APPENDIX TABLES

TABLE A1 LIST OF IMPORTANT FORMULAS

Length-weight relationship

$$W(i) = q*L(i)^{b} \qquad (2.6.1)$$

Von Bertalanffy growth equation

$$L(t) = L_{\infty}*[1 - \exp(-K*(t-t_{o}))] \qquad (3.1.0.1)$$

Growth rate, von Bertalanffy growth equation

$$\frac{\Delta L}{\Delta t} = K*(L_{\infty}-L(t)) \quad \text{cm/year} \qquad (3.1.0.4)$$

Weight-based von Bertalanffy growth equation

$$W(t) = W_{\infty}*[1 - \exp(-K*(t-t_{o}))]^{3} \qquad (3.1.2.1)$$

Inverse von Bertalanffy growth equation

$$t(L) = t_{o} - \frac{1}{K}*\ln(1 - L/L_{\infty}) \qquad (3.3.3.2)$$

Exponential decay model (1)

$$\frac{\Delta N(t)}{\Delta t} = -Z*N(t) \qquad (4.2.1)$$

Exponential decay model (2)

$$N(t) = N(Tr)*\exp[-Z*(t-Tr)] \qquad (4.2.2)$$

Baranov's equation or catch equation (1)

$$C(t1,t2) = \frac{F}{Z}*[N(t1)-N(t2)] \qquad (4.2.4)$$

Catch equation (2)

$$C(t1,t2) = N(t1)*\frac{F}{Z}*[1 - \exp(-Z*(t2-t1))] \qquad (4.2.7)$$

Average number of survivors (from t1 to t2)

$$\bar{N}(t1,t2) = N(t1) * \frac{1 - \exp(-Z*(t2-t1))}{Z*(t2-t1)} \qquad (4.2.9)$$

Total mortality from CPUE data

$$Z = \frac{1}{t2-t1}*\ln \frac{CPUE(t1)}{CPUE(t2)} \qquad (4.3.0.3)$$

Linearized length-converted catch curve

$$\ln \frac{C(L1,L2)}{\Delta t(L1,L2)} = c - Z*t\left(\frac{L1+L2}{2}\right) \qquad (4.4.5.3)$$

Pauly's formula for M (ln-based)

$$\ln M = -0.0152 - 0.279*\ln L_{\infty} + 0.6543*\ln K + 0.463*\ln T \qquad (4.7.2.1)$$

VPA equations (age-based)

$$\frac{C(y,t,t+1)}{N(y+1,t+1)} = \frac{F(y,t,t+1)}{M+F(y,t,t+1)} * \left[\exp[F(y,t,t+1)+M] - 1\right] \qquad (5.1.3)$$

$$N(y,t) = N(y+1,t+1) * \exp[F(y,t,t+1)+M] \qquad (5.1.4)$$

Pope's age-based cohort analysis (numbers)

$$N(t) = \left[N(t+\Delta t)*\exp(M*\Delta t/2) + C(t,t+\Delta t)\right]*\exp(M*\Delta t/2) \qquad (5.2.3)$$

Pope's age-based cohort analysis (fishing mortalities)

$$F(t,t+\Delta t) = \frac{1}{\Delta t}*\ln\left[\frac{N(t)}{N(t+\Delta t)}\right] - M \qquad (5.2.4)$$

Jones' length-based cohort analysis (numbers)

$$N(L1) = \left[N(L2)*H(L1,L2) + C(L1,L2)\right]*H(L1,L2) \qquad (5.3.4)$$

Length-based catch equation

$$C(L1,L2) = N(L1)*\frac{F}{Z}*\left[1 - \exp(-Z*\Delta t)\right] \qquad (5.3.5)$$

Jones' length-based cohort analysis (fishing mortalities)

$$F(L1,L2) = M*\frac{F(L1,L2)/Z(L1,L2)}{1-[F(L1,L2)/Z(L1,L2)]} \tag{5.3.6}$$

where the exploitation rate F/Z is derived from:

$$F(L1,L2)/Z(L1,L2) = \frac{C(L1,L2)}{N(L1) - N(L2)} \tag{5.3.7}$$

Logistic curve for gear selectivity (length-based)

$$S_L = \frac{1}{1 + \exp(S1 - S2*L)} \tag{6.1.1}$$

Set of formulas for age-based Thompson and Bell analysis

age interval: $i = (t_i, t_i+\Delta t)$

$$Z_i = M + X*F_i$$

$$N(t_i+\Delta t) = N(t_i)*\exp(-Z_i*\Delta t)$$

$$C_i = [N(t_i)-N(t_i+\Delta t)]*X*F_i/Z_i$$

$$\bar{w}_i = w(t_i+\Delta t/2) \tag{8.6.1}$$

$$Y_i = C_i*\bar{w}_i$$

$$\bar{B}_i = Y_i/[F_i*\Delta t*X]$$

$$V_i = Y_i*\bar{v}_i$$

Set of formulas for length-based Thompson and Bell analysis

length interval: $i = (L_i, L_{i+1})$

$$Z_i = M + X*F_i$$

$$N(L_{i+1}) = N(L_i)*\frac{1/H_i - X*F_i/Z_i}{H_i - X*F_i/Z_i} \quad \text{where}$$

