THE UNIVERSITY OF THE SOUTH PACIFIC

SPC Secretariat of the Pacific Community

COMMONWEALTH SECREARIAT

UNITED NATIONS UNIVERSITY Fisheries Training Programme

Age and growth

Assessing the status of fish stock for management: the collection and use of basic fisheries data and statistics

27 November -8 December 2006,

University of the South Pacific, Suva, Fiji Islands

Age and growth

- Why do we want to age fish?

$$changes\ in\ length\ or\ weight = \frac{dL}{dt}\ or\ \frac{dW}{dt}$$

$$changes\ in\ numbers = \frac{dN}{dt}$$

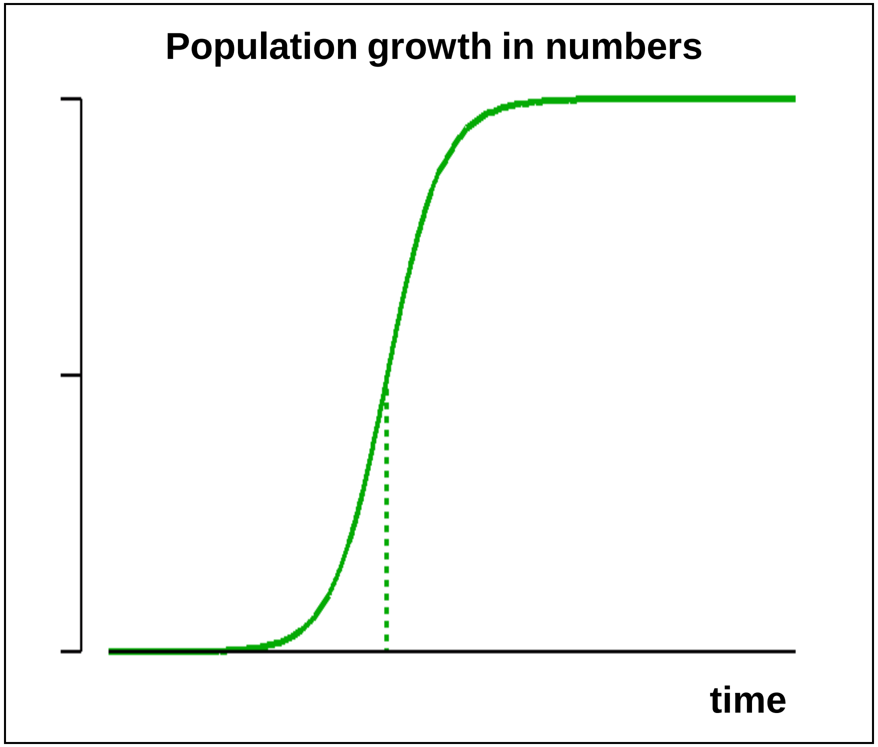
$$changes\ in\ biomass\ or\ yield = \frac{dB}{dt}\ or\ \frac{dY}{dt}$$

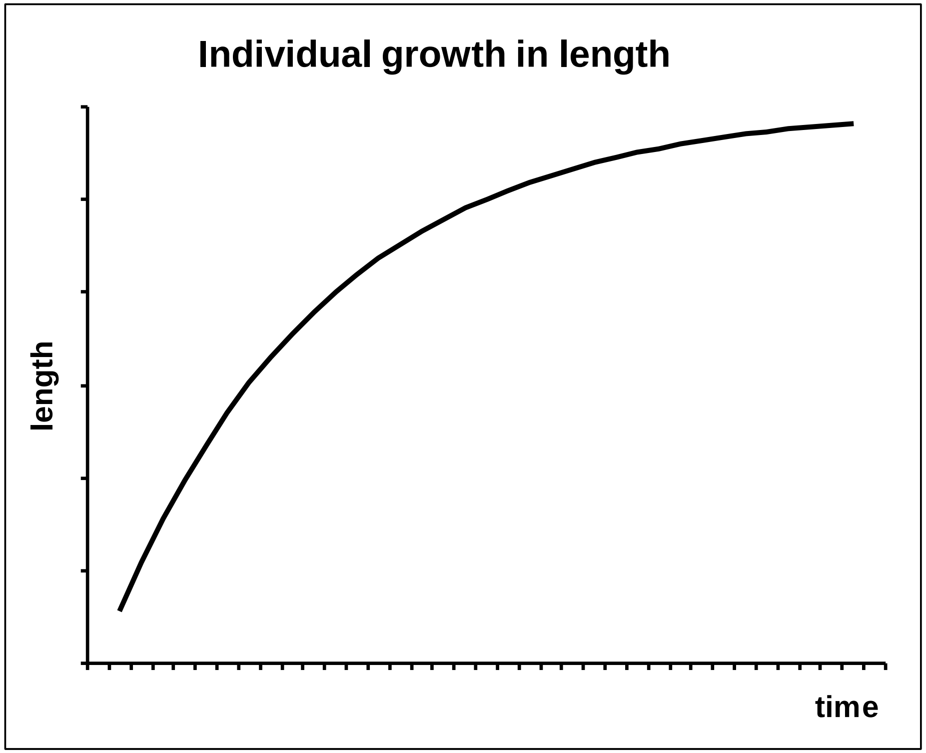
They are all values per time unit. We are working with rates. A measure of time is needed. Age or relative age of the fish is used to determine the time scale for the various processes.

Growth

There are two types of growth to be considered:

- Population growth in numbers or weight
- Individual growth in length or weight

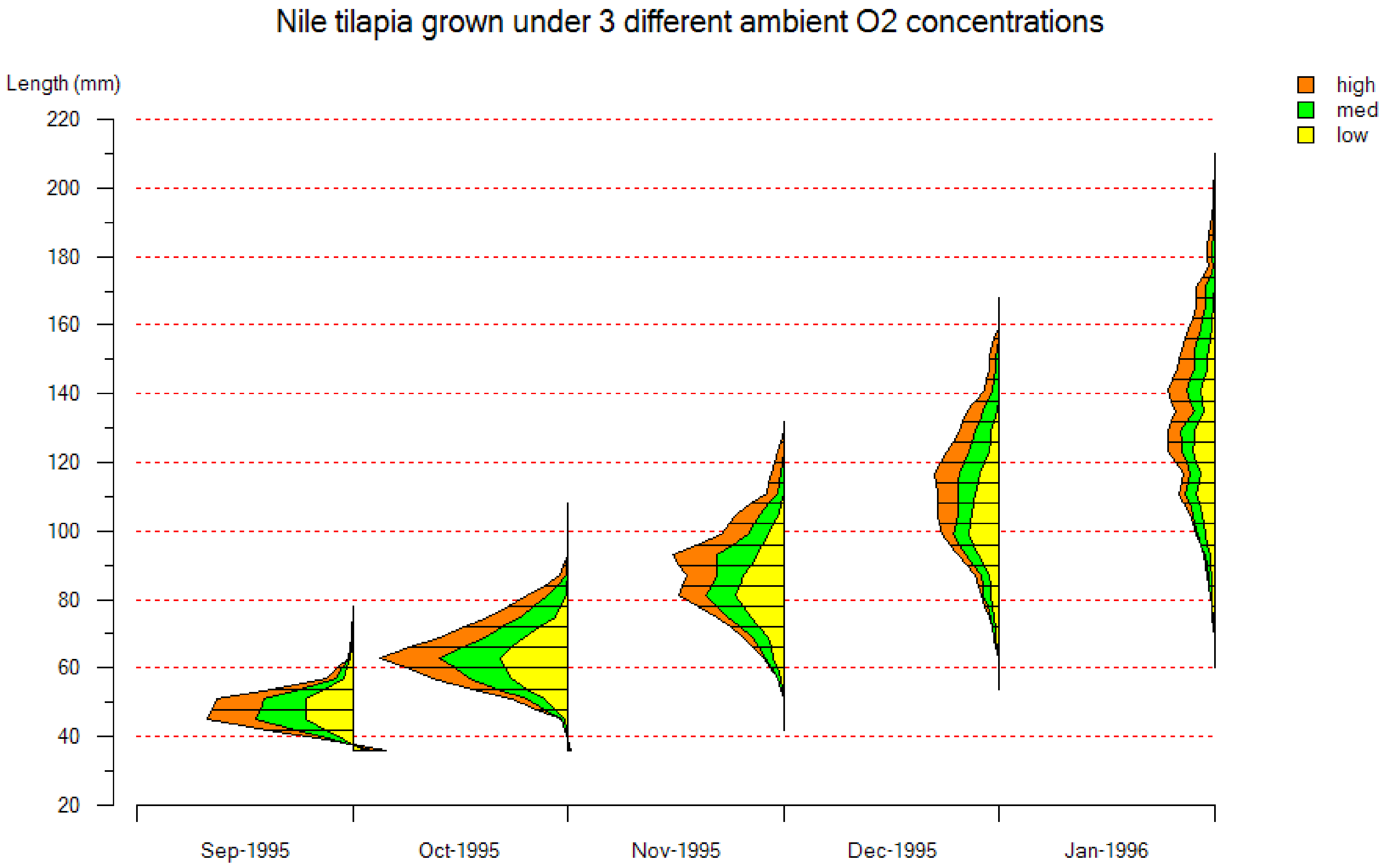




Growth

- Individual growth is within wide limits determined genetically, but is influenced by several factors:
- Environment
  - Food availability (quality/quantity)
  - Temperature (fish are poikilotherms)
  - Oxygen (very important limiting factor in water)
- Behaviour and biology
  - Variable allocation of surplus energy (somatic or gonadal tissue growth, locomotion or maintenance)
  - Sexual differences
  - Density and size distribution (hierarchical behaviour and/or competition)

Growth varies ..



Three approaches to ageing

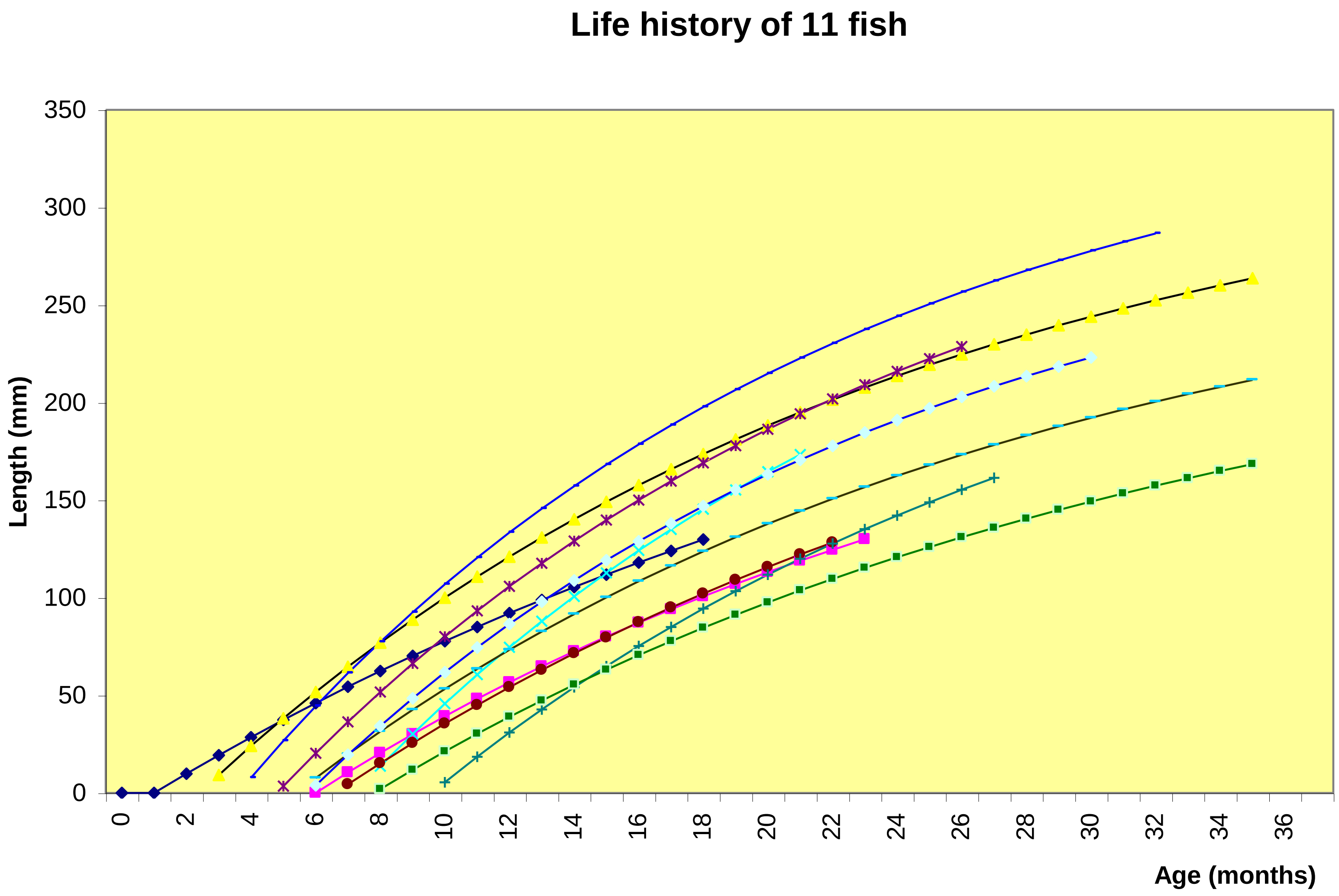
- Direct observations of individual fish, either held in confinement or from marking/recapture experiments.
- Ageing of individual fish based on annual patterns in hard structures e.g. otoliths, scales, bones etc.
- Identification of cohorts based on length frequency distributions from one or several samples representing a wide range of the population.

