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LONG RUN VERSUS SHORT RUN ESTIMATES OF SUSTAINABLE YIELD: A CASE OF SMALL-SCALE DEMERSAL FISHERIES IN OMAN

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Abstract: This paper estimates both long- and short-run reference points under equilibrium and non-equilibrium bio-economic models for five commercially important demersal fish species from 1992 to 2016. The non-stationarity of catch-and-effort series, the statistical validity and the short run dynamics of the conventional bio-economic equilibrium models were examined using co-integrating regression along with error-correction mechanism. The key findings are: Firstly, catch and effort series are I(1); secondly, the presence of long-run equilibrium relationship under the Schaefer and Fox models for each species are observed; thirdly, a significant short-run deviation was detected leading to the estimation of reference points under non-equilibrium situation; and, fourthly, the Friedman Test results ($\chi 2$ with 2 df = 6.40) indicated that overall, there were significant differences between the MSY results of the three models. Furthermore, a pair-wise comparison using a Wilcoxon Signed rank test (Z = -2.03, p = 0.042) showed that there was a significant difference between the MSY estimates of the Fox and non-equilibrium models only at 5 % level. Lastly, the equilibrium yield (MSY) for the summed single species model exceeded the aggregate model results by 21.4 % and 26.0 % for Schaefer and Fox models, respectively.

Keywords: Bio-economic models, sustainable yield, small-scale fisheries, co-integration.

Introduction

Like other coastal states, the sustainable utilization of fishery resources is one of the strategic objectives stipulated in the Five-Year Plans of the Sultanate of Oman (Bose *et al*., 2010; Al-Siyabi & Bose, 2018), which is innately connected to the sustainability of fish stocks. Therefore, it is essential to estimate appropriate reference points (target and/or limit) to guide fishery managers in assessing stock sustainability and fishery resource trends (Caddy, 1999; Gabriel & Mace, 1999; Hilborn, 2002). However, the estimation of scientifically robust reference points would require detailed information on biological, ecological and socio-economic characteristics of fisheries, which are limited in the case of developing countries, including Oman (Salas *et al*., 2007; Cochrane & Garcia, 2009; de Graaf *et al*., 2011; Cadrin & Dickey-Collas, 2015; Al-Masroori & Bose, 2016).

Consequently, relatively, less data intensive equilibrium models such as Gordon-Schaefer (Gordon, 1953; Schaefer, 1954; Cunningham, *et al*., 1985) and Fox (1970) models have been widely used to estimate reference points for a single biological unit based on collected catch-and-effort data. Application of such models can be found in Indonesia (Soukotta *et al*., 2017), Pakistan (Siyal *et al*., 2013; Memon *et al*., 2015; Mohsin *et al*., 2017), India (Singh, 2015), Bangladesh (Habib *et al*., 2014), Japan (Oishi *et al*., 2014), Oman (Al-Habsi & Mustapha, 2011; Al-Masroori & Bose, 2016), Thailand (Ahmed *et al*., 2007), Brazil (Jiménez-Badillo, 2004) and Saudi Arabia (Jin *et al*., 2012), to name a few.

Although such equilibrium models are widely used in catch-and-effort analysis and generation of reference points, to the best of the authors' knowledge, the investigation of time series properties of catch-and-effort data has not received adequate attention, and the statistical validity of their association has rarely been tested. More importantly, the investigation of short-run deviation from the long-run equilibrium path in fisheries is scant.

With the above-mentioned limitations in mind, the objectives of this paper are to examine; 1. the statistical validity of the reference point estimates obtained from conventional bio-economic equilibrium models using the co-integrating regression techniques proposed by Granger (1981); 2. the statistical significance and the extent of short-run deviation from the long-run equilibrium path using the two-stage error correction mechanism (ECM) advocated by Engle & Granger (1987); 3. to pursue the short-run non-equilibrium model advocated by Pella & Tomlinson (1969) if the results of objective (2) are significant; and, 4. to perform a non-parametric test to determine if the difference between the reference point estimates of the long-run versus short-run models was significant. To meet the objectives, five commercially important demersal species, namely catfish (*Siluriforme sp.*), emperor (*Lethrinus miniatus*), grouper (*Epinephelinae sp.*), seabream (*Pagrus major*) and snapper (*Lutjanidae sp.*) of the artisanal fishery in the Al-Batinah Governorate in Oman are considered. More specifically, in estimating the sustainable yields as the title suggests, this paper empirically tested the following three null-hypotheses: Hypothesis 1: There is no long-run equilibrium relationship (i.e., cointegrating relationship) between catch and effort series; Hypothesis 2: There is no significant short-run deviation from the long-run equilibrium path; and, Hypothesis 3: There is no significant difference between the two sets of reference points generated from the equilibrium and non-equilibrium models.

It is worth mentioning that the first two null-hypotheses are interdependent, and they were tested using the Engle & Granger (1987) two-step procedure comprising cointegration regression and error-correction mechanism. The third hypothesis was tested using non-parametric (Friedman and Wilcoxon Signed rank) tests.

