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DYNAMIC PRODUCTION MODEL FOR STOCK ASSESSMENT OF NORWAY LOBSTER (*Nephrops norvegicus* LINNAEUS, 1758) IN ICELANDIC WATERS

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ABSTRACT

Dynamic production model was used to assess the biomass status of Norway lobsters (*Nephrops norvegicus*) in southern Icelandic waters. The analyses were based on data collected from the Marine Research Institute, including both biomass indices from surveys and commercial fisheries data. Twenty five age groups and their proportions were estimated by using length frequency distribution and cohort slicing. The growth parameters of *nephrops* estimated according to von-Bertalanffy equation were: CL_∞ = 82.5 (mm), k = 0.1 (yr^{-1}), t_0 = 0.1 and ϕ'= 3.87. The relationship between CL and weight was $W = 0.55266*L^{3.14433}$. The production model shows average estimated biomass of 23,170 (tons) and fishing mortality (F_{mean}) of 0.33. The maximum sustainable yield of 3,131 tons corresponded to F_{max} = 1.071 and optimum sustainable yield of 2,768 tons with $F_{0.1}$ of 0.357. According to the model, the *nephrops* stock in southern Iceland is under exploited and higher yield can be obtained by increasing fishing mortality. The spiny lobsters fishery in Vietnam was reviewed and revealed a lack of fishery management system and data. The *nephrops* fishery management system requiring fishing license, minimum square mesh size of trawl, quota systems based on TAC and closed areas could be applied to the spiny lobsters fishery in Vietnam for the sustainable development of the fishery. Data collection programmes of commercial catches, catch index, and regular surveys including length composition by sex should be developed to assess spiny lobsters biomass status.

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1 INTRODUCTION

1.1 Background

In recent years, fisheries for crustacean species have increased, primarily due to their high unit value. The FAO statistics in 2011 showed that landings from wild marine crustacean fisheries totalled almost 6 million tons. Approximately equal amount is now farmed and increasing rapidly (FAO 2012). Norway lobster or *nephrops* (*Nephrops norvegicus*) is a high value benthic decapod crustacean species and is a commercially important target in fisheries of many European countries due to its wide distribution (Tuck and Bailey 2000). The global capture production of this species is 66.5 thousand tons (Figure 1) (FAO 2012). They are caught mainly by trawling during their periodic emergence. Because adult males are more active, they dominate in number in total catches. Creel or baited trap is also used to catch *nephrops* (Bennett 1980, Campbell *et al.* 2009).

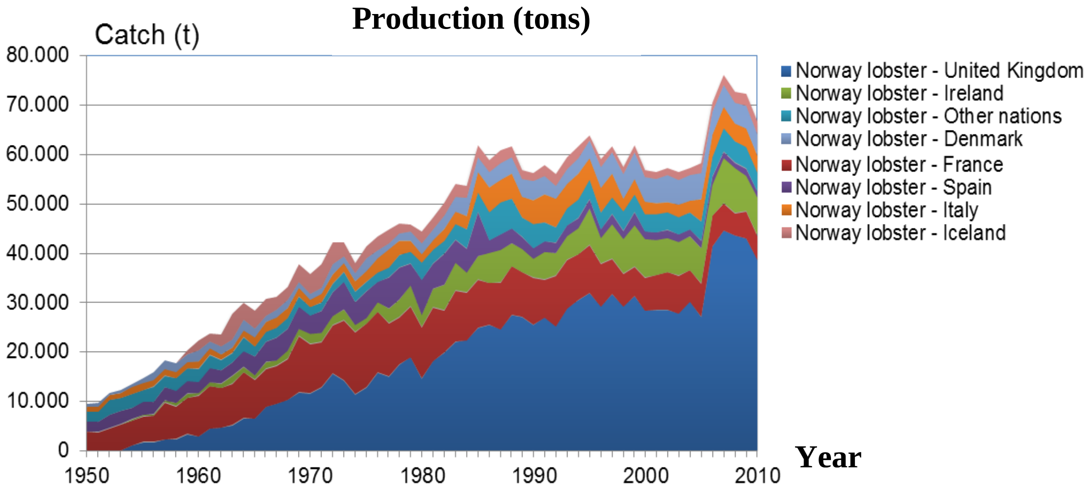

Figure 1: Global catch of *N. norvegicus* by countries (FAO, 2012).

In Icelandic waters, *nephrops* is occurred in the warmer waters off the southern coast, being most abundant at depths of 110-270 m and temperatures of 6-9 °C. This species reaches a relatively large size in Icelandic waters. Fully grown individuals range from 20 to 25 cm for males and around 18 cm for females (measured from eyes to tail). The Norway lobster (Figure 2) fishery in Iceland started in 1939. The main fishing gear is nephrops trawl. In 2011, the total *nephrops* catch was 2,240 tons (Icelandic fisheries 2012).

Figure 2: The Norway lobster (*N. norvegicus*). Large male (81 mm carapace length) and small male (16 mm carapace length).

Many studies on the biological characteristics and fishery of Norway lobster have been conducted in the Atlantic and the Mediterranean (Sarda *et at*. 1998, Chapman *et al*. 2000, Smith and Papadopoulou 2003) and regular assessments of *nephrops* stocks have been carried out for many years and informed a fisheries management policies advice (ICES 2001).

Stock assessment of *nephrops* is done separately for males and females because of different in growth rate and behaviour of the sexes. It can be complicated because of the fact that the species is only caught during the periodic emergence of the individual from them the burrows. The emergence varies with time of day, season, animal size, sex, and reproductive status. Moreover, this species lacks hard structures that can be used for ageing, so the standard age-based methodologies applied in fishery-dependent stock assessment cannot be applied. The population sizes of *nephrops* are mainly assessed using fishery-independent methods such as trawl surveys, annual larval production method, underwater video surveys and analytical assessment methods using length frequency distributions. However, those methods are often difficult to perform and costly (Morello *et al.* 2007, Campbell *et al.* 2009).

Dynamic production models have typically been used in stock assessment of whales, shrimps, lobsters and other species that are difficult to age. Not only because of their simplicity, but also because they provide estimates of management reference points (MSY, BMSY and FMSY) as well as requiring less data for parameter estimation, for example time-series of catches and an index of relative abundance (Fox 1970, Stefansson and Taylor 2012).

1.2 Objective

This study aims to assess the biomass status of Norway lobster (*N. norvegicus*) in southern Icelandic waters with the following objectives to:

- Estimate the length frequency distribution of *N. norvegicus.*
- Estimate the growth parameters of *N. norvegicus.*
- Estimate the yield and spawning stock biomass of *N. norvegicus.*
- Adopt the Norway lobster stock assessment and management system in Iceland to spiny lobster fisheries in Vietnam.

1.3 The study area

Nephrops is most abundant of the Icelandic southern coast, locates from 14°W to 24°W at depth of 100-300 m (Figure 3). Due to the warm Irminger Current, it is divided into south-western and south-eastern areas by the Ingólfshöfði peninsula. These two areas are further subdivided into 10 separate fishing grounds. The south-western fishing area with depth ranging from 130 to 180 m has soft bottom sediment (muddy). The depth in the south-eastern area is 150-250 m in which bottom sediments are mainly silt and clay (10-70%) and minor part is gravel (1%) (Eiriksson 1999).

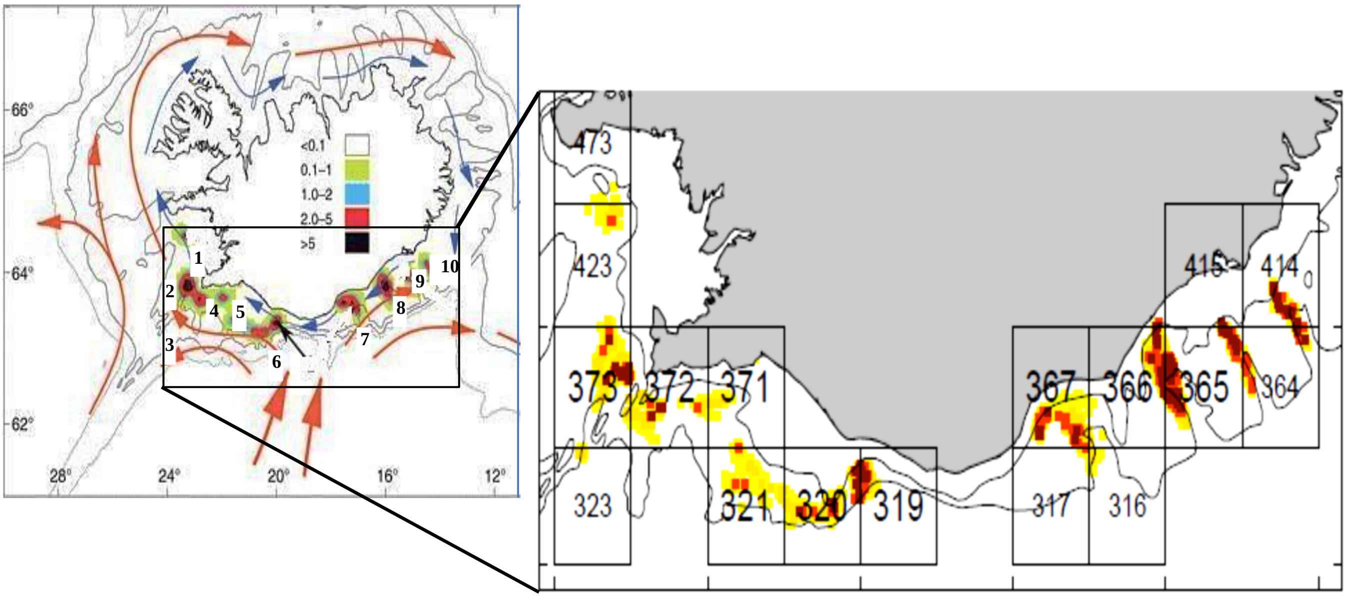

Figure 3: Study area with 10 locations of *N. norvegicus* fishing areas (Modified from Pampoulie *et al.* 2011).

1.4 The biological characteristics of Norway lobster

The Norway lobster is widely distributed in North-eastern Atlantic waters from the coast of Iceland to Morocco and in the Mediterranean Sea (Abello *et al.* 2002, Morello *et al.* 2007). This species has a slender body and longer claws than other lobsters, with colour of pale to reddish orange (Hayward and Ryland 1990). According to Farmer (1975b), *nephrops* occupies burrows on muddy bottoms in which more than 40 % is silt and clay and they can be abundant at the depths of 20 to 800 m.

The growth of this species, as in other crustaceans, is a function of the moulting frequently and the increase in length and weight at each moult. During each period, the old exoskeleton is shed and they grow very quickly before the new exoskeleton hardens (Gramitto 1998). The growth rates of *nephrops* vary widely between stocks population in different areas because of different ecological parameters such as temperature, sediment particle size, food availability, population density, and exploitation rate. Moreover, the size structure and growth parameters of *nephrops* inhabiting smaller subareas can also different within the same biological population (Bell *et al.* 2006).

N. norvegicus is a nocturnal carnivorous species and feeds on fishes, crustaceans, worms, and detritus on the bottom. When finding the food items, they use chelipeds and walking legs to capture an active prey, and for passive items, walking legs are used to close around them. Food is transferred to the mouth using the anterior walking legs and maxillipeds. Stomach contents analyses have shown the *nephrops* to be an unselective feeder that can eat any food items when it is abundant (Thomas and Davidson, 1962).

Nephrops has a complex life cycle with a long-lived adult phase and relatively late onset of maturity. Fertilisation is done by stored sperm from males. The embryos are attached to the females for several months. After one month as larvae and post-larvae in the water column, they eventually settle on the seabed, moult to a juvenile and take up a benthic existence (Farmer 1975a, Wahle and Fogarty 2006).

