STOCK ASSESSMENT OF THE BLACK SEA ANCHOVY

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ABSTRACT
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The Black Sea anchovy (*Engraulis encrasicolus*) is economically the most important fish species in Turkey since it provides 60% of the total fish catch. The Turkish fleet catches 90% of the anchovy stock in the Black Sea due to the anchovy winter migration to the Turkish coast. Over the last 50 years, the Black Sea basin has been subjected to pollution due to human sourced nutrient accumulation in the NW basin via the rivers Danube, Dniester and Dnieper and transportation. The ecosystem has been destroyed by the invasion of alien species and overfishing. Moreover, top predators have been overfished and could not recover completely, including marine mammals and large pelagic fish species. Small pelagic stocks benefited from this situation and increased in abundance, however, the invasion of the ctenophore *Mnemiopsis leidyi* caused large damage to stocks especially the anchovy stocks.

Stock assessment studies have been undertaken for different reasons, and main reasons initiated from the extreme decrease in anchovy stocks and especially in the last decade driven by accession negotiations with the European Union. Even though the first stock assessment study of anchovy stock was done in 1988 based on the surplus production model, it could not be carried out comprehensively again until the last decade. The Turkish fishery statistics based on commercial catch data and this data prevents using the analytical model which is necessary for an appropriate stock management.

The aim of the study is to explain the fluctuation of the anchovy stock as a function of fishing effort, using surplus production models. The models were applied, assuming both equilibrium and non-equilibrium conditions. Catch data for 44 years, between 1968 and 2011, were obtained from TurkStat. Fishing effort data were determined according to four scenarios: the number of boats larger than 10 m, total engine power of the boats larger than 10 m, the number of purse seiners and multi purpose trawlers, and sonar effect added form of the third scenario. Examination of the scenarios was achieved using Schaefer and Fox models and additionally Prager’s non-equilibrium based production model namely ASPIC. The non-equilibrium approach models provided more reliable results and closer estimations to the real data, when compared to equilibrium approach models. Among ASPIC simulations best fit was obtained from the Gengrid model. None of the model simulations could explain the sharp decrease observed in 1990 and 2005.

Keywords: Black Sea, Stock assessment, Surplus production model, ASPIC, Black Sea anchovy, *Engraulis encrasicolus*.

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ÖZ

KARADENİZ HAMSİSİ’NİN STOK DEĞERLENDİRMESİ

TUTAR, Özge

Yüksek Lisans, Deniz Biyolojisi ve Balıkçılık Bölümü

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Karadeniz hamsisi (Engraulis encrasicolus), Türkiye’nin toplam balık avının %60’ını karşılamasından ötürü en önemli ekonomik balık türüdür. Hamsi stoğu kışlama göçünü Türkiye kıyılarına doğru yapmakta ve stok 90% oranında Türk balıkçılık filosu tarafından avlanmaktadır. Son 50 yılda Karadeniz havzası, insan kaynaklı besin tuzlarının Tuna, Dnieper ve Dniester nehirleri ile özellikle KB havzasında birikimi ve deniz taşımacılığı kaynaklı, kirliliğe maruz kaldı. Ekosistem işgalci türler ve aşırı avcılık tarafından tahrip edildi. Ayrıca, besin zincirinin son basamağını oluşturan deniz memelileri ve büyük pelajik balıklar aşırı avladınlar ve stok kendini yenileyemedi. Küçük pelajik balıklar bu durumdan faydalandılar ve stokları büyüdü ancak *Mnemiopsis leidyi*’nin sisteme işgalci tür olarak girmesi özellikle hamsi stoğuna büyük zarar verdi.

Stok değerlendirme çalışmaları hamsi avında gözlemlenen ani düşüşler sonucunda ve son on yıllık dönemde Avrupa Birliği Uyum süreci ile ortaya çıkmıştır. İlk hamsi stok değerlendirmesi 1988’de artık ürün modeli kullanılarak yapılmış olmasına ragmen son on yıllık döneme kadar kapsamlı başka bir çalışma yapılamadı. Türk balıkçılık istatistikleri ticari tekne verilerine dayanmaktadır ve uygun bir stok yönetimi için gerekli olan analitic modellerin uygulanmasını engellemektedir.

Bu çalışmanın amacı hamsi stoğundaki dalgalanmaları, artık ürün modelleri kullanarak, balıkçılık baskısının fonksiyonu olarak açıklamaktır. Modeller denge durumu ve denge dışı durum dikkate alınarak uygulandı. 1968-2011 yılları arasında, 44 yılı apsayan av verisi TÜİK’den alındı. Balıkçılık verisi, 10 m’den uzun tekne sayısı, bu teknelerin toplam motor gücü, gırgır ve çok amaçlı gırgır teknelerinin sayısı ve son olarak sonarın av gücüne katkısını gösteren bir parametrenin üçüncü senaryoya entegrasyonu olmak üzere dört farklı senaryoya göre belirlendi. Senaryolar Schaefer ve Fox modelleri ile Prager'ın denge dışı durum modeli, ASPIC kullanılarak irdelendi. Denge durumunu baz alan modellerle karşılaştırılınca denge dışı duruma dayalı modellerin daha güvenilir ve gerçek dataya yakın tahminler sağladığı görüldü. ASPIC uygulamaları arasında gerçeğe en yakın tahminler Gengrid modelinden elde edildi. 1990 ve 2005'deki ani düşüşler modeler tarafından açıklanamadı.

Anahtar Kelimeler : Karadeniz, Stok değerlendirmesi, Artık ürün modeli, ASPIC, Karadeniz hamsisi, *Engraulis encrasicolus*.

To my mother Gülderen, my sister Özlem

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1 INTRODUCTION

The Black Sea Anchovy (*Engraulis encrasicolus ponticus*) stock has been affected by dramatic changes in the Black Sea environment during last five decades. These changes are eutrophication, pollution, invasive species and overfishing. In this chapter, base information about the Black Sea environment, oceanographic features and the life cycle of anchovy were provided.

To evaluate the state of the Black Sea anchovy stocks, surplus production models were tested considering two approaches.

1.1. Fish Stock Assessment

Stock assessment studies be needed in the situation that any decision is taken, which will affect fisheries, and fishery policies are being made (Gulland, 1983). The motivation of the studies, historically, comes up after a stock decline (Wallace & Fletcher, 2001). Even though the pioneer fisheries regulations started to be applied at the beginning of the 18th century (Russell, 1942), fisheries science arose interest of scientists and stakeholders, when scientists realized that the North Sea demersal fish stocks, which had been exploited before the second world war, had recovered (Graham, 1935; Larkin, 1978; Pauly & Maclean, 2003).

Fisheries biology investigations were started in late of the 19th century in Germany, Scandinavia and Great Britain because of economic concerns, and it especially focused on the distribution and life history of commercial fish species (Kesteven, 1973). Since the middle 1920s, a number of scientists have been interested in the production of fish stock regarding density and rate of fishing, and it caused accumulation of deep knowledge and methodology on these topics (Ricker, 1975).

Four main factors take role on population dynamics, which are the recruitment, growth, natural mortality (M) and fishing mortality (F) (Russell, 1931). Baranov (1918) stated that fluctuations in catches are related to population fluctuations and natural or fishery caused loss are compensated by recruitment (c.f. Nikolskii, 1969).

There are two methodological approaches to stock assessment: analytic and holistic. Analytic approach originated from biological research considering age determination using otoliths and scales (Hjort, 1994) or length data via cohort analysis. Analytical methods set on biological data to determine age composition of the population to assess recruitment, spawning stock biomass (SSB) and natural mortality. Since holistic approach requires only catch and effort data, it is preferred by scientists in the data poor situation, and its outputs are biological reference points (BRP), which are Maximum Sustainable Yield (MSY), Biomass at MSY (B_{MSY}), Fishing effort at MSY (F_{MSY}) and fishing pressure at MSY (f_{MSY}).

Holistic method is divided into two branches which are swept area method and surplus production models. The swept area method can be used both to estimate standing stock size and fishing mortality, however, it is mainly used for demersal fish stocks (Quinn & Deriso, 1999). The scope of this study concentrates on anchovy stock assessment by using surplus production models. Therefore, emphasis was given to surplus production models and the anchovy oriented information in the next section.

1.2. Surplus Production Models

Production model was based on logistic model which created by (Verhulst, 1845) (c.f. Kingsland, 1982) and following years introduced to fishery science by Graham (1935). The adjective of ‘surplus’ implies to increase of the population with additional productivity to compensate loss which is caused by fishing mortality (Schnute & Richards, 2002). Holistic surplus production model approach, contrast to analytical one, needs only effort and catch data. It ignores all complexity of population like age and spatial structure, and it describes the population as biomass (Hilborn & Walters, 1992). Thus, this model provides an assessment alternative for data poor situations, particularly when the demographic structure of the stock is uncertain.

1.2.1. Equilibrium Surplus Production

Production models, firstly set on the assumption of the recruitment to the stock and the survival rate of fish are constant every year and this situation named as equilibrium condition (Baranov 1918, c.f. (Ricker, 1975)). Three surplus production models are widely known and used by fishery scientist, which are Schaefer (1954), Pella & Tomlinson (1969) and Fox (1970) models. Even though, Graham introduced the logistic model to the fishery science in 1935, the model widely known as Schaefer’s production model. His model is linear, based on logistic population growth and B_{MSY} is fixed to the half of the pristine biomass. Pella & Tomlinson model, also called as generalized model, suggests a flexible form of Schaefer’s model, assigning an additional parameter which saves the model from the obligation of being symmetric. The Fox’s model is a special form of Pella & Tomlinson model and it assumes the Gompertz growth function as a logarithmic model. The parameter, which Pella & Tomlinson used in their model to make the MSY point flexible, stabilized to one in the Fox model.

In the equilibrium situation, CPUE is determined as a function of effort. However, in the non-equilibrium condition, it is demonstrated as a function of recruitment and survival of a number of year-classes (Quinn & Deriso, 1999).

1.2.2. Non-Equilibrium Surplus Production

Non-equilibrium approach in surplus production models, firstly developed by Schnute (1977) and afterward different interpretations of the approach had been done by a number of scientists who are Rivard & Bledsoe (1978) and Prager (1994). The approach has been used to fit Schaefer's surplus production model using catch and effort data by several assessment groups (Jacobson, Cadrin, & Weinberg, 2002; Prager M. H., 2011; Yeh & Wu, 1996; Nishida, Kitakado, & Wang, 2011). Prager's method widely used by other scientist for a number of fish stocks (Nishida & Matsumoto, 2011; Nishida, Kitakado, & Wang, 2011; Goodyear & Prager, 2001; Panhwar, Liu, Khan, & Siddiqui, 2012; Goodyear C. P., 1998). Since his method is a well-developed interpretation of the approach, the software developed by him, namely **A S**urplus **P**roduction Model **I**ncorporating **C**ovariates (ASPIC) version 5.0 (Prager M. H., 1994) was used in this study.

1.3. Stock Assessment Studies and Fishing Effort Regulations in Turkey

Stock assessment studies are relatively new in Turkey compared to Europe. Although catch and effort data started to be collected at the beginning of the 20th century, it is quite basic and remained limited to a small area, especially in Istanbul (Deveciyan, 2006). As Gulland (1983) emphasized, stock assessment studies be needed in the situation that any decision is taken, which will affect fisheries and fishery policies are being made. Historically, the motivation of the studies comes up after a stock decline (Wallace & Fletcher, 2001). During 1988-1992 large-scale projects had been performed: Knorr oceanographic project covered entire Black Sea basin in 1988, and NATO-TU Fisheries project considered exclusive economic zone (EEZ) of Turkey and focused on fish stock assessment by using the acoustic method, during 1988-1993. One of the important contributions of these projects is a more comprehensive approach to fisheries data collection of the Turkish government. In 1989 anchovy stock collapsed and the emphasis to fishery science and fishery management explicitly rose in Turkey.

The stock monitoring of the Black Sea EEZ fish populations has been carried out by Central Fisheries Research Institute (CFRI), which is a subunit of the Republic of Turkey Ministry of Food, Agriculture and Livestock (MFAL) General Directorate of Agricultural, Research and Policy, and by academic institutes. The fishery statistics are annually published by the TurkStat, and based on the questionnaires which were answered by fishermen. The content of the collected data changed through the time and the continuous data only could be provided for length, tonnage, engine power and number of crew of boats for each city. However, discard and bycatch data were not provided. Furthermore, the vital source of the analytical models, age and length data only collected under favor of scientific cruises, which were held in 1988-1991 within the framework of the NATO-TU project. CFRI have been started to sample detailed landing data in the last decade, however, due to length limitations zero age group has not been caught. The anchovy is caught by purse seiners, which is not a selective fishing gear, in the Black Sea. Because of that during fishing season anchovy from all ages are caught including recruits. After they are caught, they are separated according to their size, and the individuals which are under the legal length are discarded or sent to fish bait fabrics. However, in both situations they are not reported. Thus, recruitment data cannot be provided, which is the most important and variable part of fish production, and so it makes impossible to obtain a healthy solution from age based models (Gulland, 1983).

The first legislation for fisheries activities enacted during Ottoman Empire time (Deveciyan, 2006; Kürüm, 2010). However, uninterrupted nationwide fisheries data have been collected since 1967 by TurkStat. Considering this period first law passed by the MFAL for anchovy fishery in 1988 and it was announced via Fisheries Regulations Circular (circular) in the official gazette. Legislation for anchovy fishery were applied under seven different topics which are marketable permitted fish length, fishing hour limitation, closed area for fishing, length limitation for purse seine net, catch quota according to vessel size, the quota for the amount of fish will be sent to cold storage and fish processing companies.

Chronologically, first limitation was applied for fishable minimum length and it is defined as 7 cm in 22nd circular (1988) and 9 cm in 1989 and 1991. In 2007, for the first time, a legislation made only for anchovy which are fishing certificate obligation for purse seiners and decided to a time limitation as 16:00-06:00. In 2008, a weight limitation defined as 12 kg per case or box. In the same year following rules were also enforced, obligation of transfer certificate for all anchovy landings in the harbors, control of purse seiner’s mesh size, limitation for landings according to the each fishing boat size. In 2009, annually quota application was enforced for the amount of fish which will send to not market but to cold stores and processing fabrics, and size of carrying boxes was standardized.

1.4. The Black Sea

1.4.1. General characteristics

The Black Sea is a semi-enclosed sea, which located between latitudes of 41˚ to 46˚N and longitudes of 28˚ to 41.5˚E. It is connected to the Mediterranean Sea by the Bosporus Strait and to the Azov Sea by Kerch Strait.

State of the Black Sea water system is controlled by various physical processes. The oceanography of the basin affected by river input, atmospheric and thermohaline forces, fluxes come from straits and rapid changes in bottom topography. Its current system is important to clarify the occurrence of primary production, and, growth, migration and inclusion to lifecycle of pelagic sea organisms (Kıdeyş, et al., 2000).

The Black Sea surface current composed by a cyclonic Rim current, which circulates as shown in the Figure 1.1 with bold line and inside it Western and Eastern gyres, on the outer part of the Rim current there are anti-cyclonic local eddies which are Sevastopol, Crimea, Caucasus, Batumi (quasi-permanent), Kızılırmak, Sinop, Sakarya, Bosphorus and Kali-Akra.

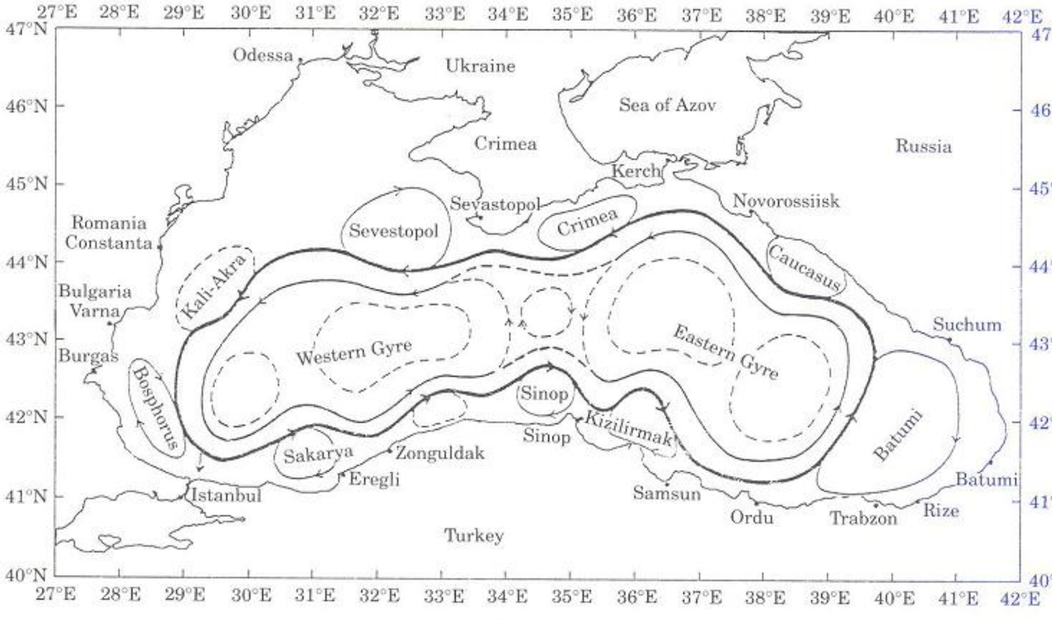

Figure 1.1: General circulation of surface current in the Black Sea (Oguz, et al., 1993)

All living activity, except anaerobic bacterial activity in the anoxic layer, limited in the upper layer to 160 m depth depending on the existence of H2S (Oguz, T.; Tuğrul, S., 1998).

1.4.2. Hydrography

In the Black Sea, mean surface temperature and salinity values in the surface layer change spatially. Mean temperature values are defined as 16˚C in the southeast area, 14-15˚C in the center and 11-13˚C in the northwest area. Mean salinity values vary in the limits between 10-24 and according to the area 18.4-20.6 in the southeast, 17-18 for surface and 22-24 for deeper water in the center part and smaller than 10 in the northwestern area (Zaitsev, Alexandrov , Berlinsky, & Zenetos, 2002).

The Black Sea is known as the largest anoxic basin in the world. A permanent halocline layer separates hydrogen sulfide (anoxic) deep water layer from the oxygenated upper layer. Oxygenated layer represents the %13 of total volume (Kıdeyş, et al. 2000).

The catchment area of the Black Sea is about 22 times larger than its surface. This feature is one of the main reasons of the quick contamination of its waters, together with the increase in development of agriculture and industry after 1960 (FAO, 1997).

1.4.3. Environmental Changes in Last 50 Years

The Black Sea has been subjected to severe ecological and environmental changes. The acceleration of the disruptive change coincided in the mid-1950s (Zaitsev Y. P., 1992). The conducive factors, which caused to the deformation, were emphasized as nutrient loading, pollution, invasive species and overfishing by several scientists (FAO, 1997; Daskalov, 2002; Zaitsev, Alexandrov , Berlinsky, & Zenetos, 2002; Temel, Tugrul, Kideys, Ediger, & Kubilay, 2004; Temel & Gilbert, 2007; Zaitsev Y. , 2008). The results of the massive impact has been observed by all Black Sea countries and discussed by many scientists all over the world. Chronologically, the problem started to be notable with nutrient loading, which caused to eutrophication. Improvement of industry and increasing human population intensified the accumulation of anthropogenic pollutants and agricultural waste to the NW Black Sea via the large river systems Danube, Dnieper and Dniester (Zonn, Fashchuk, & Ryabinin, 2007). Eutrophication caused oxygen depletion due to phytoplankton bloom, red tide and mass fish death in the NW shelf area, moreover eutrophication changed trophic link by decreasing number of species and their abundance (Tokarev & Shulman, 2007). Pollution taken effect as a result of nutrient loading, transportation and oil spill accidents which caused mass death of several animals.

Since NW Black Sea covers the largest continental shelf area biodiversity change mainly has been observed at that part, both in pelagic zone and the benthic zone. The change in the pelagic zone has taken effect from the bacterial flora to the large predators and caused a chain reaction (Zaitsev & Mamaev, 1997). Transportation’s contribution to the ecosystem change was observed in 1982 with introduction of Atlantic comb jelly, *Mnemiopsis leidyi,* to the ecosystem (Vinogradov, Shushkina, Musayeva, & Sorokin, 1989; Zaitsev Y. P., 1992). *M. leidyi* introduced to the ecosystem as a consumer and competitor of anchovy. It has consumed anchovy eggs besides other ichthyoplanktons, and according to Vinogradov, Shushkina, Musayeva, & Sorokin, (1989) at the end of the 1980s, its biomass have reached to one billion tonnes (c.f. Zaitsev Y. ,2008).

Besides eutrophication, pollution and invasion of alien species, the most effective human based damage to the ichthyofauna have become from overfishing. In 1970s industrial fishing started and number of ships continuously increased, in a short term its turnover was the depletion of large pelagic predators (Daskalov, 2002; Llope, et al., 2011).

The ecosystem change is illustrated in Figure 1.2 which shows food web before and after Mnemiopsis introduced to the system. The major changes marked with bold and thin lines. During the pre - invasion and pre-overfishing period, food web was set on the big fish eats small one and addition to that jellyfish feeds on phytoplankton and zooplankton. However, the introduction of *M. leidyi* and increased fishing mortality have been affected the food web in different stages. Consequently, *M. leidyi* consumed most of the zoo- and phytoplankton, when zooplankton biomass decreased pelagic fish stocks had a food source problem. With the effect of intensive fishing pressure fish stocks heavily damaged.

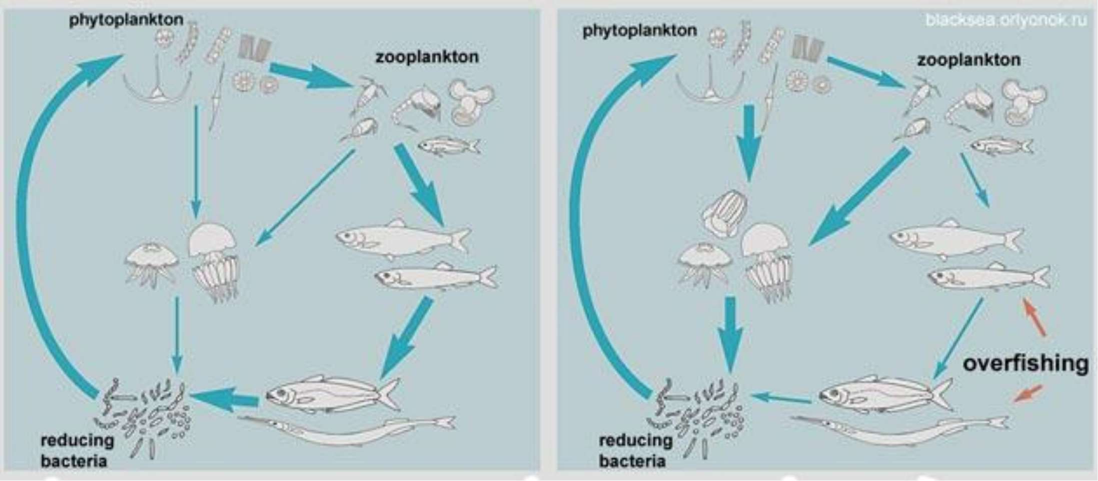

Figure 1.2: Schematic presentation of changes in the Black Sea pelagic food web due to overfishing and *M. leidyi* introduction (Figure taken from Vershinin, 2013)

Overfishing have been observed in different trophic levels, Monk Seal (*Monachus monachus*) has disappeared in the area since 1990s (Zaitsev Y. P., 1992); three dolphin species currently exist in the Black sea have been overfished in the mid-1960s and their abundance could not reach its previous state again; at the end of 1960s large pelagic fish species disappeared, especially in the NW Black Sea; the European anchovy is the most suffered and remarkably depleted stocks among other small pelagic fish species (Zaitsev Y. P., 1992; Daskalov, 2002; Zaitsev, Alexandrov , Berlinsky, & Zenetos, 2002).

1.5. Pelagic Ichthyofauna of the Black Sea

The Black Sea ichthyofauna consists of the fish species migrate between adjacent seas such as mackerel, bonito, tuna, Atlantic mackerel and common bass, and migrate inside the basin such as anchovy and sardine. While mackerel spawns in the Marmara sea and feeds on the Black Sea, anchovy migrates to the southern coast for wintering and NW shelf to feed and spawn.

According to the Turkish catch records the pelagic fish catches, which presented in the Figure 1.3, are 8.5 million tons for anchovy, 1 million tons for scad, 300 thousand tons for sprat and also for horse mackerel, and 500 thousand tons for Atlantic bonito.

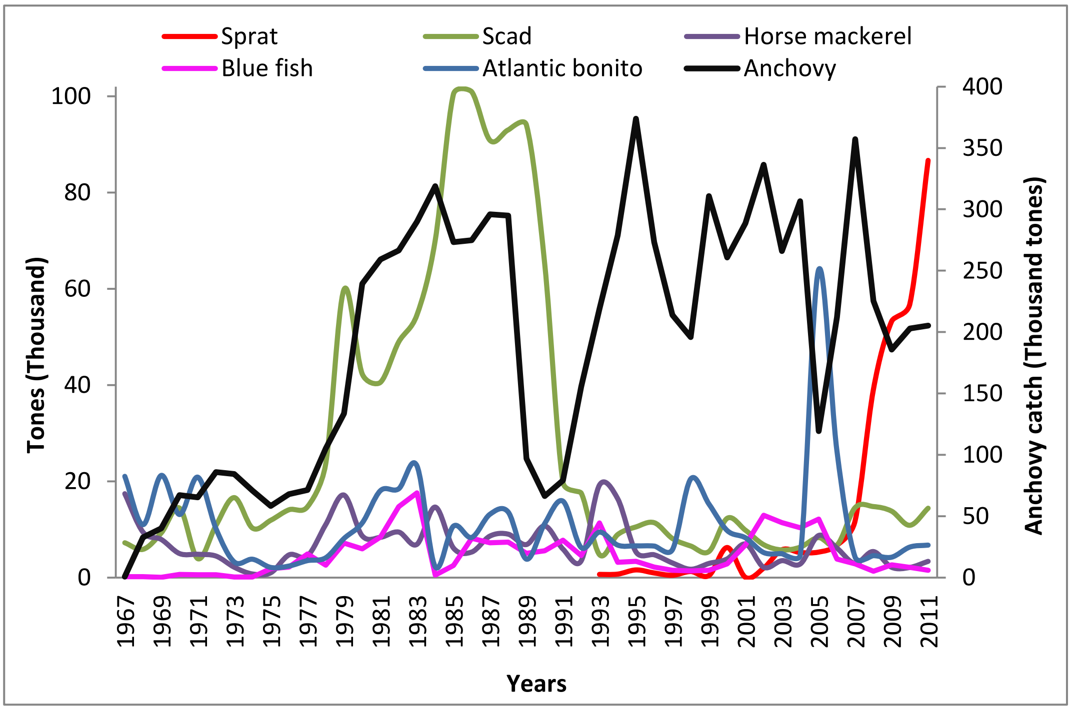

Figure 1.3: Catch values of commercially important fish species for years 1967-2011

1.5.1. European Anchovy (*Engraulis encrasicolus*)

According to Whitehead et. al. (1988), there are eight species of the genus *Engraulis* living throughout the world which are *E. australis, E. capensis, E. encrasicolus, E. eurystole, E. japonicus*, *E. anchoita*, *E. mordax* and *E. ringens*. Genus Engraulis includes the most common pelagic small fish species in the world's oceans. *Engraulis encrasicolus*, named as European anchovy, is geographically distributed in Eastern North and Central Atlantic. It mainly caught in the Mediterranean and adjacent seas by purse seiners, lampara nets, beach seines and especially in winter by midwater trawl (Whitehead, Nelson, & Wongratana, 1988).

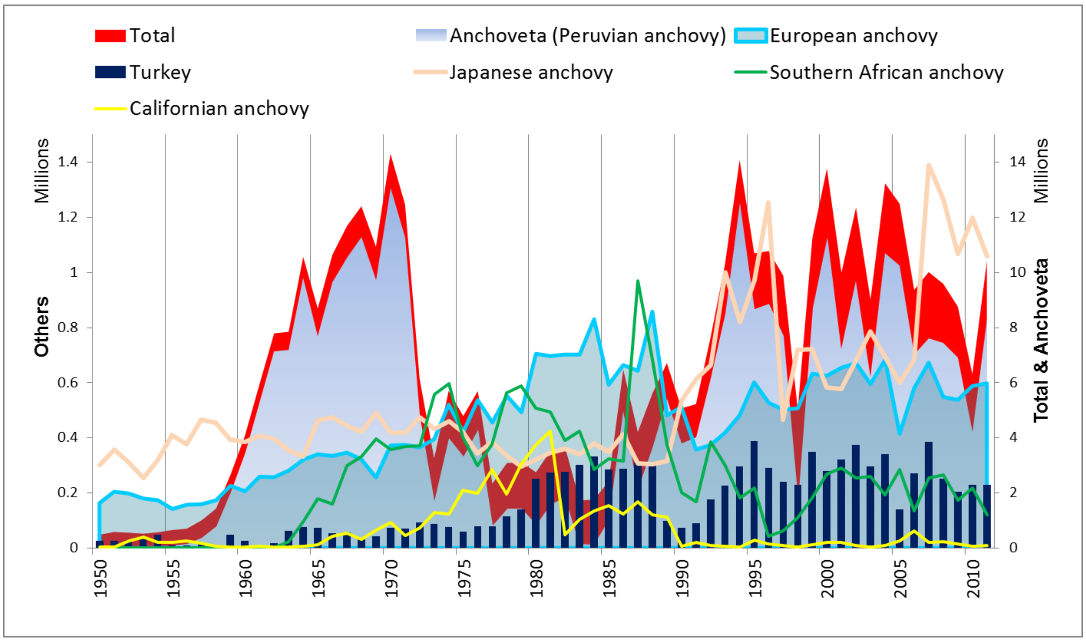

Figure 1.4: Catch values of most fished anchovy species in the world between 1950-2011

The Black Sea anchovy originates from the Mediterranean and it is a representative of Mediterranean migratory species in the Black Sea (Zaitsev Y. , 2008). Two subspecies of the European anchovy are believed to inhabit in the Black sea which are namely *E. encrasicolus ponticus* (Black Sea anchovy) and *E. encrasicolus maeoticus* (Azov Sea anchovy). According to Chashchin (1996) the Azov and Black Sea anchovies are two geographical populations of European anchovy and they adapted to reproduce in sea water having different salinity values. Their life cycle includes hatching, feed, spawn, overwintering and spawning migration. They hatch in their geographical area (Azov or Black Sea), during the period between the end of spring and the end of summer. At the end of the spawning season, a small part of each new generation of anchovy reaches sexual maturity and after hatching in two-three months they spawn (Lisovenko & Andrianov, 1996). The winter migration of anchovy has been started when the fat level in the body that they store reaches to the certain level and the seawater temperature decreases to 9-12 C° (Shulman, 2002). After wintering, they may remain in the wintering area or follow the migration route during spring as shown in the Figure 1.5. Details of the life cycle of anchovy were given under following subtitles.

1.3.1.1. Feeding

The anchovy is an omnivorous species and its main preys are composed of zooplankton species, especially the one which belongs to the Copepoda and Cladocera taxons (Bulgakova, 1996). Anchovy ingests the food that 13-55% of its body wet weight and population needs to consume up to 80000 t of plankton per day in the spawning season which is about 20% of the daily plankton production in the Black Sea and these features make the anchovy an important part of the Black Sea ecosystem dynamics (Bulgakova, 1996).

1.3.1.2. Reproduction

The Black Sea anchovy spawns from the middle of May to the second half of August and the peak of spawning lasts from the middle of June to the end of July. Its optimum spawning temperature is between 19˚C and 24˚C but during the spawning season temperature can vary from 16˚C to 28˚C (Lisovenko & Andrianov, 1996). The anchovy is a batch spawner and one female can produce 50 batches of eggs on average during the spawning season (Lisovenko & Andrianov, 1996). Early maturing, long period of spawning, multiplicity of spawning, high level of individual fecundity, high ability to restore reproduction were reported as the main factors of very high reproductive potential of the species by Lisovenko & Andrianov (1996). Development of eggs takes place approximately 24 hours depending on the water temperature.

