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RESEARCH PAPER

Comparison of Catch and Survey Data for Assessing Northern Shrimp (*Pandalus borealis*) from Arnarfjordur (NW-Iceland) Using a Stock Production Model

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Abstract

Catch Per Unit Effort (CPUE) data and survey biomass indices of Arnarfjordur (NW-Iceland) shrimp stock (*Pandalus borealis*) were used as tuning series for a Surplus Production Model (SPM) fitted using three different types of software. It is observed that many of the model assumptions in the SPM are violated in this analysis. The average estimation of *MSY*, B_{MSY} and F_{MSY} among the software platforms were 776 t, 2977 t and 0.18 respectively for survey series, and 1109 t, 2195 t and 0.51 respectively for CPUE series. The interaction of relative fishing mortality over relative biomass for survey data is relatively more realistic based on empirical observation where fishing intensity, predation by cod and effect of physical parameters on the shrimp stock were revealed by many researchers. It is concluded that survey or fisheries independent data is more reliable than catch data or fisheries dependent data.

Keywords: Stock production model, Iceland, *Pandalus borealis*, CPUE data, survey data.

Introduction

One of the main purposes of fisheries scientist is to advise authority or decision makers on predictions of the reaction of a stock (Punt & Hilborn, 1997). This advice may include estimates on the level of fishing effort so that maximum weight or yield may be taken from a stock on a sustainable basis without affecting the catch of future years. Stock assessment or the advice on stock is not a one-off activity as the dynamic nature of fish stocks, fluctuating population and changes in the amount and efficiency of fishing efforts (King, 1995). Catch and fishing effort data are commonly collected for all commercial fisheries, as they are used to elucidate catch rate or catch per unit effort (CPUE). Catch rates are often used as an index of stock abundance and to demonstrate the condition of fish stock.

The Maximum Sustainable Yield (MSY) estimated by the stock production models has been an accepted fishery management goal, though its application has often been questioned (Hilborn & Walters, 1992; Quinn & Deriso, 1999). Stock production models (SPM) are also known as biomass dynamic models or surplus production models. They are among the simplest and most widely used models that refer to catch of excess or surplus biomass from a fish stock. In its simplest terms, stock size increases by reproduction and growth of small fish. Contrary to the production, the stock is reduced by natural mortality or by fishing mortality. This feature of stock dynamics was first formulated by Russel in 1931. The biomass in any year equals the previous year's biomass plus recruitment and growth minus natural mortality and the catch. As recruitment and growth refers to production and, if this is greater than mortality, biomass will increase. Biomass produced in excess of that required to replace losses is regarded as surplus production, which can be harvested without impairment of the stock. In this regard, maximum sustainable yield refers to the point at which the rate of surplus production is maximized (King, 1995). These models are flexible and have different formulation either assuming equilibrium or non-equilibrium, they can be either single species or multi-species (Pella & Tomlinson, 1969). The Schaefer, Fox and Pella-Tomlinson models are among the best known (Jennings *et al*., 2001). The first model that was associated with MSY concept was the surplus production model of Schaefer (1954). They are among the most used fish stock assessment models and pool all the effects of recruitment, growth, and mortality into a single production function and are widely used in tropical fisheries where age estimation is difficult or impossible (Haddon, 2011). Equilibrium surplus production models have been used widely for managing fisheries, because they are only require catch and effort data, which is relatively easy to

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collect (King, 1995). Since many fish stocks remain unstable at non-equilibrium state because of natural mortality or environmental fluctuations, equilibrium modeling has failed (Hilborn & Walters, 1992). Non-equilibrium models include process-error and observation-error methods (Hilborn & Walters, 1992; Quinn & Deriso, 1999) and the use of the equilibrium SPM's has not been recommended (Polacheck, *et al.*,1993). However, there has been a fundamental change in the perception of MSY as a limit to be avoided rather than a target that has routinely been exceeded (Mace, 2001). MSY reference points such as optimum biomass (B_{MSY}) and optimum harvest (F_{MSY}) are commonly used as management benchmarks (Jacobson *et al*., 2002).