$$H_i = \left[\frac{L_\infty - L_i}{L_\infty - L_{i+1}}\right]^{M/2K}$$

$$C_i = [N(L_i) - N(L_{i+1})]*X*F_i/Z_i \qquad (8.7.7)$$

$$\bar{w}_i = q*[(L_i + L_{i+1})/2]^b$$

$$Y_i = C_i*\bar{w}_i$$

$$V_i = Y_i*\bar{v}_i$$

$$\bar{N}_i*\Delta t_i = [N(L_i) - N(L_{i+1})]/Z_i$$

$$\bar{B}_i*\Delta t_i = \bar{N}_i*\Delta t_i*\bar{w}_i$$

Schaefer model

$$Y(i)/f(i) = a + b*f(i) \quad \text{if } f(i) \le -a/b \qquad (9.1.2)$$

Fox model

$$\ln(Y(i)/f(i)) = c + d*f(i) \qquad (9.1.3)$$

TABLE A2
METHODS BASED ON LINEAR TRANSFORMATIONS AND ORDINARY LINEAR REGRESSION ANALYSIS: $y = a + b*x$

Method	Assumption	Independent (x)	Dependent (y)	Slope (b)	Intercept (a)	Eq.
Length-weight relationship	$W_i = q*L^b_i$	$\ln L_i$	$\ln W_i$	b	ln q	2.6.1
Bhattacharya plot	lengths-at-age are $N(\bar{x},s^2)$	x + dL/2	$\Delta\ln N(x+dL/2)$	$-dL/s^2$	$\bar{x}*dL/s^2$	2.6.5
GROWTH						
Gulland and Holt plot	Δt small but not constant	$\bar{L}(t)$	ΔL/Δt	-K	$K*L_\infty$	3.3.1.1
Ford-Walford plot	Δt constant	L(t)	L(t+Δt)	exp(-K*Δt)	$[1 - \exp(-K*\Delta t)]*L_\infty$	3.3.2.1
Chapman's method	Δt constant	L(t)	L(t+Δt)-L(t)	exp(-K*Δt) - 1	$[1 - \exp(-K*\Delta t)]*L_\infty$	3.3.2.2
Von Bertalanffy plot	L_∞ known	t	$-\ln(1 - L(t)/L_\infty)$	K	$-K*t_o$	3.3.3.1
MORTALITY	**Steady state**					
Age-based	t ≥ T'					
Catch curve	Δt small and variable	t+Δt/2	ln[C(t,t+Δt)/Δt]	-Z	not used	4.4.4.2
Catch curve	Δt constant	t	ln C(t,t+Δt)	-Z	not used	4.4.3.1
Cumulated catch curve	Δt = ∞	t	ln C(t,∞)	-Z	not used	4.4.4.1
Length-based	L ≥ L'					
Catch curve		$t(\frac{L1+L2}{2})$	$\ln \frac{C(L1,L2)}{\Delta t(L1,L2)}$	-Z	not used	4.4.5.3
Jones-van Zalinge	L_∞ known	$\ln(L_\infty-L1)$	$\ln C(L1,L_\infty)$	Z/K	not used	4.4.6.1
Powell-Wetherall	L ≥ L1 = L'	L1	$\bar{L}$ - L1	-1/(1+Z/K)	$L_\infty/(1+Z/K)$	4.5.4.1