The male and female *nephrops* reach maturity a carapace length (CL) of approximately 26 mm and 20-23 mm, respectively. After that they moult during the period from May to July, with a peak in May. Mating takes place immediately after the female completes moulting. From August to September, the ovaries mature are fertilised and incubated on the pleopods of females. The following April-June next year the larvae hatch. During the incubation time, the females of *nephrops* are mainly confined to their burrows (Chapman 1980). Temperature affects egg incubation time and survival rate of the *nephrops* larvae. The eggs of *nephrops* are successfully incubated between 11ºC and 14ºC and this temperature was also found to be an optimum temperature for survival rate of larvae (7.7-13.2% in the second zoea[1] stage and 0-7.3% in the first larval instar) (Figueiredo and Vilela, 1972). The eggs of *nephrops* hatch at night and undergo a brief pre-zoea stage before becoming planktonic. In the planktonic stage, the larvae are distributed widely in the water column and most abundant at depths of 20-40 to 80 m during daytime (Bell *et al.* 2006). At metamorphosis stage, the juvenile size is 3-4 mm of CL and moult once or twice before settling on the sea bed. After that, the juvenile grows rapidly, moult ten times attaining a mean length of 14 mm CL after one year. Juveniles inhabit burrows in a similar area as the adults and rarely emerge from their burrows during their first year, until they have reached a size of 10-15 mm CL (Farmer, 1973).

1.5 The fishery of Norway lobster

Nephrops were mainly landed as by-catch of trawl and seine fisheries until they became a target of substantial commercial fisheries the late 1950s (Bell *et al.* 2006). The types of gear vary depending on region and habitat. In most European countries, this species is caught by trawls and baited traps in specifically targeted or mixed fisheries with other fish like cod, haddock and monkfish. The traditional trawls used to catch *nephrops* have a low headline, short wings and large rubber discs threaded onto the footrope. In the Mediterranean Sea, three different types of otter trawls are used to catch *nephrops*, in Spain (western areas), Italy (central areas) and Greece (eastern areas). They differ in size and structure of net, included proportions and width of mouth opening, size of otter doors reflecting local conditions and vessel types (Sarda 1998).

Due to a high impact of trawl fisheries on seabed communities and also unsuitable construction of seabed for trawling, in some areas in Faeroe Islands waters and at the west coast of Scotland, creel or baited traps are used there (Bell *et al.* 2006). Moreover, in some areas like the northern Aegean and Adriatic Sea, traps and trammel nets are also used to catch *nephrops* by small-scale fishermen where trawling is prohibited (Maynou *et al*. 2003).

Length and sex composition of catches vary diurnally and seasonally, large individuals with carapace length of more than 52 mm are proportionally higher in catches during daytime compared to nighttime. After reaching sexual maturity, the males grow faster and moult more frequently than the females, and are a higher proportion of the catches. Therefore, the sex ratio in the catches is unrepresentative of the sex composition in the population. In fact, the proportion of females may be higher than males because of the lower rate of exploitation (Chapman 1980).

The natural mortality of *nephrops* can be caused by predation, parasites and diseases and density-dependent factors and vary from year to year. Natural mortality rate of *nephrops* is influenced by predators. Cod (*Gadus morhua*) is generally identified as the most important predator (Bell *et al.* 2006). According to Farmer (1975b), other predators of *nephrops*

[1] The planktonic larval of decapod crustaceans

include giant squid (*Architeuthis sp*.), anglerfish (*Lophius spp*.), various elasmobranchs, hake (*Merluccius merluccius*), weevers (*Trachinus spp*.), gurnards (*Trigla spp*.), scorpion-fish (*Scorpaena spp*.) (Gauss-Garady 1912 as cited by Farmer 1975b).

For the purposes of stocks assessment, the natural mortality is considered to be a constant and is estimated based on a relationship between growth parameters and environmental temperature (Pauly 1984). According to Maynou *et al.* (2003), the natural mortality of *nephrops* in Mediterranean Sea ranged from 0.25 to 0.82 (22-56%) for females and from 0.25 to 0.65 (22-52%) for males.

The catchability of *nephrops* is strongly influenced by its behaviour and the on type of fishing gears used. The catchability of *nephrops* trawling depends on their availability on the seabed, which depends on pattern of burrow emergence. For the creel or baited trap fishery, the catchability is related to bait attraction as feeding patterns and agonistic behaviour. These factors vary considerably over time with sex and individual size therefore, show different seasonal patterns in exploited population of *nephrops* (Bell *et al.* 2006).

1.6 Management of the Norway lobster fishery in Iceland

The *nephrops* fishery in Icelandic waters started in 1939 and *nephrops* trawl was used. Studies on the status of *nephrops* stocks were first initiated in 1959, sampling of catches for length compositions by sex. After 1960, catch and effort data have been monitored by fleet logbooks and surveys have been conducted annually from 1960 and onwards (Sigurdsson 1965 as cited by Eiriksson 1999).

The fishing activity in sub-areas and in the whole fishing area has been regulated based on the relationship between the average effort and the CPUE based on the Gulland-Schaefer model (Eiriksson 1992).

In 1976, Cohort/VP-analysis was first used based on length frequency distribution of male animals in two fishing areas in the Southeast (Eldey or spot 373) and in the Southwest (Breiðamerkudjúp or spot 365 and 366), where information on growth was used to split the stock up into age-groups for the years 1962-1975 (Eiriksson 1979). Since 1978, the VP-analysis has been performed on the total male stock, but males are the majority of the landed catch. In later years VP-analysis has also been performed and in some years separately for the southwest and southeast areas as the development of the stock components and recruitment has been different (Eiriksson 1999).

2 METHODOLOGY

2.1 Data collection

The dynamic production model used in this study is a statistical model with input data collected from the Marine Research Institute database including both biomass indices from survey and commercial fisheries data.

The data covers routine samples from landings and land based samples from commercial fleet. In the standard survey, the research vessel is rigged with a conventional lobster-trawl of 45m headline and mesh size 80 mm (headline length 150 feet). Two 200 mm window-panels are on the upper deck of the trawl, the one towards the opening is 3x4 m and the other 2x2 m located 2 m behind that. As the research trawl has the same design as commercial ones all tows from the research vessels are usable as catch-samples for estimation of stock-size. Tow-speed is kept around 2.5 nm and tow-length is usually 5 nm but a minimum of one hour is towed to be valid.

The research areas cover all *nephrops* fishing grounds from Jökuldjúp in the West to Lóndsjúp in the East. The environmental parameters such as sea condition, bottom and surface temperature and secchi depth are recorded for each station. On each station the total catch of *nephrops* is recorded (numbers and weight) and number of by-catch species. From the catch, one basket (approximately 20 kg or 200-300 *nephrops*) is taken aside for length measurements. Each *nephrops*, carapace length is recorded, it is sexed and females assigned to maturity stage and noted if the lobster has recently molted its shell. The same parameters and numbers are measured from the commercial catches. In recent years in total 200 samples of about 20 kg have been processed or roughly 1 sample for each 10 tons landed. Logbooks are mandatory in the fishery where information on catch, effort (towed hours) and locations are also given.

The landings in tons of *nephrops* from Icelandic waters were collected from 1970 to 2011, while the length, weight data came from 2011 to calculate length-weight relationship. These data were analysed by models in the R software package according to Stefansson (2012).

The CL of *nephrops* was measured as a distance between the back of the eye socket to the rear edge of body carapace (Robertson and Shanks 1989). In length distributions and cohort slicing analysis, the data were used to compute for only males. The total length was calculated based on the relationship equation with CL and then the asymptotic length (L_∞) was estimated based on total length (Sarda *et al.* 1998).

2.2 Data analyses

2.2.1 Length frequency analysis and cohort slicing

The length-frequency distributions were plotted by year and analysed as a combination of cohort length distributions, each of which is assumed to be in the form of a Gaussian distribution (Stefansson and Taylor 2012). The density function of the Gaussian distribution with mean μ and variance σ^2 is given by:

$$F(x) = \int_{-\infty}^{x} \emptyset\,(t)dt = \emptyset\left(\frac{x-\mu}{\sigma}\right)$$

and the cumulative distribution is: $f(x) = \frac{1}{\sqrt{2\pi\sigma}} e^{-(x-\mu)^2/(\sigma^2)}$

Take a fixed age group of *nephrops* and assume that they are distributed along the length axis according to Gaussian density, with a mean length (μ_a) and standard deviation of length at age (σ_a). For this age group the proportion of *nephrops* within length category *l* is:

$$\emptyset\left(\frac{\left(l+\frac{1}{2}\right)-\mu_\alpha}{\sigma_\alpha}\right) - \emptyset\left(\frac{\left(l-\frac{1}{2}\right)-\mu_\alpha}{\sigma_\alpha}\right)$$

Suppose the true proportion of *nephrops* in age group a is π_a, then the proportion of this species in length group ***l***, across all ages in the length distribution is:

$$\sum_{\boldsymbol{\alpha}} \boldsymbol{\pi_\alpha} \left\{\emptyset\left(\frac{\left(l+\frac{1}{2}\right)-\mu_\alpha}{\sigma_\alpha}\right) - \emptyset\left(\frac{\left(l-\frac{1}{2}\right)-\mu_\alpha}{\sigma_\alpha}\right)\right\}$$

From these equations, the proportions in each age group (π_a), the mean length at age and the mean length at age (μ_a) were estimated and the standard deviation (σ_a). In the length-frequency plotted, the mean lengths at age were estimated and a guess was made for a fixed standard deviation corresponding to the mean lengths (Nguyen 2007).

In order to estimate the rest of mean length at ages, the data was combined into a single estimation process. In this case, the predicted proportional length distribution is given by:

$$\widehat{yl} = \sum_{\boldsymbol{\alpha}} \boldsymbol{\pi_\alpha} \left\{ \emptyset\left(\frac{\left(l + \frac{1}{2}\right) - \mu_\alpha}{\sigma_\alpha}\right) - \emptyset\left(\frac{\left(l - \frac{1}{2}\right) - \mu_\alpha}{\sigma_\alpha}\right) \right\}$$

In which, a criterion is needed to estimate the set of unknown parameters: π_a, μ_a, σ_a. A formal statistical approach would be to estimate the unknown parameters by minimising the discrepancy between the observed and theoretical values.

The sums of squares of the observed proportion at length are calculated:

$$\sum \left(yl - \widehat{yl}\right)^2$$

where yl is the measured (observed) proportion and $\widehat{yl}$ is the modelled proportion given above.

The mean length at age of each cohort and the standard deviations have been estimated, then the average growth rate can be modelled. The von-Bertalanffy (VB) growth equation was applied to the estimated mean length-at-age and the standard deviation data according to the equation:

$$L_t = L_\infty\left(1 - e^{-k(t-to)}\right)$$

where L_t is the average length-at-age t, L_∞ is the asymptotic length, k is the growth rate parameter and t_0 is hypothetical age at length equal to 0. The VB growth model assumes that growth is faster when the species is young and get slow onwards after they mature. In order to run this equation in R, some initial values as L_∞, k and t_0 were set and the least sums of squared error (SSE) was minimised using an iterative process (Stefansson & Taylor 2012). The parameter t_0 was fixed at 0.1 as the first two age groups are completely missing from the data series and t_0 was always estimated really low.

To compare the estimated growth parameters of *nephrops* in this study with other studies, the growth performance index ($\emptyset'$) were used which calculated according to equation:

$$\emptyset' = \log_{10} k + 2 * \log_{10} L_\infty$$

where k is the growth rate parameter and L_∞ is the asymptotic length.

