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Determination of the status of utilization and effort of Bonito(Auxis rochei) caught in the Bitung Waters North Sulawesi

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Abstract : Bonito (*Auxis rochei*), needs to be managed well because even as a renewable natural resource, but can undergo depletion or extinction. One of the approach in the management of fish resources is by modeling. The analysis was performed aiming to get the best estimate for the surplus production model to determine the maximum sustainable yields (MSY), utilization level, and effort level of bonito. The data of catch and fishing effort bonito collected from the Marine and Fisheries Service of the Bitung City and the North Sulawesi Province.

Best Surplus Production Model, which is used to assess the potential of bonito is *Schaefer Model*. Optimal effort (E_{MSY}) of 16,205 trips per year, with catches of optimal C_{MSY} 9,577.214 tons per year. The effort level for 2005 is 95.86%, which shows the inefficiency of effort, the utilization level of 114.46%, showing occur overfishing.

Keywords : *Bonito, Surplus Production Model, Maximum Sustainable Yield, Bitung.*

Introduction

Bonito (*Auxis rochei*) classified as pelagic fishery resource is important and one of the non-oil export commodity in North Sulawesi. Bonito production in North Sulawesi (including Bitung waters) in 2011 reached 30,000 tons per year, with a value of about 300 billion rupiahs[1]. Research on bonito generally discusses the exploitation to increase production, not much research on the status of utilization (including aspects of sustainability and efficiency) resources. Catching bonito in Bitung waters has lasted long enough, with high intensity. Data on the level of utilization of the fish resources are very important, as it will determine whether the resource use is less than optimal, optimal, or excessive. Excessive utilization of fish resources would threaten its sustainability. By knowing the level of resource utilization on the bonito, is expected to be done in a planned and sustainable management.

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The simplest model of the dynamics of fish populations is Surplus Production Model (SPM), by treating the fish as a single biomass that can not be divided, which is subject to the rules of simple increases and decreases in biomass. This model, commonly used in the assessment of fish stocks using only the data of catch and fishing effort generally available.

This study aims to get the best SPM, as well as knowing how much the result of maximum sustainable yields (MSY), utilization level, and the level of effort of bonito in the Bitung waters.

2. Surplus Production Model

The simplest model of the dynamics of fish populations is a surplus production model that treats the fish population as a single biomass that can not be divided, which is subject to the simple rules of the rise and decline. The production model is dependent on the amount of four kinds, namely: biomass population at a given time t (B_t), catches for a certain time t (C_t), fishing effort at a certain time t (E_t), and the natural growth rate constant (r)[2]. This model was first developed by Schaefer, who was initially the same as the form of logistic growth model. According to Coppola and Pascoe[3], equation surplus consists of several constants that are affected by natural growth, the ability of fishing gear, and carrying capacity. Constants allegedly using models of biological parameter estimators of surplus production equation, namely the model: Equilibrium Schaefer, Schaefer Disequilibrium, Schnute, and Walter - Hilborn. Based on the four models were selected the most appropriate or best fit of the estimation of others. According to Sparre and Venema[4], formulas surplus production model is valid only if the slope parameter (b) is negative, which means the addition of fishing effort will lead to a decrease in the catch per fishing effort. If the parameter b positive value, then it can not be done estimating the optimum amount of stock and effort, but it can only be concluded that the addition of fishing effort is still possible to increase the catch.

Prediction of optimum fishing effort (E_{opt}) and the maximum sustainable catch (C_{MSY}) approached the surplus production model. Between the catch per unit of effort (CPUE) and fishing effort can be either linear or exponential relationship[5]. Surplus Production Model consists of two models, namely basic model of Schaefer (linear relationship) and the Gompertz model developed by Fox with forms exponential relationship[5].

