



USP

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## **Yield per recruit models**

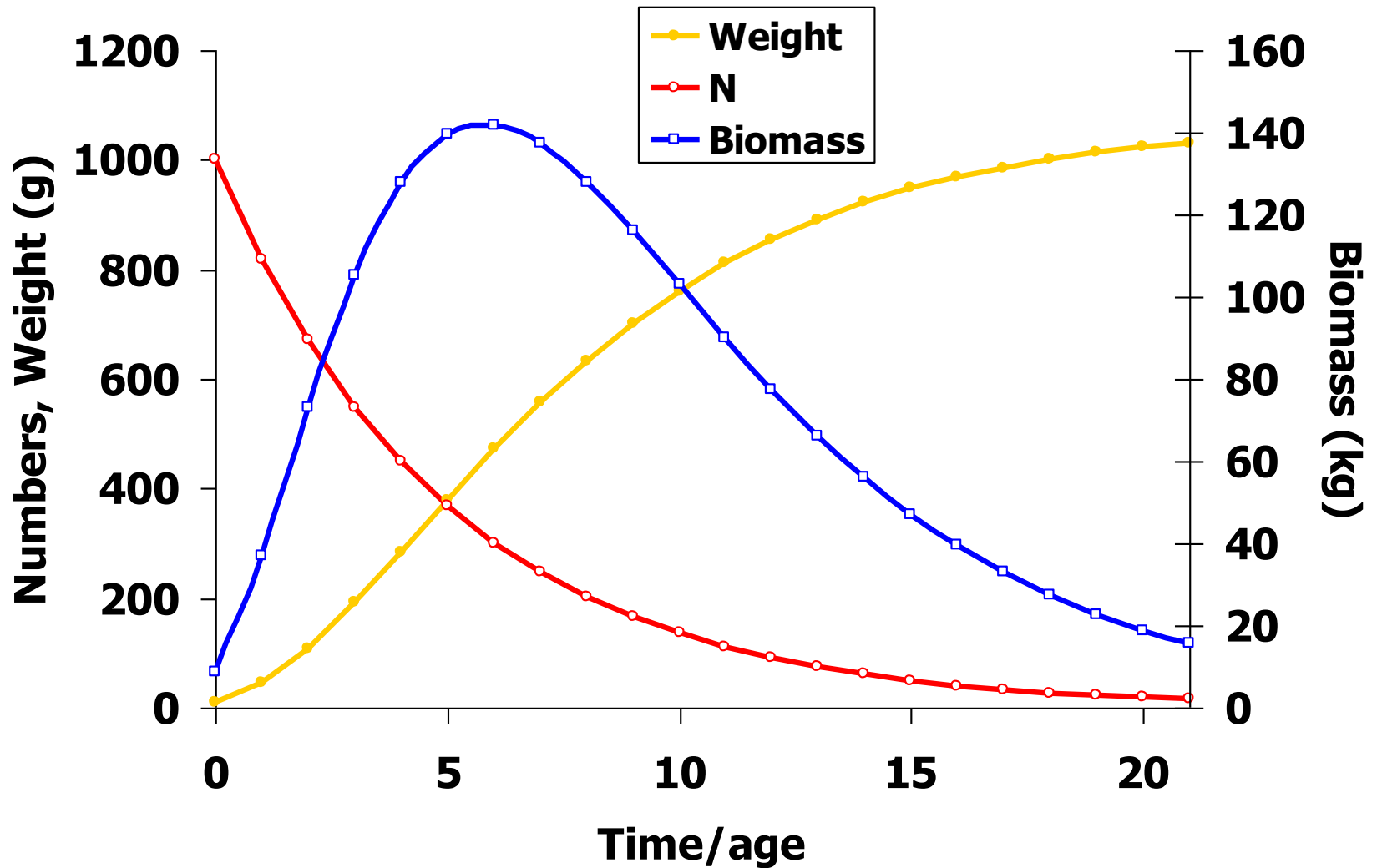
# Yield per recruit models

- Objectives
  - Since maximizing effort does not maximize catch, the question is if there is an optimum fishing rate that would lead to a maximum yield.
  - The principal purpose of yield per recruit models is to get an idea of the effect of selection pattern and fishing mortality on the yield from a fixed number of individuals that enters the fishery.
  - They often provide reference points for management purposes.
  - They are also informative in providing information on the contribution of a fixed number of individuals to the spawning component of the population (Spawning stock per recruit models).
- Type of models
  - Age based
    - Necessitates being able to age the fish
  - Length based
    - Necessitates being able to determine accurately the growth rate of a fish. Age needs thus to be known indirectly.

## Biomass development of a year class

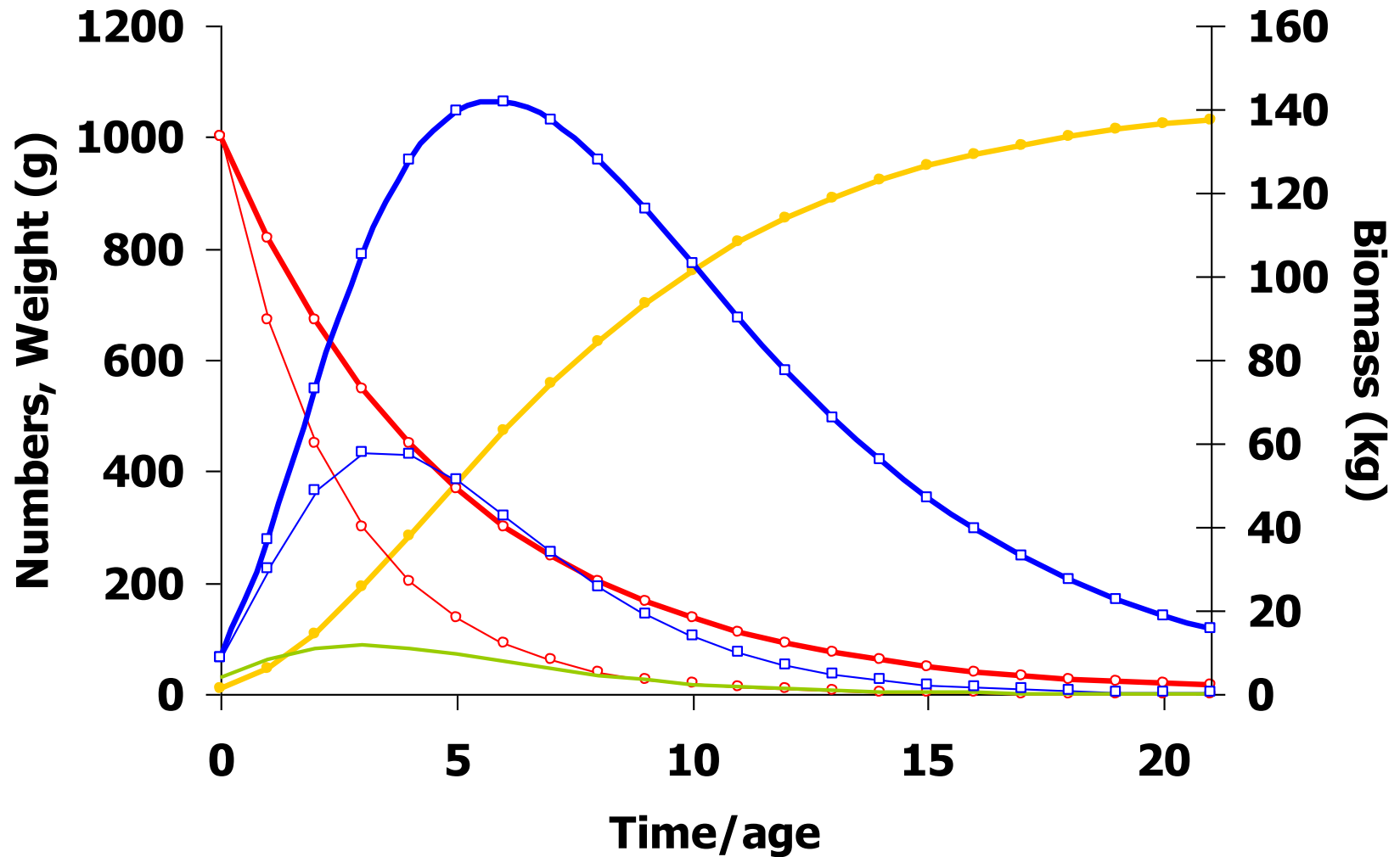
- After hatching the numbers in one cohort can only decline
- After hatching the individuals that remain in a cohort generally increase in size with age.
- The biomass of a cohort at any one time (t) is:
  - $\text{Biomass}_t = \text{Numbers}_t \times \text{mean weight}_t$
- What determines the biomass of a cohort is:
  - Number of fish in the beginning
  - Growth rate
  - Natural mortality rate
  - Selection pattern in the fishery
  - Overall fishing mortality

# Development of an unfished cohort

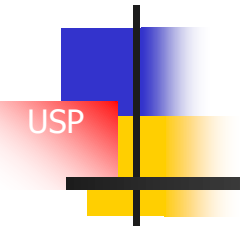


- The biomass of a cohort generally increases with age to a certain maximum, thereafter the biomass decreases with age
  - At young age, despite high abundance the weight of the individuals is generally very low, the product of the two resulting in low biomass.
  - As the individual increase in weight the biomass increases up to a maximum the loss of biomass weight due to mortality is countered by gain in biomass of the remaining growing individual.
  - Above a certain maximum biomass weight the biomass loss due to mortality is greater than the biomass gain from the sum of the growth of the remaining individuals.