2.2.2 Length weight relationship

The relationship between length and weight of this species is expressed as equation:

$$W = a * L^b$$

where W is the weight in grams, L is the carapace length in mm, and a, b are growth parameters. This equation is log-transformed as:

$$ln(W) = ln(a) + b * ln(L)$$

and a simple linear regression was applied to get the a (intercept) and b (slope) values (Mamie, 2008).

2.2.3 Dynamic production model

Dynamic production or surplus production models are used as a long tradition in stock assessment of finfish, shellfish and crustaceans, in which biomass are modelled as function corresponding to recruitment, growth and natural mortality parameters. The model estimates a number of reference points such as: maximum sustainable yield (MSY), fishing mortality regarded MSY (F_{MSY}), biomass at MSY (B_{MSY}) as well as the unexploited biomass (Oh *et al.*, 1999).

- The stock size

The stock size of *nephrops* for each year was estimated based on the number model:

$$N_{y+1} = N_y + R_y - C_y$$

where R_y represents the recruitment in year y, N_y is the number of *nephrops* that survive and C_y is the catch in the same year. The biomass is then calculated:

$$B_y = \sum \left(N_{ay} * w_a\right)$$

As a result of mortality, the plus group is reduced each year, but also a new age group enters the plus group and this is represented by equation:

$$N_{A+1,y+1} = \left(N_{A,y} + N_{A+1,y}\right)e^{-Z_A}$$

- Recruitment

The spawning stock per recruit in the *nephrops* fishery is estimated by using the Beverton-Holt equation:

$$R = \frac{\alpha s}{\left(1+\frac{s}{k}\right)}$$

where R is recruitment, S is spawning stock biomass, α is coefficient used as a multiplier for prospective recruitment and K is size of the spawning stock that produces half maximum recruitment.

- Natural mortality

Natural mortality (M) is one of the input parameters needed to estimate the model and was estimated from the empirical equation of Pauly (1984):

$$\log M = -0.0066 - 0.279 * \log L_\infty + 0.6543 * \log k + 0.4634 * \log T$$

where L_∞ (cm) and k (yr^{-1}) are the VB growth parameters and T is the mean of environmental temperature (^{o}C) (Pauly D. , 1984).

- Fitting the model

The model is fitted by using initial input parameters and then the sums of squares between each data set were computed corresponding fitted values. When this model was used for estimating fishing mortality, the catches and survey indices were typically predicted from proportionality with the biomass. Coefficients of variation (CV) for different parameters are used as weighting factors (weight) assigned to the sums of squares, which are then minimised in order to estimate the parameters in the model. Assuming that all terms are log transformed data. Each term is then of the form: $\lambda \sum_t \left(ln(x_t) - ln(\hat{x}_t)\right)^2$

Where x_t's are annual landings, catch index (CPUE), recruitment factor, fishing mortality and λ is the weighting factor. Statistically, the λ is corrected as inverse of the variance:

$$\lambda = \frac{1}{\sigma^2_{ln(x_t)}}$$

In the case of a low dispersion, the standard deviations of the log-transformed quantities are similar the CVs of the original numbers. Thus CV(x) is used as $\sigma_{ln(x_t)}$.

The CV for catch (CV_Y) was assumed to equal 0.2 due to the catch data are quite precise and the CV_Y is assumed that 95% of annual catch estimates lie within 20% (two standard deviations) of their true values. Moreover, the CV of biomass index (CV_I) was set 0.4, the CV of fishing mortality (CV_F) was 0.3 and CV of recruitment (CV_R) was 0.4.

The initial sums of squares of errors for catch (SSEY), biomass index (SSEI), fishing mortality (SSEF) and recruitment (SSER) were used to predict an output of the model. The SSEY was 0.22, SSEI = 1.05, SSEF = 0.65 and SSER = 0.1.

During the iteration process, these values were allowed to deviate freely until better CVs were obtained to fit the model. The model is evaluated by comparing the model output to the data using the sums of squares between each data set and the correspondent fitted values.

2.2.4 Yield per recruit and spawner stock per recruit

Recruitment is simply defined as the number of *nephrops* in the youngest age group of interest. Usually this is the age group corresponding to the youngest *nephrops* in the catch. The spawning stock should correspond to the *nephrops* that reach spawning age and thus contribute to spawn. This quantity is usually measured in terms of biomass (Mamie 2008).

The estimation of yield potential from a stock is done in two stages by first estimating the number of recruits and then calculating the yield per recruit, which depends on the size (age) at recruitment and the fishing mortality. These calculations are used to estimate how much of a particular year class could be caught for sustainable utilisation.

The catch in numbers of stocks at age a according to Stefansson (2012) is given by:

$$C_a = \frac{F_a}{Z_a}(1 - e^{-Z_a})e^{-\sum_{d<a} Z_d}$$

where C_a is catch at age, F_a is fishing mortality, Z_a is total mortality and R is recruitment and the catch in weight is calculated by:

$$Y_a = \frac{F_a}{Z_a}(1 - e^{-Z_a})w_a * e^{-\sum_{d<a} Z_d} * R$$

Then total yield of the year-class then sums up to:

$$Y = \sum_a Y_a = \frac{F_a}{Z_a}(1 - e^{-Z_a})w_a * e^{-\sum_{d<a} Z_d} * R$$

This gives a yield per recruit as:

$$\frac{Y}{R} = \sum \frac{F_a}{Z_a}(1 - e^{-Z_a})w_a * e^{-\sum_{d<a} Z_d}$$

Yield per recruit and spawning stock per recruit were estimated for different fishing mortalities (F) ranging from 0 to 2 to find different value of F. A yield per recruit curve was plotted with fishing mortality F_{max}, which corresponds to maximum yield per recruit. The F at value of 0.1 ($F_{0.1}$) to indicate the yield obtaining lower than the maximum yield per recruit and will result in economic optimisation of the fisheries and prevent recruitment overfishing (Gulland, 1983 as cited by Mamie, 2008). The assumption in the yield per recruit model is that recruitment is constant, and the age structure of the population is the same as if a single cohort is followed through time. Therefore, the estimate yield is calculated by multiplying the different fishing mortalities with the assumed virgin stock to give an estimate of yield.

3 RESULTS

3.1 Length frequency distributions

3.1.1 Length frequency distributions at different years

The carapace length (CL) frequency distribution of *nephrops* from 1970 to 2011 had several peaks corresponding to 25 age groups (Figure 4). The mean CL of *nephrops* at age estimated was ranged from 7.22 mm at age 1 to 76.08 mm at age 25 (Table 1).

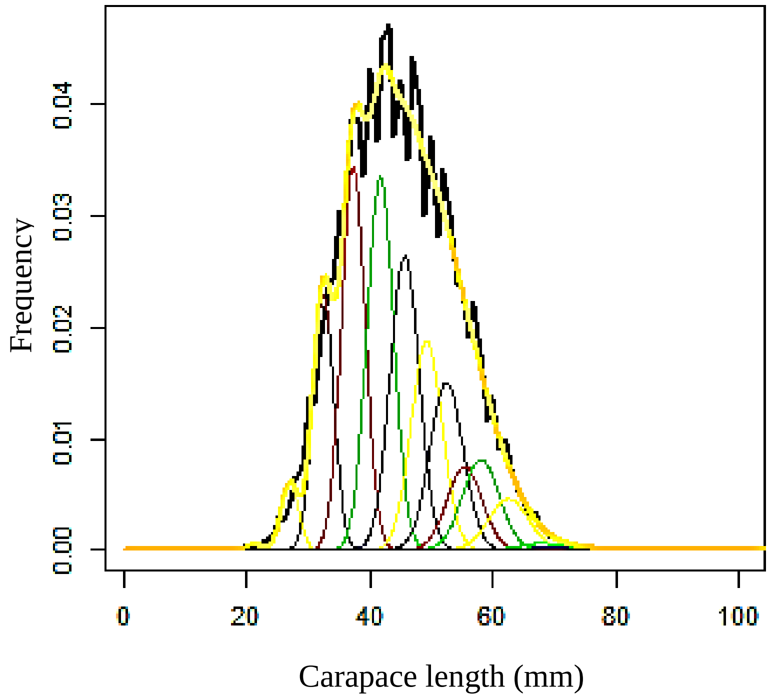

Figure 4: The carapace length distribution of *N. norvegicus* in catches from 1970 to 2011 and estimated distribution by the model

The growth rate of *nephrops* was high in the first four years with mean increment of about 7.0 mm per year. After this age, they reached a maturity size therefore, the growth rate gradually decreased. The proportions corresponding to relative ages revealed a difference between decades. In the period 1970-1979, the age groups of 5 to 9 year olds were in high abundant as the mean CL ranged 32.41-49.19 mm. The age groups of 5 to 10 year olds of *nephrops* showed a dominant proportion in the catches in the periods from 1980-1989 corresponding to mean CL of 32.41-52.42 mm. On the other hand, in recent years (1990-2009) and the whole data from 1970 to 2011, the landings showed high abundant of age groups from 6 to 10 year olds or mean CL of 37.26-52.42 mm. For the other groups, the age proportions were small (Table 1).

Table 1: Mean carapace length (CL, mm), age proportion and standard deviation of *N. norvegicus* in catches from 1970 to 2011.

Age	Mean CL (mm)	Proportion (%) 1970-1979	1980-1989	1990-1999	2000-2009	1970-2011	Standard deviation
1	7.22	3.904e-04	4.026e-04	9.454e-05	3.805e-06	1.471e-04	0.37146
2	14.51	6.690e-04	7.699e-04	1.606e-04	1.172e-04	2.719e-04	0.74646
3	21.09	0.00333	0.00135	6.967e-04	4.670e-04	0.00155	1.08544
4	27.03	0.04052	0.02019	0.02611	0.00776	0.02083	1.39185
5	*32.41*	*0.12999*	*0.10445*	*0.09711*	*0.06046*	*0.09547*	1.66882
6	*37.26*	*0.23606*	*0.14914*	*0.20350*	*0.12269*	*0.16539*	1.91919
7	*41.64*	*0.15564*	*0.21745*	*0.19869*	*0.15398*	*0.18045*	2.14551
8	*45.61*	*0.16582*	*0.16544*	*0.14899*	*0.17378*	*0.15539*	2.35008
9	*49.19*	*0.10511*	*0.11656*	*0.11814*	*0.11922*	*0.11871*	2.35008
10	*52.42*	*0.04347*	*0.12218*	*0.10038*	*0.13062*	*0.10176*	2.70215
11	55.34	0.06881	0.04140	0.06161	0.06519	0.05339	2.85326
12	57.98	0.02776	0.03125	0.03545	0.08298	0.06087	2.98984
13	60.36	6.564e-07	0.01685	1.367e-06	3.115e-06	8.279e-08	3.11330
14	62.52	0.01122	4.244e-07	0.02809	0.05616	0.03708	3.22490
15	64.46	0.00688	0.00959	2.685e-07	0.02014	1.075e-04	3.32578
16	66.22	5.898e-07	3.531e-07	4.401e-07	2.007e-06	9.292e-07	3.41697
17	67.81	2.331e-07	8.992e-08	7.086e-10	6.164e-06	0.00543	3.49939
18	69.25	5.413e-04	5.351e-08	4.058e-07	6.843e-04	0.00211	3.57391
19	70.54	9.469e-04	7.151e-08	1.810e-07	0.00549	2.967e-07	3.64126
20	71.71	3.102e-06	3.660e-08	9.089e-05	2.262e-04	3.539e-07	3.70214
21	72.77	3.665e-07	1.911e-08	2.404e-04	3.802e-06	2.488e-07	3.75713
22	73.73	3.959e-07	8.855e-08	1.732e-04	2.856e-06	7.566e-07	3.80691
23	74.59	6.670e-08	1.921e-07	3.134e-05	1.450e-06	1.331e-07	3.85189
24	75.37	9.341e-08	3.232e-07	5.930e-06	1.744e-06	1.397e-06	3.89253
25	76.08	0.00285	0.00296	4.472e-04	1.065e-06	0.00103	3.92928

In general, the mean CL of *nephrops* in catches increased from 1970 to 2011 (Figure 5). The *nephrops's* mean CL caught in 1970 was 45.10 mm and presented a fluctuation onwards with minimum value of 42.60 mm in 1973. Until 1995, the mean CL of *nephrops* increased rapidly and reached a peak of 49.66 mm in 2010.