A cohort of fish

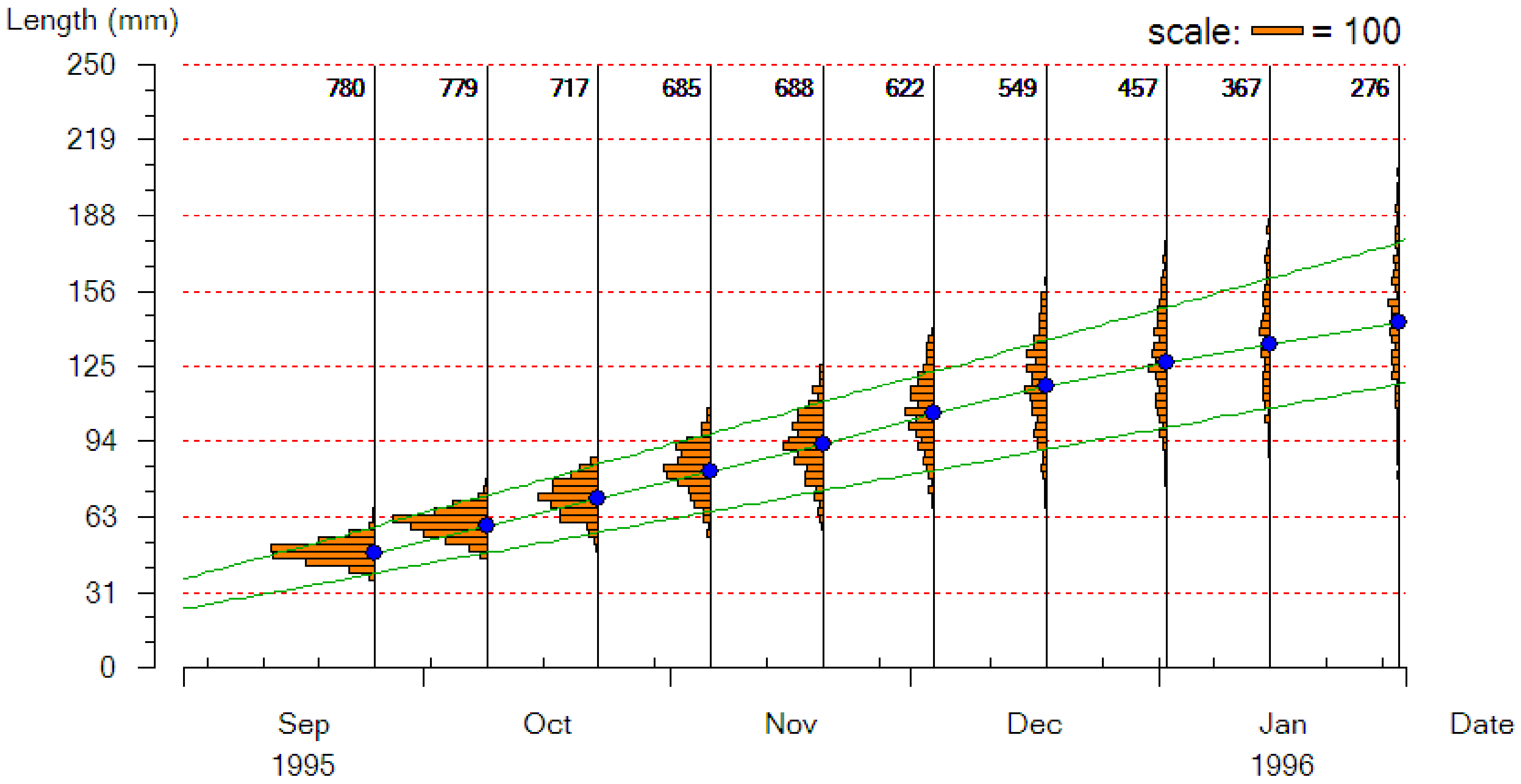
Age	Cohorts, number of survivors					
	1980	1981	1982	1983	1984	1985
0	**2435**	3456	2845	2010	1879	2456
1	679	**1336**	852	775	1103	981
2	1282	354	**733**	423	405	605
3	512	669	185	**403**	210	211
4	140	267	349	97	**221**	104
5	73	112	95	182	50	**121**

The 1980 Year-class in 6 age groups [0..5]

Birth and growth of a cohort

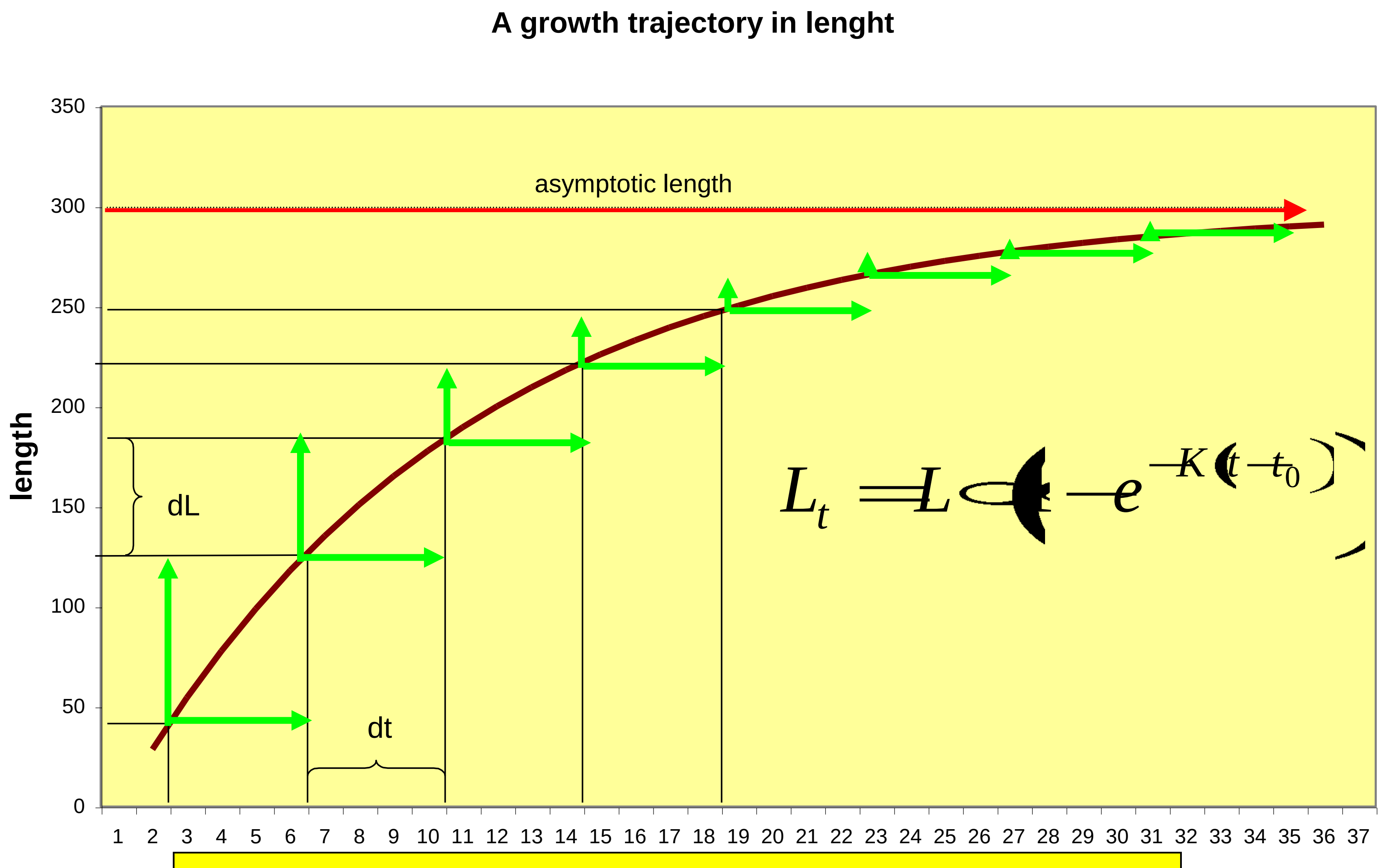


Growth



Observed length distributions and growth of a cohort of *Oreochromis niloticus* (Nile tilapia) born on August 3rd 1995

Von Bertalanffy Growth Function (VBGF):



$$L_t = L_\infty\left(1 - e^{-K(t - t_0)}\right)$$

the increase in length is a function of length

Growth and VBGF

- The increase in length is a function of length:

$$\frac{dL}{dt} = a - b \cdot L_t$$

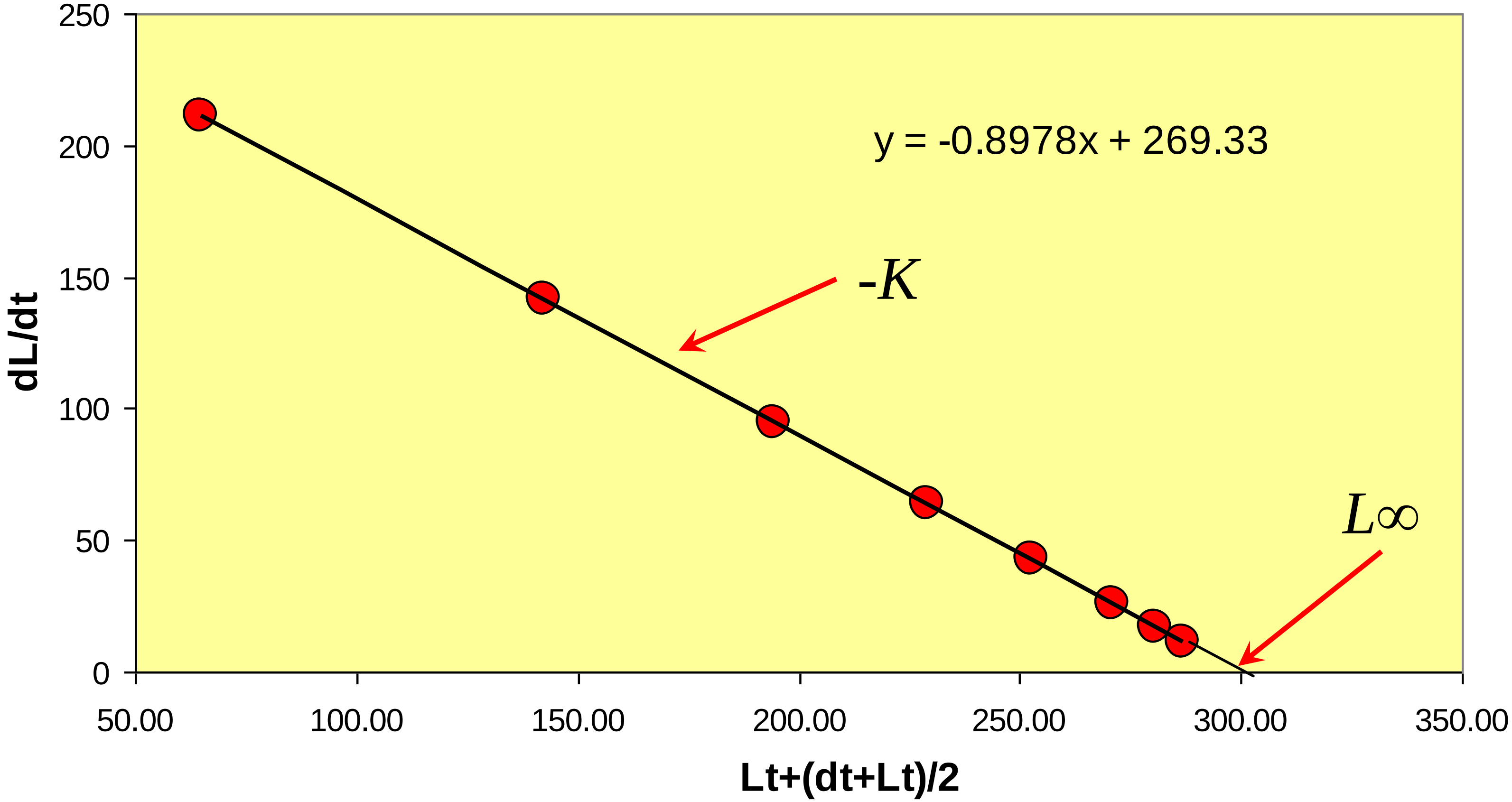
Von Bertalanffy Growth Function (VBGF):

$$\frac{dL}{dt} = a + b \cdot \bar{L}_t$$

$$a = K \cdot L_\infty$$
$$b = -K$$

$$\frac{dL}{dt} = K \cdot (L_\infty - \bar{L}_t)$$

dL/dt as a function of mean lenght



Von Bertalanffy Growth Function (VBGF):

$$\frac{dL}{dt} = K\,(L_\infty - L_t)$$

This equation can be integrated to the VBGF:

