ASSESSING SHRIMP (*PANDALUS BOREALIS*) FROM ARNARFJÖRÐUR (NW-ICELAND) USING A STOCK PRODUCTION MODEL AND TWO DIFFERENT TUNING SERIES

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ABSTRACT

Catch Per Unit Effort data (CPUE) data and survey biomass indices of Arnarfjordur shrimp stock (*Pandalus borealis*) were used as tuning series for a surplus production model fitted using three different types of software. The three software namely MS Excel, ASPIC and R all fitted the data in a similar way and gave roughly the same parameter estimates. The intrinsic growth rate, r was estimated in the range of 0.91744 to 1.11, the catchability coefficient, q ranged from 0.000088 to 0.000128 and the carrying capacity, K ranged from 3162 t to 5790 t for the CPUE tuning series. For the survey tuning series, r was 0.408 to 0.629, q was 0.95 to 1.47 and K was 5512 t to 6350 t. It is observed that many of the model assumptions in the SPM are violated in this analysis. Apart from various limitations and violation of assumptions, the most important violation is the assumption that there are no species interactions that affect the abundance and productivity of the shrimp stock, and the assumption of constant catchability. Though model assumptions are not met with the Arnarfjordur shrimp fishery, survey tuning series is less violated in the model assumptions and fairly reasonably estimated the stock compared to that of the CPUE. It was found that the average estimation of MSY, B_{MSY} and F_{MSY} were 776 t, 2977 t and 0.18 respectively for survey tuning series, and 1109 t, 2195 t and 0.51 respectively for CPUE tuning series. Besides, relative fishing mortality and relative biomass were inversely related and the scenario was different between two data series. From management reference point of view, survey tuning series estimated more reasonable estimation for all three software platforms than CPUE tuning series. The interaction of relative fishing mortality over relative biomass for survey tuning series 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.

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1 INTRODUCTION

1.1 Background information

One of the main purpose 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.

Northern shrimp (*Pandalus borealis,* Kroyer 1838) (Figure 1) 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 for acquiring practical knowledge on assessment of fishery stock.

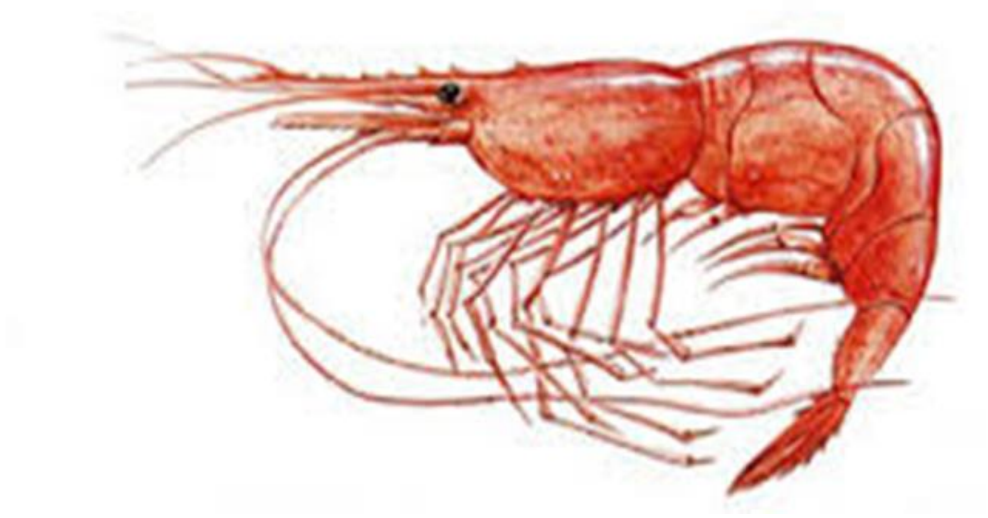


Figure 1: The northern shrimp (P. borealis).

1.2 Project objective

The status of northern shrimp stock in Arnarfjordur, Iceland was examined as a case study using a stock production model.

1.3 Goals

The goals of the project are:

1. Model and describe the trend of northern shrimp in Arnarfjordur.
2. Determine the total biomass, fishing mortality and MSY of northern shrimp.

2 REVIEW OF LITERATURE

2.1 A case study on assessment of Icelandic shrimp

Icelandic shrimp (*P. borealis*) is locally known as ‘Stori Kampalampi’. Soft bottom, muddy or sandy silt are preferred as habitat for this species within the depth range of 20 to 1380 m (FAO 1980). Among this depth range, larvae and juveniles are distributed in coastal or inshore waters but the adult shrimp dwelling in offshore waters. Maximum total lengths of this species are 120 mm (male) and 165 mm (female) (FAO 1980). The northern shrimp is able to carry out substantial horizontal and vertical migrations. The shrimp remains close to the bottom during daylight hours but has vertical migrations, ascending in the water column in the evening and returning to the sea bottom in the morning in order to feed on macroplankton (Parsons *et al.* 1998, Bergstrom 2000). Temperature, substratum and salinity are important factors that impact the distribution of *P. borealis* (Shumway 1985).

Northern shrimp are preyed upon by many fish species (Parsons *et al.* 1998) such as cod (*Gadus morhua*), Greenland halibut (*Reinhadtius hippoglossoides*) and redfish (*Sebastes marinus*) and also by sea birds and some marine mammals. In Iceland, almost all the shrimp stocks did collapse in the wake of a more northern more distribution of cod (Skúladóttir *et al.* 2001). In contrast, shrimp stock in Greenland and Newfoundland gradually collapsed due to high fishing pressure, where cod stocks had collapsed before (Vilhjalmsson *et al.* 2004).

2.2 Stock production models in fish stock assessment

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).

SPMs are easy to use because they require only two or three types of data. These models are flexible and have different formulation either assuming equilibrium or non-equilibrium, they can be either single species or multi-species. 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). There are abundant literatures on stock production models. 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 requiring catch and effort data, which is relatively easy to 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 and Walters 1992). Non-equilibrium models include process-error and observation-error methods (Hilborn and 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).

3 METHODOLOGY

3.1 Study area

Historical catch and effort data and survey data of northern shrimp catch in Arnarfjordur, north-west Iceland were used as input data in a Schaefer stock production model. Arnarfjordur is a 40 km long and 7 km wide two armed fjord (Figure 2) having 60 to 110 m deep with steep sub-surface slopes, especially on the north side (Helgadottir *et al.* 2002). A branch of the warm North Atlantic Current flows north along the west coast of Iceland and mixes with run-off from land. Part of this water flows into Arnarfjordur at intermediate depths along the south coast and out along the north coast. During winter, the water is cooled on its way in and out of Arnarfjordur.

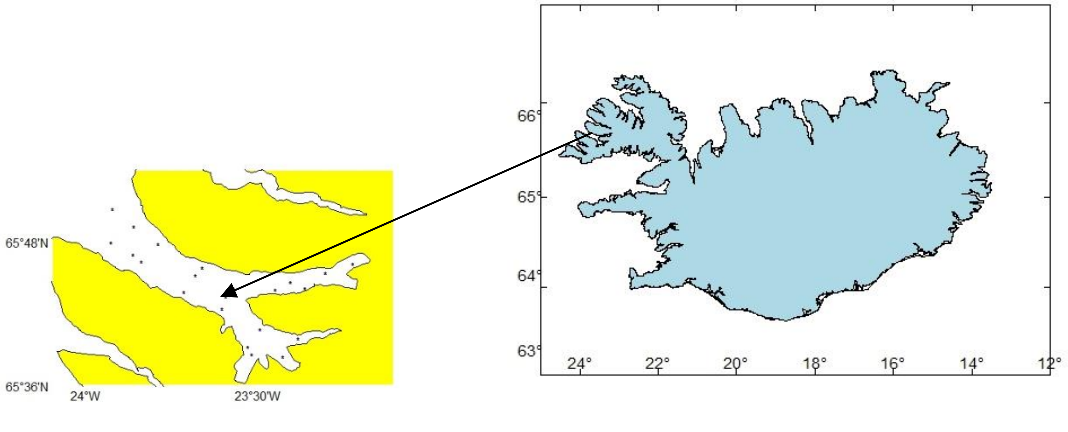


Figure 2: Map showing Arnarfjordur area in Iceland (Black spots indicate survey tow stations).

3.2 Data sources

The time series data (catch and effort) of northern shrimp in Arnarfjordur 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 (Table 1 & Figure 3). 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. Those data provide e.g. catch per unit effort (CPUE) and survey biomass index which were required in the SPM study.

3.3 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:

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

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).

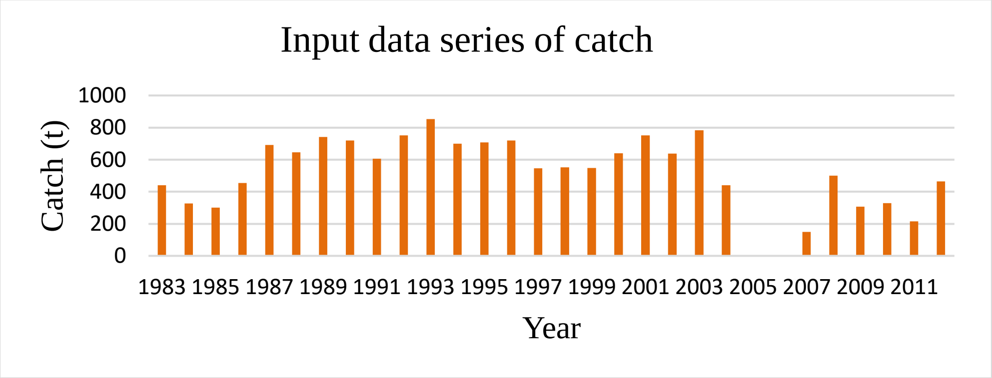
The Schaefer model of surplus production demonstrates the theoretical link between stock size and expected catch rates thereby relating to the expected level of surplus production of a particular stock size on assumption that yield treated is always surplus production from a population in equilibrium 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 fishing mortality (*F*) and biomass the equation can be written as:

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

Table 1: The time series data of northern shrimp for commercial catch, TAC and survey biomass indices (http://www.hafro.is/undir_eng.php?ID=26&REF=4).

