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Determination of the Utilization and Effort Level of Mackerel Scad (*Decapterus spp*) in the North Bolaangmongondow Waters North Sulawesi

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Abstract: This research aimed to determine utilization level and effort level of scad mackerel (*Decapterus spp*) in the North Bolaangmongondow waters. One of the approach in the management of the fisheries resources is by mathematics modelling. In this research using Surplus Production Model with 5 estimator methods, that are: Schaefer, Fox, Schnute, Walter-Hilborn, and Clarke Yoshimoto Pooley. The analysis was performed aiming to get the best estimated for the surplus production model to determine the maximum sustainable yields (MSY), utilization level, and effort level of scad mackerel. The criteria of the best model (estimator) are: sign suitability of regression equation, values of coefficient determination, validations value (residual), and significance of regression coefficients. From the best model by using the formula can be determined the maximum sustainable yields (MSY), utilization level, and effort level. The data of catch and fishing effort scad mackerel collected from the Marine and Fisheries Service of the North Bolaangmongondow Residence and the North Sulawesi Province from 2009 – 2021. The best Surplus Production Model, which is used to assess the potential of scad mackerel is *Fox Model*. Optimal effort (E_{MSY}) of 83 trips per year, with catches of optimal C_{MSY} 287.679 kgs per year. The effort level for 2021 is 63.86%, which shows the quite efficient of effort, the utilization level of 95.93%, showing the production nearly optimum.

Keywords: Scad Mackerel, Surplus Production Model, Minimum Sustainable Yield, North Bolaangmongondow

1. Introduction

Mackerel scad (*Decapterus spp*) classified as pelagic fishery resource is important and one of the non-oil export commodity in North Sulawesi. Mackerel scad in North Sulawesi (including North Bolaangmongondow waters) in 2016 reached 50,000 tons per year, with a value of about 100 billion rupiahs [1]. Research on mackerel scad generally discuss the exploitation in increase production, not much research on the status of utilization (including aspects of sustainability and efficiency) resources. 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 resources utilization on the mackerel scad, is expected to be done in a planned and suatainable management.

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 mackerel scad in the North Bolaangmongondow waters.

2. Material and Methods

The primary and secondary data of mackerel scad catching is collected from the North Bolaangmongondow waters. Production and fishing effort data collected from the Marine and Fisheries Service of North Bolaangmongodow Regency and North Sulawesi Province during years 2009-2021. Data (variables) used for the analysis of the surplus production model is the data of the Catch (C_t) per year, fishing effort (E_t) per year, and CPUE (Catch per Unit of Effort).

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

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].

The procedures for estimates of surplus production models follows these equations: 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:

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

q is catchability, and E_t 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:

$$r\ B_t\ (1 - \frac{B_t}{K}) - C_t = 0$$

or

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

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

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

So that equation (5) becomes:

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

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

Equation (7) is simplified further by Schaefer becomes:

$$\frac{C_t}{E_t} = a - b\ E_t$$

or

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

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

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 E_t 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:

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

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 = $\frac{q^2 K}{r}$ will be obtained,

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

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:

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

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

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

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

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

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

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.

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:

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

Model of 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.

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.

Estimation of biological parameters for the surplus production model can also be done through estimation techniques proposed by Clarke, Yoshimoto, and Pooley (CYP) [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. Results and Discussion

Catches of mackerel scad fisheries in the North Bolaangmongondow waters 2009-2021, are presented in Table 1.

Table 1. *Total catch, fishing efforts, and CPUE mackerel scad in North Bolaangmongondow Waters of 2009-2021.*

Years	Catch (ton), C_t	Efforts (trips), E_t	CPUE = $\frac{C_t}{E_t}$ (ton/trip)
2009	210.742	34	6.1983
2010	231.765	36	6.4379
2011	221.345	38	5.8249
2012	240.341	40	6.0085
2013	230.420	42	5.4862
2014	223.431	38	5.8798
2015	227.372	34	6.6874
2016	243.950	42	5.8083
2017	228.720	45	5.0827
2018	264.950	49	5.4071
2019	274.150	56	4.8955
2020	263.115	47	5.5982
2021	275.970	53	5.2070
Mean	241.251	43	5.7324

Source: Calculated from the Marine and Fisheries Service and Landing Station of Fish in North Bolaangmongondow

The regression análysis of Surplus Production Model is presented in *Appendix 1*. From the analysis of regression, equation for Schaefer Model: $\frac{C_t}{E_t}$ = 8.562 - 0.066 E_t, with a coefficient of determination (R^2) = 0.789 and a significance level of $p < 0.05$. Thus, a production model estimator catches Schaefer model according to the equation (8) is: $C_t = 0.789\, E_t - 0.0668\, E_t^2$.