Maximum Sustainable Yield

As a “target reference point” (TRP), maximum sustainable yield (MSY) has been used as a fisheries management objective for a long time. During the 1950s and 1960s, the theoretical development of bio-economic model for the purpose of estimating MSY and the practice of using it as de facto fisheries management objective became widespread (Larkin, 1977). This yardstick received a special priority due to its prominence in the international fisheries legislation since the 1982 United Nations Convention on the Law of the Sea as it played a crucial role in the assessment of stock sustainability in the context of both single and multi-species fisheries (Caddy, 1999).

Although, MSY has the longest history in fisheries management, it has been subjected to wide-ranging criticism in the 1970s by many distinguished practitioners in the field. Their arguments against MSY can be grouped into the following categories: 1. Simplicity, the word “maximum” in the concept of MSY is too optimistic and the likelihood of achieving its status is very low (Kesteven, 1997): 2. Suitability, as this output-based concept fails to recognize some important goals of fisheries management, such as maximization of economic and social benefits and values (Parsons, 1993; Caddy & Mahon, 1995): and, 3. Technicality as the likelihood of obtaining an accurate estimate of MSY under uncertain conditions is recognized to be small (Kesteven, 1997).

However, in spite of these above-mentioned limitations, MSY remains in practice as an operational objective of fisheries management in developed and developing countries (Barber, 1988; Mkenda & Folmer, 2001) because it serves as a yardstick for management performance, as a signal of production potential (Larkin, 1977; Barber, 1988) and facilitates communication among non-technical key stakeholders (Barber, 1988; Parsons, 1993; Dichmont *et al*., 2010). The apparent simplicity is in determining it from catch-and-effort time series data using basic surplus production models (Barber, 1988).

MSY embraces the notion of future food security and provides more employment opportunities to economies that rely on seafood to a great extent (Parsons, 1993). Larkin's (1977) farewell comment to MSY acknowledged the contribution of MSY to the conservation of world fishery resources. Finley (2009) argued that the institutional popularity of MSY is not because of its scientific strength, but because of its policy and legal roles in fisheries management.

Being a single-species concept, the estimation of MSY for mixed-species fisheries is a challenging task. In recent years, there has been considerable debate in fisheries literature about the use of single-species MSY in mixed fishery cases (Guillen *et al*., 2013; Kumar *et al*., 2017). The derivation of single-species reference points in a mixed-fishery case has been criticized on the following two grounds. First, it assumes species are ecologically and technically (joint production) separate, which do not reflect the reality in mixed-fishery cases (Quinn II & Collie, 2005; Cochrane & Garcia, 2009). Second, Hilborn and Walters (1992) pointed out that the underlying equilibrium assumption in generating MSY is not valid from a bio-ecological perspective. Recognizing these limitations, some researchers have strongly made the case for MSY based on mixed species (Guillen *et al*., 2013).

Despite these drawbacks, the use of single-species based reference points is supported by the following reasons: The results generated from the best bio-economic models may be optimal in the "model world" but may not always be practical and, hence, unacceptable in real life (Dichmont *et al*., 2010). Single-species based reference points are better suited due to the rare use of ecosystem-based reference points (Cochrane & Garcia, 2009) as there is yet no clear evidence that the estimates emerging from the ecosystem models can be treated with full confidence, as they do not capture various forms of uncertainties (for example, scientific, structural, etc.) in fisheries (Larkin, 1977; Charles, 1998; Mamat *et al*., 2011; Salleh *et al*., 2011; Supriatna, 2012; Farcas & Rossberg, 2016;)

Single-species MSY can be used as "anchor point" to promote negotiation between the management authority and resource user group to address uncertainties (Al-Masroori & Bose, 2016). The long-run bio-economic equilibrium models in generating single-species MSY are simple to use and less data intensive (Die *et al*., 1990; Laloe, 1995). The identification of an acceptable level of fishing mortality for the target species and reducing the bycatch of overfished species and undersized fish are difficult in mixed-fishery cases (Poos *et al*., 2009; Ulrich *et al*., 2012). There is difficulty in obtaining MSY for multiple species simultaneously under the joint production scenario (Kraak *et al*., 2013; Kempf *et al*., 2016). In light of this discussion, it is felt that the adoption of a single-species and aggregated species model to derive reference points would be sensible for the case in hand.

Brief Profile of the Fisheries Sector

The government of Oman has laid out its "Vision 2020" national strategic plan, with policies to achieve economic diversification and to generate suitable conditions for directing the economy towards a sustainable development path (Ministry of National Economy (MNE), 2007; Busaidi *et al*., 2018). The ninth Five-Year Plan (2015–2020) attached high priority to fisheries as it is expected to make significant contributions to the economy and its diversification (Al-Siyabi & Bose, 2018; SCP, 2018). Accordingly, strategic objectives such as sustainable utilization of fishery resources, enhancement of socio-economic welfare, food security, and job creation, among others, have been stipulated in the plan (Bose *et al*., 2010; Al-Siyabi & Bose, 2018).

