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The fishery and stock assessment of Norway lobster (*Nephrops norvegicus*) in Icelandic waters during 1950 - 2016

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Ágrip

Veiðar á leturhumri hafa verið stundaðar samfellt við Ísland frá árinu 1950. Hér er tegundin við norðurmörk útbreiðslu sinnar en aflabrögð og útbreiðsla veiðanna hafa sveiflast nokkuð með hlý og kuldaskeiðum sem og sveiflum í nýliðun. Hámarksafli náðist árið 1963 þegar yfir 6000 tonnum var landað. Afli á sóknareiningu náði hámarki á árunum 2008 - 2010, áratug eftir að að veiðihlutall var lækkað og með góðri nýliðun. Undanfarin misseri hafa humarveiðar við Ísland einkennst af minnkandi afla á sóknareiningu. Nýliðunarbrestur hefur verið viðvarandi frá og með árgangi ársins 2005 og hefur það leitt til lækkunar í metnum lífmassa. Í skýrslunni verður farið yfir þróun í aflabrögðum á humri á öllum veiðisvæðum frá árinu 1960 til 2016. Einnig er fjallað um stofnmat á humri sem byggir á aldurs afla líkönum (VPA), en lengd humra er notuð sökum erfiðleika við aldursgreiningar.

Abstract

Fisheries of Nephrops initiated in Icelandic waters in 1950. At Iceland the species lies at it's northern distributional range and fluctuation in catches have somewhat corresponded with warm and cold periods but also pulses in recruitment. The landings reached a peak in 1963 when more that 6000 tonnes were landed. More stringent management and good recruitment led to a build up of biomass during 1990 - 2010 and highest recorded catch per unit effort. In recent years the catches have been declining but from 2005 all yearclasses have been very small leading to a sharp decline in biomass. In this report fluctuation in catches and effort by different fishing grounds during 1960 – 2016 are described. Assessment of Nephrops is also reviewed which has traditionally been based on VPA-analysis with slicing of lengths into cohorts due to difficulties of ageing the animals.

Lykilorð: *Norway lobster, Nephrops, stock assesment, CPUE, fisheries, recruitment*

Undirskrift verkefnisstjóra:	**Undirskrift forstöðumanns sviðs:**
	

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1. INTRODUCTION

The Norway lobster, *Nephrops norvegicus* (Linnaeus, 1758), is widely distributed on the continental shelf of the Northeast Atlantic and in the Mediterranean Sea, supporting important trawl fisheries and lesser creel fisheries in various countries bordering these waters. At Iceland, it is only found off the southern part of the country, in the relatively warm waters of the North-Atlantic current, at depths of about 100 to 300 m (Fig. 1). The oldest reference to

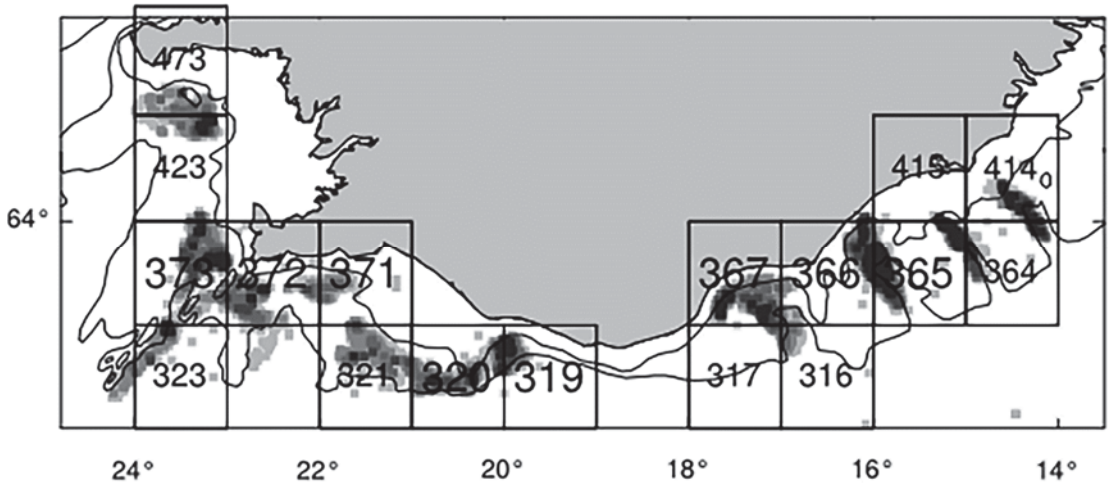

Figure 1. Cumulative catch of *Nephrops* during the years 2000 - 2017. Area boxes refer to statistical rectangles.