Year	Catch (t)	CPUE (t/h)	TAC (t)	Survey_bio index (t)
1983	441	0.222	-	-
1984	326	0.164	-	-
1985	300	0.151	-	-
1986	454	0.229	-	-
1987	692	0.348	-	-
1988	645	0.324	600	1724

1989	741	0.373	650	2301
1990	720	0.362	700	1939
1991	605	0.304	600	1674
1992	751	0.377	750	1918
1993	853	0.428	850	1809
1994	700	0.351	700	1640
1995	707	0.354	700	1452
1996	720	0.361	700	2200
1997	546	0.273	550	1511
1998	551	0.276	550	1087
1999	548	0.274	550	1098
2000	640	0.320	650	1489
2001	752	0.376	750	1869
2002	637	0.318	650	1549
2003	783	0.391	750	1856
2004	440	0.220	450	1341
2005	-	-	-	222
2006	-	-	-	854
2007	150	0.075	150	663
2008	500	0.249	500	1884
2009	306	0.152	300	934
2010	328	0.163	400	1054
2011	216	0.107	200	844
2012	465	0.231	450	1127



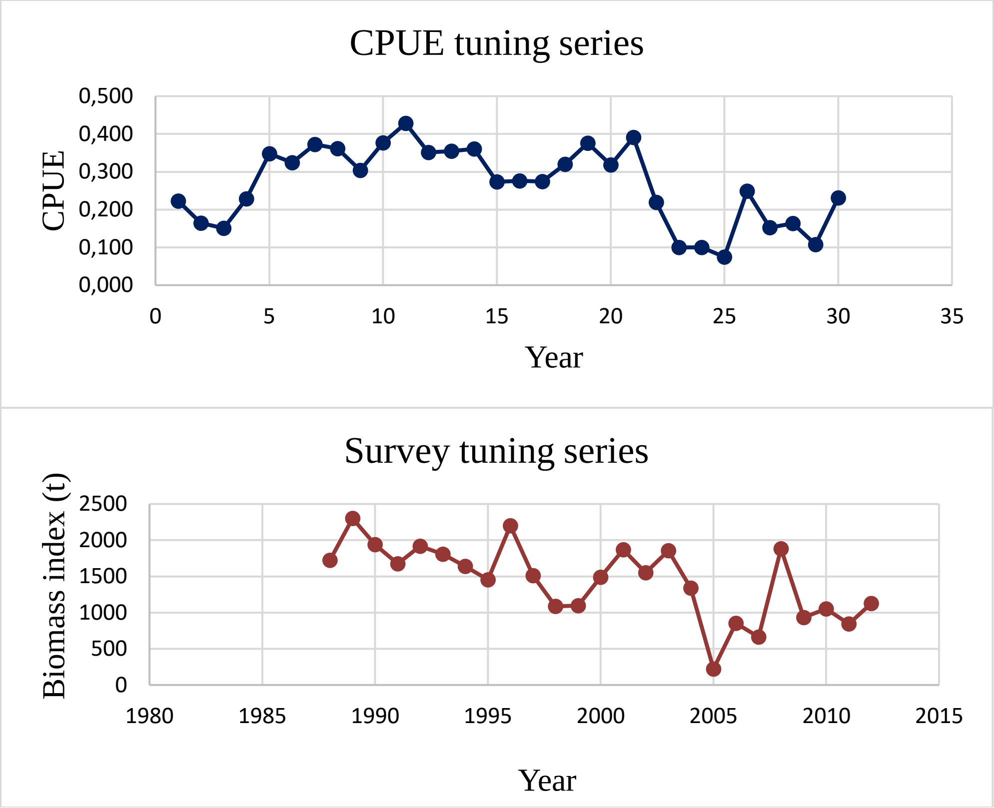


Figure 3: Input data of catch, CPUE and survey tuning series from Arnarfjordur shrimp stock.

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) are 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 2002), then the equation below can be formulated:

$CPUE_t = qB_t$ --(iii)

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:

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

The max function ensures that the stock biomass can not 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^2)*--------------------(v)

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). The routine followed in Excel are shown in the appendix.

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. The outputs of the model are shown in the appendix.

R

The file containing the input data (catch, CPUE and index) was read by R script. The value of *r, K,* B_{init} and *q* which were calculated by excel were used as initial starting values in the scripts. Then Schaefer function was used to recalculate the value of these parameters. Same minimizing routine of Excel was followed in R script. The routine followed in R script are shown in the appendix.

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:

$MSY = (\frac{rK}{4})$ ---(vi)

$B_{MSY} = (\frac{K}{2})$ ---(vii)

$F_{MSY} = (\frac{r}{2})$ or $(\frac{MSY}{B_{MSY}})$ --(viii)

4 RESULTS

4.1 Estimates of parameters

4.1.1 CPUE data

The base parameters of the stock production model were quite similar irrespective of the software used. The intrinsic growth rate *r* ranged from 0.92 to 1.11 and the carrying capacity, *K*, ranged from 3162 t to 5790 t. The catchability, *q*, ranged from 0.000088 to 0.000128 and B_{init} ranged from 583 t to 778 t (Table 2).

ASPIC and R estimated almost the same level of MSY's (1123 t ~ 1328 t) from fitting the model to the commercial CPUE data but the lowest MSY (878 t) was estimated by Excel. The highest B_{MSY} (2895 t) was observed by ASPIC, which is almost double to what was estimated by Excel. The three methods produced similar F_{MSY}'s (0.45~0.55) (Table 2).

Table 2: The estimated parameters through SPM from the three different 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

4.1.2 Survey data

The parameter estimates from the fit of the model to the survey tuning data are presented in table 3. The intrinsic growth rate *r* is estimated in the range of 0.46 to 0.63 and the carrying capacity, *K*, has a range of 5512 t to 6350 t. Catchability or *q* is estimated between 0.95 and 1.47 and B_{init} (1613 t ~ 2475 t) (Table 3).

For survey biomass indices, R produced almost an average MSY value (735 t) among the three methods. ASPIC and R were calculated almost same B_{MSY} value (3000 t ~ 3175 t) but excel estimated slightly lowest B_{MSY} (2756 t). Excel and R produced the same F_{MSY} (0.23) and ASPIC produced slightly higher F_{MSY} (~0.31) (Table 3).

Table 3: The estimated parameters through SPM from the three different 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

4.2 4.2 Fitting of data series and estimated population trajectory and reference points

4.2.1 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 (Figure 4). 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.

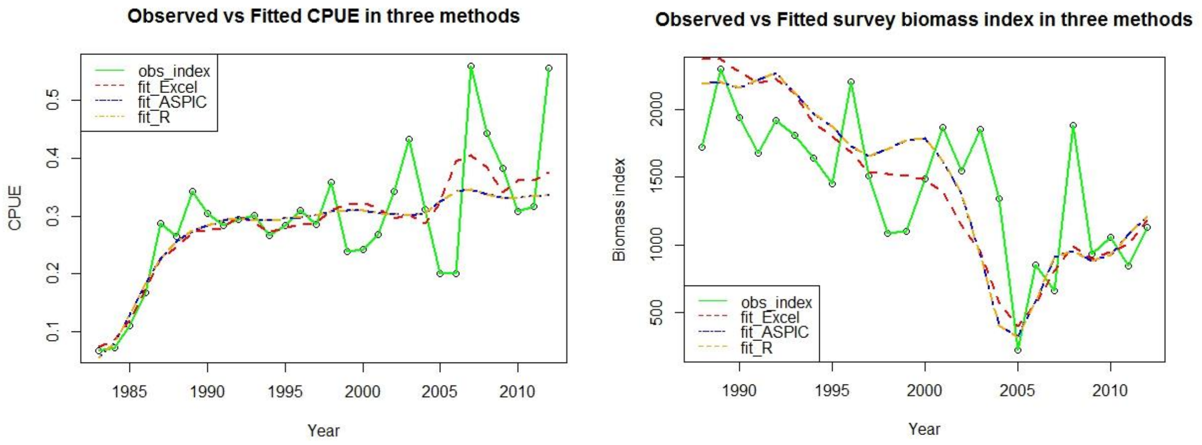


Figure 4: Observed and expected index fit to the CPUE (left) and survey index (right) used for tuning the stock production model.

4.2.2 Parameter correlation

Same input data to different methods showed intrinsic growth rate (*r*) and carrying capacity (*K*) were inversely related (Figure 5). In specifically, Excel predicted highest *r* and lowest *K* but ASPIC estimated lowest *r* and highest *K* and that of R was in between them. This means that even though the absolute estimates of the parameters may be quite different the resulting stock trajectory may be very similar.