The Ministry of Agriculture and Fisheries (MAF) is the authority for managing fishery resources in Oman, and The Marine Fishing and Living Aquatic Resources Protection Law (MFLARPL) — which was implemented in 1981 according to the Royal Decree number 53/8

— provides legal mandate for the conservation and exclusive management of fishery resources within the country's territorial waters (Al Balushi *et al*., 2016).

Oman's coastline spans 3,165 km and is home to 150 species of fish and crustaceans (Belwal *et al*., 2012). The fisheries sector consists of commercial and traditional sub-sectors. Historically, the traditional sector has been the dominant one, both in terms of share in landings (99.07 % in 2016) and total value (98.03 % in 2016) (MAF, 2017). The Sultanate's fish production had increased from 158,000 tonnes in 2011 to 280,000 tonnes towards the end of 2016 (MAF, 2016), with an average growth rate of 12.12 %. With regard to the demersal species selected in this study, the respective shares of catfish, emperor, grouper, seabream and snapper landings from 1992 to 2016 on average were 2.94 %, 21.15 %, 14.09 %, 9.09 % and 6.72 %, respectively, of the total 70,469 tonnes of fish caught during the period. The selection of catfish is based on its positive trend in landing data.

For generations, the fisheries sector has provided the country with not only a significant source of foreign exchange earnings — which increased from 37 million OMR in 2000 to 73 million OMR in 2016 (Al-Naabi, 2018) — but also employment opportunities to locals. It was reported that more than 280,000 people depend on fishing and related activities to sustain their livelihood (Al-Busaidi *et al*., 2016). There has also been a steady increase in the net export of fish in the past 12 years, from 62.3 thousand metric tonnes in 2002 to 132.5 thousand metric tonnes in 2014, experiencing an average growth rate of 11.38 %.

The governorate of Al-Batinah (north and south) is the location of study (Figure 1) and its coastline is about 270 km along the Sea of Oman (Al-Subhi *et al*., 2013). It has 12 wilayats (i.e., towns): Sohar, Al-Suwaiq, Al-Khabourha, Saham, Liwa, Shinas, Barka, Wadi Al Mawil, Nakhal, Al Awabi, Rustaq and Al Masana'h (https://omantourism.gov.om, accessed Sept 12, 2018). Of these wilayats, Shinas, Liwa, Sohar, Saham, Khabourah, Suwaiq, Musana'a and Barka are located on the coast. These wilayats host the key fish landing ports analyzed in this study (Figure 1).

Al Oufi *et al*. (2000) reported that Al-Batinah is home to 35 % of Oman's traditional fishermen, who in turn, account for around 28 % of the total landings in the traditional fisheries sector. The intense competition among fishermen has led to overfishing (Al Oufi *et al*., 2000; Belwal *et al*., 2012) and, consequently, caused the fishermen to struggle for a subsistence source of income (Belwal *et al*., 2015). Further details on fisheries in Al-Batinah have been published by Belwal *et al*. (2012), Al-Subhi *et al*. (2013), Al- Jabri *et al*. (2015) and Belwal *et al*. (2015).

Materials and Methods

Data Source

The time series data from 1992 to 2016 for total landings (in weight and value) of selected demersal species and fishing effort (measured as number of fishermen) were obtained from the statistical yearbooks published by MAF.

Empirical Models: Equilibrium Models

Long-run bio-economic equilibrium models such as Schaefer (1954, 1957) and Fox (1970) that were widely used for estimating reference points were presented by Equations (1) and (2), respectively:

$$\frac{C_t}{E_t} = \alpha_0 + \alpha_1 E_t + \varepsilon_t; \quad (Schaefer\ Model) \qquad (1)$$

$$\ln\left(\frac{C_t}{E_t}\right) = \beta_0 + \beta_1 E_t + \eta_t; \quad (Fox\ Model) \qquad (2)$$

where, C_t and E_t are catch and fishing effort at time t, respectively, and $(\frac{C_t}{E_t})$ represents catch per unit of effort (CPUE). The symbols ε_t and η_t represent the error terms that are assumed to be white noise. The MSY is calculated as in Equations (3) and (4):

$$MSY\ (Schaefer\ Model) = -(\frac{\alpha_0^2}{4\alpha_1}) \qquad (3)$$

$$MSY\ (Fox\ Model) = \left(-\frac{1}{\beta_1}\right) \times \exp(\beta_0 - 1) \qquad (4)$$