Data used in stock assessment can be classified as fishery-dependent data or fishery-independent data. Fishery-dependent data is collected from the fishery itself, using both commercial and recreational sources. There are a variety of methods for obtaining fishery-dependent data. The most common approach is to use recorded landings. Another common mode for acquiring fishery-dependent data is through portside sampling of the catch to obtain age and length information on the stock. Other less common methods for obtaining data is through the use of onboard observers, self-reporting, telephone surveys and vessel monitoring surveys (Cooper, 2006). Fishery-independent data is obtained in the absence of any fishing activity. A wide variety of methods and gear types are used to acquire fishery-independent data. Sampling equipment can include trawls, seines, acoustic and video surveys. These surveys are specifically designed to follow consistent methods using the same gear for the duration of the survey in order to obtain unbiased and independent indices of abundance. Since the data are not influenced by specific management measures (size and bag limits, season closures, mesh sizes) or socioeconomic factors, they present an unbiased accounting of stock health. The data obtained after independent survey, when coupled with fishery-dependent data from fishermen reports, provide an overall picture of the fishery and stock status (Kilduff *et al*., 2009).

Northern shrimp (*Pandalus borealis* Kroyer, 1838) is an important target fishery of the North Atlantic (FAO, 1980) but it is also widely distributed in the North Pacific. It was first exploited as an experimental fishing in north-west Icelandic waters in 1924 (Garcia, 2007). However, a commercial fishery was started in 1935 when processing facilities was established in Ísafjörður. The shrimp fishery was then extended to Arnarfjordur in 1938. Later, other inshore areas were discovered at the periphery of Iceland and then offshore shrimp fishery initiated in 1974. It played an important role in increasing catches from a maximum of 7300 mt in 1973 (only of inshore fishery) to 76,000 mt in 1995 (Garcia, 2007). For stock assessment of inshore shrimp, the first trawl survey was conducted in 1988 (Skúladóttir *et al.*, 2001). Then, total allowable catch (TAC) in shrimp fishery was established based on these surveys. Hence, the available catch and effort data on northern shrimp in the Icelandic waters from both surveys and commercial fishing fleet would be a good case study to compare best fitting between two data series during assessment of fishery stock.

Materials and Methods

Data Sources

The time series data (catch and effort) of northern shrimp in Arnarfjordur, Iceland (Figure 1) was taken from the logbook database since 1983 to 2012 and standardized stratified bottom trawl survey biomass index data of northern shrimp in Arnarfjordur was taken from Marine Research Institute (MRI) database since 1988 to 2012 (Hafro.is 2013-14) (Figure 2). MRI total allowable catch (TAC) recommendations also shows in Table 1. The catch was in the form of weight in metric tons (t), effort was in the form of number of fishing unit (fishing hours), the survey biomass was in the form of weight in metric tons and TAC recommendations was also in the form of weight in metric tons. The data series was catch per unit effort (CPUE) and survey biomass index.

Stock Production Models

For this study a Schaefer model was applied. It is based on the logistic population growth model.

The model is described as:

$$B_{t+1} = B_t + rB_t\left(1 - \frac{Bt}{K}\right) - C_t$$

Where, *B* is the biomass, *t* is the time (year), *K* is the carrying capacity, *C* is the catch and *r* is the intrinsic rate of population increase. The carrying capacity of the system is the maximum population size that can be achieved. Mortality, age-structure, reproduction and tissue growth are all expressed by a simple parameter called the intrinsic rate of increase or intrinsic rate of production, *r*. In theory, *r* is fully realized at the lowest population level while the finite rate of population growth is highest at the midpoint of *K* (Schaefer, 1954).