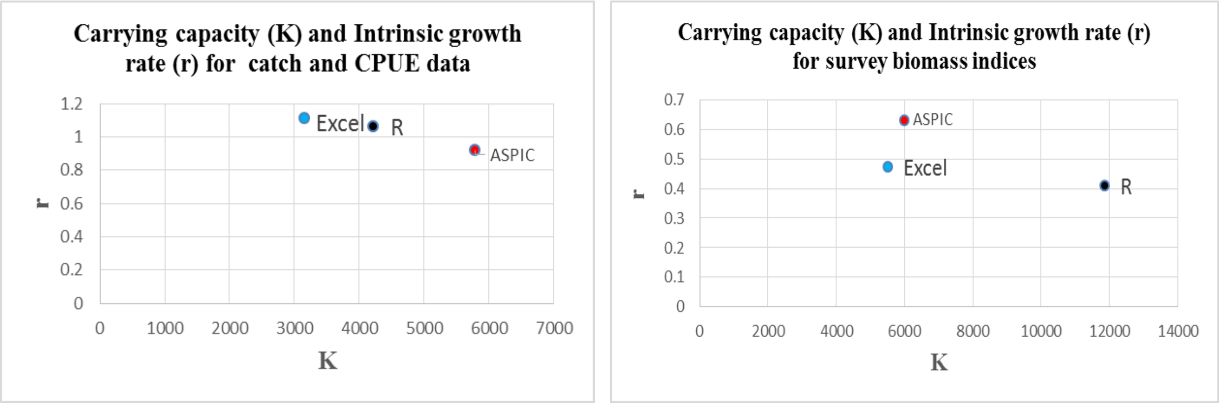


Figure 5: Relationship between K and r from a stock production model using three different software platforms in two tuning series.

4.2.3 Estimates of population trends

As the estimates from the three software types used are quite similar only the results from the ASPIC model are discussed in detail.

Estimates from ASPIC fitted to commercial CPUE (Table 4 and Figure 6) 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 kt in 1985 to about 5.5 kt in 2012 (Figure 6).

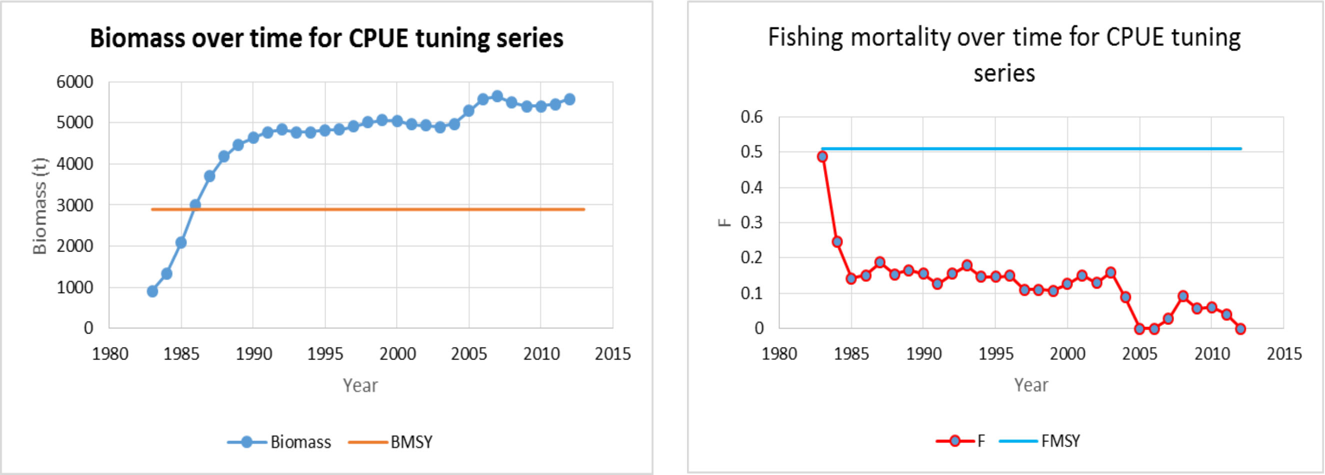


Figure 6: Estimates of exploitable biomass (left) and fishing mortality (right) from a stock production model fitted to CPUE tuning series.

When fitted to the survey biomass index, ASPIC estimated (Table 5 and Figure 7) that total fishing mortality has been relatively constant or around 0.5 for the years surveyed except in 2003 and 2004 when it peaked. Average biomass depicted gradual reduction from 1.5 kt to 0.25 kt since 1988 to 2005. Then, the biomass showed continuous increase and finally rose to around 1 kt in 2012 (Figure 7).

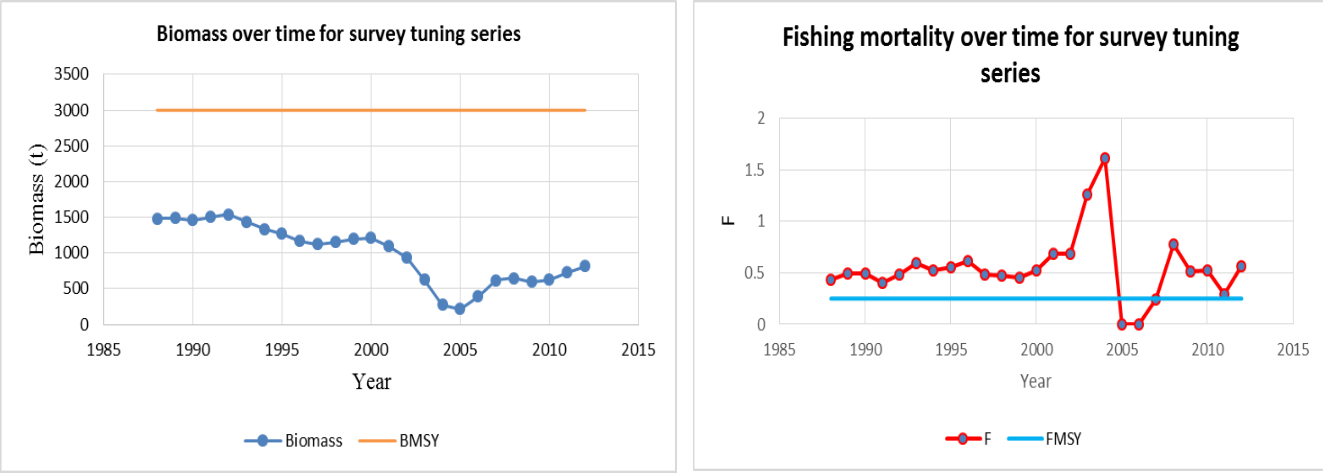


Figure 7: Estimates of exploitable biomass (left) and fishing mortality (right) from a stock production model fitted to survey tuning series.

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 8 and Table 4)

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 8 and Table 5). 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.

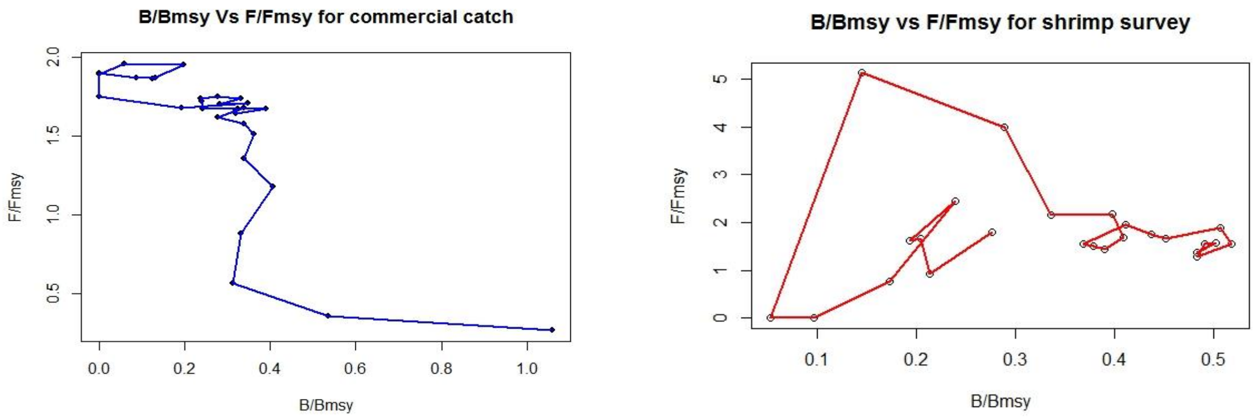


Figure 8: B/B_{MSY} Vs F/F_{MSY} for CPUE (left) and survey (right) tuning series.

5 DISCUSSION

5.1 Are model assumptions met with the input data series?

These three fittings of the surplus production models estimation have demonstrated some results of Arnarfjordur shrimp stock. These results 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 following assumptions:

a) there are no species interactions,
b) no environmental factors affect the population,
c) intrinsic growth rate r responds instantaneously to changes in population biomass (no time laps),
d) catchability coefficient *q* is constant,
e) there is a single stock,
f) fishing and natural mortality take place simultaneously,
g) no changes in gear or vessel efficiency have taken place, and
h) catch and effort statistics are accurate.

Practically, many of the above 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).

5.1.1 There are no species interactions

Northern shrimp are preyed upon by many fish species such as cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), Greenland halibut (*Reinhadtius hippoglossoides*) and redfish (*Sebastes marinus*) and also by sea birds and some marine mammals (Parsons *et al.* 1998). In Iceland, almost all the shrimp stocks did collapse in the wake of increased abundance of cod and haddock on the shrimp grounds (Skúladóttir *et al.* 2001). It is strongly believed that northern shrimp biomass is influenced by the predation of cod. Skuladottir *et al.* (2007) also noted that the biomass of shrimp increased greatly on the Flemish Cap since 1997 after the collapse of the cod. Increased cod abundance was inversely related to shrimp abundance in inshore and offshore areas of Iceland (Jonsdottir *et. al*. 2012) and predation by cod on demersal stages of northern shrimp has been well documented in various geographical habitats (Albers & Anderson 1985, Magnusson & Palsson 1989, Lily *et al.* 2000). Particularly in Arnarfjordur area, immature cod and haddock were found to migrate to the inner part of the fjord, where they mostly preyed on northern shrimp (Bjornsson *et al.* 2011). In light of these studies, it is clear that there are naturally real time species interaction between shrimp stock and gadoid predation, and it was same for Arnarfjordur shrimp stock.

It is therefore likely that the assumption of production of shrimp (*r*) only being related to the stock size of shrimp is likely not met as predation can have considerable effect on the realized production.