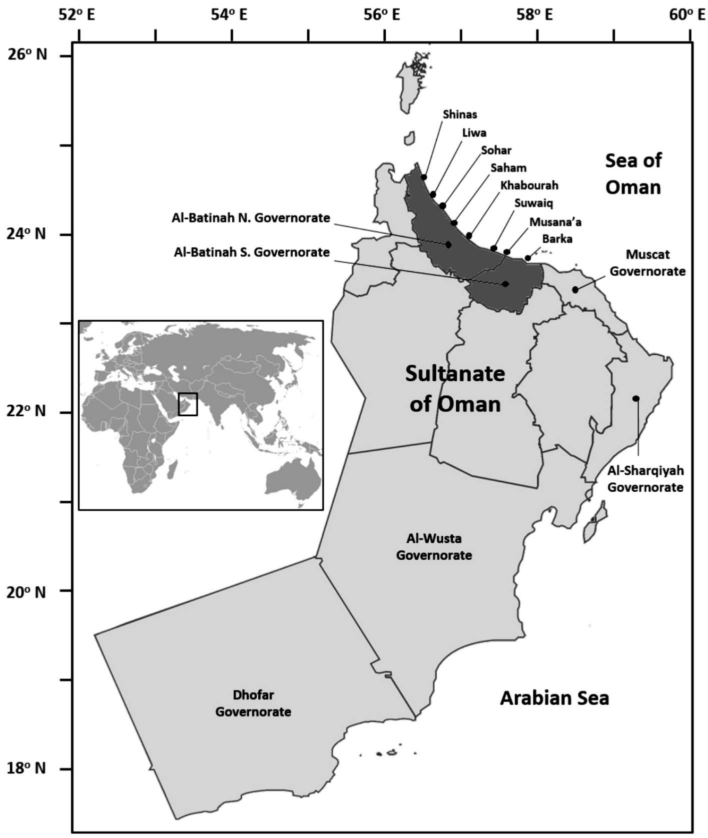

Figure 1: Map of the Sultanate of Oman, coastal governorates and study sites.

These models were based on the assumption that the net natural growth of fish biomasses was equal to the rate of harvest in the long run. The Schaefer and Fox models assumed a logistic and Gompertz growth function, respectively, and were the foundation of other bio-economic models. The derivation of the models could be found in Cunningham *et al*. (1985) and King (1995).

Investigations into long-run equilibrium properties of the above-mentioned models represented by Equations (1) & (2) involved certain key steps proposed by Granger (1981, 1986) and Engle & Granger (1987). They were testing for the stationarity (or unit roots) of the individual series involved, cointegration analysis to ensure non-spurious long-run equilibrium relationship and error correction mechanism (ECM) to detect short-run deviation from the long-run equilibrium path, respectively.

The Augmented Dickey-Fuller (ADF) and non-parametric Phillips-Perron (PP) tests were used and the null hypothesis (H_0) of no unit root, (i.e. the series is non-stationary) was tested. Further details on ADF and PP test could be found in Dickey & Fuller (1981) and Phillips & Perron (1988). According to Bose & McIlgorm (1996), sufficient number of lag terms were considered into the regressions to make the residuals' white noise.

Co-integration regression of Equations (1) and (2) involved satisfying the condition that the residual from the regression was stationary at its level. That implied that the residual was integrated of order 0, denoted as I(0). The ADF and PP tests were also used for testing whether the residual was I(0). The fully modified OLS technique was used to estimate the co-integration parameter according to Phillips & Perron (1988). It should be stressed that Ordinary Least Squares (OLS) estimator was "superconsistent" in estimating co-integrating coefficient (Stock, 1987). To detect short-run deviation from the long-run equilibrium path, the error-correction model proposed by Engle & Granger (1987) is stated in Equation (5):

$$\Delta Y_t = -\rho EC_{t-1} + \emptyset_0 \Delta X_t + \sum_{k=1}^{p} \emptyset_k \Delta X_{t-k} + \sum_{k=1}^{p} \delta_k \Delta Y_{t-k} + \varepsilon_t \quad (5)$$

where, represents the error-correction term, and are the variables under consideration representing the "CPUE" and "E", respectively.

The coefficient of the error correction term showed the extent of short-run deviations and its statistical significance justified for the estimation of reference points in short-run disequilibrium conditions.

Non-Equilibrium Model

The non-equilibrium model developed by Pella & Tomlinson (1969) and applied by others (Campbell & Hall, 1988) was used as in Equation (6).

$$\frac{U_{t+1} - U_t}{U_t} = r - \frac{r}{AK} U_t - AE_t \quad (6)$$

where $u_t = \frac{h_t}{E_t}$ represents CPUE, h_t represents catch, and K is the carrying capacity.

As stated by Campbell & Hall (1988), Equation (8) was estimated using OLS and the estimated parameters were used to calculate the reference points; MSY and maximum economic yield (MEY). The derivation of the model and its application had been stated by Campbell & Hall (1988) and Clarke *et al*. (1992). Econometric software packages SHAZAM and E-Views were used to estimate the models.

Results

This section presents the results of the overall empirical undertakings. Table 1 presents the results of the unit root tests for catch-and-effort (for individual species) series used in Schaefer and Fox models. The test results showed that the series under consideration were stationary at the first difference form. That series was labelled as I(1). In a bi-variate context, this finding enabled co-integrating regression to be applied.

Table 2 and 3 present the co-integrating regression results for the five species under the Schaefer and Fox models, respectively. The unit root results for the residuals presented in Table 4 confirmed that the variables used in the regressions were co-integrated as the residual series was integrated of order zero, i.e. I(0). In addition, the coefficient of effort was found to be negative and, therefore, consistent with the theory. It should be noted that the inclusion of deterministic trend polynomial into the cointegrating regression had helped to produce the theoretically consistent sign of the effort variable.