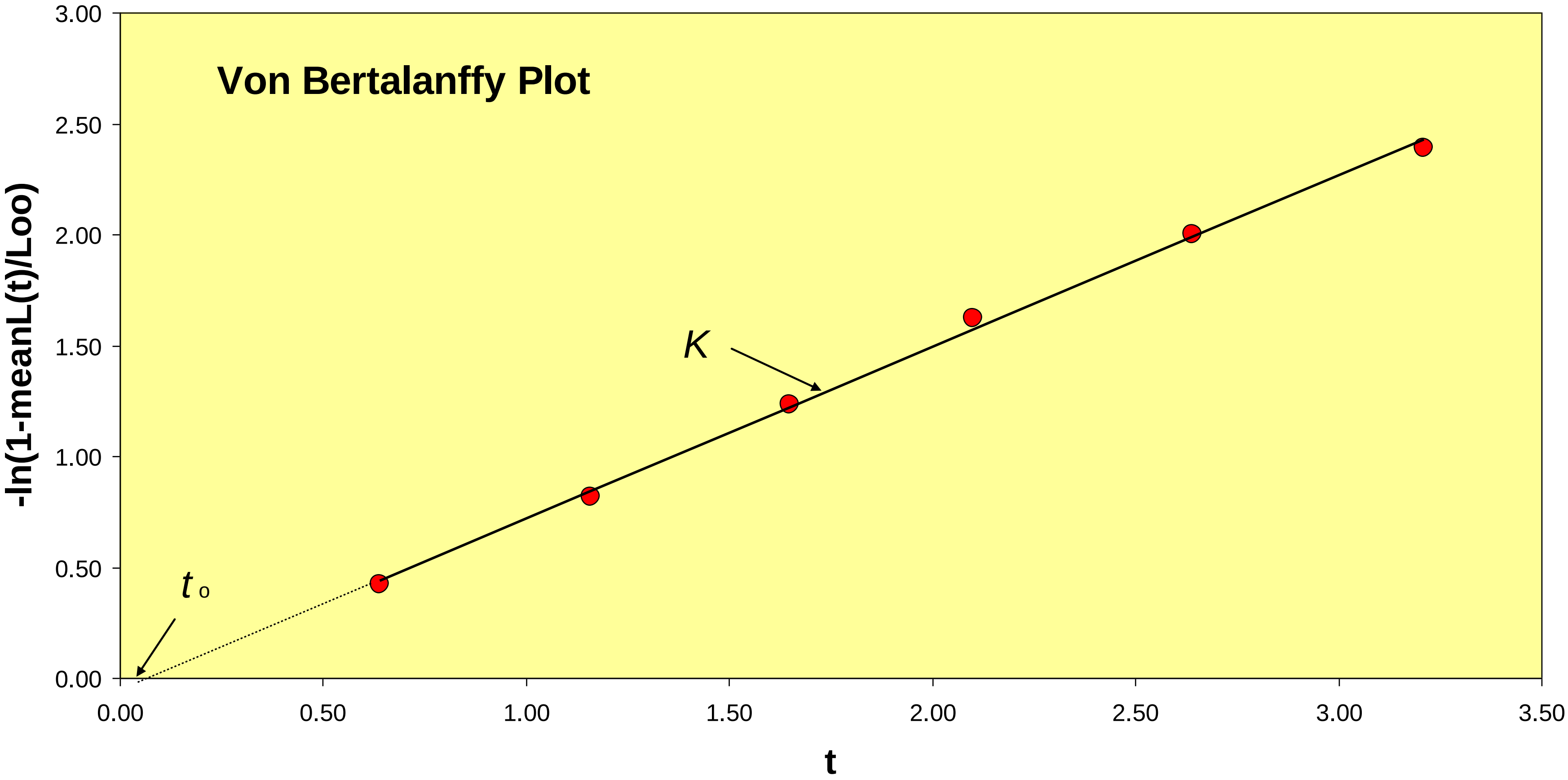
$$L_t = L_\infty\left(1 - e^{-K(t - t_0)}\right)$$

One new parameter t_0:

Also called the ‘initial condition factor’. It gives the start of the curve, i.e. the time where the theoretical length is zero

$$t_0 = \frac{1}{K}\ln\left(\frac{L_\infty - L_t}{L_\infty}\right) - t$$

Estimating t_o



Linear regression: $-\ln\left(1-\frac{\bar{L}_t}{L_\infty}\right) = a + bt$

$K = b$

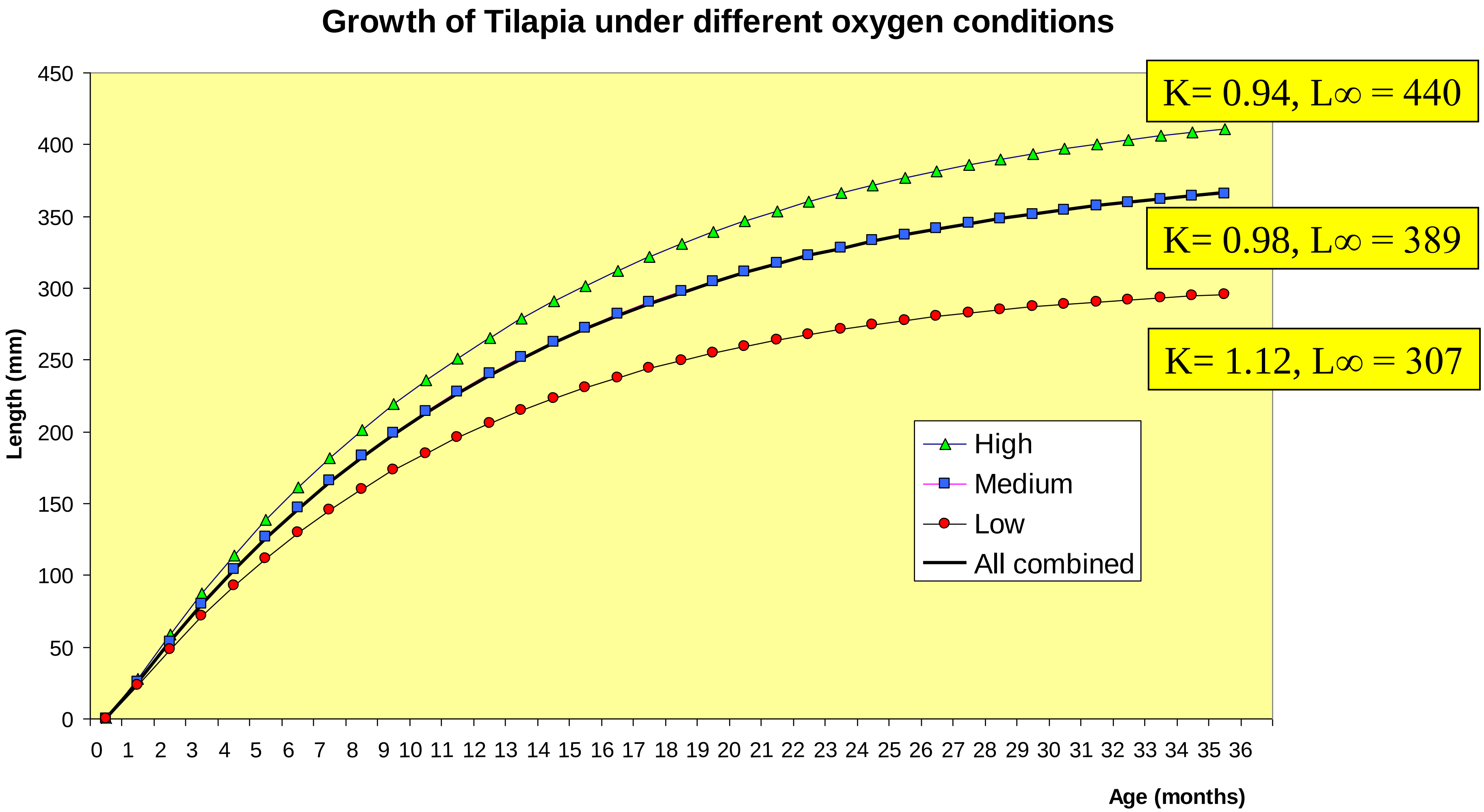
$t_0 = -\frac{a}{b}$

K and L∞

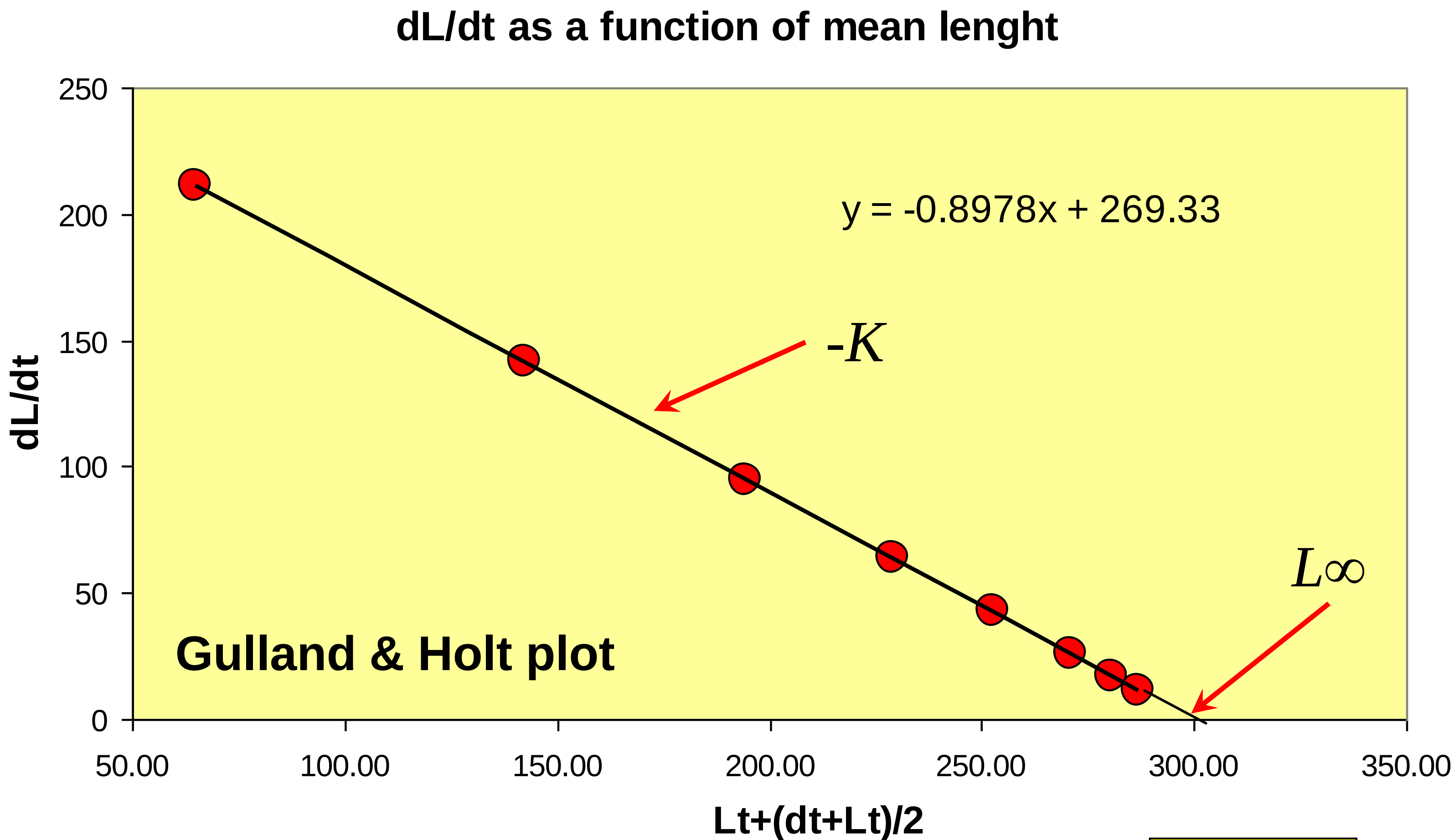
- *L∞* is called "*L-infinity*" or the "asymptotic length", representing the maximum length of an infinitely old fish of the given stock. *L∞* can be estimated from graphical plots, or it can be approximated by the mean of a selection of the biggest specimens recorded from the population, or the relation $L\infty \approx$ Lmax/0.95.
- *K* is called the "*curvature parameter*". It determines how fast the growth is **relative** to *L∞*, i.e. how fast the fish reaches its maximum size. An estimate of *K* is calculated from the slopes of the different graphical plots. Note that *K* **is not** a growth rate as it has the unit ‘per time’ only.
- Different *K*’s cannot be compared when *L∞* is also different!