The Schaefer model of surplus production demonstrates the theoretical link between stock size and expected catch rates thereby relating to the expected level of surplus production of a particular stock size on assumption that yield treated is always surplus production from a population in equilibrium and hence it is possible to estimate maximum sustainable yield (MSY) and the associated effort that will give rise to the MSY (E_{MSY}) given appropriate biomass (B_{MSY}). Given that catch is a product of

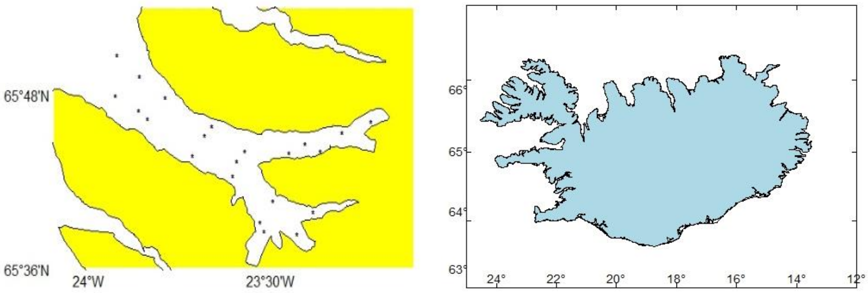

Figure 1. Map showing Arnarfjordur area in Iceland (Black spots indicate survey tow stations).

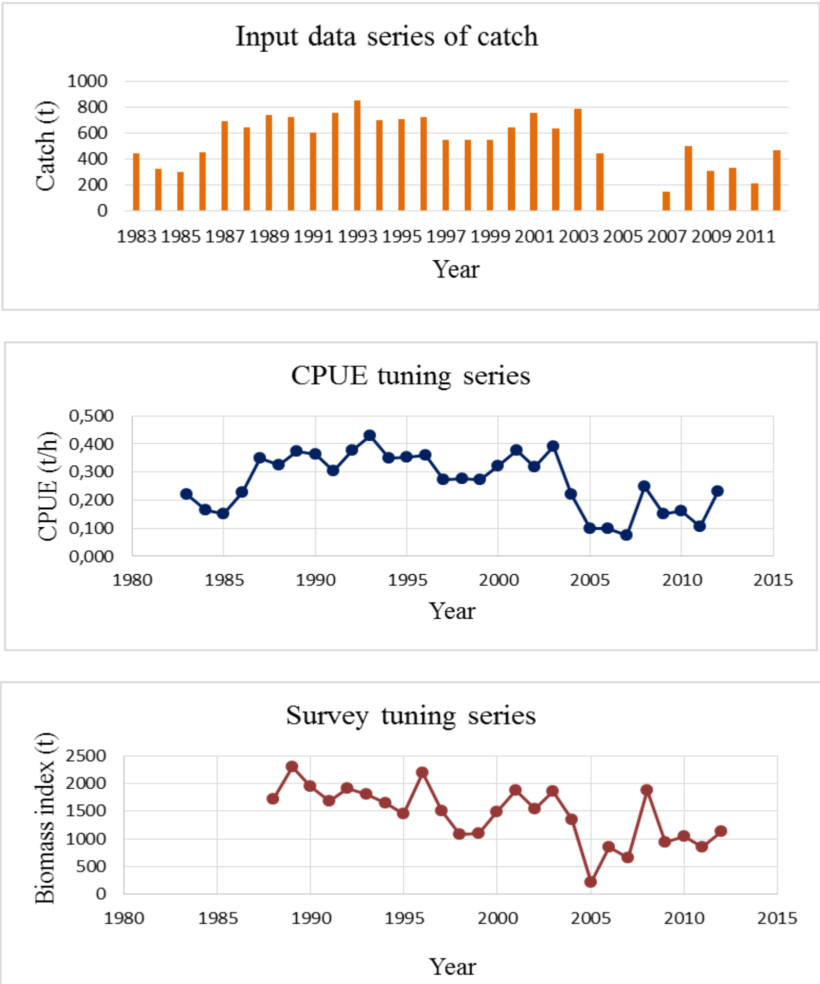

Figure 2. Input data of catch, CPUE and survey tuning series from Arnarfjordur shrimp stock (Hafro.is 2013-14).