1.3.1.3. Migration

Since the anchovy is thermophilic species, just after cooling of the sea water in Autumn it migrates to the southern part and when the sea water gets warmer the species migrate to the northern part of the Black Sea to spawn (Zaitsev Y. , 2008). According to Chashchin (1996) Azov and Black Sea anchovies spawn in different areas, but they mix during the wintering time most frequently when they reached Batumi region. As explained in Figure 1.5 Azov and Black Sea anchovies follow particular paths for wintering, spawning and foraging. While Black Sea anchovy following the route from northwest to south following rim current, Azov anchovy follows the route through the Caucasus until Georgia coast and another part reaches to Crimea and remains there. During spring migration, Black Sea anchovy follows on the eastern part the area which covers the eastern part of Anatolia and Batumi to Sinop then through the northwestern shelf. On the other hand Azov anchovy follows two routes which it may mix with the Black Sea anchovy population and follows its route or it can turn back to the Azov Sea. Chashchin (1996) made some additional comments in his article about migration routes and he suggested that migration route may change depending on weather condition of Georgia during winter season. If the region had a long and snowy winter, the spring migration predominantly observed in the direction of Sinop and then to the northwest sea. According to Chashchin (1996) the reason why Black Sea anchovy moves from west and south part of the sea to the Caucasian coast is that the region is protected from the northern winds by Main Caucasus Ridge and not influenced by cold currents, which is dominant in the western part.

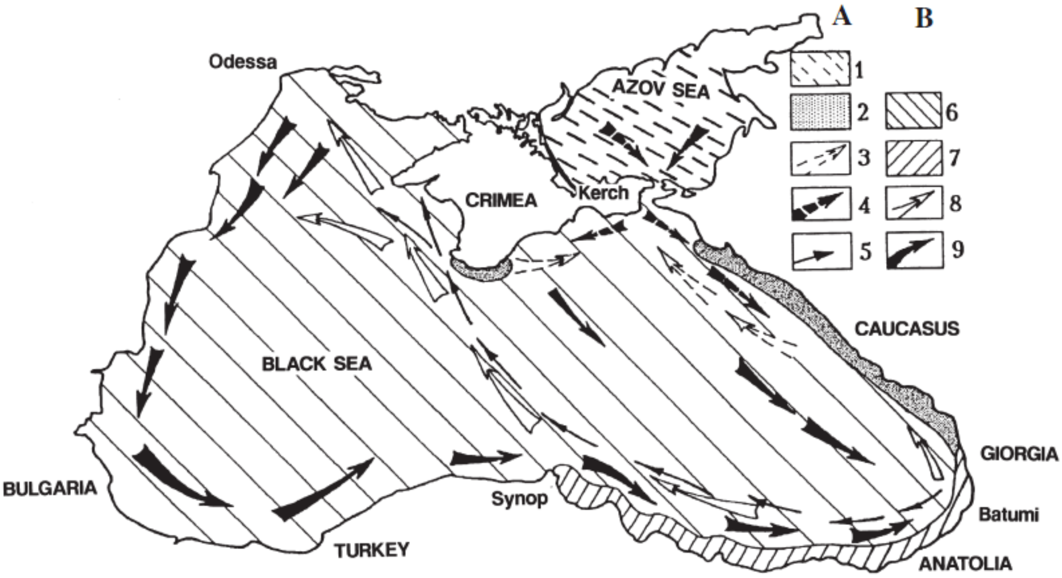

Figure 1.5: The general scheme of anchovy migration.

(A) Azov anchovy: 1- spawning and foraging region; 2- wintering region; 3- spring migration; 4-autumnal migrations; 5- periodic migrations of a mingled population. (B) Black Sea anchovy: 6- spawning and foraging region; 8- spring migration; 9- autumnal migrations. (Chashchin, 1996)

2 MATERIAL AND METHOD

To evaluate the state of the Black Sea anchovy stocks two different approach and surplus production models were tested. The models require the same input variables, namely catch and fishing effort. The catch data is the anchovy landings of Turkey published by the former State Institute of Statistics, SIS (1968-2005) for 38 years and Turkish Statistical Institute, TurkStat (2005-2011) for six years. The data are available for eastern (Hopa – Sinop) and western (İnebolu – İğneada) Black Sea coast of Turkey. In this study the catch data from these two parts were combined.

For estimation of effort, four progressive assumptions were made to estimate the fishing effort spent on the anchovy stock in the Black Sea. The assumptions were given below.

1. Size of fleet: The total number of boats larger than 10 meters given formerly by SIS and TurkStat (2005-2011) were used as the size of the fishing fleet operated in the Black Sea.
2. Engine power: Kilowatt of the engines of the fishing boats, which is more than 10 m, was included in the estimation of fishing power and used for the years from 1968 to 2011.
3. Type of gear: The number of boats registered as purse seiner and multipurpose (purse seiner & trawler) was used for the years from 1984 to 2011. However, data is only available after 1987 in TurkStat archive because of that data of previous years before 1987 were taken from Ministry of Agriculture report (Anonymous, 1992).
4. Use of sonar: Sonar number started to be given after 2007 by TurkStat, the years between 1968 and 1991 sonar data were taken from the survey reports of the Central Fisheries Research Institute of the Ministry of Food, Agriculture and Livestock (Anonymous, 1992) for the years from 1992 to 2006 purse seiner number were assumed that as sonar number and taken from SIS and TurkStat data set.

Available data used for these models and approaches were as follows: All these approaches utilize the catch data which are common fixed for all, and the second dataset relates to effort given in the Appendix 1, under the name of scenarios. Discard of anchovy was neglected in all models.

The approaches and models were explained in the following section.

2.1 Surplus Production Model

The basic outputs of Schaefer and Fox models are the biological reference points which are f_{MSY}, and MSY. Their equations were given in Table 2.3. While MSY indicates the maximum permitted yield that can be harvested to protect the sustainability of the stock; f_{MSY} is the fishing effort which would let the stock to produce sustainable biomass (B_{MSY}).

In this section, three different approaches of surplus production model were described. Schaefer and Fox models, both describe the equilibrium condition, whereas Prager (Prager M. H., 1994) approach model (**A** **S**tock **P**roduction **I**ncorporating **C**ovariate – **ASPIC**) is describing a non-equilibrium condition.

The four assumptions described above were examined in four scenarios given below.

Size of the fleet:

Scenario 1 (S1): In order to use the maximum benefit of the longest data set available (from 1968 to 2011; Appendix 1) it was assumed that all boats larger than 10 meters regardless of their size, engine power and type of fishing gear used contributed to the total anchovy landing. The impact of size and specifications of a fishing boat on the catchability is henceforth disregarded. The catch per unit effort is assumed to be a function of the number of vessels in the fleet.

Engine power:

Scenario 2 (S2): If we assume that the number of the vessel and their size does not change by the year, technological development has a positive effect on vessels' fishing effort. Unit of engine power was changed from HP to kW[1] as explained in Equation 1 and Table 2.1.

Beverton & Holt (1957) stated that the engine power of a vessel may have an effect on fishing power, which increase linearly with the total horsepower of a vessel. Therefore, in this scenario, in addition to the number of boats in the fleet their average horsepower were used to estimate fishing effort. Categorized HP data were taken from SIS and TurkStat.

For TurkStat data, engine power of the vessels was categorized as in Table 2.1. Calculation of the total engine power of the fleet was carried out by the following formula.

Equation 1: Transformation of total engine power from the unit of HP to kW

$$f_{kW} = \overline{HP_{cat}} * n_{HP} * 0.75$$

Where,

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[1] During the European Union negotiations in order to comply with common fisheries policy, Turkey has adapted kW after 2005 .

F_{kW}: Fishing effort in the unit of kW

HP_{cat}: Mean horse power category*

n_{HP}: Number of the boat which belongs to the engine power group

Table 2.1: Mean engine power group values used calculation of total engine power

Unit of engine power/ Engine power groups	1 - 9	10 - 19	20 - 49	50 - 99	100+ -199	200-499	500+
HP	4	11	26	56	112	-	-
kW	5	15	35	75	150	350	750

Type of gear:

Scenario 3 (S3): Until 1980s, the type of gear (trawl, purse seine, etc.) was in the boat owners' will. However, with a regulation enforced in 1980s, the boats were licensed according to the gears they use. Purse seiners are by far the greatest contributors to anchovy fishery in the Black Sea and the landings of other types of fishing are not considerable. A part of vessels use two types of gear depends on seasons' abundant fish species. These vessels change their gear from trawl to purse seiner or vice versa within the same year. As anchovy is the most commercial species in the region, it was assumed that any fishing vessel authorized to use a purse seine would prefer to practice anchovy fishing during the season. The multipurpose boats (trawl and purse seine) were considered as purse seiners.

Use of sonar:

Scenario 4 (S4): Sonar as a tool to locate anchovy schools should evidently increase the fishing efficiency of a vessel. Therefore, in S4 it was assumed that having sonar in a fishing vessel, irrespective of the other specifications of a purse seiner, increases the fishing power. The scenario considers the technological improvement's effect on fishing effort and accepts sonar as the most important part of it. Sonar has started to be used in 1950 for commercial purposes and it entered the Turkish fleet in 1965. As can be seen in Appendix 1, sonar number increased continuously after 1974 and in the present boats its number is close to the number of boats.

With this argument, fishing effort value which is under the effect of sonar calculated as using the steps shown in Table 2.2. Its improvement effect on the vessel was calculated defining a coefficient. Sonar coefficient was calculated using Excel Solver optimizing correlation coefficient to the best value. After that sonar number was multiplied by the coefficient and the new sonar number added to the year's number of boats.

Table 2.2: Calculation steps of fishing effort which added sonar effect

Step/ Time Period	**1968-1991 & 2007-2011 (Observed years)**	**1992-2006 (Calculated years)**
1= Sonar number per years	S/B=C	$C_{mean}=(C_{1991}+C_{2007})/2$ $C_{i+1}=C_i + C_{mean}$
2=Sonar coefficient (S_{coef})	Calculated by Microsoft Excel Correlation coefficient value (R) was set as changing variable Sonar coefficient set as an objective to minimum value.	
3	$F_s= (B-S)+C*S_{coef}$	$F_s= B*(1-C_i) + (B*C_i*S_{coef})$

The explanations of abbreviations

S: Number of sonar

B: Number of boat

C: Rate of S to B

F_s: Fishing effort value which added sonar effect

S_{coef}: Coefficient of sonar's contribution the improvement of fishing effort to a boat

2.1.1 Equilibrium Surplus Production Model

The number of the boat and type of vessel has an impact on fishing effort (Ricker, 1975). Besides these factors, also size of engine power assumed that has an impact on fishing effort. Usage of sonar has a notable impact on the increase of fishing effort.

Schaefer and Fox surplus production models were used to calculate MSY and f_{MSY}. The formulas used to calculate MSY are given below.

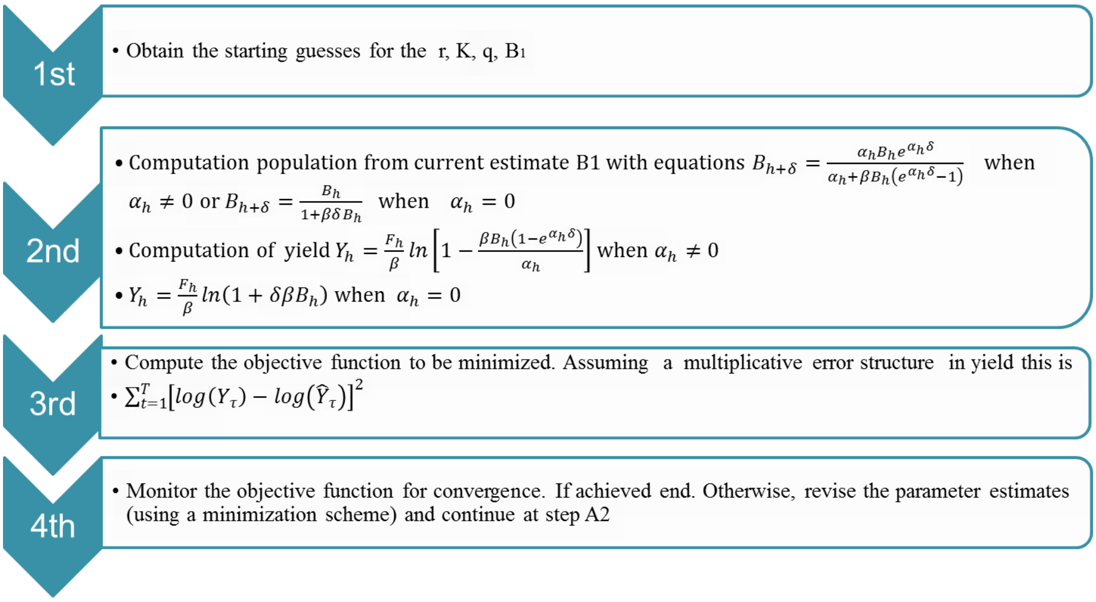
Table 2.3: The calculation procedure for estimating MSY (Sparre & Venema, 1998)

	Schaefer	Fox
MSY	$-0{,}25 * (\frac{a^2}{b})$	$-\left(\frac{1}{a}\right) * \exp(b-1)$
f_{MSY}	$-0{,}5 * a/b$	$-1/b$
Intercept	$a = (\Sigma y - b\Sigma x)/n$	
Slope	$b = \frac{\sum xy - [\frac{\sum x \sum y}{n}]}{x^2 - [\frac{(\sum x)^2}{n}]}$	

2.1.2 Non – Equilibrium Surplus Production Model

The software applications are based on two well known model which are Schaefer's logistic model and Pella & Tomlinson Generalized model. In the software, Pella & Tomlinson was represented with Fox model and its varieties Genfit and Gengrid model shapes. Genfit is direct optimization and Gengrid is a grid of fits in the model shape (Prager M. H., 2011). In this study, all of them were examined.

Catchability coefficient (q) generally taken as one, to stay on the safe side. Though, when q used at more than 0.01, optimization is more difficult with ASPIC (Prager M. H., 2011). Because of that, q was used in the study less than one and its sensitivity defined according to the scenario. The parameters' starting guess and bounds were determined according to the directions presented by Prager M. H. (2011). The algorithm of the ASPIC software was given in Figure 2.1.



- Obtain the starting guesses for the r, K, q, B_1

- Computation population from current estimate B1 with equations $B_{h+\delta} = \frac{\alpha_h B_h e^{\alpha_h \delta}}{\alpha_h + \beta B_h (e^{\alpha_h \delta} - 1)}$ when $\alpha_h \neq 0$ or $B_{h+\delta} = \frac{B_h}{1 + \beta \delta B_h}$ when $\alpha_h = 0$
- Computation of yield $Y_h = \frac{F_h}{\beta} ln \left[1 - \frac{\beta B_h (1 - e^{\alpha_h \delta})}{\alpha_h} \right]$ when $\alpha_h \neq 0$
- $Y_h = \frac{F_h}{\beta} ln(1 + \delta \beta B_h)$ when $\alpha_h = 0$

- Compute the objective function to be minimized. Assuming a multiplicative error structure in yield this is
- $\sum_{t=1}^{T} \left[log(Y_\tau) - log(\hat{Y}_\tau) \right]^2$

- Monitor the objective function for convergence. If achieved end. Otherwise, revise the parameter estimates (using a minimization scheme) and continue at step A2

Figure 2.1: Algorithm used in ASPIC software

Non-equilibrium surplus production model results were subjected to an elimination system to reach a more reliable result. The system is based on a search of the simulation provided highest goodness of fit value, and includes two steps. Elimination requires 24 simulations to test the sensitivity of the four model shapes to differentiate optimization modes and catchability coefficient (q) values. At the end of the first elimination step, first three model shapes, which have the highest R^2 value, were selected to use in the second elimination step. At the second step, elimination required 12 simulations, and it was based on two determining variables which are B_1/K (0.25 and 0.5) and the penalty term (on and off modes).

In non-equilibrium approach to surplus production models, the most successful results were determined according to their R^2 value. If it is higher than 0.4, they were counted as considerable. The simulations resulted with lower than this value and it was eliminated. At the second step, only the highest values were considered. Some of the simulations resulted in SSE[2], MSY>K[3], K[4] or q[5] errors, this kind of results was directly eliminated regardless their R^2 value is high or not.

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[2] Minimum SSE found at lowest or highest B_{MSY}/K in user range. This is not a true minimum.
[3] Estimate of MSY is at or near estimate of K. An internal constraint of ASPIC does not allow MSY > K.
[4] Estimate of K is at or near maximum bound, 7.400E+06.
[5] One or more estimates of q are at program-assigned maximum or minimum bounds.

3 RESULTS

In this section, catch, fishing effort and CPUE values evaluated separately. Afterward model results were presented in each scenario and lately some environmental parameters were presented.

3.1 Catch, Fishing effort and CPUE

Examination of the total anchovy landing data available showed quite irregular distribution over the years (Figure 3.1). Five distinct periods may be recognized. The first period lasted until 1977, during which the catch level was almost stable. The second period marks the rapid increase in the landed anchovies and the catch level remained very high for almost ten years. The third period is the time of the first noticeable collapse in the Black Sea anchovy fishery in Turkey. The collapse period lasted three years and recovered rapidly in the fourth period. The recovery is followed by the fifth period during which the landing is characterized by ups and downs, but the overall trend in this period is remarkably negative. A noteworthy year within the fifth period is 2005 when a very sharp decline in the catch was observed. During the last 44 years, minimum catch obtained in 1968, which is 32 828 tones, and the maximum one obtained was in 1995 (which is 373 782 tonnes). The largest decreases were observed in the years 1989 and 2005.

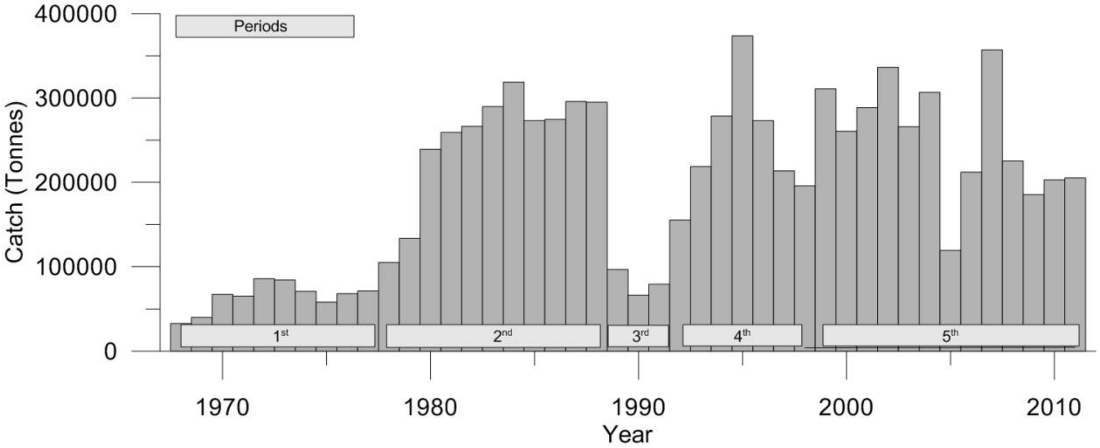

Figure 3.1: Anchovy catch graph for the year 1968 to 2011

In this study, four different fishing effort data were used to describe the fishery (Figure 3.2). The first effort data used for S1 includes the number of boats larger than 10 m. In this approach, three distinct periods may be recognized; the first is the period between 1968 and 1982, during which the number of boats in the Black Sea has been low, not exceeding 100 boats and has not been changed much over the years. In the following period the number of boats has smoothly increased until in 2005 with some minor fluctuations. After year 2005, when the number of boats reached to its maximum with 5 084, a noticeable decrease can be noticed in Figure 3.2.

In the second approach the effort figures, the total engine power of the fleet have not changed much until 1992. During the following period, the effort has gradually increased until 2005. The total engine power of the fleet displayed a dramatic jump (634 000 kW) in the year 2005 and dropped in the preceding years.

Third fishing effort data represent the number of purse seiners (including multipurpose boats), used in the S3. Number of vessels continuously and very smoothly increased until 1992. After this year, some fluctuations were observed. After 1983, the lowest value observed in 1992 with 163 vessels and the following year it increased again to 287 vessels. Maximum number of vessels are 566 and observed in 2008.

The fourth fishing effort data set, which represents the number of purse seiners, tuned with a sonar factor. A very similar pattern to S3 was estimated. The effort continuously increased until 1992 and the minimum value after 1983 was observed in 1992. Maximum effort is 2196 and observed in 2005.

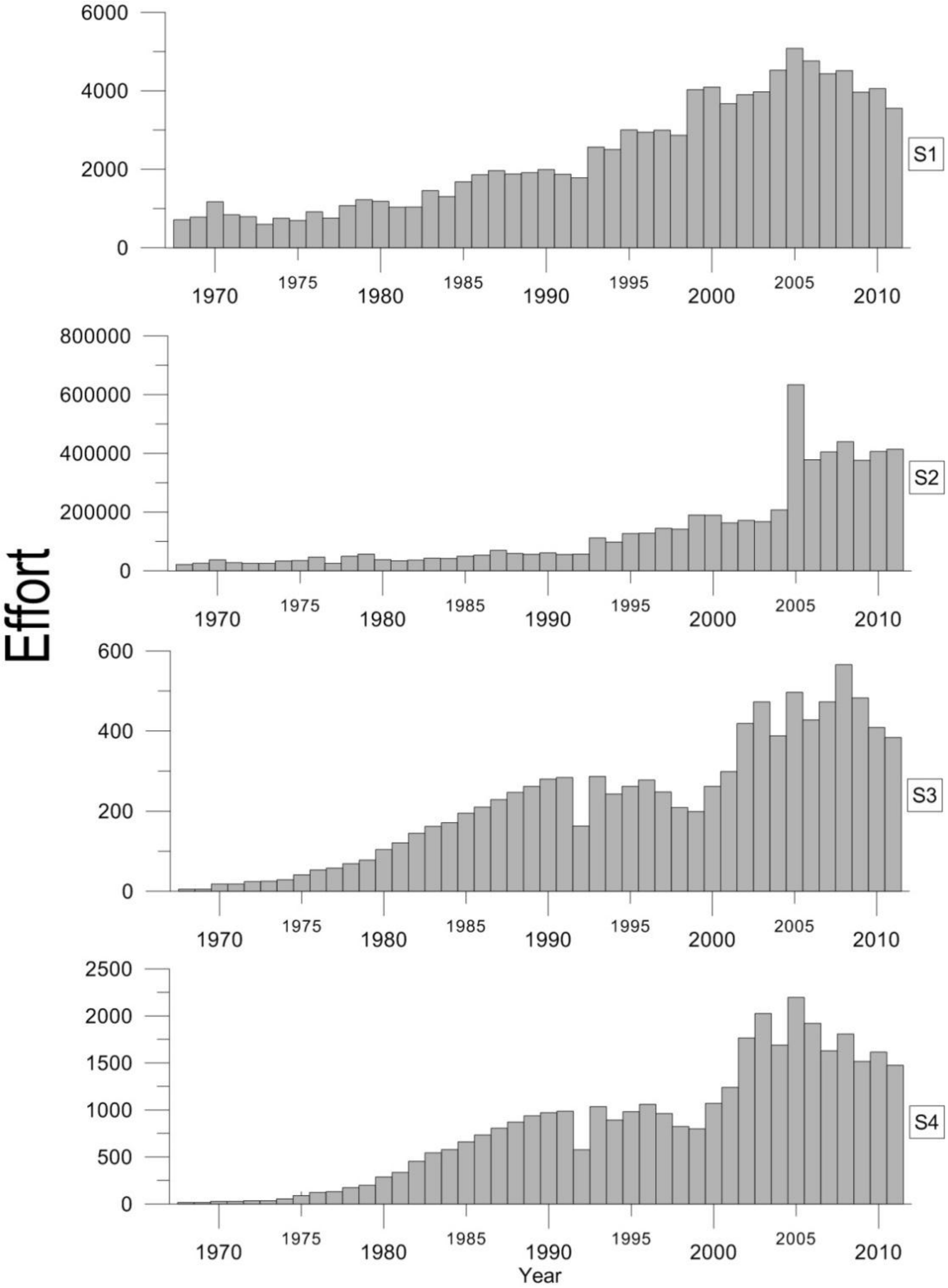

Figure 3.2: Fishing effort graph according to scenarios

Apparently CPUE displayed different patterns with the effort data used. The main differences are in the first part of the data set. The first two scenarios, S1 and S2 suggested a relatively lower CPUE figure compared to the rest of the data set. In S3 and S4, the very first part of the data set displayed the largest figures ever recorded. However, there are still some patterns common to all CPUE figures. All of the graphs displayed a very low CPUE value in 1990 and 2005.

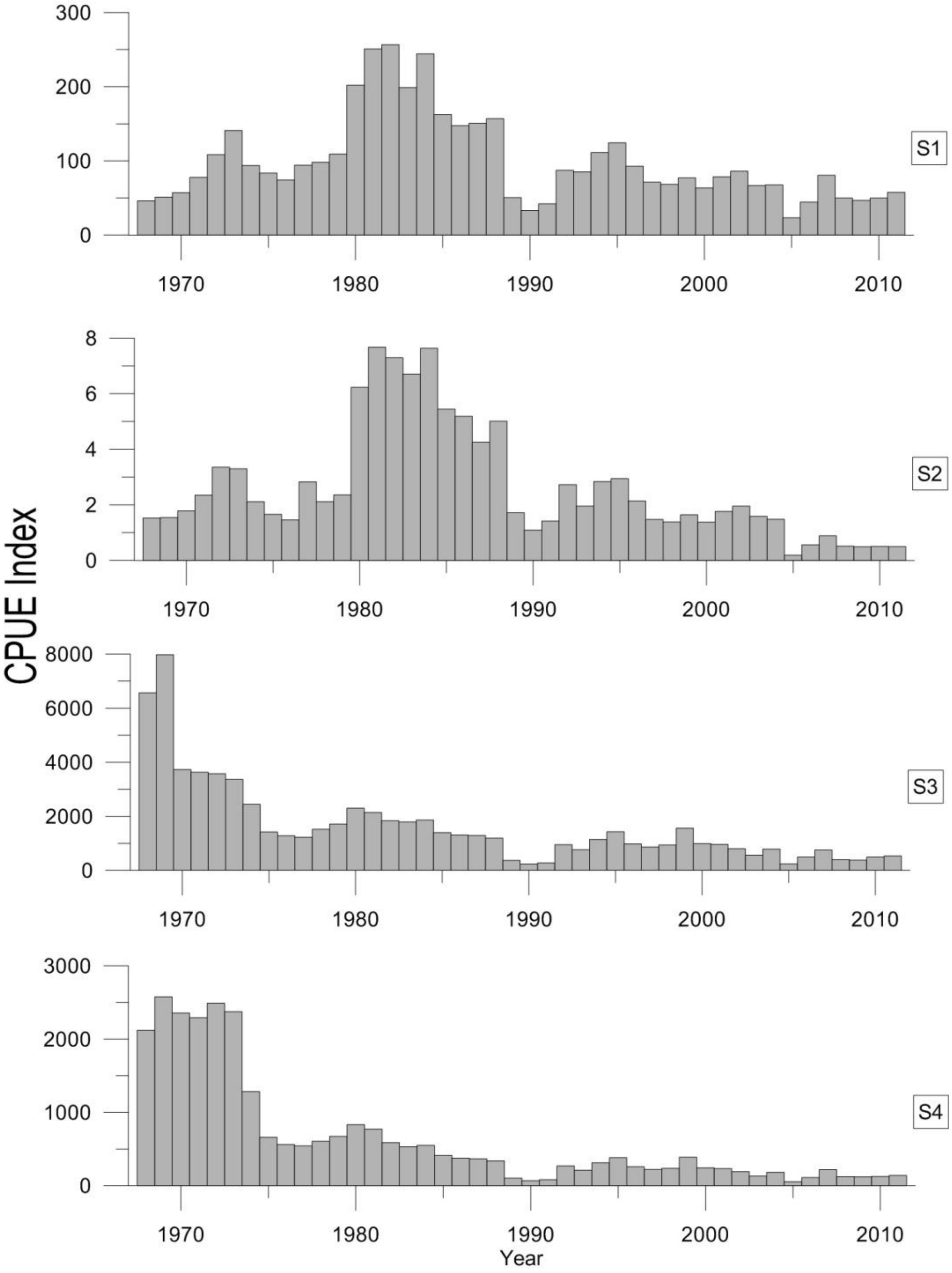

Figure 3.3: CPUE Results According Scenarios

3.2 Scenarios

The model results are presented first for the equilibrium and then for the non-equilibrium variants. Related model results were given according to scenarios. Each result was presented as a figure, gathered at a table and explained under the related chapter. In this section, scenario results were divided into three parts. First one is the catch-effort relation according to the derived fishing effort data; second and third parts include a comparison of observed and calculated results. As mentioned above calculated results derived using estimated parameters of each model.

For equilibrium models, the first type of figures comprises observed catch value and the effort data. In this type of graph, some labels indicate the corresponding years and they were extracted from the graph to avoid masking due to overlaps. The marked periods on the figures were explained under the related scenario.

The second type of figures was presented under models for each scenario. The figures refer to the catch and calculated catch results, as explained above, and periods were marked with colors and shapes on it. While biological reference point F_{MSY} value was marked with dashed lines in a vertical direction, MSY was marked with the same type of line in the horizontal direction and both of marked with labels. At each graph calculated catch marked with red line and observed catch marked with the symbol and linked with half transparent, gray dashed line.

The third type of figures also marked with colors and shapes, and they refer to the observed and calculated CPUE as explained earlier. While observed CPUE was marked with a black line, calculated one was marked with a red line.

Non-equilibrium approach to surplus production models were applied as explained in 2.1.2. During the study, model shapes' sensitivity was also examined. According to the results, all model shapes are sensitive to optimization mode and none of them is sensitive to B_1/K value changes. Penalty term is one of the effective one, however, there is an exception for the variable, which is the Pella & Tomlinson applications of S1 simulations. Catchability coefficient (q) generally not effective, but there are a few exceptions and they were noted in advanced.

Examination phase for the best result were explained in detail in 2.1.2. The best R^2 was provided in every scenario from Gengrid model shape. Among all scenarios the best $R^2$was found as 0.7 and it obtained from the combination of the parameters Gengrid model shape, based on EFT mode and penalty term is on in S4.

Non-equilibrium approach applications provided several outputs, basically the production parameters. Some of the parameters are the maximum sustainable yield (MSY), carrying capacity (K), catchability coefficient (q), stock biomass giving MSY (B_{MSY}), fishing mortality rate at MSY (F_{MSY}), fishing effort rate at MSY (f_{MSY}), approximate yield available at F_{MSY} in 2012 (Y. (F_{MSY}) '12), equilibrium yield available in 2012 (Ye '12) and starting relative biomass in 1968 (B_1/K '68). Two types of output were presented as figure for each scenarios' successful simulation. First one is CPUE values, F/F_{MSY} and B/B_{MSY}. F/F_{MSY} and B/B_{MSY} results were given in the same figure to understand their response to each other through the time period. Both figure types also plotted for comparison of successful simulation, in the case of their R^2 values are equal. On some of the graphs, two model shapes were given together because of their estimations are the same or quite similar. The one of the differential feature of Gengrid and Genfit models from the others is their B/B_{MSY} estimations starts with high value and continuously decrease while the others starting with low values, getting increased and afterward decrease again through the time period.

3.2.1. Scenario 1 (S1)

S1 assumes all boats larger than 10 meters regardless of their size, engine power and type of fishing gear used, contributed to the total anchovy landing. The catch per unit effort is assumed to be a function of the number of vessels in the fleet.

The catch data plotted with respect to fishing effort is far from following a pattern, and it is spread out over a wide range (Figure 3.4). However, four data patches may still be recognized. The ellipse on the left part of the figure displays the very early phase of the fishery when the anchovy stock was near to the virgin state and represents the late 60's and 70's. Although the fishing effort has not changed much, a very sharp jump in the catch is observed in the patch formed by the data pairs of the 1980's, which is marked with a circle on the graph. Another sharp change followed this patch and a remarkable decrease observed in the first half of 90's. The last patch covers the years after 1999, which is on the right part of the graph and marked with a rectangle. This is essentially the high effort period when the number of boats reached to a platoo.

