



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

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**Abstract:** Determination of utilization level and effort level of scad mackerel (*Decapterus spp*) are very important to know the status of fisheries management. This fish needs to be managed well because even as a renewable natural resources, but can undergo depletion or extinction. One of the approach in the management of fish resources is by mathematics modeling. In this research using Surplus Production Model (SPM) with 5 estimator methods, that are: Schaefer, Fox, Schnute, Walter-Hilborn, and Clarke Yoshimoto Pooley. 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 scad mackerel. The criteria of the best model (estimator) are: sign suitability of regression equation, value of coefficient determination, validation values (residual), and significance of regression coefficients. From the best model by using the formula can be determined the maximum sustainable yields (MSY) of catching, utilization level, and effort level. The data of catch and fishing effort of scad mackerel collected from the Marine and Fisheries the Bitung City and North Sulawesi Province from 1998 - 2016. The best SPM, which is used to assess the potential of scad mackerel is Schaefer Model. Optimal effort (EMSY) of 4,449 trips per year, with catch of optimal CMSY19,793.601 tons per year. The effort level for 2014 is 86.58%, which shows the quite efficient effort, the utilization level of 73.10% showing the production still can be increased.

**Keywords:** Scad Mackerel, Surplus Production Model, Maximum Sustainable Yield, Bitung

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## 1. Introduction

Mackerel scad (*Decapterus spp*) classified as important pelagic fisheries resources and one of the non-oil export commodity in North Sulawesi. Mackerel scad production in North Sulawesi (including Bitung waters) in 2016 reach 50,000 tons per year, with a value of about 100 billion rupiahs [1]. Research on mackerel scad generally discusses the exploitation to increase production, not much research on the status of utilization (including aspects of sustainability and efficiency) resources.

Catching mackerel scad 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 mackerel scad, is expected to be done in a planned and sustainable management.

The simplest model of the dynamics of fish populations is Simple 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 Bitung waters.

## 2. Surplus Prodction Model

The simplest model of the dynamics of fish populations is surplus production model that treats the fish population as a single biomass that cannot 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 acertain time  $t$  ( $C_t$ ), fishing effort at a certain time  $t$  ( $E_t$ ), and the natural growth rate constant ( $r$ ) (Boer dan Aziz, 1995) [2].

This model was first developed by Schaefer, who was initially the same as the form of logistic 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 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 (SPM) 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 SPM. Between the catch per unit of effort (CPUE) ang fishing effort can be either linear or exponential relationship [5]. SPM 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

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

$$\frac{dB_t}{dt} = G(B_t) = rB_t(1 - \frac{B_t}{K}) \quad (1)$$

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

$$\frac{dB_t}{dt} = rB_t(1 - \frac{B_t}{K}) - C_t \quad (2)$$

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

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

$q$  is catchability, and  $E_t$  is fishing effort. This equation can be written:

$$\frac{C_t}{E_t} = q B_t = CPUE \quad (4)$$

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:

$$rB_t(1 - \frac{B_t}{K}) - C_t = 0, \text{ or}$$

$$C_t = rB_t(1 - \frac{B_t}{K}) = qE_t B_t \quad (5)$$

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

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

So that equation (5) becomes:

$$C_t = q K E_t (1 - \frac{qE_t}{r}) = q K E_t \frac{q^2 K}{r} E_t^2 \quad (7)$$

Equation (7) is simplified further by Schaefer becomes:

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

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

while  $a = q K$  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  $E_t$  is:  $\frac{dC_t}{dE_t} = a - 2bE_t$  in order to

obtain the alleged  $E_{opt}$  (optimum fishing effort) and  $C_{MSY}$  (maximum sustainable yields of catch), respectively:

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

By entering the value of  $E_{opt}$  in equation (8), will be obtained as follow:

$$C_{MSY} = aE_t - bE_t^2 = a(\frac{a}{2b}) - b(\frac{a}{2b})^2 = \frac{a^2}{4b}$$

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 value of  $a$  and  $b$  are estimated by the least squares method approach that is commonly used to estimate the

coefficients of a simple regression equation. Furthermore, by including the value of  $E_{opt}$  in the 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 value of parameter  $q$ ,  $K$ , and  $r$  can be calculated using the Fox algorithm, as referenced in Sularso [5], as follows:

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

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  $q_t$ . From the values of  $a$ ,  $b$ , and  $q$ , can 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 [6]. The relation of CPUE with efforts ( $E$ ) follows a negative exponential pattern:

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

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

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

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

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

## 2.3. Schnute Model

Schnute, suggest another version of the SPM is dynamic and deterministic [7]. Schnute method is considered as a modification of the model in the form of discrete Schaefer (Roff, 1983, referred by Tinungki) [8].

$$\ln \left( \frac{U_{t+1}}{U_t} \right) = r - \frac{r}{qK} \left( \frac{U_t + U_{t+1}}{2} \right) - q \left( \frac{E_t + E_{t+1}}{2} \right) \quad (16)$$

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

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 [8], to develop other types of SPM, known as the regression model. Walter-Hilborn model, using a simple differential equation, by the following equation:

$$\frac{U_{t+1}}{U_t} - 1 = r - \frac{r}{qK} U_t - q E_t = a - b U_t - c E_t \quad (17)$$

## 2.5. Clarke Yoshimoto Pooley (CYP) Model

Estimation of biological parameter for the SPM can also be done through estimation techniques proposed by Clarke, Yoshimoto, and Pooley (Fauzi and Anna) [9]. The parameters which allegedly is  $r$ ,  $K$ , and  $q$ , the model is expressed as follows:

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

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:

$$\ln(U_{t+1}) = a' \ln(qK) + b \ln(U_t) - c(E_t + E_{t+1}) \quad (19)$$

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

# 3. Research Methods

## 3.1. Source of Data

The primary and secondary data of mackerel scad 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 1998-2016.

Data (variables) used for the analysis of the SPM is the data of 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 SPM 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 (trips) in year  $t$
3.  $\frac{C_t}{E_t}$  catch per unit of efforts

## 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 results of statistical evaluation (mark of conformity, the value of  $R^2$ , the validation (residual) value, and significance of the regression coefficient of the model), we get the “best” as estimator. From the best of model can be calculated  $C_{MSY}$  value, optimum fishing effort ( $E_{MSY}$ ), utilization:  $n$  level, and the level of effort of mackerel scad.

# 4. Result and Discussion

Catch of mackerel scad fisheries in the Bitung waters fluctuate from year to year. Data catching in 1998-2016, are presented in Table 1.

**Table 1.** Total catch, fishing efforts, and CPUE mackerel scad in Bitung waters of 1998-2016.

Years	Catch (tons)	Efforts (trips)	CPUE= $\frac{C_t}{E_t}$ (ton/trip)
1998	16,424.9	3,189	5.1505
1999	16,226.6	2,449	6.6258
2000	14,818.4	2,681	5.5272
2001	13,645.9	3,842	3.5518
2002	20,147.2	4,216	4.7787
2003	15,356.5	3,360	4.5704
2004	13,772.1	2,114	6.5147
2005	13,357.0	2,014	6.6321
2006	19,236.7	2,986	6.4423
2007	19,485.0	3,184	6.1197
2008	21,347.3	4,526	4.7166
2009	21,817.5	4,814	4.5321
2010	20,332.7	4,765	4.2671
2011	14,394.1	4,164	3.4568
2012	14,535.8	4,494	3.2345
2013	10,966.2	4,684	2.3412
2014	14,469.7	3,852	3.7564
2015	14,421.6	3,761	3.8345
2016	14,234.0	3,452	4.1234

Source: Calculated from the Marine and Fisheries Service Bitung City and North Sulawesi Province data

The results of the regression analysis for the SPM is presented in Appendix 1, which is described as follows:

#### 4.1. Schaefer Model

From the analysis of regression equation  $\frac{C_t}{E_t} = 8.898 - 0.001E_t$  with a coefficient of determination ( $R^2 = 0.639$ ) and a significance level of  $p < 0.01$ . Thus, a production model estimator catches Schaefer model according to equation (8) is:  $C_t = 8.898 E_t - 0.001 E_t^2$ .