5.1.2 No environmental factors affect the population

Temperature, substratum and salinity are important environmental factors that affect the distribution of *P. borealis* (Shumway 1985) and may be the cause of the rapid changes in abundance seen in some stocks (Anderson, 2000). According to Idone (2006), growth, development rate and reproductive success of northern shrimp stock in the Gulf of Maine have been affected by temperature changes. Garcia (2007) also studied temperature tolerance and salinity on Icelandic northern shrimp stock and found the same result. During late summer concurrent with rising temperature, the local northern shrimp stock of Arnarfjordur moved back into the north-east arm of the fjord (Bjornsson *et al.* 2011). Apart from cod abundance, summer sea surface temperature was found to have a negative effect on shrimp recruitment (Jonsdottir *et al.* 2013). This strongly indicates that environmental factors may affect the shrimp stock.

5.1.3. Intrinsic growth rate r responds instantaneously to changes in population biomass

Population growth at its unrestricted way or instantaneous rate of population growth can be imagined as a population growing in an unlimited environment in a new and empty location (Haddon 2011). But, shrimp fishery started in Arnarfjordur in 1938 (Garcia 2007). So, it was not a new stock. In this study, intrinsic growth rate, *r* was inversely related with stock biomass, *K*, where higher intrinsic growth was observed during lower stock biomass. Theoretically, *r* is fully realized at the lowest population level while the finite rate of population growth is higher at the midpoint of *K* (Schaefer 1954). In Arnarfjordur, there was no fishing in 2005 to 2006 (Table 1 and Figure 3) for rebuilding stock due to massive decline of stock more likely by predation and fishing pressure in 2003 to 2004. Neither tuning series showed sharp surplus production in 2005 to 2006 and subsequent years (Table 4 & 5 and Figure 10 (Appendix)). But, the production of survey tuning series is much higher than that of CPUE tuning series. So, it does not appear that intrinsic growth rate responds instantaneously to changes in population biomass.

5.1.4. Catchability coefficient q is constant

One major assumption in the use of surplus production models is that the relationship between catch rate and stock biomass is constant through time. It is most likely that catchability has changed through time in the commercial fishery (Haddon 2011, Prager 1994). But, the survey was standardized, and has been run the same way, with the same gear and vessel, sampling at the same stations during the entire survey period. Therefore, it was not expected to see changes in catchability in the survey. However, other factors such as temperature and predation might affect catchability. Increased gadoid abundance in Arnarfjordur cause changes in the behavioral pattern of shrimp that lead to shoaling of shrimp, like rockpool prawn *Palaemon elegans* (Evans *et al.* 2007) as a strategy to reduce predation risk. Thing is that the relative predation pressure by gadoid preying is much higher on scattered than shoaling northern shrimp (Bjornsson *et al.* 2011). This contributed to increased catchability for trawl survey. Different species and fish of different sizes of the same species have different behavior shows very different catchability (Jennings *et al.* 2001). For northern shrimp, different sizes and maturity of species, sex change and distribution pattern showed different value of *q* (36th SAW Consensus Summary). Though survey data showed roughly same catchability over the time, it is likely that *q* has not been constant in this fishery.

5.1.5. There is a single stock unit

Northern shrimp are treated as localized populations in inshore and offshore Icelandic areas, with limited connectivity during adult stages (Jonsdottir *et al.* 1998). Shrimp usually do not show any spatial migration except some diurnal and vertical migration for feeding purposes (Parsons *et al.* 1998, Bergstrom 2000). Arnarfjordur shrimp stock can be regarded as a single stock unit.

5.1.6. Fishing and natural mortality take place simultaneously

Though, the assumption hold fishing and natural mortality takes place simultaneously, common perception of natural mortality is highly distorted by predation, like mentioned above. Sometimes this predation may represent a greater source of mortality of shrimp than commercial fishing pressure (Sevenkoff *et al*. 2007). There is no explanation to interpret impact of predation on stock biomass through this model and it is not necessarily true that fishing and natural mortality occurred concurrently in this stock.

5.1.7. No changes in gear or vessel efficiency have taken place

Other model assumption that might prove problematic to the assessment is that no changes in gear or vessel efficiency have taken place. Catch rates are directly related to profitability due to fluctuating populations and changes in the amount and efficiency of fishing year by year as a fishery develop over time (King 1995, Jennings *et al.* 2001, Haddon 2011). It is really impractical for commercial fishing, where change of efficiency of gear over time is an obvious phenomenon and it was also true for Arnarfjordur commercial shrimp fishery. As discussed in 5.1.4, there were no changes observed in gear and vessel efficiency for survey vessel engaged in this fishery.

5.1.8. Catch and effort statistics are accurate

Perhaps, the most important assumption to the reliability of the model is the assumption on catch per unit effort (CPUE). This method assumes that catch and effort data have been measured without error, and all error is attributed to the functional relationship between population growth rate and population size (Hilborn &Walters 1992). This assumption is strongly opposed to the concept of Pella & Tomlinson (1969), who's mentioned all the error occurs in the observation, in the CPUE values that are used as an index of stock size. Polacheck *et al.* (1993) also recommended observation-error method that means catch and effort statistics are not accurate. Though, unreported catch, unregulated landing and inaccurate logbook were commonly observed in commercial fishery (Jennings *et al.* 2001), these are not believed in Arnarfjordur shrimp fishery because of properly maintained all landings and reported accordingly (Hafro.is 2013/14).

5.1.8 Can the model be used?

Many of the model assumptions in the SPM are violated in the shrimp analysis. 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.

5.2 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 better meet with the SPM assumptions than commercial CPUE.

In CPUE data series, the disparity between catch and effort was not reportedly observed. This indicates that efforts or fishing efficiency were not increased proportionately over time, what is common trend in commercial fisheries for profitability point of view (King 1995, Jennings *et al.* 2001, Haddon 2011). This also indicates that r and q were reasonably estimated but there was variation in K among three estimations of SPM model. The main drawback of CPUE input data series is misleading indication of estimation if efficiency has changed over time (Masters, 2007).

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 through all three methods 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 (Table 1 & Figure 3), due to gadoid predation (Skuladottir *et al.* 2001 & Jonsdottir *et al.* 2012) and fishing pressure in 2003 to 2004 (Table 1 & Figure 3) in comparison to biomass level in those years (Figure 7). 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).

5.3 Management reference points of the stock

The ultimate goal of any stock assessment is to inform fishery manager so that sound management decisions can be made. In this context the parameters from a stock production model can be quite informative such as the size or biomass of stock in virgin state (K), maximum sustainable yield (MSY), the fishing mortality that will give MSY (F_{MSY}) and the biomass that give MSY (B_{MSY}). For any rational stock, interpretation of management target is more likely an average, long term expected potential yield. Few of these potential management outputs are of value without some idea of the uncertainty around their values (Haddon 2011).

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 7). 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 6). 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 777 t. The observed catch showed always the level below MSY except in the year of 1993. Commercial harvest constantly followed the total allowable catch recommended by Marine Research Institute (MRI) (Table 1 & Figure 11 (Appendix)). In 1993 TAC recommendation was also the highest (850 t) among the years studied. Though, recommended TAC followed by commercial fishers, the stock is in gradually decreasing trend since 1993 to 2004. The reason may either be that the stock is over estimated or 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). Moreover, this relative biomass and relative fishing mortality are some recommended scale that aware to the fishery manager where the fishing effort stands in comparison with management reference points and what should be done to make the fishery output more amicable.

6 CONCLUSION

Stock production model though has several assumptions, the beauty inherent in the model is their simplicity. The model may be a useful tool in the assessment of stock for a population where limited information is available. However, source of data entered into the model and any conclusions drawn from their outputs should be treated with caution. Though, model assumptions are not met with the tuning series of Arnarfjordur shrimp fishery, this model might be studied on this stock as an experiment for obtaining knowledge on SPM modeling, as a powerful tool for stock assessment at initial stage. Between two tuning series, survey biomass index produced more reasonable estimation than CPUE input data series. The management reference points were found from this study, though in need of fine tuning, are not unrealistic. Nevertheless, better methods for estimating parameters, which have surprising flexibility and risk assessment amenities could be recommended.

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APPENDIX

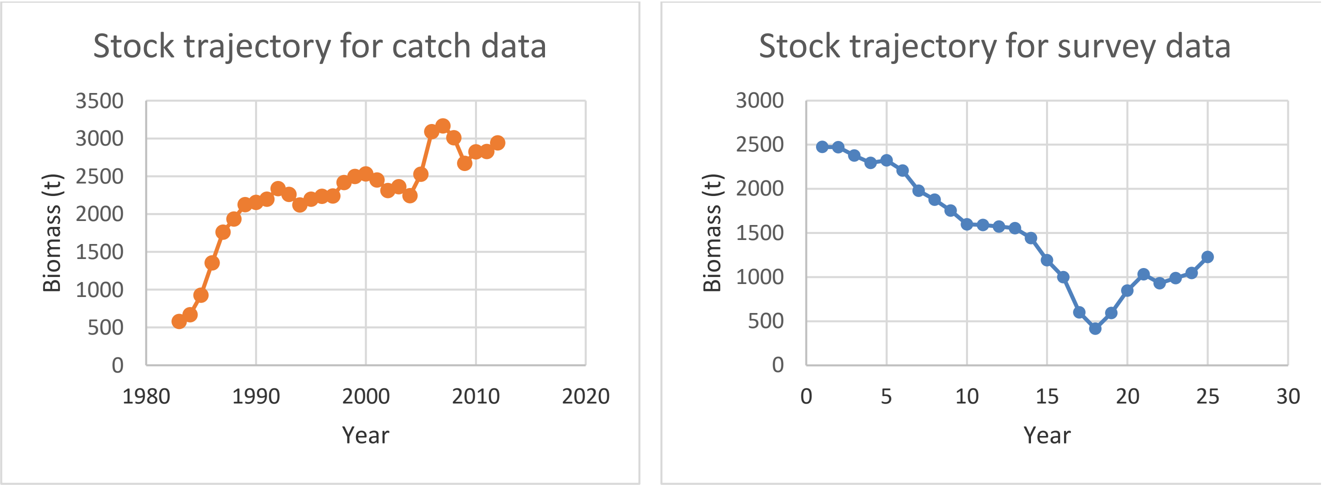


Figure 9: Trend of stock trajectory for CPUE (left) and survey (right) series.