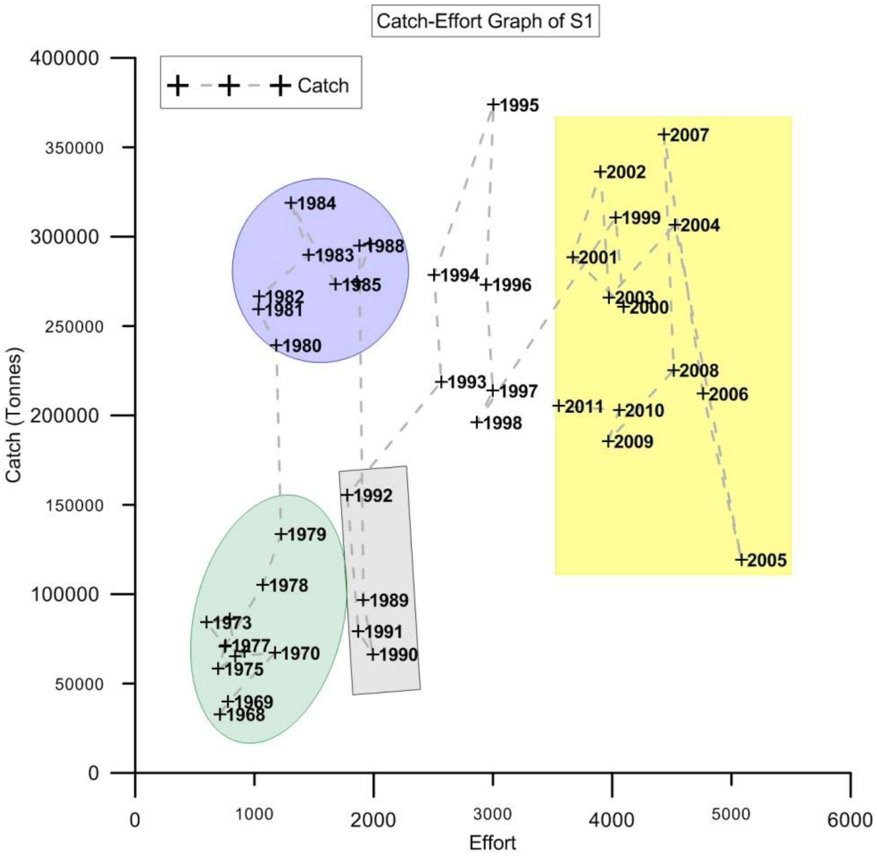

Figure 3.4: S1, Catch-Effort graph

According to CPUE results lowest CPUE value was obtained in 2005 and the highest one was obtained in 1982. The series of calculated and actual CPUE for the respective year are depicted in Figure 3.6 and Figure 3.8.

3.2.1.1 Equilibrium Surplus Production Model Results

3.2.1.1.1 Schaefer Model

The observed data were modelled by the Schaefer model and the results were presented in Figure 3.5. The model indicates that, the level of fishing that would produce the maximum sustainable yield, F_{MSY} has been exceeded after 1999. The closest effort corresponds to the fleet size was observed during the period from 1999 to 2003 and 2009 to 2011. The closest value to MSY and F_{MSY} was reached in 2003. As can be seen from the Figure 3.5, small effort range corresponds a wide range catch value at some points. Schaefer model which based on the relation between CPUE and number of boats was found to be statistically significant (P<0.01), and MSY is estimated as 273 000 tones. The estimated fishing effort that would yield the MSY under the given situation is about 3821 boats.

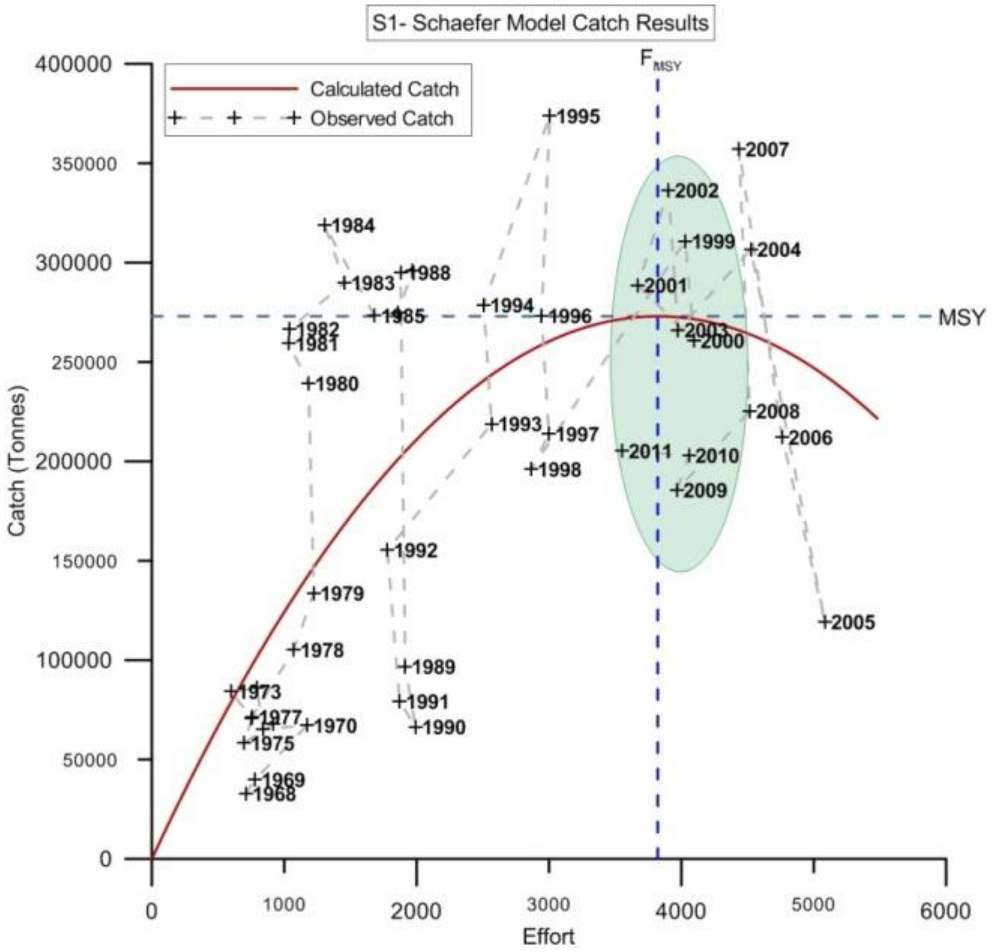

Figure 3.5: S1, Schaefer Model Catch Result

As might be seen in the Figure 3.6 model captured the general decreasing trend in CPUE. Although the model also explains some fluctuations, it remained incapable to explain the largest fluctuation, which previously marked as second period.

Figure 3.6: S1, CPUE Result

3.2.1.2.1 Fox Model

Surprisingly, the Fox model result suggests that F_{MSY} has never been reached. Although the fleet size has remained blow the the optimum level the maximum sustainable yield estimated by the model has been exceeded several times in the past. The closest effort to F_{MSY} was reached in 2005 (Figure 3.7), however, this is the year when the catch was the lowest. The model failed to explain the fluctuations over the years. Despite all the discrepancies, the Fox model, which actually based on to the relation between CPUE and number of boats was found to be statistically significant ($P<0.01$), and the MSY is estimated as 260 000 tones. The estimated fishing effort that would yield the MSY under the given situation is about 5 345 boats. In may worth noting that these results are quite close to the values estimated by the Scheafer model.

As the model predicted CPUE is compared with the actual CPUE there are very few in common. The model captured the decreasing trend over the years (Figure 3.8). The increasing trend during the first early phases of fishery has not been simulated well.

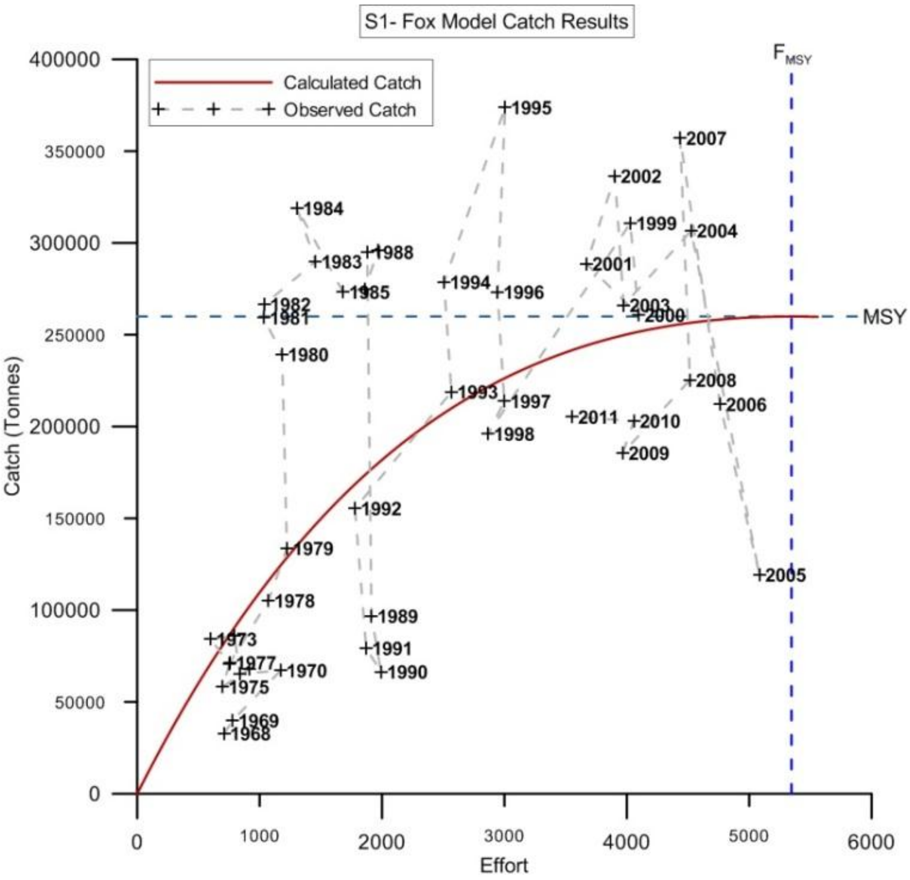

Figure 3.7: S1, Fox Model Catch Result

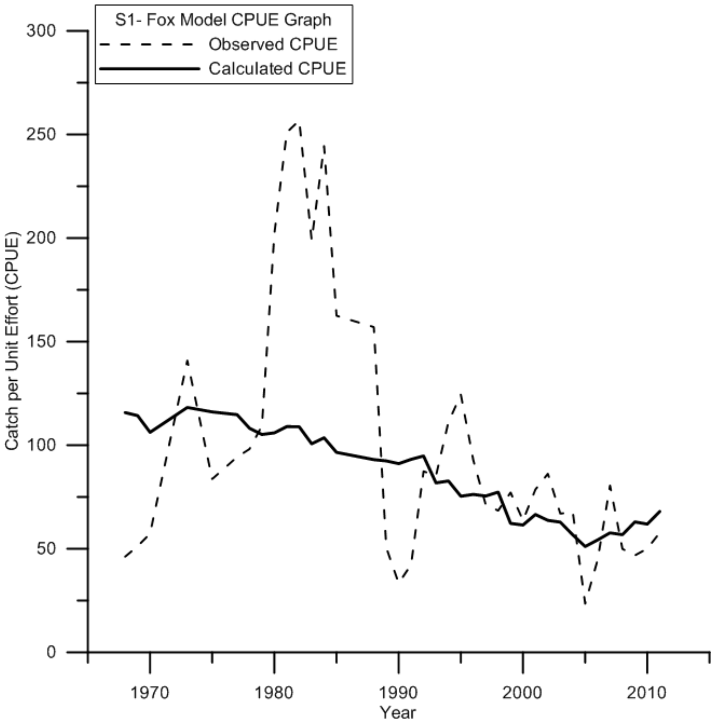

Figure 3.8: S1, Fox Model CPUE Graph

3.2.2.1 Non-equilibrium Surplus Production Model

Non-equilibrium approach to S1 provided low R^2 value Model shapes were responsive to optimization mode changes. However, sensitivity to other parameters were different, as shown in the following section. Highest R^2 value was provided by simulations of GenGrid algorithm and Fox model shapes. Even though these values are lower than 0.5, they are worth to consider for further examinations. GenFit model was eliminated in this scenario because it ended with the SSE and it was marked with a gray background in the table. At the second step of elimination, starting guess of the catchability coefficient (q) was estimated by the program, and simulations have performed with a **q** value of 8.6E-05. Starting guess of B_1/K parameter was set at 0.5 as suggested by (Prager M. H., 2011).

Table 3.1: S1 Non-equilibrium approach results correlation coefficient results

S1	**Logistic**	**Fox**	**Genfit**	**Gengrid**	**q**
YLD	0.30	0.33	0.35	0.35	**1.00E-04**
	0.30	0.33	0.35	0.35	**5.00E-04**
	0.30	0.33	0.35	0.35	**8.57E-5**
EFT	0.38	0.42	0.44	0.44	**1.00E-04**
	0.38	0.42	0.44	0.44	**5.00E-04**
	0.38	0.42	0.44	0.44	**8.57E-5**
B1/K	**1^{Gengrid}**	**2^{Genfit}**	**3^{Fox}**	**Penalty term**	
0.25	0.44	0.44	0.42	**On**	
	0.44	0.44	0.42	**Off**	
0.5	0.44	0.44	0.42	**On**	
	0.44	0.44	0.42	**Off**	

Logistic Model

Non-equilibrium approach to Schaefer's logistic model provided a low R^2 value, which is 0.30 for YLD based simulations and 0.38 for EFT based simulations. Since the results are not reliable, this model excluded from further examinations. The results indicated that optimization mode is the determining variable in this model. The model's estimations for MSY is 223 000 t and at YLD mode it is 207 000 t (Table 3.2). EFT based simulations suggested lower values for B_{MSY}, B_1/K and K when it compared with YLD based simulations. For the remaining part of the parameters, EFT based simulations suggested higher values.

Table 3.2: S1 Non-equilibrium approach, Logistic model result

	Logistic--YLD			**Logistic--EFT**		
MSY	2.07E+05	2.07E+05	2.07E+05	2.23E+05	2.23E+05	2.23E+05
B_{MSY}	1.63E+06	1.63E+06	1.63E+06	1.09E+06	1.09E+06	1.09E+06
F_{MSY}	1.27E-01	1.27E-01	1.27E-01	2.05E-01	2.05E-01	2.05E-01
f_{MSY}	2.30E+03	2.30E+03	2.30E+03	2.85E+03	2.85E+03	2.85E+03
K	3.25E+06	3.25E+06	3.25E+06	2.17E+06	2.17E+06	2.17E+06
q (estimated)	5.53E-05	5.53E-05	5.53E-05	7.21E-05	7.21E-05	7.21E-05
Y.(F_{MSY}) '12	9.89E+04	9.89E+04	9.89E+04	1.40E+05	1.40E+05	1.40E+05
Ye '12	1.47E+05	1.47E+05	1.47E+05	1.88E+05	1.88E+05	1.88E+05
B_1/K '68	2.81E-01	2.81E-01	2.81E-01	2.44E-01	2.44E-01	2.44E-01
R- squared	*0.299*	*0.299*	*0.299*	*0.384*	*0.384*	*0.384*
q (starting guess)	1.00E-04	5.00E-04	8.57E-05	1.00E-04	5.00E-04	8.57E-05
Warning	No	No	No	No	No	No

Pella & Tomlinson Generalized Model Applications

Pella & Tomlinson model variations were sensitive only optimization mode changes. They provided higher R^2 value than Logistic model for EFT based simulations, except Genfit model shape (Table 3.1).

Fox and Gengrid model shape simulations suggested nearly same estimations for CPUE, on the contrary of F/F_{MSY} and B/B_{MSY} estimations (Figure 3.9). While Gengrid simulations suggested higher value for F/F_{MSY}, Fox suggested lower value for B/B_{MSY}.

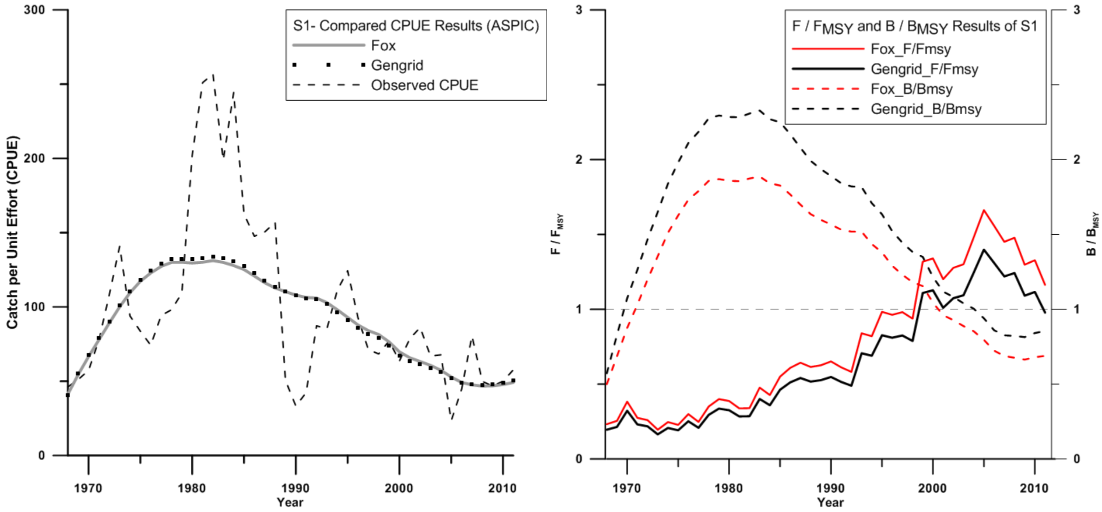

Figure 3.9: S1, Non-equilibrium approach, compared CPUE results (left) and F/F_{MSY} and B/B_{MSY} (right) results

Fox

Fox model application to S1 was sensitive only to optimization mode changes. EFT based model simulations provided higher R^2 value than YLD simulations. Since EFT based simulations ended with more reliable results, only it was considered for further examinations.

According to the YLD based simulations population parameters are 207 000 t for MSY, 1.3 million t for B_{MSY}, 0.160 for F_{MSY}, 2540 for f_{MSY}, 3.5 million t for K and 0.00006 for q. Approximate yield available at F_{MSY} in 2012 (Y. (F_{MSY}) '12) was estimated as 114 000 t and equilibrium yield available in 2012 (Ye '12) as 181 000 t. It suggested that starting relative biomass in 1968 (B_1/K '68) is 0.2.

EFT based simulations estimated that the population parameters are 213 000 t for MSY, 869 000 t for BMSY, 0.245 for FMSY, 3060 for fMSY, 2.4 million t for K and 0.00008 for q. Approximate yield available at FMSY in 2012 (Y. (FMSY) '12) was estimated as 155 000 t and equilibrium yield available in 2012 (Ye '12) as 204 000 t. It suggested that starting relative biomass in 1968 (B1/K '68) is 0.2.

Table 3.3: S1 Non-equilibrium approach, Fox model result

	Fox--YLD			**Fox--EFT**		
MSY	2.07E+05	2.07E+05	2.07E+05	2.13E+05	2.13E+05	2.13E+05
B_{MSY}	1.29E+06	1.29E+06	1.29E+06	8.69E+05	8.69E+05	8.69E+05
F_{MSY}	1.60E-01	1.60E-01	1.60E-01	2.45E-01	2.45E-01	2.45E-01
f_{MSY}	2.54E+03	2.54E+03	2.54E+03	3.06E+03	3.06E+03	3.06E+03
K	3.52E+06	3.52E+06	3.52E+06	2.36E+06	2.36E+06	2.36E+06
q	6.30E-05	6.30E-05	6.30E-05	8.03E-05	8.03E-05	8.03E-05
Y.(F_{MSY}) '12	1.14E+05	1.14E+05	1.14E+05	1.55E+05	1.55E+05	1.55E+05
Ye '12	1.81E+05	1.81E+05	1.81E+05	2.04E+05	2.04E+05	2.04E+05
B_1/K '68	2.02E-01	2.02E-01	2.02E-01	1.84E-01	1.84E-01	1.84E-01
R-squared	*0.327*	*0.327*	*0.327*	*0.417*	*0.417*	*0.417*
q (starting guess)	1.00E-04	5.00E-04	8.57E-05	1.00E-04	5.00E-04	8.57E-05
Warning	No	No	No	No	No	No

As given in Figure 3.10, Fox model shape simulations suggested an increasing trend for CPUE until late 70’s. Until 1982 it nearly had stayed stable and started to decrease through the time till 2007 and stabilized again (Figure 3.10).

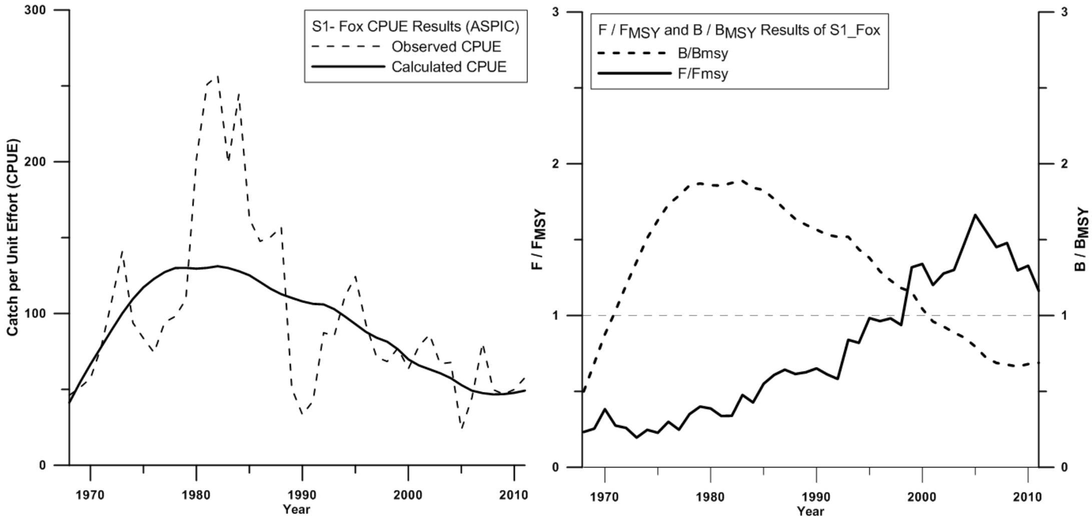

Figure 3.10: S1, Fox model CPUE (left), B/B_{MSY} and F/F_{MSY} (right) results

Genfit

Genfit model shape simulations were ended by SSE[2] error which is stated in Table 3.4. Although it provided high R^2 value, it was not considered for further examinations.

Table 3.4: S1 Non-equilibrium approach, Genfit simulation result

	Genfit--YLD			**Genfit--EFT**		
MSY	2.07E+05	2.07E+05	2.07E+05	2.10E+05	2.10E+05	2.10E+05
B_{MSY}	1.06E+06	1.05E+06	1.05E+06	6.81E+05	6.81E+05	6.81E+05
F_{MSY}	1.96E-01	1.98E-01	1.98E-01	3.09E-01	3.09E-01	3.09E-01
f_{MSY}	2.92E+03	2.94E+03	2.94E+03	3.64E+03	3.64E+03	3.64E+03
K	4.22E+06	4.19E+06	4.19E+06	2.72E+06	2.72E+06	2.72E+06
q	0.347	0.348	0.348	0.435	0.435	0.435
Y.(F_{MSY}) '12	6.70E-05	6.74E-05	6.74E-05	8.49E-05	8.49E-05	8.49E-05
Ye '12	1.34E+05	1.34E+05	1.34E+05	1.82E+05	1.83E+05	1.82E+05
B_1/K '68	1.99E+05	2.00E+05	2.00E+05	2.10E+05	2.10E+05	2.10E+05
R- squared	*1.47E-01*	*1.47E-01*	*1.47E-01*	*1.43E-01*	*1.43E-01*	*1.43E-01*
q (starting guess)	1.00E-04	5.00E-04	8.57E-05	1.00E-04	5.00E-04	8.57E-05
Warning	**SSE**	**SSE**	**SSE**	**SSE**	**SSE**	**SSE**

Gengrid

The Gengrid model shape was only sensitive to optimization mode. Model simulations provided higher goodness of fit value, when it was based on EFT (Table 3.5). Since EFT based simulations ended with more reliable results, it was used for further examinations and only it has been documented as a graph in Figure 3.11. As mentioned before Gengrid model shape simulations suggested nearly the same results with the Fox model (Figure 3.9).

Gengrid model shape's YLD based simulations suggested that the population parameters are 207 000 t for MSY, 1 million t for B_{MSY}, 0.2 for F_{MSY}, 2940 for f_{MSY}, 4.1 million t for K and 0.00007 for q. Approximate yield available at F_{MSY} in 2012 (Y. (F_{MSY}) '12) was estimated as 134 000 t and equilibrium yield available in 2012 (Ye '12) as 200 000 t. It suggested that starting relative biomass in 1968 (B_1/K '68) is 0.14.

On the other hand the EFT based simulations suggested that the population parameters are 210 000 t for MSY, 680 000 t for B_{MSY}, 0.3 for F_{MSY}, 3640 for f_{MSY}, 2.7 million t for K and 0.00008 for q. Approximate yield available at F_{MSY} in 2012 (Y. (F_{MSY}) '12) was estimated as 183 000 t and equilibrium yield available in 2012 (Ye '12) as 210 000 t. It suggested that starting relative biomass in 1968 (B_1/K '68) is 0.14.

Table 3.5: S1 Non-equilibrium approach, Gengrid simulation result

	Gengrid--YLD			**Gengrid--EFT**		
MSY	2.07E+05	2.07E+05	2.07E+05	2.10E+05	2.10E+05	2.10E+05
B_{MSY}	1.05E+06	1.05E+06	1.05E+06	6.80E+05	6.80E+05	6.80E+05
F_{MSY}	1.98E-01	1.98E-01	1.98E-01	3.09E-01	3.09E-01	3.09E-01
f_{MSY}	2.94E+03	2.94E+03	2.94E+03	3.64E+03	3.64E+03	3.64E+03
K	4.19E+06	4.19E+06	4.19E+06	2.72E+06	2.72E+06	2.72E+06
q (estimated)	6.74E-05	6.74E-05	6.74E-05	8.49E-05	8.49E-05	8.49E-05
Y.(F_{MSY}) '12	1.34E+05	1.34E+05	1.34E+05	1.83E+05	1.83E+05	1.83E+05
Ye '12	2.00E+05	2.00E+05	2.00E+05	2.10E+05	2.10E+05	2.10E+05
B_1/K '68	1.47E-01	1.47E-01	1.47E-01	1.43E-01	1.43E-01	1.43E-01
R- squared	*0.348*	*0.348*	*0.348*	*0.435*	*0.435*	*0.435*
q (starting guess)	1.00E-04	5.00E-04	8.57E-05	1.00E-04	5.00E-04	8.57E-05
Warning	No	No	No	No	No	No

Gengrid model shape suggested very similar estimations for CPUE values through the time (Figure 3.11). It just estimated the 1977-1984 period higher and 1994-2004 period lower than the Fox model with few differences.

The model suggested that F/F_{MSY} value exceeded, later than Fox model's estimation, in 1999 (Figure 3.9). The both models followed the same pattern, however the difference between their estimations getting larger through the time and Gengrid model always underestimated than the Fox model. The Gengrid's last year estimation indicated that F/F_{MSY} is 1. The B/B_{MSY} estimation of Gengrid model shape is parallel with Fox models' estimation and higher than them (Figure 3.9). Through the time it increased until 1978, have passed a stable period and in 1985 started to decrease continuing until 2006. After 2006 it stabilized and in 2009 started to increase with a small slope. Its estimation for 2012 is 0.9.

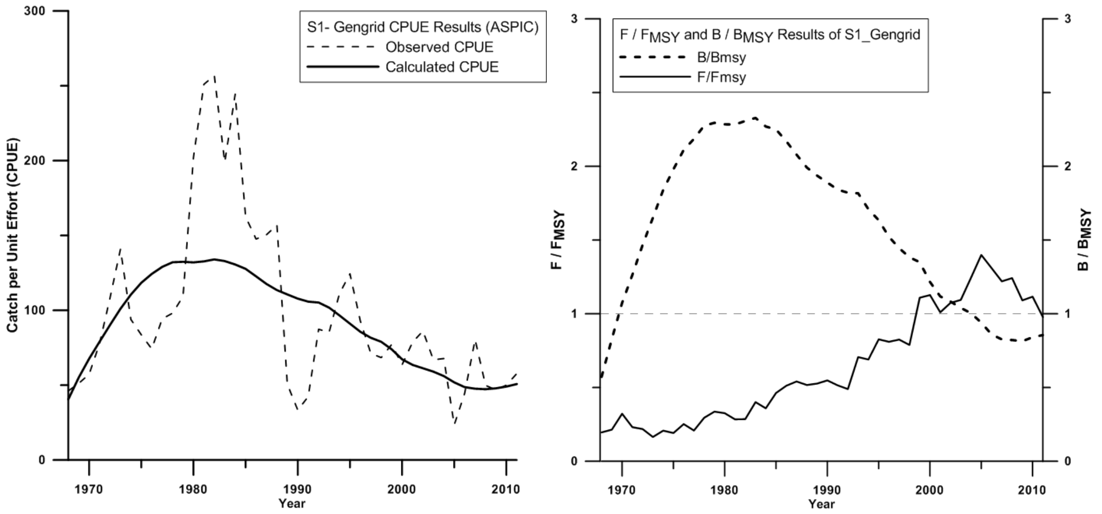

Figure 3.11: S1, Gengrid model CPUE (left), B/B_{MSY} and F/F_{MSY} (right) results

Logarithmic residuals of S1 were represented in Figure 3.12. As can be seen of the figure while Gengrid and Fox-ASPIC simulations provided closer estimations to the real data, equilibrium based models provided weak estimations. Two periods distinguished with all models fail to explain the reality at the same level. The years between 1989-1991 and 2005 could not be explained by any of the models.

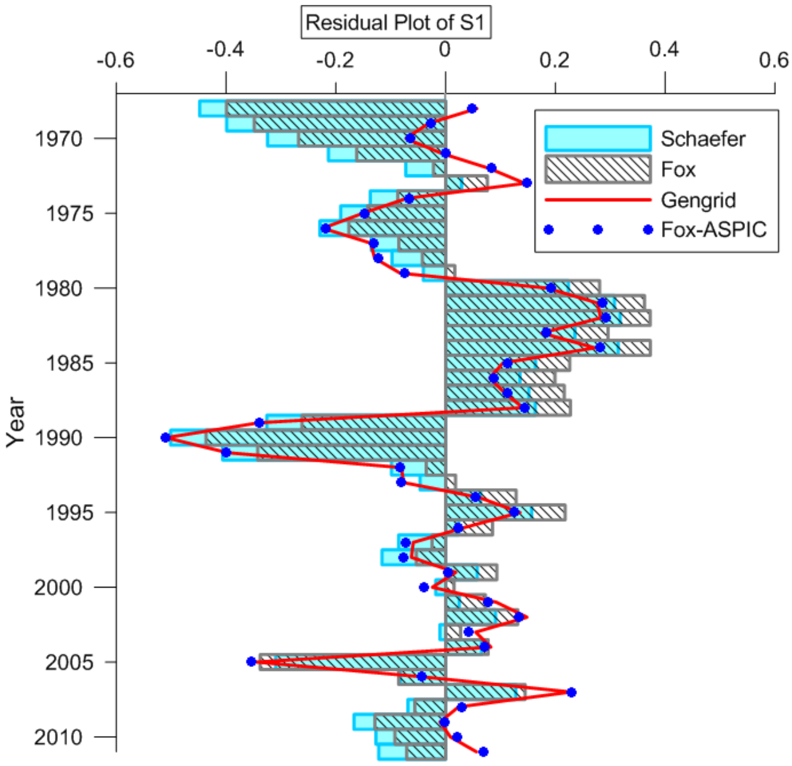

Figure 3.12: Logarithmic residual plot of successive S1 simulations

3.2.2. Scenario 2 (S2)

S2 assumes that the number of the vessel and their size does not change by the year and technological development has a positive effect on fishing effort. Therefore kilowatt of the engines of the fishing boats, which is more than 10 m, was included in the estimation of fishing power.