# Development of a fished cohort

 $F = M = 0.2$ 

- The effect of fishing on a cohort of a certain fixed initial size results in lowering of the biomass!
- In general the biomass peaks at a younger age and fewer individuals from the cohort reach older age
  - Note that the sum of the standing biomass and the yield in the catches are not equivalent to the sum of the standing biomass under unfished state.
  - Note density independence:
    - Growth rate of the individual
    - Natural mortality
      - Natural mortality is here the same for all age groups, although that can easily be modified if (g)estimates available



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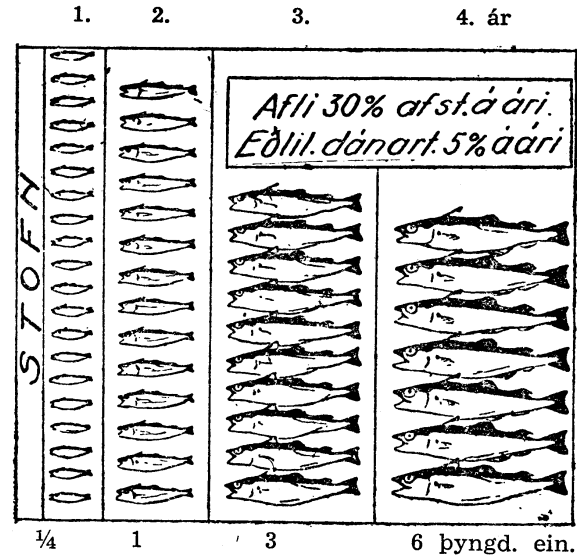
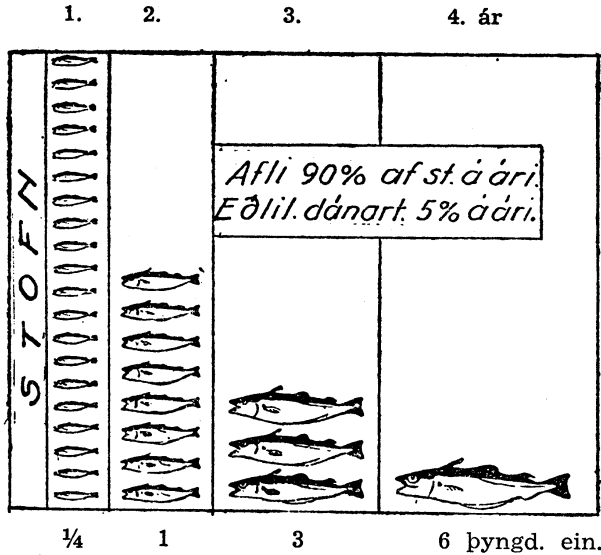
## Age based yield per recruit models

# Russel 1930: The first calculation

## Higher effort

## Lower effort

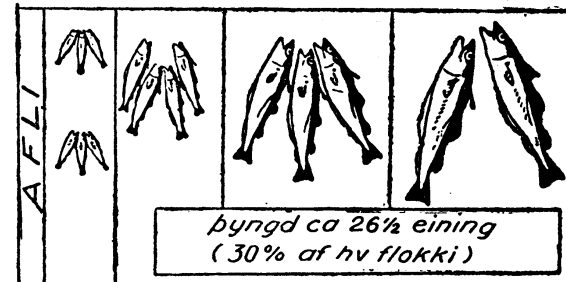
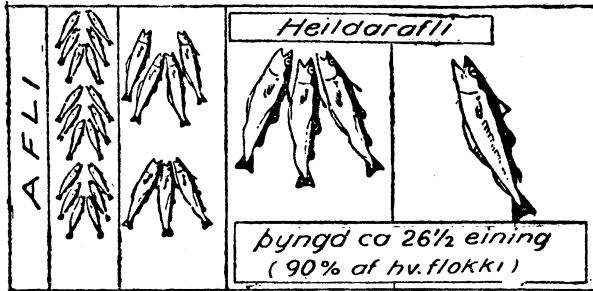
years



weight

Stock

Catch



# The calculation by Russel

		0.8			0.5		
<b>Catch rate (%)</b>		0.8			0.5		
<b>Natural mortality (%)</b>		0			0		
<b>Total mortality (%)</b>		0.8			0.5		
<b>tc</b>		1			1		
<b>Weight</b>	<b>Age</b>	<b>N (number)</b>	<b>Catch (number)</b>	<b>Catch (weight)</b>	<b>N (number)</b>	<b>Catch (number)</b>	<b>Catch (weight)</b>
0.042	0	1000			1000		
0.082	1	200	800	66	500	500	41
0.175	2	40	160	28	250	250	44
0.283	3	8	32	9	125	125	35
0.400	4	2	6	3	63	63	25
0.523	5	0	1	1	31	31	16
0.700	6	0	0	0	16	16	11
0.850	7	0	0	0	8	8	7
0.925	8	0	0	0	4	4	4
0.990	9	0	0	0	2	2	2
1.000	10	0	0	0	1	1	1
<b>Totals</b>		<b>1250</b>	<b>1000</b>	<b>106</b>	<b>1999</b>	<b>999</b>	<b>186</b>

- Increase in exploitation rate does not necessarily mean increase in yield
- Different effort/fishing mortality affect both stock size and catch
- Different effort/fishing mortality affect the size composition of the stock and the catch
- Increasing effort results in fewer individuals in a stock becoming large and old
- Increase effort results in individuals in the catch become smaller and lighter

- Russel assumptions:
  - Natural mortality zero
    - Conclusions reasonable if  $F \gg M$
    - Effectively his calculation is limited to exploring how one obtains the best yield from a given fixed number of fish caught
  - Ignored different vulnerability to the fishing gear of different sized/aged animals
  
- Analytical methods were derived in the 1950's taking on board the limitation above.

# Length based Y/R models

- Minimum data needed:
  - $K$  and  $L_{\infty}$
  - Relationship between length and weight
  - Some likely values of natural mortality
  - Selection pattern in the fishery
- Often also have:
  - maturity at length (to estimate Spawning Potential)
- The algorithm
  - Effectively the same as in the age based yield per recruit
    - In length based Y/R the inverse VBGF acts is used to convert length to time, the rest of the model algorithm is then the same as in the age based models
- The general conclusion when using length based models
  - Principally the same as in the age based yield per recruit

# The step by step guide

INPUT			RESULTS				Biomass	Catch	Yield
F-oldest	1.000					Summation	551	382	263
Age	Length	Weight	M	Sel	Fay	N	Biomass	Catch	Yield
0.00	20.00	0.0655	0.4	0.02	0.02	1000	65	2	0
0.10	21.09	0.0779	0.4	0.02	0.02	959	75	2	0
0.20	22.17	0.0917	0.4	0.03	0.03	920	84	2	0
0.30	23.23	0.1069	0.4	0.03	0.03	881	94	3	0
0.40	24.27	0.1235	0.4	0.04	0.04	844	104	4	0
0.50	25.30	0.1414	0.4	0.05	0.05	807	114	4	1
0.60	26.31	0.1608	0.4	0.07	0.07	771	124	5	1
0.70	27.31	0.1817	0.4	0.08	0.08	736	134	6	1
0.80	28.29	0.2039	0.4	0.10	0.10	701	143	7	1
....									
5.90	62.55	2.7500	0.4	1.00	1.00	2	5	0	0
6.00	62.99	2.8135	0.4	1.00	1.00	2	5	0	0
6.10	63.42	2.8770	0.4	1.00	1.00	1	4	0	0
6.20	63.85	2.9405	0.4	1.00	1.00	1	4	0	0

- At each time step calculate:

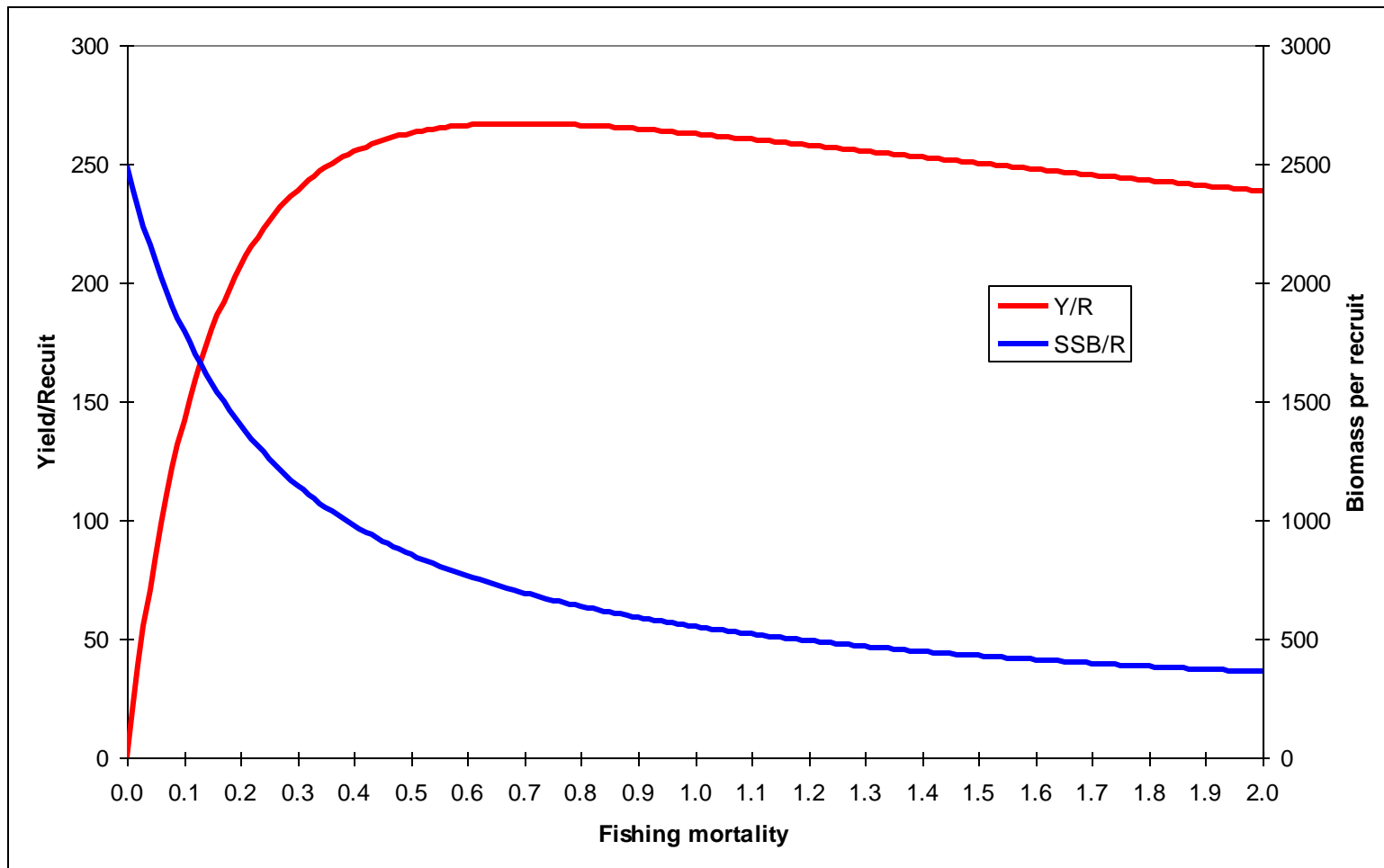
- The stock size  $N_{t+\Delta t} = N_t e^{-\Delta t (M_t + F_t)}$
- The catches  $\Delta C_t = F_t / (F_t + M_t) (1 - e^{-\Delta t (F_t + M_t)}) N_t$
- The biomass  $B_t = N_t w_t$
- The yield  $Y_t = C_t w_t$
- Sum the latter two for the whole life time of the cohort