2.1 Schaefer Model

Surplus production models first developed by Schaefer, who was initially the same as the form of logistic growth model. The model is as follows:

$$\frac{dB_t}{dt} = G(B_t) = r\,B_t\,(1 - \frac{B_t}{K}) \qquad (1)$$

This equation does not include the effect of the catching, so Schaefer wrote back to :

$$\frac{dB_t}{dt} = r\,B_t\,(1 - \frac{B_t}{K}) - C_t \qquad (2)$$

K is the carrying capacity of the marine environment, and C_t is the catch that can be written as:

$$C_t = q\,E_t\,B_t \qquad (3)$$

catchability, and Et indicates fishing effort. This equation can be written as:

$$\frac{C_t}{E_t} = q\,B_t = \text{CPUE} \qquad (4)$$

From the differential equation (2), the optimum catchment can be calculated at the time $\frac{dB_t}{dt}$ = 0, also called settlement at the point of balance (equilibrium), in the form of:

$$r B_t \left(1 - \frac{B_t}{K}\right) - C_t = 0, \quad \text{or}$$

$$C_t = r B_t \left(1 - \frac{B_t}{K}\right) = q E_t B_t \qquad (5)$$

From equation (3) and (5), find value of B_t obtained as follows :

$$B_t = K\left(1 - \frac{qE_t}{r}\right) \qquad (6)$$

So that equation (5) becomes :

$$C_t = q K E_t \left(1 - \frac{qE_t}{r}\right)$$

$$= q K E_t - \frac{q^2 K}{r} E_t^2 \qquad (7)$$

Equation (7) is simplified further by Schaefer becomes:

$$\frac{C_t}{E_t} = a - b E_t, \quad \text{or}$$

$$C_t = a E_t - b E_t^2 \qquad (8)$$

while the $a = q K$ and $b = .\frac{q^2 K}{r}$

This linear relationship is used widely for calculating C_{MSY} through the determination of the first derivative of C_t with E_t to find optimal solutions, both to catch and fishing effort. The first derivative of C_t to Et is : $\frac{dC_t}{dE_t} = a - 2b E_t$, in order to obtain the alleged E_{opt} (optimum fishing effort) and C_{MSY} (maximum sustainable yields) respectively :

$$E_{opt} = \frac{a}{2b} = \frac{r}{2q} \qquad (9)$$

by entering the value of E_{opt} in equation (8), will be obtained C_{MSY} as follows:

$$C_{MSY} = a E_t - b E_t^2$$

$$= a\left(\frac{a}{2b}\right) - b\left(\frac{a}{2b}\right)^2$$

$$= \frac{a^2}{4b}$$

by substituting a = qK and b = $\frac{q^2K}{r}$ will be obtained,

$$C_{MSY} = \frac{a^2}{4b} = \frac{q^2K^2}{4q^2K/r} = \frac{rK}{4} \qquad (10)$$

The values of a and b are estimated by the least squares method approach that is commonly used to estimate the coefficient of a simple regression equation. Furthermore, by including the value of E_{opt} in equation (6) is obtained optimum biomass (B_{MSY}) as follows :

$$B_{MSY} = K - \frac{Kq}{r}E_{opt}$$

$$= K - \frac{Kq}{r}\left(\frac{r}{2q}\right)$$

$$= K - \frac{K}{2}$$

$$= \frac{K}{2} \qquad (11)$$

The values of the parameter q, K, and r can be calculated using the Fox algorithm, as referenced in Sularso[6], as follows:

$$q_t = \ln\left[\left|\left(zU_t^{-1} + \frac{1}{b}\right)/\left(zU_{t+1}^{-1} + \frac{1}{b}\right)\right|\right]/(z) \qquad (12)$$

where z = - (a / b) / E *, E * = (E_t + E_{t+1}) / 2, $U_t = \frac{C_t}{E_t}$ and the value of q is the geometric mean of the value of q_t. From the values of a, b, and q, can then be calculated values of K and r.

2.2 Fox Model

Model of Fox has several characteristics that are different from the model Schaefer, that it biomass growth following the Gompertz growth model[7]. The relation of CPUE with effort (E) follows a negative exponential pattern :

$$C_t = E_t . \exp(a - b\,E_t) \quad (13)$$

Efforts optimum is obtained by equating the first derivative of Ct to E_t equal to zero and find :

$$E_{opt} = \frac{1}{b} \quad (14)$$

The maximum sustainable yields of catch (C_{MSY}) is obtained by inserting the value of the optimum effort into equation (13), and obtained:

$$C_{MSY} = \frac{1}{b} e^{a-1} \quad (15)$$

2.3 Schnute Model

Schnute[8], suggests another version of the surplus production model is dynamic and deterministic. Schnute method is considered as a modification of the model in the form of discrete Schaefer (Roff, 1983, referred by Tinungki)[9].

$$\ln\left(\frac{U_{t+1}}{U_t}\right) = r - \frac{r}{qK}\left(\frac{U_t + U_{t+1}}{2}\right) - q\left(\frac{E_t + E_{t+1}}{2}\right)$$

$$= a - b\left(\frac{U_t + U_{t+1}}{2}\right) - c\left(\frac{E_t + E_{t+1}}{2}\right) \quad (16)$$

where a = r, $b = \frac{r}{qK}$, and c = q, is the regression coefficient estimators.