From the results of the regression analysis for Fox Model: Ln $\frac{C_t}{E_t}$ = 2.239 - 0.012 E_t, with R^2 = 0.801 ($p < 0.05$). Estimates of catches corresponding to the model Fox equation (13): $C_t = E_t.\, e^{(2.239-0.012\, E_t)}$

For Schnute model according to equation (16), obtained regression equation:

$$\ln\left(\frac{U_{t+1}}{U_t}\right) = 0.298 - 0.034\left(\frac{U_t + U_{t+1}}{2}\right) - 0{,}003\left(\frac{E_t + E_{t+1}}{2}\right)$$

with R^2 = 0.004, and all the regression coefficient was not significant ($p > 0.05$).

In Walter-Hilborn Model using equation (17) derived regression equation:

$$\frac{U_{t+1}}{U_t} - 1 = 2.188 - 0.272\, U_t - 0.015\, E_t$$ with R^2 = 0.505 and not all regression coefficients were significant.

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

$$ln(U_{t+1}) = 3.485 - 0.561\, ln(U_t) - 0.009\,(E_t + E_{t+1})$$

with R^2 = 0.765, and not all the regression coefficient are significant ($p < 0.05$).

The results of calculations for validation surplus production model of 5 models is presented in *Appendix 2*, 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	Not Appropriate
R^2 Value	0.789	0.801	0.004	0.505	0.765
Validation Value	0,0838	0,0767	0.1262	0.1281	0.3782
Significance Coefficient	Significant	Significant	Not Significant	Not all Significant	Not all Significant

From the results of the calculations in Table 2, it appears that the most appropriate is Fox model with the R^2 value is quite large (R^2 = 0.801) and validation (residual value) is smallest. Fox model obtained values of a = 2.239 and b = 0.012, with equation (14) and (15) can be calculated optimum value of Effort (E_{opt}) and the maximum sustainable catch (C_{MSY}) as follows:

$E_{opt} = \frac{1}{b} = \frac{1}{0.012} = 83$ trips per year.

$C_{MSY} = \frac{1}{b} e^{a-1} = \frac{1}{0.012} e^{(2.239-1)}$ = 287.679 kgs per year.

This means that in order to preserve the mackerel scad fisheries resources technically and biologically, in a year the number of units should not exceed 83 trips. To preserve the mackerel scad resources in the North Bolaangmongondow waters, the maximum of fish that can be caught at 287.679 kgs per year. Furthermore, from the value of E_{opt} and C_{MSY} can be calculated fishing efforts level and utilization level of mackerel scad for a particular year for example in 2021, as follows:

The level of effort in 2021 = $\frac{E_{2021}}{E_{opt}}$ x 100% = $\frac{53}{83}$ x 100% = 63.86%`

The utilization level in 2021 = $\frac{C_{2021}}{C_{MSY}}$ x 100% = $\frac{275.970}{4287.679}$ x 100% = 95.93%.

From the calculation, it turns out mackerel scad fishing effort at the North Bolaangmongondow waters in 2021 is 63.86%, less than the maximum sustainable level of effort. This shows that fishing effort is quite efficient. The utilization level for the year 2021 (95.93%) is almost optimum level.

The distribution of mackerel scad (*Decapterus spp*) in almost of regións in Indonesia, especially in Java Waters, South of Makasar, until North Sulawesi Waters [11]. As a comparison to scad mackerel in other waters in Indonesia, the catches of optimal (C_{MSY}) of mackerel scad in East of South East Sulawesi waters is 5,747.61 tons per year [12]. Mackerel scad in South East Sulawesi waters showing the intensive production [13]. In South Sulawesi at Flores Sea Waters, C_{MSY} of mackerel scad is 10,456 tons per year, with the effort level 83.15% and the utilization level 76.60%, showing the intensive exploitation [14]. In North Sulawesi at Bitung Waters, C_{MSY} of mackerel scad is 19,793.601 tons per year, with the effort level 86.58% and the utilization level 73.10%, showing the production still can be increased [15]. From these data, for mackerel scad in East Indonesia Waters (include in North Bolaangmongondow), generally the production still can be increased.

This research 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.

4. Conclusion and Recommendation

4.1. Conclusions

The surplus production model that can be used to predict the catch of mackerel scad in the North Bolaangmongondow waters is Fox model, by the equation: $C_t = E_t.\ e^{(2.239-0.012\ E_t)}$.

The maximum sustainable yield of mackerel scad C_{MSY} is 287.679 kgs per year, obtained at the of fishing effort E_{MSY} 83 trips per year. For the year 2021 the amount of 95.93% utilization level is lower than optimum, with the level effort 63.86% indicating efficiencies in fishing effort.