# The effect of changing fishing mortality

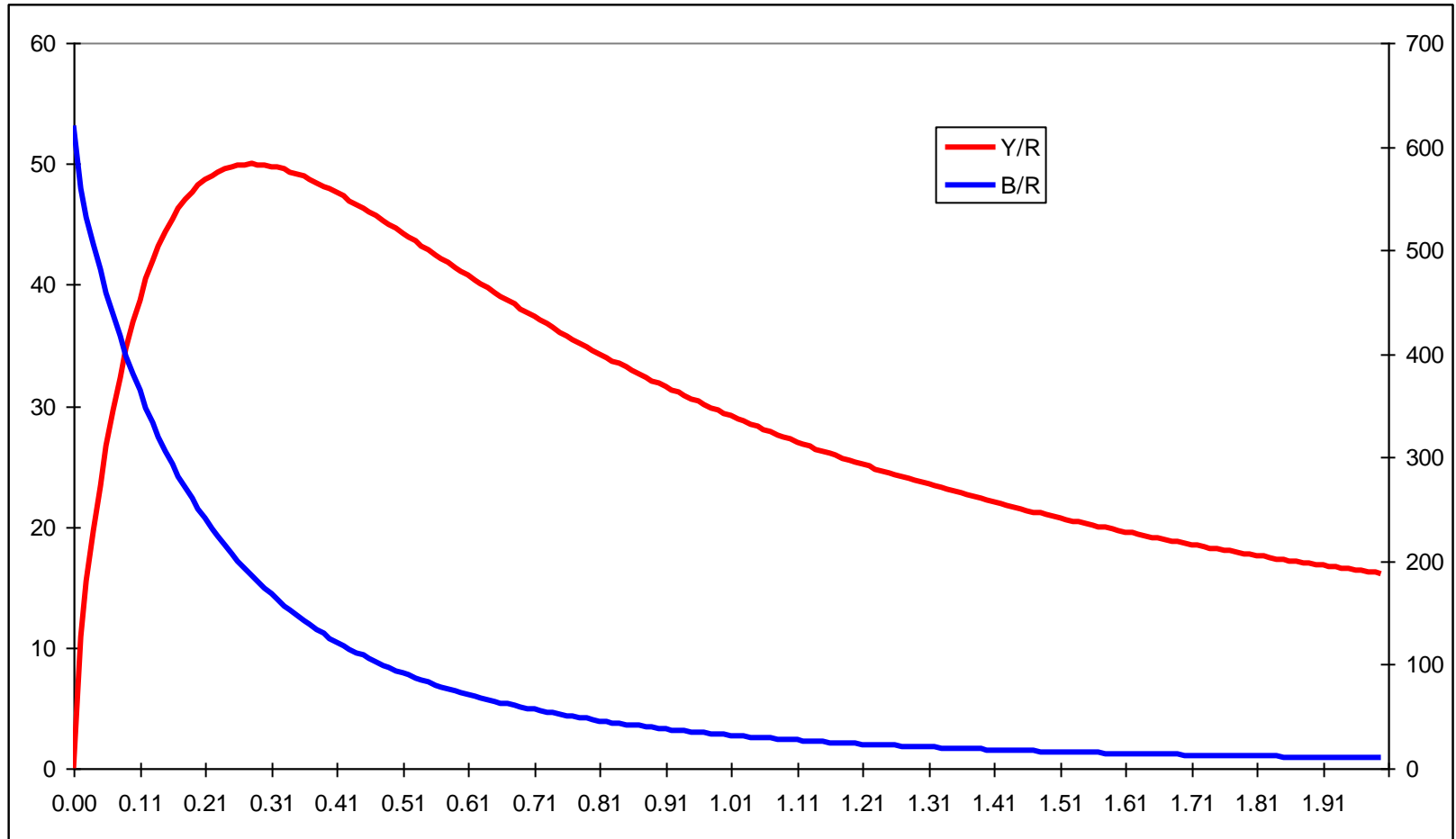
INPUT		RESULTS					Biomass	Catch	Yield
F-oldest	0.200	Summation					1399	165	207
Age	Length	Weight	M	Sel	Fay	N	Biomass	Catch	Yield
0.00	20.00	0.0655	0.4	0.02	0.00	1000	65	0	0
0.10	21.09	0.0779	0.4	0.02	0.00	960	75	0	0
0.20	22.17	0.0917	0.4	0.03	0.01	922	85	0	0
0.30	23.23	0.1069	0.4	0.03	0.01	886	95	1	0
0.40	24.27	0.1235	0.4	0.04	0.01	850	105	1	0
0.50	25.30	0.1414	0.4	0.05	0.01	816	115	1	0
0.60	26.31	0.1608	0.4	0.07	0.01	784	126	1	0
0.70	27.31	0.1817	0.4	0.08	0.02	752	137	1	0
0.80	28.29	0.2039	0.4	0.10	0.02	721	147	1	0
....									
5.90	62.55	2.7500	0.4	1.00	0.20	43	119	1	2
6.00	62.99	2.8135	0.4	1.00	0.20	41	115	1	2
6.10	63.42	2.8770	0.4	1.00	0.20	38	111	1	2
6.20	63.85	2.9405	0.4	1.00	0.20	36	106	1	2

INPUT		RESULTS					Biomass	Catch	Yield
F-oldest	1.000	Summation					551	382	263
Age	Length	Weight	M	Sel	Fay	N	Biomass	Catch	Yield
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0.10	21.09	0.0779	0.4	0.02	0.02	959	75	2	0
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0.30	23.23	0.1069	0.4	0.03	0.03	881	94	3	0
0.40	24.27	0.1235	0.4	0.04	0.04	844	104	4	0
0.50	25.30	0.1414	0.4	0.05	0.05	807	114	4	1
0.60	26.31	0.1608	0.4	0.07	0.07	771	124	5	1
0.70	27.31	0.1817	0.4	0.08	0.08	736	134	6	1
0.80	28.29	0.2039	0.4	0.10	0.10	701	143	7	1
....									
5.90	62.55	2.7500	0.4	1.00	1.00	2	5	0	0
6.00	62.99	2.8135	0.4	1.00	1.00	2	5	0	0
6.10	63.42	2.8770	0.4	1.00	1.00	1	4	0	0
6.20	63.85	2.9405	0.4	1.00	1.00	1	4	0	0

# The effect of changes in fishing mortality



# The yield per recruit calculation is species specific





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Case example: Icelandic cod  
(age based)

# The output of the analysis

## Input

age	M	Way	Way(SSB)	pa	fa
1	0.2	100	100	0.00	0.00
2	0.2	400	499	0.00	0.00
3	0.2	1265	1101	0.03	0.08
4	0.2	1784	1634	0.12	0.32
5	0.2	2595	2410	0.32	0.59
6	0.2	3617	3525	0.57	0.85
7	0.2	4901	4852	0.78	1.04
8	0.2	6207	6284	0.89	1.22
9	0.2	7469	7675	0.95	1.18
10	0.2	8990	9370	0.96	1.13
11	0.2	10645	11313	0.99	1.02
12	0.2	12261	13063	0.98	1.08
13	0.2	13931	14402	0.99	1.10
14	0.2	15587	15587	1.00	1.08
15	0.2	16637	16637	1.00	1.07
16	0.2	18588	18588	1.00	1.07
17	0.2	18768	18768	1.00	1.07
18	0.2	20509	20509	1.00	1.07

## Output

age	Na	Na(SSB)	Ca	Ya (g)	SSBa (g)
1	1.492	0.000	0.000	0	0
2	1.222	0.000	0.000	0	0
3	1.000	0.032	0.029	36	35
4	0.793	0.096	0.091	163	157
5	0.567	0.181	0.113	293	436
6	0.362	0.206	0.099	358	725
7	0.208	0.162	0.067	329	786
8	0.110	0.098	0.040	250	619
9	0.054	0.051	0.019	143	391
10	0.027	0.026	0.009	83	242
11	0.014	0.014	0.004	47	154
12	0.007	0.007	0.002	29	93
13	0.004	0.004	0.001	19	55
14	0.002	0.002	0.001	11	31
15	0.001	0.001	0.000	6	16
16	0.001	0.001	0.000	3	9
17	0.000	0.000	0.000	2	5
18	0.000	0.000	0.000	1	3
				Y	SSB
				1.77	3.76 kg

**M:** Natural mortality

**Wa:** Weight in the catch

**Wa (SSB):** Weight of mature fish

**pa:** Proportion of fish mature

**fa:** fishing patter

**Na:** Number of fish alive at age a

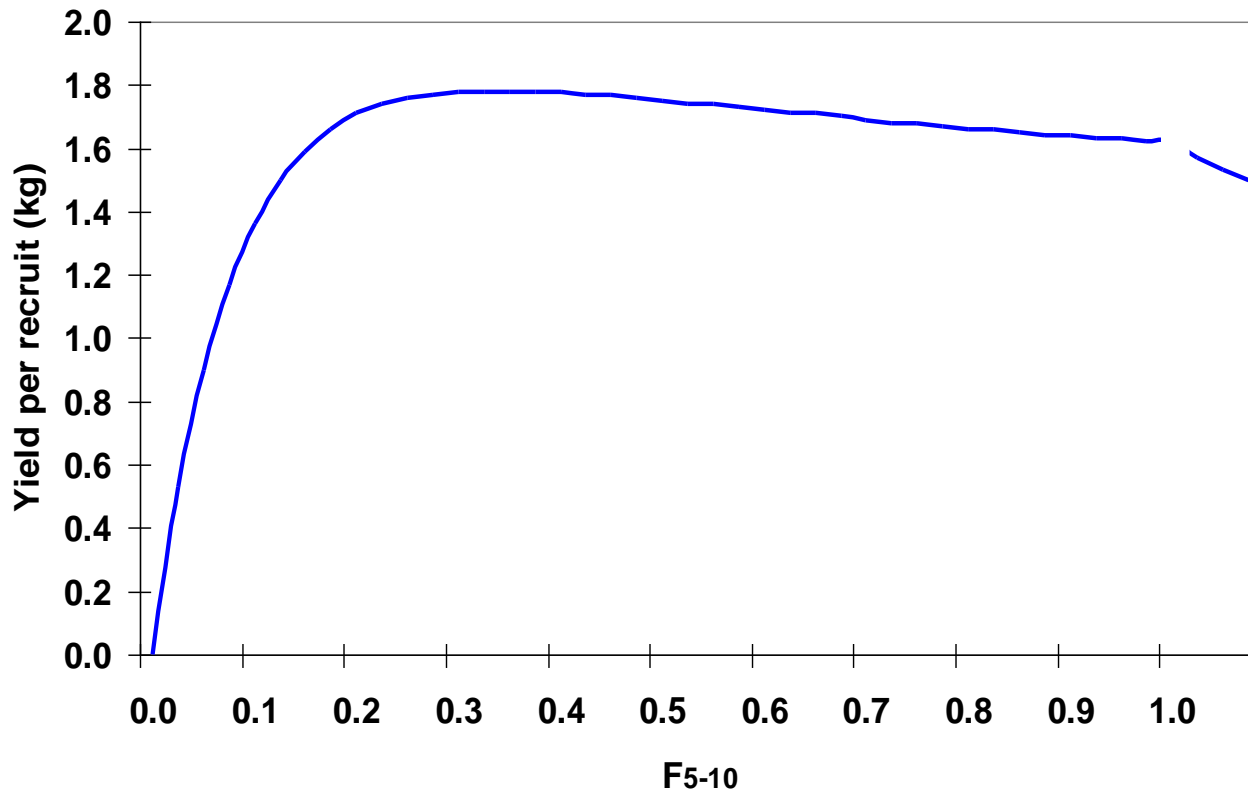
**Na: (SSB):** Number of mature fish alive