The catch data plotted with respect to fishing effort is far from following a pattern, and it is spread out over a wide range (Figure 3.13). However, three data patches may still be recognized. The ellipse on the left part of the figure displays the very early phase of the fishery when the anchovy stock was near to the virgin state and a period which a strict decrease happened. This patch covers the years from 1968 to 1979 and the years 1989, 1990 and 1991. Despite the fact that during this period, effort value changed in a very limited range, which is 20 000 to 60 000, catch value changed in the very wide range which is between 50 000 to 150 000. Second patch, which is marked with bigger circle, includes a long time period which is 80’s, late 90’s to 2004. Between 2004 and 2005 there is a remarkably sharp increase in effort and decrease in the catch value. In this year F_{MSY} is exceeded for the first time and after that year it has remained at high value. On the right part of the graph, smaller circle represents a stable period in terms of catch-effort relationship. There are only two deviations from this period which are in 2007, which a sharp increase in the catch, and 2005 which a sharp increase in effort.

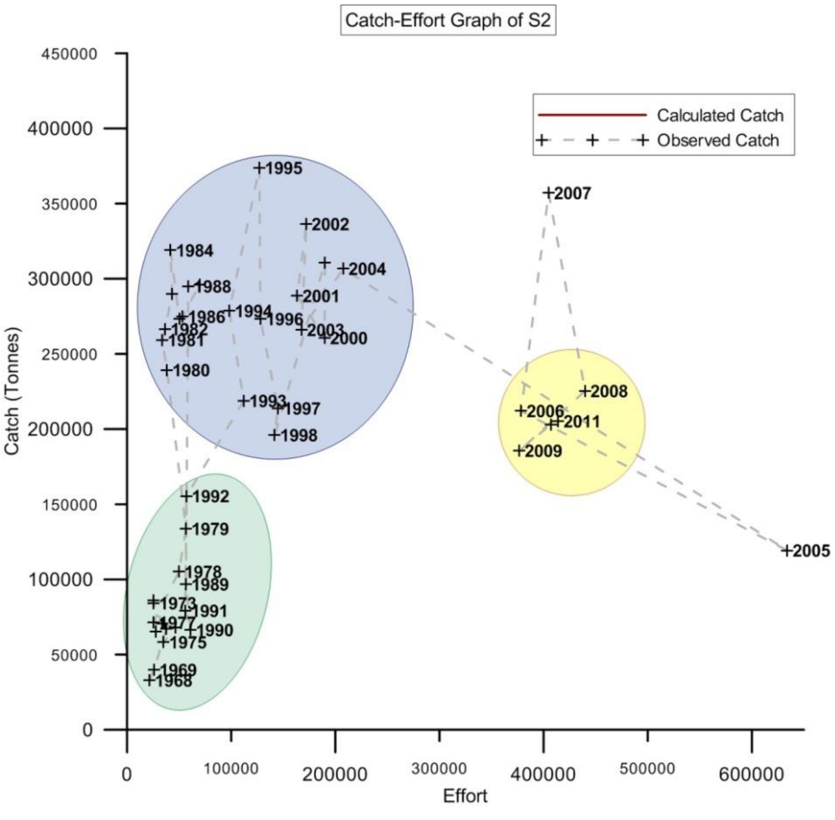

Figure 3.13: S2, Catch- Effort Graph

According to CPUE results lowest CPUE value was obtained in 2005 and the highest one was obtained in 1982. The series of calculated and actual CPUE for the respective year are depicted in Figure 3.15 and Figure 3.17.

3.2.2.1 Equilibrium Surplus Production Model

3.2.2.2.1 Schaefer Model

A striking feature of Schaefer model for S2 is that F_{MSY} have not been exceeded until 2005 and after that year it sharply decreased and remained stable at high levels (Figure 3.14). Another feature of the scenario result is that F_{MSY} is exceeded, but this effort could not give the estimated MSY. The closest value to FMSY was reached in 2004. Schaefer model which based on to the relation between CPUE and number of boats was found statistically significant ($P<0.01$), and the MSY is estimated as 437000 tones. The estimated fishing effort that would yield the MSY under the given situation is about 240 000 kW engine power.

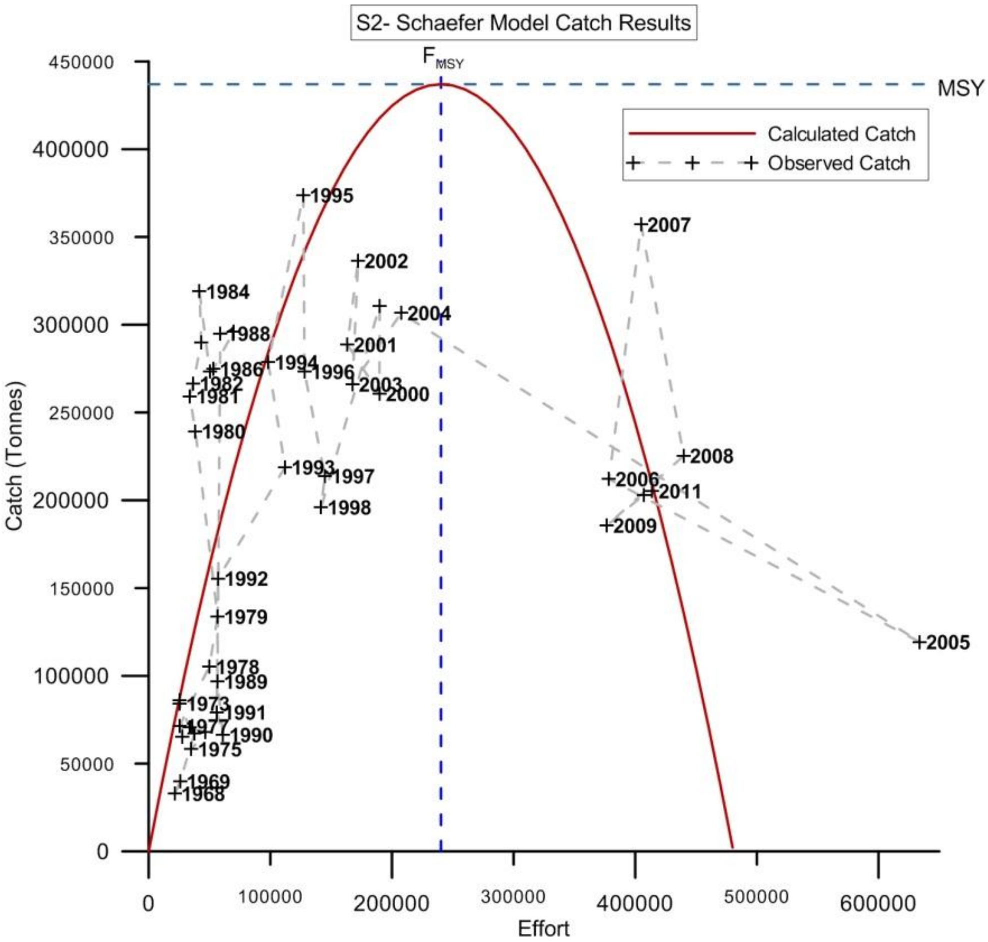

Figure 3.14: S2, Schaefer Model Catch Results

The estimated parameters of the Schaefer model for the second approach, is used to calculate the hypothetical CPUE as a function of fishing effort. The series of calculated and actual CPUE for the respective year are depicted in Figure 3.15. Although the decreasing trend in the CPUE over the years is captured by the model, the severe ups (1981-1984) and downs (1989-1991) could not be explained by the Schaefer model. In general, the agreement between model results and the actual CPUE is better after 1995. However, it should be noted that the slight increase in the CPUE suggested by the model after 2005, is not verified by the actual catch.

The predicted CPUE is, in general, too course and failed to explain the extreme fluctuations except the decline observed in the last five years; however, it was over-responsive to the sharp decline in 2005 as can be seen from the negative CPUE value in Figure 3.15. It should be noted that for S2 max effort obtained in 2005.

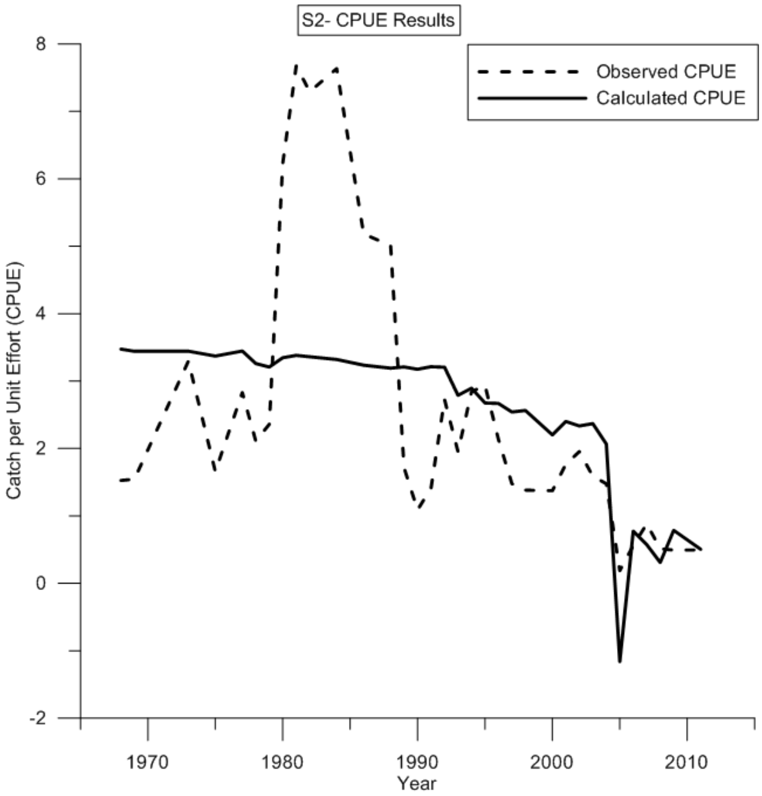

Figure 3.15: S2, CPUE Result

3.2.2.1.2 Fox Model

F_{MSY} was exceeded after 2004. Except some deviations observed catch data follows the model. Deviations mainly were observed in 80's, 1995, 2002 and 2007 (Figure 3.16). The closest values to interval of F_{MSY} and MSY were obtained in 2000, 2001 and 2004. Fox model which based on to the relation between CPUE and number of boats was found statistically significant ($P<0.01$), and the MSY is estimated as 289 000 tones. The estimated fishing effort that would yield the MSY under the given situation is about 218 000 kW engine power.

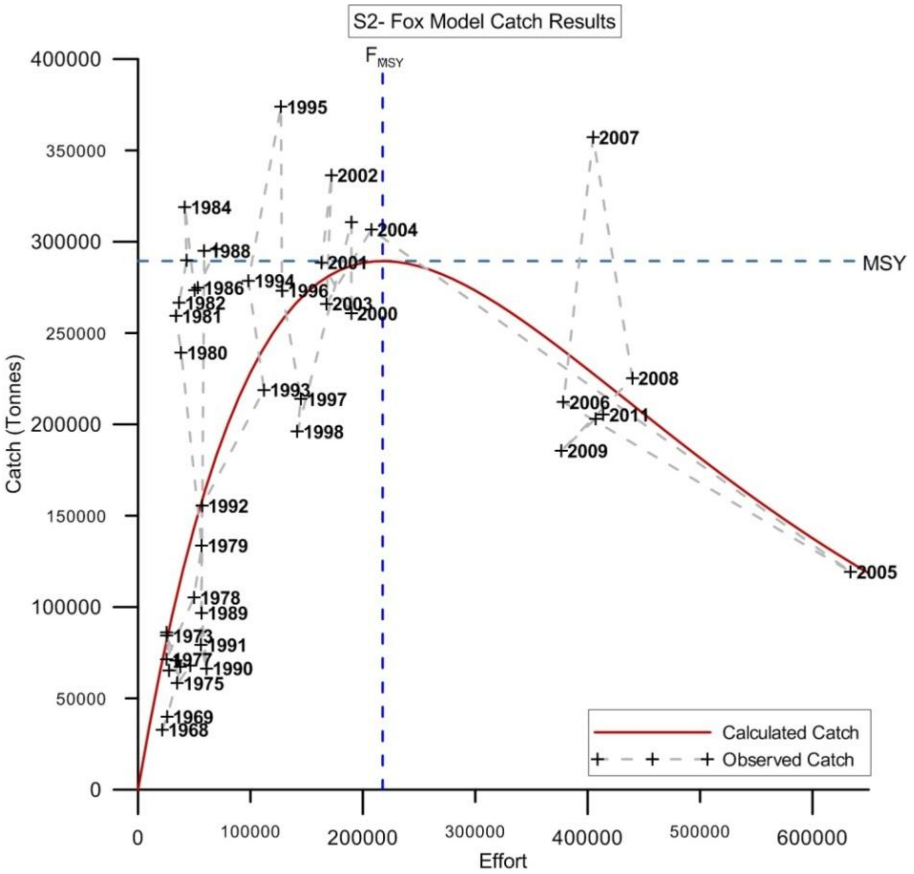

Figure 3.16: S2, Fox Model Catch Results

The model’s CPUE output is mostly parallel to the Schaefer model results of the second approach (Figure 3.17). The model especially captured two decreases including the sharp decrease which observed in 2005. While the Fox model suggests lower values than Schaefer model until 2005, it was estimated higher values for the years 2005 and 2008 than the other one. As observed from Schaefer model results also Fox model results could not explain severe up and downs.

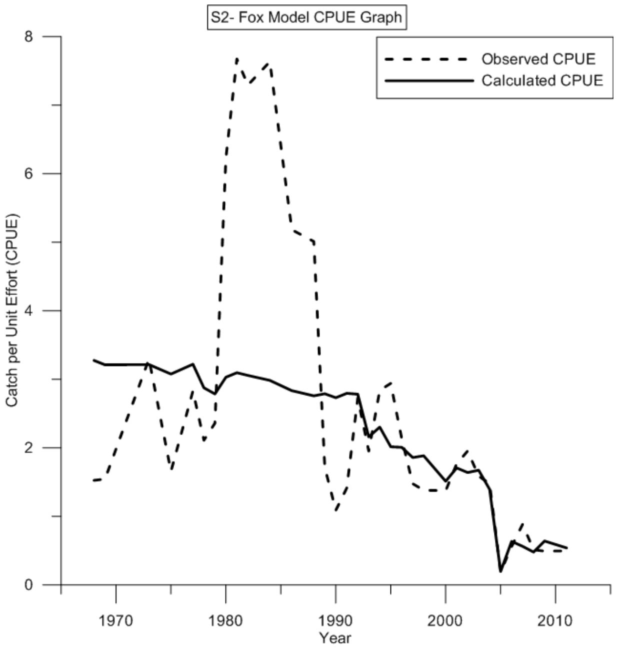

Figure 3.17: S2, Fox Model CPUE Graph

3.2.2.2 Non-Equilibrium Surplus Production Model

Non-equilibrium approach to S2 resulted with inconsistent estimations. Only a quarter of simulations ended normally and remaining part of it ended with SSE^2, MSY>K^3 or K^4 warnings indicating that one of these parameters has exceeded or reaches the limits set for the model. Because of that in the further examinations they were not counted. As marked in the Table 3.6 with zigzag lines, normally ended simulations were obtained from Fox and Gengrid model shapes when optimization mode set on YLD. However, the Fox model eliminated because it has a very low goodness of fit value and hence not counted in further examinations. In the second step of elimination only Gengrid model shape included to detailed examination. Simulations have been performed considering two parameters;, B_1/K and a penalty term for B_1/K parameter. Only two of three simulations ended normally and the other two ended with before mentioned constraints. As might be seen in the second part of Table 3.6 normally ended simulations performed with the combinations of parameters: $B_1/K= 0.25$ with a penalty term for both optimization modes; $B_1/K=0.25$, optimization is conditioned based on catch (YLD mode) but the penalty term is not incorporated; $B_1/K=0.5$, optimization is applied and penalty term is disregarded. Among them the highest correlation coefficient value 0.41 obtained when a combination of parameters was set to $B_1/K=0.\ 25$, with a penalty term and optimization is carried out on the effort (EFT mode).

After deciding to the parameter combination, which might give reliable output, their statistical results were examined and documented as numeric in tables and as the graph. All of the model shape detailed results were given under their topics.

Table 3.6: S2 Used parameters to find best R^2 value and their results

<table>
<tr><th>S2</th><th colspan="2">Logistic</th><th>Fox</th><th>Genfit</th><th>Gengrid</th><th>q</th></tr>
<tr><td rowspan="3">YLD</td><td colspan="2">0.28</td><td>0.03</td><td>0.29</td><td>0.33</td><td>1.00E-06</td></tr>
<tr><td colspan="2">0.28</td><td>0.03</td><td>0.29</td><td>0.33</td><td>5.00E-06</td></tr>
<tr><td colspan="2">0.28</td><td>0.03</td><td>0.28</td><td>0.33</td><td>1.48E-06</td></tr>
<tr><td rowspan="3">EFT</td><td colspan="2">0.25</td><td>0.32</td><td>0.33</td><td>0.33</td><td>1.00E-06</td></tr>
<tr><td colspan="2">0.25</td><td>0.32</td><td>0.33</td><td>0.33</td><td>5.00E-06</td></tr>
<tr><td colspan="2">0.25</td><td>0.32</td><td>0.33</td><td>0.33</td><td>1.48E-06</td></tr>
<tr><td>B1/K</td><td colspan="2">$1^{Gengrid}$</td><td>2^{Genfit}</td><td>3^{Log}</td><td>Penalty</td><td></td></tr>
<tr><td></td><td>YLD</td><td>EFT</td><td colspan="3"></td><td></td></tr>
<tr><td rowspan="2">0.25</td><td>0.33</td><td>0.41</td><td>0.41</td><td>0.281</td><td>On</td><td></td></tr>
<tr><td>0.33</td><td>0.33</td><td>0.41</td><td>0.281</td><td>Off</td><td></td></tr>
<tr><td rowspan="2">0.5</td><td>0.33</td><td>0.33</td><td>0.41</td><td>0.32</td><td>On</td><td></td></tr>
<tr><td>0.41</td><td>0.33</td><td>0.41</td><td>0.32</td><td>Off</td><td></td></tr>
</table>

Logistic

Logistic model is responsive optimization mode changes. However, all simulations ended with MSY>K and K errors (Table 3.7). Because of that they were not used for further examinations.

Table 3.7: S2 Non-equilibrium approach, Logistic model result

	Logistic--YLD			**Logistic--EFT**		
MSY	1.69E+05	1.69E+05	1.69E+05	3.81E+05	3.81E+05	3.81E+05
B_{MSY}	3.70E+06	3.70E+06	3.70E+06	1.91E+05	1.91E+05	1.91E+05
F_{MSY}	4.56E-02	4.56E-02	4.56E-02	2.00E+00	2.00E+00	2.00E+00
f_{MSY}	5.42E+04	5.42E+04	5.42E+04	2.54E+05	2.54E+05	2.54E+05
K	7.40E+06	7.40E+06	7.40E+06	3.81E+05	3.81E+05	3.81E+05
q (estimated)	8.40E-07	8.40E-07	8.41E-07	7.89E-06	7.89E-06	7.89E-06
Y.(F_{MSY}) '12	1.37E+04	1.37E+04	1.37E+04	2.36E+05	2.36E+05	2.36E+05
Ye '12	2.57E+04	2.57E+04	2.57E+04	2.36E+05	2.36E+05	2.36E+05
B_1/K '68	3.59E-01	3.59E-01	3.58E-01	1.25E-01	1.25E-01	1.25E-01
R- squared	*0.281*	*0.281*	*0.281*	*0.254*	*0.254*	*0.254*
q (starting guess)	1.00E-06	5.00E-06	1.48E-06	1.00E-06	5.00E-06	1.48E-06
Warning	**K**	**K**	**K**	**MSY>K**	**MSY>K**	**MSY>K**

Pella & Tomlinson Generalized Model Applications

The Pella & Tomlinson generalized model applications, mostly resulted with errors. Only Fox and Gengrid model shapes provided normally ended simulations, just in the case that they based on YLD mode (Table 3.6). Nevertheless, only Gengrid model shape results could be used for further examinations, because the Fox model provided very low R^2 value which cannot be reliably.

Fox

Fox model was responsive to parameter changes, and simulations ended normally with YLD optimization mode (Table 3.8). On the contrary, at the EFT optimization mode, it gave MSY>K error. YLD based simulations suggested the lowest goodness of fit value among all scenarios. Because of that Fox model simulations for S2 were not included in further examinations.

Table 3.8: S2 Non-equilibrium approach, Fox model result

	Fox--YLD			**Fox--EFT**		
MSY	3.45E+04	7.37E+05	8.24E+05	2.83E+05	2.83E+05	2.83E+05
B_{MSY}	2.17E+05	7.17E+05	8.23E+05	1.04E+05	1.04E+05	1.04E+05
F_{MSY}	1.59E-01	1.03E+00	1.00E+00	2.72E+00	2.72E+00	2.72E+00
f_{MSY}	2.68E+03	1.73E+04	1.69E+04	2.04E+05	2.04E+05	2.04E+05
K	5.89E+05	1.95E+06	2.24E+06	2.83E+05	2.83E+05	2.83E+05
q (Estimated)	5.93E-05	5.94E-05	5.94E-05	1.33E-05	1.33E-05	1.33E-05
Y.(F_{MSY}) '12	0.00E+00	0.00E+00	0.00E+00	1.41E+05	1.41E+05	1.41E+05
Ye '12	0.00E+00	0.00E+00	0.00E+00	2.06E+05	2.06E+05	2.06E+05
B_1/K '68	5.01E-01	9.68E-01	4.83E-01	3.71E-02	3.71E-02	3.71E-02
R- squared	***0.033***	***0.034***	***0.034***	*0.319*	*0.319*	*0.319*
q (starting guess)	1.00E-06	5.00E-06	1.48E-06	1.00E-06	5.00E-06	1.48E-06
Warning	No	No	No	**MSY>K**	**MSY>K**	**MSY>K**

Genfit

Genfit model was responsive to parameter changes, except the penalty term. However, none of the simulations ended normally. Except the first one of EFT based simulations, all ended with SSE warning and the mentioned one ended with MSY>K warning Table 3.9. Because of that, these simulations were not used in further examinations.

Table 3.9: S2 Non-equilibrium approach, Genfit model result

	Genfit--YLD			**Genfit--EFT**		
MSY	1.88E+05	1.89E+05	1.92E+05	2.65E+05	2.26E+05	2.26E+05
B_{MSY}	1.28E+06	1.24E+06	5.55E+06	8.65E+04	4.79E+05	4.79E+05
F_{MSY}	1.47E-01	1.52E-01	3.46E-02	3.07E+00	4.72E-01	4.71E-01
f_{MSY}	9.40E+04	9.62E+04	5.07E+04	2.01E+05	1.71E+05	1.71E+05
K	5.13E+06	4.97E+06	7.40E+06	2.65E+05	1.91E+06	1.92E+06
q	1.56E-06	1.58E-06	6.83E-07	1.53E-05	2.77E-06	2.76E-06
Y.(F_{MSY}) '12	2.80E+04	2.91E+04	1.32E+04	1.23E+05	7.69E+04	7.68E+04
Ye '12	1.17E+05	1.19E+05	1.45E+04	2.10E+05	1.88E+05	1.88E+05
B_1/K '68	1.95E-01	1.98E-01	4.79E-01	1.63E-02	1.70E-01	1.70E-01
Goodness of fit	*0.325*	*0.324*	*0.285*	*0.326*	*0.413*	*0.413*
q (starting guess)	1.00E-06	5.00E-06	1.48E-06	1.00E-06	5.00E-06	1.48E-06
Warning	**SSE**	**SSE**	**SSE**	**MSY>K**	**SSE**	**SSE**

Gengrid

Gengrid mode is sensitive to changes in optimization mode, B_1/K and its penalty term, but not to the catchability coefficient. EFT based simulations ended with MSY>K warning, however YLD based simulations ended normally with a 0.325 goodness of fit value and all suggested that MSY is 188 000 t while B_{MSY} is 128 000 t and F_{MSY} is 148 000 kW (Table 3.10). Additionally, when the model was run with 0.25 B_1/K value and penalty term is on, it resulted with the highest goodness of fit value, which is 0.413. Even though it is lower than the expected goodness of fit value, it is quite close and worth to consider for further examinations. On the contrary, others not considered.

The mentioned simulation was performed under the combination of the parameter values B_1/K= 0.25, penalty term=ON, q is 1.48E-06 and optimization mode is EFT. As noted in Table 3.10, its population parameter estimations are 226 000 t for MSY, 479 000 t for B_{MSY}, 0.47 for F_{MSY}, 171 000 for f_{MSY}, 1.9 million t for K and 0.000002 for q. Approximate yield available at F_{MSY} in 2012 (Y.(F_{MSY}) '12) was estimated as 76 900 t and equilibrium yield available in 2012 (Ye '12) as 188 000 t. It suggested that starting relative biomass in 1968 (B_1/K '68) is 1.9.

Table 3.10: S2 Non-equilibrium approach, Gengrid model result

	Gengrid--YLD			**Gengrid--EFT**			**Gengrid, B_1/K= 0.25**
MSY	1.88E+05	1.88E+05	1.88E+05	2.49E+05	2.49E+05	2.49E+05	2.26E+05
B_{MSY}	1.28E+06	1.28E+06	1.28E+06	6.22E+04	6.22E+04	6.22E+04	4.79E+05
F_{MSY}	1.48E-01	1.48E-01	1.48E-01	4.00E+00	4.00E+00	4.00E+00	4.71E-01
f_{MSY}	9.42E+04	9.42E+04	9.42E+04	2.22E+05	2.22E+05	2.22E+05	1.71E+05
K	5.10E+06	5.10E+06	5.10E+06	2.49E+05	2.49E+05	2.49E+05	1.92E+06
q (est.)	1.57E-06	1.57E-06	1.57E-06	1.81E-05	1.81E-05	1.81E-05	2.76E-06
Y.(F_{MSY}) '12	2.81E+04	2.81E+04	2.81E+04	9.86E+04	9.86E+04	9.86E+04	7.69E+04
Ye '12	1.18E+05	1.18E+05	1.18E+05	2.26E+05	2.26E+05	2.26E+05	1.88E+05
B_1/K '68	1.95E-01	1.95E-01	1.95E-01	1.12E-04	1.12E-04	1.12E-04	1.70E-01
R-squared	0.325	0.325	0.325	0.325	0.325	0.325	0.413
q (starting guess)	1.00E-06	5.00E-06	1.48E-06	1.00E-06	5.00E-06	1.48E-06	1.48E-06
Warning	No	No	No	**MSY>K**	**MSY>K**	**MSY>K**	No

The model captured the general trend in observed CPUE value (Figure 3.18). Even though it could not explain the sharp decrease in 1974 and the increase in 1980, it captured the increase in 1970 and decrease in 2005. According to the results, the B/B_{MSY} ratio sharply increased to 3.6 in 1977, and it stayed stable with small fluctuations until 1993. Afterward, it has been followed by a decreasing trend in 1985 and it is followed by a sharp decrease in 1994. F/F_{MSY} were increased through the time with a small slope until 1992 and continued to accelerated increase. In 1999 it exceeded the ratio 1 and in 2005 it performed an extreme increase from 1 to 3.7. The next year it decreased to 2.3 and continued with fluctuation.

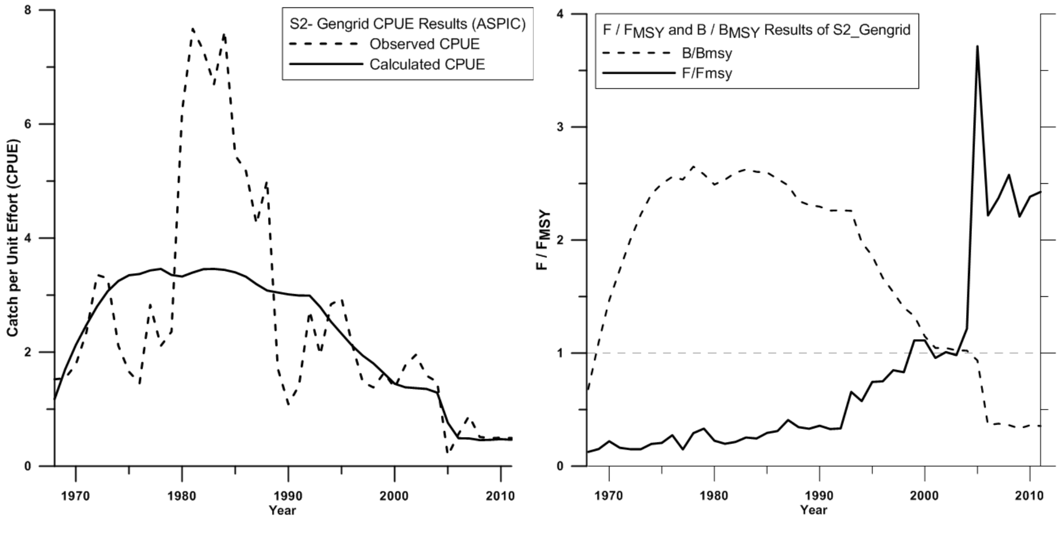

Figure 3.18: S2, Gengrid model CPUE (left) and F/F_{MSY} & B/B_{MSY} (right) graphs

Logarithmic residual results were given in Figure 3.19. The weak results were generally provided by Schaefer and Gengrid-2 model. More realistic results obtained from especially Gengrid-1.

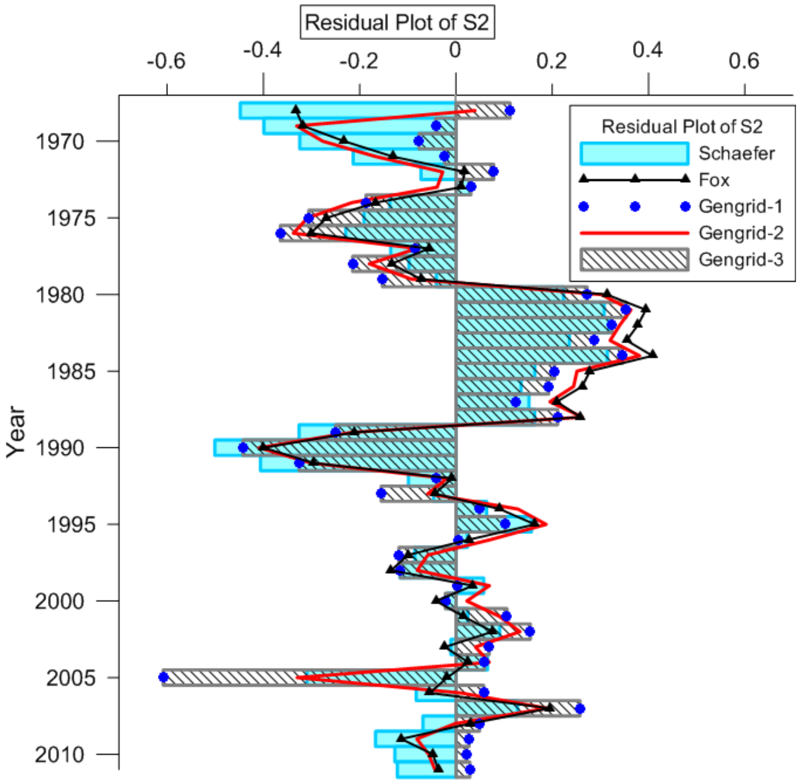

Figure 3.19: Logarithmic residual plot of successive S2 simulations

3.2.3.Scenario 3 (S3)

S3 was assumed that purse seiners are by far the greatest contributors to anchovy fishing in the Black Sea, and the landings of other types of fishing are not considerable. Any fishing vessel authorized to use a purse seine would prefer to practice anchovy fishing during the season because of that also multipurpose boats (trawl and purse seine) were considered as purse seiners.

According to third scenario used fishing effort data and catch values spread out into wide range and largest effort spent in 2008. However, still three main patches may be recognized on the Figure 3.20. The first patch marked with ellipse shape, represents the early stages of the stock and includes late 60’s and 70’s. Second patch shows up with a sharp jump in 1980 and covers wide effort range with more limited catch range. Third patch indicates a sharp decrease in catch value in 1989 and includes the years 1989, 1990 and 1991. After 2001 catch value does not follow a pattern, but it spread out into wide range and it started with a sharp increase of effort in 2002.