Table 1. The estimated parameters through SPM from the three software platforms using the CPUE tuning series

Parameters	MS Excel	ASPIC	R
r	1.11	0.92	1.06
K	3162	5790	4220
q	0.000128	0.00006132	0.000088
B_{init}	583	778	715
MSY	878	1328	1123
B_{MSY}	1581	2895	2110
F_{MSY}	0.55	0.46	0.53

fishing mortality (F) and biomass the equation can be written as:

$$B_{t+1} = B_t + rB_t\left(1 - \frac{B_t}{K}\right) - F_t B_t$$

This equation is usually referred to as the biological model, where the population trajectory is simply a function of the initial biomass, the intrinsic growth rate (r), the carrying capacity (K) and the fishing mortality (F) (Polacheck *et al*. 1993). Indices of stock size such as catch rate (CPUE) is the most common available type of fisheries information where biomass information is inadequate. With the assumption that these indices are proportional to the stock size (Schnute & Richards 1998), then the equation below can be formulated:

$$CPUE_t = qB_t$$

Here, q stands for catchability coefficient, which acts as a simple scaling factor. The CPUE data can either be from the commercial fishery or based on survey abundance information.

MS-Excel

A non-equilibrium Schaefer surplus production model was fitted to the time series input data. The initial biomass (B_0), K and r for the stock was predicted at the beginning of the trend analysis. Then next year biomass was calculated by following function:

$$Biomass = max\ (B_0 + r * B_0 * (1 - B_0/K) - catch)$$

The max function ensures that the stock biomass cannot go extinct when using the solver. The values of catch and survey indices (CPUE) above were used to estimate catchability (q), while altering r and K in order to establish the most suitable fittings between observed and expected index for estimating these parameters. Sums of squared normal residual error (RSS) were then calculated. These estimated parameters were also transformed into log natural in order to calculate negative log likelihood (neglogL), using the following formula:

$$neglogL = 0.5*n*LN(2*PI()) + n*LN(sigma) + RSS\ /(2*sigma\text{^}2)$$

Where, n was number of year, LN was log natural, and sigma was residue of error.

This was done to check the uncertainty of the model. Then, solver was used to estimate the most reasonable output of desired parameters by targeting minimum residue sum of square (RSS).

ASPIC Computer Package (Prager, 2005)

A stock production model incorporating covariates (ASPIC, ver. 5.34.9) is a computer programme based on the non-equilibrium assumption state of the stocks. For ASPIC, the initial guesses of the parameter B1/K, MSY and their range including the value of q were input into by default program. The package then computed trajectories of absolute biomass, maximum sustainable yield (MSY), initial biomass over carrying capacity (B1/K), relative biomass (B/B_{MSY}) and relative fishing mortality (F/F_{MSY}). ASPIC also allows for forward projections. The estimated bootstrapped parameters were used to determine bias corrected trajectories.

R Programs

The value of r, K, B_{init} and q which were calculated by excel were used as initial starting values. Then Schaefer function was used to recalculate the value of these parameters. Same minimizing routine of Excel was followed in R script.

Derived Parameters

The estimated parameters r, q and K can be used to calculate management reference points such as maximum sustainable yield (*MSY*), Biomass that gives MSY (B_{MSY}), fishing mortality at MSY (F_{MSY}) as in:

$$MSY = \left(\frac{rK}{4}\right)$$

$$B_{MSY} = \left(\frac{K}{2}\right)$$

$$F_{MSY} = \left(\frac{r}{2}\right) or \left(\frac{MSY}{B_{MSY}}\right)$$

Results

Model Fit to the Tuning Series

The three software platforms used to fit the SPM to the two tuning series all have very similar fit indicated the most likely precision between observed and expected fit (Figure 3). The fit from R and ASPIC is the same for the CPUE data but the Excel fit is slightly different in the most recent years. The negative log likelihood were same as 8.70 for survey series for all software platforms. For CPUE series, R package showed the lowest negative log likelihood (-1.49) than other two software platforms.