**Ca:** Catch in numbers

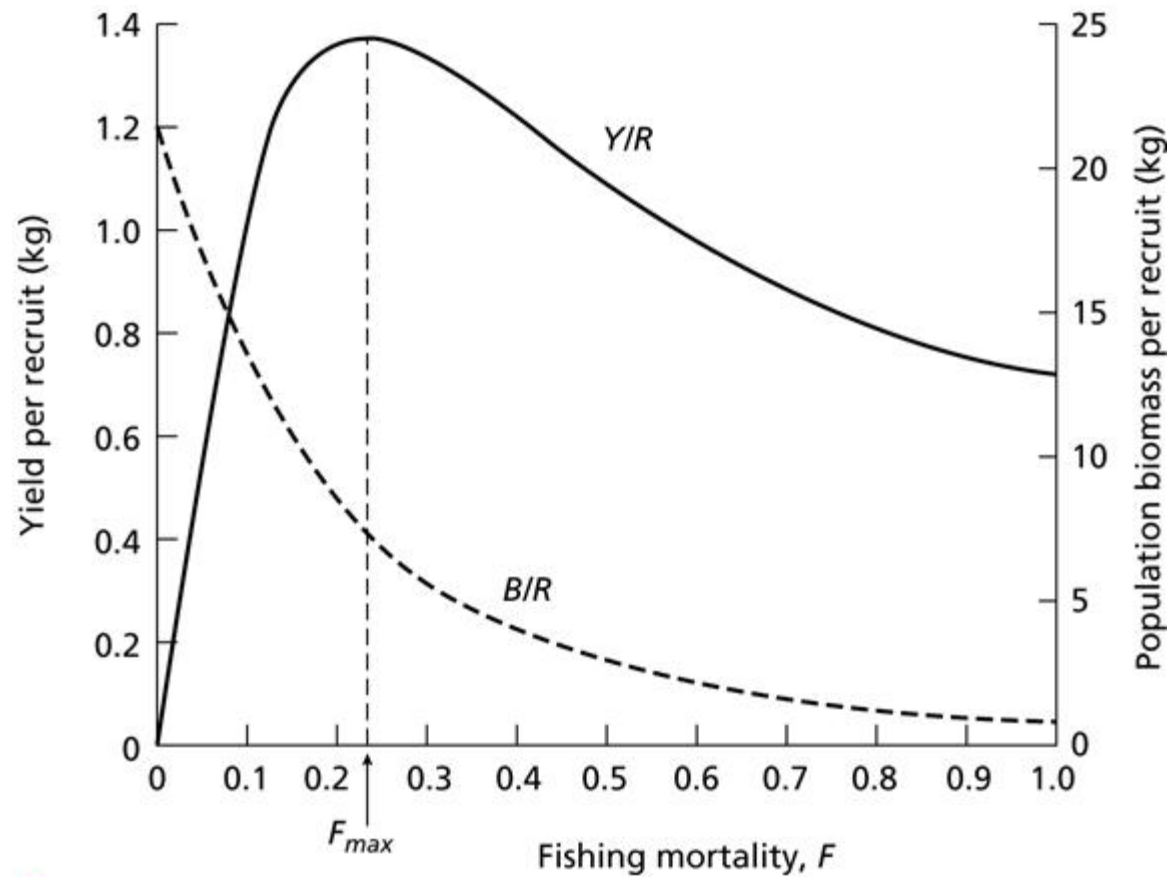
**Ya:** Catch in weight

**SSBa:** Spawning stock weight

# Icelandic cod: The yield from one fish



1. No fishing, no catch
2. Yield increases dramatically as fishing mortality increases
3. Maximum yield obtained at some  $F$ , defined as  $F_{max}$
4. Yield falls slowly (and sometimes not at all) as  $F$  increases above  $F_{max}$
5. If  $F$  becomes very high, the yield is equal to the youngest fish entering the fisheries



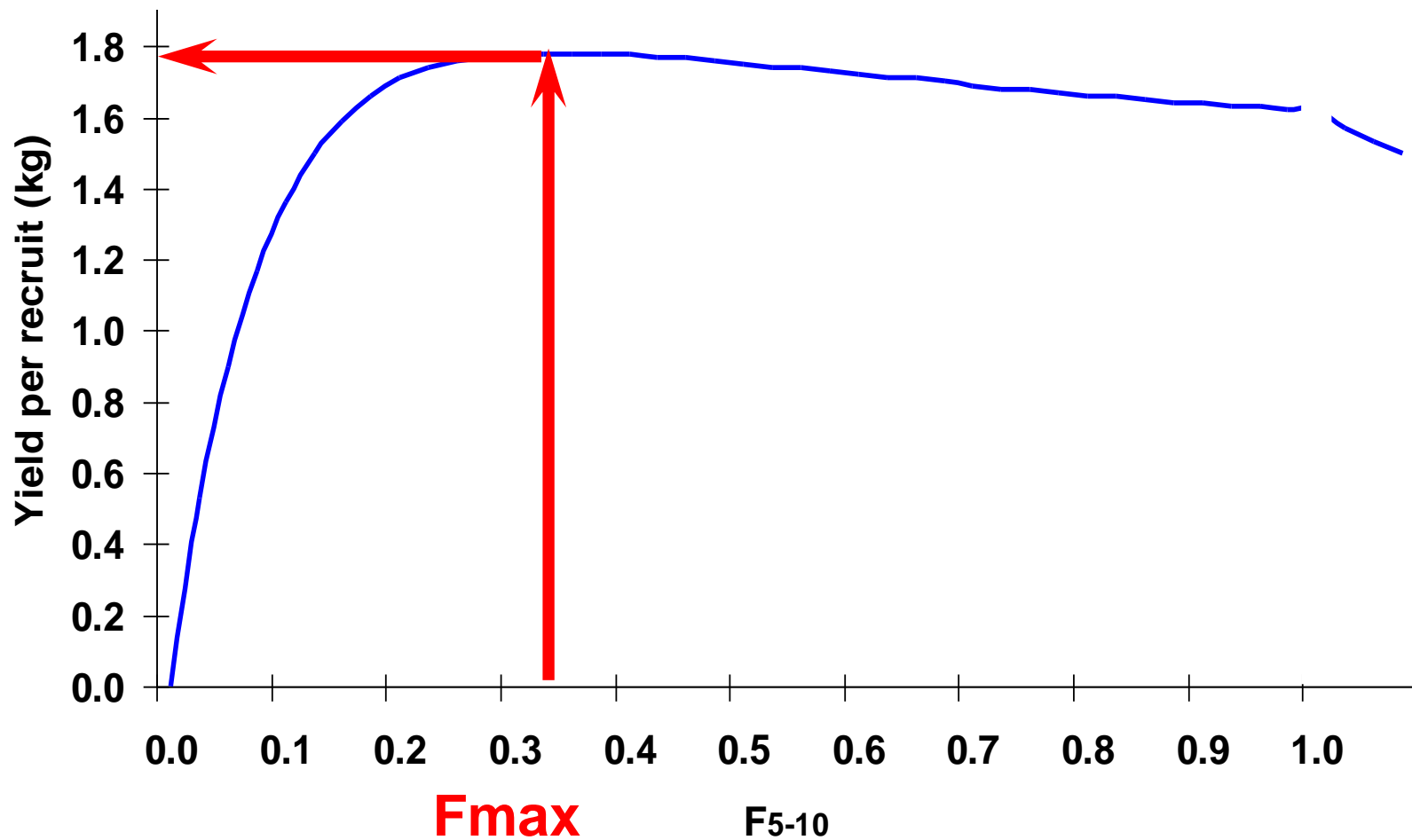
Y/R models are stock specific

# The shape of the yield per recruit curve

- The shape of the yield per recruit curve depends on the combined effect of weight increase of the cohort due to growth of surviving fish and weight loss of the cohort due to decline in numbers (mortality).
  - When fishing mortality is very high ( $F_{inf}$ ) all the fish in the cohort are caught in the first time period (year/month) that they enter the fisheries. In this case the Y/R is equivalent to the mean weight of the individual fish at that time.
  - With lower fishing mortality more fish remain in the stock for a longer time and individuals are caught at a later and larger size. The reduction in fishing mortality from very high to some moderate level result in some gain in yield since although more fish have died because of natural reasons the weight increase of remaining fish weighs up the biomass loss due to the former process.
  - If fishing mortality is very low, the biomass loss of the cohort due to natural mortality is greater than the biomass increase do the growth of the remaining individuals. The extreme case is if  $F=0$ , then the Yield = 0!