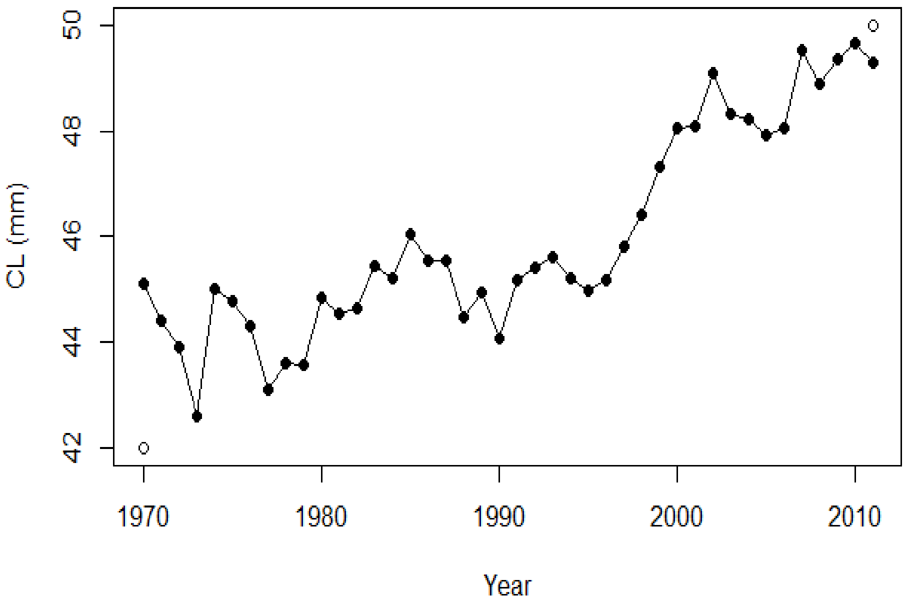

Figure 5: The mean carapace length of *N. norvegicus* in catches from 1970 to 2011.

3.1.2 Length frequency distributions at different fishing areas

The CL frequency distributions of *nephrops* were compared for the Southeast (SE) and Southwest (SW) fishing grounds (Figure 6). The plotted of CL frequency distributions were similar, but in the SW areas, the distribution was wider than in the SE areas, which revealed a difference in the proportion of age groups (Table 2).

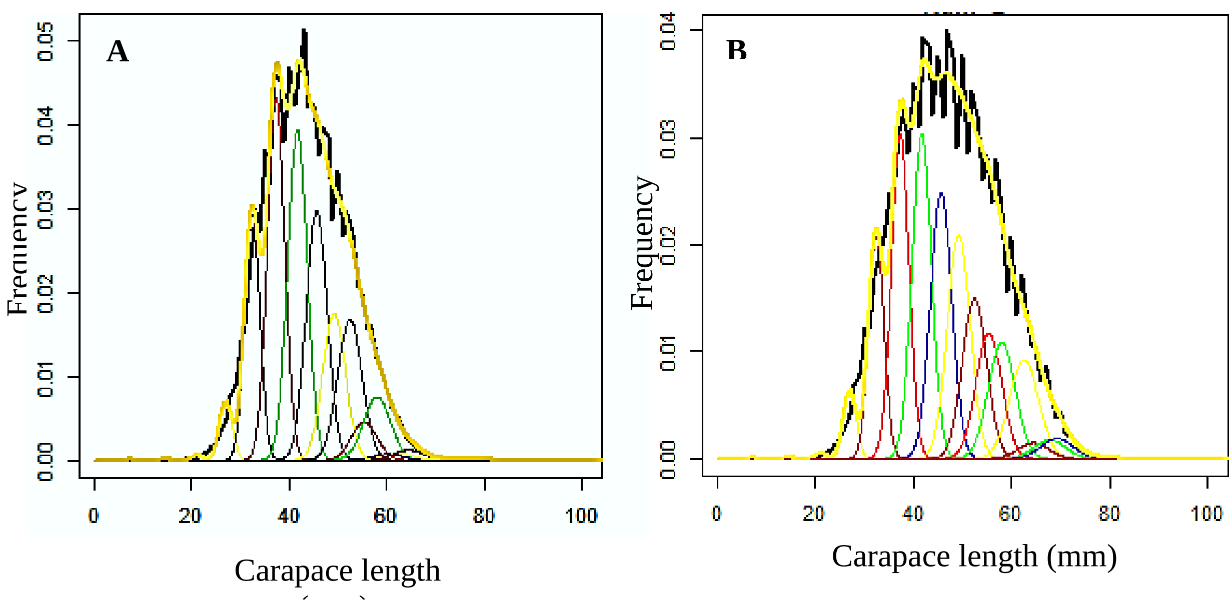

Figure 6: The carapace length distributions of *N. norvegicus* in catches from 1970 to 2011 at different fishing areas and estimated distribution by the model. A: Southeast area (SE) and B: the Southwest area (SW).

Table 2: Age proportion of *N. norvegicus* in catches at different fishing areas from 1970 to 2010.

Age	Proportion (%)	
	SE area	SW area
1	2.106e-04	2.023e-04
2	3.733e-04	3.489e-04
3	0.00159	0.00144
4	0.02245	0.02029
5	0.11301	0.08017
6	0.19184	0.13409
7	0.19557	0.15062
8	0.16140	0.13479
9	0.10207	0.12198
10	0.10534	0.09338
11	0.02944	0.07735
12	0.05462	0.07474
13	5.323e-07	3.542e-07
14	0.01436	0.06853
15	0.00406	0.01124
16	4.538e-04	2.992e-05
17	7.999e-04	0.01403
18	8.431e-04	0.01562
19	6.784e-06	5.318e-08
20	3.183e-07	3.339e-07
21	1.625e-07	2.269e-07
22	1.087e-07	4.741e-07
23	4.469e-07	1.386e-09
24	1.988e-07	7.967e-06
25	0.00155	0.00142

In the SE fishing areas, age groups with the highest proportions ranged between 5 and 10 corresponding to mean CL of 32.41-52.42 mm, while the proportion of age groups 5 to 12 with mean CL ranged from 32.441 to 57.98 mm were most abundant in the SW areas.

The mean CL of *nephrops* caught in the SE areas fluctuated but did not show any consistent trend, the mean was 44.84 mm from 1970 to 2011 (Figure 7). Meanwhile, in the SW areas, the mean CL of *nephrops* revealed an increase from a minimum value of 40.27 mm in 1970 to maximum value of 61.42 mm in 2003 and the mean was 47.94 which is significantly higher when compared to SE areas ($p<0.01$).

3.1.3 The von-Bertalanfy growth parameters

The mean CL at ages of *nephrops* obtained from the length frequency distribution and cohort slicing analysis were then fitted to the von Bertalanffy growth curve model to calculate the growth parameters (Figure 8). The growth parameters were: CL_{∞} = 82.5 (mm), k = 0.1 (yr^{-1}), t_0 = 0.1 and the growth performance index (ϕ') were 3.87.

3.2 Length-weight relationship

The CL-weight relationship of *N. norvegicus* was calculated based on length, weight data from 2011 and is presented below (Figure 9). The equation of relationship between CL and weight of *nephrops* is given as $W = 0.55266*L^{3.14433}$, in which a coefficient was a = 0.55266 and b = 3.14433.

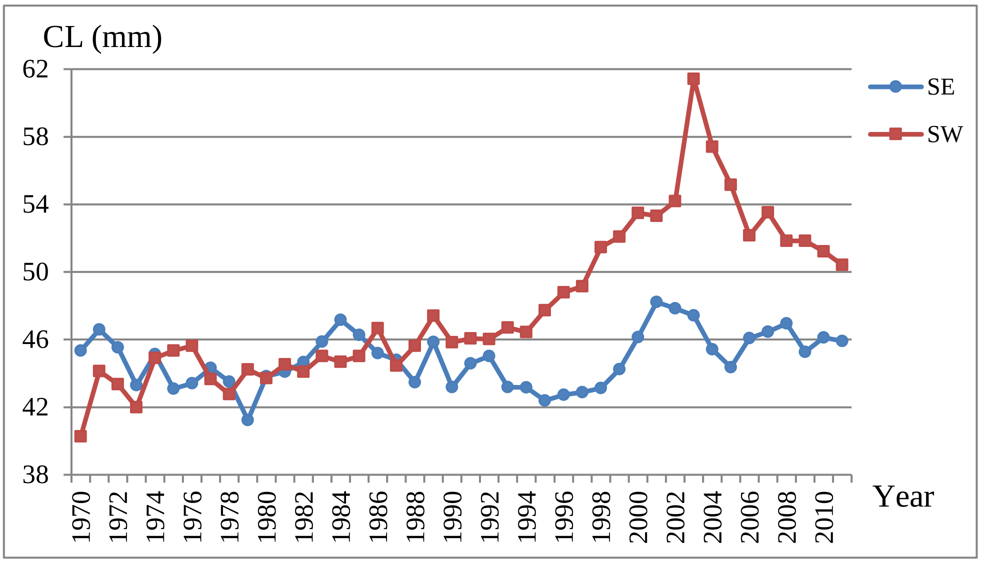

Figure 7: The mean carapace length of *N. norvegicus* in catches at different fishing areas from 1970 to 2011.

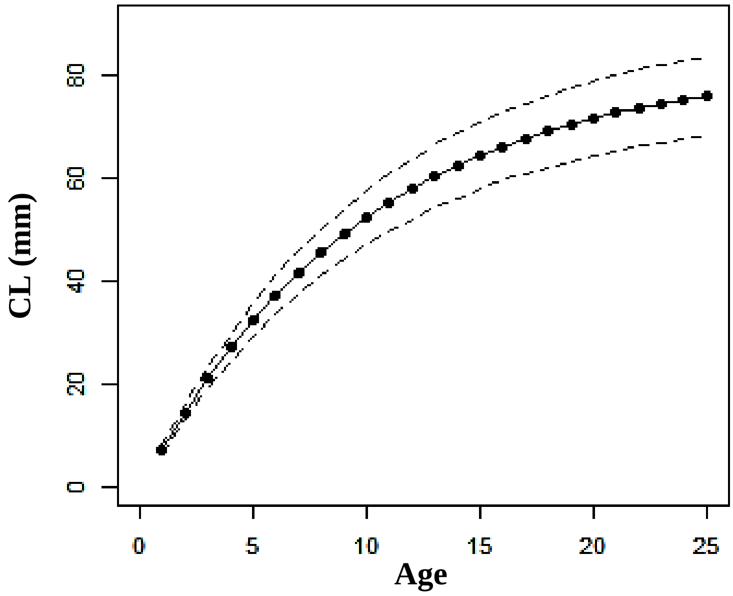

Figure 8: von-Bertalanfy growth curve of *N. norvegicus* at different ages in catches from 1970 to 2011. Broken lines show standard deviation.

