Most modern software does this, one way or other.

It is not without problems, because the r and the K are confounded, and also because small changes in the parameters will have large consequences over time.

An example from a real stock, to show an fit of a surplus production model to catch and biomass data. The data here were taken from a full assessment.



The message from this figure is how well the simple production model can explain changes in biomass. It picks up some of the large fluctuations, but looses changes in productivity caused by changes in recruitment.

Having the parameters, the model can be used for two purposes:

1) One may estimate reference points, in particular MSY and the corresponding $B_{MSY.}$

At equilibrium where not only recruitments, growth and mortalities are constant, but also the catches balance the surplus production we have:

$C = r*B*(1-B/K)$ or $C = -r/K*B^2 + rB$

Here:
C = 0 at B = K and at B=0
The maximum C is at B = K/2, where C is r*K/4

The maximum C is referred to as the Maximum Sustainable Yield (MSY), and the corresponding biomass as B_{MSY}

2) One may also predict how the stock can be expected to developed, given future proposed catches. That is using the production model as a dynamic model for the stock. The advantage over an age structured model is that it is simple, the disadvantage is that it does not account for changes in productivity, for example caused by changes in the environment, and it does not account for the variation in year classes..

The basic assumption in the production model is that the surplus production is a simple function of the current biomass.

Is it that simple?

We have seen previously that it is not. The production depends on the recruitment a few years ago, and to some extent on fluctuations in growth. The recruitment depends on the spawning biomass, but with great variation.

Still, production models are used extensively by people who know what they are doing, so it cannot be stupid.
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Length based assessments

Seems very logical - biology is more related to size that to chronological age
Length data are much easier to get

Fish do not grow uniformly
To each length these is several ages, and to each age there is a range of lengths.
Therefore, the information on changes over time is blurred, and there is far less information about dynamics in a length distribution than in an age distribution.

The same length distribution can be explained in several ways, by selectivity, growth rate and mortality, and on to of that, recruitment fluctuates and the length distribution is influenced by strong and weak year classes.

So, attempts to establish length based assessments have been disappointing, and they are not much used.

Estimating growth parameters

In any length based method, you will need growth parameters: Linf and k

The simplest way is if you have length at age data. Then you can fit the growth function to those data, for example by linear regression in a Walford plot.

If you only have length distributions, there is still some possibility, but the information is much more limited. The FMSP package LFDA5 has a fair selection of such routines. But, as we have just seen, the length distribution essentially depends on the ratio M/k, not on each of them separately.
In addition, the cathces at length depend on the selectivity, which adds to the estimation problem.
So this is an example of observations that can be explained by many combinations of parameters, making the parameter estimates confounded.

You may also have to pick values from the literature or related stocks or even species. hat often is the only way, and may be better than nothing, but be aware that many methods for analyzing length data are very sensitive to the assumed growth parameters.

There are three directions that can be taken to make length-based assessments.:

- Equilibrium methods, which can fit a yield at length per recruit fucntion
  to a length distribution. Can be useful in selected contexts.

- Convert length to age and apply age structured models
  Conversion is done by allocating ages to each length class, either as
  single values or age distributions. The basis is the assumed length at age
  according to the growth equation, and the procedure is called 'slicing'.

- Dynamic population models:
  Construct a model population with both age and length structure, and
  fit that to data at length.

Equilibrium methods - Jones' length cohort analysis

This is a classical method, making a VPA from catches at length assuming that they come from a single cohort, which is equivalent to assuming that recruitment is constant throughout the year

For each length class, the time Δt it takes to pass through the length class is :

$$\Delta t = \frac{1}{k} * \log \frac{L\infty - L}{L\infty - (L + \Delta L)}$$

The natural mortality that applies in the time interval is M*Δt

Apply Popes equation to the numbers at the start of the length class, where the time t is the time when the cohort enters the length class starting at L:

N(t) = N(t+Δt)*exp(M*Δt) + C*exp(M*Δt/2)

Combining the and Popes equation gives a useful intermediate step X_L:

$$X_L = e^{M * \Delta t/2} = \left(\frac{L\infty - L}{L\infty - (L + \Delta L)}\right)^{\frac{M}{2k}}$$

Then, Popes equation becomes:

N(t+Δt) = (N(t)*X_L + C(L))*X_L for the number at the lower end of the length class

Jones' length cohort analysis cont.