Table 1: Unit root test of Schaefer and Fox models for demersal fish species caught in Al-Batinah Governorate, Oman

Test Statistics	**Catfish**		**Emperor**		**Grouper**		**Seabream**		**Snapper**		**Effort**
Level Form	**Schaefer**	**Fox**	**Schaefer**	**Fox**	**Schaefer**	**Fox**	**Schaefer**	**Fox**	**Schaefer**	**Fox**	
ADF											
with constant	-2.948	-2.274	-1.246	-1.711	-1.815	-1.68	-1.531	-1.43	-3.514	-3.516	-1.739
with constant and trend	-3.141	-2.41	-2.891	-3.261	-2.547	-1.648	-2.241	-1.748	-3.816	-3.94	-2.882
Phillips-Perron											
with constant	-2.962	-2.262	-1.246	-1.438	-1.768	-1.535	-1.571	-1.418	-3.522	-3.554	-1.722
with constant and trend	-3.168	-2.398	-2.878	-3.966	-2.569	-2.817	-2.456	-2.64	-3.835	-3.987	-2.831
First Difference Form											
ADF											
with constant	-7.893	-5.761	-6.274	-7.045	-5.702	-7.155	-4.865	-6.211	-8.09	-8.723	-4.955
with constant and trend	-7.709	-5.654	-6.118	-6.964	-5.565	-6.942	-4.745	-6.031	-7.895	-8.47	-4.882
Phillips-Perron											
with constant	-8.999	-5.826	-6.274	-8.478	-5.855	-6.913	-4.972	-6.064	-8.897	-8.755	-5.069
with constant and trend	-8.988	-5.91	-6.118	-8.903	-5.69	-6.715	-4.828	-5.903	-8.686	-8.489	-4.966

Note: For the ADF and Phillips-Perron tests 5 and 1 lag terms were considered, respectively.

Table 2: Cointegration regression results for Schaefer model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Catfish				
Constant	0.015	0.006	2.359	0.028
Effort	-9.70E-07	8.37E-07	-1.158	0.260
Time	-0.000	0.000	-0.581	0.567
$(Time)^2$	3.01E-05	1.76E-05	1.708	0.103
R-squared	0.295			
Adjusted R-squared	0.190			
S.E. of regression	0.003			
Emperor				
Constant	0.072	0.041	1.760	0.093
Effort	-8.21E-06	5.35E-06	-1.536	0.140
Time	0.003	0.003	1.198	0.244
$(Time)^2$	9.26E-05	0.000	0.822	0.420
R-squared	0.750			
Adjusted R-squared	0.712			
S.E. of regression	0.019			
Grouper				
Constant	0.103	0.038	2.699	0.013
Effort	-1.31E-05	4.97E-06	-2.644	0.015
Time	0.004	0.002	1.377	0.183
$(Time)^2$	7.97E-05	0.000	0.761	0.455
R-squared	0.610			
Adjusted R-squared	0.552			
S.E. of regression	0.020			
Seabream				
Constant	0.079	0.020	3.815	0.001
Effort	-9.94E-06	2.70E-06	-3.676	0.001
Time	0.002	0.001	1.575	0.130
$(Time)^2$	6.81E-05	5.70E-05	1.196	0.245
R-squared	0.683			
Adjusted R-squared	0.636			
S.E. of regression	0.011			
Snapper				
Constant	0.034	0.017	2.009	0.058
Effort	-1.93E-06	2.21E-06	-0.873	0.392
Time	-0.000	0.001	-0.661	0.516
$(Time)^2$	7.30E-05	4.66E-05	1.567	0.132
R-squared	0.245			

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$(\text{Time})^2$	3.01E-05	1.76E-05	1.708	0.103
R-squared	0.295			
Adjusted R-squared	0.190			
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Time	0.004	0.002	1.377	0.183
$(\text{Time})^2$	7.97E-05	0.000	0.761	0.455
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Adjusted R-squared	0.552			
S.E. of regression	0.020			
Seabream				
Constant	0.079	0.020	3.815	0.001
Effort	-9.94E-06	2.70E-06	-3.676	0.001
Time	0.002	0.001	1.575	0.130
$(\text{Time})^2$	6.81E-05	5.70E-05	1.196	0.245
R-squared	0.683			
Adjusted R-squared	0.636			
S.E. of regression	0.011			
Snapper				
Constant	0.034	0.017	2.009	0.058
Effort	-1.93E-06	2.21E-06	-0.873	0.392
Time	-0.000	0.001	-0.661	0.516
$(\text{Time})^2$	7.30E-05	4.66E-05	1.567	0.132
R-squared	0.245			