2.4 Walter - Hilborn Model

Walter and Hilborn (1976) referred by Tinungki[9], to develop other types of surplus production model, known as the regression model. Walter - Hilborn Model, using a simple differential equation, by the following equation :

$$\frac{U_{t+1}}{U_t} - 1 = r - \frac{r}{Kq} U_t - q\,E_t$$

$$= a - b\,U_t - c\,E_t \quad (17)$$

where a = r, $b = \frac{r}{Kq}$, and c = q, is the regression coefficient estimators.

2.5 Clarke Model Yoshimoto Pooley (CYP)

Estimation of biological parameters for the surplus production model can also be done through estimation techniques proposed by Clarke, Yoshimoto, and Pooley[9, 10]. The parameters which allegedly is r, K, and q, the model is expressed as follows:

$$\ln(U_{t+1}) = \left(\frac{2r}{2+r}\right)\ln(qK) + \frac{2-r}{2+r}\ln(U_t) - \frac{q}{2+r}(E_t + E_{t+1}) \quad (18)$$

where : $a' = \frac{2r}{2+r}$, $a = a'\ln(qK)$, $b = \frac{2-r}{2+r}$, $c = \frac{q}{2+r}$

thus equation (18) can be written in the form :

$$\ln(U_{t+1}) = a' \ln(qK) + b\ln(U_t) - c(E_t + E_{t+1})$$

$$= a + b\ln(U_t) - c(E_t + E_{t+1}) \quad (19)$$

3. Research Methods

3.1 Source of Data

The primary and secondary data of bonito catching is collected from the Bitung waters. Production and fishing effort data collected from the Marine and Fisheries Service of Bitung City and North Sulawesi Province during the years 1995-2014.

Data (variables) used for the analysis of the surplus production model is the data of the catch (C_t) per year and fishing effort (E_t) per year, and CPUE (Catch Per Unit of Effort). The data (variables) used for the analysis of the surplus production model is as follows :

1. The catch (C_t): weight of fish landed (tons) in year t
2. The Effort of catching (E_t) : the number of fishing boat landing result in a landing (trip) in year t
3. $\frac{C_t}{E_t}$ Catch per Unit of Effort (tons per trip) in year t

3.2 Methods of Data Analysis

The models estimator who analyzed and evaluated are : Schaefer, Fox, Schnute, Walter-Hilborn, and Clarke-Yoshimoto-Pooley (CYP). Based on the results of statistical evaluation (sign suitability of regression coefficient, the value of R^2, the validation value, and significance of the regression coefficient of the models), we get the "best" as estimator. From the best of model can be calculated C_{MSY} value, optimum fishing effort (E_{MSY}), utilization level, and the level of effort of bonito fishery.

4. Results and Discussion

Catches of bonito fisheries in the Bitung waters fluctuate from year to year. Data catching in 1995-2014, are presented in Table 1.

Table 1. Total catch, fishing efforts, and CPUE (Catch per Unit of Efforts) of bonito in Bitung waters 1995-2014

Years	Catch (ton), C_t	Effort (trip), E_t	CPUE = $\frac{C_t}{E_t}$ (ton/trip)
1995	6,500.2	13,101	.4962
1996	7,152.1	13,212	.5413
1997	9,121.4	14,102	.6468
1998	10,169.3	14,512	.7008
1999	9,824.3	14,671	.6696
2000	10,517.4	15,600	.6742
2001	10,657.4	15,523	.6866
2001	10,404.6	15,212	.6840
2003	10,492.7	15,372	.6826
2004	10,821.4	15,400	.7027
2005	10,962.5	15,534	.7057
2006	10,121.5	15,540	.6513
2007	9,554.1	17,953	.5322
2008	9,621.4	18,488	.5204
2009	9,059.4	18,788	.4822
2010	8,513.5	19,610	.4341
2011	8,747.5	19,712	.4438
2012	8,781.5	20,824	.4217
2013	7,517.4	21,840	.3442
2014	7,222.3	22,121	.3265
Mean	**9,288.095**	**16,856**	**0.5673**