lobster (*Cancer gammarus*) in South Icelandic waters dates back to 1772 (Olafsen & Povelsen, 1772), presumably describing *Nephrops norvegicus* since *Homarus gammarus* (Linnaeus, 1758) is not known from Iceland. This finding was later referred to by Mohr (1786) (cited in Stephensen, 1939). A century later, *Nephrops* was listed in the zoology written by Gröndal (1878). The specimen of *Nephrops* referred to was most likely obtained from cod stomachs fished off the south or southwest coast of the country. However, following the introduction of trawl fishing in the early 1900s, *Nephrops* was caught frequently, especially off Vestmannaeyjar (Vestman Islands) and on Selvogsbanki, Eldeyjarbanki and Jökuldjúp, often 1 - 2 or more baskets per haul (Sæmundsson, 1937). Moreover, Friðriksson (1937) describes that in one of his "Thor" cruises during August 1935 or 1936 "11 Grimsby baskets" of *Nephrops* were caught in Jökuldjúp in a haul of two hours' duration at 179 m depth. The individuals weighed from 12 to 200 g (approx. 25-65 mm carapace length (CL)) with a mean wt. of 57 g (42 mm CL).

Earliest fishing trials for *Nephrops* in Icelandic waters date back to 1939 with limited success, but in 1951 - 1954 a second trial period turned out successful with good catches of *Nephrops*, although discontinued due to market and financial difficulties (Björnsson, 1980). A continuous history of *Nephrops* fisheries in Icelandic waters dates back to the early 1950s when Belgian

trawlers began targeting *Nephrops* at the end of their fishing trips to Southeast Iceland (Leloup and Gilis, 1965). A few years later, in the year 1958, an Icelandic fishery was initiated off the southwest coast of the country, mainly on Eldeyjarbanki. The fishery expanded rapidly, reaching an all-time record of 6.062 tonnes in 1963, of which 5.550 tonnes were taken by Icelandic boats. During the five decades since then, landings have fluctuated from around 1.000 - 4.500 tonnes, thereof amounting to 1.400 - 2.500 tonnes annually in 2005 - 2016 (Fig. 2).

Typically, the southern continental shelf of Iceland contains banks of 100 - 150 m depth that are crossed by a series of intervening troughs 200 - 300 m below sea level. The distribution of *Nephrops* is mainly limited to substrates of high concentration (generally >50%) of clay and silt within these areas (Boulton *et al*., 1988) with average monthly bottom temperatures ranging from 5 - 9°C. Therefore, the anomalous records of *Nephrops* in the relatively much colder waters off East Greenland, Spitzbergen and Bear Island must be doubted, although indicated by Sæmundsson (1937), Thomas (1961) and Farmer (1975) and quoted by later authors. In addition, Sæmundsson (1937) mentions personal findings of specimens of *Nephrops*, both in bottom trawls and in cod stomachs in relatively cold waters off southern part of East Iceland (*e.g*. Litladjúp and Hvalbaksbanki) and off Northwest Iceland (Vestfirðir) and Stephensen (1939) also mentions occurrences off Northwest Iceland (Látrabjarg), East Iceland (Litladjúp) and even North Iceland (Eyjafjörður). Although North-Atlantic waters enjoyed a period of warm water regimes in the period 1930 to the mid-1960s, followed by a colder period until the mid - 1990s, a consistent warming period has reoccurred over the last 20 years. No records are listed, however, in the Icelandic fisheries research data base in 1985 - 2016 (Marine and Freshwater Research Institute, Reykjavík), of either *Nephrops* being caught or found in cod stomachs off the East and Northwest of Iceland in the recent warm era. Thus, the present authors considers the presence of *Nephrops* in those relatively cold waters not only incidental but rather equivocal, being obviously too cold for both reproduction and growth, although not necessarily survival, of this species (Eiríksson, 2014). Yet, in late 2012 northern shrimp fishers in Ísafjarðardjúp (Northwest Iceland) caught 3 - 4 male *Nephrops* of approximately 50 - 55 mm carapace length which apparently had recently moulted (Hjalti Karlsson, scientist MFRI, pers. comm.). Therefore, survival and growth of *Nephrops* appears to have been successful in somewhat colder waters than previously certified although successful reproduction still remains unresolved.