TABLE A2 (CONTINUED)
METHODS BASED ON LINEAR TRANSFORMATIONS AND ORDINARY LINEAR REGRESSION ANALYSIS: $y = a + b*x$

Method	Assumption	Independent (x)	Dependent (y)	Slope (b)	Intercept (a)	Eq.
Plot of Z on effort (f)	constant catchability (q)	f_i	Z_i	q	M	4.6.1
GEAR SELECTIVITY						
Covered codend	logistic curve	L	$\ln(1/S_L-1)$	-S2	S1	6.1.2
Resultant curve (from catch curve)	steady state $M_t = Z - Fm*S_t$	t	$\ln(1/S_t-1)$	-T2	T1	6.4.3.3
Gill net selection (two net experiment)	bell-shaped curve (Lm,s^2): $Lm = SF*m$	(L1+L2)/2	$\ln\left[\frac{Cb(L1,L2)}{Ca(L1,L2)}\right]$	$SF*(m_b-m_a)/s^2$ (not given	$-(SF)^2*(m_b^2-m_a^2)/(2s)^2$ in Chapter 6)	6.2.1.2
SURPLUS PRODUCTION MODELS	**STEADY STATE**					
Schaefer model	$f < -a/b$	f_i	Y_i/f_i	$-MSY/f^2_{MSY}$	$2*MSY/f_{MSY}$	9.1.2
Fox model	constant catchability (q)	f_i	$\ln(Y_i/f_i)$	$-1/f_{MSY}$	$1+\ln(MSY/f_{MSY})$	9.1.3
STATISTICS						
Mean	n data: (x_i,y_i)	$\bar{x} = \frac{1}{n}*\Sigma x_i$	$\bar{y} = \frac{1}{n}*\Sigma y_i$	$b = sxy/sx^2$	$a = \bar{y} - \bar{x}*b$	2.1.1 2.4.5/6
Standard deviation		sx	sy	sb	sa	
Variance	the y's are $N(ax+b,s^2)$ with constant s	$sx^2 = \frac{\Sigma[x(i)-\bar{x}]^2}{n-1}$	$sy^2 = \frac{\Sigma[y(i)-\bar{y}]^2}{n-1}$	$sb^2 = \frac{\left[\frac{sy}{sx}\right]^2-b^2}{n-2}$	$sa^2 = sb^2*[\bar{x}^2 + \frac{n-1}{n}*sx^2]$	2.1.2 2.4.11/12
Covariance		$sxy = \frac{1}{n-1}[\Sigma x(i)y(i) - \frac{1}{n}\Sigma x(i)\Sigma y(i)]$				2.4.9
Confidence limits	t-values in Table 2.3.1			$b \pm sb*t_{n-2}$	$a \pm sa*t_{n-2}$	

TABLE A3
IMPORTANT DATES EXPRESSED AS FRACTIONS OF A YEAR FROM 1 JANUARY

date	no. of days (cumulated)	fraction of year	date	no. of days (cumulated)	fraction of year
1 Jan	0	0.00	15 Jan	14	0.04
1 Febr	31	0.08	15 Febr	45	0.12
1 March	59	0.16	15 March	74	0.20
1 April	90	0.25	15 April	104	0.28
1 May	120	0.33	15 May	135	0.37
1 June	151	0.41	15 June	165	0.45
1 July	181	0.50	15 July	196	0.54
1 Aug	212	0.58	15 Aug	227	0.62
1 Sept	243	0.67	15 Sept	257	0.70
1 Oct	273	0.75	15 Oct	288	0.79
1 Nov	304	0.83	15 Nov	318	0.87
1 Dec	334	0.92	15 Dec	349	0.96
1 Jan	365	1.00	15 Jan	365	1.00
1 Febr	396	1.08	15 Febr	379	1.04
1 March	424	1.16	15 March	407	1.12
etc.	etc.	etc.	etc.	etc.	etc.

TABLE A4 FRACTILES OF THE t-DISTRIBUTION (STUDENT'S DISTRIBUTION)

degrees of freedom f	fractiles 90% t_f	95% t_f	99% t_f	degrees of freedom f	fractiles 90% t_f	95% t_f	99% t_f
1	6.31	12.71	63.66	15	1.75	2.13	2.95
2	2.92	4.30	9.93	16	1.75	2.12	2.92
3	2.35	3.18	5.84	17	1.74	2.11	2.90
4	2.13	2.78	4.60	18	1.73	2.10	2.88
5	2.02	2.57	4.03	19	1.73	2.09	2.86
6	1.94	2.45	3.71	20	1.73	2.09	2.85
7	1.90	2.37	3.50	25	1.71	2.06	2.79
8	1.86	2.31	3.36	30	1.70	2.04	2.75
9	1.83	2.26	3.25	40	1.68	2.02	2.70
10	1.81	2.23	3.17	50	1.67	2.01	2.68
11	1.80	2.20	3.11	60	1.67	2.00	2.66
12	1.78	2.18	3.06	80	1.67	1.99	2.64
13	1.77	2.16	3.01	100	1.66	1.98	2.63
14	1.76	2.15	2.98	∞	1.65	1.96	2.58

This volume describes in detail a selection of methods on fish stock assessment, with examples of calculations. Special emphasis is placed on methods based on the analysis of length frequencies. After a short introduction to statistics, the publication covers the estimation of growth parameters and mortality rates; virtual population methods, including age-based and length-based cohort analysis; gear selectivity; sampling; prediction models, including Beverton and Holt's yield-per-recruit model and Thompson and Bell's model; surplus production models; multispecies and multifleet problems; the assessment of migratory stocks; stock/recruitment relationships; and demersal trawl surveys, including the swept-area method. The manual ends with a review of stock assessment, giving an indication of methods to be applied at different levels of availability of input data. The publication also includes a review of relevant computer programs produced by or in cooperation with FAO, and a bibliography, including material for further reading. The companion volume, Part 2: Exercises, gives a number of exercises (and their solutions) directly related to the various chapters and sections of the manual.

ISBN 92-5-103996-8 ISSN 0429-9345

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M-43 W5449E/1/10.98/2200