Source : *Calculated from the Marine and Fisheries Service of Bitung City and North Sulawesi*

The results of the regression analysis for the surplus production model is presented in Appendix 1, which is described as follows**:**

4.1 Schaefer Model

From the analysis of regression equation $\frac{C_t}{E_t}$ = 1.182 - 0.00003647 E_t, with a coefficient of determination (R^2) = 0.647 and a significance level of $p < 0.05$. Thus, a production model estimator catches Schaefer model according to the equation (8) is: $\mathbf{C_t = 1.182\ E_t - 0.00003647\ E_t^2}$.

4.2 Fox Model

From the results of the regression analysis regression equation:

Ln $\frac{C_t}{E_t}$ = 0.627 - 0.00007244 E_t, with R^2 = 0.685 ($p < 0.05$). Estimates of catches corresponding to the model Fox equation (13) **:**

$$C_t = E_t .\ e^{(0.627\ -\ 0.00007244\ E_t)}$$

4.3 Schnute Model

Schnute method according to equation (16), obtained regression equation:

$$\ln\left(\frac{U_{t+1}}{U_t}\right) = 0.843 - 0.417\left(\frac{U_t + U_{t+1}}{2}\right) - 0{,}0000371\left(\frac{E_t + E_{t+1}}{2}\right)$$

with $R^2 = 0.457$, and not all the regression coefficient was significant ($p < 0.05$).

4.4 Walter Model - Hilborn

In Walter-Hilborn method using equation (17) derived regression equation

$$\frac{U_{t+1}}{U_t} - 1 = 0.905 - 0.514\, U_t - 0.00003762\, E_t$$

With $R^2 = 0.522$ and all regression coefficients were significant ($p < 0.05$) .

4.5 Clarke Model Yoshimoto Pooley (CYP)

In the regression equation CYP method, according to equation (19) :

$$\ln(U_{t+1}) = 0.500 + 0.673\ln(U_t) - 0.00002102(E_t + E_{t+1})$$

with $R^2 = 0.947$, and all of the regression coefficient are significant ($p < 0.05$).

5. Discussion

The results of calculations for validation surplus production model of 5 models is presented in Appendix 2, which is summarized in Table 2.

Table 2. Results of the surplus production model validation

	Model Schaefer	**Model Fox**	**Model Schnute**	**Model Walter-Hilborn**	**Model CYP**
Sign Suitability	**Appropriate**	**Appropriate**	**Appropriate**	**Appropriate**	**Appropriate**
R^2 Value	**0.647**	0.685	0.457	0.522	0.947
Validation Value	**0.0984**	0.1015	0.2827	0.2219	3.3910
Significance Coefficient	**Significant**	Significant	Significant	Not all significant	Significant

From the results of the calculations in Table 2, it appears that the most appropriate is Schaefer model with the R^2 value is quite large ($R^2 = 0.647$) and validation (residual value) is smallest. Schaefer model obtained values of a = 1.182 and b = 0.00003647, with equation (9) and (10) can be calculated optimum value of Effort (E_{opt}) and the maximum sustainable catch (C_{MSY}) as follows:

$$E_{opt} = \frac{a}{2b} = \frac{1.182}{2(0.00003647)} = 16{,}205.10 \approx 16{,}205 \text{ trips per year.}$$

$$C_{MSY} = \frac{a^2}{4b} = \frac{1.182^2}{4(0.00003647)} = 9{,}577.214 \text{ tons per year.}$$

This means that in order to preserve the bonito fisheries resources technically and biologically, in a year the number of units should not exceed 16,205 trips. To preserve the bonito resources in the waters Bitung, the maximum of fish that can be caught at 9,577.214 tons per year. Furthermore, from the value of E_{opt} and C_{MSY} can be calculated fishing effort levels and utilization level of bonito for a particular year for example in 2005, as follows:

$$\text{The level of effort in 2005} = \frac{E_{2005}}{E_{opt}} \times 100\%$$

$$= \frac{15{,}534}{16{,}205} \times 100\% = 95.86\ \%$$

$$\text{The utilization level in 2005} = \frac{C_{2005}}{C_{MSY}} \times 100\%$$

$$= \frac{10{,}962.5}{9{,}577.214} \times 100\% = 114.46\ \%.$$

From the calculation, it turns out bonito fishing effort at the Bitung waters in 2005, nearly exceeding the maximum sustainable level of effort. This shows that fishing effort is not efficient. The utilization level for the year 2005, is more than optimum level, its mean a sign of *overfishing* (catch-over). The same result of bonito fishing effort and utilization level at the Talaud waters shows not efficient and overfishing[11], also at Manado waters[12].