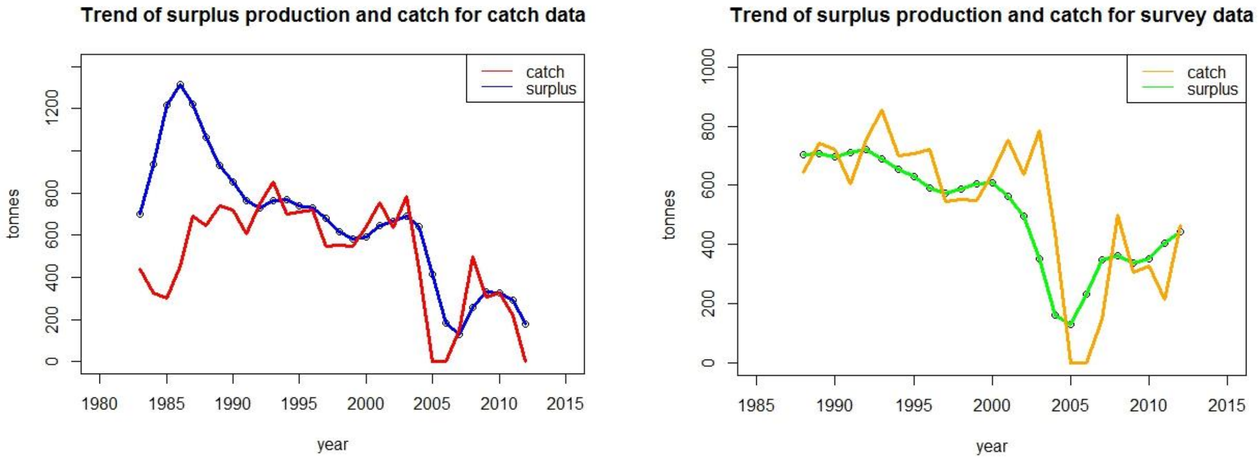


Figure 10: Trend of surplus production and catch for both CPUE (left) and survey (right) series.

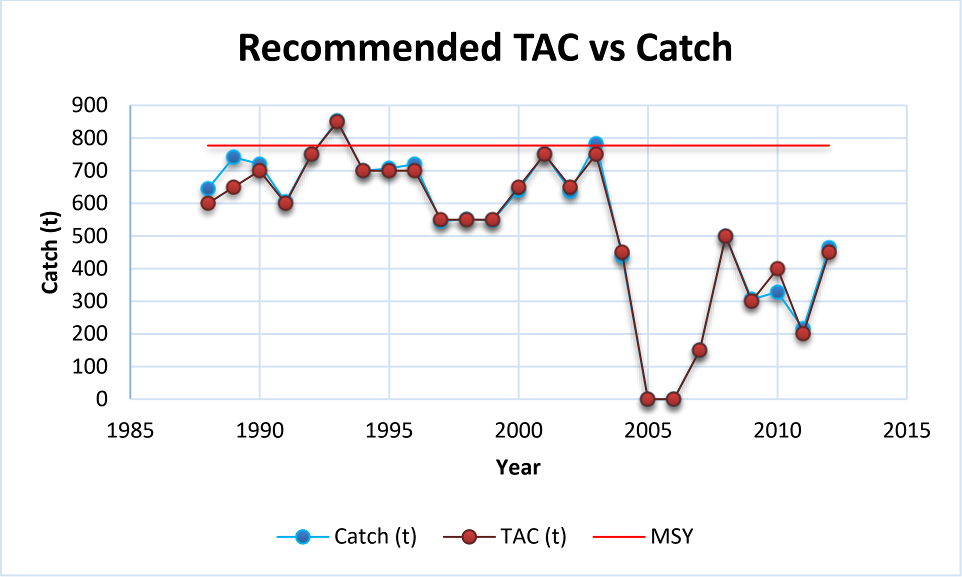
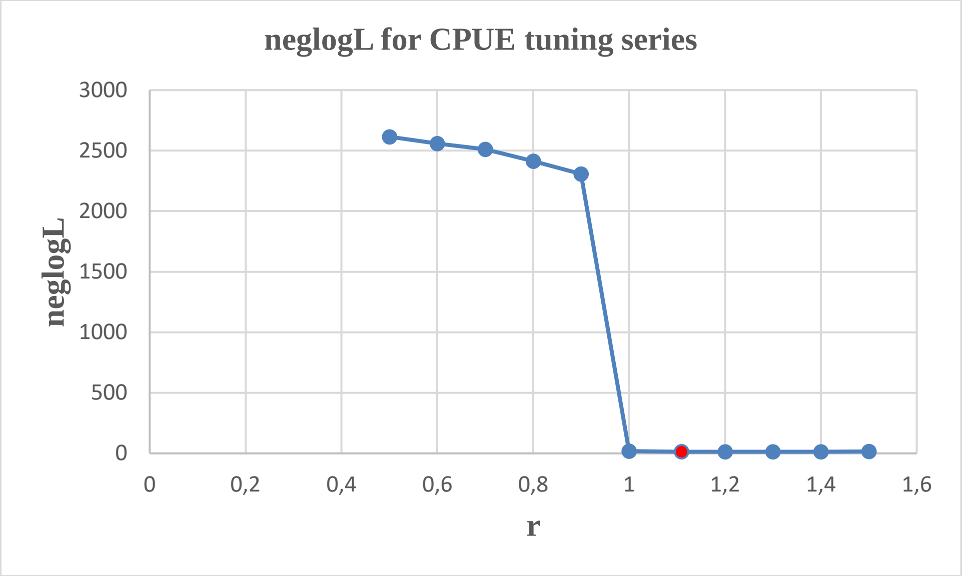
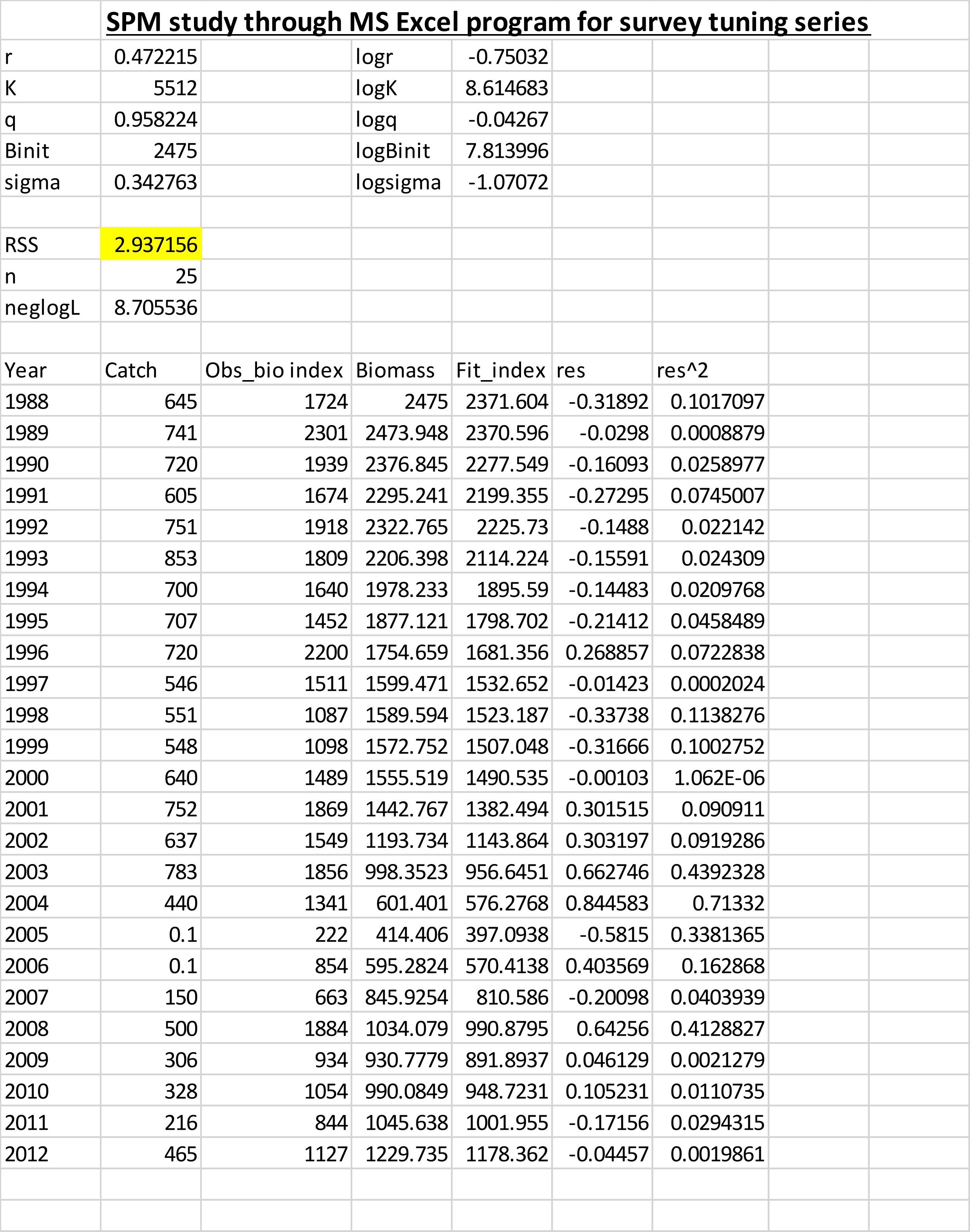


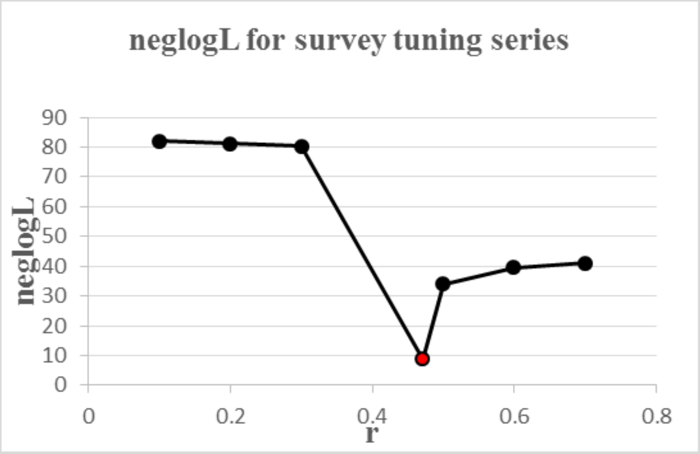
Figure 11: Recommended TAC and observed catch in Arnarfjordur shrimp fishery.