Estimates of Parameters

The estimated parameters through SPM from three software platforms using the CPUE and survey tuning series were shown in Table 1 and Table 2. The average estimation of *MSY*, B_{MSY} and F_{MSY} among the software platforms were 776 t, 2977 t and 0.18 respectively for survey series, and 1109 t, 2195 t and 0.51 respectively for CPUE series.

Estimates of Population Trends

Commercial CPUE series showed that fishing mortality has a decreasing trend, from about 0.2 in the late eighties to well below 0.1 in recent years. At the same time, the biomass shows an increasing trend from about 2 t in 1985 to about 5.5 t in 2012 (Figure 4).

Survey biomass index estimated that total fishing mortality has been relatively constant or around 0.5 for the years surveyed except in 2003 and 2004 when it was peaked. Average biomass depicted gradual reduction from 1.5 t to 0.25 t since 1988 to 2005. Then, the biomass showed continuous increase and finally rose to around 1 t in 2012 (Figure 5).

For CPUE tuning series, the relative biomass (B/B_{MSY}) projected higher value, which was always more than 1.0. But, the relative fishing mortality (F/F_{MSY}) went through fluctuation around 0.4 and finally showed in decreasing trend (Figure 6)

For survey tuning series, the projected value of relative biomass (B/B_{MSY}) was always less than 0.5. At the same time, the relative fishing mortality (F/F_{MSY}) always showed the higher value, which was more than 1.0 (Figure 6). Particularly, the highest value of around 5.0 was in the year of 2003 to 2004 and the lowest value (0.9) was in the year of 2011.

Commercial harvest constantly followed the total allowable catch (TAC) recommended by Marine Research Institute (MRI) (Figure 7). In 1993, TAC recommendation was also the highest (850 t) among the years studied. The stock was in gradually decreasing trend since 1993 to 2003. Sharp decline of TAC was observed since 2003 (750 t) to 2005 (0 t).

Discussion

The collection and accurate interpretation of both fisheries dependent and fisheries independent data are of primary importance to assess any fish stock. Both should be considered together in order to provide a full information of stock (Kilduff *et al*., 2009).It is presumably said that fisheries independent data more reliable than fisheries dependent data.

Which Input Data Series is Better and Why?

Among tuning series used in parameter estimation through surplus production models, CPUE must have historical variation in stock size and fishing pressure to estimate the parameters of the model with any reliability (Hilborn & Walters, 1992). Hence, the estimation produced by the stock assessment models has an impact of greater extent on outcome, which was implanted with the tuning data itself. Moreover, commercial fisheries develop by nature with continuous increasing fishing effort and catch per effort decline accordingly (Jennings *et al.*, 2001). CPUE is an index of biomass and directly linked to the biomass by a constant catchability coefficient, *q*. As mentioned early, *q* was relatively constant for the survey vessel. Therefore, survey input data is likely to