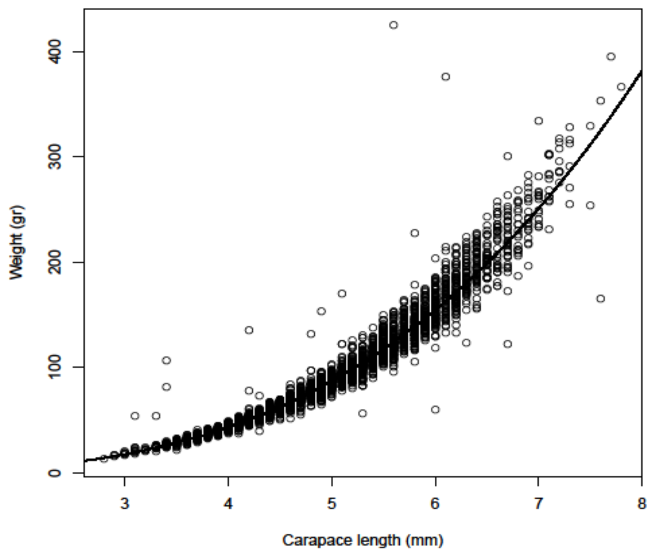

Figure 9: The carapace length-weight relationship of *N. norvegicus*

3.3 The dynamic production model

The outputs of dynamic biomass model are shown in Figure 10. In general, the yield and fishing mortality decreased from 1970 to 2010. Inversely, the catch index, recruitment and biomass increased during this period.

The yield of *nephrops* had a maximum value in 1970 with 4,336 tons and then decreased substantially and fluctuated highly with minimum value (1,302 tons) in 2000. After that it gradually increased to 2,577 in 2010 (Figure 10A). Meanwhile, the catch index (CPUE) and estimated biomass showed the same trend (Figure 10B and 10E). The catch index and estimated biomass of *nephrops* was 40.2 (kg/hour) and 24,740 (tons), respectively, in 1974. After that, they fluctuated and reached a maximum value of 112.7 (kg/hour) for catch index in 2008 and 43,048 (tons) for the estimated biomass in 2010.

The fishing mortality increased from 1970 to maximum value of 0.66 in 1976 and then declined to the minimum value of 0.19 in 2010 (Figure 10D). Inversely, the recruitment of *nephrops* was 161.5 million in 1970 and gradually declined to a minimum value (92.2 millions) in 1990. A rapid increase onward was presented after this year and reached a maximum value (284.6 millions) in 2006 (Figure 10C).

3.4 Yield per recruit and spawner stock per recruit models

The yield per recruit and spawner stock per recruit model of *nephrops* is shown in Figure 11. The estimate of average recruitment of *nephrops* from dynamic production model was 165.4 million individuals, which were assumed as an initial stock. Then, the yield and spawner stock biomass was calculated at different fishing mortalities based on the model and showed in Table 3. The yield increased from 2,218 tons at F = 0.2 to 3,067 tons at F = 2.0. Whereas, the spawner stock biomass decreased from 3,172 tons at F = 0 (no fishing) to 830 tons at F = 2.0.

The maximum yield of *nephrops* was also calculated to be 3,131 tons corresponded to F_{max} = 1.071 and the $F_{0.1}$ was 0.357 with 2,768 tons.

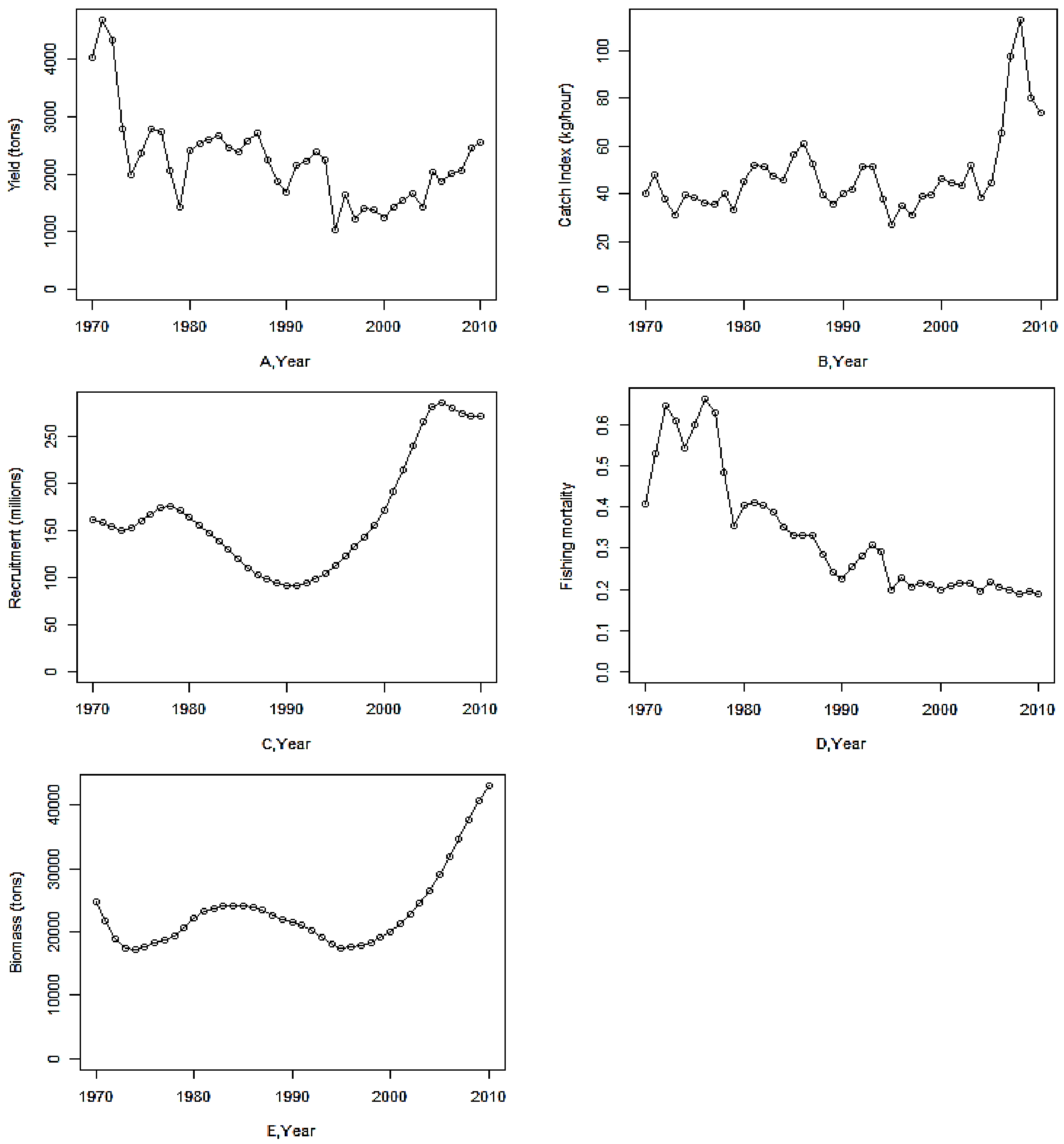

Figure 10: The dynamic production model of *N. norvegicus* output from 1970 to 2010. A and B present the annual catch and biomass index; C, D and E show the prediction of recruitment, fishing mortality and biomass.

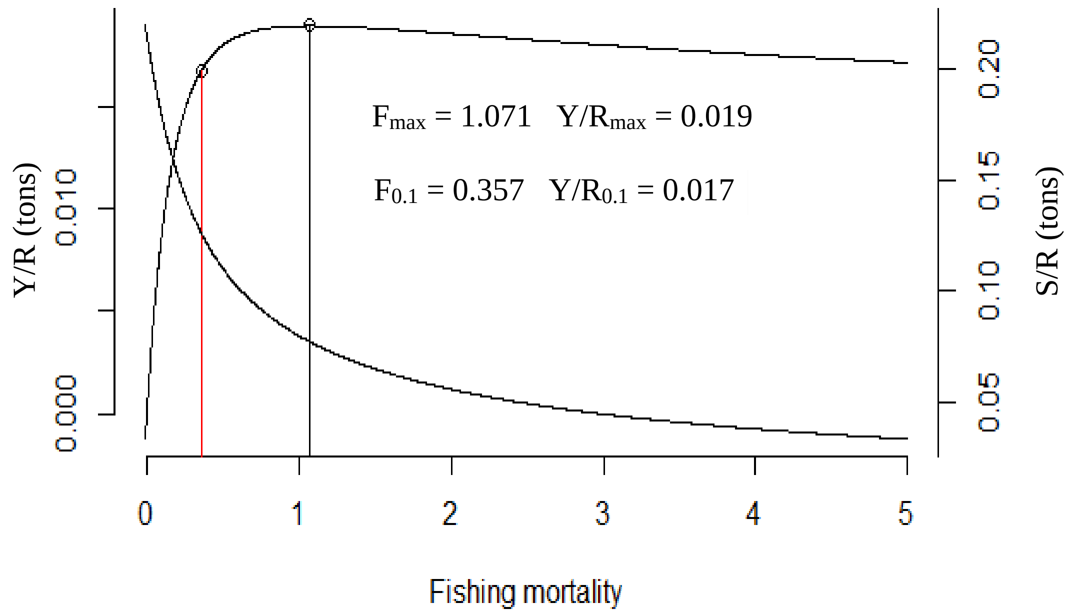

Figure 11: The yield per recruit and spawner stock per recruit models of *N. norvegicus* at different fishing mortality. Dark line presents a F_{max} and red line is a $F_{0.1}$

Table 3: Yield and spawner stock biomass estimated from the models for different fishing mortalities of *N. norvegicus.*

Fishing mortality	Yield (tons)	Spawner stock biomass (tons)
0	0	3,172
0.2	2,218	2,261
0.4	2,849	1,787
0.6	3,046	1,505
0.8	3,112	1,319
1.0	3,130	1,184
1.2	3,128	1,082
1.4	3,118	1,000
1.6	3,103	934
1.8	3,085	878
2.0	3,067	830

4 DISCUSSION

4.1 Growth and biomass parameters

Nephrops caught in Southern Icelandic waters had a CL_∞ of 82.5 mm. That is fairly similar when compared with previous studies in different fishing areas although using different methods. The CL_∞ of *nephrops* in the Catalan Sea ranged from 84.4 to 96.6 mm (Mytilineou and Sarda 1995) (Table 4). Meanwhile, the asymptotic length (L_∞) calculated based on the relationship equation between CL and total length (Sarda *et al.* 1998) in this study was 300 mm which is higher than L_∞ of 226 mm in Ancona Sea as observing by Froglia and Gramitto (1987).

The growth rate parameter (k) of *nephrops* obtained in this study (0.1 yr^{-1}) is higher than those stated by Mytilineou and Sarda (1995) in Catalan Sea (0.05-0.08 yr^{-1}) but consistent with value of 0.11 in Ancona Sea (Marano *et al.* 1998) (Table 4).

On the other hand, the growth performance index (ϕ') calculated 3.87 in this study is higher than reported by Mytilineou and Sarda (1995) in Catalan Sea (2.6 – 2.8) but lower than values of 6.33 – 6.64 in Ancona Sea (Marano *et al.* 1998). The values of k and ϕ' (0.1 yr^{-1} and 3.87) obtained in this study are in good agreement with observation before in Iceland (0.1 yr^{-1} and 2.81, respectively) (Eiriksson 1982a). These results are contrary to Pauly (1984), who stated that growth performance index would be constant. However, it is consistent with other studies on *nephrops* that show that the growth rate can vary considerably due to environmental forces such as temperature, sediment particle size, food availability, population density and fishing pressure, each of which may have different and possibly interactive effects (Bell *at al.* 2006).