Table 3: Cointegration regression results for Fox model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Catfish				
Constant	-3.293	1.402	-2.347	0.029
Effort	-0.0002	0.0001	-1.152	0.262
Time	-0.069	0.108	-0.633	0.533
$(Time)^2$	0.006	0.003	1.621	0.120
R-squared	0.308			
Adjusted R-squared	0.204			
S.E. of regression	0.660			
Emperor				
Constant	-3.580	0.651	-5.499	0.000
Effort	-9.43E-05	8.16E-05	-1.155	0.262
D_{1995}	0.028	0.384	0.073	0.942
Time	0.132	0.079	1.679	0.109
$(Time)^2$	-0.001	0.003	-0.456	0.653
R-squared	0.701			
Adjusted R-squared	0.638			
S.E. of regression	0.439			
Grouper				
Constant	-2.323	0.913	-2.542	0.019
Effort	-0.0002	0.0001	-2.132	0.045
Time	0.050	0.070	0.708	0.487
$(Time)^2$	0.003	0.002	1.393	0.178
R-squared	0.657			
Adjusted R-squared	0.605			
S.E. of regression	0.464			
Seabream				
Constant	-1.983	0.965	-2.055	0.053
Effort	-0.0003	0.0001	-2.954	0.007
Time	0.070	0.074	0.935	0.360
$(Time)^2$	0.004	0.002	1.563	0.133
R-squared	0.662			
Adjusted R-squared	0.611			
S.E. of regression	0.516			
Snapper				
Constant	-2.416	1.812	-1.333	0.197
Effort	-0.0002	0.0002	-1.182	0.250
D_{1995}	-0.844	0.772	-1.093	0.287
Time	0.094	0.057	1.645	0.115
R-squared	0.214			
Adjusted R-squared	0.096			
S.E. of regression	0.567			

Table 4: Unit root test of residuals under Schaefer and Fox models

Test Statistics	Catfish		Emperor		Grouper		Seabream		Snapper	
Level Form	**Schaefer**	**Fox**	**Schaefer**	**Fox**	**Schaefer**	**Fox**	**Schaefer**	**Fox**	**Schaefer**	**Fox**
ADF										
with constant	-4.18	-3.21	-3.40	-4.194	-3.87	-4.095	-4.69	-4.401	-4.70	-3.334
with constant and trend	-4.07	-3.123	-3.35	-4.069	-3.78	-4.034	-4.64	-3.755	-4.70	-3.295
Phillips-Perron										
with constant	-4.18	-3.21	-3.40	-4.194	-3.94	-4.18	-4.68	-4.448	-4.69	-3.445
with constant and trend	-4.07	-3.123	-3.40	-4.069	-3.94	-4.115	-4.68	-4.414	-4.69	-3.41

Note: For the ADF and Phillips-Perron tests 5 and 1 lag terms were considered, respectively.

Table 5 outlays the results of the ECM. It is noted that the coefficient of the error correction term was negative as expected theoretically and statistically significant at conventional levels of significance (1 % and 5 %). For groupers and snappers, subsequent lags in the dependent and the independent variables of the estimation equation were introduced to ensure white-noise residuals.

Table 6 presents the MSY and estimates of the Schaefer, Fox and non-equilibrium (Pella & Tomlinson, 1969) models for comparison. The statistical comparison between MSY estimates was done using a non-parametric test. The Friedman test results (χ^2 with 2 df = 6.40) indicated that overall there were statistically significant differences between MSY results of the three models. Furthermore, a pair-wise comparison was conducted using a Wilcoxon Signed rank test. The results (Z=-2.03, $p = 0.042$) showed that there was a significant difference between the MSY estimates of the Fox and non-equilibrium models only at the 5 % level. In the present case, the equilibrium yield (MSY) for the summed single species model exceeded the aggregate model results by 21.4 % and 26.0 % for Schaefer and Fox models, respectively.

Table 7 shows the estimates of MEY and associated cost and revenue for the non-equilibrium model. In order to estimate MEY, average price for the study period was calculated from the gross value and quantity of each species. Monthly cost per boat per month (307.32 OMR) was obtained from Bose *et al.* (2017). Since effort was measured as number of fishermen, this cost estimate was adjusted by the ratio of boats to fishermen, which was found to be 0.456. To convert the given cost to per year measure, the cost was multiplied by 12. Therefore, the cost was calculated as 1681.65 OMR/fisherman/year. It was important to note that for four out of five cases, the landings were higher than the reference point estimates (MSY and MEY).

Table 5: Results of error correction model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Catfish				
Constant	5.72E-06	0.000	0.007	0.994
ρ	-0.845	0.204	-4.134	0.000
ΔE	9.07E-07	8.02E-07	1.129	0.271
R^2	0.504	Akaike info criterion		-8.406
SSE	0.000	Schwarz criterion		-8.258
Log likelihood	99.678	Durbin-Watson stat		2.273
F-test	10.198	Jarque-Bera		1.162
Emperor				
Constant	0.007	0.003	1.858	0.077
ρ	-0.675	0.201	-3.351	0.003
ΔE	-7.49E-06	4.01E-06	-1.867	0.076
R^2	0.432	Akaike info criterion		-5.163
SSE	0.005	Schwarz criterion		-5.015
Log likelihood	62.376	Durbin-Watson stat		2.010
F-test	7.615	Jarque-Bera		2.513
Grouper				
Constant	0.004	0.003592	1.117	0.277
ρ	-0.846	0.178139	-4.752	0.000
ΔE	-2.02E-06	3.73E-06	-0.542	0.593
R^2	0.538	Akaike info criterion		-5.312
SSE	0.005	Schwarz criterion		-5.164
Log likelihood	64.097	Durbin-Watson stat		1.373
F-test	11.677	Jarque-Bera		2.567
Seabream				
Constant	0.003	0.0018	1.677	0.109
ρ	-0.901	0.1558	-5.788	0.000
ΔE	-2.82E-06	1.88E-06	-1.503	0.148
R^2	0.634	Akaike info criterion		-6.685
SSE	0.001	Schwarz criterion		-6.537
Log likelihood	79.881	Durbin-Watson stat		1.110
F-test	17.363	Jarque-Bera		3.092
Snapper				
Constant	0.003	0.001	1.674	0.112
ρ	-0.821	0.221	-3.718	0.001
ΔE	-3.33E-06	2.00E-06	-1.668	0.113
ΔE (-2)	-3.64E-06	1.96E-06	-1.858	0.080
ΔCPUE(-2)	0.010	0.143	0.071	0.944
R^2	0.581	Akaike info criterion		-6.624
SSE	0.001	Schwarz criterion		-6.376
Log likelihood	77.86	Durbin-Watson stat		1.813
F-test	5.896	Jarque-Bera		4.452