K and L∞

K and L∞ are inversely related



Estimating K and L∞

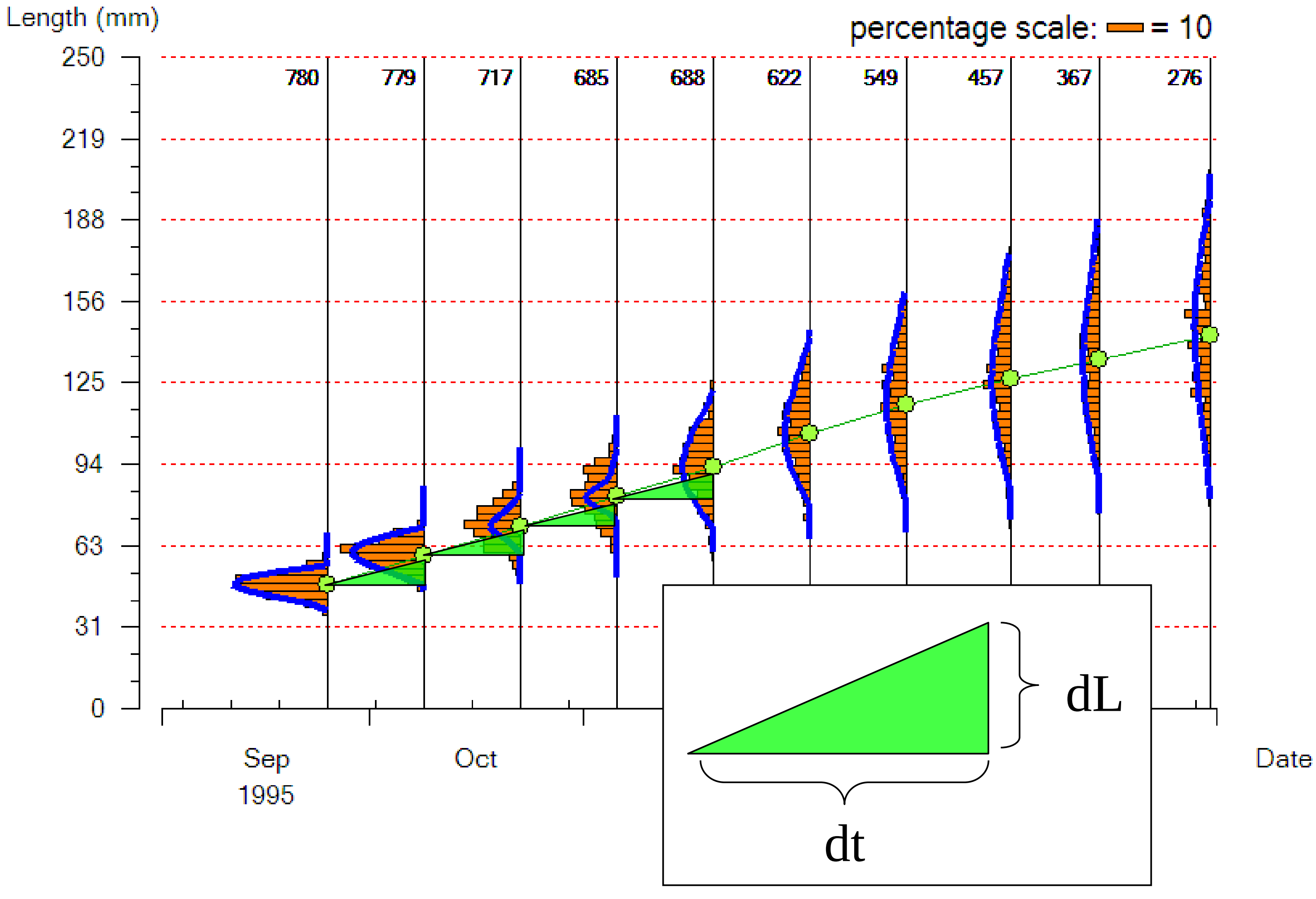


Linear regression: $$\frac{dL}{dt} = a - b \cdot \bar{L}_t$$

$$K = -b$$

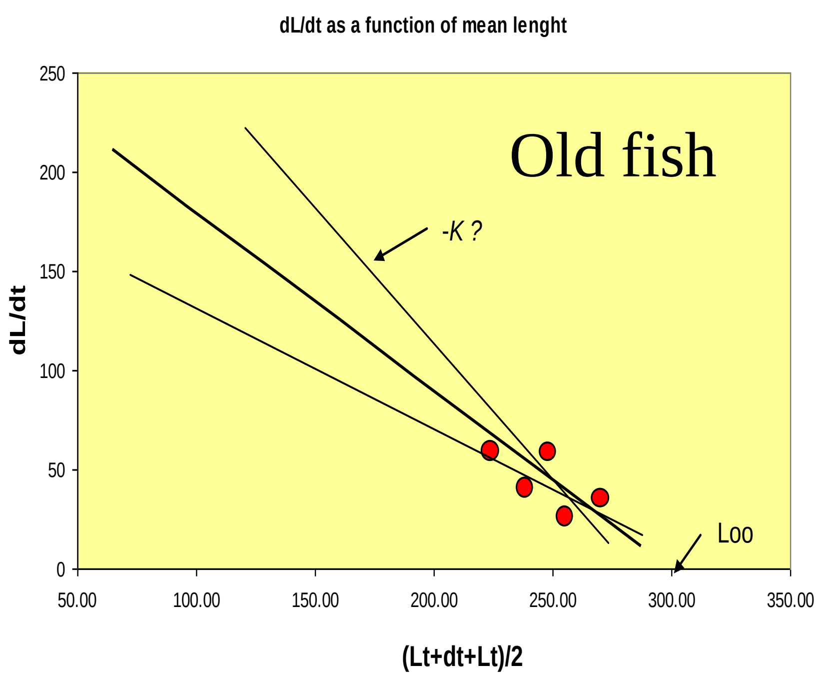
$$L_\infty = -\frac{a}{b}$$

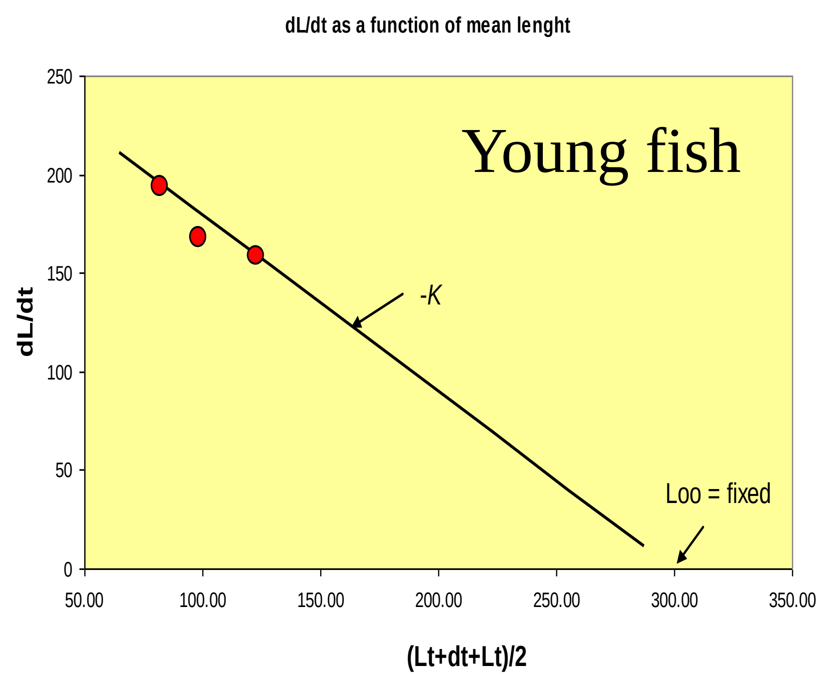
Getting dL/dt and mean length



Estimating K and L∞

Practical hints: Use young fish!!





Gulland & Holt Plot:

$$K = -b$$

Linear regression:

$$\frac{dL}{dt} = a - b\left(\frac{L_t + L_{t+dt}}{2}\right)$$

$$L_\infty = -\frac{a}{b}$$

Relative age and t_0

- In most length-based stock assessment models absolute age is not used, only in relative age. When computing the time it takes to grow from L_1 to L_2 we use the *inverse* VBGF:

$$t_L = -\frac{1}{K}\ln\left(\frac{L_\infty - L_t}{L_\infty}\right) + t_0$$

- Subtracting two such equations in order to find the time interval between L_1 and L_2 will give

$$\Delta t_{L_2 - L_1} = \frac{1}{K}\ln\left(\frac{L_\infty - L_1}{L_\infty - L_2}\right)$$

t_0 no longer used

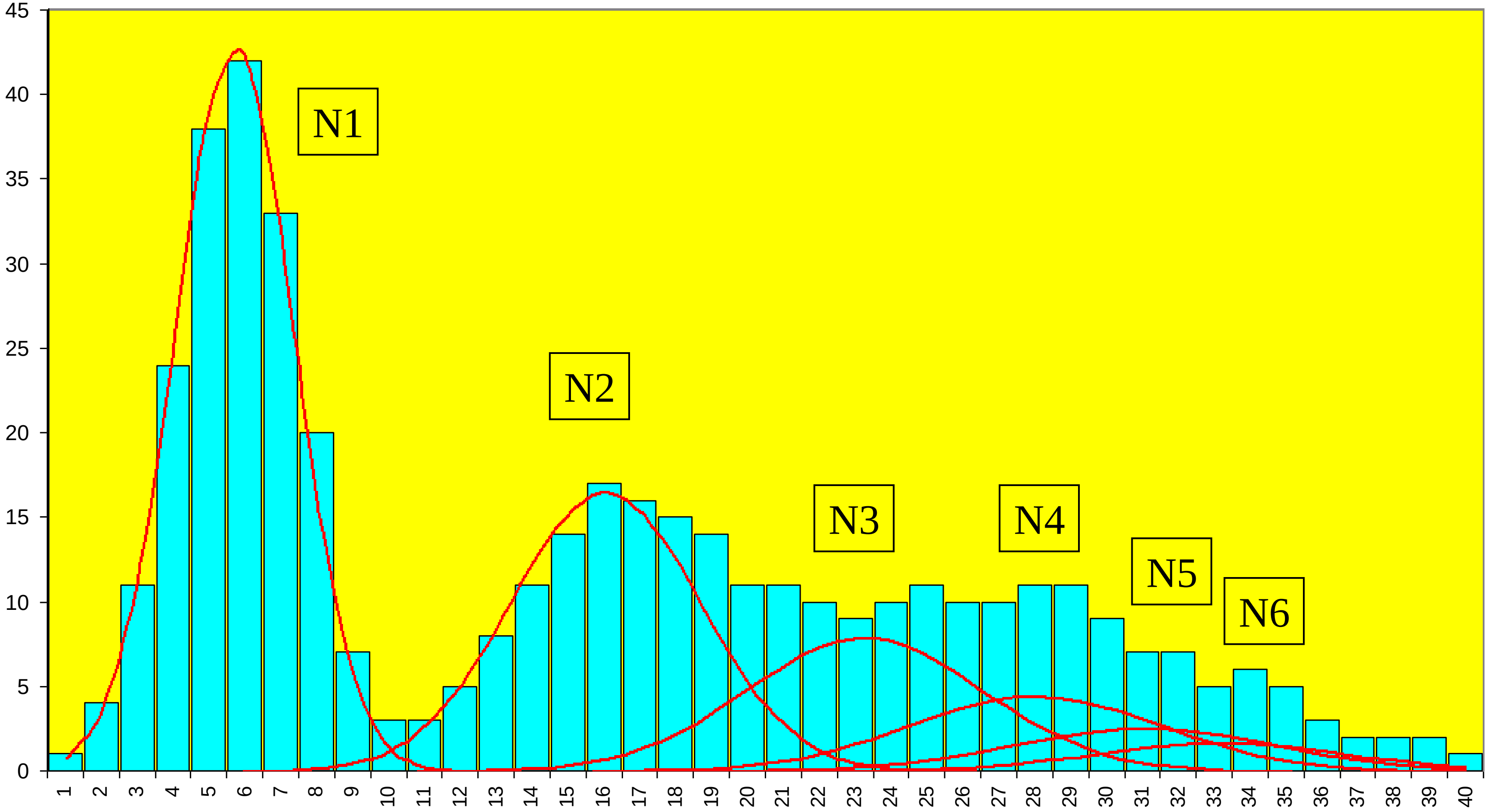
Length frequency analysis
- composite cohorts