#### 4.2. Fox Model

From the results of the regression analysis for Fox model is:  $\ln C_t = 2.397 - 0.000243 E_t$ , with  $R^2 = 0.577$  ( $p < 0.01$ ). Estimates of catches corresponding to the model Fox

equation (13):

$$C_t = E_t \cdot e^{(2.397 - 0.000243 E_t)}$$

#### 4.3. Schnute Model

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

$$\ln\left(\frac{U_{t+1}}{U_t}\right) = 0.647 - 0.059\left(\frac{U_t + U_{t+1}}{2}\right) - 0.000105\left(\frac{E_t + E_{t+1}}{2}\right)$$

with  $R^2 = 0.043$ , and all the regression coefficient were not significant ( $p > 0.05$ ).

#### 4.4. Walter - Hilborn Model

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

$$\frac{U_{t+1}}{U_t} - 1 = 1.386 - 0.169U_t - 0.000156E_t$$

with  $R^2 = 0.282$ , and all the regression coefficient were not significant ( $p > 0.05$ ).

#### 4.5. Clarke Yoshimoto Pooley (CYP) Model

The regression equation CYP method, according to equation (19):

$\ln(U_{t+1}) = 1.838 + 0.272 \ln(U_t) - 0.000102(E_t + E_{t+1})$ , with  $R^2 = 0.634$ , not all the regression coefficient were significant.

## 5. Discussion

The results of calculation for validation (residual) SPM 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	Fox	Schnute	Walter-Hilborn	CYP Model
Sign Suitability	Appropriate	Appropriate	Appropriate	Appropriate	Appropriate
R <sup>2</sup> Value	0.639	0.557	0.043	0.282	0.634
Validation Value	0.2043	0.1513	0.1569	0.1768	1.0215
Significance Coefficient	Significant	Significant	Not significant	Not all significant	Not all significant

From the results of the calculation in Table 2, it appears that the most appropriate is Schaefer model with the largest  $R^2 = 0.639$  and validation (residual value) is relatively small. Schaefer model obtained value of  $a = 8.898$  and  $b = 0.001$ , with equation (9) and (10) can be calculated optimum value of effort ( $E_{opt}$ ) and the maximum sustainable catch ( $C_{MSY}$ ) as follows:

$$E_{opt} = \frac{a}{2b} = \frac{8.898}{2(0.001)} = 4,449$$

trips per year

$$C_{MSY} = \frac{a^2}{4b} = \frac{8.898^2}{4(0.001)} = 19,793.601$$

tons per year

This mean that in order to preserve the mackerel scad fisheries resources technically and biologically, in a year the number of units should not exceed 4,449 trips. To preserve the mackerel scad resources in Bitung waters, the maximum of fish that can be caught at 19,793.601 tons per year. Furthermore, from the value of  $E_{opt}$  and  $C_{MSY}$  can be calculated fishing effort level and utilization level of mackerel scad for a particular year for example in 2014, as follows:

$$\text{The level of effort in 2014} = \frac{E_{2014}}{E_{opt}} \times 100\% = \frac{3,852}{4,449} = 86.58\%$$

$$\text{The utilization level in 2014} = \frac{C_{2014}}{C_{MSY}} \times 100\% = \frac{14,469.7}{19,793.601} = 73.10\%$$

From the calculation, it turns out mackerel scad fishing effort at the Bitung waters in 2014 (86.58%), lower than the optimum effort so that still can be increased. The utilization level for the year 2014 (73.10%), is lower than the optimum level, its mean the catching can be increased.

The researchs to know utilization level and effort level for pelagic fish, especially to little tuna in North Sulawesi waters by Kekenusa *et al* in Talaud and Bitung waters showing that the overfishing of production and inefficient of effort [10], [11].

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

## 6. Conclusions and Recommendation

### 6.1. Conclusion

1. The surplus production model that can be used to examine the catch of mackerel scad in the Bitung waters is Schaefer model, by the equation:  $C_t = 8.898 E_t - 0.001 E_t^2$ .

2. The maximum sustainable yield of mackerel scad  $C_{MSY}$  is 19,793.601 tons per year, obtained at the level of fishing effort  $E_{opt}$  4,449 trips. According to data at year 2014, for next years the catch and effort still can be increased.

### 6.2. Suggestion

1. 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 based on statistical criteria. The criteria involve, among others: suitability sign of the coefficient of models, coefficient of determination ( $R^2$ ), the value of validation (residual), and the significance of the regression coefficients.