Reference points:  $F_{\max}$ 

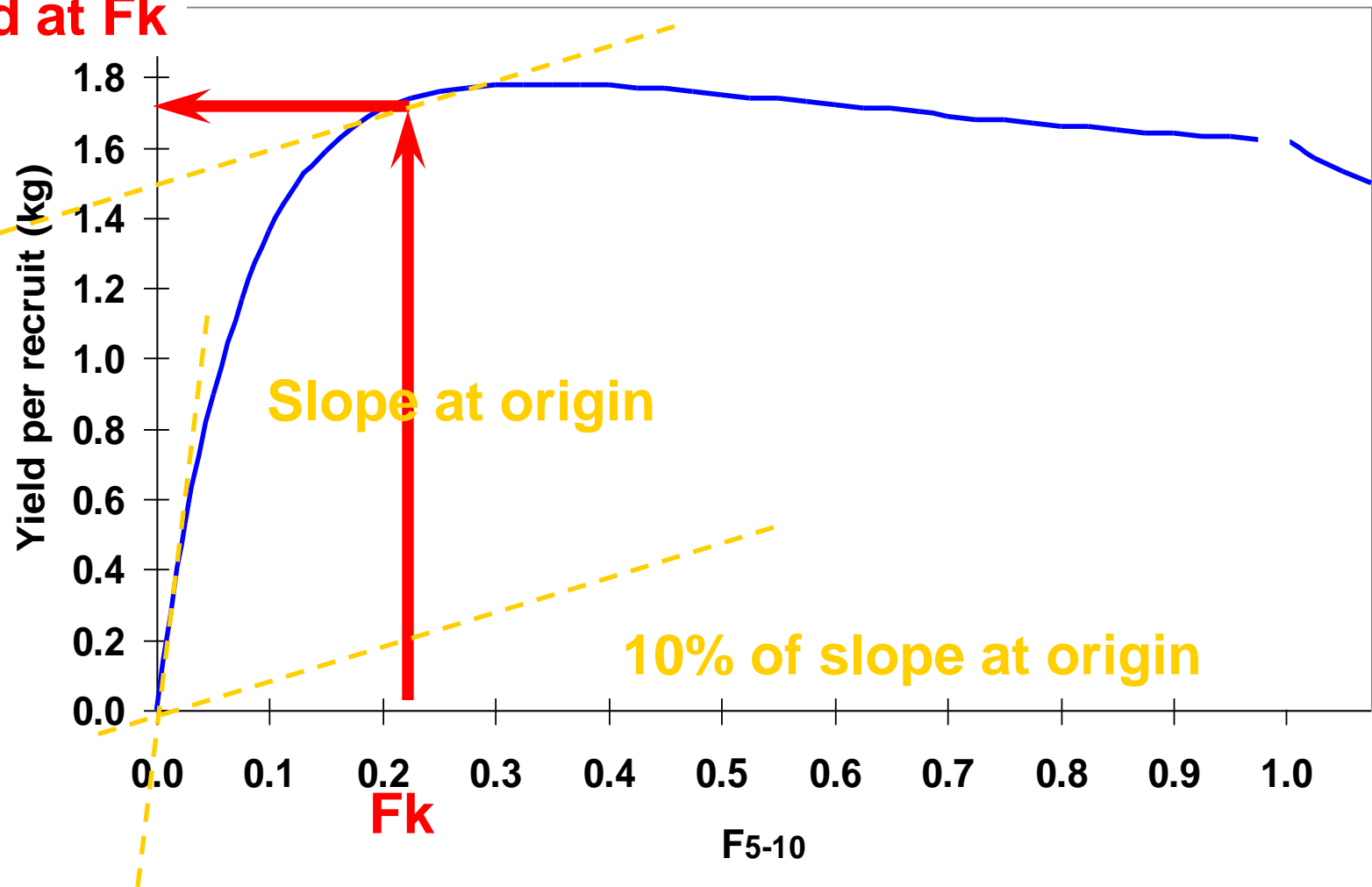
The maximum yield

**Y/R at  $F_{\max}$** 

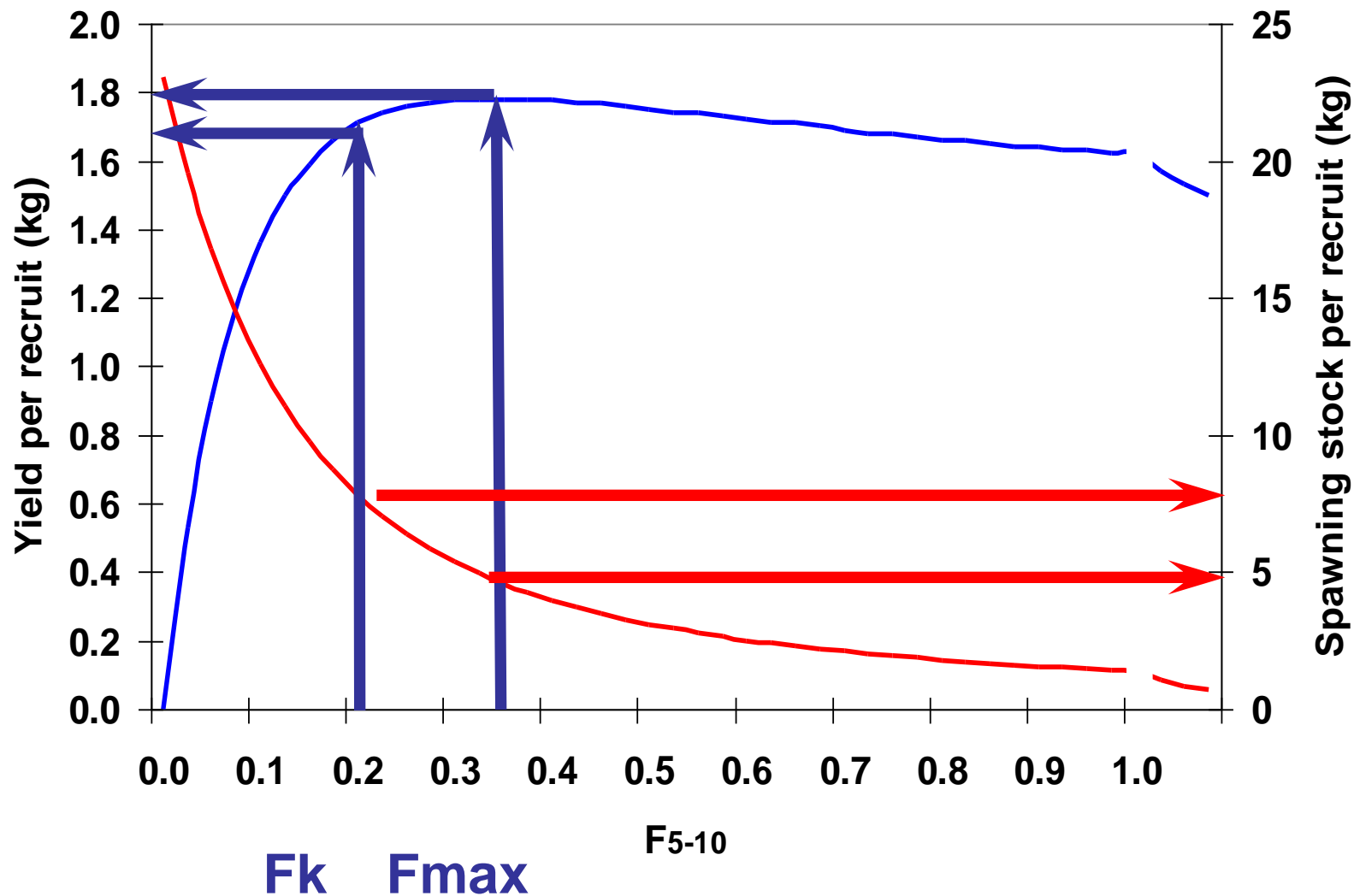
# Reference points: $F_{0.1}$

The yield at 10% of the slope at the origin

## Yield at $F_k$



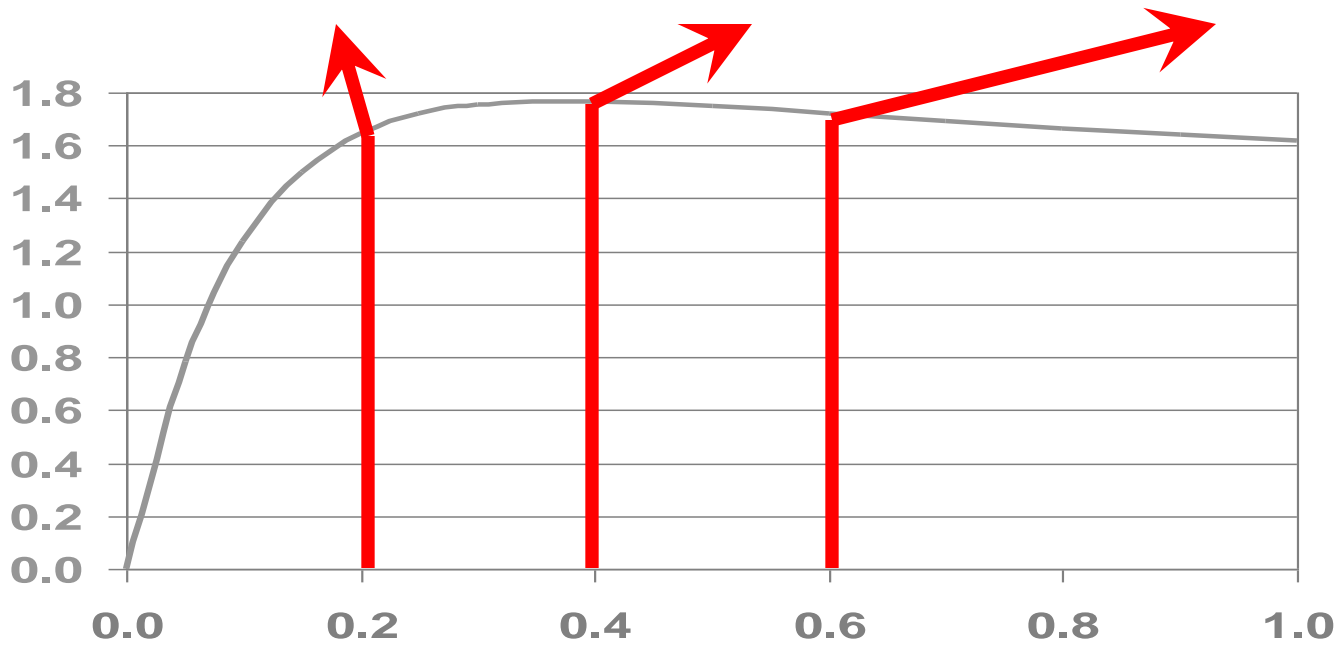
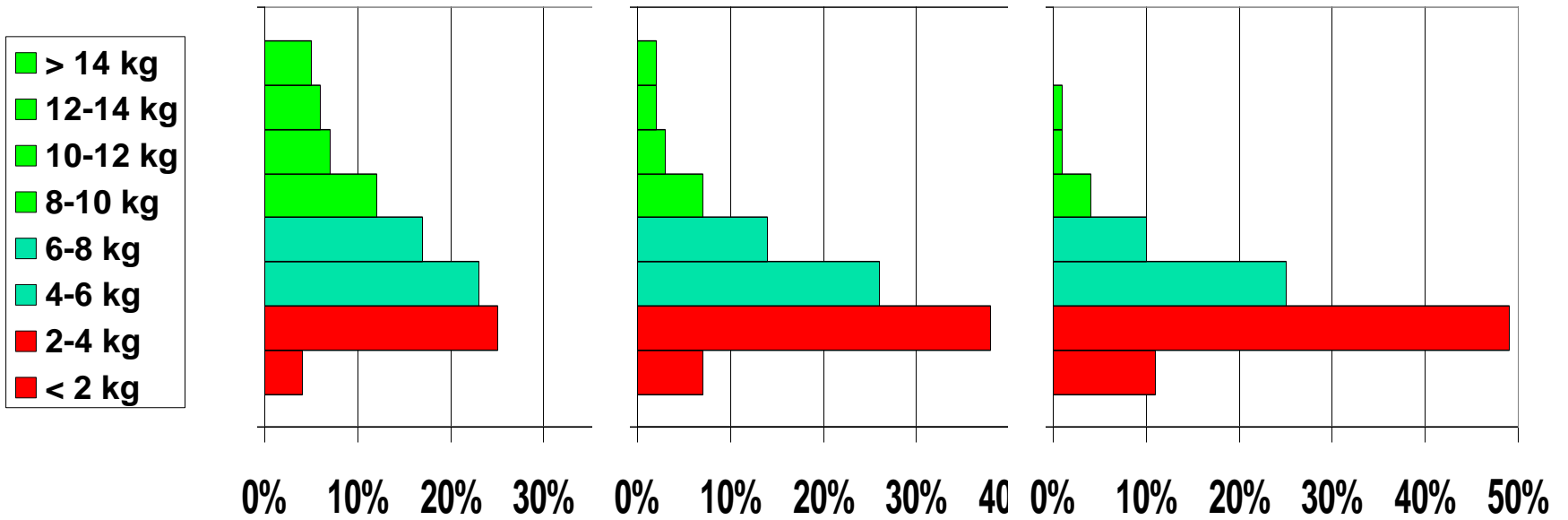
## Fmax or Fk?