Table 4: von-Bertalanfly growth parameters of *N. norvegicus* from different areas estimated by different methods.

Areas	CL_∞ (mm)	k (yr^{-1})	t_0	ϕ'	Method/references
Catalan Sea	84.4	0.07	2.52	2.70	Captivity/Sarda, 1985 cited by (Mytilineou & Sardá, Age and growth of Nephrops norvegicus in the Catalan Sea, using length-frequency analysis, 1995)
Catalan Sea	87.0	0.08	- 1.27	2.80	VB-ELEFAN/ (Mytilineou & Sarda, 1995)
Catalan Sea	90.0	0.05	- 3.75	2.60	SOVB-ELEFAN/ (Mytilineou & Sardá, Age and growth of Nephrops norvegicus in the Catalan Sea, using length-frequency analysis, 1995)
Catalan Sea	96.6	0.06	- 2.90	2.80	FISHPARM/ (Mytilineou & Sardá, Age and growth of Nephrops norvegicus in the Catalan Sea, using length-frequency analysis, 1995)
Ancona Sea	-	0.11	- 1.24	6.64	FISHPARM/Marano *et al.*, 1998
Ancona Sea	-	0.11	- 1.18	6.33	Gauss-Newton/Marano *et al.*, 1998
Iceland	-	0.10	-	2.81	Eiriksson, 1982
South Iceland	82.5	0.10	0.1	3.87	VB-Cohort slicing/this study

The mean CL of *nephrops* caught in SW areas (48.35 mm) was significantly higher than ones caught in SE areas (45.15 mm) from 1970 to 2011 (Figure 7). This may be caused by different type of bottom structure in their habitat. This is in good agreement with observation by Tuck *et al.* (1997), who stated that local variations in size composition, density and growth of *nephrops* might be related to type of bottom sediment. According to Tuck *et al.* (1997), the mean CL size of *nephrops* was positively correlated with increasing clay/silt content from 30 – 90% in the Firth of Forth and showed an inverse relationship in the Irish Sea with bottom sediment ranges between 4 – 49% of clay/silt. Eiriksson (1999) found that, the fishing areas bottom of *nephrops* in the southern Icelandic waters consist of higher clay/silt of 70% contents of bottom sediments. This is consistent with the bottom sediments as muddy in the SW fishing area in this study.

Moreover, the variation in mean CL of *nephrops* is also negatively correlated with depth (Eiriksson 1999). In the SW areas, the depth ranged from 130 – 180 m and it could explain the higher average CL than found in the SE areas with depth of 180 – 250 m.

The natural mortality (M) used in this study is 0.18 based on the empirical equation of Pauly (1984) with average seawater temperature of 6°C (Jonsson 1999). Although this equation was developed for fish, it is also applicable to lobsters because both of them share the same habitats, predators and environmental conditions and therefore, they are not likely to differ widely in their vital parameters. The M (0.18) used to estimate the yield per recruit of *nephrops* in this study is in good agreement with those reported by Tully *et al.* (1989) in Irish Sea (0.18) and Eiriksson (1982a) in Iceland (0.2).

The fishing mortality of *nephrops* decreased from 0.4 in 1970 to 0.19 in 2010, resulting in decrease of the yield from 4,336 tons to 2,577 tons during period. However, the catch per hour increased from 40.2 tons in 1970 to 74.1 tons in 2010 indicating highly efficient fishery (Figure 11).

The estimation of recruitment and biomass of *nephrops* showed a similar trend (Figure 11C and 11E). In years when biomass was high, so was recruitment. The estimated biomass increased about two times from 2000 to 2010 indicated that the recruitment to stock was high. However, estimate of recruitment and stock biomass which regular obtained by analytical assessment of fishery is difficult because of it is based on using length data to infer ages. Therefore, it does not present the true range of variation.

In the SE areas, the stock biomass and recruitment relationship showed a linear and positive correlation because of high *nephrops* stock density in this area. Conversely, the negative relationship has been reported for several *nephrops* stocks in the North Sea (ICES 2000). The relationship between stock biomass and recruitment was explained to be a density-dependent factor, which reduces in the numbers of juveniles compensating to the stocks at high adult densities. Moreover, it is also likely density dependence of predation and cannibalism, which may increase the mortality of juveniles at high densities (ICES 2002).

In term of environmental conditions, Ligas *et at.* (2011) stated that the temporal variations in the abundance of *nephrops* were highly correlated with both environmental and fishing activity variables. The biomass of *Nephrops* as demersal deep-sea community showed a negative correlation with environmental parameters variation in the North Atlantic. This can be explained in associated to mechanisms linking the productivity in the upper layers.

The yield per recruit curve revealed that the maximum yield per recruit corresponded to fishing mortality of 1.071 (F_{max}). The fishing mortality at the economic optimisation of the fisheries ($F_{0.1}$) was 0.357. The fishing mortality of *nephrops* in South Icelandic waters in recent years ranged around 0.2 indicated that they are under-exploited (Figure 11). Therefore, technically, the higher yield could be achieved with increasing fishing mortality. However, the slope of the yield curve indicates that the long term yield increase is low (Figure 11, Table 3). Based on the yield per recruit model, the mean fishing mortality (F_{mean}) in this study was (0.33) is similar to $F_{0.1}$ (0.357) and lower than F_{max} (1.071). This indicating that the *nephrops* stock is lightly exploited and is well managed. This is similar as with stock in the Eastern Mediterranean and North Sea. The stocks in West of Scotland and Western Mediterranean were fully or over exploited because F_{mean} was equal and higher than F_{max}, respectively (Table 5).

Table 5: The fishing mortality of male *N. norvegicus* from different areas.

Area	Stock	F_{mean}	F_{max}	Reference
North Sea	Fladen Ground	0.31	1.43	(ICES, 2003)
West of Scotland	North Minch	0.58	0.7	(ICES, 2003)
Western Mediterranean	Catalan Sea	0.82	0.32	Sarda *et al.*, (1998)
Eastern Mediterranean	Adriatic Sea	0.42	0.77	Sarda *et al.*, (1998)
	Gulf of Euboikos	0.29	0.93	Sarda *et al.*, (1998)
Iceland	Southern	0.33	1.07	This study

4.2 Management of the spiny lobster fishery in Vietnam

In Vietnamese waters, there are seven species of spiny lobsters belong to *Panulirus* genus in which four of them: *P. ornatus*, *P. homarus*, *P. longipes* and *P. stimpsoni* are highly abundant and of commercial value. They are found in three areas along coastal zone from the North to the South but mainly distributed off central Vietnam (Thuy and Ngoc 2004).

In the North, spiny lobsters are present from the Gulf of Tonkin to Quang Ngai province. This area has fishing ground of 50,000 hectares included reefs and rocks. The climate is typically divided into two different seasons of summer and winter. Therefore, the temperate lobster species *P.stimpsoni* is high abundant with 80% of total population (Cuc 1985). The second area is located in the central Vietnam extending from Quang Ngai to Ninh Thuan province. The bottom structure is combined of reefs and rocks with areas of 30,000 hectares. The dominant lobster species include *P. homarus*,*P. longipes*, *P. penicillatus* and *P. polyphagus* (Hieu 1994). The largest area with 70,000 hectares of fishing ground as reefs and rocks stretches from Ninh Thuan to Vung Tau province in the South. It is divided into two sub-zones, one consisting of the deep waters close inshore and the other around the offshore islands. This area is a completely tropical zone, with *P. ornatus* is the dominant species (Thuy and Ngoc 2004) (Figure 12).

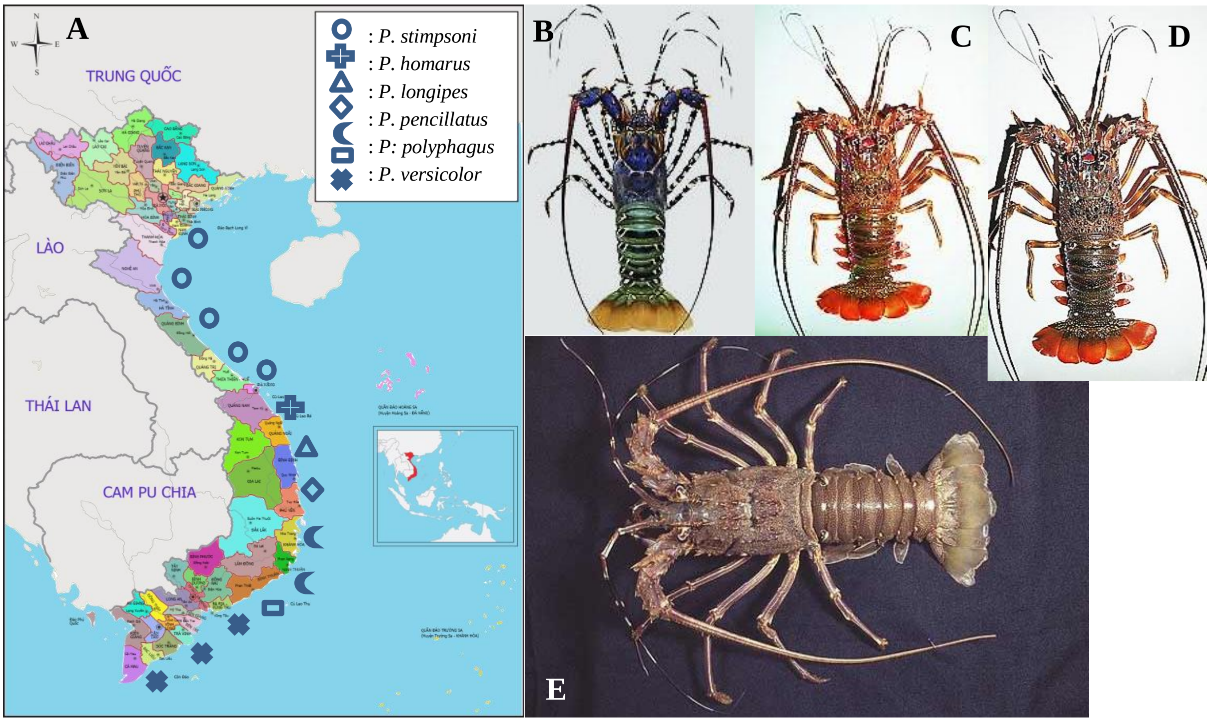

Figure 12: The distribution of spiny lobsters in Vietnamese waters (A), *P. ornatus* (B), *P. longipes* (C), *P. homarus* (D) and *P. stimpsoni* (E) (Modified from Thuy and Ngoc 2004).

The spiny lobster fishery in Vietnam is a traditional artisanal fishery in which fishing methods vary depending on the different physical geography and seabed topography of each area. The commercial fishing was first conducted before 1975 but the quantity was low. During the period of 1975 to 1980, spiny lobsters were mainly exploited by diving using hooks or pitchforks. The annual catch was several hundreds of tonnes per year for the domestic market. Since 1980, lobster fishing gear has improved rapidly to meet the export demand. The diving methods were replaced by trawls with two or three-layered nets and high capacity fishing boats which can catch lobsters offshore. This resulted in increasing yields to 500–700 tons per year. This decade was the most prosperous period for exploiting spiny lobsters in the central area (Thuy and Ngoc 2004).