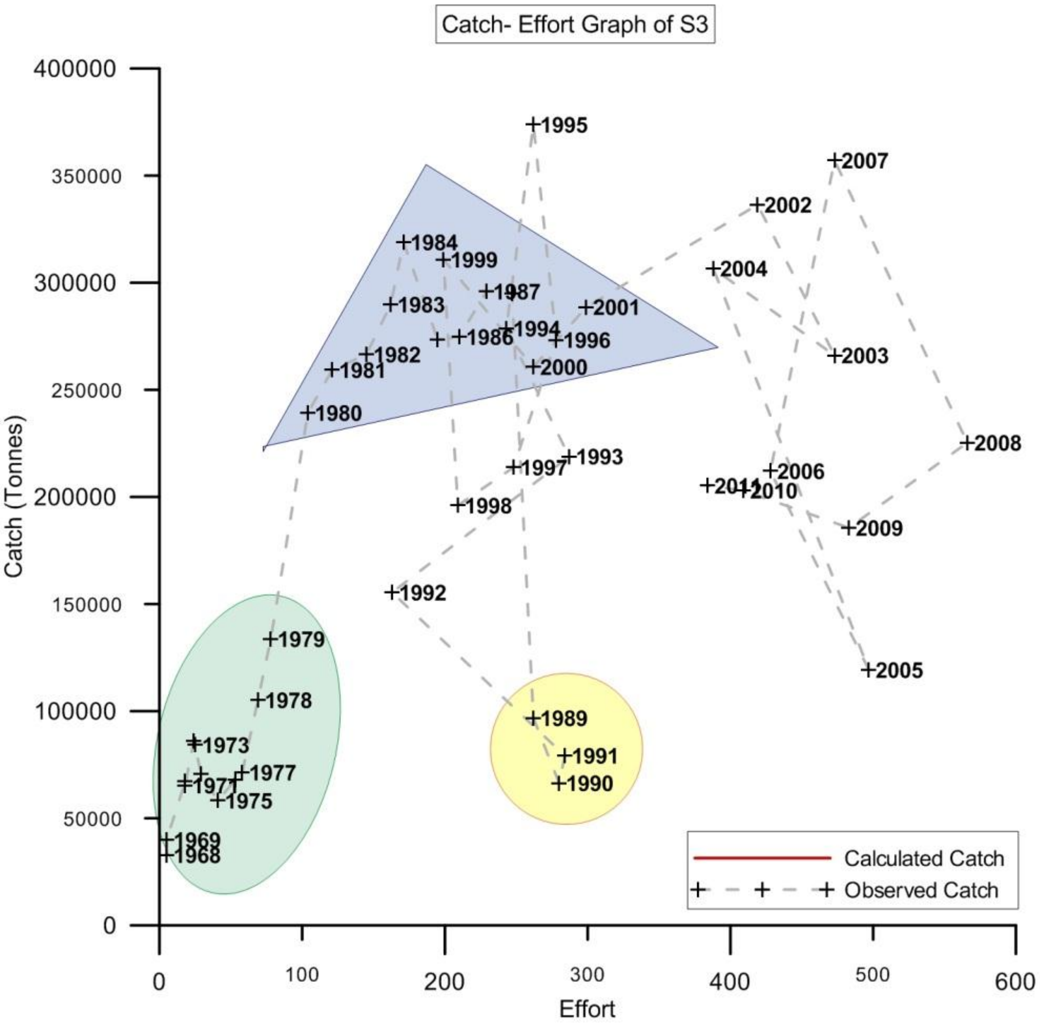

Figure 3.20: S3, Catch- Effort Graph

According to CPUE results lowest CPUE value was obtained in 2005 and the highest one was obtained in 1969. The series of calculated and actual CPUE for the respective year are depicted in Figure 3.22 and Figure 3.24.

3.2.2.3 Equilibrium Surplus Production Model

3.2.2.3.1 Schaefer Model

Model results suggest that F_{MSY} is exceeded after 1987 and this year has the closest effort value to F_{MSY}. The closest value to MSY and F_{MSY} was reached in 1995 (Figure 3.21). This scenario indicates that for similar effort values wide range catch obtained. Especially the first two decades follows the model. Schaefer model which based on to the relation between CPUE and number of boats was found statistically significant ($P<0.01$), and the MSY is estimated as 358 000 tones. The estimated fishing effort that would yield the MSY under the given situation is about 230 boats.

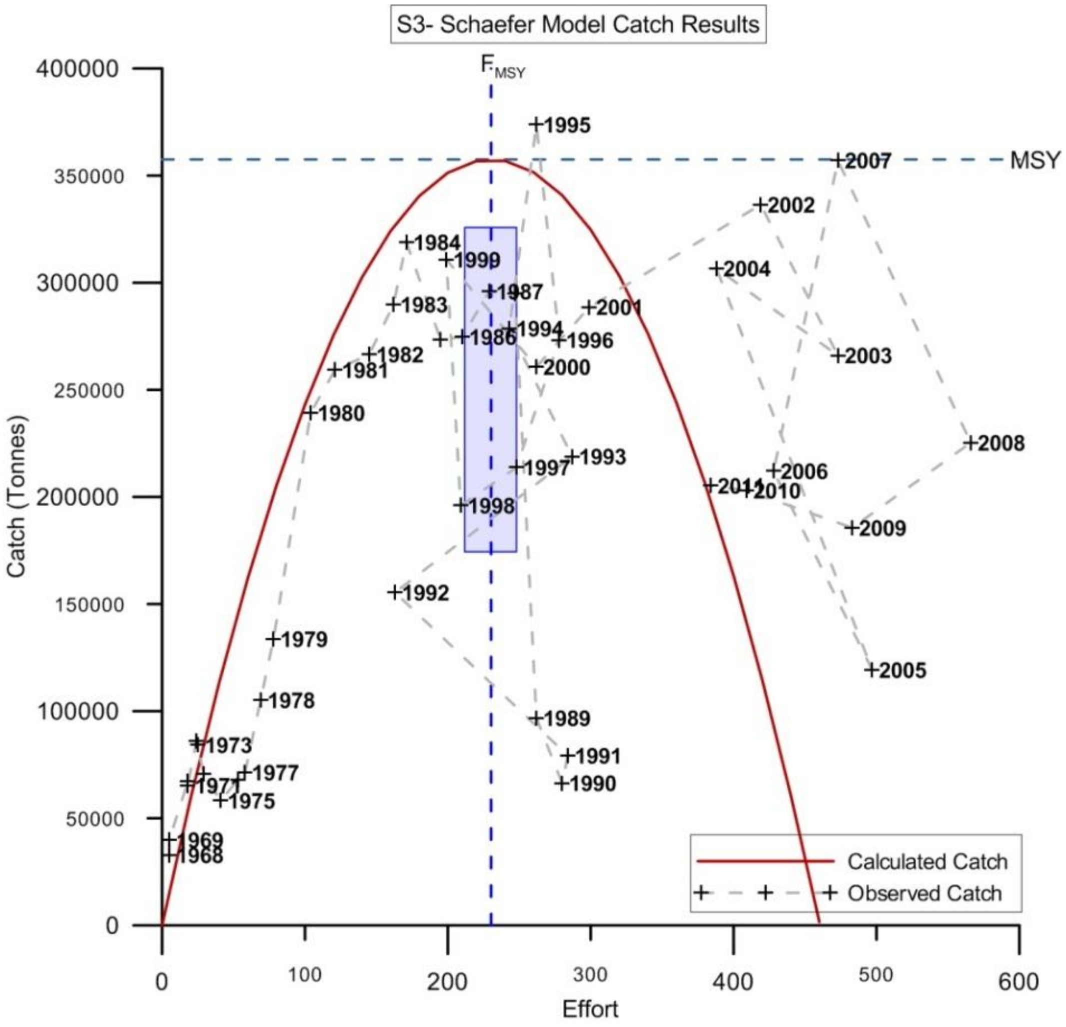

Figure 3.21: S3, Schaefer Model Catch Results

Schaefer model CPUE results captured the negative trend of observed result, but until 1991 it could not explain the sharp decrease in 1970 and other minor fluctuations. Especially it captured increase in 1999, 2003 and 2006, but it gave more extensive results for the increase in 1993 and decrease in 2008. Schaefer model is over responsive to fluctuations when it compared with Fox’s model. Until 2001 Schaefer model suggested higher value than Fox after that year it suggested fewer values.

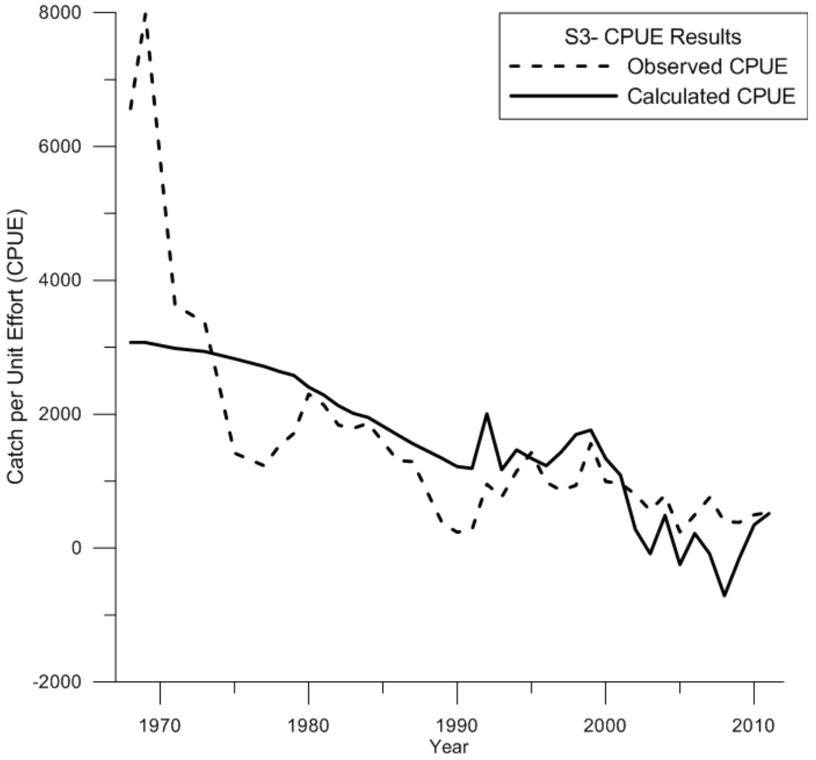

Figure 3.22: S3, Schaefer Model CPUE graph

3.2.3.1.2 Fox Model

Model results suggest that F_{MSY} is exceeded after 1981 and this year has the closest effort value to F_{MSY}. The closest values to the intercept of MSY and F_{MSY} are 1986, 1994 and 2000 (Figure 3.23). This scenario indicates that for similar effort values wide range catch obtained. Especially the first two decades follows the model. Fox model which based on to the relation between CPUE and number of boats was found statistically significant ($P<0.01$), and the data the MSY is estimated as 257 000 tones. The estimated fishing effort that would yield the MSY under the given situation is about 234 boats.

Fox model failed to explain severe up and downs, but it predicted quite close values to the actual CPUE result especially after 1980 and captured the negative trend. The model pattern is mostly parallel to the Schaefer model results and it predicted closer values than Schaefer's model to the actual result. While the values which suggested by the Fox model are lower than Schaefer model until 2001, after that year it suggested higher values than the Schaefer model. It captured increase in 1992, 2004 and decrease in 2002 properly.

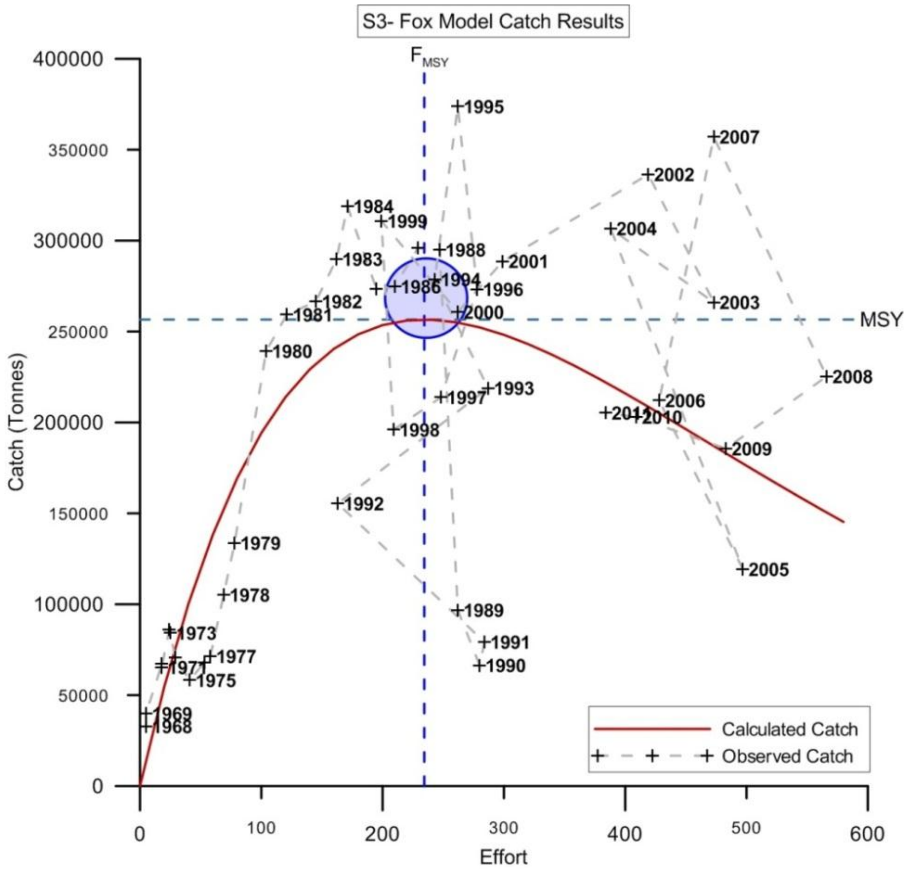

Figure 3.23: S3, Fox Model Catch Results

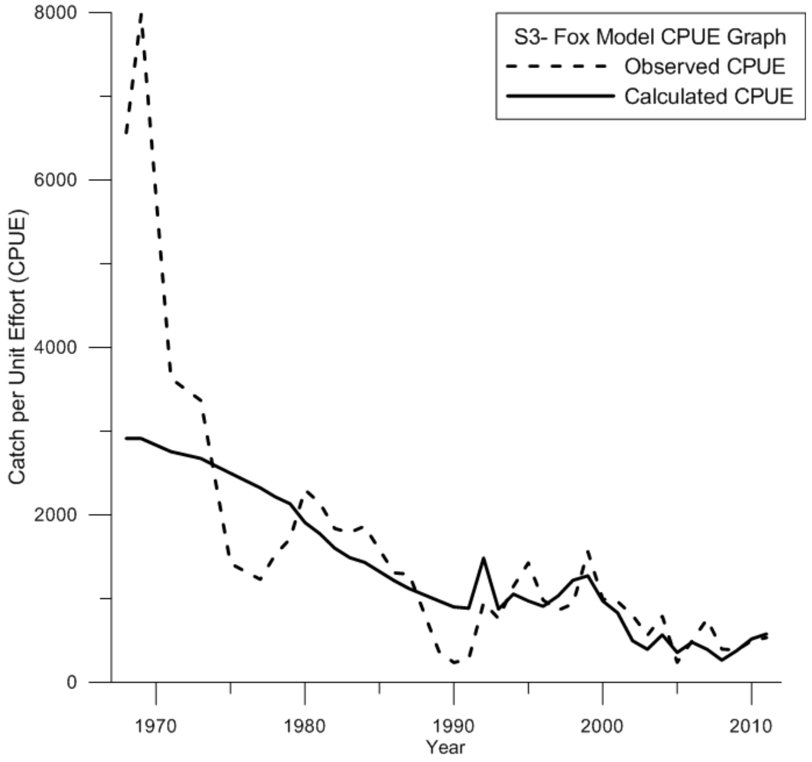

Figure 3.24: S3, Fox Model CPUE Graph

3.2.2.4 Non-Equilibrium Surplus Production Model

The non-equilibrium approach was suggested high goodness of fit values. Only three simulations ended with errors and they are marked with a bold box line in Table 3.11. The error in Logistic model is MSY>K and it suggested lowest R^2. The other errors obtained from Genfit model which are MSY errors. In general view, all models responsive to changes of optimization mode and penalty term parameters. Catchability coefficient was estimated at 9.87E-04 by the program and it used as rolled to 1.00E-03. Sensitivity to change of q value observed when it was set to 1.00E-02. Highest R^2 obtained in the second step of elimination from Gengrid and Fox models, when the penalty term was off. Detailed results for each model shape were presented under their topic. The models which provided the highest R^2 value are Gengrid, Genfit and Fox, because of that only they were considered for further examinations.

Fox and Gengrid model shapes suggested very close CPUE values through the time period. Only the years between 1994-1996 were estimated lower by Gengrid model when it is compared. They were suggested very close F/F_{MSY} and B/B_{MSY} ratio estimations with similar pattern. However, when compared, the Fox model estimated lower values than Gengrid for F/F_{MSY} and higher values for B/B_{MSY}.

Table 3.11: S3 Used parameters to find best R^2 value and their results

S3	**Logistic**	**Fox**	**Genfit**	**Gengrid**	**q**
YLD	0.63	0.62	0.62	0.58	**1.00E-02**
	0.63	0.62	0.62	0.58	**1.00E-03**
	0.63	0.62	0.62	0.58	**1.00E-04**
EFT	0.32	0.67	0.68	0.68	**1.00E-02**
	0.25	0.67	0.68	0.68	**1.00E-03**
	0.64	0.67	0.68	0.68	**1.00E-04**
B_1/K	**$1^{Gengrid}$**	**2^{Genfit}**	**3^{Fox}**	**Penalty**	
0.25	0.68	0.68	0.67	**On**	
	0.79	0.78	0.79	**Off**	
0.5	0.68	0.68	0.67	**On**	
	0.79	0.78	0.79	**Off**	

Logistic

Logistic model was responsive to q and optimization mode changes. It provided the highest R^2 value 0.635 provided from EFT based simulations when q value is at 1.00E-03 and 1.00E-04 (Table 3.12). However, it gave an MSY>K error, which is marked with bold line box in Table 3.12, because of that it was not considered. Since Logistic model provided lowest R^2 value among other models, it was not considered for further examinations.

The model is not sensitive to q changes in YLD mode and suggested same estimation with 0.625 goodness of fit value. According to YLD based simulation results MSY was estimated at 133000 t, BMSY is 2.5 million t, FMSY is 0.52 and K is 5 million tones. It estimated approximate yield available at F_{MSY} in 2012 (Y.(F_{MSY}) '12) as 53 600t and equilibrium yield available in 2012 (Ye '12) as 84 500. The fishing effort rate at (f_{MSY}) was estimated at 148 and q estimated at 0.0004.

EFT based simulations provided R^2 value as 0.635. The model estimated that MSY is 136000 t, B_{MSY} is 2.4 million t, F_{MSY} is 0.56 and f_{MSY} is 292, q is 0.0007 and K is 5 million tones. Its approximate yield available at F_{MSY} in 2012 (Y.(F_{MSY}) '12) estimation is 53900t and equilibrium yield available in 2012 (Ye '12) is 85400. It suggested that starting relative biomass in 1968 (B_1/K '68) is 2.53.

Table 3.12: S3, Non-equilibrium approach, Logistic model results

	Logistic--YLD			**Logistic--EFT**		
MSY	1.33E+05	1.33E+05	1.33E+05	3.23E+05	1.36E+05	1.36E+05
B_{MSY}	2.52E+06	2.53E+06	2.52E+06	1.61E+05	2.46E+06	2.46E+06
F_{MSY}	5.26E-02	5.26E-02	5.26E-02	2.00E+00	5.53E-02	5.53E-02
f_{MSY}	1.48E+02	1.48E+02	1.48E+02	2.92E+02	1.51E+02	1.51E+02
K	5.05E+06	5.05E+06	5.05E+06	3.23E+05	4.92E+06	4.92E+06
q (estimated)	3.56E-04	3.56E-04	3.56E-04	6.85E-03	3.66E-04	3.66E-04
Y.(F_{MSY}) '12	5.36E+04	5.36E+04	5.36E+04	2.56E+05	5.39E+04	5.39E+04
Ye '12	8.45E+04	8.45E+04	8.45E+04	2.73E+05	8.54E+04	8.54E+04
B_1/K '68	2.49E+00	2.49E+00	2.49E+00	1.27E+00	2.53E+00	2.53E+00
Goodness of fit	0.625	0.625	0.625	0.32	0.635	0.635
q (starting guess)	1.00E-02	1.00E-03	1.00E-04	1.00E-02	1.00E-03	1.00E-04
Warning	No	No	No	**MSY>K**	No	No

Pella & Tomlinson Generalized Model Applications

Pella & Tomlinson generalized model applications ended normally and all provided high goodness of fit values. At the second step of elimination Genfit model shape gave MSY error for the penalty term: off mode simulations, because of that it was not used for further examinations. All models belong to this group were sensitive to optimization mode and penalty term changes, but not to B_1/K and q parameter changes. The second step's simulations provided a quite high R^2 value which is 0.79 for both of Gengrid and Fox model shapes.

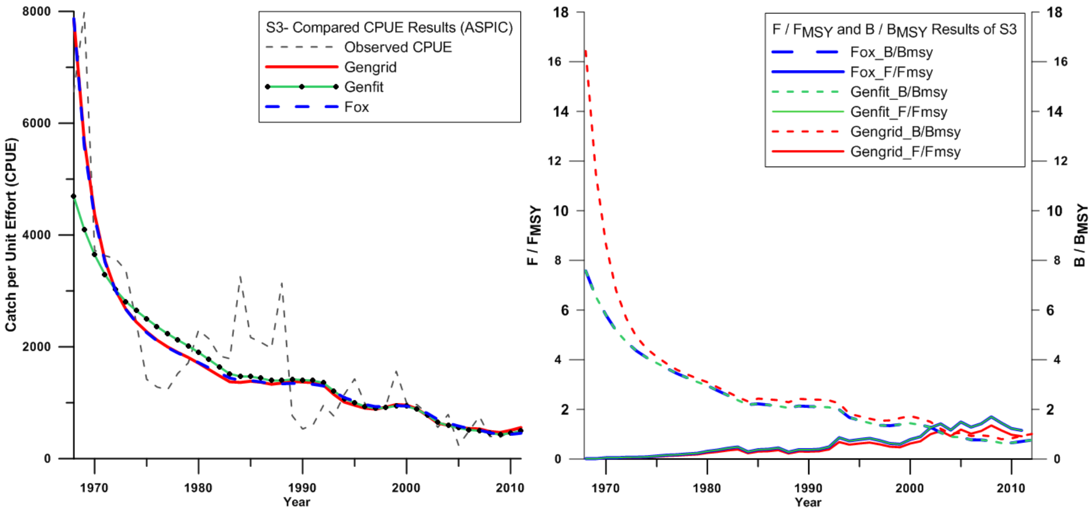

Figure 3.25: S3, Pella & Tomlinson generalized model application's compared results

Fox

Fox model did not give response to changes of q as might be seen in Table 3.13. The model simulations, which based on YLD and EFT optimization mode, suggested same population parameter estimations among themselves.

Table 3.13: S3, Non-equilibrium approach Fox model results, first step

	Fox--YLD			**Fox--EFT**		
MSY	1.78E+05	1.78E+05	1.78E+05	2.01E+05	2.01E+05	2.01E+05
B_{MSY}	1.41E+06	1.41E+06	1.41E+06	1.04E+06	1.04E+06	1.04E+06
F_{MSY}	1.26E-01	1.26E-01	1.26E-01	1.94E-01	1.94E-01	1.94E-01
f_{MSY}	2.43E+02	2.43E+02	2.43E+02	2.54E+02	2.54E+02	2.54E+02
K	3.82E+06	3.82E+06	3.82E+06	2.82E+06	2.82E+06	2.82E+06
q (estimated)	5.21E-04	5.21E-04	5.21E-04	7.65E-04	7.65E-04	7.65E-04
Y.(F_{MSY}) '12	9.88E+04	9.88E+04	9.88E+04	1.08E+05	1.08E+05	1.08E+05
Ye '12	1.56E+05	1.56E+05	1.56E+05	1.74E+05	1.74E+05	1.74E+05
B_1/K '68	2.16E+00	2.16E+00	2.16E+00	2.26E+00	2.26E+00	2.26E+00
R- squared	0.621	0.621	0.621	0.665	0.665	0.665
q (starting guess)	1.00E-02	1.00E-03	1.00E-04	1.00E-02	1.00E-03	1.00E-04
Warning	No	No	No	No	No	No

The second step presents more detailed test results and it was presented in Table 3.14. Since EFT based simulations provided higher R^2, only they were chosen for the second step. The model sensitive to penalty term changes and when it was set on off mode higher R^2 results were obtained. Since it is not sensitive to B_1/K parameter the 0.25 ad 0.5 ratios were suggested same results and for further examinations they were used. They estimated that MSY is 218 000 t, B_{MSY} is 783 000 t, F_{MSY} 0.28, f_{MSY} 296, K 2.1 million tones and q is 0.0009. Approximate yield available at F_{MSY} in 2012 (Y.(F_{MSY}) '12) was estimated as 140 000 t and equilibrium yield available in 2012 (Ye '12) as 201000 t. It suggested that starting relative biomass in 1968 (B_1/K '68) is 4.78.

Table 3.14: S3, Non-equilibrium approach Fox model results, second step

	Fox--EFT		
	0.25 off	**0.25 on**	**0.5 off**
MSY	2.18E+05	2.01E+05	2.18E+05
B_{MSY}	7.83E+05	1.04E+06	7.83E+05
F_{MSY}	2.79E-01	1.94E-01	2.79E-01
f_{MSY}	2.96E+02	2.54E+02	2.96E+02
K	2.13E+06	2.82E+06	2.13E+06
q (estimated)	9.43E-04	7.65E-04	9.43E-04
Y.(F_{MSY}) '12	1.40E+05	1.08E+05	1.40E+05
Ye '12	2.01E+05	1.74E+05	2.01E+05
B_1/K '68	4.78E+00	2.26E+00	4.78E+00
R- squared	0.789	0.665	0.789
q (starting guess)	1.00E-04	1.00E-04	1.00E-04
Warning	**No**	**No**	**No**

According to the model’s CPUE estimation the general decreasing trend was captured, but it could not explain the sharp increase in 1969 and estimated the first year’s CPUE higher than the observed one. It followed the sharp decrease after 1969 until 1977 but could not explain the fluctuation between 1977 and 1990 (Figure 3.26).

As figured in Figure 3.26, the model estimated that F/F_{MSY} has increased through the time until 2008 with small fluctuations. The ratio exceeded 1 in 2001 and it reached to 2 in 2008. After 2008 it decreased. The B/B_{MSY} ratio started with a quite high value which is 13 and continuously decreased. In 2004 it decreased below 1 and the ratio was predicted for 2012 as 0.63.

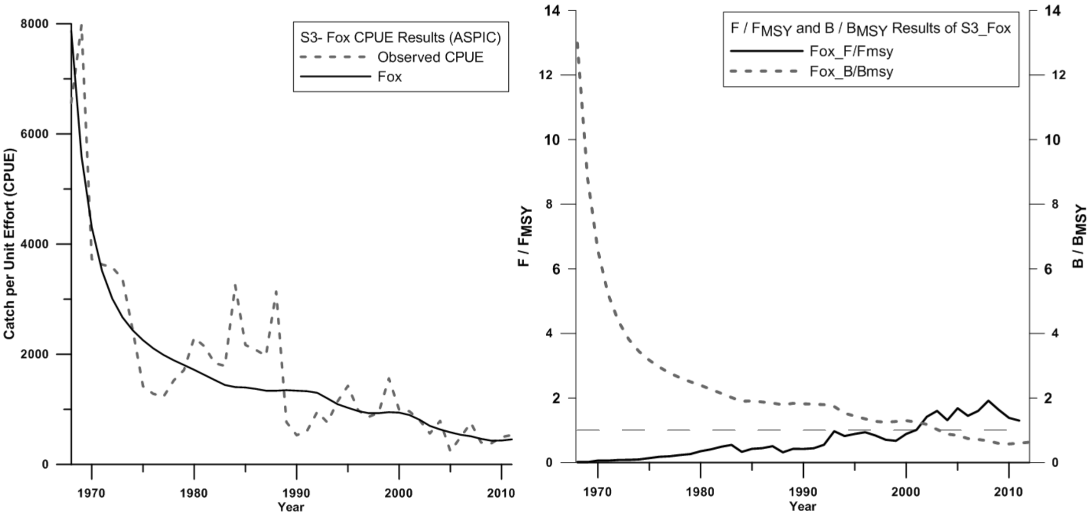

Figure 3.26: S3, Fox model CPUE (left) and F/F_{MSY} & B/B_{MSY} (right) results

Genfit

Genfit model shape is sensitive to optimization mode and the penalty term. It provided same R^2 values when the penalty term is on and off, independently from the q and B_1/K parameter changes. The highest R^2 value, 0.775 provided when the penalty term is off. However, the simulations ended giving MSY error and the other simulation, at the second step of elimination (Table 3.16), ended normally when the penalty term is on.

According to YLD based simulations' estimated population parameters are 178 000t for MSY, 1.3 million t for B_{MSY}, 0.12 for F_{MSY}, 244 for f_{MSY}, 3.8 million t for K and 0.0005 for q. Approximate yield available at F_{MSY} in 2012 (Y.(F_{MSY}) '12) was estimated as 99 800 t and equilibrium yield available in 2012 (Ye '12) as 157 000 t. It suggested that starting relative biomass in 1968 (B_1/K '68) is 2.15.

Population parameter estimations of EFT based simulations are 222 000 t for MSY, 496 000 for B_{MSY}, 0.45 for F_{MSY}, 333 for f_{MSY}, 1.85 million t for K and 0.0013 for q. Estimated approximate yield available at F_{MSY} in 2012 (Y.(F_{MSY}) '12) is 165 000 t and equilibrium yield available in 2012 (Ye '12) is 218 000 t. The model suggested that starting relative biomass in 1968 (B_1/K '68) is 2.04.

Table 3.15: S3, Non-equilibrium approach, Genfit model result, first step

	Genfit--YLD			**Genfit--EFT**		
MSY	1.78E+05	1.78E+05	1.78E+05	2.22E+05	2.22E+05	2.22E+05
B_{MSY}	1.39E+06	1.39E+06	1.39E+06	4.96E+05	4.96E+05	4.96E+05
F_{MSY}	1.28E-01	1.28E-01	1.28E-01	4.48E-01	4.48E-01	4.48E-01
f_{MSY}	2.44E+02	2.44E+02	2.44E+02	3.33E+02	3.33E+02	3.33E+02
K	3.81E+06	3.81E+06	3.81E+06	1.85E+06	1.85E+06	1.85E+06
q (estimated)	5.23E-04	5.23E-04	5.23E-04	1.34E-03	1.34E-03	1.34E-03
Y.(F_{MSY}) '12	9.98E+04	9.98E+04	9.98E+04	1.65E+05	1.65E+05	1.65E+05
Ye '12	1.57E+05	1.57E+05	1.57E+05	2.18E+05	2.18E+05	2.18E+05
B_1/K '68	2.15E+00	2.15E+00	2.15E+00	2.04E+00	2.04E+00	2.04E+00
R- squared	0.62	0.62	0.62	0.678	0.678	0.678
q (starting guess)	1.00E-02	1.00E-03	1.00E-04	1.00E-02	1.00E-03	1.00E-04
Warning	No	No	No	No	No	No

As mentioned before EFT based simulations provided higher R^2 value and they considered for further examinations. In Table 3.15 and Table 3.16 there are three boxes marked with bold lines. These boxes include same result which had been run with different parameters.