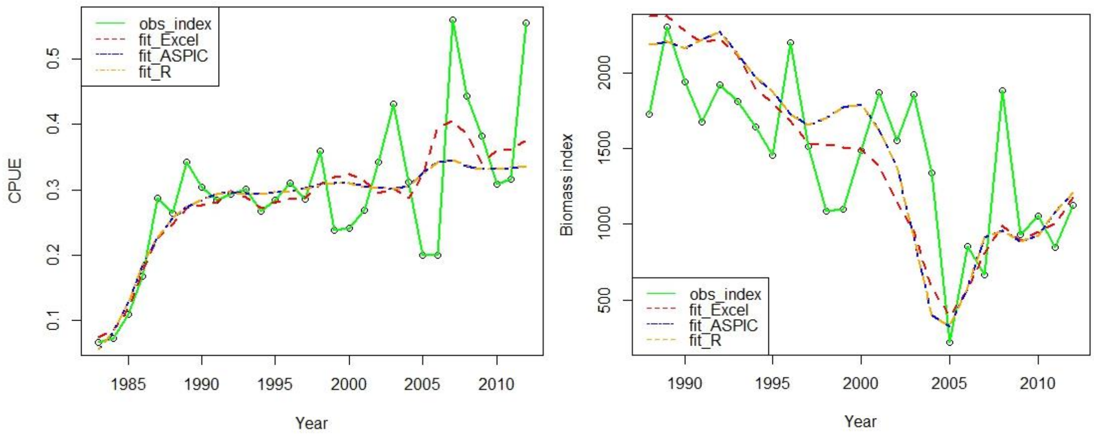

Figure 3. Observed and expected index fit to the CPUE (left) and survey index (right) used for tuning the stock production model.

Table 2. The estimated parameters through SPM from the three software platforms using survey tuning series

Parameters	MS Excel	ASPIC	R
r	0.47	0.63	0.46
K	5512	6000	6350
q	0.96	1.48	1.00
B_{init}	2475	1613	2227
MSY	651	944	736
B_{MSY}	2756	3000	3175
F_{MSY}	0.23	0.31	0.23

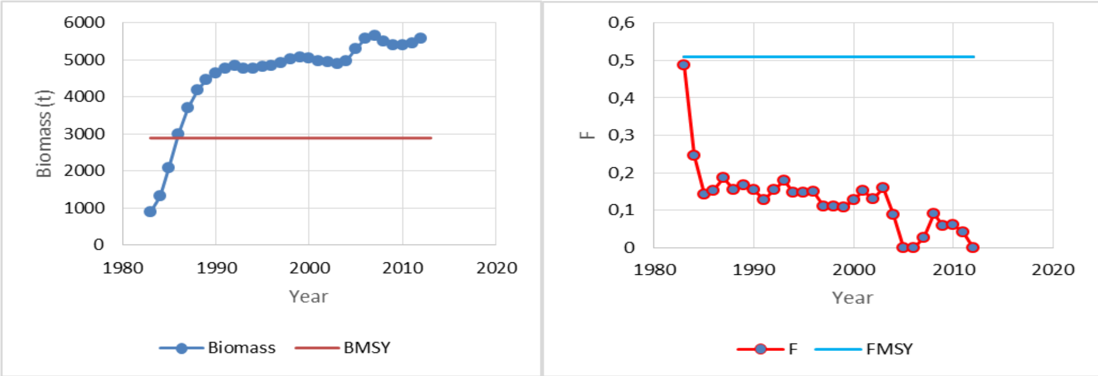

Figure 4. Estimates of exploitable biomass (left) and fishing mortality (right) from a stock production model fitted to CPUE tuning series.

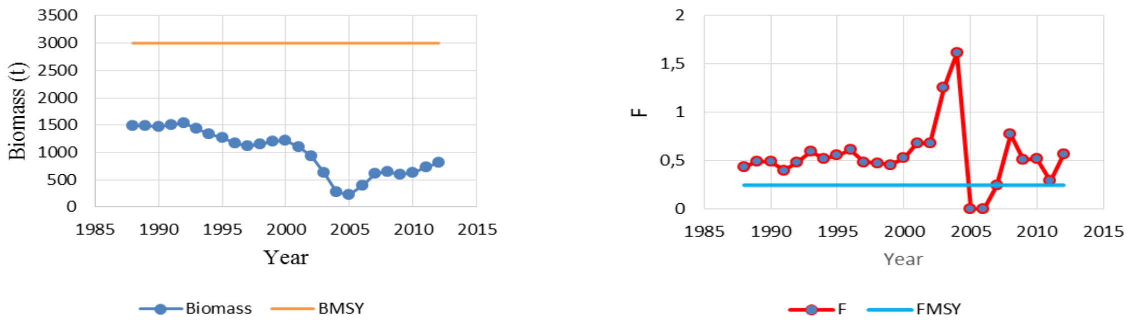

Figure 5. Estimates of exploitable biomass (left) and fishing mortality (right) from a stock production model fitted to survey tuning series.