	SPM study through MS Excel program for CPUE tuning series						
r	1.11		logr	0.10436			
K	3162.398		logK	8.059086			
Binit	582.9		LogBinit	6.368016			
q	0.000128		Logq	-8.965024			
sigma	0.571707		Logsigma	-0.559129			
RSS	1.57812						
n	30						
neglogL	13.20845						
Year	Time (h)	Catch (t)	CPUE (t/h)	Biomass	Fit. Index	residuals	res^2
1983	6586	441	0.067	582.9	0.074496	-0.10665	0.01137
1984	4544	326	0.072	669.6591	0.085584	-0.17641	0.03112
1985	2719	300	0.110	929.5774	0.118802	-0.07394	0.00547
1986	2718	454	0.167	1358.105	0.173569	-0.03838	0.00147
1987	2415	692	0.287	1764.2	0.225469	0.23970	0.05746
1988	2438	645	0.265	1938.011	0.247683	0.06592	0.00435
1989	2159	741	0.343	2125.889	0.271694	0.23368	0.05461
1990	2367	720	0.304	2158.317	0.275838	0.09781	0.00957
1991	2131	605	0.284	2198.977	0.281035	0.01016	0.00010
1992	2553	751	0.294	2337.584	0.298749	-0.01547	0.00024
1993	2836	853	0.301	2263.336	0.28926	0.03904	0.00152
1994	2618	700	0.267	2124.577	0.271526	-0.01539	0.00024
1995	2486	707	0.284	2198.507	0.280975	0.01209	0.00015
1996	2324	720	0.310	2235.317	0.285679	0.08109	0.00658
1997	1911	546	0.286	2242.7	0.286623	-0.00317	0.00001
1998	1534	551	0.359	2420.674	0.309368	0.14932	0.02230
1999	2290	548	0.239	2499.884	0.319491	-0.28901	0.08352
2000	2641	640	0.242	2533.212	0.323751	-0.28966	0.08390
2001	2792	752	0.269	2452.656	0.313456	-0.15168	0.02301
2002	1856	637	0.343	2311.659	0.295436	0.14989	0.02247
2003	1814	783	0.432	2364.941	0.302245	0.35636	0.12699
2004	1409	440	0.312	2243.905	0.286777	0.08519	0.00726
2005	0.5	0.1	0.200	2527.318	0.322998	-0.47933	0.22975
2006	0.5	0.1	0.200	3090.589	0.394985	-0.68053	0.46312
2007	268	150	0.560	3168.387	0.404928	0.32369	0.10478
2008	1126	500	0.444	3011.727	0.384906	0.14294	0.02043
2009	801	306	0.382	2671.003	0.341361	0.11254	0.01267
2010	1064	328	0.308	2825.696	0.361131	-0.15826	0.02505
2011	682	216	0.317	2831.643	0.361891	-0.13334	0.01778
2012	838	465	0.555	2944.382	0.376299	0.38839	0.15085


neglogL for CPUE tuning series
neglogL
3000
2500
2000
1500
1000
500
0
0
0,2
0,4
0,6
0,8
1
1,2
1,4
1,6
r



	SPM study through MS Excel program for survey tuning series					
r	0.472215		logr	-0.75032		
K	5512		logK	8.614683		
q	0.958224		logq	-0.04267		
Binit	2475		logBinit	7.813996		
sigma	0.342763		logsigma	-1.07072		
RSS	2.937156					
n	25					
neglogL	8.705536					
Year	Catch	Obs_bio index	Biomass	Fit_index	res	res^2
1988	645	1724	2475	2371.604	-0.31892	0.1017097
1989	741	2301	2473.948	2370.596	-0.0298	0.0008879
1990	720	1939	2376.845	2277.549	-0.16093	0.0258977
1991	605	1674	2295.241	2199.355	-0.27295	0.0745007
1992	751	1918	2322.765	2225.73	-0.1488	0.022142
1993	853	1809	2206.398	2114.224	-0.15591	0.024309
1994	700	1640	1978.233	1895.59	-0.14483	0.0209768
1995	707	1452	1877.121	1798.702	-0.21412	0.0458489
1996	720	2200	1754.659	1681.356	0.268857	0.0722838
1997	546	1511	1599.471	1532.652	-0.01423	0.0002024
1998	551	1087	1589.594	1523.187	-0.33738	0.1138276
1999	548	1098	1572.752	1507.048	-0.31666	0.1002752
2000	640	1489	1555.519	1490.535	-0.00103	1.062E-06
2001	752	1869	1442.767	1382.494	0.301515	0.090911
2002	637	1549	1193.734	1143.864	0.303197	0.0919286
2003	783	1856	998.3523	956.6451	0.662746	0.4392328
2004	440	1341	601.401	576.2768	0.844583	0.71332
2005	0.1	222	414.406	397.0938	-0.5815	0.3381365
2006	0.1	854	595.2824	570.4138	0.403569	0.162868
2007	150	663	845.9254	810.586	-0.20098	0.0403939
2008	500	1884	1034.079	990.8795	0.64256	0.4128827
2009	306	934	930.7779	891.8937	0.046129	0.0021279
2010	328	1054	990.0849	948.7231	0.105231	0.0110735
2011	216	844	1045.638	1001.955	-0.17156	0.0294315
2012	465	1127	1229.735	1178.362	-0.04457	0.0019861


neglogL for survey tuning series
neglogL
90
80
70
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
r

SPM study through R program for CPUE tuning series

```
setwd('C:\\Users\\suman\\Documents\\Project_Suman\\Project work')
getwd()
shrimp_catch<-read.table('C:\\Users\\suman\\Documents\\Project_Suman\\Project
work\\shrimp_catch.txt', header=TRUE,)
colnames(shrimp_catch)<-c("Year","effort","Catch","CPUE")
head(shrimp_catch)
best<-c(logr=0.10436, logK=8.059086, logBinit=6.368016, logq=-8.965024)
Schaefer<-function(par, data, verbose=FALSE)
{
 r <- exp(par["logr"])
 K <- exp(par["logK"])
 Binit <- exp(par["logBinit"])
 q <- exp(par["logq"])
 year <- data$Year
 C <- data$Catch
 I <- data$CPUE
 n <- length(year)
 B <- numeric(n)
 B[1] <- Binit
 for(i in 1:(n-1))
 {
  B[i+1] <- max(B[i] + r*B[i]*(1-B[i]/K) - C[i], 1)
 }
 Ifit <- q*B
 res <- log(I) - log(Ifit)
 RSS <- sum(res^2)
 sigma <- sqrt(RSS/n)
 neglogL <- -sum(dnorm(log(I), log(Ifit), sigma, log=TRUE))

 if(verbose)
  output <- list(B=B, Ifit=Ifit, res=res)
 else
  output <- neglogL
 return(output)
 }
Schaefer(par=best, data=shrimp_catch)
init<-c(logr=0.10436, logK=8.059086, logBinit=6.368016, logq=-8.965024)
k<-optim(init, Schaefer, data=shrimp_catch)
exp(k$par)
```

SPM study through R program for survey tuning series

```
setwd('C:\\Users\\suman\\Documents\\Project_Suman\\Project work')
getwd()
survey<-read.table('C:\\Users\\suman\\Documents\\Project_Suman\\Project
work\\shrimp_survey2.txt', header=T, sep='\t')
colnames(survey)<-c("year","biomass","catch","CPUE")
head(survey)
best<-c(logr=log(0.472215), logK=log(5512), logBinit=log(2475), logq=log(0.958224))
Schaefer<-function(par, data, verbose=FALSE)
{
 r <- exp(par["logr"])
 K <- exp(par["logK"])
 Binit <- exp(par["logBinit"])
 q <- exp(par["logq"])
 year <- data$year
 C <- data$catch
 I <- data$CPUE
 n <- length(year)
 B <- numeric(n)
 B[1] <- Binit
 for(i in 1:(n-1))
 {
  B[i+1] <- max(B[i] + r*B[i]*(1-B[i]/K) - C[i], 1)
 }
 Ifit <- q*B
 res <- log(I) - log(Ifit)
 RSS <- sum(res^2)
 sigma <- sqrt(RSS/n)
 neglogL <- -sum(dnorm(log(I), log(Ifit), sigma, log=TRUE))

 if(verbose)
  output <- list(B=B, Ifit=Ifit, res=res)
 else
  output <- neglogL
 return(output)
}
Schaefer(par=best, data=survey)
init<-c(logr=log(0.472215), logK=log(5512), logBinit=log(2475), logq=log(0.958224))
k<-optim(init, Schaefer, data=survey)
exp(k$par)
```

ASPIC output file

Table 4: Stock performance as determined from non-equilibrium time series fitting in ASPIC 5.34.9 computer programme for CPUE tuning series.