Table 3.16: S3, Non-equilibrium approach, Genfit model result, second step

	Genfit--EFT			
	0.25 Off	**0.25 On**	**0.5 Off**	**0.5 On**
MSY	1.56E+04	2.22E+05	1.56E+04	2.22E+05
B_{MSY}	2.87E+06	4.96E+05	2.87E+06	4.96E+05
F_{MSY}	5.43E-03	4.48E-01	5.43E-03	4.48E-01
f_{MSY}	3.50E+01	3.33E+02	3.50E+01	3.33E+02
K	5.05E+06	1.85E+06	5.05E+06	1.85E+06
q (estimated)	1.55E-04	1.34E-03	1.55E-04	1.34E-03
Y.(F_{MSY}) '12	1.39E+04	1.65E+05	1.39E+04	1.65E+05
Ye '12	1.54E+04	2.18E+05	1.54E+04	2.18E+05
B_1/K '68	1.35E+01	2.04E+00	1.35E+01	2.04E+00
R- squared	0.775	0.678	0.775	0.678
q (starting guess)	1.00E-04	1.00E-04	1.00E-04	1.00E-04
Warning	MSY	No	MSY	No

After elimination steps, only penalty term=on mode simulations remained to consider. According to the model's CPUE estimation the general decreasing trend was captured, but it underestimated first years CPUE. It captured fluctuations as delayed and underestimated and especially could not explain the sharp increase in (Figure 3.27).

As presented in Figure 3.27, the model estimated that F/F_{MSY} has increased through the time until 2008 with small fluctuations. The ratio exceeded 1 in 2001 and it reached to 2 in 2008. After 2008 it decreased to nearly 1. The B/B_{MSY} ratio started with a quite high value which is 8 and it continuously decreased. In 2004 it decreased below 1 and the ratio was predicted for 2012 as 0.76.

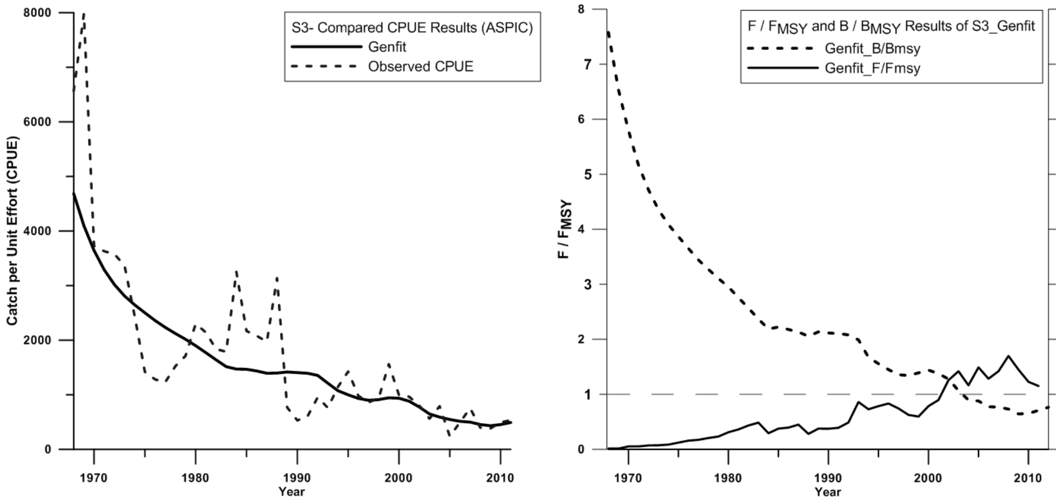

Figure 3.27: S3, Genfit model CPUE (left) and F/F_{MSY} & B/B_{MSY} (right) results

Gengrid

Gengrid model shape suggested too close estimations to the Fox model and all simulations ended normally. The model is sensitive to optimization mode, q and penalty term. EFT based simulations and off mode penalty term was provided the highest R^2 value (Table 3.17 and Table 3.18).

The simulation of the model suggested population parameter estimations are 240 000t for MSY, 319 000 t for B_{MSY}, 0.75 for F_{MSY}, 419 for f_{MSY}, 1.3 million t for K and 0.0017 for q (Table 3.18). Approximate yield available at F_{MSY} in 2012 (Y.(F_{MSY}) '12) was estimated as 222 000 t and equilibrium yield available in 2012 (Ye '12) as 240 000 t. It suggested that starting relative biomass in 1968 (B_1/K '68) is 4.11.

YLD based simulations suggested same estimations for different q values. It provided a considerable R^2 value with 0.582 nevertheless there are more reliable results and because of that it was not considered for further examinations. Its estimations of population parameters are 193 000 for MSY, 918 000t for B_{MSY}, 0.21 for F_{MSY}, 370 for f_{MSY}, 3.7 million t for K and 0.0005 for q. Approximate yield available at F_{MSY} in 2012 (Y.(F_{MSY}) '12) was estimated as 163 000 t and equilibrium yield available in 2012 (Ye '12) as 192 000 t. It suggested that starting relative biomass in 1968 (B_1/K '68) is 1.86.

EFT based simulations were more responsive to q parameter change. It provided R^2 value as 0.679 for first two simulations and 0.678 for the last one (Table 3.17). Even though there is a small difference, simulations which resulted with higher R^2 value will be considered. The model's EFT based estimations of population parameters are 225 000 for MSY, 438 000t for B_{MSY}, 0.51 for F_{MSY}, 355 for f_{MSY}, 1.8 million t for K and 0.0014 for q. Approximate yield available at F_{MSY} in 2012 (Y.(F_{MSY}) '12) was estimated as 177 000 t and equilibrium yield available in 2012 (Ye '12) as 223 000 t. It suggested that starting relative biomass in 1968 (B_1/K '68) is 2.

Table 3.17: S3, Non-equilibrium approach, Gengrid model result, first step

	Gengrid--YLD			**Gengrid--EFT**		
MSY	1.93E+05	1.93E+05	1.93E+05	2.25E+05	2.25E+05	2.22E+05
B_{MSY}	9.18E+05	9.18E+05	9.21E+05	4.38E+05	4.38E+05	4.96E+05
F_{MSY}	2.10E-01	2.10E-01	2.10E-01	5.13E-01	5.13E-01	4.48E-01
f_{MSY}	3.70E+02	3.70E+02	3.70E+02	3.55E+02	3.55E+02	3.33E+02
K	3.67E+06	3.67E+06	3.69E+06	1.75E+06	1.75E+06	1.85E+06
q (estimated)	5.68E-04	5.68E-04	5.65E-04	1.44E-03	1.44E-03	1.34E-03
Y.(F_{MSY}) '12	1.63E+05	1.63E+05	1.63E+05	1.77E+05	1.77E+05	1.65E+05
Ye '12	1.92E+05	1.92E+05	1.92E+05	2.23E+05	2.23E+05	2.18E+05
B_1/K '68	1.86E+00	1.86E+00	1.86E+00	2.00E+00	2.00E+00	2.03E+00
R- squared	0.582	0.582	0.582	0.679	0.679	0.678
q (starting guess)	1.00E-02	1.00E-03	1.00E-04	1.00E-02	1.00E-03	1.00E-04
Warning	No	No	No	No	No	No

In the second step of the elimination, the Gengrid model shape was run with different penalty terms and B_1/K values as based on EFT optimization mode. Best R^2 value was obtained, when B_1/K was 0.25 and 0.5, as 0.788 which is at the same time the best considerable R^2 among all scenarios.

The simulation of the model suggested population parameter estimations are 240 000t for MSY, 319 000 t for B_{MSY}, 0.75 for F_{MSY}, 419 for f_{MSY}, 1.3 million t for K and 0.0017 for q (Table 3.18). Approximate yield available at F_{MSY} in 2012 (Y.(F_{MSY}) '12) was estimated as 222 000 t and equilibrium yield available in 2012 (Ye '12) as 240 000 t. It suggested that starting relative biomass in 1968 (B_1/K '68) is 4.11.

Table 3.18: S3, Non-equilibrium approach, Gengrid model result, second step

	Gengrid--EFT		
	0.25 Off	**0.25 On**	**0.5 Off**
MSY	2.40E+05	2.25E+05	2.40E+05
B_{MSY}	3.19E+05	4.38E+05	3.19E+05
F_{MSY}	7.51E-01	5.13E-01	7.51E-01
f_{MSY}	4.19E+02	3.55E+02	4.19E+02
K	1.28E+06	1.75E+06	1.28E+06
q (estimated)	1.79E-03	1.44E-03	1.79E-03
Y.(F_{MSY}) '12	2.22E+05	1.78E+05	2.22E+05
Ye '12	2.40E+05	2.23E+05	2.40E+05
B_1/K '68	4.11E+00	2.00E+00	4.11E+00
R- squared	0.788	0.679	0.788
q (starting guess)	1.00E-03	1.00E-03	1.00E-03
Warning	No	No	No

In Figure 3.28 considered simulation’s CPUE and F/F_{MSY} & B/B_{MSY} results were presented. Estimation of the model were overestimated first year’s CPUE and could not explain second year’s peak. On the other hand it captured the sharp decreasing trend. It suggested same values as might be seen in Figure 3.25 as compared and in Figure 3.28 as itself.

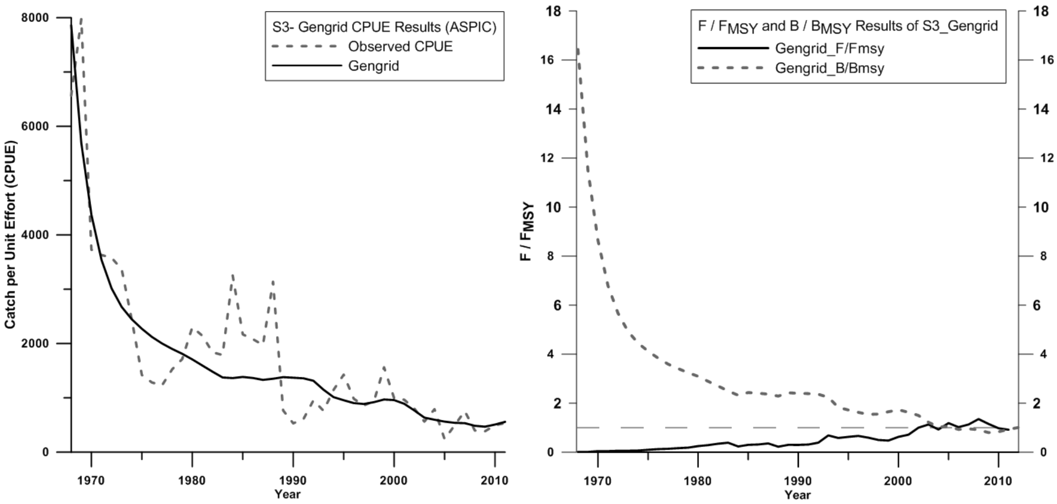

Figure 3.28: S3, Gengrid model CPUE (left) and F/F_{MSY} & B/B_{MSY} (right) results

The logarithmic residual plot was presented in Figure 3.29. In general closest results were obtained from Gengrid model.

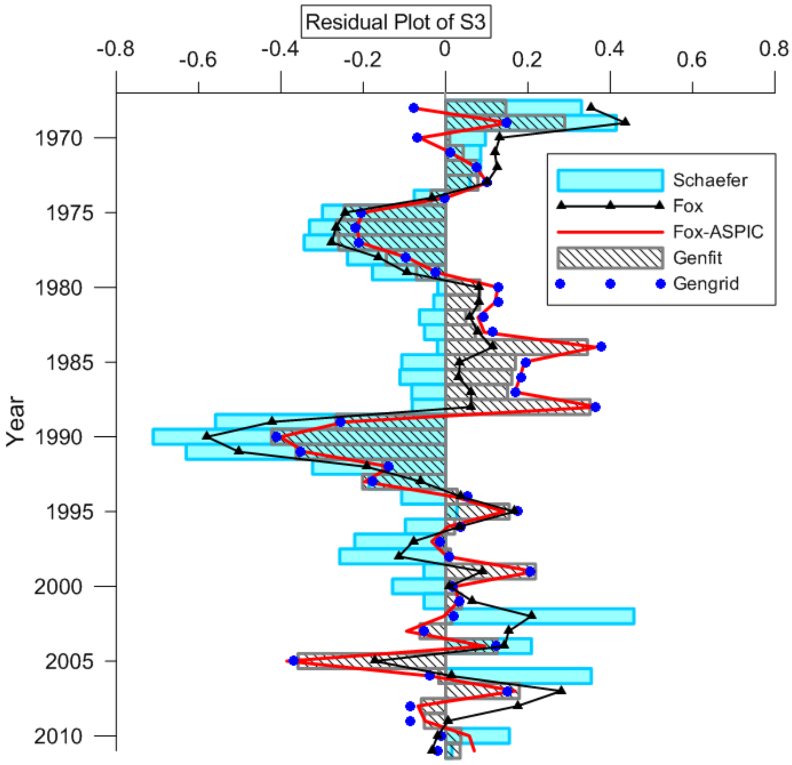

Figure 3.29: Logarithmic residual plot of successive S3 simulations

3.2.4.Scenario 4 (S4)

Sonar as a tool to locate anchovy schools should evidently increase the fishing efficiency of a vessel. Therefore, in S4 it is assumed that having sonar in a fishing vessel irrespective of the other specifications of a purse seiner increases the fishing power.

As mentioned in Chapter 2, for S4 the S3's fishing effort data tuned with a technological improvement coefficient. The calculation procedure details were given in Chapter 2, Table 2.2. The best correlation coefficient was obtained as 0.835 at the point which technological improvement coefficient is 2.9. The sonar coefficient, which gives that result, found at 6.24 by Excel solver. In Figure 3.30 the reaction of the correlation coefficient to technological improvement were given.

According to the fourth scenario used fishing effort data and catch values spread out into wide range and largest effort spent in 2005. However, still four main patches may be recognized on the Figure 3.31. The first patch marked with ellipse shape, represents the early stages of the stock and includes late 60's and 70's. Second patch shows up with a sharp jump in 1980 and covers wide effort range with more limited catch range. This patch includes years from different decades, but 80's are abundant. Except first two patches there is not a specific period, but data spread out into wide range with many sharp jump and decreases. On the other hand, there are two notably close values which belong to following years. Third patch indicates a sharp decrease of catch value in 1989 and includes the years 1989, 1990 and 1991. The last patch covers last three years and indicates. After 2001 catch data spread out into wide range and it started with a sharp increase of effort in 2002.

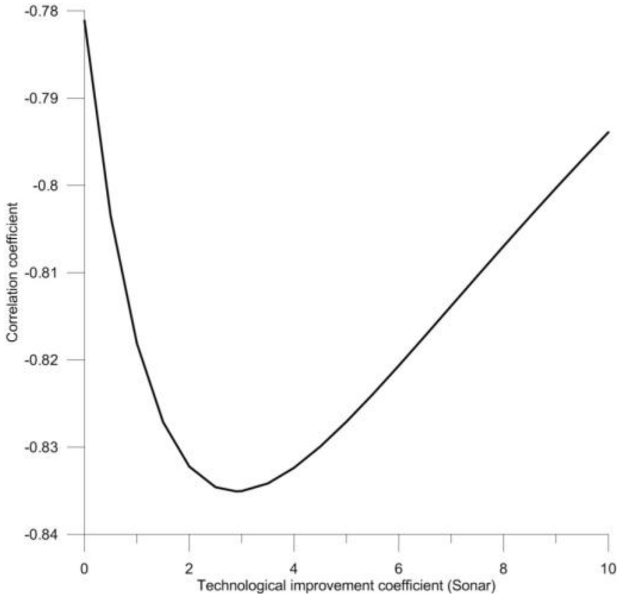

Figure 3.30: Technological improvement coefficient and r relationship

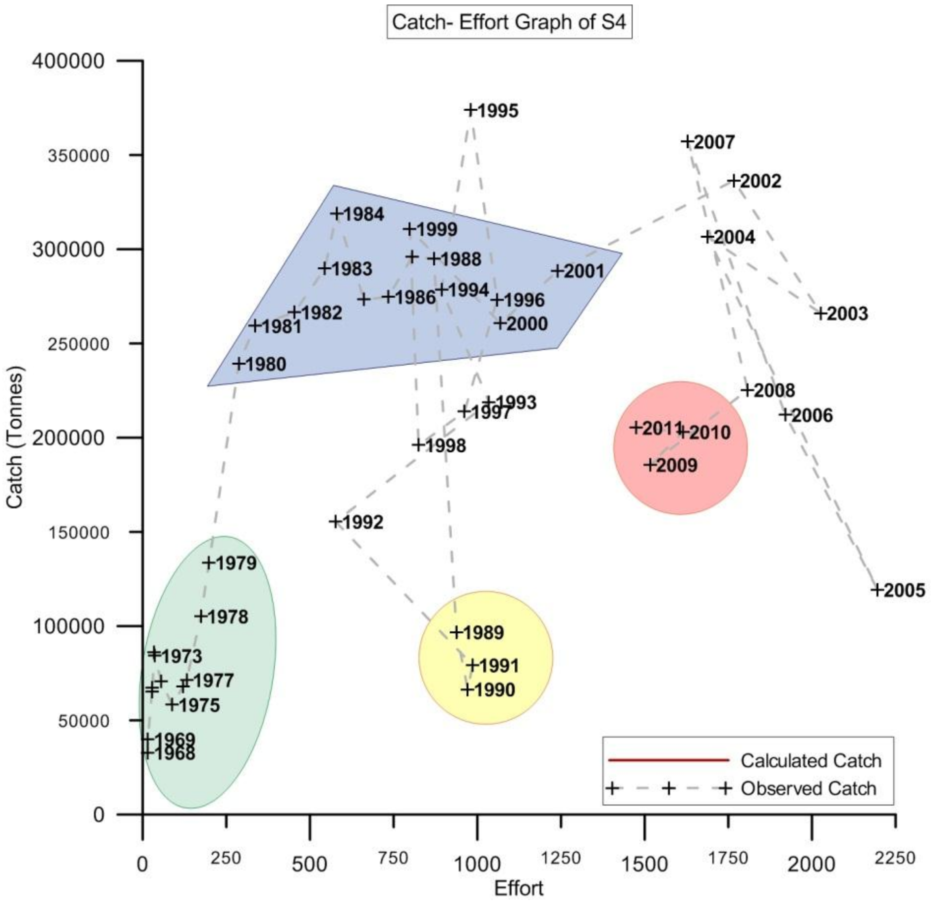

Figure 3.31: S4, Catch-Effort Graph

According to CPUE results lowest CPUE value was obtained in 1990 and the highest one was obtained in 1969. The series of calculated and actual CPUE for the respective year are depicted in Figure 3.33 and Figure 3.35.

3.2.4.1 Equilibrium Surplus Production Model Results

3.2.4.1.1 Schaefer Model

Model results suggest that F_{MSY} is exceeded after 1999 and this year has the closest effort value to F_{MSY}. The other close values to F_{MSY} are marked with a rectangle on the graph are 1987 and 1998 (Figure 3.32). This scenario indicates that for similar effort values wide range catches obtained and the best example of that are the years 1998 and 1999 which observed a sharp increase of catch. The model explains only the first decade. Although F_{MSY} exceeded never be reached to MSY besides that the suggested value is 1/4 more than the largest catch value. This scenario indicates that for similar effort values wide range catch obtained. Schaefer model which based on to the relation between CPUE and number of boats was found statistically significant ($P<0.01$), the MSY is estimated as 518 000 tones. The estimated fishing effort that would yield the MSY under the given situation is about 798.

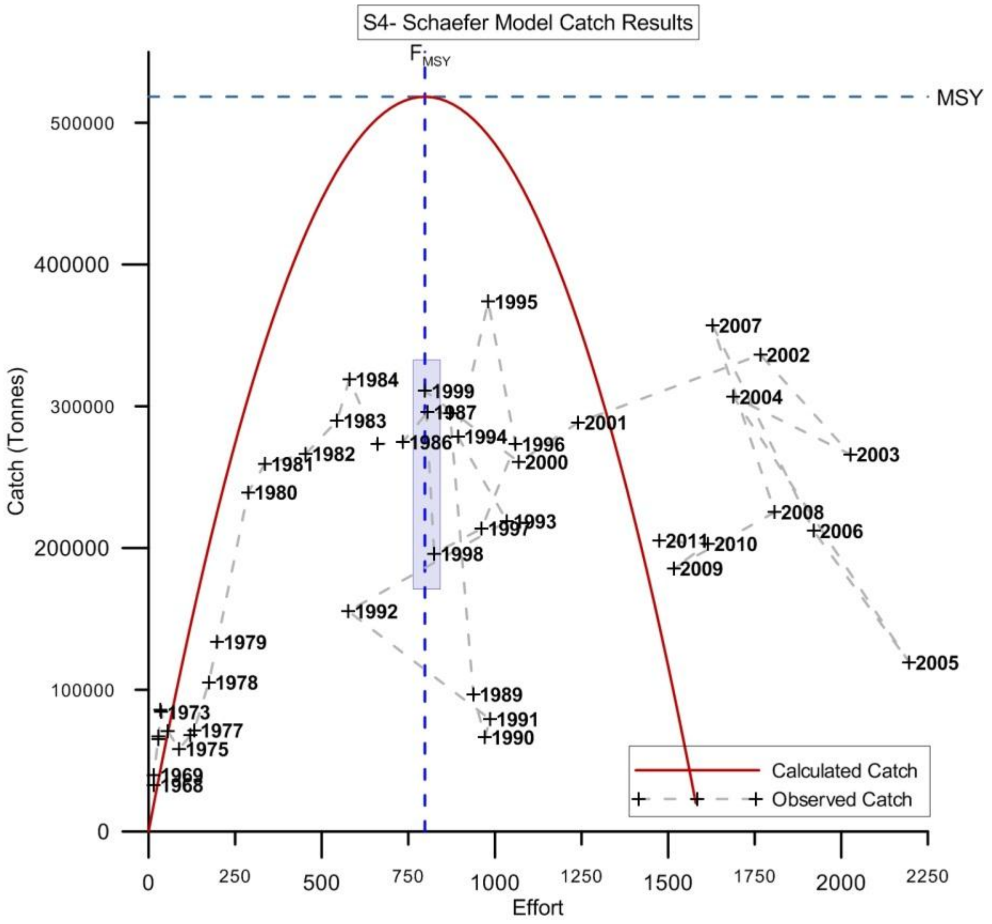

Figure 3.32: S4, Schaefer Model Catch Results

Schaefer model CPUE results captured the negative trend of observed result, but it could not explain the sharp decrease in 1970 and other minor fluctuations until 1991 (Figure 3.33). As well as it captured most of the fluctuation after 1991 it is over responsive to fluctuations and especially between 2002 and 2009 it suggested quite fewer values. Schaefer model is over responsive to fluctuations when it compared with Fox's model. Until 2001 Schaefer model suggested higher value than Fox after that year it suggested fewer values.

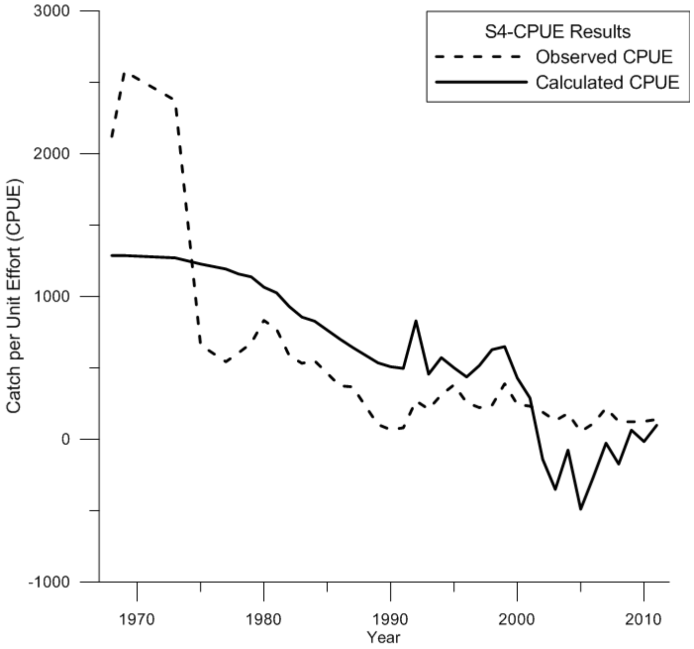

Figure 3.33: S4, CPUE Result

3.2.4.1.2 Fox Model

Model results suggest that F_{MSY} is exceeded after 1986 and this year has the closest effort value to F_{MSY}. The closest values to the intercept of F_{MSY} and MSY were obtained in the years 1987 and 1999 (Figure 3.34). Actual catch data followed the model result except some deviations. Fox model which based on to the relation between CPUE and number of boats was found statistically significant ($P<0.01$), the MSY is estimated as 305 000 tones. The estimated fishing effort that would yield the MSY under the given situation is about 724. Fox model failed to explain severe up and downs, but it predicted quite close values to the actual CPUE result, especially after 1980 and captured the negative trend. The model pattern is mostly parallel to the Schaefer model results and it predicted closer values than Schaefer's model to the actual result. It suggested lower values when it is compared with S3 result, and it is over-responsive to fluctuations. While the values which suggested by the Fox model are lower than Schaefer model until 2001, after that year it suggested higher values than the Schaefer model. It captured increase in 1992, 2004 and decrease in 2000 properly.

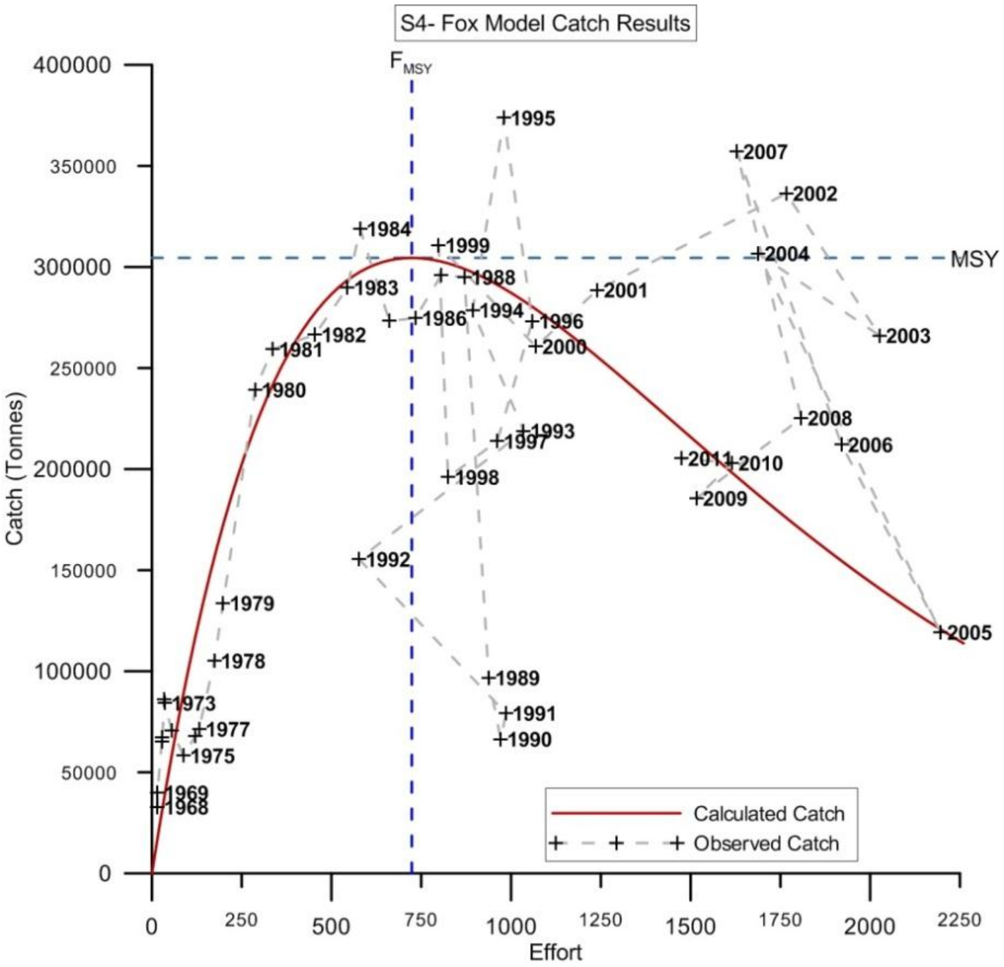

Figure 3.34: S4, Fox Model Catch Results

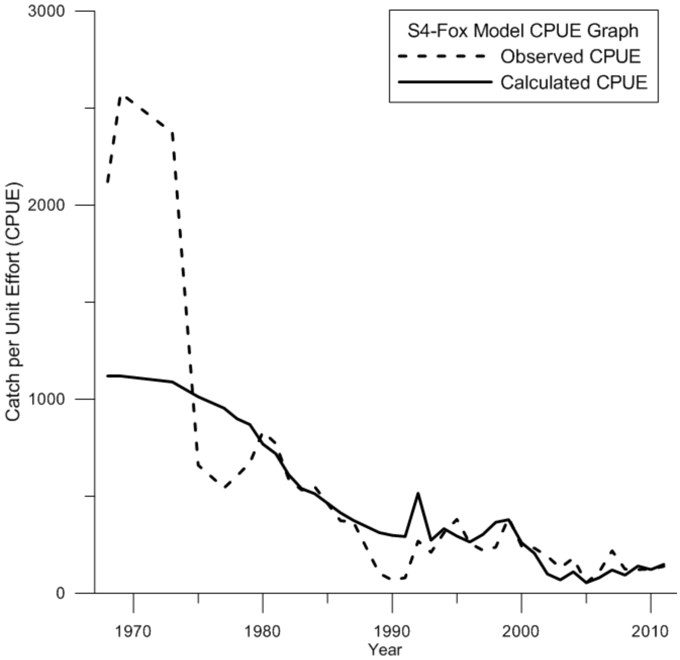

Figure 3.35: S4, Fox Model CPUE Graph

3.2.4.2 Non-Equilibrium Surplus Production Model

Sensitivity of model shapes to parameter changes has a variety. While Logistic and Fox models sensitive only to the penalty term and optimization mode, Gengrid is also sensitive to the q value additionally to others. The non-equilibrium approach to S4 resulted providing high goodness of fit values. The highest considerable R^2 value 0.771 obtained from the Gengrid model shape, when the penalty term is on and q is 1.00E-04 (Table 3.19). Few simulations eliminated because of giving SSE, q and MSY errors which are marked in Table 3.19 with bold line covered boxes. Genfit model shape could not provide reliable results because of SSE error, so also it was eliminated.

Table 3.19: S4, Non-equilibrium approach, provided R^2 values according to model shapes

S4	**Logistic**	**Fox**	**Genfit**	**Gengrid**	**q**
YLD	0.597	0.708	0.754	0.753	**1.00E-03**
	0.597	0.708	0.755	0.753	**1.00E-04**
	0.597	0.708	0.754	0.753	**1.00E-05**
EFT	0.626	0.712	0.770	0.770	**1.00E-03**
	0.626	0.712	0.771	0.771	**1.00E-04**
	0.626	0.712	0.772	0.772	**1.00E-05**
B_1/K	**1^{Gengrid}**	**2^{Fox}**	**3^{Logistic}**	**Penalty**	
0.25	0.771	0.712	0.626	**On**	
	0.856	SSE	0.703	**Off**	
0.5	0.771	0.712	0.626	**On**	
	0.856	SSE	0.651	**Off**	

Non-equilibrium approach to S4 suggested different CPUE and F/F_{MSY} & B/B_{MSY} estimations for different model shapes. As before mentioned, the Genfit model shape excluded from further examinations. The other three approaches' comparison was presented in Figure 3.36 and Figure 3.37. Since the models were not responsive to change of B1/K value they provided same results also for CPUE and F/F_{MSY} & B/B_{MSY}, as might be seen in the figure.

Logistic and Fox models suggested close CPUE estimations and Gengrid respond differently. All of them captured the decreasing trend. However, Logistic model underestimated first year's CPUE value on the contrary Gengrid and Fox models, which were suggested quite good estimations. The estimations Gengrid model is higher than others until 1983 and lower until 2000. Same trend change also observed between Logistic and Fox models for the same time periods with a small difference.