Stock assessments of crustaceans have always been limited by unreliable data on age, growth and mortality rates. Therefore, early assessments of the Icelandic *Nephrops* stock were based on the relationship between catch and effort (see *e.g.* Schaefer, 1954; Gulland, 1961). Thus an indication of the maximum sustainable yield (MSY) of *Nephrops* was obtained (Skúladóttir, 1967; Eiríksson, 1974). However, Jones (1974) pointed out that it should be possible to apply

a virtual population or “cohort analysis” technique to length as well as age composition data using Faeroe haddock data. Later Jones described a preliminary “steady state” assessment of the Firth of Forth *Nephrops* stock in East Scotland, using length composition data without definite data on age (Jones, 1976). In addition, Eiríksson (1976, 1979) experimented on an annual cohort analysis of two fishing areas at Iceland during 1962 - 1975, assuming a von Bertalanffy growth curve with the number of mm length groups per “age group” approximated to d*t* = 1 (time elapsing between the beginning and end of each length group). Such slicing of length distributions of total *Nephrops* catches have been employed annually in Iceland since 1977 (Eiríksson, 1982a, 1992; *e.g.* Anon., 1992a, 2012).

In this report we will discuss fluctuations in landings, catch per unit effort (CPUE) and population parameters of *Nephrops* from the onset of the fisheries until 2016.

2. MATERIALS AND METHODS

2.1. Catch, effort and length distribution data

The *Nephrops* fishery has since 1960 been subject to a licence issued to each vessel by the Ministry of Fisheries, *e.g.* stipulating engine power limitations, fishing season, authorised fishing areas for *Nephrops* (8 areas demarcated by number of lat.-long. positions), minimum 80 mm stretched inside diamond mesh size (enforced in 1965 with a two years’ period of grace for using up smaller-meshed gear), as well as two square mesh upper panels of minimum 135 mm mesh size, primarily designed for escapement of juvenile haddock and whiting. One of the provisions of the licence is filling out of logbooks, including trawling locations, duration of haul, time information, depth, headline length, single- or double-rigged gear and weather condition for each haul. Moreover, catches of *Nephrops* (whole or tail wt.) should be recorded for each haul along with main by-catch species of groundfish and flatfish. Electronic log-books have been legalized since 2009, providing more up-to-date catch statistics, trawl tracks etc. The CPUE, presented here has been standardized to only include the months of May - August, as they were the traditional fishing season. When two trawls are being deployed the catch was divided with 1.8. The fishing season has however lengthen and begins now 16th of March and lasts until end of October, but in some recent years few boats have got permission and stretched the season into December. During 1999 - 2003 there was also permission to fish from January. In recent decades the fishery has usually started on the grounds off SE Iceland, before spreading to other areas.

Nephrops (as a rule one basket or approx. 20 kg) from both research and commercial vessel catches from various fishery rectangles have been sampled annually since around 1960. All

research samples have been carried out with commercial trawls. Carapace length (CL), from the posterior edge of the eye socket to the posterior edge of the carapace midline, of male and female *Nephrops*, has been measured to the nearest mm by a sliding steel calliper.

These measurements constitute the Marine and Freshwater Research Institute´s *Nephrops* database of some 1.176.560 males and 162.893 females (12.2% of total) registered from *Nephrops* trawl catches in 1960 - 2016. Length measurement are scarce in the early years between 1960 - 1964, apart from 1963 when around 3.000 *Nephrops* were measured. Between 1965 - 1971, 5.000 males were measured annually on average, with low numbers in 1967 - 1968, when 2.600 and 1.800 males were measured respectively. Since 1972 more than 8.000 males have been measured each year or on average 22.000. These samples (n = 4.864) along with mandatory logbook catch data from each statistical rectangle compose the basis of the annual stock assessments using cohort slicing of length distributions from each fishery rectangle. Total catches are weighted by reported logbook catches in each fishery rectangle and raised proportionally according to official total landings. The oldest logbook records are from 1960, data are missing from 1961, but with relatively good coverage from 1962/1963 and onwards. In recent years reported logbook catches have corresponded well with those of weighed official landings (+/- 3%).