Starting at the highest length, we can now reconstruct the numbers backwards.
If we want mortality estimates, they follow from

$Z = \ln[N(t)/N(t+\Delta t)] / \Delta t$

and $F = Z-M$

We have to assume the starting point for the reconstruction. We do that by stating the F/Z at highest length, deriving F from that and M, and setting
$N = C*Z/F$ at the highest length.

The following assumptions are required:

- k and Linf
- M at length
- Terminal F/Z

Note that the disappearance rate at length L: $e^{M*\Delta t/2} = \left(\frac{L\infty - L}{L\infty - (L+\Delta L)}\right)^{\frac{M}{2k}}$

depends on the ratio M/k.

This is the interplay between growth and mortality which, together with the removal by catches determines the shape of the length distribution. That explains why it is hard to estimate both mortality and growth rate from a length distribution

Length - age structured assessment models

Here. we build up an age-structured population model, but in addition, we also account for the length distribution at each age

From there, we can derive expected catches at length and survey data at length, to fit the model to observation.

Parameters

- Recruitment, fishing mortalities, selction (at length) and catchability (at length) as in an age-structured model
- Linf and k in the growth model
- Parameters (usually sigma at age or length) of the dispersion of length at age

Two ways of generating distributions of length at age.

- Markov chain - a matrix stating the probability that a fish at length L1 will grow to L2 in the next time step.
- Super-individuals: Each has its own k and Linf, and grows accordingly, and represent a number of fish that declines according to mortaity. The stock numbers and catches at length is the sum of the super-individuals having that length at the actual time.

Both are used, and both can be very computer.intensive.

Experience: Disappointing - too many confounded parameters, sensitivity to assumptions etc.

The management perspective again

Reference points

Reference points are landmarks related to biomass or exploitation
typically values for spawning stock biomass (SSB) or fishing mortality (F),
and are key elements in a management strategy.

Two kinds:

Targets:
That is a value to aim for. Normally, the F or SSB should fluctuate around the target.

Limits.
Limits should not be exceeded. The management should ensure that the risk of exceeding limits is kept low.
In simulation work, a 5% probability is usually considered as acceptable.

Sometimes, other reference points are defined to make decision rules operative.

Note that there is a fundamental difference between limits and targets, and the requirement that the risk should be low of exceeding limits can be quite restrictive if the uncertainty is large.

Precautionary reference points are basically elements in a management strategy, typically represented by objectives to maintain a stock at high productivity.

The choice of reference points and their values depends on

- To what extent they can be determined according to their definitions.
- To what extent the stock can be monitored relative to the reference points.

Some examples:

Limit biomass representing the point where recruitment is impaired.
Standard in Europe and some other places.

The basis is stock-recruit plots, where one will be looking for levels of biomass where the recruitment generally is poorer than at higher biomasses.
Sometimes, recruitment becomes more variable when SSB is low, and finding a good value can be problematic. There are statistical procedures for identifying this biomass, but they sometimes fail, and the fact that SSB depends on previous recruitments and the sensitivity to environmental factors adds to the problem.
At the end, there may be a good deal common sense in the decision.

Sometimes, the lowest observed biomass or the lowest biomass that generated a 'good' year class are used.

MSY-related reference points.

- To use MSY as a target annual catch is generally not a good ideas, as we have seen.
- Having the BMSY as a target is often recommended, but operationally problematic if the productivity is sensitive to environmental influences.
- Using FMSY (or some proxy) as a target is probably the most rational way to obtain maximum catches on average over time

We have seen various ways of deriving MSY, BMSY and FMSY. They may give quite different results, and be quite sensitive to assumptions made.
In particular production models can have quite uncertain estimates of these reference values, and naive applications of 'quick and easy' methods can give terribly misleading results. Hopefully, some of what you have learned during the course may help you to be critical to what you have get.

In some parts of the world, BMSY is treated as a limit. That gives a quite conservative management, and it may be worth looking at the expected effective fishing mortality.

Main elements in a management strategy:
It is not just doing an assessment and advice on a quota.

Establish an infrastructure for obtaining data:
- On basic biology (growth rate, turnover, distribution, migrations etc.)
- Regular catch statistics
- Measures of stock abundance
  (surveys and/or catch-effort data)

- This is a major task, but critical for proper advice.
- There is a trade-off between the investment in data infrastructure and
  the value of the fishery.
- The quality of assessments and advice is largely determined by the quality of the data.
- With poor data, detailed management is not possible.
  Either, one has to be extremely cautious, or one will end up with a depleted stock.
  We shall see why and how later on.