4.2. Recommendations

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

Appendix

Appendix 1. Regression analysis of Surplus Production Model of mackerel scad data in North Minahasa Waters

Model Schaefer

Table 3. *Summary of Schaefer Model.*

Model Summary				
Model	**R**	**R square**	**Adjusted R square**	**Std Error The Estimate**
1	.889	.789	.770	.2521756

a. Predictors: (Constant), E_t

Table 4. *Coefficient Regression of Schaefer Model.*

Coefficienta						
Model		**Unstandardized Coefficient**		**Standardized oefficient**		
		B	**Std. Error**	**Beta**	**t**	**Sig.**
1	(Constant)	8.562	.446		19.194	.000
	Et	-.066	.010	-.889	-6.422	.000

a. Dependent Variabel U_t

Table 5. *Anova of Schaefer Model.*

Anova						
Model		**Sum of Squares**	**Df**	**Mean Squares**	**F**	**Sig.**
1	Regression	2.623	1	2.623	41.241	0.000^b
	Residual	0.700	11	.064		
	Total	3.322	12			

a. Dependent Variabel: U_t
b. Predictor: (Constant), E_t

Model Fox

Table 6. *Summary of Fox Model.*

Model	**R**	**R square**	**Adjusted R square**	**Std Error the Estimate**
1	.895	.801	.783	.0426858

a. Predictors: (Constant), E_t

Table 7. *Coefficient Regression of Fox Model.*

Coefficienta					
Model	**Unstandardized Coefficient**		**Standardized oefficient**		
	B	**Std. Error**	**Beta**	**t**	**Sig.**
(Constant)	2.239	.076		29.656	.000
1					
Et	-.012	.002	-.895	-6.663	.000

a. Dependent Variabel Ln U_t

Table 8. *Anova of Fox Model.*

Anova						
Model		**Sum of Squares**	**Df**	**Mean Squares**	**F**	**Sig.**
	Regression	.081	1	.081	44.394	0.000[b]
1	Residual	.020	11	.002		
	Total	.101	12			

a. Dependent Variabel: Ln U_t
b. Predictor: (Constant), E_t

Model Schnute

Table 9. *Summary of Schnute Model.*

Model Summary				
Model	**R**	**R square**	**Adjusted R square**	**Std Error the Estimate**
1	.063	.004	-.217	.1112960

a. Predictors: (Constant), E_t

Table 10. *Coefficient Regression of Schnute Model.*

Coefficient[a]						
Model		**Unstandardized Coefficient**		**Standardized Coefficient**		
		B	**Std. Error**	**Beta**	**t**	**Sig.**
	(Constant)	.298	1.881		.159	.877
1	$(U_{t+1}+U_t)/2$	-.034	.220	-.149	-.156	.880
	$(E_{t+1}+E_t)/2$	-003	.015	-.175	-.183	.859

a. Dependent Variabel: Ln (U_{t+1}/U_t)

Table 11. *Anova of Schnute Model.*

Model		**Sum of Squares**	**Df**	**Mean Squares**	**F**	**Sig.**
	Regression	.000	2	.000	.018	.983[b]
1	Residual	.111	9	.012		
	Total	.112	11			

a. Dependent Variabel: Ln (U_{t+1}/U_t)
b. Predictor: (Constant), $(E_{t+1}+E_t)/2$, $(U_{t+1}+U_t)/2$

Model Walter-Hilborn

Table 12. *Summary of Walter-Hilborn Model.*

Model Summary				
Model	**R**	**R square**	**Adjusted R square**	**Std Error the Estimate**
1	.711[a]	.505	.395	.0789778

a. Predictors: (Constant), U_t (trip), C_t per E_t

Table 13. *Coefficient Regression of Waiter-Hilborn Model.*

Coefficient[a]						
Model		**Unstandardized Coefficient**		**Standardized Coefficient**		
		B	**Std. Error**	**Beta**	**t**	**Sig.**
	(Constant)	2.188	.858		2.550	.031
1	Ct per Et	-.272	.097	-1.405	-2.806	.021
	E_t (trip)	-.015	.008	-.974	-1.945	.084

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

Table 14. *Anova of Walter-Hilborn Model.*

Anova[a]						
Model		**Sum of Squares**	**Df**	**Mean Squares**	**F**	**Sig.**
	Regression	.057	2	.209	4.589	.042[b]
1	Residual	.056	9	.006		
	Total	.113	11			