2.2. Stock assessments

Since most of the *Nephrops* landings are composed of the larger-bodied males (>90 - 95%) stock assessments by virtual population analysis (VPA) have been mostly concentrated on males. In applying the VPA technique to numbers caught in each varying-sized length group, that is estimated to compose a certain virtual “age group”, a number of input values are required such as asymptotic length (L_∞), natural mortality (*M)* and growth rate (*K)*. Maximum recorded size of males on all major *Nephrops* grounds at Iceland ranges from 77 - 85 mm CL (Eiríksson, 2014) (a specimen of 88 mm CL has been recorded after submission of the 2014 article) and the authors have chosen 80 mm CL for the L_∞. Moreover, by assuming that the growth curve is of the von Bertalanffy type, the value of K (growth rate coefficient, *i.e.* the rate at which L_∞ is approached) for a given value of L_∞ can be determined provided that at least one annual growth increment is known. Annual length frequency modal progressions, as well as certain amount of data on growth from tagging experiments, have indicated that the growth of male *Nephrops* decreases with size (age) from approximately 5 to 3 mm per annum within the size range of 25 to 50 mm CL (Eiríksson, 1982b, 1992). As the slope of the Ford-Walford plot is exp(-*K*), the growth coefficient *K* was obtained from the relation $L_\infty - CL_{i+1} / L_\infty - CL_i$, giving *K* around 0.10 depending on points chosen in the length distribution. Therefore, the growth coefficient *K* = 0.10 was accepted as a near average.

Cohorts ("year-classes") were formed by slicing the length frequency distributions into knife-edged demarcations ranging from 6 mm (19 - 24 mm CL) to 2 mm (56+ mm CL). The validity of the cohorts were diagnosed by a steady state cohort analyses for a period of some 5 years and the value of d*t* (the time required to grow from the beginning to the end of each length group) was approximated at around 1 in each case. Further, by using the von Bertalanffy equation and the parameters described above, or $L_1 = L_\infty - (L_\infty - L_0 / \exp(K))$, with L_0 being the carapace length at the beginning of year x and L_1 the carapace length at the end of year x or equivalent to annual growth from year x to year x+1, gives similar divisions into length groups (Eiríksson, 1976, 1979).

In fisheries research there are often no reliable data on natural mortality coefficients (*M*). Therefore, natural mortality has to be chosen somewhat at random, although with some reference to the known or expected longevity of the species in question. Regarding Icelandic *Nephrops* one would theoretically expect *M* to vary with age, with higher values at each extremity of the length distribution, due to greater predation on the smaller *Nephrops* and senility in the largest. Virgin stock samples and the apparent longevity of this species, approx. 10 - 11 years old at 50 - 55 mm CL (Eiríksson,1982a), seems to indicate some 20+ years at the asymptotic length of 80 mm CL. Thus, *M* much over 0.2 is unlikely over the major range of the length distribution of the catch. Moreover, *M* less than 0.1 seems implausible, considering virgin stock length distribution, and the prevalence of numerous predators such as cod. Therefore, trials with *M* ranging from 0.1 - 0.2 were made, leading to a final choice of the somewhat omnipresent *M* = 0.2 and M/K = 2.0 for stock assessments of Icelandic *Nephrops* (Eiríksson, 1976, 1979). In addition, Eiríksson (1982a), plotted the regression of annual average total mortality (Z) of size groups 30 - 59 mm CL (estimated age classes 5 - 13), weighted by stock in numbers, on fishing effort for the period 1969 - 1981. The resulting intercept of the y axis at around Z = 0.2 at zero fishing effort further substantiated the use of M = 0.2.