		Cohorts, number of survivors					
		1980	1981	1982	1983	1984	1985
Age	0	2435	3456	2845	2010	1879	2456
	1	679	**1336**	852	775	1103	981
	2	1282	354	**733**	423	405	605
	3	512	669	185	**403**	210	211
	4	140	267	349	97	**221**	104
	5	73	112	95	182	50	**121**

The 1980 Year-class in 6 age groups [0..5]

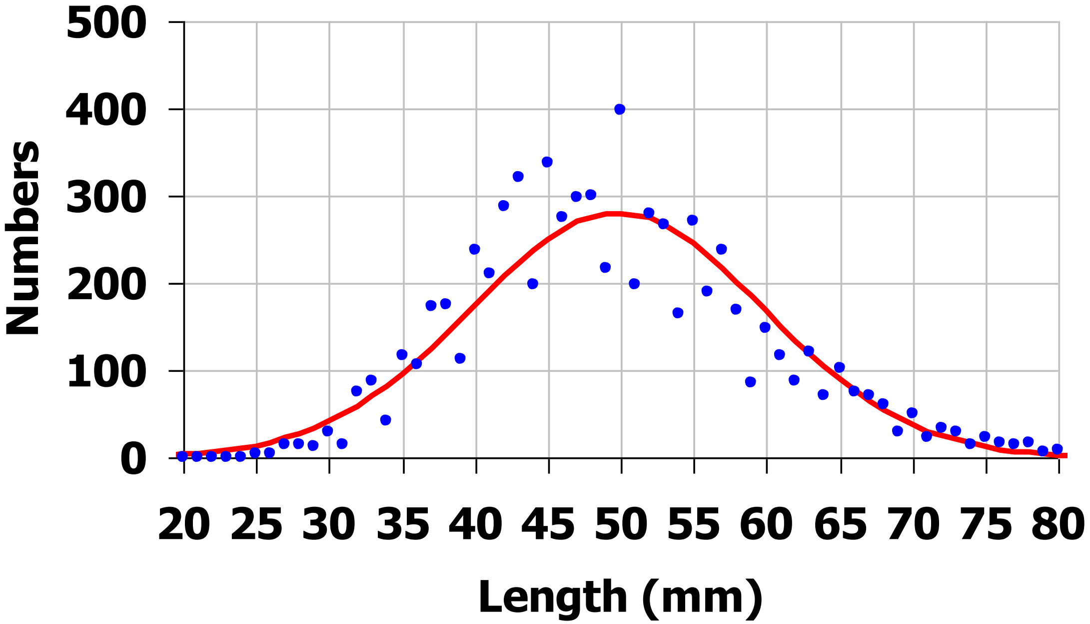
Length frequency analysis

Composite lenght frequency distribution - how many cohorts?



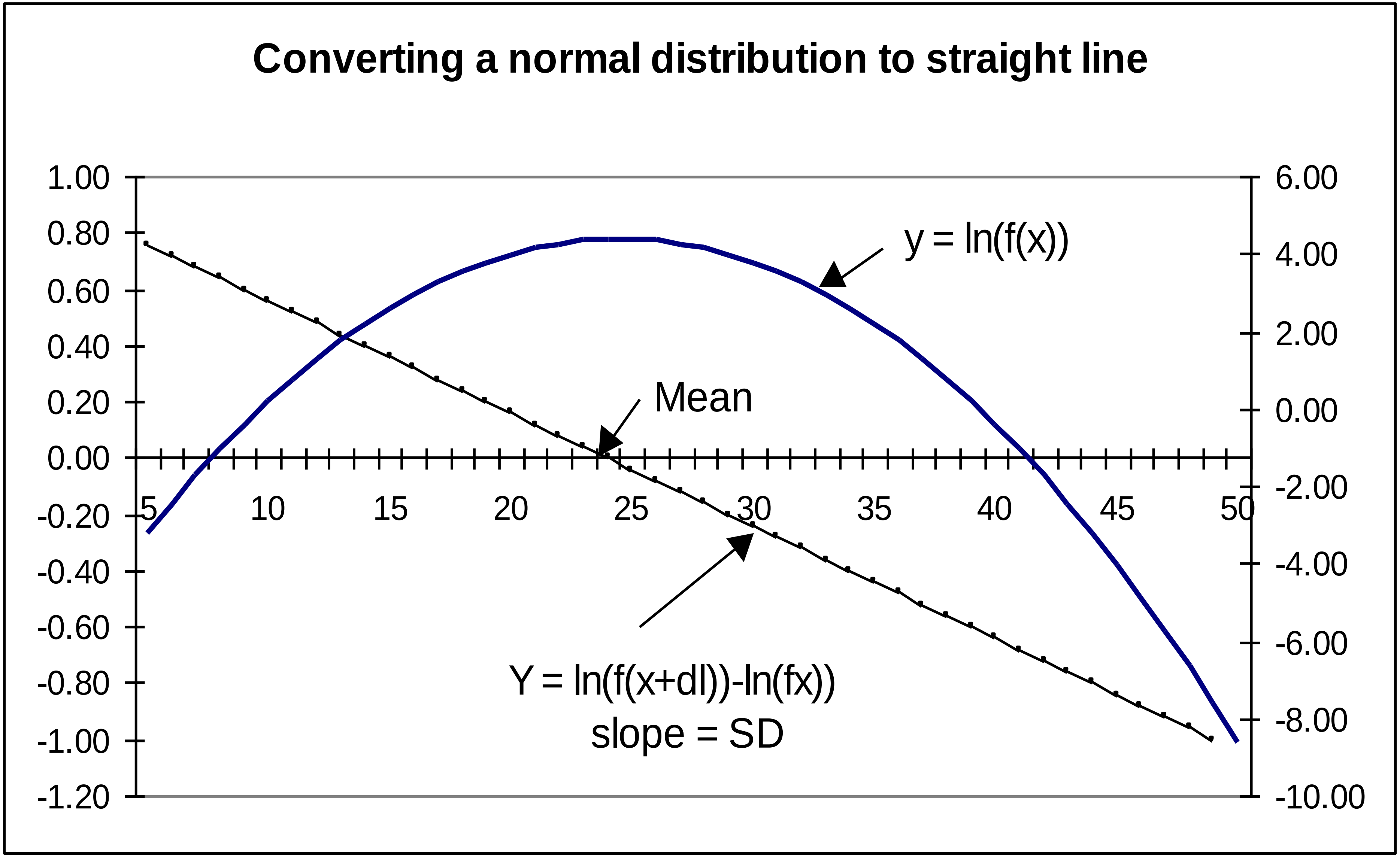
The normal distribution

$$n_{L_i} = \mathrm{n} \cdot \mathrm{d}_{\mathrm{L_i}} \; \frac{1}{s\sqrt{2\pi}} e^{\left(-\frac{1}{2}\left(\frac{X_i - \bar{X}}{s}\right)^2\right)}$$



- Described by 3 parameters:
  - – n (number)
  - – s (SD)
  - – $\bar{X}$ (mean)

Bhattacharya method

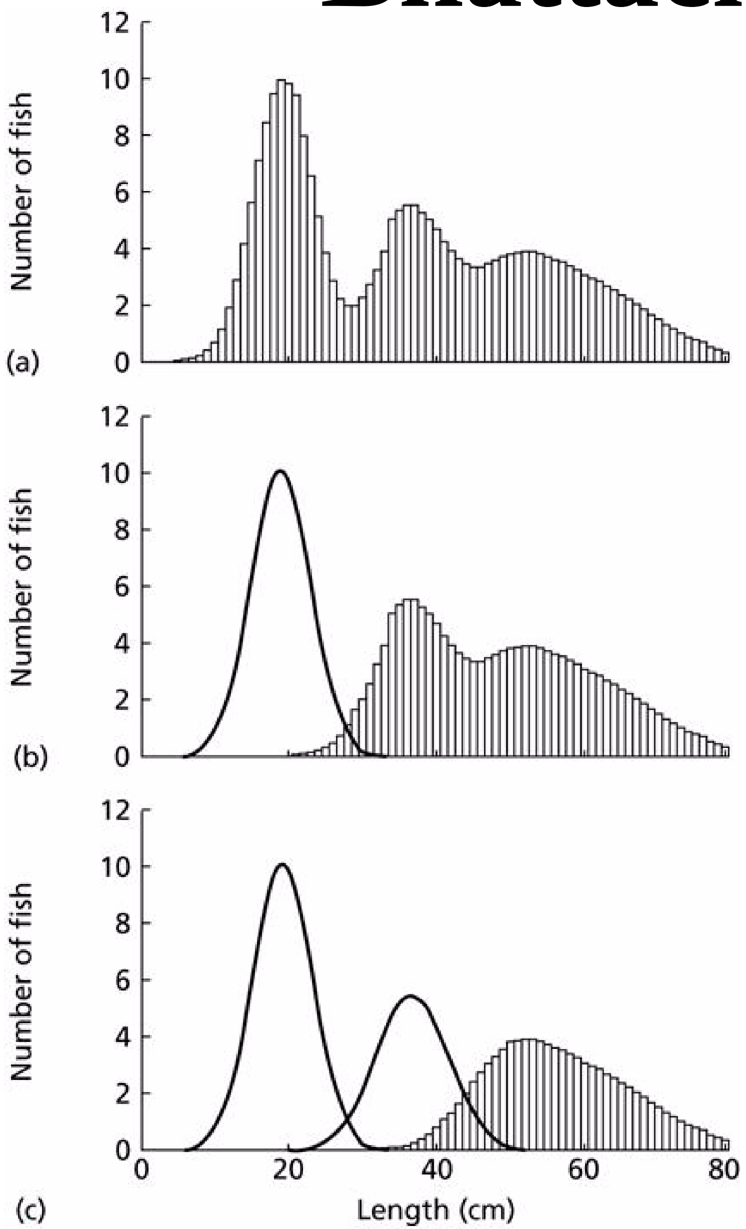


Bhattacharya method

Based on:

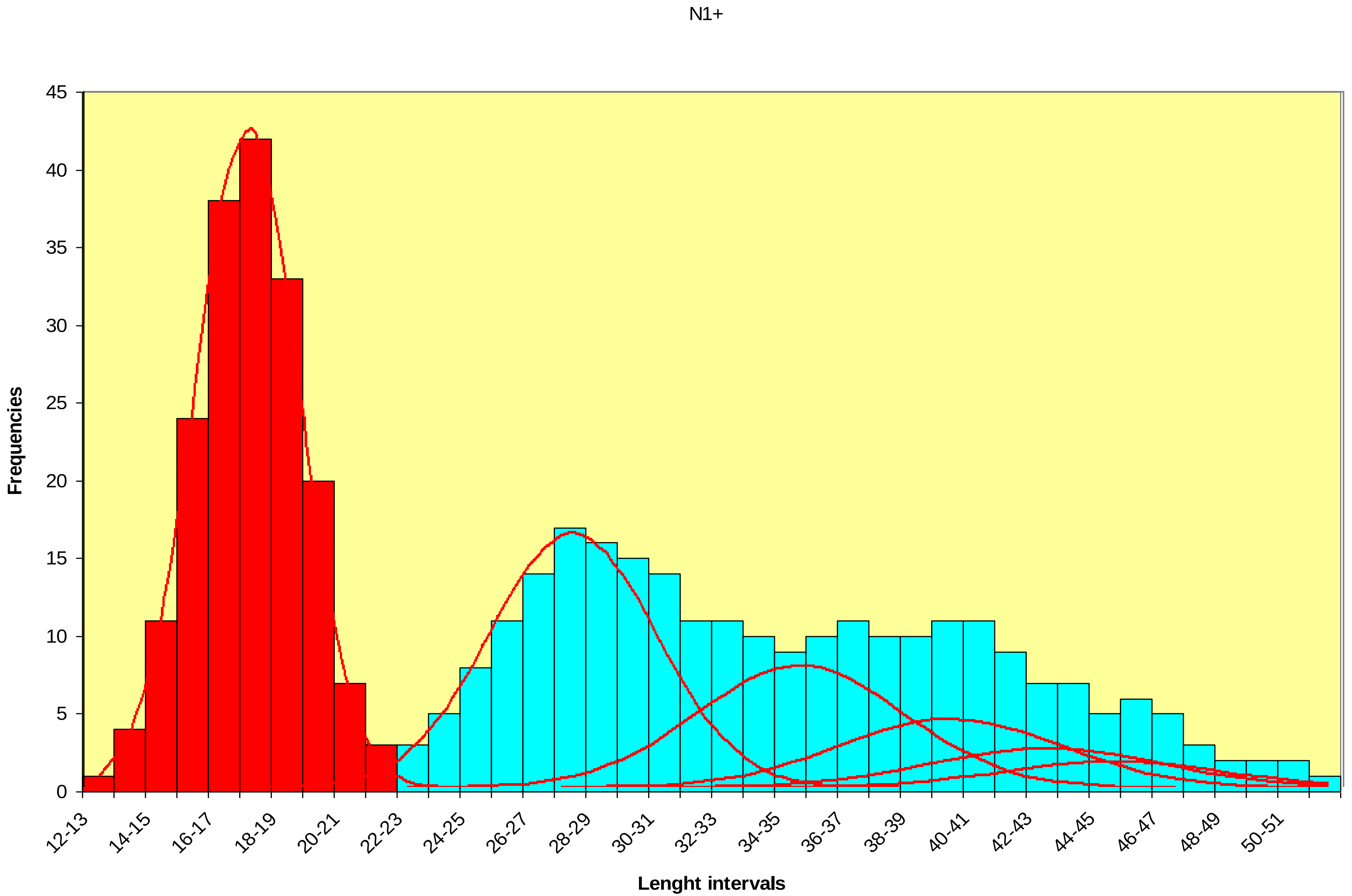
- Assumed normal distributions of the components in a composite length frequency distribution.
- Transformation of the normal distributions into straight lines.
- Calculation of N, $\bar{x}$, and SD by regression analysis.

Bhattacharya method



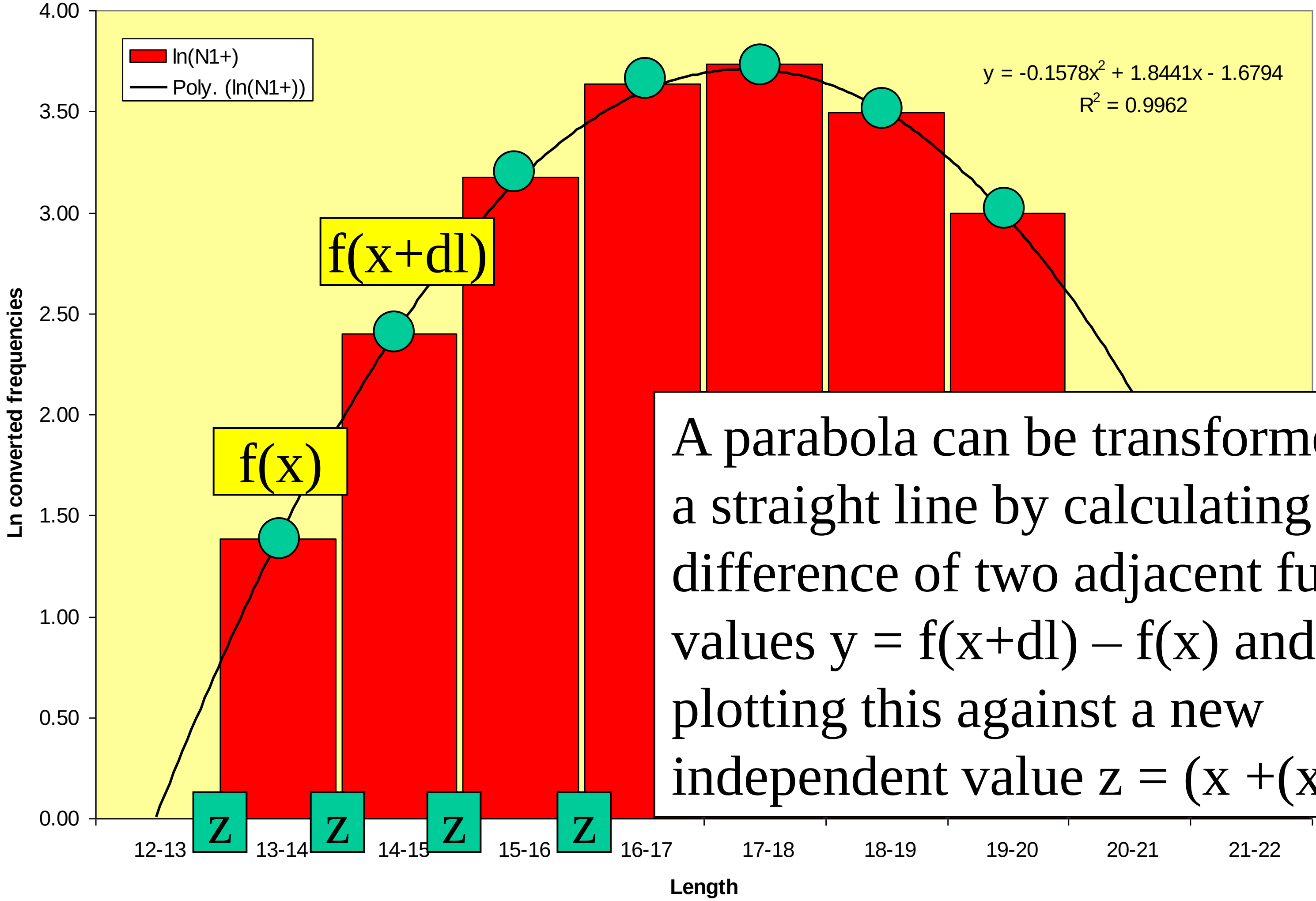
- From a composite length-frequency distribution (a)
- Identify, separate and remove one cohort at a time starting from the left (b, c)
- Each cohort is identified by transforming the ‘normal’ distribution into a straight line and find mean and SD by regression

Bhattacharya method



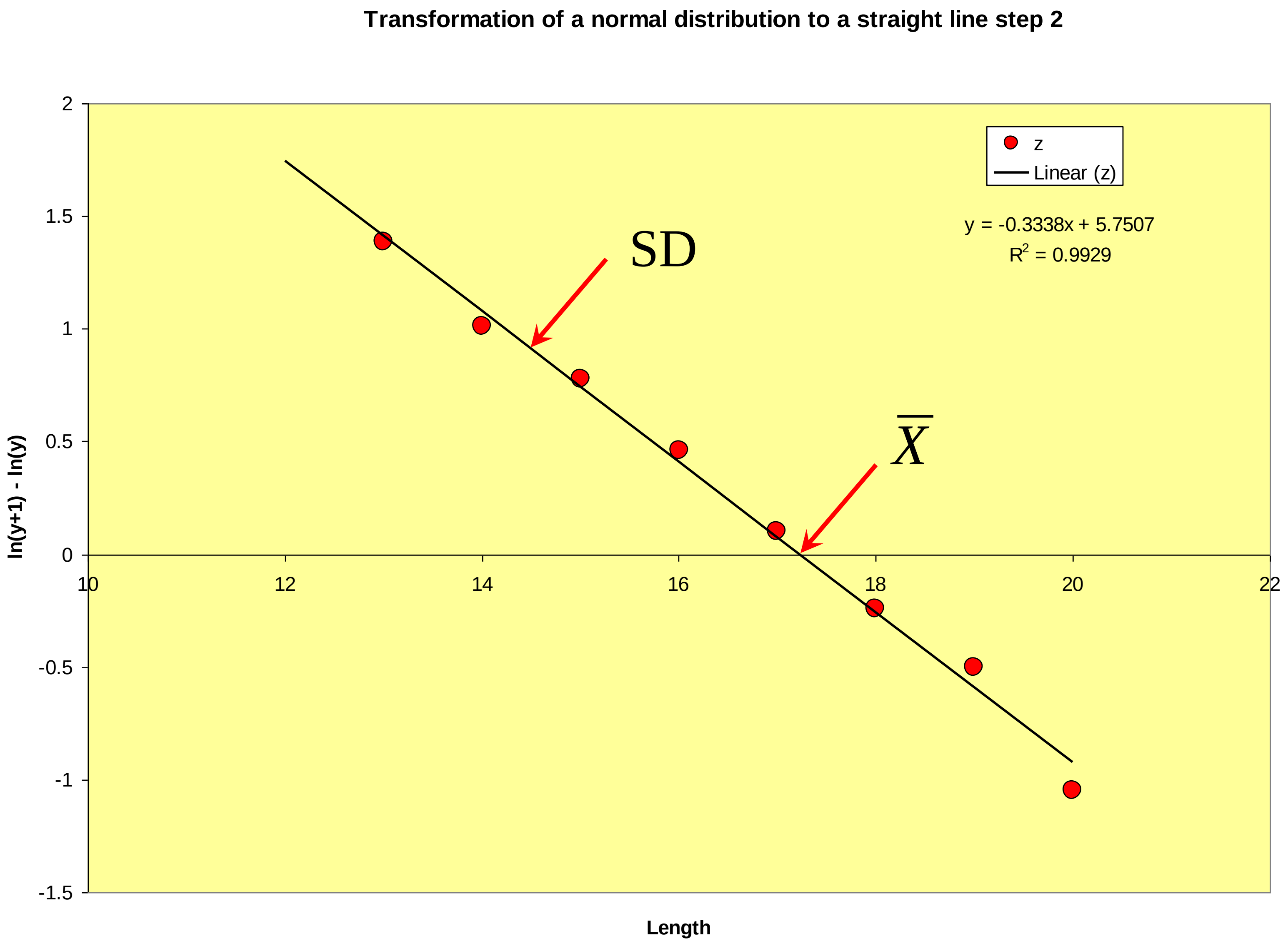
Bhattacharya method – step 1

Taking natural logarithm (ln) of the function will make a parabola



A parabola can be transformed into a straight line by calculating the difference of two adjacent function values y = f(x+dl) – f(x) and plotting this against a new independent value z = (x +(x+dl))/2

Bhattacharya method – step 2



Bhattacharya method – step 3

- From the linear regression coefficients we can now calculate the expected function values

$$Y = a - bX$$

- Use this to back-calculate the expected normal distribution of the cohort in the area of the composite distribution where there is overlap with the next cohort