Table 6: MSY and E_{MSY} estimates of the Schaefer, Fox and non-equilibrium models

Species	Items	Schaefer	Fox	Non-Equilibrium
Catfish	Effort (No. of Fishermen)	7,600	4,784.68	6,424.52
	MSY (tonnes)	57.76	65.37	87.57
Emperor	Effort (No. of Fishermen)	4,384.90	10,604.45	9,903.84
	MSY (tonnes)	157.86	108.74	1,286.28
Grouper	Effort (No. of Fishermen)	3,931.30	3,968.25	2,699.20
	MSY (tonnes)	202.46	143.03	166.24
Seabream	Effort (No. of Fishermen)	4,019.11	2,717.39	4,686.81
	MSY (tonnes)	160.56	137.61	744.51
Snapper	Effort (No. of Fishermen)	8,808.29	3,610.10	5,558.33
	MSY (tonnes)	149.74	118.56	154.47

Aggregate Species Model

		Schaefer (%)	**Fox (%)**
	Effort (No. of Fishers)	3,933.33 (86.31)	5,050.5 (80.33)
	MSY (tonnes)	728.38 (21.39)	573.31 (26.01)

Table 7: Results of MSY, MEY and economic profit under non-equilibrium model

Species	Landings 2017 (tons)	MSY					MEY				
		Catch (Tonnes)	Effort (No. of Fishers)	Revenue (OMR)	Cost (OMR)	Profit (OMR)	Catch (Tonnes)	Effort (No. of Fishers)	Revenue (OMR)	Cost (OMR)	Profit (OMR)
Catfish	125	87.57	6,424.52	35,708.42	10,816.54	24,891.88	85.55	5,449.63	34,884.72	9,174.86	25,709.86
Emperor	1491	1,286.28	9,903.84	1,477,819.95	16,674.37	14,61,145.58	1,286.15	9,847.68	14,77,670.6	16,580.08	14,61,090.51
Grouper	891	166.24	2,699.2	1,46,886.34	4,544.5	1,42,341.84	160.46	2,196.49	1,41,779.25	3,697.56	1,38,081.69
Seabream	451	744.51	4,686.81	9,37,717.79	7,890.15	9,29,827.64	743.42	4,488.91	9,36,344.92	7,556.76	9,28,788.16
Snapper	368	154.47	5,558.33	1,30,868.53	9,358.39	1,21,510.14	154.27	5,359.56	1,30,699.09	9,023.32	1,21,675.76

Note: OMR represents Omani Rials. 1 OMR≈2.60 USD, 1 OMR≈2.28 Euros

Discussion

Sustainable utilization of fishery resources was among the goals of fisheries management in Oman. Bearing this in mind, this paper estimated the long- and short-run sustainable yields using both equilibrium and non-equilibrium models. The results of the unit root tests of the catch and effort series were consistent with the characteristics of the economic time series, that is, they were non-stationary at level form (i.e. I(1)). This implied that conditional mean, variance and auto-covariance of those series were not constant (Granger & Newbold 1974). Failure to recognize this property would lead to spurious estimates of MSY that could threaten the effectiveness of fisheries resource management and stock sustainability. As the catch-and-effort series were I(1) – a long memory series, any external shocks in the form of government policy and environmental change would cause considerable impact on the current value of catch and effort (Engle & Granger, 1991).

The results from the cointegrating regression indicated that the conventional bio-economic equilibrium models confirmed the statistical requirements and, hence, the sufficient condition for the existence of long-run equilibrium relations between the catch and effort series of individual species. The cointegration condition was satisfied in both Schaefer and Fox models and, hence, the null-hypothesis 1 could be rejected. This finding was partly similar to the findings of Mkenda & Folmer (2001), where the conditions were fulfilled only in the case of the Fox model, but not the Schaefer model.