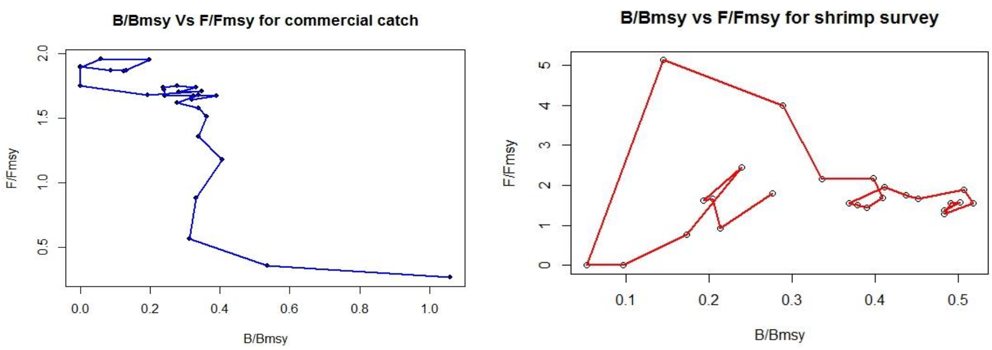

Figure 6. B/B$_{MSY}$Vs F/F$_{MSY}$ for CPUE (left) and survey (right) tuning series.

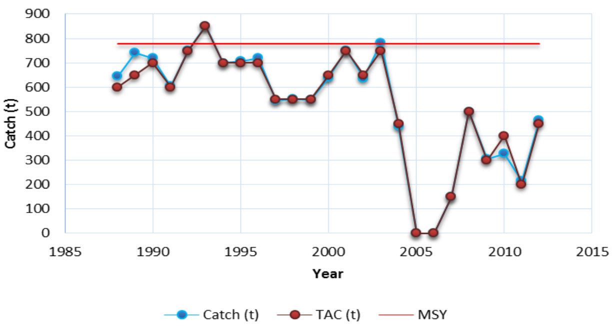

Figure 7. Recommended TAC and observed catch in Arnarfjordur shrimp fishery.

better meet with the SPM assumptions than commercial CPUE.

The maximum *r* of northern shrimp in CPUE tuning series was 1.02, which is much higher than the estimate (0.33) on northern shrimp off Greenland (Hvingel & Kingsley 2000) and the reported value (0.63) on the Gulf of Maine fishery for northern shrimp (36th SAW Consensus Summary). But in case of survey tuning series of Arnarfjordur shrimp stock, the value of *r* was projected within range of two recognized studies on northern shrimp. Moreover, the surplus production of survey data showed much greater value than commercial CPUE series during rebuilding of stock, which was roughly met with the model assumption.

For the survey biomass tuning series, observed and estimated biomass index were well corresponded and *r*, *q* and *K* reasonably estimated. Therefore, the product of *r* and *K*, that is management reference points, *MSY*, B_{MSY} and F_{MSY} for survey biomass input data were projected more reasonable estimation of SPM than that of CPUE tuning series.

Particularly, the value of F_{MSY} for survey biomass data showed much lower reference point (0.25 average) than that of CPUE data series (0.51 average). Though the value of F_{MSY} may be area specific, survey tuning series showed more reasonable reference point for fishing mortality, which has in accordance the value (0.29) by Hvingel & Kingsley (2000) and the reported value (0.16) in 36th SAW Consensus Summary on northern shrimp. Practically the survey biomass index was very low (below B_{LIM}) in 2005 (Figure 2), due to gadoid predation (Skuladottir *et al*.,2001 & Jonsdottir *et al.*, 2012) and fishing pressure in 2003 to 2004 (Figure 2) in comparison to biomass level in those years (Figure 5). Therefore, the area was not opened for fishing in 2005 to 2006. Protandric (sequential) hermaphrodites, spawning migration (36th SAW consensus summary) and aggregating behavioral pattern of shrimp by gadoid abundance likely to affect the commercial CPUE, which thereby influence the reliability of their result. In light of this notion, the F_{MSY} reference point from survey tuning series is more sensible than CPUE tuning series.