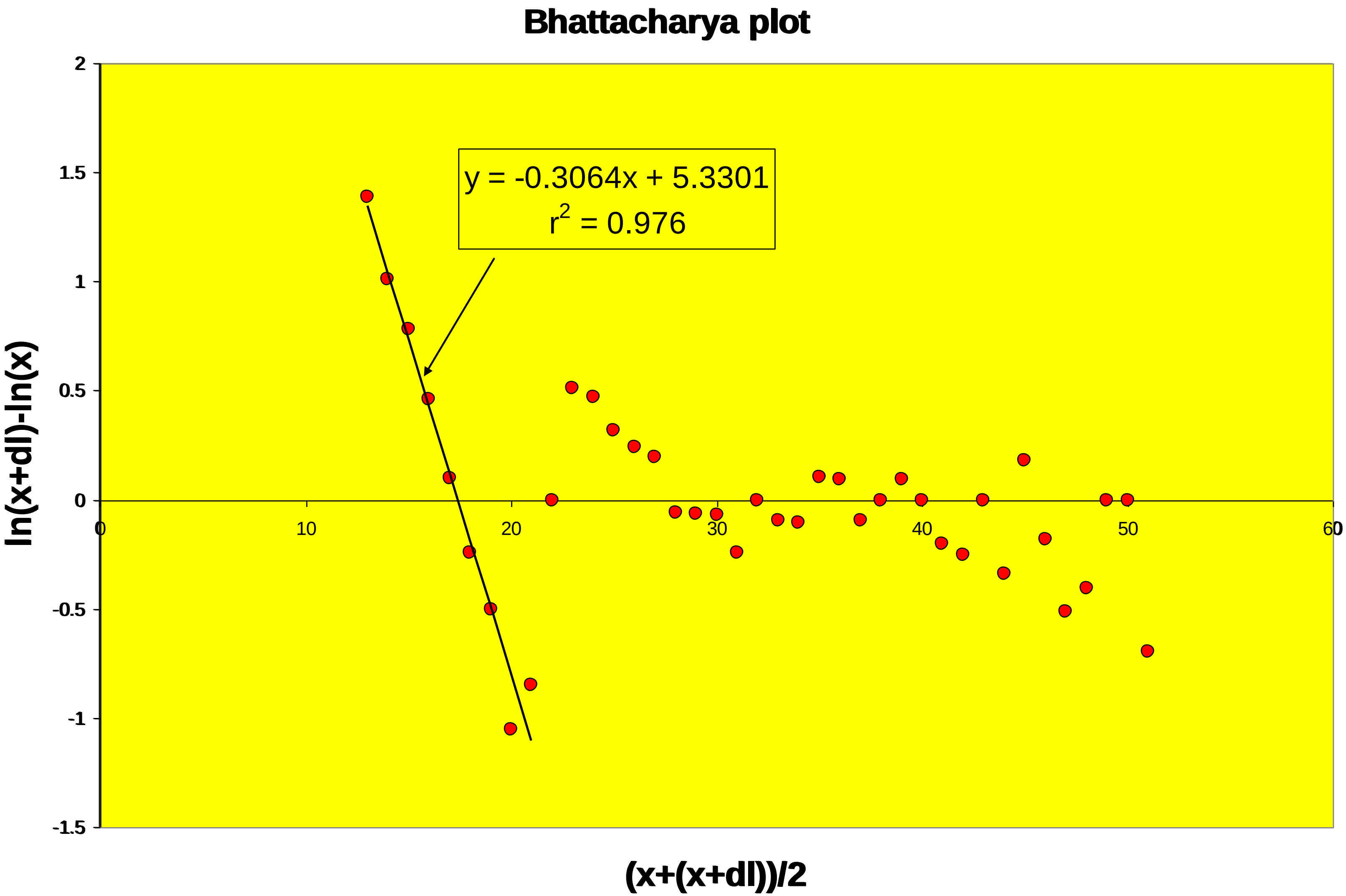
Bhattacharya in Excel

regression

Observation | Parabola | Y-values | X-values

A	B	C	D	E	F	G	H	I
Length(x)	N1+	ln(N1+)	ln(x+1)-ln(x)	z	Calculated	ln(N1)	N1	N2+
12-13	1	0.00		12				
13-14	4	1.39	1.39	13				
14-15	11	2.40	1.01	14				
15-16	24	3.18	0.78	15				
16-17	38	3.64	0.46	16				
17-18	42	3.74	0.10	17				
18-19	33	3.50	-0.24	18				
19-20	20	3.00	-0.50	19				
20-21	7	1.95	-1.05	20				
21-22	3	1.10	-0.85	21				
22-23	3	1.10	0.00	22				
23-24	5	1.61	0.51	23				
24-25	8	2.08	0.47	24				
25-26	11	2.40	0.32	25				
26-27	14	2.64	0.24	26				
27-28	17	2.83	0.19	27				
28-29	16	2.77	-0.06	28				
29-30	15	2.71	-0.06	29				
30-31	14	2.64	-0.07	30				
31-32	11	2.40	-0.24	31				

Bhattacharya plot



Bhattacharya in Excel

regression (Y-values, X-values) → Predicted

Go backwards (Parabola, N1 isolated)

	Observation	Parabola	Y-values	X-values	Predicted	Parabola	N1 isolated	Substract N1
A	B	C	D	E	F	G	H	I
Length(x)	N1+	ln(N1+)	ln(x+1)-ln(x)	z	Calculated	ln(N1)	N1	N2+
12-13	1	0.00		12	y = a+b*z		1	0
13-14	4	1.39	1.39	13	1.35		4	0
14-15	11	2.40	1.01	14	1.04		11	0
15-16	24	3.18	0.78	15	0.73		24	0
16-17	38	3.64	0.46	16	0.43	3.64	38	0
17-18	42	3.74	0.10	17	0.12	3.76	42.90	-0.90
18-19	33	3.50	-0.24	18	-0.19	3.57	35.65	-2.65
19-20	20	3.00	-0.50	19	-0.49	3.08	21.81	-1.81
20-21	7	1.95	-1.05	20	-0.80	2.28	9.82	-2.82
21-22	3	1.10	-0.85	21	-1.10	1.18	3.25	-0.25
22-23	3	1.10	0.00	22	-1.41	-0.23	0.79	2.21
23-24	5	1.61	0.51	23	-1.72	-1.95	0.14	4.86
24-25	8	2.08	0.47	24	-2.02	-3.97	0.02	7.98
25-26	11							11
26-27	14							14
27-28	17							17
28-29	16							16
29-30	15							15
30-31	14							14
31-32	11	2.40	-0.24	31				11

'clean'

A clean value is one that does not overlap with the next cohort

Limitations to length-frequency analysis

- It is can difficult to separate the components of a composite frequency distribution.
  - In the older parts where the overlaps become increasingly bigger.
  - If continuous spawning (cohorts not discrete)
- To assess the reliability of resolving the components a separation index has been introduced (it is an automatic feature in the Bhattacharya method implemented in FiSAT)

$$I = \frac{\bar{L}_{a+1} - \bar{L}_a}{\left(SD_{a+1} + SD_a\right)/2}$$

If the separation index (I) is less than 2 it is more or less impossible to properly separate the two components

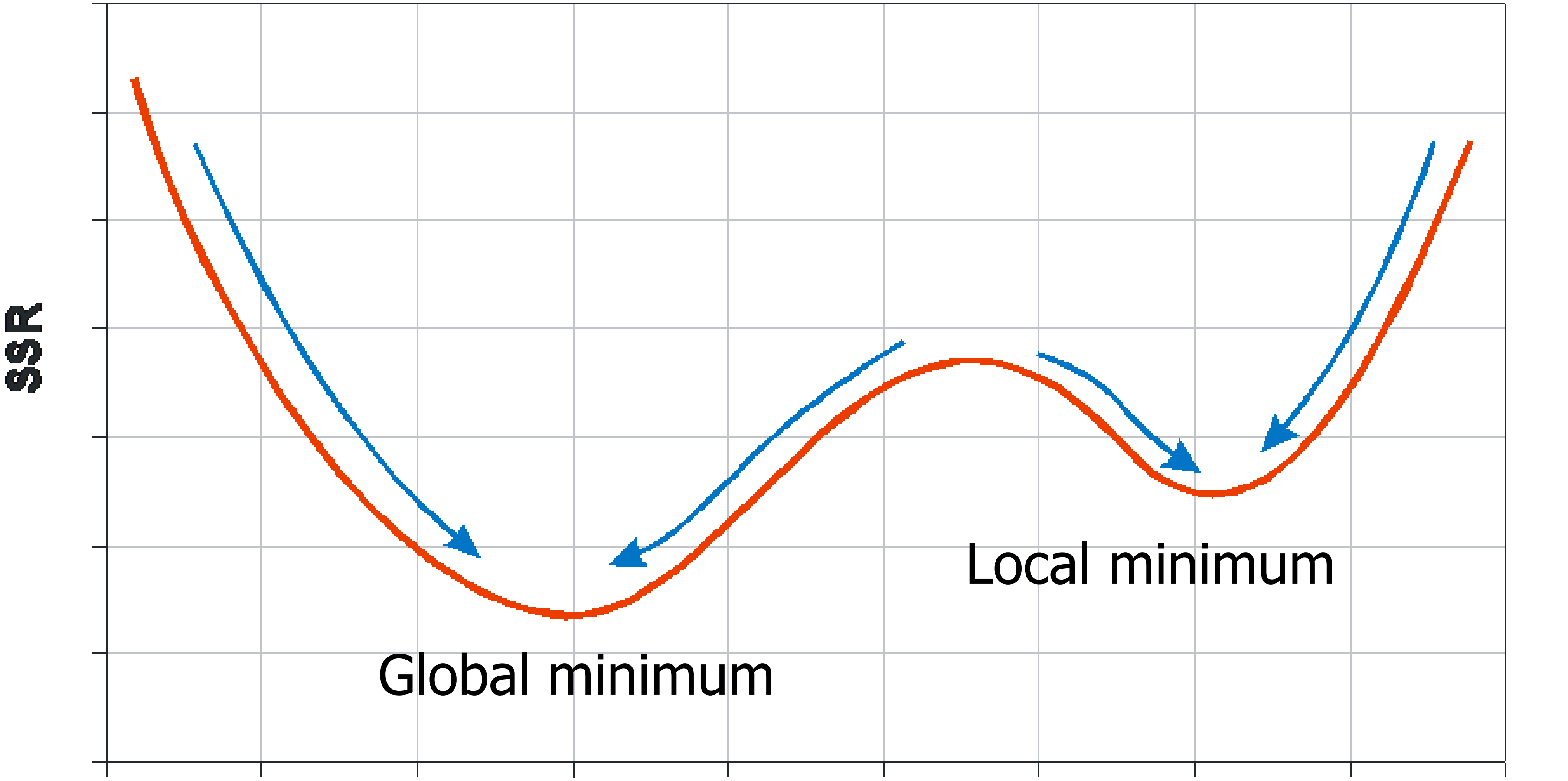
Computerised versions of length frequency analysis

- ELEFAN (Electronic LEngth Frequency ANalysis) developed by Pauly & David (1981) and with later refinements and extensions (ELEFAN I..IV). (BASIC)
- LFSA (Length Frequency Stock Assessment) developed by P. Sparre (1987a) (BASIC).
- The MAXIMUM-LIKELIHOOD-METHOD: NORMSEP developed by Tomlinson (1971) and later extensions and modifications by MacDonald & Pitcher (1979), Schnute & Fournier (1980) and Sparre (1987b). (FORTRAN)
- FiSAT (FAO/ICLARM Stock Assessment Tools) (Gayanilo and Pauly 1997) is a package combining ELEFAN and LFSA together with additional features and a more user friendly interface. FiSAT is now available in upgraded Windows version

ELEFAN and FiSAT

- Automatic search routine (works like Solver) un restructured length-frequency data
- Requires reasonable input (seed) values to avoid local minima
- Has a reputation for overestimating $L\infty$
- Good tool if used with critical precaution

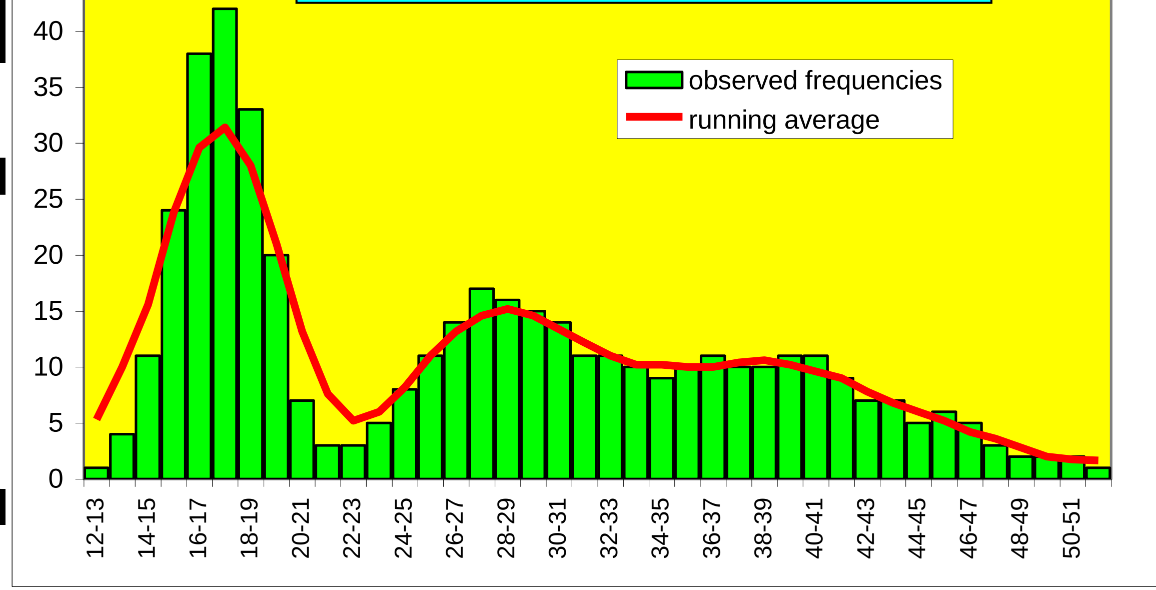
Local minima in automatic search routines