2. The catches and efforts for mackerel scad in Bitung waters are lower than the optimum, so that still can be increased.

## Appendix

### Appendix 1. Regression Analysis of Surplus Production Model of Mackerel scad Data in Bitung Waters

#### Model Schaefer

Table 3. Model Summary.

Model	R	R square	Adjusted R square	Std Error The Estimate
1	.800	.639	.618	.7900942

a. Predictors: (Constant),  $E_t$

Table 4. Coefficients regression.

Model	Unstandardized Coefficient		Standardized coefficient		
	B	Std. Error	Beta	t	Sig.
(Constant)	8.898	.778		11.438	.000
1 $E_t$	-.001	.000	-.800	-5.489	.000

a. Dependent Variabel  $U_t$

Table 5. Anova.

Model		Sum of Squares	Df	Mean Squares	F	Sig.
1	Regression	18.807	1	18.807	30.127	0.000b
	Residual	10.612	17	.624		
	Total	29.419	18			

a. Dependent Variabel:  $U_t$

b. Predictor: (Constant),  $E_t$

*Model Fox**Table 6. Model Summary.*

Model	R	R square	Adjusted R square	Std Error the Estimate
1	.760	.577	.552	1900054

a. Predictors: (Constant),  $E_t$ *Table 7. Coefficients Regression.*

Model	Unstandardized Coefficient		Standardized coefficient		
	B	Std. Error	Beta	t	Sig.
(Constant)	2.397	.187		12.815	.000
1 Et	.000243	.000	-.760	-4.818	.000

a. Dependent Variabel Ln  $U_t$ *Table 8. Anova.*

Model		Sum of Squares	Df	Mean Squares	F	Sig.
1	Regression	.838	1	.838	23.215	0.000b
	Residual	.614	17	.036		
	Total	1.452	18			

a. Dependent Variabel: Ln  $U_t$ b. Predictor: (Constant),  $E_t$ *Model Schnute**Table 9. Model Summary.*

Model	R	R square	Adjusted R square	Std Error the Estimate
1	.208	.043	-.084	.24796212

a. Predictors: (Constant),  $E_t$ *Table 10. Coefficients Regression.*

Model		Unstandardized Coefficient		Standardized Coefficient		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	.846	.846		.765	.456
	$(U_{t+1}+U_t)/2$	-.059	.089	-.297	-.663	.518
	$(E_{t+1}+E_t)/2$	-.000105	.000	-.369	-.824	.423

a. Dependent Variabel: Ln  $(U_{t+1}/U_t)$ *Table 11. Anova.*

Model		Sum of Squares	Df	Mean Squares	F	Sig.
1	Regression	.042	2	.021	.340	.717b
	Residual	.922	15	.061		
	Total	.964	17			

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. Model Summary.*

Model	R	R square	Adjusted R square	Std Error the Estimate
1	.531a	.186	.2277233	.24796212

a. Predictors: (Constant),  $U_t$  (trip),  $C_t$  per  $E_t$ *Table 13. Coefficient Regression.*

Model		Unstandardized Coefficient		Standardized Coefficient		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	1.386	.687		2.019	.062
	$C_t$ per $E_t$	-.169	.072	-.873	-2.336	.034
	$E_t$ (trip)	-.000156	.000	-.564	-1.508	.152

a. Dependent Variable:  $(U_{t+1}/U_t - 1)$

Table 14. Anova.

Model		Sum of Squares	Df	Mean Squares	F	Sig.
1	Regression	.306	2	.153	2.947	.083 <sup>b</sup>
	Residual	.778	15	.052		
	Total	1.083	17			

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

b. Predictors: (Constant), Et (trip), Ct per Et

*Model CYP*

Table 15. Model Summary.

Model	R	R square	Adjusted R square	Std Error the Estimate
1	.796 <sup>a</sup>	.634	.585	.1872859

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

Table 16. Coefficients Regression.

Model		Unstandardized Coefficient		Standardized Coefficient		Sig.
		B	Std. Error	Beta	t	
1	(Constant)	1.838	.535		3.434	.004
	Ln CPUE	.272	.210	.272	1.297	.214
	Et + Et+1	-.000102	.000	-.588	-2.803	.013

a. Dependent Variable: Ln (Ut+1)

Table 17. Anova.