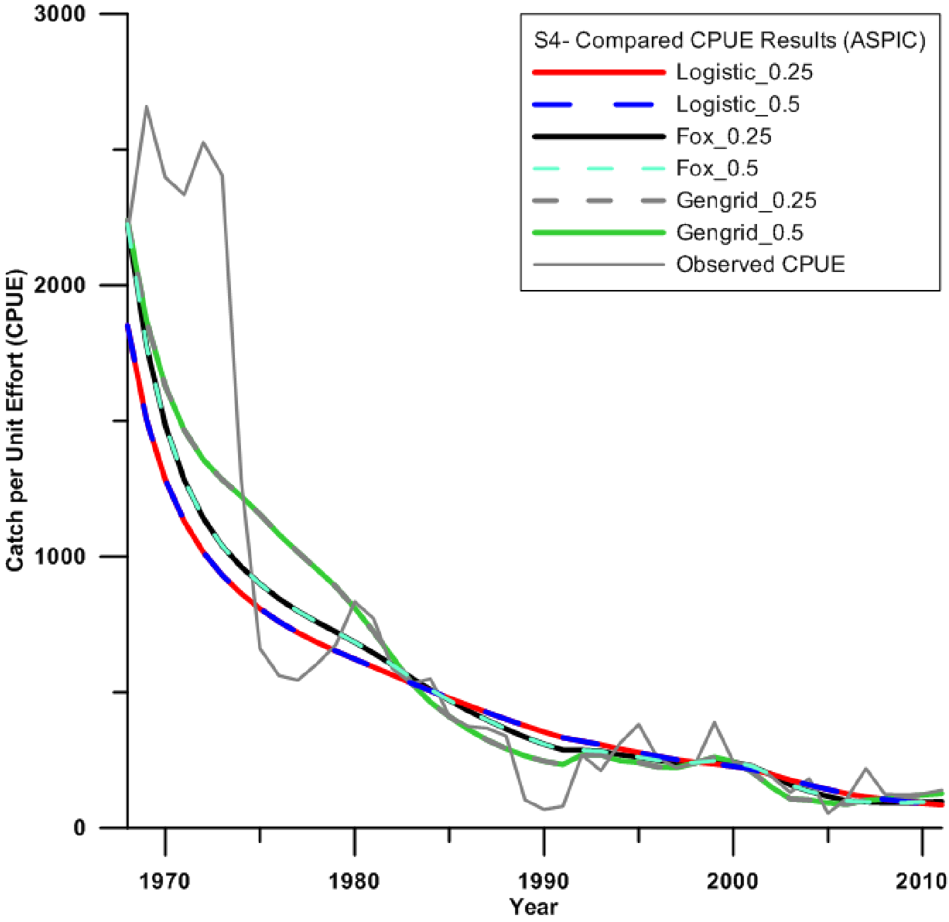

Figure 3.36: S4, Non-equilibrium approach compared CPUE results

The F/F_{MSY} ratio was estimated by models following the same pattern. Gengrid and Fox models were suggested very close estimations and Logistic model's estimations were higher than them. It has some fluctuations, but critical changes observed in 1993, 2000 and 2005. More detailed explanations were presented under their topic.

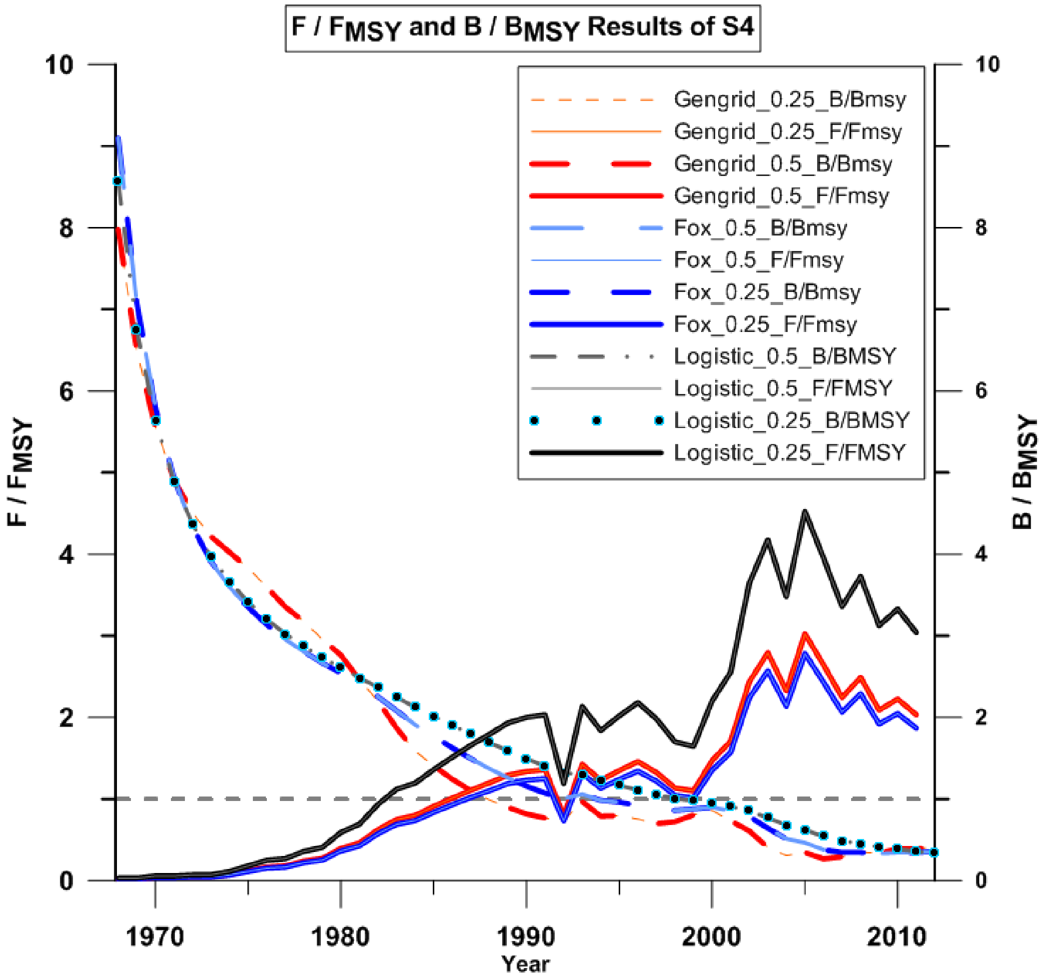

Figure 3.37: S4, Non-equilibrium approach compared F/F_{MSY} & B/B_{MSY} results

Logistic

Non-equilibrium approach to Logistic model was responsive to optimization mode and the penalty term change. Simulations resulted providing high R^2 values. The highest is 0.626 and it has been obtained by EFT based simulations. Simulations ended providing the same results independent from q value.

YLD based simulations were provided considerable R^2 value which is 0.597 however, it is not one of the first three results so it was not included to further examinations. Its estimations of population parameters are 95 000 t for MSY, 2.7 million t for B_{MSY}, 0.035 for F_{MSY}, 460 for f_{MSY}, 5.3 million t for K and 0.000077 for q. Approximate yield available at F_{MSY} in 2012 (Y.(F_{MSY}) '12) was estimated as 40 100 t and equilibrium yield available in 2012 (Ye '12) as 62 800 t. It suggested that starting relative biomass in 1968 (B_1/K '68) is 4.94.

Table 3.20: S4, Non-equilibrium approach, Logistic model results

	Logistic--YLD			**Logistic--EFT**		
MSY	9.50E+04	9.50E+04	9.50E+04	1.19E+05	1.19E+05	1.19E+05
B_{MSY}	2.66E+06	2.66E+06	2.66E+06	2.78E+06	2.78E+06	2.78E+06
F_{MSY}	3.57E-02	3.57E-02	3.57E-02	4.27E-02	4.27E-02	4.27E-02
f_{MSY}	4.60E+02	4.60E+02	4.60E+02	4.85E+02	4.85E+02	4.85E+02
K	5.32E+06	5.32E+06	5.32E+06	5.55E+06	5.55E+06	5.55E+06
q (estimated)	7.76E-05	7.76E-05	7.76E-05	8.80E-05	8.80E-05	8.80E-05
Y.(F_{MSY}) '12	4.01E+04	4.01E+04	4.01E+04	4.07E+04	4.07E+04	4.07E+04
Ye '12	6.28E+04	6.28E+04	6.28E+04	6.67E+04	6.67E+04	6.67E+04
B_1/K '68	4.94E+00	4.94E+00	4.94E+00	4.30E+00	4.29E+00	4.29E+00
R- squared	*0.597*	*0.597*	*0.597*	*0.626*	*0.626*	*0.626*
q (starting guess)	1.00E-03	1.00E-04	1.00E-05	1.00E-03	1.00E-04	1.00E-05
Warning	No	No	No	No	No	No

Provided R^2 value, by EFT based simulations', is 0.626 (Table 3.21). As mentioned before B_1/K has no effect on simulations, but the penalty term has. In the second step, off mode penalty term cause different results, however both of them gave MSY error. Because of that only one considerable simulation obtained from Logistic model.

According to the simulation result, population parameters are 119 000 t for MSY, 2 million t for B_{MSY}, 0.043 for F_{MSY}, 485 for f_{MSY}, 5.6 million t for K and 0.00009 for q. Approximate yield available at F_{MSY} in 2012 (Y.(F_{MSY}) '12) was estimated as 40 700 t and equilibrium yield available in 2012 (Ye '12) as 66 700 t. It suggested that starting relative biomass in 1968 (B_1/K '68) is 4.29.

Table 3.21: S4, Non-equilibrium approach, Logistic model result, second step

	Log--EFT		
	0.25 Off	**0.25 On**	**0.5 Off**
MSY	1.87E+04	1.19E+05	1.87E+04
B_{MSY}	2.06E+06	2.78E+06	2.08E+06
F_{MSY}	9.08E-03	4.27E-02	9.01E-03
f_{MSY}	2.87E+02	4.85E+02	2.97E+02
K	4.12E+06	5.55E+06	4.15E+06
q (estimated)	3.17E-05	8.80E-05	3.03E-05
Y.(F_{MSY}) '12	2.97E+04	4.07E+04	3.11E+04
Ye '12	1.21E+04	6.67E+04	1.03E+04
B_1/K '68	3.72E+01	4.29E+00	4.47E+01
R- squared	*0.703*	*0.626*	*0.651*
q (starting guess)	1.00E-04	1.00E-04	1.00E-04
Warning	**MSY**	No	**MSY**

In Figure 3.38, CPUE and F/F_{MSY} & B/B_{MSY} estimations of Logistic model were presented. According to results Logistic model were captured the sharply decreasing trend, however, underestimated the first year's CPUE and missed the second year's peak. It could not explain fluctuation.

According to the suggestion of the model, F/F_{MSY} increased continuously until 1991 and exceeded the ratio of 1 in 1982. In 1992 first decrease suggested and after that year, fluctuations continued. A four-year-increase started in 2001 and highest ratio was suggested for 2005. After 2005 decreasing trend started and continued until the ratio became 3.

B/B_{MSY} started with a high value which is 8.5 and continuously decrease until the end of the time period. In 1998 the ratio decrease to 1, with this year a stationary phase suggested until 2002.

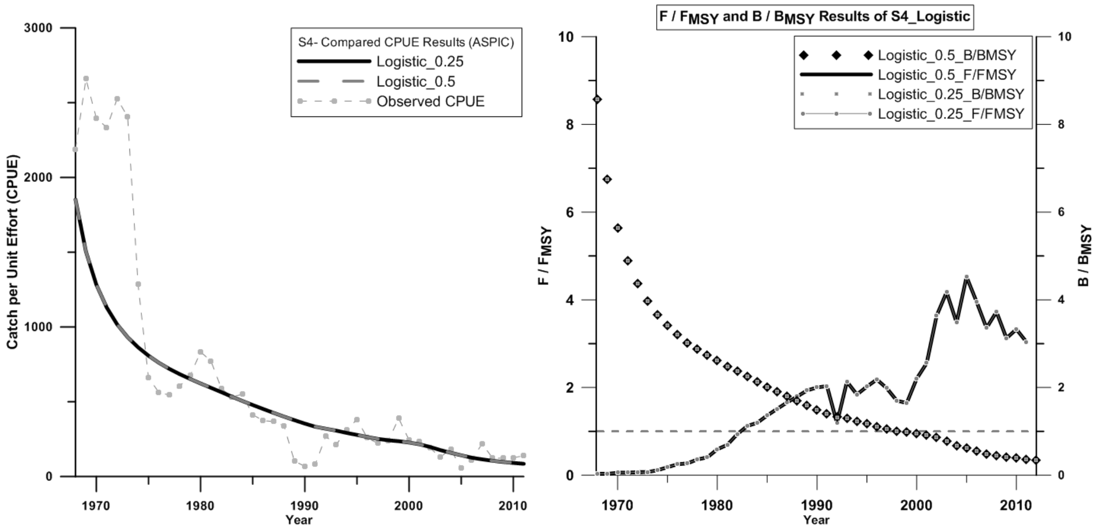

Figure 3.38: S4, Logistic model CPUE (left) and F/F_{MSY} & B/B_{MSY} (right) results

Pella & Tomlinson Generalized Model Applications

The Pella & Tomlinson generalized model application to S4 was sensitive to optimization mode and the penalty term changes. Genfit model shape resulted in errors; however Fox and Gengrid models ended normally with an exception of Gengrid model shape as was explained in advanced.

In Figure 3.36, three successively ended model shapes were presented. Since Genfit model shape could not provide considerable results, one of these models is logistic. On the left figure CPUE estimations of models together for comparison. All of the models were captured general trend and as can be seen from the figure Gengrid estimated closer values to the observed one, especially after 1980. The models provided similar estimations however differently from others Gengrid suggested higher estimations for the period between 1973 and 1982.

In Figure 3.37, F/F_{MSY} estimations were given together for different simulations of same model shapes, because of their results are same. Gengrid and Fox models suggested quite close values with the same pattern. Nevertheless the logistic model suggested higher values with an increasing difference through the time. Their pattern was explained in detail under model topics, but another difference between the logistic and other models is the logistic model exceeded the ratio 1 nearly five years earlier than them.

The B/B_{MSY} suggestions of the models are quite close until 1973 (Figure 3.37). After that year Gengrid model shape estimations are higher than others, but in 1982 it sharply decreased and stayed below of other models estimated values until 2008. Fox and logistic models suggested very similar values until 1982 and afterward, Fox started to decrease with a higher slope than logistic model. While Gengrid increased to the ratio of 1 in 1988, Fox increased in 1992 and logistic in 1999.

Fox

Non-equilibrium approach to Fox model for S4 was not sensitive to q and B_1/K values. It resulted with providing high goodness of fit value. Although there are few differences between YLD and EFT based simulations, only EFT based simulation was considered for further examination since it has provided the highest R^2 value (Table 3.22).

According to the YLD based simulations population parameters are 178 000 t for MSY, 1.3 million t for B_{MSY}, 0.135 for F_{MSY}, 1000 for f_{MSY}, 3.6 million t for K and 0.00013 for q. Approximate yield available at F_{MSY} in 2012 (Y.(F_{MSY}) '12) was estimated as 103 000 t and equilibrium yield available in 2012 (Ye '12) as 159 000 t. It suggested that starting relative biomass in 1968 (B_1/K '68) is 4.96.

Table 3.22: S4, Non-equilibrium approach, Fox model results

	Fox--YLD			**Fox--EFT**		
MSY	1.78E+05	1.78E+05	1.78E+05	2.19E+05	2.19E+05	2.19E+05
B_{MSY}	1.32E+06	1.32E+06	1.32E+06	9.68E+05	9.68E+05	9.68E+05
F_{MSY}	1.35E-01	1.35E-01	1.35E-01	2.27E-01	2.26E-01	2.26E-01
f_{MSY}	1.00E+03	1.00E+03	1.00E+03	7.89E+02	7.89E+02	7.89E+02
K	3.60E+06	3.60E+06	3.60E+06	2.63E+06	2.63E+06	2.63E+06
q (estimated)	1.34E-04	1.34E-04	1.34E-04	2.87E-04	2.87E-04	2.87E-04
Y.(F_{MSY}) '12	1.03E+05	1.03E+05	1.03E+05	8.10E+04	8.09E+04	8.09E+04
Ye '12	1.59E+05	1.59E+05	1.59E+05	1.59E+05	1.59E+05	1.59E+05
B_1/K '68	4.96E+00	4.96E+00	4.96E+00	3.35E+00	3.35E+00	3.35E+00
R- squared	*0.708*	*0.708*	*0.708*	*0.712*	*0.712*	*0.712*
q (starting guess)	1.00E-03	1.00E-04	1.00E-05	1.00E-03	1.00E-04	1.00E-05
Warning	No	No	No	No	No	No

The model was responsive only optimization mode and the penalty term changes for that reason in the second step results only change according to their penalty term on or off.

The off mode set simulations could not finish because of SSE error. Because of that same simulation from first step were considered (Table 3.23). According to its suggestions population parameters are 219 000 for MSY, 968000 t for B_{MSY}, 0.226 for F_{MSY}, 789 for f_{MSY}, 2.6 million t for K and 0.00029 for q. Approximate yield available at F_{MSY} in 2012

($Y.(F_{MSY})$ '12) was estimated as 80 900 t and equilibrium yield available in 2012 (Ye '12) as 159 000 t. It suggested that starting relative biomass in 1968 (B_1/K '68) is 3.35.

Table 3.23: S4, Non-equilibrium approach, Fox model result, second step

	Fox--EFT		
	0.25 Off	**0.25 On**	**0.5 Off**
MSY	NaN	2.19E+05	NaN
B_{MSY}		9.68E+05	
F_{MSY}		2.26E-01	
f_{MSY}		7.89E+02	
K		2.63E+06	
q (estimated)		2.87E-04	
$Y.(F_{MSY})$ '12		8.09E+04	
Ye '12		1.59E+05	
B_1/K '68		3.35E+00	
R- squared		0.712	
q (starting guess)		1.00E-04	
Warning	**SSE**	No	**SSE**

In Figure 3.39, CPUE and F/F_{MSY} & B/B_{MSY} estimations of the model were presented. First year's CPUE value estimation is too close to the observed one, however model could not explain the increase of the second year. It captured the general decreasing trend. Although it could not explain fluctuations, after 1982 estimations are closer to the observed values.

F/F_{MSY} estimations of the model suggested an increasing trend through the time until 1991. It exceeded the ratio of 1 in 1987 and in 1992 it decreased to the below 1 with a sudden change. The next year it exceeded 1 again. After that year fluctuation continued and in 1999 it started to increase until 2005. It reserved the decreasing trend until the end of the time period with small fluctuations.

B/B_{MSY} estimation of the model presented a sharp decrease until 1973 and the decreasing trend continued in a more limited range. In 1992 it dropped below the ratio 1, until 2000 it stayed nearly stable and after that year continued to decrease. Model's 2012 estimation is 0.36.

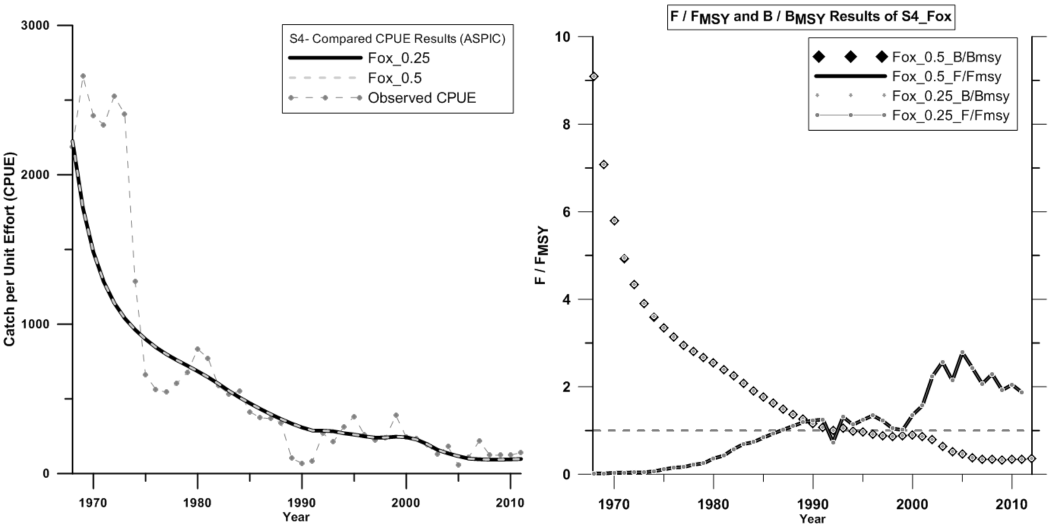

Figure 3.39: S4, Fox model CPUE (left) and F/F_{MSY} & B/B_{MSY} (right) results

Genfit

Non-equilibrium approach to S4 with Genfit model shape were ended with errors. None of the simulations ended normally end except the last simulation of EFT based tests all ended with SSE errors. The last simu lation was ended with SSE and q errors. Because of that it was not considered for further examinations.

Table 3.24: S4, Non-equilibrium approach, Genfit model results

	Genfit--YLD			**Genfit--EFT**		
MSY	2.18E+05	2.18E+05	2.18E+05	2.27E+05	2.27E+05	2.26E+05
B_{MSY}	6.21E+05	6.21E+05	6.22E+05	3.01E+05	3.02E+05	3.09E+05
F_{MSY}	3.51E-01	3.51E-01	3.50E-01	7.54E-01	7.51E-01	7.32E-01
f_{MSY}	1.48E+03	1.48E+03	1.48E+03	7.25E+02	7.25E+02	7.32E+02
K	2.49E+06	2.48E+06	2.48E+06	1.99E+00	1.21E+06	1.24E+06
q (estimated)	2.36E-04	2.37E-04	2.36E-04	1.04E-03	1.04E-03	1.00E-03
Y.(F_{MSY}) '12	1.78E+05	1.78E+05	1.78E+05	9.13E+04	9.14E+04	9.21E+04
Ye '12	2.17E+05	2.17E+05	2.17E+05	1.98E+05	1.98E+05	1.98E+05
B_1/K '68	4.17E+00	4.19E+00	4.18E+00	1.20E+06	2.00E+00	2.02E+00
R- squared	*0.754*	*0.755*	*0.754*	*0.77*	*0.771*	*0.772*
q (starting guess)	1.00E-03	1.00E-04	1.00E-05	1.00E-03	1.00E-04	1.00E-05
Warning	**SSE**	**SSE**	**SSE**	**SSE**	**SSE**	**SSE + q**

Gengrid

The Non-equilibrium approach to S4 with Gengrid model shape was provided quite satisfying R^2 value. Except the last EFT based simulation, all simulations ended normally. It was sensitive to the optimization mode, penalty term and q value changes. Provided R^2 value is 0.77 for EFT based simulations and 0.75 for YLD based simulations (Table 3.25). Because of the highest R^2 considered YLD based simulations eliminated for further simulations.

The YLD based simulations provided the same results for different q values. The model's estimation of population parameters is 218 000t for MSY, 621 000 t for B_{MSY}, 0.35 for F_{MSY}, 1480 for f_{MSY}, 2.5 million t for K and 0.00023 for q. Approximate yield available at F_{MSY} in 2012 (Y.(F_{MSY}) '12) was estimated as 178 000 t and equilibrium yield available in 2012 (Ye '12) as 217 000 t. It suggested that starting relative biomass in 1968 (B_1/K '68) is 4.16.

Table 3.25: S4, Non-equilibrium approach, Gengrid model results

	Gengrid--YLD			**Gengrid--EFT**		
MSY	2.18E+05	2.18E+05	2.18E+05	2.27E+05	2.27E+05	2.26E+05
B_{MSY}	6.21E+05	6.21E+05	6.21E+05	3.02E+05	3.02E+05	3.09E+05
F_{MSY}	3.51E-01	3.51E-01	3.51E-01	7.51E-01	7.51E-01	7.32E-01
f_{MSY}	1.48E+03	1.48E+03	1.48E+03	7.26E+02	7.26E+02	7.32E+02
K	2.48E+06	2.48E+06	2.48E+06	1.21E+06	1.21E+06	1.24E+06
q (estimated)	2.37E-04	2.37E-04	2.37E-04	1.04E-03	1.04E-03	1.00E-03
Y.(F_{MSY}) '12	1.78E+05	1.78E+05	1.78E+05	9.14E+04	9.14E+04	9.21E+04
Ye '12	2.17E+05	2.17E+05	2.17E+05	1.98E+05	1.98E+05	1.98E+05
B_1/K '68	4.16E+00	4.15E+00	4.15E+00	2.00E+00	2.00E+00	2.02E+00
R- squared	*0.753*	*0.753*	*0.753*	*0.77*	*0.771*	*0.772*
q (starting guess)	1.00E-03	1.00E-04	1.00E-05	1.00E-03	1.00E-04	1.00E-05
Warning	No	No	No	No	No	**q**

Because of the model is not sensitive to B_1/K, the second step of the elimination was provided same estimations with the first step. Although the model is sensitive to the penalty term, it was ended with MSY error so that it was eliminated.

The EFT based model's estimation of population parameters is 227 000 t for MSY, 302 000 t for B_{MSY}, 0.75 for F_{MSY}, 726 for f_{MSY}, 1.2 million t for K and 0.001 for q. Approximate yield available at F_{MSY} in 2012 (Y.(F_{MSY}) '12) was estimated as 91 400 t and equilibrium yield available in 2012 (Ye '12) as 198 000 t. It suggested that starting relative biomass in 1968 (B_1/K '68) is 2.

Table 3.26: S4, Non-equilibrium approach, Gengrid model result, second step

	Gengrid		
	0.25 Off	**0.25 On**	**0.5 Off**
MSY	1.50E+05	2.27E+05	1.50E+05
B_{MSY}	6.50E+05	3.02E+05	6.50E+05
F_{MSY}	2.30E-01	7.51E-01	2.30E-01
f_{MSY}	1.65E+03	7.26E+02	1.65E+03
K	2.60E+06	1.21E+06	2.60E+06
q (estimated)	1.40E-04	1.04E-03	1.40E-04
Y.(F_{MSY}) '12	1.52E+05	9.14E+04	1.52E+05
Ye '12	1.50E+05	1.98E+05	1.50E+05
B_1/K '68	8.14E+00	2.00E+00	8.14E+00
R- squared	*0.856*	*0.771*	*0.856*
q (starting guess)	1.00E-04	1.00E-04	1.00E-04
Warning	**MSY**	No	**MSY**

CPUE estimations captured the sharp decrease and suggested quite close value for the first year (Figure 3.40). Although it could not explain the large fluctuation between the beginning and 1980, it suggested quite close estimation for the after of 1980.

F/F_{MSY} and B/B_{MSY} estimations are quite parallel with Fox model's suggestions (Figure 3.39). F/F_{MSY} represented an increasing trend until 1992 and it decreased to below one (Figure 3.40). The next year it exceeded 1 again and continued with small fluctuations. Started to increase in 2000 and continued until 2005. After 2005 it decreased with small fluctuations at the end of the time period.

The model's estimations of B/B_{MSY} indicate that the ratio begins with 8 and presents a decreasing trend 1993 with dropping below 1 in 1988. In 1994 it increased to 1 and the next year decreased again. In 2000 presented a small increase and after that decreased again. The model's estimate of the B/B_{MSY} ratio for 2012 is 0.42.

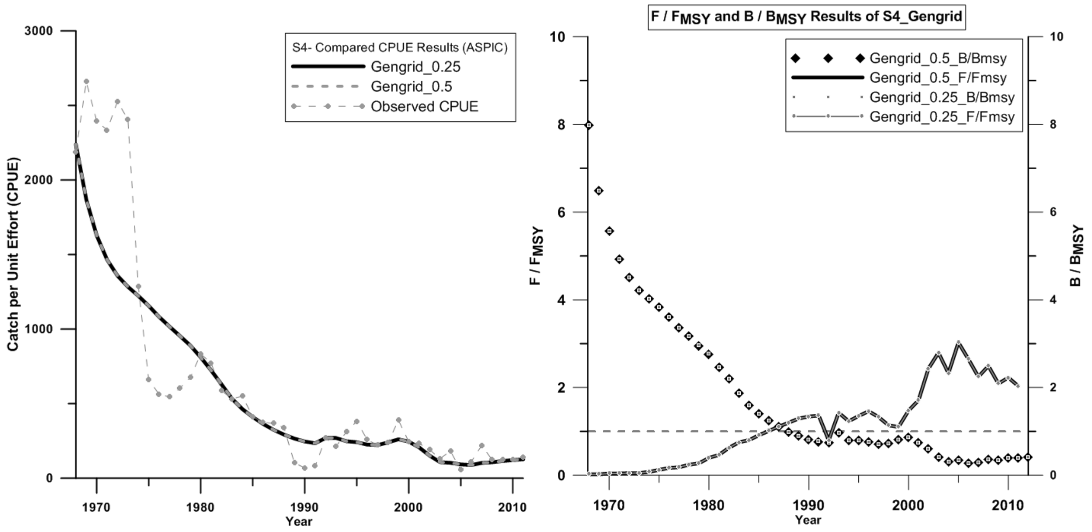

Figure 3.40: S4, Gengrid model CPUE (left) and F/F_{MSY} & B/B_{MSY} (right) results

Logarithmic residual results of S4 were given in Figure 3.41. The more realistic results were obtained from Fox and Gengrid models.

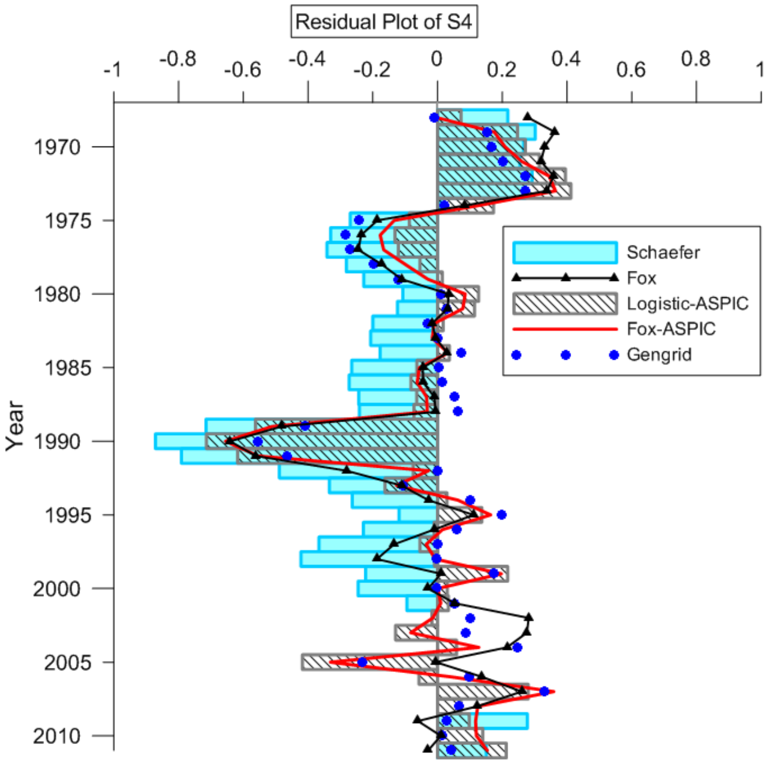

Figure 3.41: Logarithmic residual plot of successive S4 simulations

4 DISCUSSION

The Black Sea has a very complex system which has recently been subjected to severe ecological changes. In the 1960s nutrients, either used in extensive agriculture or discharged as a result of an increased human population, drained into the main rivers such as the Danube, Dnieper, Dniester and Cuban. Consequently the ecological status of some basins such as the NW shelf area and the Azov Sea, which were already eutrophic, has been further elevated. Additionally, the construction of reservoirs over the rivers trapped some of the exclusively natural nutrients like silicate and altered the nutrient composition of the sea in favor of those originating from anthropogenic sources. Changes in the nutrient composition have been reflected first in the lower trophic level, and then moved upward on the food chain towards fish (Zaitsev Y. P., 1992).

Anchovy as a planktivorous species originally benefitted from the situation. Primary production, induced by increased nutrient level, increased the carrying capacity of the anchovy in the ecosystem. Later with improved fishing technology, fishing effort increased. At first the fishes at the higher trophic levels and of higher economic value such as Bluefish, Atlantic bonito, mackerel etc. were targeted. The increase in the fishing pressure on these piscivorous species, in return, removed fishing pressure on their prey species such as anchovy. Also, the cetacean population, which is an important predator of anchovy was hunted and numbers reduced dramatically until 1982.