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

Model CYP

Table 15. *Summary of CYP Model.*

Model Summary				
Model	**R**	**R square**	**Adjusted R square**	**Std Error the Estimate**
1	.875[a]	.765	.713	.0492154

a. Predictors: (Constant), Et + Et+1, Ln CPUE

Table 16. *Coefficient Regression of CYP Model.*

Coefficient[a]						
Model		**Unstandardized Coefficient**		**Standardized Coefficient**		
		B	**Std. Error**	**Beta**	**t**	**Sig.**
	(Constant)	3.485	.574		6.068	.000
1	Ln CPUE	-.561	.254	-.557	-2.210	.054
	Et + Et+1	-.009	.002	-1.226	-4.864	.001

a. Dependent Variable: Ln (Ut+1)

Table 17. *Anova. Of CYP Model.*

Anova[a]						
Model		**Sum of Squares**	**Df**	**Mean Squares**	**F**	**Sig.**
	Regression	.071	2	.036	14.659	.001[b]
1	Residual	.022	9	.002		
	Total	.093	11			

a. Dependent Variable: Ln (Ut+1)
b. Predictors: (Constant), Et + Et+1, Ln CPUE

Appendix 2. Validation (residual) of Surplus Production Model of Mackerel Scad Data.

Table 18. *Validation (residual) of model.*

Validation: Abs (Ct-$\widehat{C}_t$)/Ct							
Years	**C_t (tons)**	**E_t (trips)**	**Schaefer**	**Fox**	**Schnute**	**Walter-Hilborn**	**CYP**
2009	210.742	34	.0435	.0265	.1404	.3138	.4881
2010	231.765	36	.0202	.0744	.2933	.0955	.4749
2011	221.345	38	.0748	.0365	.1109	.0375	.1984
2012	240.341	40	.4235	.0165	.1404	13138	.4881
2013	230.420	42	.0202	.0744	.2933	.0955	.7749
2014	223.431	38	.2117	.0628	.0761	.1180	.0337
2015	227.372	34	.0413	.0093	.0992	.0397	.1085
2016	243.950	42	.0380	.0158	.1069	.0428	.1943
2017	228.720	45	.0823	.0743	.1321	.1534	.1980
2018	264.950	49	.0663	.0716	.0446	.0386	.2462
2019	274.150	56	.0731	.0242	.4023	.1441	.2358

Validation: Abs (Ct-$\widehat{C}_t$)/Ct							
Years	**C_t (tons)**	**E_t (trips)**	**Schaefer**	**Fox**	**Schnute**	**Walter-Hilborn**	**CYP**
2020	263.115	47	.0989	.1472	.0923	.1677	.1461
2021	275.970	53	.0314	.0909	.1401	.1054	.1655
Mean	241.251	43	0.0838	0.0767	0.1262	0.1281	0.3782

Schaefer Model:

$$\hat{C}_t = 0.789\, E_t - 0{,}0668\, E_t{}^2$$

Fox Model:

$$\hat{C}_t = E_t . e^{(2.239 - 0{,}012 E_t)}$$

Schnute Model:

$$\hat{Y} = a - b X_1 - c X_2 = 0.298 - 0.034 X_1 - 0.003 X_2$$

$$r = a = 0.298 \quad q = c = 0.003 \quad b = \frac{r}{Kq} = 0.034$$

$$K = \frac{r}{bq} = \frac{0.298}{(0.034)(0.003)} = 2{,}921.5683$$

$$\hat{C}_t = KqE_t - \frac{Kq^2}{r} E_t{}^2 = 8.7647\, E_t - 0.0882\, E_t^2$$

Walter – Hilborn Model:

$$\hat{Y} = a - b X_1 - c X_2 = 2.188 - 0.272 X_1 - 0.015 X_2$$

$$r = a = 2.188 \quad q = c = 0.015 \quad b = \frac{r}{Kq} = 0.272$$

$$K = \frac{r}{bq} = \frac{2.188}{(0.272)(0{,}015)} = 536.2745$$

$$\hat{C}_t = KqE_t - \frac{Kq^2}{r} E_t{}^2 = 8.0441\, E_t - 0.0551\, E_t^2$$

CYP Model:

$$\hat{Y} = a - b X_1 - c X_2 = 3.485 + 0.561 X_1 - 0.009 X_2$$

$$r = \frac{2(1-b)}{1+b} = \frac{2(1-0.561)}{1+0.561} = 0.5625$$

$$q = -c(2-r) = 0.009\,(2-0.5625) = 0.0129$$

$$Q = \frac{a(2+r)}{2r} = \frac{3.485\,(2+0.5625)}{2\,(0.5625)} = 7.9381$$

$$K = \frac{e^Q}{q} = \frac{e^{7.9381}}{0.0129} = 217{,}211.7519$$

$$\hat{C}_t = KqE_t - \frac{Kq^2}{r} E_t{}^2 = 2{,}802.0316\, E_t - 64.2599\, E_t^2$$

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