The negative sign of the coefficient of effort variable in all cases satisfied the theoretical construct that stated negative relationship effort and CPUE. It was worth mentioning that the statistical significance of the coefficient in both models for two species, namely grouper and seabream, had important economic implications. For instance, the current landings of grouper were higher than MSY (see Table 7), indicating, perhaps, the occurrence of biological overfishing. Under the Gordon-

Schaefer framework, this situation suggested that the yield would decrease with increase in fishing effort. Given the market demand, and in the absence of close substitutes for grouper, this scenario under perfectly competitive market structure might cause the supply curve to shift leftward, resulting in new market equilibrium with increased price of fish and decreased quantity traded (Keen, 1991).

The second-stage ECM results showed a statistically significant deviation from the long-run equilibrium path which rejected the null-hypothesis. The coefficient of error-correction term explained the extent of disequilibrium that could be corrected at each period of time. This empirical result had important policy relevance since the fisheries sector had a considerable amount of uncertainty (Mangel & Clark, 1983; Charles, 1998; Al-Masroori & Bose, 2016; Al-Siyabi *et al*., 2018). As a result, reference points generating from a short run non-equilibrium model would be more realistic. The low values of the error correction estimates indicated that the speed of adjustment between short-run dynamics and long-run equilibrium path was slow, which might perhaps be caused by external shocks to the fishery system.

It was worth noting that in the case for two species, namely emperor and seabream, the short-run yield estimates were higher than those of the long-run counterparts. This, perhaps, indicated the supply side instability in the short-run for these regularly exploited species (Pontecorvo, 1973). The management implication, as pointed out by Pontecorvo (1973), was that if this short-run variation was inherent in the fishery system, this would call for an adaptive management approach. The comparative results obtained using non-parametric tests had caused the null hypothesis to be rejected. This was consistent with the above-mentioned argument regarding emperor and seabream species.

Turning to the estimates of MSY and MEY, it was observed that the magnitude of MEY estimates for yield and effort were lower than that of its counterpart and consistent with the theoretical expectation of the conventional equilibrium models. Under single-species modelling scenario, a legitimate question could be raised regarding the different fishing effort level attached to each species in a mixed-fishery case. While this exercise was based on a very restrictive assumption of "non-joint production" which might not reflect reality, fishery managers should know the stock status of each species to ensure a sustainable harvest. All the more, to address this concern, the aggregated species model (assuming a combination of different species is produced for a given set of fishing effort) was also estimated, which was not uncommon in developing countries (Ahmed *et al*., 2007). It was important to highlight that the single-species approach provided a valuable signal to the upper limit of the production potential of each species, which an aggregate analysis failed to provide.

In the lack of biological and ecological information, as argued by Cochrane & Garcia (2009), the results from single species models should not be abandoned but be supplemented by information on the fishery and ecosystem from other sources, including interested parties, socio-economic studies and the use of ecosystem indicators and models. The results also revealed that the summation of single-species reference point estimates was higher than that of the aggregate species model, which was consistent with the findings by Guillen *et al*. (2013) regarding multispecies and multifleet demersal fishery in the Bay of Biscay, off France. Similar findings were also reported by Fogarty *et al*. (2012) for demersal species of the Gulf of Maine in the United States and by Rijnsdorp *et al*. (2012) for flatfish fisheries in the North Sea, off the United Kingdom.

To summarize, reference point estimates obtained from the single-species, aggregated and non-equilibrium models provided a rudimentary signal of the yield and effort situation of the fishery. The ultimate decision of which reference point estimate to be used should be guided by the inherent management objectives and, more importantly, on the extent of uncertainties associated with fisheries (Larkin, 1977; Ludwig *et al*., 1993; Charles, 1998). If social objective (i.e. employment creation) outweighed the economic objective (MEY), then open access equilibrium (i.e. Total revenues = Total Costs) that maximized the level of fishing effort with no net economic returns from the fishery would be an option. However, this option was neither economically efficient nor biologically desirable. Therefore, following the precautionary approach (Garcia, 1994), it was recommended that the lower bound of the set of MSY estimates should be utilized to ensure long term sustainability of the fishery. Rijnsdorp *et al*. (2012) pointed out that initial MSY estimates should be tailor-made by involving stakeholders to trade-off the ecological and economic objectives. Also, Mace (2001) suggested that MSY should be used as a limit reference point rather than a target reference point to avoid the risk associated with the over-estimated MSY. Following the recent study by Al-Masroori & Bose (2016), it was recommended that this set of reference point estimates should be contested using other types of biological models if the data permits.

Conclusion

Using time series catch and effort data for five demersal species, this paper had generated long- and short-run reference point estimates. The time series properties of and long-run equilibrium relations between catch and effort were examined using unit roots tests and cointegrating regression, respectively. The error-correction mechanism was employed to examine the extent and significance of disequilibrium from the steady-state condition. Non-parametric tests confirmed a significant difference between the estimates of equilibrium and non-equilibrium models. However, these results should be interpreted with caution. Firstly, this study only represented a regional fishery incorporating only five commercially important demersal species. As a result, it did not embody the whole of Oman's demersal fishery scenario. Secondly, though the use of equilibrium models might not get support from a bio-ecological perspective, as mentioned earlier, the same was not true from a statistical standpoint. Despite the limitation, it is believed that the findings of this study would be pivotal for future research in this area.

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