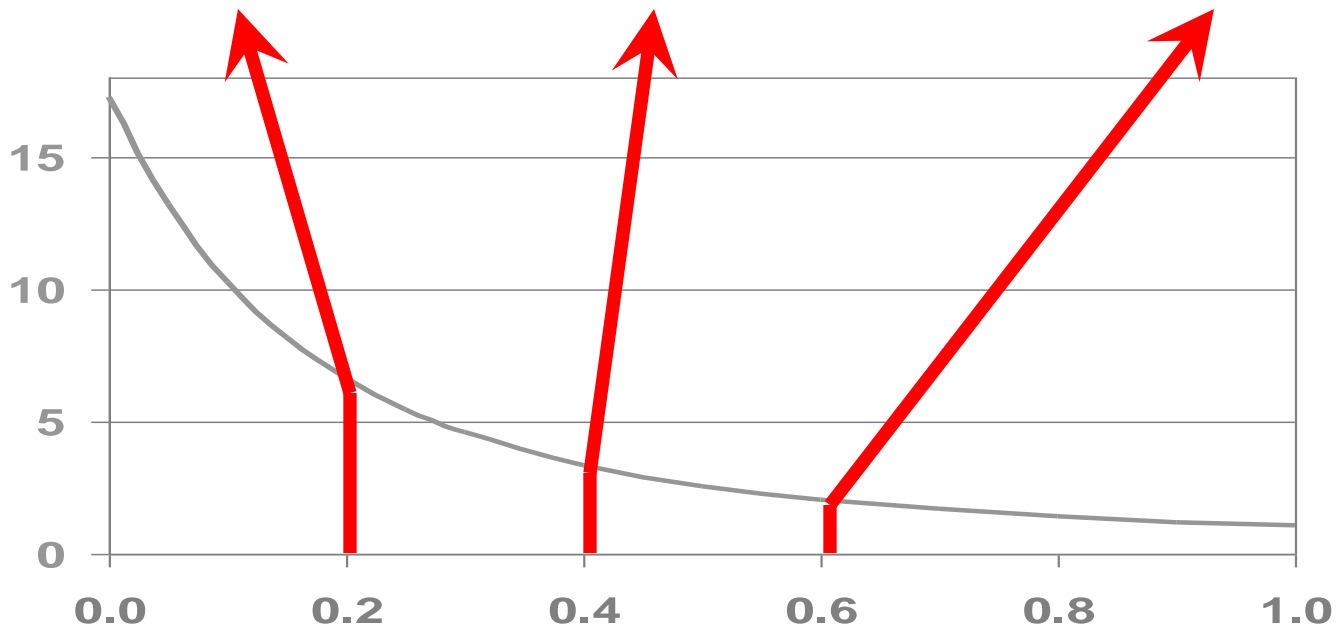
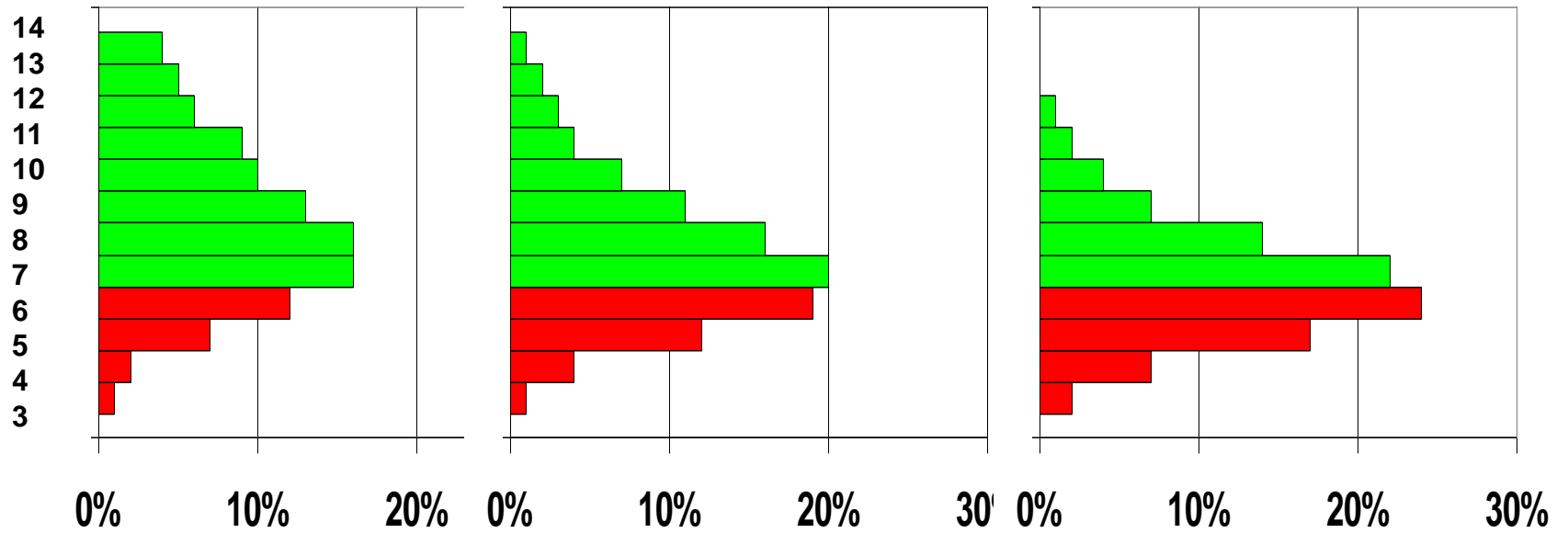
# Effect of fishing mortality on catch and stock

- Often observe that once effort reaches a certain level, increase in effort does not result in increased yield
- Changes in effort may however affect the amount of fish that is left to spawn.
- Thus lowering of effort from  $F_{\max}$  to  $F_{0.1}$  results in some slight loss in yield. The increase in the contribution to spawning is however almost 50%
  - The 0.1 reference value is an arbitrary value
- In some cases fishing mortality reference points have been defined from SSR/R analysis. E.g.
  - FSPR30%: Fishing mortality where there spawning stock per recruit is 30% of that what is obtained under no fishing ( $F=0$ ).

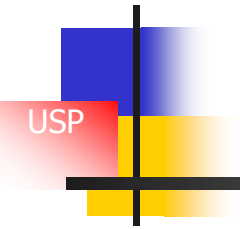
# Catch composition



# Spawning stock composition



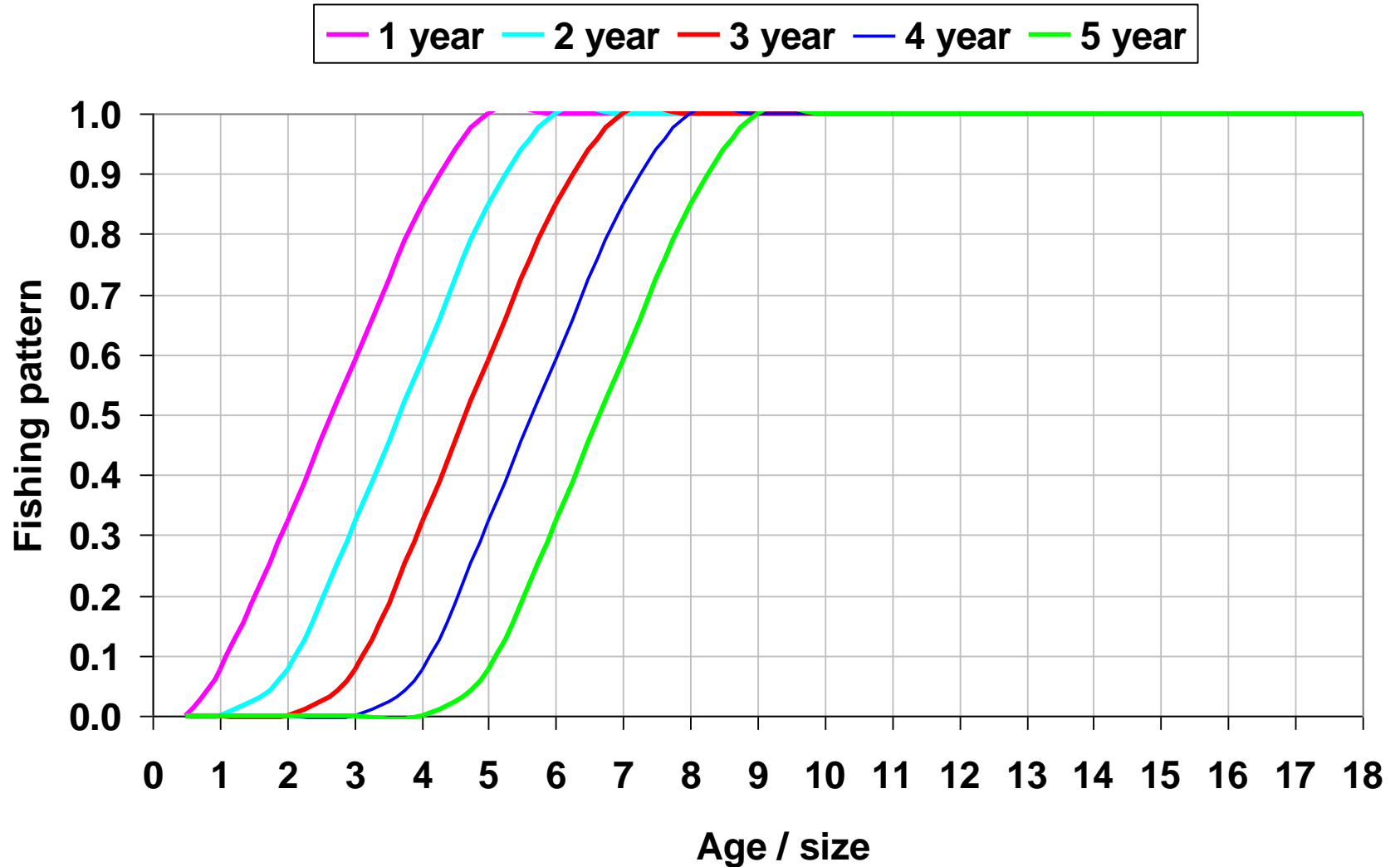
- Although the total yield may not change much under different effort we observe a change in the catch composition:
  - Moderate effort normally results in yield that is composed of number of age classes at any one time (if generations overlap)
- The effort has profound effect on the stock size and also stock composition:
  - Moderate effort results in stock size that is composed of a number of age classes at any one time (if long lived)