As presented in Figure 3.1 the anchovy catch displays drastic oscillations with extreme peaks and troughs. The first period which is characterized by low catch values coincides with the period when the fishery mainly targeted large pelagics mentioned above. The second period displaying a very sharp increase is the time when the carrying capacity of the Black Sea for anchovy increased. Use of fish technology increased the anchovy catch level.

To explain the sudden drop in catch observed in the third period has been a great challenge for scientists. The outbreak of an introduced alien ctenephore, *Mnemiopsis leidyi*, has been blamed for the loss of anchovy by some scientists (Kideys, 2002). Another group of scientist pointed to a dramatic increase in the fishing fleet (Gucu, 2002). The increase has been observed both, in the number of boats and at the level of new fishing technologies used (Figure 3.2). The decrease in stock does not correlate with a decline in catches, however, after a decline in stock a higher proportion of the population is harvested (Bailey, 1992) and the sharp decreases in the anchovy catch can be interpreted as a sign of SSB overfishing.

The fourth period, which represents a very sharp recovery, is another debatable issue. Some claimed that the so blamed source of the problem, the mass invasion of the *M. leidyi* population, was heavily preyed on by another ctenophore *Beroe ovata* whilst others explained the recovery by the replacement of the fishing fleet. In the absence of anchovy the Black Sea fishing fleet has migrated south in search of new fishing grounds, so that the fishing pressure of anchovy has been temporarily reduced.

The fifth period represents the most recent situation in which the catch values fluctuate with no foreseen explanation except the sudden drop in 2005. The biomass of Atlantic bonito *Sarda sarda* which, to a certain extent, feeds on anchovy has apparently increased, as can be inferred from the tripled catch record in 2005 (Figure 1.3). Therefore, one possible explanation could be that the sudden drop in anchovy during the same period might be due to predation pressure rather than fishery pressure.

Until now critical periods of the anchovy catch were explained independently, however, during the study they have been evaluated together as one period. The study is based on the explanation of anchovy stock state changes as a function of fishing pressure as presented in the results section. The first scenario is based on the idea that the number of boats has an effect on fishing pressure, while the second assumption considered the total engine power of the specified size range fishing boats. The third and fourth scenarios are based on the idea that, for small pelagic fish species, the type of fishing gear determines the fishing pressure. While the third scenario only considered the multipurpose and purse seine boats, the fourth scenario combined the sonar factor with the third scenario as a technological improvement contributor to fishing pressure. After sensitivity tests and model studies with equilibrium and non-equilibrium approach simulations explained the general trend of CPUE however, considering the best R^2 value among all scenarios, S4 with Gengrid model shape provided the best result. The range of MSY estimations changes between 133 000 and 227 000. B_{MSY} changes 280 000 and 300 000.

The estimated parameters of the Schaefer model on first approach, is used to calculate the hypothetical CPUE as a function of fishing effort. Although the decreasing trend in the CPUE over the years is captured by the model, the severe peaks (1981-1984) and troughs (1989-1991) could not be explained by the Schaefer model. In general, the agreement between model results and the actual CPUE is better after 1995. However, it should be noted that the slight increase in the CPUE suggested by the model after 2005, is not verified by the actual catch. This is most probably a positive consequence of the measures recently enforced by the Turkish fisheries authorities in an attempt to reduce fishing pressure on the anchovy stock.

The fishing capacity of the anchovy fleet had been developed over the years. All estimates of CPUE based on different effort scenarios (Figure 3.3) indicated that the recent values are much lower than the first of the data set. This means that the fleet been over-capitalized beyond profitability for the last 2-3 decades. Essentially a drop in the CPUE and the consequences of over-capitalization on the fish stocks have been recognized in the mid-1990s, when a significant reduction in stocks hit the fishery sector. However, a comprehensive measure could only be enforced at the beginning of the 21st century. As the initial step, the licensing of new fishing boats was stopped in 2002 with the aim of reducing the fishing pressure on the stocks and to maintain sustainable fisheries. This measure was twice interrupted in 2004 and 2005. Since then, new entries to the fleet are only allowed when a vessel of the same size is exiting from the fleet. In such cases a maximum of 20% increase in length is tolerated. Similarly, in case of modification and modernization of vessels, a maximum of 20% increase in size is allowed. The consequences of effort reduction regulations may be seen in the outputs of all non-equilibrium models (Figure 3.2). The rise of F/F_{MSY} which intensified after 2000 has been stopped and its trend reversed. This is an indication of the positive effects of applied policy on the control of increasing fleet capacity.

The estimated parameters of the Fox model for the first approach are used to calculate the hypothetical CPUE as a function of fishing effort. Therefore, the obtained results are analogous to Schaefer model’s results. Especially for the years 2001, 2003 and 2005 the Fox model calculated values are closer to the actual values if compared with the Schaefer model. Until 1999 the Fox model suggests higher values as compared to the Schaefer model. As observed from the Schaefer model results, the Fox model results also could not explain the severe peaks and troughs.

On the contrary, over-development of the fleet has been unintentionally encouraged through the exemption of a Special Consumption Tax on the fuel used in the fishing boats. The quantity of tax-free fuel provided to a vessel is determined based on the engine power of a vessel. When combined with unregulated engine power modification practices, the subvention, in practice, resulted in cases where the larger the engine power of a vessel the more tax free fuel it could get. Consequently, although the number of fishing vessels remained unchanged over the years the total engine power and the fuel consumed by the fleet has increased remarkably. When this is associated with the reduction in the stock sizes, the fuel consumed (and the carbon emitted) to catch the same amount doubled during the last decade. The impact of the subvention which was first applied in 2004 is evident in the outputs of second scenario in which the effort takes the engine power of the fleet into consideration (Figure 3.18). However, to what extent the figure reflects the reality is questionable because the scenario relies on the linearity between engine power of a vessel and its fishing efficiency. Therefore the question as to whether the increased engine power of the fishing boats increases the fishing capacity of the fleet may be a matter of concern; however, comparison of daily catch of the boats with respect to their total engine power shows no significant relation (STECF, 2013). The lack of connection is explained by dense school forming behavior of the anchovy on the overwintering grounds. In summary the size of the main anchovy fishing fleet in the Black Sea is stable since 2005.

Another very substantial and promising remedy is the fishing boat buyback program launched in 2012. Given that by far the greater part of the catch is landed by the industrial boats, the first phase of the program targets fishing vessels larger than 12 meters in 2012. Although the ultimate goal is to reach greater percentages in time, with the available funds allocated for the buyback program only 407 boats (156 boats of them were registered to ports on the Black Sea coast) were removed from the fleet during the first phase in 2013.

As of 2012 the minimum depth limit allowed for purse seine and for pelagic trawls has been increased from 18 to 24 meters. Considering that the anchovy overwintering on the Anatolian coast are confined to 0 to 100 meters, the regulation has noticeable positive effect on the reduction of fishing pressure on the anchovy stocks.

One critical consideration in the parameterization of the model is selection of parameters. Some of the parameters, such as catchability coefficient “**q**” were elaborated and tested for their accuracy. However, for some suggestions proposed by other authors certain parameters have been adapted without any questioning. The most critical one is the B1/K which is assumed to be 0.5 in all models. All the models in essence rely on the surplus production theory and the carrying capacity principles. By adopting 0.5, it was assumed that halfing the virgin state biomass would produce the MSY for the stock in question. On the other hand, there are some studies criticizing the use of constant carrying capacity. When these considerations are applied to the Black Sea ecosystem, several drawbacks are inevitable. It is very well known that the Black Sea has undergone severe ecological changes; such as changes in the river regimes, increased pollution, etc. All these changes should, to a noticeable extent, have an impact on stocks and fisheries. The periodic fluctuations which could not be simulated by the fishing models are most probably the signatures of the “other” factors rather than fishery.

Another critical concern about the anchovy’s carrying capacity is the shift in the ecosystem state. The oligotrophy in the Black Sea has been levelled up to eutrophy in the 70s, which in turn, was believed to increase the carrying capacity of the Black Sea anchovy. Therefore, in an attempt to evaluate the increased carrying capacity the B_1/K value was reduced to 0.25 in some of the scenarios. As can be seen from the outputs of the models (Table 3.11, Figure 3.25) changing the carrying capacity did not influence the MSY and F_{MSY} values but rather increased the model residuals.

Although the 4th scenario seems to be the best amongst all others, the estimate of technological development (sonar constant) may be underestimated, particularly for the period prior to the 1970s. Prodanov, et al., (1997) estimated exploited biomass of the Black Sea anchovy in the 1967-1993 period (Figure 4.1). Their results are in agreement with Appendix 1 which shows an increase in the biomass between 1975-80 and afterwards a gradual steady decrease until 1994. The only difference between Prodanov's work and the fourth scenario is the very first part of the data set. Actually, this is not surprising as the number of boats representing the fleet was unrealistically very low (Figure 3.2)

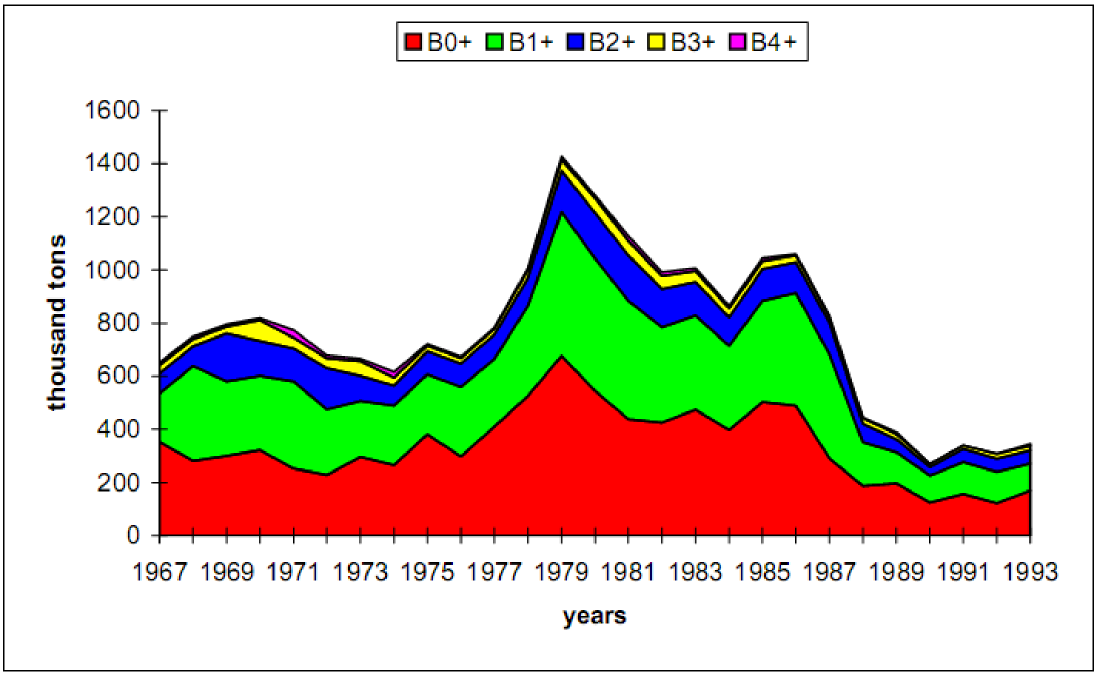

Figure 4.1: Anchovy exploited biomass (B0+ in thousand tonnes) in early November during the period (1967-1993) (Taken from Prodanov, et al., (1997))

In general the selectivity of a purse seine, used to catch small pelagics, is considered negligible and it is assumed that all small pelagic fish caught by the purse seine fishery are landed. In the last 10 years, the great increase in demand for fish meal and oil factories led to the fishers targeting all fish schools detected on the sonars, including those under the minimum allowable size limits. For better enforcement of the minimum size regulation, controls at both the landing sites and in the factories have been increased by the Turkish authorities. However, due to schooling behavior of the anchovy during winter, it is practically impossible to discriminate undersized fishes from the larger sized anchovies during the purse seining operation. Therefore, in an attempt to get rid of undersized fished before landing the use of "fish graders" became very common. With this device legal sized fishes are retained and the remainders are simply discarded at sea. In some cases, when the catch in an operation is mainly composed of undersized anchovies, the operation is aborted and the fish in the net are released. However, the survival of fish after such an operation is almost zero and it is quite common to find huge amounts of decaying fish lying on the bottom in the areas where the purse seining is concentrated. Very critical consequences of this unreported anchovy catch are the under representation of zero year class in the landings. Figure 4.2 is the comparison of length distribution of landed anchovies and those sampled by a fine meshed (14 mm stretched) pelagic trawl in the same region at the same time. Moreover the percentage of the anchovy catch discarded in this way increased remarkably in 2013. The estimated discard rates in the number of fish were 4% in 2011 and 14% in 2012.

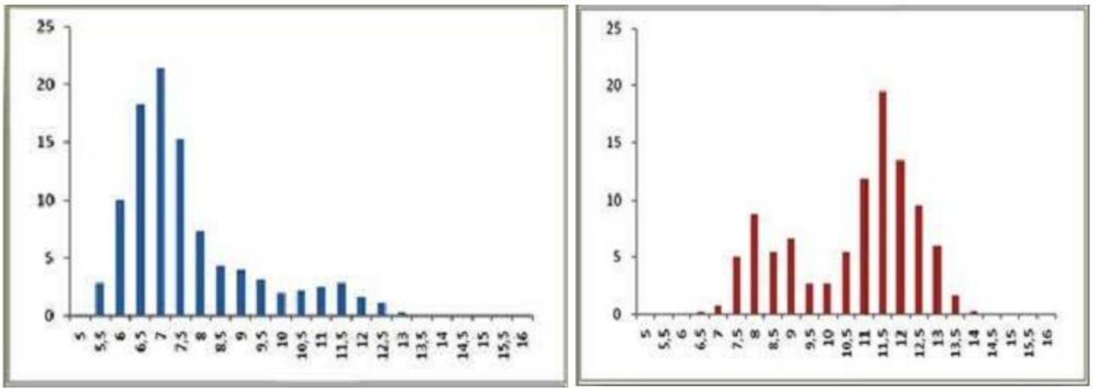

Figure 4.2: Length frequency distribution of anchovies sampled at sea by fine-med pelagic trawl (left) and at the landing sites (right) (Taken from STECF-2013)

5 CONCLUSION

The Black Sea anchovy experienced huge fluctuations which cannot be explained by only fishing effort data. In this study the main focus was the changes in the level of fishery. So that it was tested to what extent fluctuations in the anchovy landings can be explained fisheries alone. Yet, the residuals were evaluated as the possible signatures of non-fisheries factors affecting the ecosystem. Results indicate that the non-equilibrium approach to the production models are more successful. As results showed that there are several deficiencies in the data collection system which both fishermen sourced and management sourced.

The ongoing anchovy stock assessment studies performed under Scientific, Technical and Economic Committee for Fisheries (STECF) is exclusively focused on variants of Virtual Population Analysis which might not be suitable for very short lived, very fast growing small pelagic species such as anchovy of which only very limited data is available. First of all, the VPA approach extensively relies on the demographic structure of the landed fish in question. It requires near perfect representation of a sufficient number of age classes. The maximum age of anchovy is 4 years and the individuals belonging to the IV year class are very few in the landings. The 0 year class is below the minimum legal landing size during the overwintering period, when almost all fishing mortality takes place. As the main fishing gear, purse seine is not selective; the undersized fishes are discarded at sea. A part of the I year class is also below the 9 cm minimum legal landing size. Therefore, it should not be taken granted that the I year class caught by the fishery is fully represented in the landed catch. The results produced by VPA approach, based only on two fully represented age classes in the landings would not be reliable. Eventually, the assessments provided on anchovy stocks until now do not suggest consistent recommendations. Therefore elaborating an alternative method disregarding the demography in the stock would help understanding the response of the stocks to changing fisheries intensity and pattern over time. At this point we proposed to use the benefit of 44 years long catch and effort data series and apply a holistic stock production model.

The most reliable result was obtained from S4 non-equilibrium approached simulations. As obtained in general, the best result was obtained from Gengrid simulation. According to the results MSY estimated as 227 000 and equilibrium yield available in 2012 (Ye '12) as 198 000 t. When we compared the prediction with MSY estimated it is obvious that present fishing effort needs to be reduced.

The study showed that the stock production models which has long been criticized for their very crude underlying assumptions should not be overlooked in the assessment of short lived small pelagic species. The various scenarios applied to the catch and fishing effort data explained the variability in the stocks to a statistically significant extent. It was also shown that the impacts of factors other than fishery on Black Sea anchovy stock are as strong as the fisheries itself. The sharp fluctuations that could not be explained by the models are clearly the signals of climate (mild weather conditions during the spawning and nursery periods), predation by apex predators (such as bonito) and competition with other organisms sharing the same ecological niche.

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APPENDICES

Appendix 1: Input data for each scenario, sonar number and CPUE results

		Effort				CPUE				
Year	**Catch**	**S1**	**S2**	**S3**	**S4**	**S1**	**S2**	**S3**	**S4**	**Sonar**
1968	32828	711	21521	5	15	46	1.53	6566	2121	2
1969	39888	779	25827	5	15	51	1.54	7978	2578	2
1970	67109	1171	37632	18	28	57	1.78	3728	2357	2
1971	65353	840	27800	18	28	78	2.35	3631	2295	2
1972	85906	793	25607	24	34	108	3.35	3579	2492	2
1973	84216	598	25555	25	35	141	3.30	3369	2374	2
1974	70801	754	33501	29	55	94	2.11	2441	1283	5
1975	58216	696	35126	41	88	84	1.66	1420	661	9
1976	67992	916	46733	53	121	74	1.45	1283	562	13
1977	71366	757	25223	58	131	94	2.83	1230	543	14
1978	105183	1072	49820	69	174	98	2.11	1524	605	20
1979	133678	1223	56666	78	198	109	2.36	1714	674	23
1980	239289	1184	38422	104	287	202	6.23	2301	833	35
1981	259267	1033	33784	121	336	251	7.67	2143	772	41
1982	266523	1038	36543	145	454	257	7.29	1838	587	59
1983	289860	1457	43243	162	544	199	6.70	1789	533	73
1984	318917	1305	41774	171	580	244	7.63	1865	550	78
1985	273274	1682	50160	195	661	162	5.45	1401	413	89
1986	274740	1861	53016	210	734	148	5.18	1308	374	100
1987	295902	1966	69607	229	805	151	4.25	1292	368	110
1988	295000	1879	58873	247	870	157	5.01	1194	339	119
1989	96806	1914	56490	262	938	51	1.71	369	103	129
1990	66409	1992	61017	280	971	33	1.09	237	68	132
1991	79225	1871	56006	284	986	42	1.41	279	80	134
1992	155417	1779	56998	163	577	87	2.73	953	269	163
1993	218866	2567	112086	287	1035	85	1.95	763	211	287
1994	278667	2507	98168	243	893	111	2.84	1147	312	243
1995	373782	3005	127127	262	980	124	2.94	1427	381	262
1996	273239	2944	128044	278	1059	93	2.13	983	258	278
1997	213780	2999	144800	248	962	71	1.48	862	222	248
1998	195996	2866	141799	209	825	68	1.38	938	238	209
1999	310801	4029	189855	199	799	77	1.64	1562	389	199
2000	260670	4096	189710	262	1069	64	1.37	995	244	262
2001	288616	3671	163346	299	1240	79	1.77	965	233	299
2002	336419	3903	172126	419	1766	86	1.95	803	190	419
2003	266069	3975	167570	473	2026	67	1.59	563	131	473
2004	306656	4525	207539	388	1688	68	1.48	790	182	388

2005	119255	5084	633965	497	2196	23	0.19	240	54	497
2006	212081	4762	378460	428	1920	45	0.56	496	110	428
2007	357089	4436	404800	473	1629	80	0.88	755	219	321
2008	225344	4516	439745	566	1808	50	0.51	398	125	345
2009	185606	3967	376695	483	1516	47	0.49	384	122	287
2010	203026	4058	406875	409	1615	50	0.50	496	126	335
2011	205243	3554	413955	384	1475	58	0.50	534	139	303

Appendix 2: Results of ASPIC simulations

	Logistic--YLD			Logistic--EFT			Fox--YLD			Fox--EFT			Genfit--YLD			Genfit--EFT			Gengrid--YLD			Gengrid--EFT			
MSY	2.1E+05	2.1E+05	2.1E+05	2.2E+05	2.2E+05	2.2E+05	2.1E+05	2.1E+05	2.1E+05	2.1E+05	2.1E+05	2.1E+05							2.1E+05	2.1E+05	2.1E+05	2.1E+05	2.1E+05	2.1E+05	
MSY																			1.9E+05	1.9E+05	1.9E+05				2.3E+05
MSY	1.3E+05	1.3E+05	1.3E+05		1.4E+05	1.4E+05	1.8E+05	1.8E+05	1.8E+05	2.0E+05	2.0E+05	2.0E+05	1.8E+05	1.8E+05	1.8E+05	2.2E+05	2.2E+05	2.2E+05	1.9E+05	1.9E+05	1.9E+05	2.2E+05	2.2E+05	2.2E+05	
MSY	9.5E+04	9.5E+04	9.5E+04	1.2E+05	1.2E+05	1.2E+05	1.8E+05	1.8E+05	1.8E+05	2.2E+05	2.2E+05	2.2E+05							2.2E+05	2.2E+05	2.2E+05	2.3E+05	2.3E+05		
BMSY	1.6E+06	1.6E+06	1.6E+06	1.1E+06	1.1E+06	1.1E+06	1.3E+06	1.3E+06	1.3E+06	8.7E+05	8.7E+05	8.7E+05							1.0E+06	1.0E+06	1.0E+06	6.8E+05	6.8E+05	6.8E+05	
BMSY																			1.3E+06	1.3E+06	1.3E+06				4.8E+05
BMSY	2.5E+06	2.5E+06	2.5E+06		2.5E+06	2.5E+06	1.4E+06	1.4E+06	1.4E+06	1.0E+06	1.0E+06	1.0E+06	1.4E+06	1.4E+06	1.4E+06	5.0E+05	5.0E+05	5.0E+05	9.2E+05	9.2E+05	9.2E+05	4.4E+05	4.4E+05	5.0E+05	
BMSY	2.7E+06	2.7E+06	2.7E+06	2.8E+06	2.8E+06	2.8E+06	1.3E+06	1.3E+06	1.3E+06	9.7E+05	9.7E+05	9.7E+05							6.2E+05	6.2E+05	6.2E+05	3.0E+05	3.0E+05		
FMSY	1.3E-01	1.3E-01	1.3E-01	2.1E-01	2.1E-01	2.1E-01	1.6E-01	1.6E-01	1.6E-01	2.5E-01	2.5E-01	2.5E-01							2.0E-01	2.0E-01	2.0E-01	3.1E-01	3.1E-01	3.1E-01	
FMSY																			1.5E-01	1.5E-01	1.5E-01				4.7E-01
FMSY	5.3E-02	5.3E-02	5.3E-02		5.5E-02	5.5E-02	1.3E-01	1.3E-01	1.3E-01	1.9E-01	1.9E-01	1.9E-01	1.3E-01	1.3E-01	1.3E-01	4.5E-01	4.5E-01	4.5E-01	2.1E-01	2.1E-01	2.1E-01	5.1E-01	5.1E-01	4.5E-01	
FMSY	3.6E-02	3.6E-02	3.6E-02	4.3E-02	4.3E-02	4.3E-02	1.3E-01	1.3E-01	1.3E-01	2.3E-01	2.3E-01	2.3E-01							3.5E-01	3.5E-01	3.5E-01	7.5E-01	7.5E-01		
fMSY	2.3E+03	2.3E+03	2.3E+03	2.8E+03	2.8E+03	2.8E+03	2.5E+03	2.5E+03	2.5E+03	3.1E+03	3.1E+03	3.1E+03							2.9E+03	2.9E+03	2.9E+03	3.6E+03	3.6E+03	3.6E+03	
fMSY																			9.4E+04	9.4E+04	9.4E+04				1.7E+05
fMSY	1.5E+02	1.5E+02	1.5E+02		1.5E+02	1.5E+02	2.4E+02	2.4E+02	2.4E+02	2.5E+02	2.5E+02	2.5E+02	2.4E+02	2.4E+02	2.4E+02	3.3E+02	3.3E+02	3.3E+02	3.7E+02	3.7E+02	3.7E+02	3.6E+02	3.6E+02	3.3E+02	
fMSY	4.6E+02	4.6E+02	4.6E+02	4.9E+02	4.9E+02	4.9E+02	1.0E+03	1.0E+03	1.0E+03	7.9E+02	7.9E+02	7.9E+02							1.5E+03	1.5E+03	1.5E+03	7.3E+02	7.3E+02		
K	3.3E+06	3.3E+06	3.3E+06	2.2E+06	2.2E+06	2.2E+06	3.5E+06	3.5E+06	3.5E+06	2.4E+06	2.4E+06	2.4E+06							4.2E+06	4.2E+06	4.2E+06	2.7E+06	2.7E+06	2.7E+06	
K																			5.1E+06	5.1E+06	5.1E+06				1.9E+06
K	5.0E+06	5.0E+06	5.0E+06		4.9E+06	4.9E+06	3.8E+06	3.8E+06	3.8E+06	2.8E+06	2.8E+06	2.8E+06	3.8E+06	3.8E+06	3.8E+06	1.8E+06	1.8E+06	1.8E+06	3.7E+06	3.7E+06	3.7E+06	1.8E+06	1.8E+06	1.8E+06	
K	5.3E+06	5.3E+06	5.3E+06	5.6E+06	5.6E+06	5.6E+06	3.6E+06	3.6E+06	3.6E+06	2.6E+06	2.6E+06	2.6E+06							2.5E+06	2.5E+06	2.5E+06	1.2E+06	1.2E+06		
q	5.5E-05	5.5E-05	5.5E-05	7.2E-05	7.2E-05	7.2E-05	6.3E-05	6.3E-05	6.3E-05	8.0E-05	8.0E-05	8.0E-05							6.7E-05	6.7E-05	6.7E-05	8.5E-05	8.5E-05	8.5E-05	
q																			1.6E-06	1.6E-06	1.6E-06				2.8E-06
q	3.6E-04	3.6E-04	3.6E-04		3.7E-04	3.7E-04	5.2E-04	5.2E-04	5.2E-04	7.7E-04	7.7E-04	7.7E-04	5.2E-04	5.2E-04	5.2E-04	1.3E-03	1.3E-03	1.3E-03	5.7E-04	5.7E-04	5.6E-04	1.4E-03	1.4E-03	1.3E-03	
q	7.8E-05	7.8E-05	7.8E-05	8.8E-05	8.8E-05	8.8E-05	1.3E-04	1.3E-04	1.3E-04	2.9E-04	2.9E-04	2.9E-04							2.4E-04	2.4E-04	2.4E-04	1.0E-03	1.0E-03		
Y.(Fmsy) '12	9.9E+04	9.9E+04	9.9E+04	1.4E+05	1.4E+05	1.4E+05	1.1E+05	1.1E+05	1.1E+05	1.6E+05	1.6E+05	1.6E+05							1.3E+05	1.3E+05	1.3E+05	1.8E+05	1.8E+05	1.8E+05	
Y.(Fmsy) '12																			2.8E+04	2.8E+04	2.8E+04				7.7E+04
Y.(FMSY) '12	5.4E+04	5.4E+04	5.4E+04		5.4E+04	5.4E+04	9.9E+04	9.9E+04	9.9E+04	1.1E+05	1.1E+05	1.1E+05	1.0E+05	1.0E+05	1.0E+05	1.6E+05	1.6E+05	1.6E+05	1.6E+05	1.6E+05	1.6E+05	1.8E+05	1.8E+05	1.6E+05	
Y.(FMSY) '12	4.0E+04	4.0E+04	4.0E+04	4.1E+04	4.1E+04	4.1E+04	1.0E+05	1.0E+05	1.0E+05	8.1E+04	8.1E+04	8.1E+04							1.8E+05	1.8E+05	1.8E+05	9.1E+04	9.1E+04		
Ye '12	1.5E+05	1.5E+05	1.5E+05	1.9E+05	1.9E+05	1.9E+05	1.8E+05	1.8E+05	1.8E+05	2.0E+05	2.0E+05	2.0E+05							2.0E+05	2.0E+05	2.0E+05	2.1E+05	2.1E+05	2.1E+05	
Ye '12																			1.2E+05	1.2E+05	1.2E+05				1.9E+05
Ye '12	8.4E+04	8.5E+04	8.4E+04		8.5E+04	8.5E+04	1.6E+05	1.6E+05	1.6E+05	1.7E+05	1.7E+05	1.7E+05	1.6E+05	1.6E+05	1.6E+05	2.2E+05	2.2E+05	2.2E+05	1.9E+05	1.9E+05	1.9E+05	2.2E+05	2.2E+05	2.2E+05	
Ye '12	6.3E+04	6.3E+04	6.3E+04	6.7E+04	6.7E+04	6.7E+04	1.6E+05	1.6E+05	1.6E+05	1.6E+05	1.6E+05	1.6E+05							2.2E+05	2.2E+05	2.2E+05	2.0E+05	2.0E+05		
B1/K '68	2.8E-01	2.8E-01	2.8E-01	2.4E-01	2.4E-01	2.4E-01	2.0E-01	2.0E-01	2.0E-01	1.8E-01	1.8E-01	1.8E-01							1.5E-01	1.5E-01	1.5E-01	1.4E-01	1.4E-01	1.4E-01	
B1/K '68																			2.0E-01	2.0E-01	2.0E-01				1.7E-01
B1/K '68	2.5E+00	2.5E+00	2.5E+00		2.5E+00	2.5E+00	2.2E+00	2.2E+00	2.2E+00	2.3E+00	2.3E+00	2.3E+00	2.2E+00	2.2E+00	2.2E+00	2.0E+00	2.0E+00	2.0E+00	1.9E+00	1.9E+00	1.9E+00	2.0E+00	2.0E+00	2.0E+00	
B1/K '68	4.9E+00	4.9E+00	4.9E+00	4.3E+00	4.3E+00	4.3E+00	5.0E+00	5.0E+00	5.0E+00	3.4E+00	3.4E+00	3.4E+00							4.2E+00	4.2E+00	4.2E+00	2.0E+00	2.0E+00		
R-squared	3.0E-01	3.0E-01	3.0E-01	3.8E-01	3.8E-01	3.8E-01	3.3E-01	3.3E-01	3.3E-01	4.2E-01	4.2E-01	4.2E-01							3.5E-01	3.5E-01	3.5E-01	4.4E-01	4.4E-01	4.4E-01	
R-squared																			*3.3E-01*	*3.3E-01*	*3.3E-01*				*4.1E-01*
R-squared	6.3E-01	6.3E-01	6.3E-01		6.4E-01	6.4E-01	6.2E-01	6.2E-01	6.2E-01	6.7E-01	6.7E-01	6.7E-01	6.2E-01	6.2E-01	6.2E-01	6.8E-01	6.8E-01	6.8E-01	5.8E-01	5.8E-01	5.8E-01	6.8E-01	6.8E-01	6.8E-01	
R-squared	6.0E-01	6.0E-01	6.0E-01	6.3E-01	6.3E-01	6.3E-01	7.1E-01	7.1E-01	7.1E-01	7.1E-01	7.1E-01	7.1E-01							7.5E-01	7.5E-01	7.5E-01	7.7E-01	7.7E-01		

TEZ FOTOKOPİ İZİN FORMU

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Adı : Özge ....
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TEZİN ADI (İngilizce) : Stock Assessment of the Black Sea Anchovy ....
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TEZİN TÜRÜ : Yüksek Lisans ☒ Doktora ☐

1. Tezimin tamamı dünya çapında erişime açılsın ve kaynak gösterilmek şartıyla tezimin bir kısmı veya tamamının fotokopisi alınsın. ☐
2. Tezimin tamamı yalnızca Orta Doğu Teknik Üniversitesi kullancılarının erişimine açılsın. (Bu seçenekle tezinizin fotokopisi ya da elektronik kopyası Kütüphane aracılığı ile ODTÜ dışına dağıtılmayacaktır.) ☐
3. Tezim bir (1) yıl süreyle erişime kapalı olsun. (Bu seçenekle tezinizin fotokopisi ya da elektronik kopyası Kütüphane aracılığı ile ODTÜ dışına dağıtılmayacaktır.) ☒

Yazarın imzası .... Tarih ....