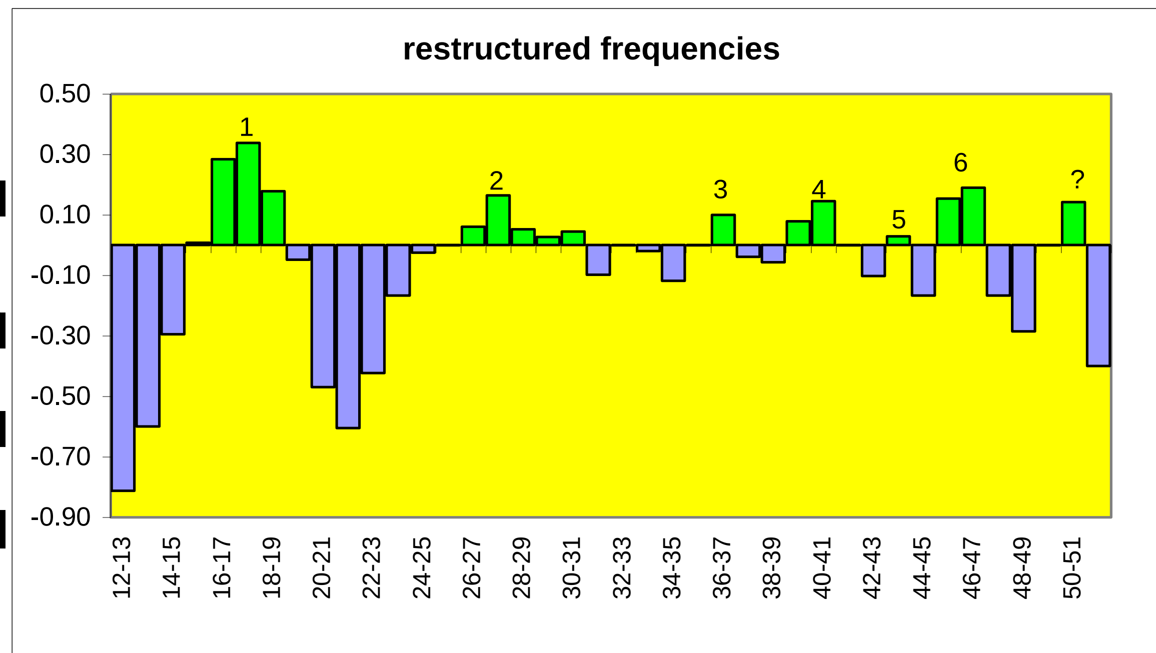


The restructuring principles of ELEFAN

Length(x)	x	running average	restructured values	ASP= 2.00
12-13	1	5.3	-0.81	TRUE mean
13-14	4	10.0	-0.60	
14-15	11	15.6	-0.29	
15-16	24	23.8	0.01	
16-17	38	29.6	0.28	
17-18	42	31.4	0.34	17.3
18-19	33	28.0	0.18	
19-20	20	21.0	-0.05	
20-21	7	13.2	-0.47	
21-22	3	7.6	-0.61	
22-23	3	5.2	-0.42	
23-24	5	6.0	-0.17	
24-25	8	8.2	-0.02	
25-26	11	11.0	0.00	
26-27	14	13.2	0.06	
27-28	17	14.6	0.16	27.9
28-29	16	15.2	0.05	
29-30	15	14.6	0.03	
30-31	14	13.4	0.04	
31-32	11	12.2	-0.10	
32-33	11	11.0	0.00	
33-34	10	10.2	-0.02	
34-35	9	10.2	-0.12	
35-36	10	10.0	0.00	
36-37	11	10.0	0.10	35.3
37-38	10	10.4	-0.04	
38-39	10	10.6	-0.06	
39-40	11	10.2	0.08	
40-41	11	9.6	0.15	40.2
41-42	9	9.0	0.00	
42-43	7	7.8	-0.10	
43-44	7	6.8	0.03	43.3
44-45	5	6.0	-0.17	
45-46	6	5.2	0.15	
46-47	5	4.2	0.19	45.5
47-48	3	3.6	-0.17	
48-49	2	2.8	-0.29	
49-50	2	2.0	0.00	
50-51	2	1.8	0.14	

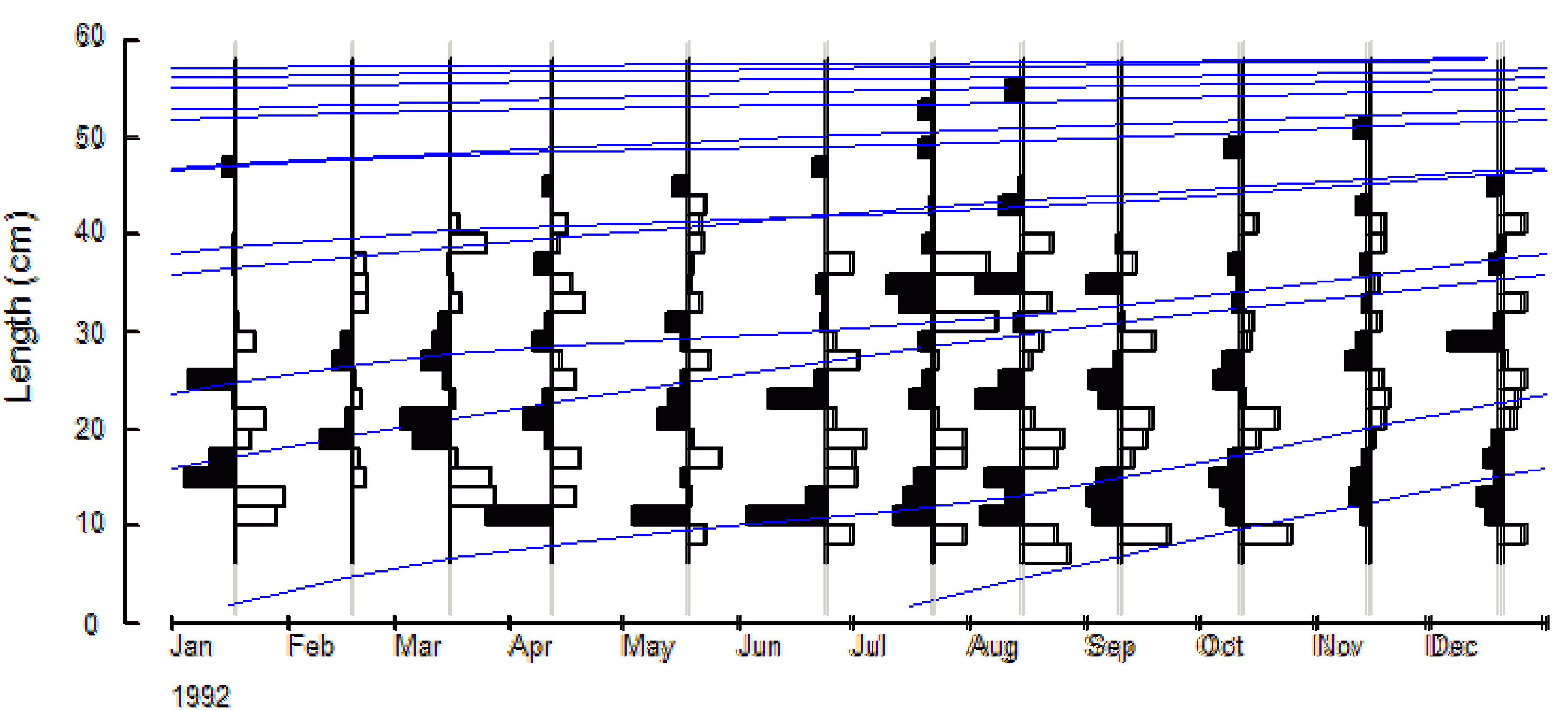
=(x/running average) - 1





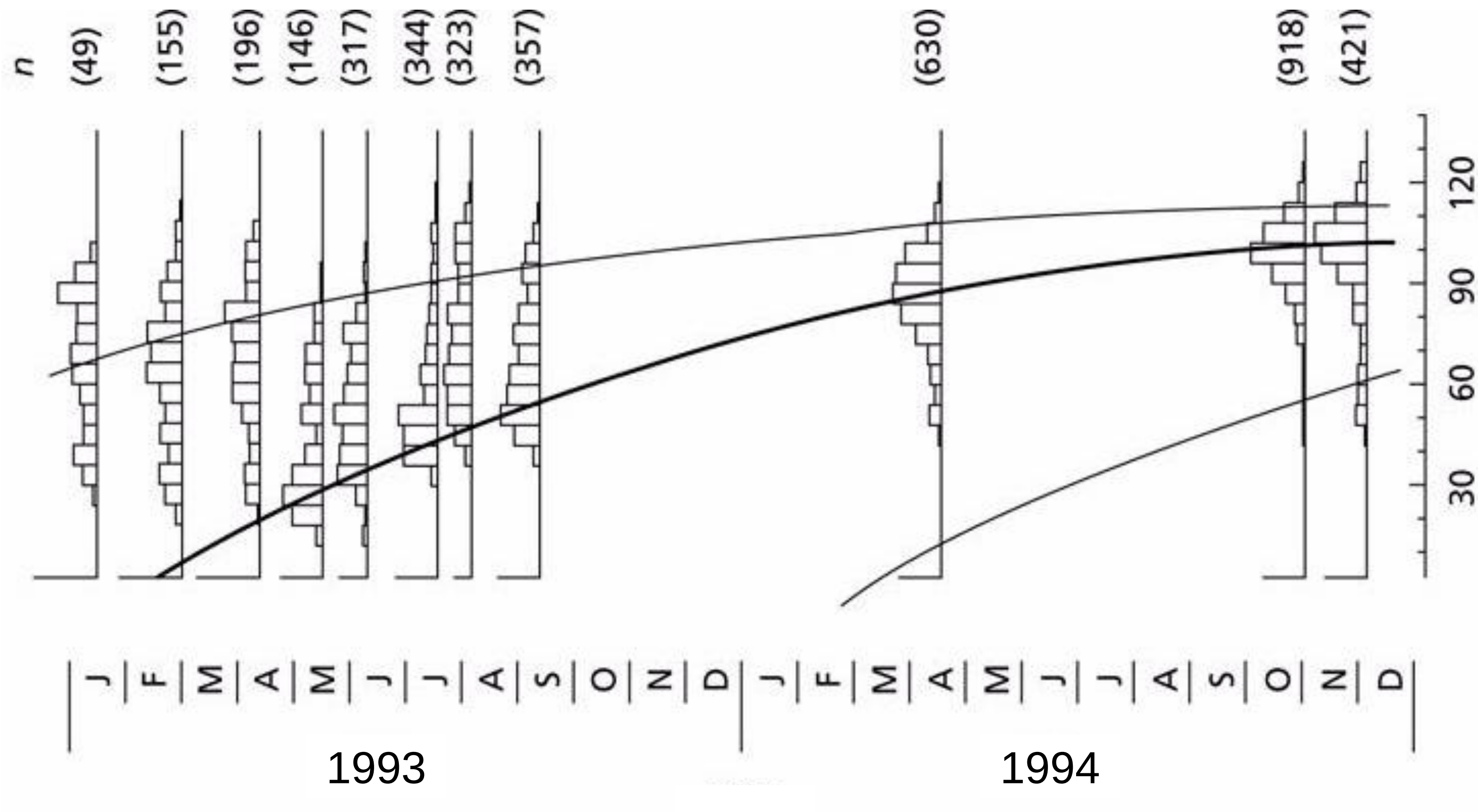
FiSAT - ELEFAN

Restructured length-frequencies



Normal VBGF fitted Seasonal VBGF fitted

Variable time intervals



General comments

- What you cannot see you cannot fit.
- If there is no reasonable clear visual indications of growth in the data, do not try to fit a model.
- Software packages will always give a result (even on French fried potatoes!)
- Never show results without superimposing the growth curve on the frequencies.
- Sometimes migrations can be misinterpreted as growth