From 1990 onwards, the increasing fishing pressure and lack of any regulatory management resulted in decreasing size of lobster in catches, mostly smaller than commercial size for export trade demands. This lead the fishermen along the central coastal zones to hold the undersized lobsters in simple sea-cages net to grow them up to commercial size. This resulted in the establishment of spiny lobster farming in Vietnam. This was not only highly profitable to the fishermen but also increased effort to catch juvenile lobsters for the aquaculture to the growing industry (Tuan and Mao 2004). The FAO catch database has only information on spiny lobster catch in Vietnamese waters from 1997 and onward. In recent years, the total production of spiny lobsters in Vietnam increases and reached 2,913 tons in 2010, in which the capture production of wild lobster was 1,713 tons (Figure 13) (FAO 2012).

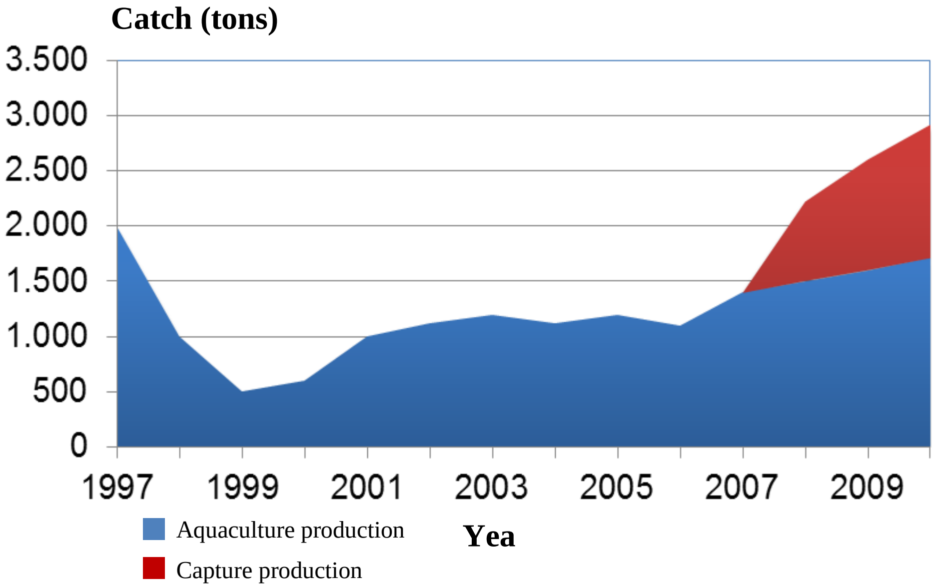

Figure 13: Spiny lobsters production in Vietnam, statistics are only available after 1996 (FAO 2012).

Because there is no fishery management system, the lobster fishery in Vietnam is facing challenges as the size of adults is decreasing in commercial catches and number of juveniles in catches is decreasing. Therefore, it is necessary to apply fishery management methods for sustainable development of spiny lobsters. Based on considerations of this study, the *nephrops* fishery management could be applied to spiny lobsters in Vietnam.

Management regulations for spiny lobsters could include fishing licenses, minimum square mesh size of trawl and quota systems based on total allowable catches (TAC). Moreover, marine protected areas can be established to protect a habitat of juveniles and adults of spiny lobsters. On the other hand, assessment methods should be developed to understand spiny lobster biomass status to implement the management regulations. To do this, data collection programmes, which include annual commercial catches and catch, rates (catch per unit effort – CPUE) should be implemented. An annual survey could be conducted to collect data on catches. Keeping logbooks and recording catches by the commercial fleet should be mandatory by law.

The status of the spiny lobsters fisheries can be assessed based on catch statistics and abundance indices in form of CPUE. Furthermore, analytical assessment should be applied to provide information on stock dynamics and population parameters which are needed to enable managers developing management schemes for sustainable exploitation of the resources.

5 CONCLUSION

Length frequency distributions and cohort slicing of *nephrops* in Icelandic waters revealed twenty five age groups in the fishery corresponding to mean CL ranging from 7.22 mm at age 1 to 76.08 mm at age 25. The dominant age groups in the catch are 5 to 10 year old. The proportion of other age groups is low. The mean CL of *nephrops* in catches increased from 45.10 mm in 1970 to 49.3 in 2011. The mean CL of *nephrops* of 47.94 mm caught in the SW is significantly higher than those of 44.84 mm in the SE areas ($p<0.01$).

The growth parameters of *nephrops* are: $CL_\infty = 82.5$ (mm), $k = 0.1$ (yr^{-1}), $t_0 = 0.1$ and the growth performance index (ϕ') is 3.87. The relationship equation between CL and weight is $W = 0.55266*L^{3.14433}$ (coefficient of a = 0.55266 and b = 3.14433).

From the production model, the average of estimated biomass of *nephrops* was 23,170 (tons) and fishing mortality (F_{mean}) was 0.33. The maximum sustainable yield is 3,131 tons corresponded to $F_{max} = 1.071$ and optimum sustainable yield is 2,768 tons with $F_{0.1}$ of 0.357. According to this the *nephrops* stock in southern Iceland is under-exploited because F_{mean} is lower than F_{max}. The fishing mortality could be increased to obtain higher yield because of the fishing mortality in recent years has even been lower (around 0.2).

In Vietnamese waters, the spiny lobsters species *P. ornatus*, *P. homarus, P. longipes* and *P. stimpsoni* are common. The spiny lobster fishery in Vietnam is a traditional and artisanal fishing. In recent years, the increasing fishing pressure without any regulatory management has resulted in the size of adults is decreasing in commercial catches and number of juveniles in catches is decreasing. For sustainable development, the *nephrops* fishery management systems as fishing license, minimum square mesh size of trawl, quota systems based on TAC and marine protected areas should be applied to the spiny lobsters fishery in Vietnam. Dynamic production model should be applied to assess spiny lobsters biomass status as well as developing data collection programmes of annual commercial catches, catch index and sea survey including length composition by sex.

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LIST OF REFERENCES

Abello, P., Abella, A., Adamidou, A., Jukic-Peladic, S., Maiorano, P., & Spedicato, M. (2002). Geographical patterns in abundance and population structure of Nephrops norvegicus and Parapenaeus longirostris (Crustacea: Decapoda) along the European Mediterranean coasts. *Scientia Marina 66*:125-141.

Bell, M., Redant, F., & Tuck, I. (2006). Nephrops species. In B. Philipps, *Lobsters: Biology, Management, Aquaculture and Fisheries* (pp. 412-450). Oxford: Blackwell Publishing Ltd.

Bennett, D. (1980). Perspectives on European lobster management. In J. Cobb, & B. Phillips, *The Biology and Management of Lobsters* (Vol. 2, p. 390). New York: Academic Press.

Cuc, H. (1985). *Some biological characteristics of spiny lobsters.* Nha Trang: Fisheries University.

Campbell, N., Allan, L., Weetman, A., & Dobby, H. (2009). Investigating the link between Nephrops norvegicus burrow density and sediment coposition in Scottish waters. *ICES Journal of Marine Science 66*:2052-2059.

Chapman, C. (1980). Ecology of juvenile and adult Nephrops. In J. Cobb, & B. Phillips, *The Biology and Management of Lobsters. 2. Ecology and Management* (pp. 143-178). New York: Academic Press.

Chapman, C., Shelton, P., Sharnks, A., & Gaten, E. (2000). Survival and growth of the Norway lobster Nephrops norvegicus in relation to light-induced eye damage. *Marine Biology 136*:233-241.

Eiriksson, H. (1992). A synosis of age based assessments and predictions on Nephrops at Iceland during 1977-1992. *ICES Shellfish Committee C.M. 1992/K:20*, 12.

Eiriksson, H. (1979). A study of the Icelandic Nephrops fishrey with emphasis on stock assessments. *International Council for the Exploration of the Sea 175*:270-279.

Eiriksson, H. (1982b). A trial VPA on the nephrops stock at Iceland with comparisons to catch and effort data. *ICES. Shelfish Committee. C.M. 1982/K:17*, 16.

Eiriksson, H. (1982a). Estimating the growth of Nephrops at Iceland. *ICES. Shellfish Committee, C.M. 1982/K:16*, 9.

Eiriksson, H. (1999). Spatial variabilities of CPUE and mean size as possible criteria for unit stock demarcations in analytical assessments of Nephrops at Iceland. *Rit Fiskideildar 16*:239-245.

FAO. (2012). *Fisheries and Aquaculture Department*. [December 15, 2012] <http://www.fao.org/fishery/species/2674/en>

Farmer, A. (1973). Age and growth in Nephrops norvegicus (Decapoda: Nephropidae). *Marine Biology 23*:315-325.

Farmer, A. (1975a). Reproduction in Nephrops norvegicus (Decapoda:Nephropidae). *Journal of Zoology 174*:161-183.

Farmer, A. (1975b). Synopsis of data on the Norway lobster Nephrops norvegicus (Linnaeus, 1758). *FAO Fisheries Synopsis No. 112*:1-97.

Figueiredo, M., & Vilela, M. (1972). On the artificial culture of Nephrops norvegicus reared from the eggs. *Aquaculture 1*:173-180.

Fisheries, I. (2012). *Information Centre of the Icelandic Ministry of Fisheries and Agriculture*. [December 2012] <http://www.fisheries.is/main-species/invertebrates/nephrops-lobster/>

Fox, W. (1970). An exponential surplus-yield model for optimizing exploited fish populations. *Transaction of the American Fisheries Society 99*:80-87.

Froglia, C., & Grammitto, M. (1987). An estimate of growth and mortality parameters for Norway lobster (Nephrops norvegicus) in the Central Adriatic Sea. *FAO Fisheries Report , 345*:111-118.

Gramitto, M. (1998). Moult pattern identification through gastrolith examination on Nephrops norvegicus (L) in the Mediterranean Sea. *Scientia Marina 62*:17-23.

Hayward, P., & Ryland, J. (1990). *The marine fauna of the British Isles and North-West Europe - Introduction and protozoan to arthropods.* Oxford: Clarendon Press.

Hieu, T. (1994). The environmental-geological elements of Quang Binh - Binh Thuan seawaters. *Marine Colleage 4*:88-99.

ICES. (2000). Report of the ICES Study Group on Life History of Nephrops. *ICES CM*, G:06.

ICES. (2001). Overview of Nephrops stocks. *ICES CM 2001/Ref. ACFM*, 247-248.

ICES. (2002). Report of the Working Group on Nephrops Stocks. *ICES CM*, ACFM:15.

ICES. (2002). Report of the Working Group on Nephrops Stocks. *ICES CM*, ACFM:15.

ICES. (2003). Report of the Working Group on Nephrops Stocks. *ICES CM*, ACFM:18.

Jonsson, S. (1999). Temperature time series from Icelandic Coastal Stations. *Rit Fishideildar 16*:59-68.

Ligas, A., Sartor, P., & Colloca, F. (2011). Trends in pupolation dynamics and fishery of Parapenaeus longirostris and Nephrops norvegicus in the Tyrrhenian Sea (NW Mediterranean): the relative importance of fishery and environmental variables. *Marine Ecology 32*:25-35.

Nguyen, L. (2007). *Dynamic production model for shrimp stock assessment: a case study of northern shrimp (Pandalus borealis) in Húnaflói, Icelandic water.* Reykjavik: UNU-FTP final report.

Mamie, J. (2008). *Stock assessment of shrimp Pandalus borealis (Krøyer 1838) in Skjálfandi bay, Northern Iceland.* Reykjavik: UNU-FTP final report.

Marano, G., Marsan, R., Pastorelli, A., & Vaccarella, R. (1998). Areale di distribuzione e pesca dello scampo, Nephrops norvegicus (L), nelle acque del basso Adriatico. *Biology Marine Mediterranean 2*:284-292.

Maynou, F., Sarda, F., Mytilineou, C., & Sartor, P. (2003). *The biology and fisheries of Nephrops norvegicus in the Mediterranean.* Report of Concerted Action Project number QLK5 1999 01272, European Decapod Fisheries: Assessment and Management (EDFAM), Work Package I, III Review of the Biology and Fisheries of Decapod crustaceans in Europe.