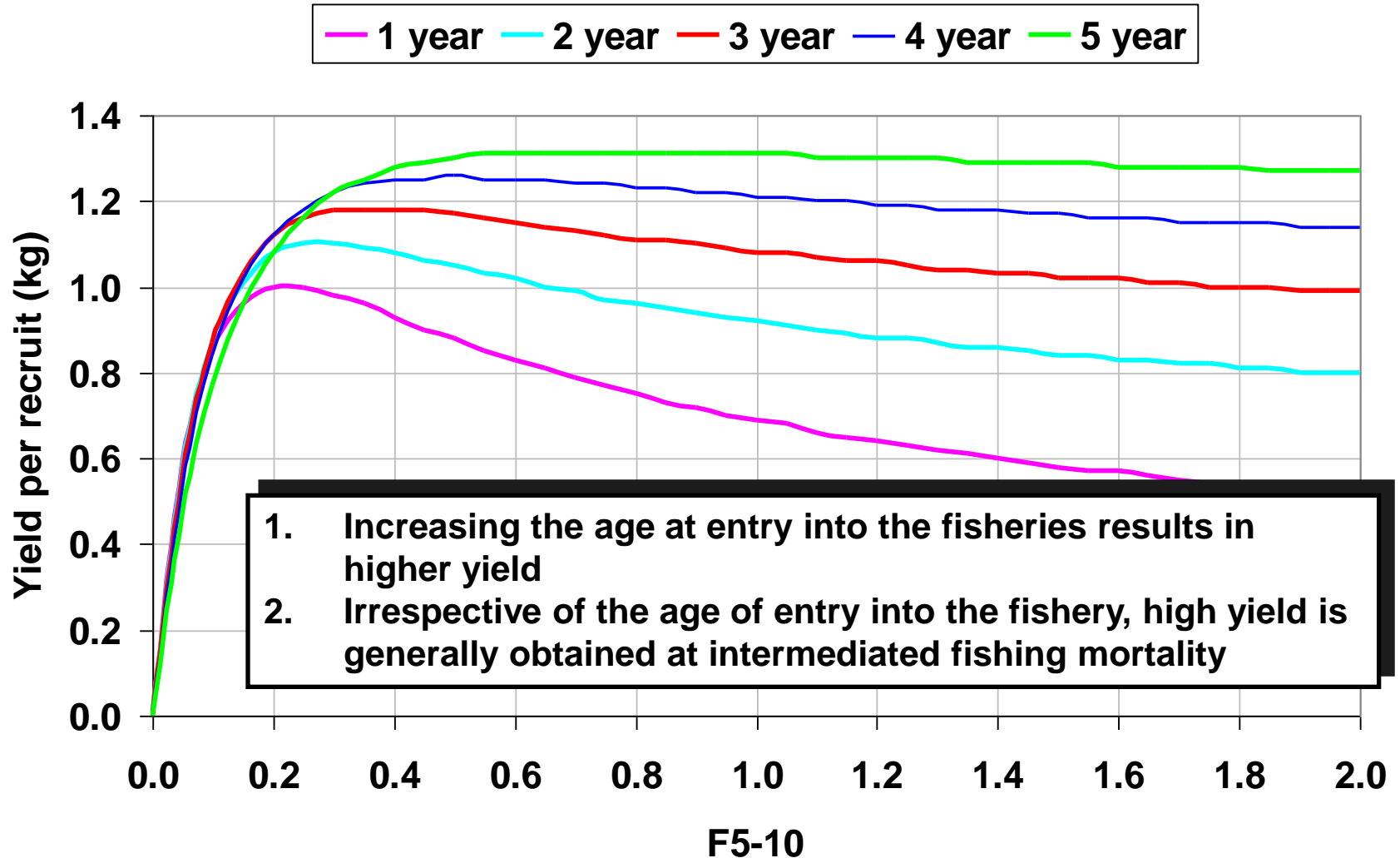
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## Effect of different values