Year	Estimated total F mort	Estimated starting biomass	Estimated average biomass	Observed total yield	Model total yield	Estimated surplus production	Ratio of F mort to F_{MSY}	Ratio of biomass to B*MSY*
1983	0.488	7.78E+02	9.03E+02	4.41E+02	4.41E+02	6.99E+02	1.06E+00	2.69E-01
1984	0.246	1.04E+03	1.33E+03	3.26E+02	3.26E+02	9.33E+02	5.36E-01	3.58E-01
1985	0.143	1.64E+03	2.09E+03	3.00E+02	3.00E+02	1.22E+03	3.13E-01	5.68E-01
1986	0.151	2.56E+03	3.00E+03	4.54E+02	4.54E+02	1.32E+03	3.30E-01	8.84E-01
1987	0.187	3.42E+03	3.70E+03	6.92E+02	6.92E+02	1.22E+03	4.07E-01	1.18E+00
1988	0.154	3.95E+03	4.18E+03	6.45E+02	6.45E+02	1.07E+03	3.36E-01	1.36E+00
1989	0.166	4.37E+03	4.48E+03	7.41E+02	7.41E+02	9.32E+02	3.61E-01	1.51E+00
1990	0.155	4.56E+03	4.63E+03	7.20E+02	7.20E+02	8.50E+02	3.39E-01	1.58E+00
1991	0.127	4.69E+03	4.78E+03	6.05E+02	6.05E+02	7.65E+02	2.76E-01	1.62E+00
1992	0.155	4.85E+03	4.84E+03	7.51E+02	7.51E+02	7.30E+02	3.38E-01	1.68E+00
1993	0.178	4.83E+03	4.78E+03	8.53E+02	8.53E+02	7.65E+02	3.89E-01	1.67E+00
1994	0.147	4.74E+03	4.78E+03	7.00E+02	7.00E+02	7.66E+02	3.19E-01	1.64E+00
1995	0.147	4.81E+03	4.82E+03	7.07E+02	7.07E+02	7.38E+02	3.19E-01	1.66E+00
1996	0.149	4.84E+03	4.84E+03	7.20E+02	7.20E+02	7.27E+02	3.24E-01	1.67E+00
1997	0.111	4.85E+03	4.92E+03	5.46E+02	5.46E+02	6.78E+02	2.42E-01	1.67E+00
1998	0.11	4.98E+03	5.01E+03	5.51E+02	5.51E+02	6.16E+02	2.40E-01	1.72E+00
1999	0.108	5.04E+03	5.06E+03	5.48E+02	5.48E+02	5.83E+02	2.36E-01	1.74E+00
2000	0.127	5.08E+03	5.05E+03	6.40E+02	6.40E+02	5.92E+02	2.76E-01	1.75E+00
2001	0.151	5.03E+03	4.97E+03	7.52E+02	7.52E+02	6.46E+02	3.30E-01	1.74E+00
2002	0.129	4.92E+03	4.94E+03	6.37E+02	6.37E+02	6.66E+02	2.81E-01	1.70E+00
2003	0.16	4.95E+03	4.90E+03	7.83E+02	7.83E+02	6.91E+02	3.48E-01	1.71E+00
2004	0.088	4.86E+03	4.97E+03	4.40E+02	4.40E+02	6.43E+02	1.93E-01	1.68E+00
2005	0	5.06E+03	5.30E+03	1.00E-01	1.00E-01	4.13E+02	4.12E-05	1.75E+00
2006	0	5.48E+03	5.58E+03	1.00E-01	1.00E-01	1.85E+02	3.91E-05	1.89E+00
2007	0.027	5.66E+03	5.65E+03	1.50E+02	1.50E+02	1.28E+02	5.79E-02	1.96E+00
2008	0.091	5.64E+03	5.50E+03	5.00E+02	5.00E+02	2.55E+02	1.98E-01	1.95E+00
2009	0.057	5.39E+03	5.41E+03	3.06E+02	3.06E+02	3.29E+02	1.23E-01	1.86E+00
2010	0.061	5.42E+03	5.41E+03	3.28E+02	3.28E+02	3.23E+02	1.32E-01	1.87E+00
2011	0.04	5.41E+03	5.45E+03	2.16E+02	2.16E+02	2.91E+02	8.63E-02	1.87E+00
2012	0	5.49E+03	5.59E+03	0.00E+00	0.00E+00	1.79E+02	0.00E+00	1.90E+00
2013		5.66E+03						1.96E+00

Table 5: Stock performance as determined from non-equilibrium time series fitting in ASPIC V 5.34.9 computer programme for survey tuning series.

Year	Estimated total F mort	Estimated starting biomass	Estimated average biomass	Observed total yield	Model total yield	Estimated surplus production	Ratio of F mort to F_{MSY}	Ratio of biomass to B_{MSY}
1988	0.435	1.45E+03	1.48E+03	6.45E+02	6.45E+02	7.02E+02	1.38E+00	4.84E-01
1989	0.497	1.51E+03	1.49E+03	7.41E+02	7.41E+02	7.06E+02	1.58E+00	5.03E-01
1990	0.493	1.47E+03	1.46E+03	7.20E+02	7.20E+02	6.96E+02	1.57E+00	4.91E-01
1991	0.403	1.45E+03	1.50E+03	6.05E+02	6.05E+02	7.09E+02	1.28E+00	4.83E-01
1992	0.488	1.55E+03	1.54E+03	7.51E+02	7.51E+02	7.20E+02	1.55E+00	5.18E-01
1993	0.594	1.52E+03	1.44E+03	8.53E+02	8.53E+02	6.88E+02	1.89E+00	5.08E-01
1994	0.525	1.36E+03	1.33E+03	7.00E+02	7.00E+02	6.53E+02	1.67E+00	4.53E-01
1995	0.556	1.31E+03	1.27E+03	7.07E+02	7.07E+02	6.31E+02	1.77E+00	4.37E-01
1996	0.616	1.24E+03	1.17E+03	7.20E+02	7.20E+02	5.92E+02	1.96E+00	4.12E-01
1997	0.487	1.11E+03	1.12E+03	5.46E+02	5.46E+02	5.74E+02	1.55E+00	3.69E-01
1998	0.478	1.14E+03	1.15E+03	5.51E+02	5.51E+02	5.87E+02	1.52E+00	3.79E-01
1999	0.457	1.17E+03	1.20E+03	5.48E+02	5.48E+02	6.04E+02	1.45E+00	3.90E-01
2000	0.528	1.23E+03	1.21E+03	6.40E+02	6.40E+02	6.09E+02	1.68E+00	4.09E-01
2001	0.685	1.20E+03	1.10E+03	7.52E+02	7.52E+02	5.64E+02	2.18E+00	3.99E-01
2002	0.682	1.01E+03	9.35E+02	6.37E+02	6.37E+02	4.97E+02	2.17E+00	3.36E-01
2003	1.255	8.67E+02	6.24E+02	7.83E+02	7.83E+02	3.50E+02	3.99E+00	2.89E-01
2004	1.614	4.35E+02	2.73E+02	4.40E+02	4.40E+02	1.63E+02	5.13E+00	1.45E-01
2005	0	1.58E+02	2.17E+02	1.00E-01	1.00E-01	1.32E+02	1.46E-03	5.26E-02
2006	0	2.90E+02	3.95E+02	1.00E-01	1.00E-01	2.32E+02	8.05E-04	9.65E-02
2007	0.244	5.21E+02	6.16E+02	1.50E+02	1.50E+02	3.47E+02	7.74E-01	1.74E-01
2008	0.773	7.19E+02	6.47E+02	5.00E+02	5.00E+02	3.63E+02	2.46E+00	2.40E-01
2009	0.512	5.82E+02	5.98E+02	3.06E+02	3.06E+02	3.39E+02	1.63E+00	1.94E-01
2010	0.523	6.15E+02	6.28E+02	3.28E+02	3.28E+02	3.54E+02	1.66E+00	2.05E-01
2011	0.295	6.40E+02	7.32E+02	2.16E+02	2.16E+02	4.04E+02	9.38E-01	2.14E-01
2012	0.568	8.29E+02	8.18E+02	4.65E+02	4.65E+02	4.45E+02	1.81E+00	2.76E-01
2013		8.08E+02						2.69E-01