Model		Sum of Squares	Df	Mean Squares	F	Sig.
1	Regression	.911	2	.455	12.985	.001 <sup>b</sup>
	Residual	.526	15	.035		
	Total	1.083	17			

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.

Years	C <sub>t</sub> (tons)	E <sub>t</sub> (trips)	Validation: Abs(Ct-Ĉ <sub>t</sub> )/Ct				
			Schaefer	Fox	Schnute	Walter-Hilborn	CYP
1998	16,424.9	3,189	.4235	.2165	.1404	.3138	1.4881
1999	16,226.6	2,449	.0202	.1744	.2933	.0955	.7749
2000	14,818.4	2,681	.1248	.0365	.1109	.0375	.7984
2001	13,645.9	3,842	.4235	.2165	.1404	.3138	1.4881
2002	20,147.2	4,216	.0202	.1744	.2933	.0955	.7749
2003	15,356.5	3,360	.2117	.0628	.0761	.1180	1.0337
2004	13,772.1	2,114	.0413	.0093	.0992	.0397	.6085
2005	13,357.0	2,014	.0380	.0158	.1069	.0428	.5943
2006	19,236.7	2,986	.0823	.1743	.1321	.1534	.4980
2007	19,485.0	3,184	.0663	.1716	.1446	.1386	.5462
2008	21,347.3	4,526	.0731	.2242	.4023	.1441	.7358
2009	21,817.5	4,814	.0989	.2472	.4923	.1677	.7461
2010	20,332.7	4,765	.0314	.1909	.4401	.1054	.8655
2011	14,394.1	4,164	.3695	.1558	.0040	.2642	1.4679
2012	14,535.8	4,494	.3616	.1401	.1106	.2572	1.5406
2013	10,966.2	4,684	.7999	.5040	.0827	.6623	2.4329
2014	14,469.7	3,852	.3433	.1474	.0735	.2398	1.3500
2015	14,421.6	3,761	.3397	.1492	.0943	.2364	1.3247
2016	14,234.0	3,452	.3208	.1520	.1525	.2187	1.2330
Mean	16,262.60	3,607.74	0.2043	0.1513	0.1569	0.1768	1.0215

1. Schaefer Model:

$$\hat{C}_t = 8.898 E_t - 0.001 E_t^2$$

2. Fox Model:

$$\hat{C}_t = E_t \cdot e^{(2.397 - 0.000243 E_t)}$$

3. Schnute Model:

$$\hat{Y} = a - bX_1 - cX_2 = 0.647 - 0.059X_1 - 0.00105X_2$$

$$r = a = 0.647 \quad q = c = 0.000105 \quad b = \frac{r}{Kq} = 0.059$$

$$K = \frac{r}{bq} = \frac{0.647}{(0.059)(0.000105)} = 104,439.064$$

$$\hat{C}_t = KqE_t - \frac{Kq^2}{r}E_t^2 = 10.966E_t - 0.0018E_t^2$$

#### 4. Walter – Hilborn Model:

$$\hat{Y} = a - bX_1 - cX_2 = 1.386 - 0.169X_1 - 0.000156X_2$$

$$r = a = 1.386 \quad q = c = 0.000156 \quad b = \frac{r}{Kq} = 0.169$$

$$K = \frac{r}{bq} = \frac{1.386}{(0.169)(0.000156)} = 52,571.69$$

$$\hat{C}_t = KqE_t - \frac{Kq^2}{r}E_t^2 = 8.2012E_t - 0.000923E_t^2$$

#### 5. CYP Model:

$$\hat{Y} = a + bX_1 - cX_2 = 1.838 - 0.272X_1 - 0.000102X_2$$

$$r = \frac{2(1-b)}{1+b} = \frac{2(1-0.272)}{1+0.272} = 1.1447$$

$$q = -c(2-r) = 0.000102(2-1.1447) = 0.000087$$

$$Q = \frac{a(2+r)}{2r} = \frac{1.838(2+1.1447)}{2(1.1447)} = 2.5247$$

$$K = \frac{e^Q}{q} = \frac{e^{2.5247}}{0.000087} = 143,530.443$$

$$\hat{C}_t = KqE_t - \frac{Kq^2}{r}E_t^2 = 12.487E_t - 0.00095E_t^2$$

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