# Changing the fishing pattern



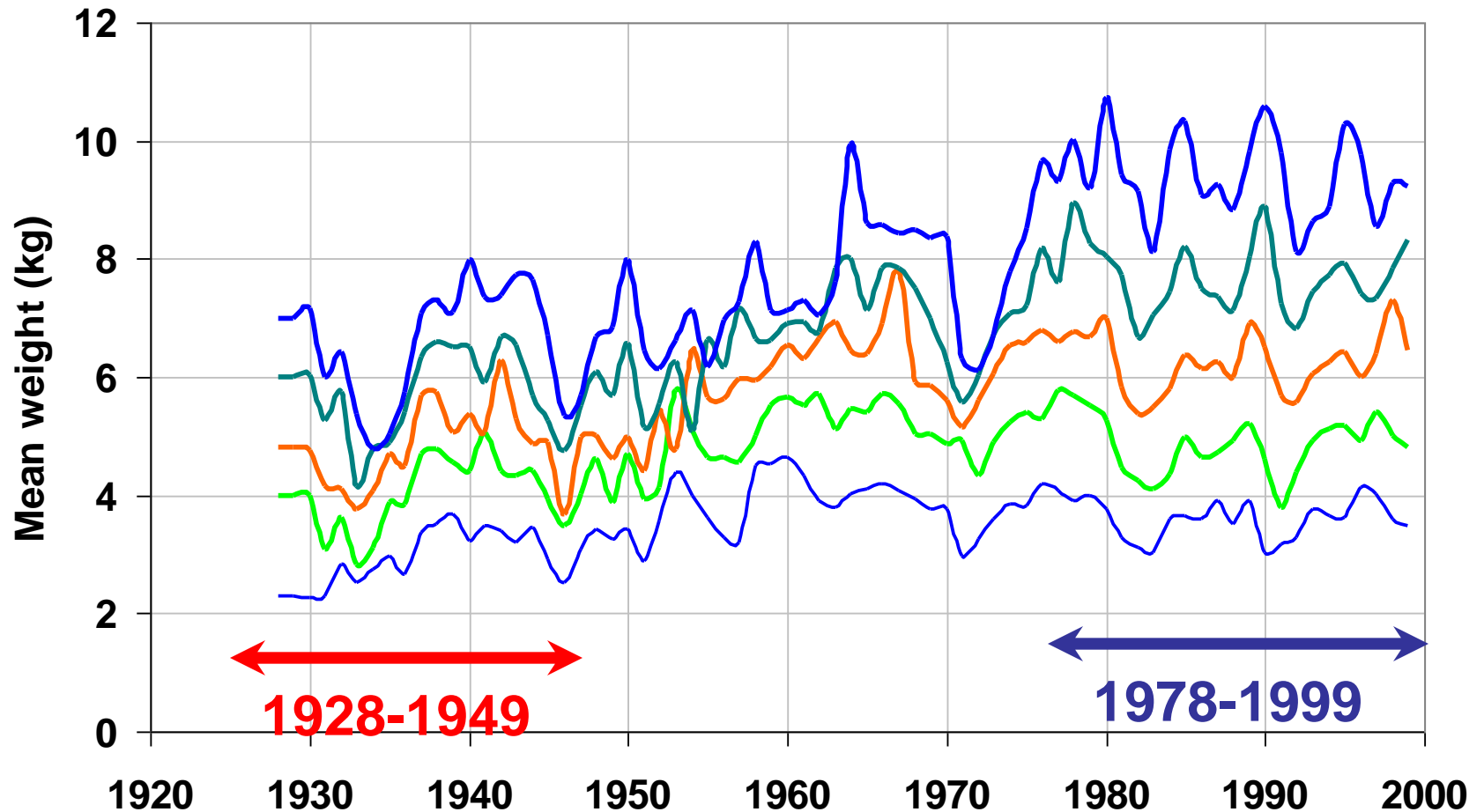
# Effect of selection patterns



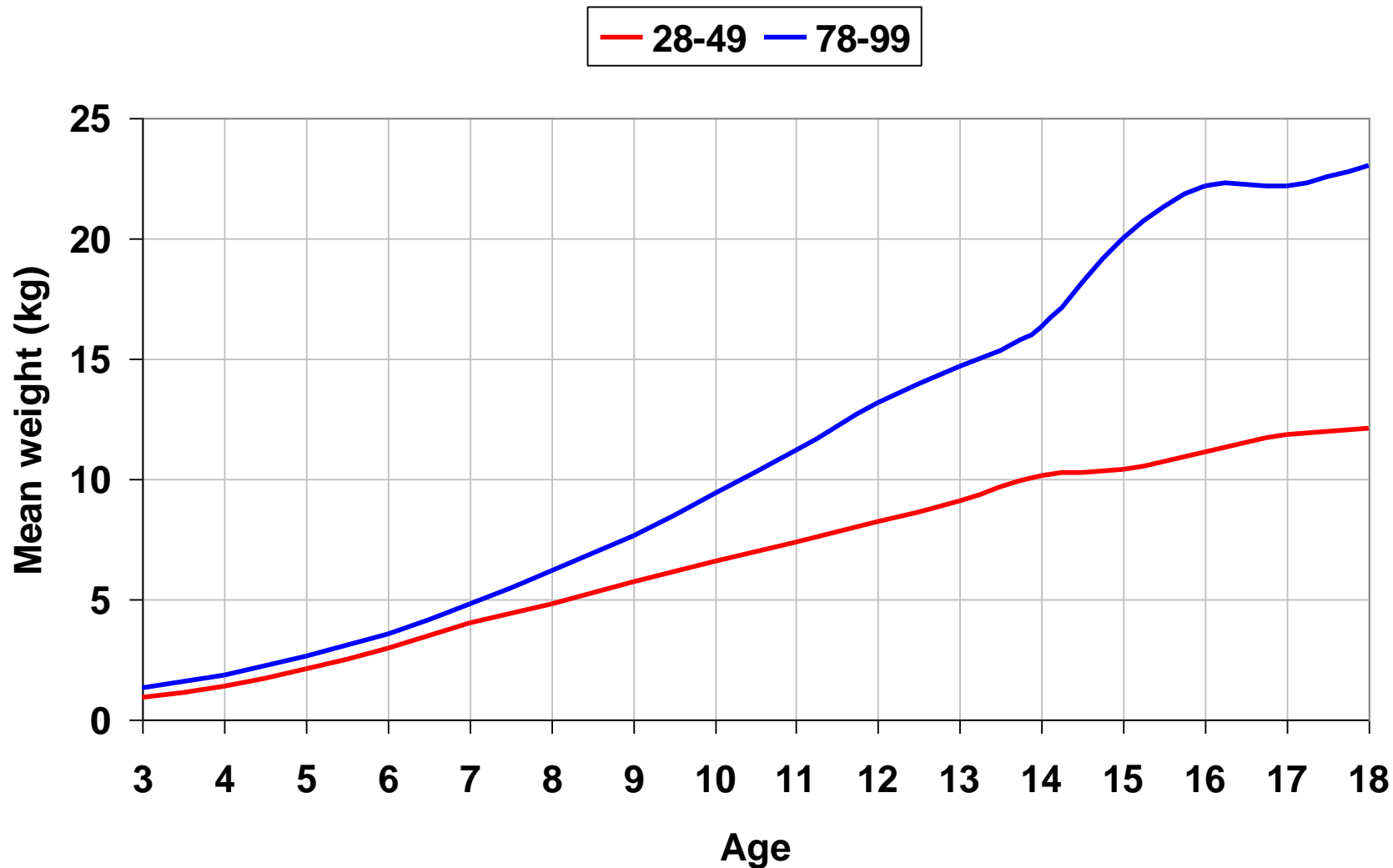
# Effect of change in growth (mean weight at age)

Cod

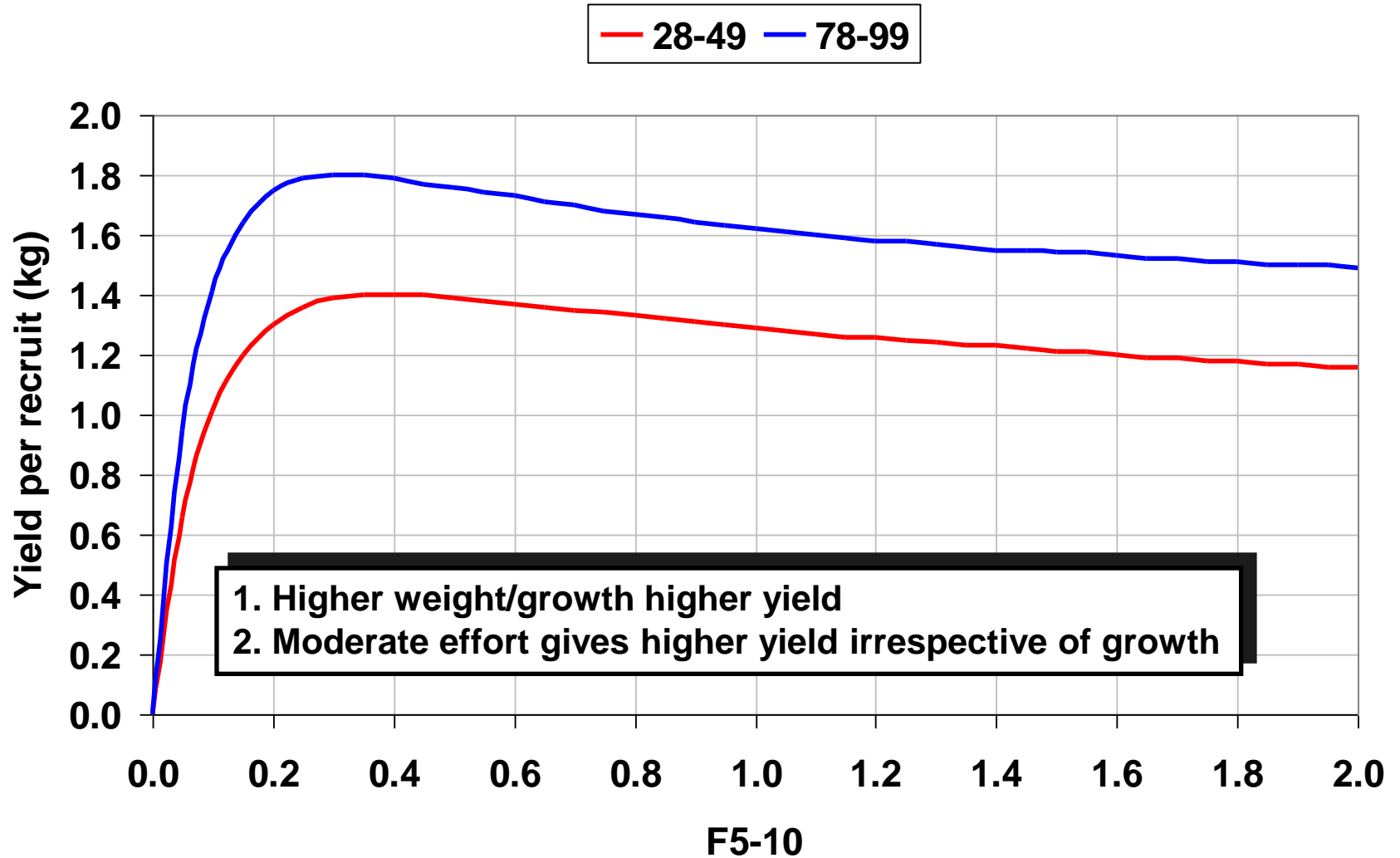
— 6 year — 7 year — 8 year — 9 year — 10 year



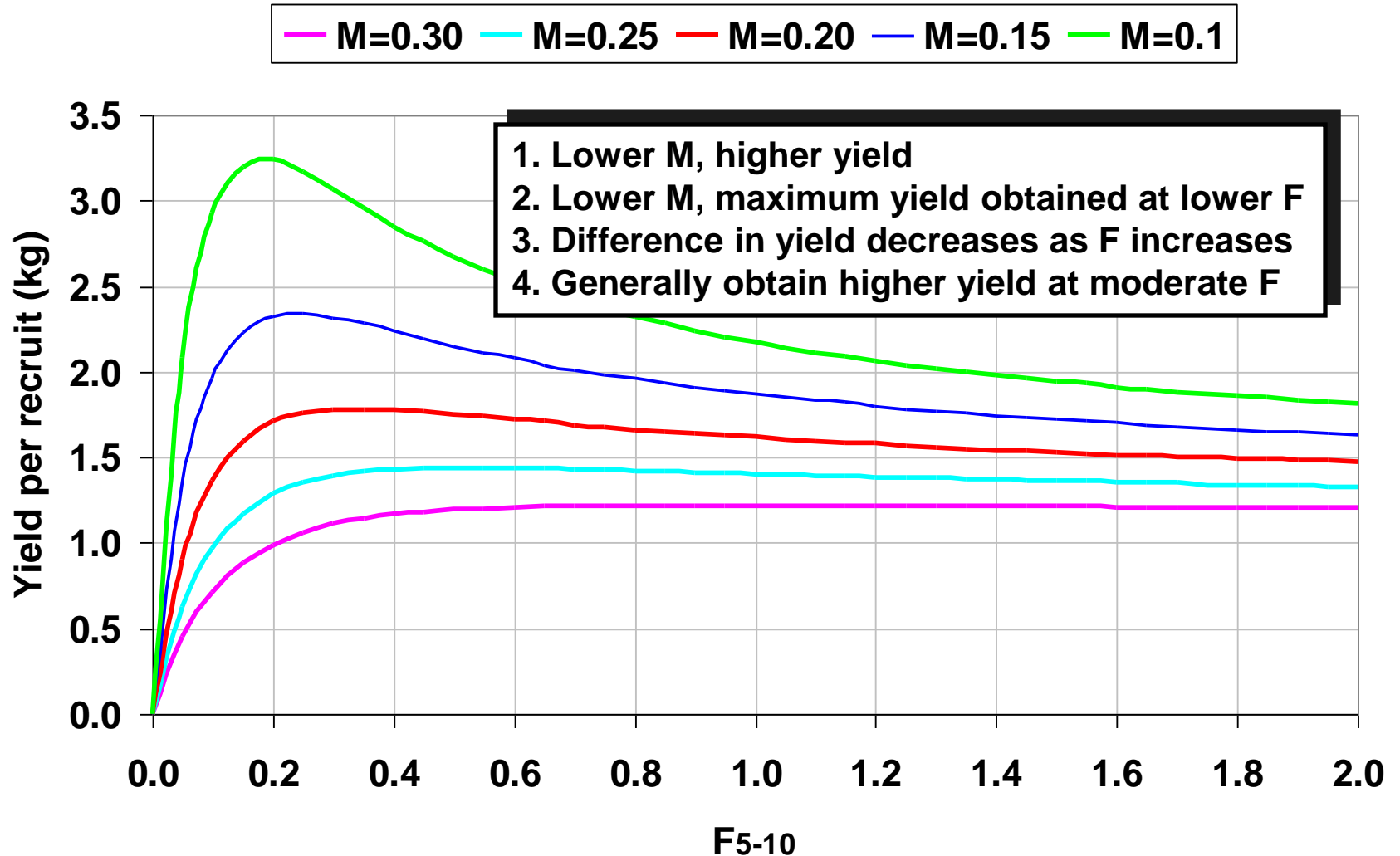
# Cod: Mean weight at age over two periods



# Effect of different mean weight



# The effect of M on yield



- Minimum data needed:
  - K and  $L_{\infty}$
  - Relationship between length and weight
  - Some likely values of natural mortality
- The algorithm
  - Effectively the same as in the age based yield per recruit
    - In length based Y/R the inverse VBGF acts is used to convert length to time, the rest of the model algorithm is then the same as in the age based models
- The general conclusion when using length based models
  - Principally the same as in the age based yield per recruit

## Limitation of yield per recruit model

- There is normally no density dependency in the model
  - The weight at age is constant irrespective of stock size
  - The natural mortality is constant irrespective of stock size
- Natural mortality is generally unknown
  - The conclusions drawn are often highly dependent on the assumption of natural mortality.
- Does not take into account potential effect population crash at high fishing mortality
- Is a single species model and is thus if used only applicable as a management tool for single species fisheries

# "Multi"-species yield per recruit

YF: Yellow tail flounder  
AC: Atlantic cod  
H: Haddock  
WF: Winter flounder