The knowledge base:

This is the assembly of information that is the basis for advice:

- Stock assessment: Abundance and exploitation - history and present
- Productivity: Yield/recruit, production functions:
  Long term average yield and variability. Tolerance to exploitation
  Depends on stock-recruitment, growth rates, selectivity in fishery,
  natural mortality.
- Short term predictions: Tactical decisions = recommended removals for next year

Decision rules:

Given the knowledge base, derive advice for the coming years.
The modern trend is to establish firm decision rules (harvest control rules),
that can be tested by simulations.

Decisions include next years exploitation, but may also apply for several years.

Fishery infrastructure:
This is setting rules and regulations for how the fishery is performed.
Such rules are elements in controlling the exploitation.
Typical examples are:

- Access control, licensing
- Conditions for participation (e.g. reporting, registration, control)
- Gear restrictions - to target ages and sizes that are preferable, and to avoid unnecessary damage
- Area and time restrictions
- Effort restrictions (days at sea, tie up etc)
- Rules for discarding

Implementation and enforcement.
There is no point having rules that are not followed, but:
- There are limitations to what can be controlled, regulations have to be adapted to that
- One may have to consider the likely effects of the rules, and adapt the rules accordingly.
- The bottom line is that removals do not exceed the renewal capacity of the stock.

Simulation and evaluation

A management strategy can to some extent be evaluated:
- How will it work - what can we expect?
- Can the objectives be reached?
- What is the risk of things going very wrong?

The standard evaluation method is simulations (Management Plan Evaluations):
- Create an artificial stock with properties similar to the real one
- Extract from the stock the information you can expect to get, imitating sampling procedures etc.
- Convert these data to a basis for decisions This is the assessment process.
- Use the information to make decisions according to rules in the strategy
- Expose the stock to those decisions.
- See how the stock responds.

The simulation tools take the uncertainties in each step into account - stochastic models.

Such evaluations have become key elements of management strategy development over the last 10-20 years.

Simulation of management strategies.

Simulation tools are computer programs that can imitate the response of a stock to management measures.

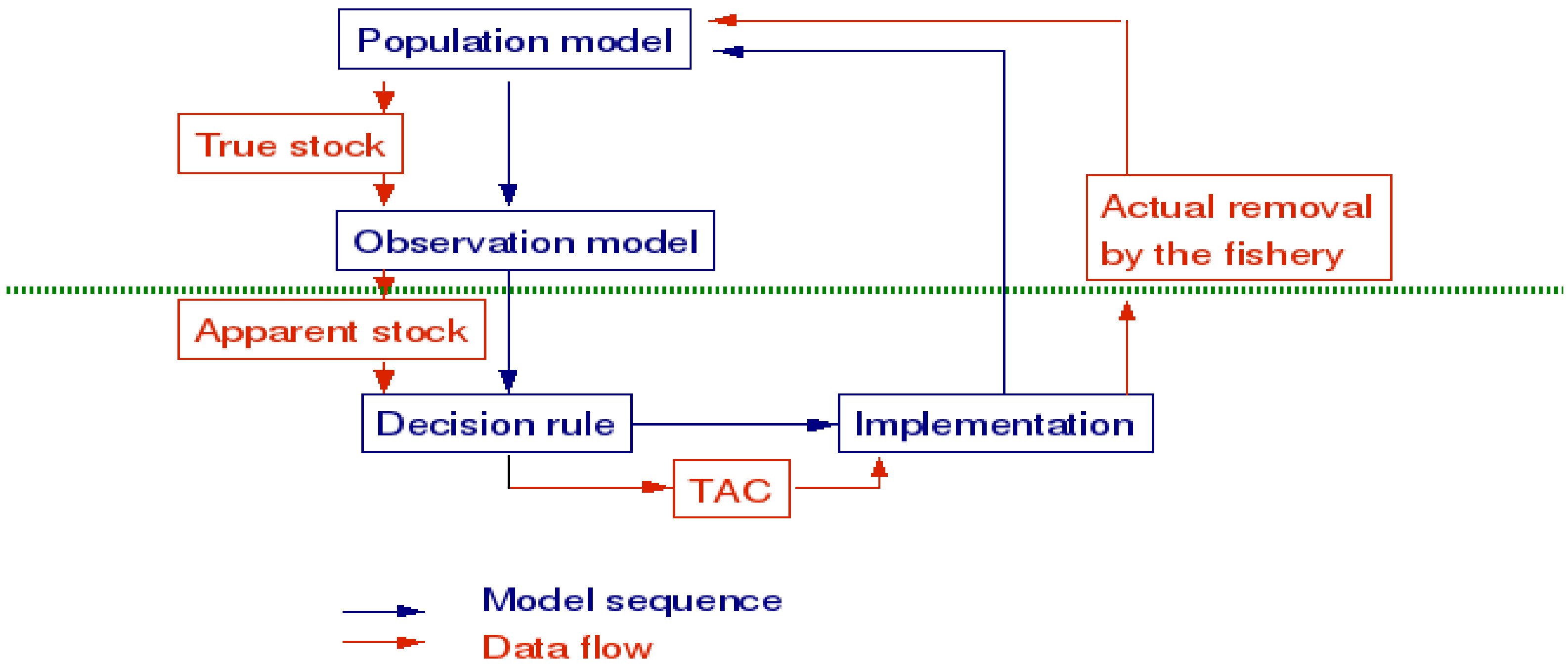
Simulations can inform about the likelihood of reaching objectives, and reveal weak spots in a strategy.