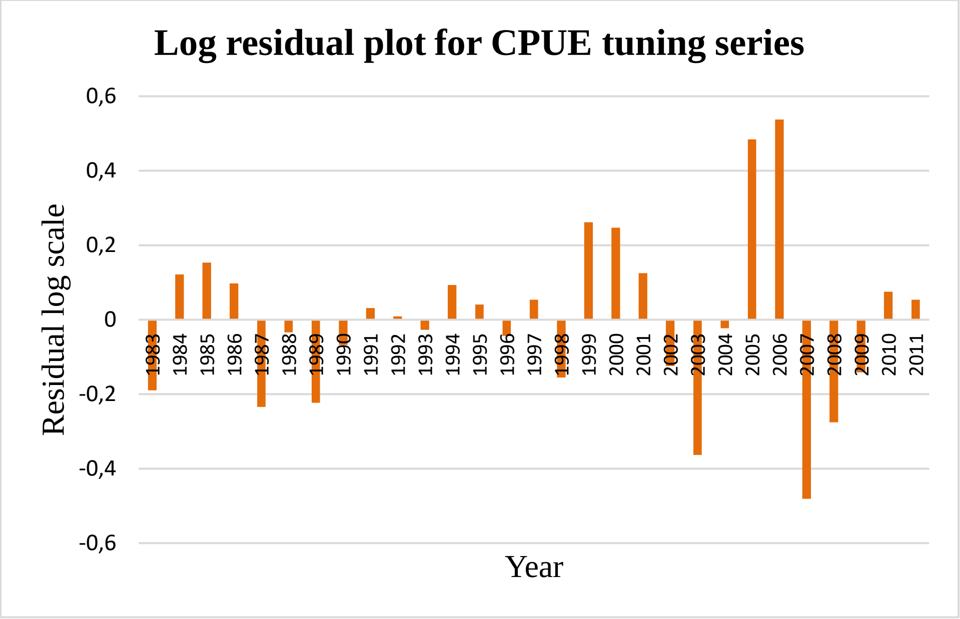


Figure 12: ASPIC produced log residual plot for CPUE tuning series

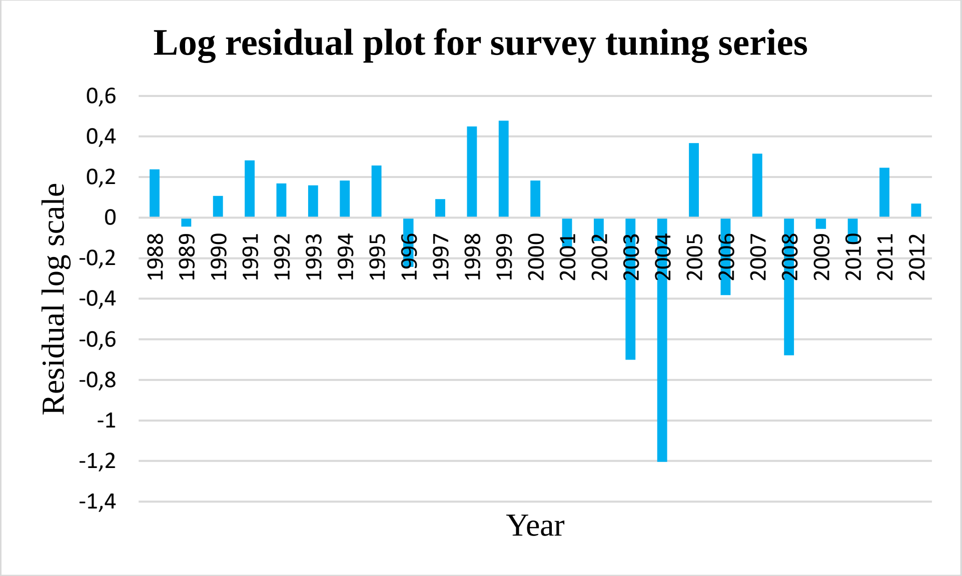


Figure 13: ASPIC produced log residual plot for survey tuning series

R scripts

```
############################
# Map of Iceland
geoplot(xlim=c(-25,-12), ylim=c(63, 67),grid=FALSE)
geoworld(database="worldHires",fill=T,col="grey80")
# Add the lines over
geoworld(database="worldHires")
geopoints(my.pie, pch=16, col='red')
par(new=TRUE)
geoworld(regions='Iceland', fill=TRUE, col='lightblue', database="worldHires")
geoworld(regions='Iceland', database="worldHires")
##############################
# Map of Arnarfjordur in Iceland
geoplot(grid=F, country="none",xlim=c(-23.1,-24.1), ylim=c(65.6,65.9),
       axlabels=F, plotit=F)
geoaxis(1, inside=F,dlon=0.5, cex=1, dist=.2,r=1.6,aftertext="W")
geoaxis(2, inside=F,dlat=0.2, cex=1, dist=.9,r=2.4, aftertext="N")
gbplot(c(100,200,500), col="yellow")
geopolygon(bisland,col="yellow")
geolines(bisland)
##############################
#Survey point of Arnarfjordur Area
map<-read.csv('C:\\Users\\suman\\Documents\\Project_Suman\\Project
work\\arnarfj_location.csv',)
map
geopoints(map$lat, map$lon, col='black')
```

For CPUE tuning series

```
s<-source("C:\\Users\\suman\\Documents\\Project_Suman\\Project work\\ASPIC\\catch2.rdat")
s
result<-s$value$t.series
plot(result$year, result$U.01.ob, xlab='year', ylab='CPUE', main='Commercial catch index')
lines(result$year,result$U.01.ob, col='green', lwd=3)
lines(result$year,result$U.01.pr, col='red', lwd=3)
legend('topleft',c('obs_index','exp_index'), border='white',lty=c(1,1),col=c('green','red'))
#Three model fitting
setwd('C:\\Users\\suman\\Documents\\Project_Suman\\Project work')
getwd()
cat<-read.table('C:\\Users\\suman\\Documents\\Project_Suman\\Project work\\shrimp_catch1.txt',
header=T,)
head(cat)

#######################
# Model fit to tuning series
plot(cat$year, cat$CPUE, xlab='Year', ylab='CPUE', main='Observeb vs Fitted CPUE in three models')
lines(cat$year, cat$CPUE, col='green', lwd=2, lty=1,)
lines(cat$year, cat$fit_CPUE, col='red', lwd=2, lty=2)
lines(cat$year, cat$est_CPUE, col='blue', lwd=2, lty=6)
lines(cat$year, cat$u.01.pr, col='orange', lwd=2, lty=4)
```

```
legend('topleft', c('obs_index', 'fit_Excel', 'fit_ASPIC', 'fit_R'), border='white', lty=c(1,2,6,4), col=c('green', 'red', 'blue', 'orange'))


#######################
#Graph on F over time
tmp<-read.table('C:\\Users\\suman\\Documents\\Project_Suman\\Project work\\shrimp_catch2.txt', header=T,)
head(tmp)
plot(tmp$year, tmp$est_F, xlab='Year', ylab='F', main='F over time for commercial catch')
lines(tmp$year, tmp$est_F, col='red', lwd=2, pch=16)

######################
# B/BMSY Vs F/FMSY
tmp<-read.table('C:\\Users\\suman\\Documents\\Project_Suman\\Project work\\shrimp_catch2.txt', header=T,)
head(tmp)
sunflowerplot(tmp$F.Fmsy, tmp$B.Bmsy,  xlab='B/Bmsy', ylab='F/Fmsy', main='F/Fmsy Vs B/Bmsy for commercial catch')
lines(tmp$F.Fmsy, tmp$B.Bmsy, col='blue', lwd=2, pch=16)

######################
# Surplus production Vs observed yield for CPUE input data
catch<-read.table('C:\\Users\\suman\\Documents\\Project_Suman\\Project work\\shrimp_catch3.txt', header=T,)
head(catch)
plot(catch$year, catch$sp, xlab='year', ylab='tonnes', xlim=c(1980, 2015), ylim=c(0,1400), main='Trend of surplus production and catch for catch data')
lines(catch$year, catch$sp, col='blue', lwd=3)
lines(catch$year, catch$obs_yield, col='red', lwd=3)
legend('topright', c('catch', 'surplus'), border='white', lty=c(1,1), col=c('red', 'blue'))
```

For survey tuning series

```
s<-source("C:\\Users\\suman\\Documents\\Project_Suman\\Project work\\ASPIC\\survey2.rdat")
s
result<-s$value$t.series
plot(result$year, result$U.01.ob, xlab='year', ylab='Biomass index', main='Survey biomass index')
lines(result$year,result$U.01.ob, col='blue', lwd=3)
lines(result$year,result$U.01.pr, col='red', lwd=3)
legend('topright',c('obs_index','exp_index'), border='white',lty=c(1,1),col=c('blue','red'))

############################
#Model fit to tuning series
library('xlsx')
tmpsur<-read.xlsx('C:\\Users\\suman\\Documents\\Project_Suman\\Project work\\Arnarfjordur survey analysis3 final.xlsx',3)
tmpsur(colnames)<-c('year', 'biomass', 'catch', 'obs_bio', 'fit_bio', 'obs_ind', 'exp_ind', 'F_mort', 'yield', 'mod_yield', 'F.Fmsy', 'b.bmsy', 'r_obs', 'r_exp')
head(tmpsur)
############################
```

Three fittings in one graph for survey data

```
sur<-read.table('C:\\Users\\suman\\Documents\\Project_Suman\\Project work\\shrimp_survey6.txt', header=T, sep=('\t'))
head(sur)
plot(sur$year, sur$obs_bio, xlab='Year', ylab='Biomass index', main='Observeb vs Fitted survey biomass index in three models')
lines(sur$year, sur$obs_bio, col='green', lwd=2, lty=1)
lines(sur$year, sur$fit_bio, col='red', lwd=2, lty=2)
lines(sur$year, sur$exp_index, col='blue', lwd=2, lty=6)
lines(sur$year, sur$u.01.pr, col='orange', lwd=2, lty=4)
legend('bottomleft', c('obs_index', 'fit_Excel', 'fit_ASPIC', 'fit_R'), border='white', lty=c(1,2,6,4), col=c('green', 'red', 'blue', 'orange'))

##############################
# B/BMSY vs F/FMSY
plot(result$b.bmsy, result$F.Fmsy, xlab='B/Bmsy', ylab='F/Fmsy', main='B/Bmsy vs F/Fmsy for shrimp survey')
lines(result$b.bmsy, result$F.Fmsy, col='red', lwd=2)

#############################
# Surplus Vs catch plot for survey input data
survey<-read.table('C:\\Users\\suman\\Documents\\Project_Suman\\Project work\\shrimp_survey3.txt', header=T,)
head(survey)
plot(survey$year, survey$sp, xlab='year', ylab='tonnes', xlim=c(1985, 2015), ylim=c(0, 1000), main='Trend of surplus production and catch for survey data')
lines(survey$year, survey$sp, col='green', lwd=3)
lines(survey$year, survey$obs_L, col='orange', lwd=3)
legend('topright', c('catch', 'surplus'), border='white', lty=c(1,1), col=c('orange', 'green'))
```