This study describes the use of some statistical criteria in selecting the best surplus production model. By applying some statistical criteria in selecting a surplus production model, will obtain better results. Researchers in the field of fisheries get guidelines for setting selection criteria for surplus production models, as well as avoiding the direct application of one model in analyzing the surplus production model in a waters.

6. Conclusions and Recommendations

6.1 Conclusion

1. The surplus production model that can be used to examine the catch of bonito in the Bitung waters is Schaefer model, by the equation: $C_t = 1.182\ E_t - 0.00003647\ E_t^2$

2. The maximum sustainable yield of bonito C_{MSY} is 9,577.214 tons per year, obtained at the level of fishing effort E_{MSY} 16,205 trips. For the year 2005 the amount of 114.46% utilization level is a sign of overfishing (overfished), with the level of effort for 95.86% indicating inefficiencies in fishing effort.

6.2 Suggestion

1. In applying surplus production models in a waters location, not only directly using one particular model, but should use some of the models are chosen based on statistical criteria. These criteria involve, among others : suitability sign of the coefficient of models, coeffient of determination (R^2), the value of validation, and the significance of the regression coefficients.

2. There are indications will occur overfishing, and the presence of inefficiency of fishing effort of bonito in the waters Talaud, recommended immediate supervision by competent institutions to handle this issue. Especially the efficiency of fishing effort.

Appendix

Appendix 1. Regression analysis of Surplus Production Model of bonito data in Bitung waters

Schaefer Model

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.804[a]	.647	.627	.0780335

a. Predictors: (Constant), Et

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.200	1	.200	32.921	.000[b]
	Residual	.110	18	.006		
	Total	.310	19			

a. Dependent Variable: Ut
b. Predictors: (Constant), Et

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.182	.109		10.890	.000
	Et	-3.647E-005	.000	-.804	-5.738	.000

a. Dependent Variable: Ut

Fox Model

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.827[a]	.685	.667	.14230162

a. Predictors: (Constant), Et

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.791	1	.791	39.062	.000[b]
	Residual	.364	18	.020		
	Total	1.155	19			

a. Dependent Variable: LnCtperEt
b. Predictors: (Constant), Et

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.627	.198		3.168	.005
	Et	-7.244E-005	.000	-.827	-6.250	.000

a. Dependent Variable: LnCtperEt

Schnute Model

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.676[a]	.457	.390	.0717516

a. Predictors: (Constant), (Et+1 + Et)/2, (Ut+1 + Ut)/2

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.069	2	.035	6.745	.008[b]
	Residual	.082	16	.005		
	Total	.152	18			

a. Dependent Variable: Ln (Ut+1/Ut)

b. Predictors: (Constant), (Et+1 + Et)/2, (Ut+1 + Ut)/2

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
	(Constant)	.843	.336		2.505	.023
1	(Ut+1 + Ut)/2	-.417	.260	-.551	-1.603	.129
	(Et+1 + Et)/2	-3.714E-005	.000	-1.074	-3.123	.007

a. Dependent Variable: Ln (Ut+1/Ut)

Walter – Hilborn Model

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.722[a]	.522	.462	.0663465

a. Predictors: (Constant), Et, Ut

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
	Regression	.077	2	.038	8.729	.003[b]
1	Residual	.070	16	.004		
	Total	.147	18			

a. Dependent Variable: (Ut+1 / Ut) -1
b. Predictors: (Constant), Et, Ut

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
	(Constant)	.905	.254		3.558	.003
1	Ut	-.514	.203	-.668	-2.528	.022
	Et	-3.762E-005	.000	-1.081	-4.088	.001

a. Dependent Variable: (Ut+1 / Ut) -1

CYP Model

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.973[a]	.947	.940	.0615884

a. Predictors: (Constant), (Et + Et+1), LnCtperEt

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.082	2	.541	142.623	.000[b]
	Residual	.061	16	.004		
	Total	1.143	18			

a. Dependent Variable: Ln(Ut+1)

b. Predictors: (Constant), (Et + Et+1), LnCtperEt

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.500	.108		4.612	.000
	LnCtperEt	.673	.107	.586	6.304	.000
	(Et + Et+1)	-2.102E-005	.000	-.443	-4.768	.000

a. Dependent Variable: Ln(Ut+1)