Morello, E., Froglia, C., & Atkinson, R. (2007). Underwater television as a fishery-independent method for stock aassessment of Norway lobster (*Nephrops norvegicus*) in the Central Adriatic Sea (Italy). *ICES Journal of Marine Science 64:*1116-1123.

Mytilineou, C., & Sarda, F. (1995). Age and growth of Nephrops norvegicus in the Catalan Sea, using length-frequency analysis. *Fisheries Research* 283-299.

Mytilineou, C., Papaconstantiou, C., & Fourtouni, A. (1990). Some aspects of the biology of Norway lobster, Nephrops norvegicus in the N. Euvoikos Gulf (Greece). *International Commission for Scientific Exploration of the Meditteranean Sea 1*:32:34.

Oh, C., Hartnoll, R., & Nash, R. (1999). Population dynamic of the common shrimp, Crangon crangon (L), in Port Erin Bay, Isle of Man, Irish Sea. *ICES Journal of Marine Science 56*:718-733.

Pampoulie, C., Skirnisdottir, S., Hauksdottir, S., Olafsson, K., Eiriksson, H., Chosson, V., et al. (2011). A pilot genetic study reveals the absence of spatial genetic structure in Norway lobster (Nephrops norvegicus) on fishing grounds in Icelandic waters. *ICES Journal of Marine Science 68*:20-25.

Pauly, D. (1984). Some simple methods for the assessment of tropical fish stocks. *Fish. Tech. Pap. No. 234*, p. 52. Rome: FAO.

Robertson, J., & Shanks, A. (1989). *Further studies of the size selection of nephrops by different condents.* Scottish Fisheries Working.

Sarda, F. (1998). Comparative technical aspects of the Nephrops norvegicus (L) fishery in the north Mediterranean Sea. *Scientia Marina 62*:101-106.

Sarda, F., Leonart, J., & Cartes, J. (1998). An analysis of the population dynamics of Nephrops norvegicus (L.) in the Mediterranean Sea. *Scientia Marina 62*:135-143.

Smith, C., & Papadopoulou, K. (2003). Burrow density and stock size fluctuations of Nephrops norvegicus in a semi-enclosed bay. *ICES Journal of Marine Science 60*:798-805.

Stefansson, G. (2012). *Yield per recruit analysis.* [January 15, 2012] <http://tutor-web.net/fish 510.5>

Stefansson, G., & Taylor, L. (2012). *Modelling length at age distribution*. Retrieved [December 24, 2012] <http://www.tutor-web.net/fish510.3>

Thomas, H., & Davidson, C. (1962). *The food of the Norway lobster Nephrops norvegicus (L).* Aberdeen: Deparment of Agriculture and Fisheries for Scotland, Marine Laboratory.

Thuy, N., & Ngoc, N. (2004). Current status and exploitation of wild spiny lobsters in Vietnam water. In W. K.C. (Ed.), *Spiny lobster ecology and exploitation in the South China Sea region* (pp. 13-16). Canberra: Australian Centre for International Agricultural Research .

Tuan, L., & Mao, N. (2004). Present status of lobster cage culture in Vietnam. In K. Williams (Ed.), *Spiny lobster ecology and exploitation in the South China Sea region* (pp. 21-25). Caberra: Australian Centre for International Agricultural Research.

Tuck, I., & Bailey, N. (2000). *Assessment of Nephrops stocks in Loch Torridon area.* Aberdeen: Marine Laboratory Report.

Tuck, I., Chapman, C., & Atkinson, R. (1997). Population biology of the Norway lobster, Nephrops norvegicus (L.) in the Firth of Clyde, Scotland - I: Growth and density. *ICES Journal of Marine Science 54*:125-135.

Tully, O., Hillis, J., & McMullan, D. (1989). Fitting normal curves to polymodal length frequencies to assess growth in Nephrops. *ICES. Shellfish Committee*, 1989 C.M./K:32, 18.

Wahle, R., & Fogarty, M. (2006). Growth and Development: Understanding and Modelling Growth Variability in Lobsters. In B. Phillips, *Lobsters: Biology, Management, Aquaculture and Fisheries* (pp. 1-36). Oxford: Blackwell Publishing.

APPENDIX

Data collected from Marine Research Institute

TAFLA 3.26.1

Humar. Afli (í tonnum) á Íslandsmiðum árin 1951–2010.

phrops. Landings (in tonnes) from Icelandic waters 1951–2010.

Ár *Year*	Ísland *Iceland*	Aðrar þjóðir *Other nations*	Samtals *Total*
1951	-	26	26
1952	-	53	53
1953	-	144	144
1954	-	236	236
1955	-	203	203
1956	-	138	138
1957	-	312	312
1958	728	593	1 321
1959	1 404	602	2 006
1960	2 081	451	2 532
1961	1 490	322	1 812
1962	2 662	154	2 816
1963	5 550	512	6 062
1964	3 487	586	4 073
1965	3 706	409	4 115
1966	3 465	546	4 011
1967	2 731	208	2 939
1968	2 489	157	2 646
1969	3 512	189	3 701
1970	4 026	119	4 145
1971	4 657	155	4 812
1972	4 321	260	4 581
1973	2 791	5	2 796
1974	1 983	6	1 989
1975	2 357	-	2 357
1976	2 780	-	2 780
1977	2 723	-	2 723
1978	2 059	-	2 059
1979	1 440	-	1 440
1980	2 398	-	2 398
1981	2 520	-	2 520
1982	2 603	-	2 603
1983	2 672	-	2 672
1984	2 459	-	2 459
1985	2 385	-	2 385
1986	2 564	-	2 564
1987	2 712	-	2 712
1988	2 240	-	2 240
1989	1 866	-	1 866
1990	1 692	-	1 692
1991	2 157	-	2 157
1992	2 230	-	2 230
1993	2 381	-	2 381
1994	2 238	-	2 238
1995	1 027	-	1 027
1996	1 633	-	1 633
1997	1 228	-	1 228
1998	1 411	-	1 411
1999	1 376	-	1 376
2000	1 239	-	1 239
2001	1 420	-	1 420
2002	1 548	-	1 548
2003	1 666	-	1 666
2004	1 437	-	1 437
2005	2 030	-	2 030
2006	1 875	-	1 875
2007	2 006	-	2 006
2008	2 070	-	2 070
2009	2 464	-	2 464
2010[1)]	2 540	-	2 540

Bráðabirgðatölur. *Provisional figures.*

TAFLA 3.26.4
Humar. Stofnstærð í fjölda eftir aldri (í milljónum) og stærð veiðistofnsins í þúsundum tonna á árunum 1982–2011.
Nephrops. Stock abundance in numbers by age (millions) and fishable stock in thousand tonnes in the years 1982–2011.

Ár	Aldur age														Veiðistofn 6+
Year	3	4	5	6	7	8	9	10	11	12	13	14	15	16	*Fishable stock*
1982	141.11	111.90	99.20	74.29	58.99	45.88	30.36	20.53	13.90	6.04	4.50	4.39	1.12	0.45	15.73
1983	132.83	115.46	90.73	76.33	55.22	41.68	30.34	19.64	12.65	8.22	3.79	2.82	3.31	0.77	15.51
1984	122.75	108.65	93.87	70.23	56.35	39.23	28.14	20.57	11.58	6.96	5.14	2.06	1.74	2.40	14.96
1985	131.26	100.27	87.65	72.57	52.12	39.95	26.56	19.43	13.77	6.61	4.32	3.06	0.98	1.00	14.53
1986	136.51	107.42	81.29	68.42	54.71	37.46	26.78	17.11	12.30	8.34	4.22	2.64	2.00	0.50	14.22
1987	147.62	111.76	87.55	63.62	50.26	37.04	23.91	17.20	10.30	7.11	5.75	2.59	1.69	1.43	13.57
1988	142.99	120.81	91.12	69.48	47.32	34.54	22.86	14.70	10.08	5.45	4.36	3.75	1.57	1.04	12.87
1989	130.55	116.99	98.25	72.17	52.80	33.30	22.71	13.99	8.45	5.98	3.39	2.77	2.64	0.95	12.84
1990	124.05	106.82	95.11	77.41	55.65	39.09	22.70	15.42	8.77	4.59	3.80	2.04	1.80	1.85	13.46
1991	113.85	101.49	86.47	72.96	56.93	40.22	28.02	16.09	10.71	5.76	3.01	2.54	1.29	1.17	14.00
1992	100.64	93.18	82.31	66.39	52.55	38.45	26.64	19.49	10.60	7.05	3.96	1.92	1.75	0.82	13.86
1993	105.51	82.38	75.88	64.57	48.65	35.48	24.00	17.39	13.13	6.86	4.95	2.75	1.30	1.27	13.56
1994	116.24	86.34	67.14	59.88	48.67	34.11	22.80	15.01	10.73	7.96	4.35	3.25	1.79	0.78	12.88
1995	100.36	95.06	69.88	52.92	45.37	34.93	22.45	14.65	8.88	5.98	5.04	2.65	2.22	1.15	12.19
1996	121.67	82.11	82.76	55.67	41.46	35.11	26.27	16.68	10.39	6.04	4.26	3.73	1.83	1.60	12.82
1997	137.93	99.55	66.57	60.53	41.76	30.16	25.02	18.98	11.60	6.71	4.03	2.74	2.49	1.16	12.87
1998	129.21	112.90	81.05	52.26	46.36	30.96	22.10	18.85	14.11	8.19	4.78	2.72	1.82	1.78	13.15
1999	133.11	105.78	92.27	65.09	40.50	34.79	22.35	16.07	13.74	10.01	5.84	3.20	1.67	1.11	13.57
2000	123.27	108.95	86.45	74.41	50.90	29.89	24.86	15.75	11.26	9.76	7.50	4.30	2.29	1.11	14.42
2001	122.59	100.90	89.03	69.72	59.47	39.68	21.99	18.34	10.90	7.54	7.14	5.54	3.11	1.61	15.30
2002	127.74	100.36	82.41	72.10	55.68	46.57	29.92	15.99	12.91	6.99	5.06	5.03	3.97	2.19	16.04
2003	131.11	104.58	82.01	65.87	57.03	43.57	35.86	22.71	11.21	8.78	4.62	3.19	3.28	2.61	16.43
2004	128.05	107.28	85.38	66.20	50.95	43.44	32.95	27.42	16.88	7.58	6.17	2.85	1.82	1.99	16.62
2005	132.68	104.82	87.33	68.11	51.86	37.52	31.48	24.89	20.88	12.70	5.61	4.59	1.95	1.14	17.11
2006	131.83	108.61	85.62	69.91	52.65	38.91	26.07	21.62	17.19	14.71	9.15	3.90	3.25	1.20	17.03
2007	132.05	107.93	88.72	69.02	54.69	39.38	27.99	18.11	14.72	11.73	10.9	6.70	2.67	2.29	17.07
2008	136.52	108.10	88.25	71.90	54.84	42.11	28.73	20.37	12.51	9.82	8.15	7.89	4.59	1.43	17.11
2009	130.00	111.76	88.29	71.16	56.68	41.75	30.87	20.23	13.59	7.82	6.63	5.76	5.60	3.10	17.11
2010	130.00	106.40	91.27	71.12	56.11	43.38	30.32	21.93	13.47	8.47	4.77	4.33	3.62	3.55	16.67
2011	130.00	106.42	86.89	73.46	55.92	42.74	31.60	21.63	14.75	8.46	5.23	2.81	2.32	1.94	16.26