Hence, it is concluded for Arnarfjordur shrimp stock that, survey tuning series is less violated the model assumptions and fairly reasonable estimated the stock than that of CPUE for prescribing management reference points. However, it should not be wise to forget that the information embedded in the data might not be sufficient to answer that are asked of it (Haddon, 2011).

Are Model Assumptions Met with the Input Data Series?

The results of SPM estimation of Arnarfjordur shrimp stock are interpreted on the basis of limitations of the model and input data of CPUE and survey biomass indices being studied and obviously fine tuning of assumptions. The surplus production model (SPM) has the several assumptions:no species interactions, intrinsic growth rate *r* responds instantaneously to changes in population biomass (no time laps),Catchability coefficient *q* is constant, fishing and natural mortality take place simultaneously, No changes in gear or vessel efficiency have taken place and Catch & effort statistics are accurate.

Practically, some of the assumptions are not met but this does not mean that the method cannot be used or is not meaningful for the population estimation. As long as it is used critically, the production model is a very powerful tool for an initial assessment of a stock (Musick & Bonfil, 2004), though an equilibrium is assumed to be contrasting in a fished population (Haddon, 2011). Some of the model assumptions in the SPM are violated in the analysis in this present study. The most important violation is the assumption that there are no species interactions that affect the abundance and productivity of the shrimp stock. Another violation is the assumption that catchability has remained constant over the period. This assumption is likely to hold true for the survey model but it is obviously said that it is violated in the commercial CPUE.

Management Reference Points of the Stock

The model estimated constant lower biomass in comparison to projected B_{MSY} for survey tuning series and at the same time, fishing mortality constantly showed higher value than F_{MSY} except in the year 2005 to 2006 (Figure 5). Surprisingly it was totally inverse for CPUE tuning series, where biomass exceeded the level of B_{MSY} in the year 1986 and gradually increased over the study period. Simultaneously, fishing mortality constantly showed lower value than F_{MSY} (Figure 4). It is likely to be stated that survey biomass index projected more rational estimation about Arnarfjordur shrimp stock because the result of this has more likely correspondence with practical observation. In reality, Arnarfjordur shrimp fishery is in rebuilding pace after massive decline of biomass in the year 2005 to 2006 due to long time effect of predation and fishing pressure; and perhaps this catastrophe reached at peak in the year of 2003 to 2004. This also indicated the need to reduce fishing pressure from existing scale.

The average estimation of MSY through survey tuning series was 776 t. The observed catch showed always the level below MSY except in the year of 1993, when TAC recommendation was also the highest among the years studied. Though, recommended TAC followed by commercial fishers, the stock is in gradually decreasing trend since 1993 to 2004, while sharp decline was observed since 2003. The reason may either be that the stock is over estimated or presence of high gadoid predation.

Fishing activities may also distort the shoaling behavior of shrimp that indirectly encourage predation because scattered shrimp is more preyed upon by gadoid than shoaling shrimp (Bjornsson *et al.*, 2011).

Relative fishing mortality and relative biomass were also found to be inversely related and the scenario was different between two data series. This interaction of relative fishing mortality over relative biomass of survey input data series is likely to be more realistic with empirical observation, where predation by cod, fishing intensity and effect of physical parameters on the shrimp stock were demonstrated by many researchers (Skúladóttir *et al*.,2001; Jonsdottir *et al*.,2012; Anderson, 2000; Idone, 2006).Hence, it is conclude that survey or fisheries independent data is more reliable than catch data.

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