Appendix 2. Validation of surplus production models of bonito data

Years	C_t (tons)	E_t (trips)	**Validation**: Abs($\frac{C_t - \hat{C}_t}{C_t}$)				
			Schaefer	**Fox**	**Schnute**	**Walter-Hilborn**	**CYP**
1995	6500.2	13101	.4193	.4606	.7271	.6158	.2361
1996	7152.1	13212	.2934	.3280	.5648	.4660	.2148
1997	9121.4	14102	.0323	.0420	.1872	.1262	.5657
1998	10169.3	14512	.0685	.0663	.0439	.0033	.6786
1999	9824.3	14671	.0339	.0342	.0712	.0256	.8513
2000	10517.4	15600	.0907	.1031	.0585	.0822	1.3886
2001	10657.4	15523	.1029	.1143	.0655	.0905	1.3009
2002	10404.6	15212	.0830	.0907	.0215	.0538	1.1281
2003	10492.7	15372	.0897	.0994	.0404	.0690	1.2260
2004	10821.4	15400	.1172	.1269	.0714	.0986	1.1782
2005	10962.5	15534	.1279	.1391	.0922	.1163	1.2446
2006	10121.5	15540	.0554	.0676	.0172	.0432	1.4358
2007	9554.1	17953	.0092	.0418	.2003	.1609	3.7903
2008	9621.4	18488	.0243	.0574	.2736	.2172	4.3087
2009	9059.4	18788	.0303	.0046	.2714	.2007	4.9777
2010	8513.5	19610	.0753	.0417	.3590	.2508	6.3948
2011	8747.5	19712	.0436	.0116	.3934	.2839	6.3261
2012	8781.5	20824	.0020	.0179	.5960	.4395	7.7616
2013	7517.4	21840	.1200	.1179	.7675	.5293	10.9120
2014	7222.3	22121	.1493	.1548	.8314	.5668	11.9017
Mean	**9,288.09**	**16856**	**0,0984**	**0,1059**	**0,2827**	**0.2219**	**3.3910**

1. Schaefer Model : $\hat{C}_t = 1.182 E_t - 0{,}00003647\, E_t^{\,2}$
2. Fox Model : $\hat{C}_t = E_t . e^{(0.627 - 0{,}00007244 E_t)}$
3. Schnute Model : $\hat{Y} = a - b\, X_1 - c\, X_2 \;= 0.843 - 0.417\, X_1 - 0{,}0000371 X_2$

r = a = 0.843 q = c = 0,00003371 b = $\frac{r}{Kq} = 0.417$

K = $\frac{r}{bq} = \frac{0.843}{(0.417)(0.0000371)} = 54{,}490..10$

$\hat{C}_t = Kq\,E_t - \frac{Kq^2}{r} E_t^{\,2}$ = 2.0216 E_t - 0.0000889 E_t^2

4. Walter – Hilborn Model :

$\hat{Y} = a - b\,X_1 - c\,X_2 \quad = 0.905 - 0.514\,X_1 - 0{,}00003762\,X_2$

r = a = 0.905 q = c = 0.00003762 b = $\frac{r}{Kq} = 0.514$

K = $\frac{r}{bq} = \frac{0.905}{(0.514)(0{,}00003762)} = 46{,}802.24$

$\hat{C}_t = Kq\,E_t - \frac{Kq^2}{r} E_t^{\,2}$ = 1.7607 E_t - 0.0000732 E_t^2

5. CYP Model : $\hat{Y} = a + b\,X_1 - c\,X_2 \quad = 0.500 + 0.673\,X_1 - 0.00002102\,X_2$

$$r = \frac{2(1-b)}{1+b} = \frac{2(1-0.673)}{1+0.673} = 0.3909 \quad q = -c\,(2-r) = 0.00002102(2-0.3909) = 0.0000338$$

$$Q = \frac{a(2+r)}{2r} = \frac{0.500(2+0.3909)}{2(0.3909)} = 1.5291$$

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