They are also very valuable in designing decision rules, for example for setting quotas or for adjusting effort.

Over the last 15-20 years, this has become a standard procedure in the development and evaluation of management strategies.

There are a large number of computer programs available, at various level of sophistication. Nevertheless, each management is unique, and programs usually have to be adapted to just the management under consideration. This may be a large task, and require considerable amounts of skilled manpower.

Building blocks in a simulation program



Above the line is a model for a stock, from which observations are derived. This is the 'real' world, sometimes referred to as the operating model
Below the line is what managers see and the decisions they make.
These decisions are implemented, i.e. the real stock is exposed to the removals according to the decisions and their implementation.

Back to management objectives
They typically include:

- Maximizing long term yield, or sometimes more explicitly long term income
  To achieve this, the stock has to be kept in a good shape, i.e. with optimal productivity. The precautionary approach is implicit here.
- Stabilizing catches from year to year is often a priority, to make long term planning possible for the industry. May cost something in terms of long term yield.
- Rebuilding of the stock if it is depleted, including a realistic time frame.
- Fair distribution of the opportunities on fleet segments and interests.
- Ecosystem objectives.
  - Optimal balance between species in the ecosystem
    Question: Engineering the ecosystem?
  - Preserve elements in the ecosystem for their own sake
  - (vulnerable habitats, natural reserves, biodiversity)

Sometimes, conflicting objectives are stated, directly or implicitly.
The solution is often not either- or, but to find compromises by clarifying the trade-offs

Some standards for good management:

International conventions set some standards:

- The precautionary approach (Rio convention, FAO code of conduct etc.)
- Maximum sustainable yield as a limit for exploitation (Johannesburg declaration)
- Biodiversity
- Ecosystem approach to management

Non-official 'trendsetters' may have a strong impact:

- Certifying schemes (MSC, FAO guidelines etc.) - market access
- NGOs - public attitudes
- IUCN - redlists.

The role of science in setting management objectives -
the science border:

Different attitudes around.

- One attitude is that decisions are for managers -
  science shall ensure that managers know what they are doing.
- Many scientists have strong views on how stocks should be managed.
  One may claim that science cannot just sit and look at managers doing the wrong things - we have to put on pressure where we can.
  Note that much of the international conventions were initiated by science.

On the other hand:
- Managers can use science as a hostage, give their preferences a 'quasi-scientific' justification, or blame science if something goes wrong.
- Science can and should give warnings when management measures violate managers objectives.

Scientists are also members of the society, and have opinions on how the society should be. Fair enough, but don't call it science.
And the task for managers is not to satisfy scientists.

Cooperation, governance, culture.

There is a growing literature regarding why management sometimes works well, and sometimes not.

One key condition seems to be that those involved can accept the rules and regulations, and feel an ownership to the management strategy.

Some elements that seem important:
- Common understanding of the objectives
- Common understanding of what it takes to reach the objectives
- Clear understanding of the limitations set by nature.
- Clear understanding of limitations set by infrastructure and data availability.
- Stakeholder involvement in the development of management strategies
- Cooperation between stakeholders rather than competition
- Fair balance between interests
- Mutual respect and understanding
- Rules that can be followed in practice