3. *NEPHROPS* FISHERIES IN ICELANDIC WATERS 1950-2016

3.1. The Belgian fishery

According to available data the largest foreign fleets in Icelandic waters, those of British and German trawlers, never targeted *Nephrops*, although when fishing on southern grounds in deeper waters than 110 - 120 m, *Nephrops* was probably caught in some numbers as by-catch. By the year 1950, however, Belgian trawlers began reporting catches of *Nephrops*, targeting of the species being confined to the end of fishing trips at Southeast Iceland due to the perishable nature of Norway lobsters (Leloup and Gilis, 1965). The Belgian fishery expanded from only some 15 tonnes in 1950 to over 600 tonnes in 1959 (Fig. 2), remaining between 200 - 550 tonnes annually until 1967. Although the fishery continued with reported catches averaging

around 150 tonnes a year until 1972 they rapidly diminished and the fishery was discontinued in 1974. The end of this fishery was largely related to the unilateral extension of the Icelandic fishery limit (EEZ) to 50 miles in 1971 and the exclusion of *Nephrops* in the bilateral fishery negotiations between Iceland and Belgium for a period of some years following the extension of the limit. No other foreign catches of *Nephrops* in Icelandic waters have been reported apart from 178 tonnes by France in 1972 (Anon., 1974).

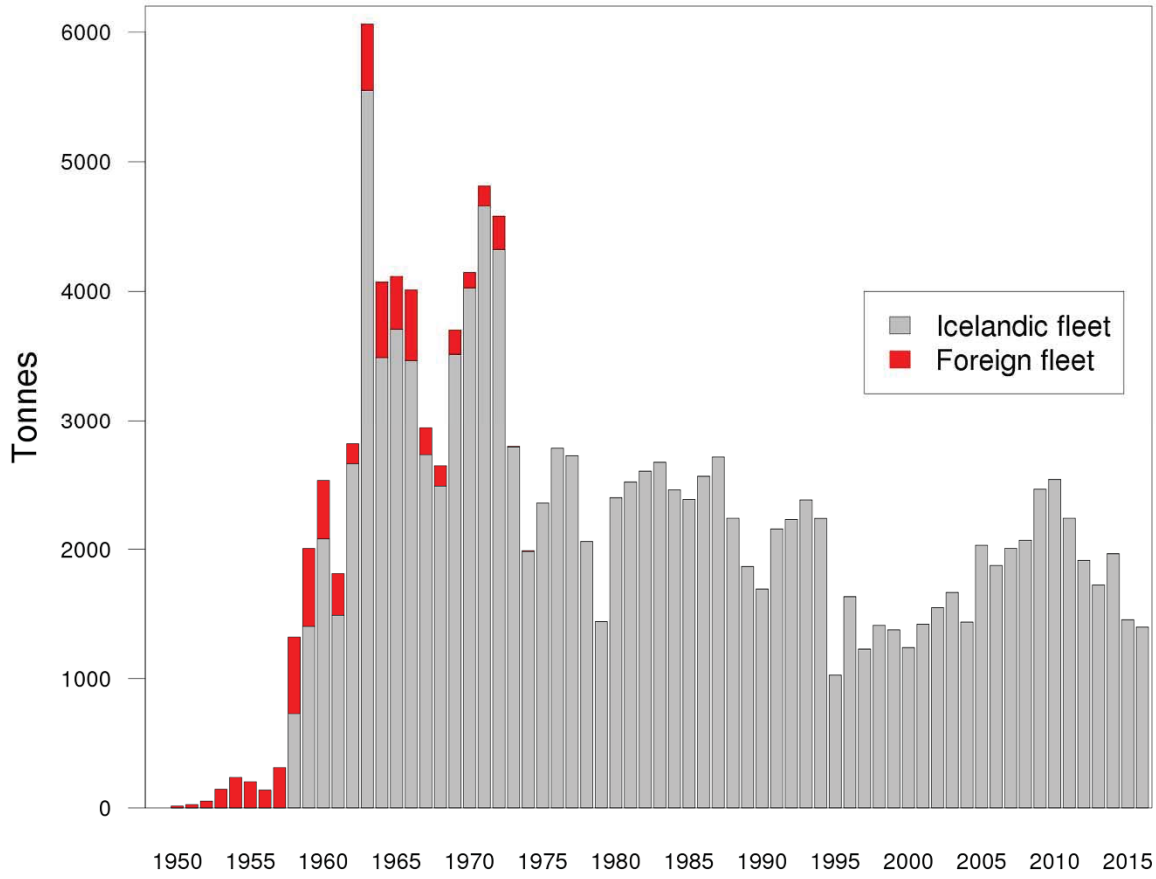

Figure 2. Landings of Nephrops from Icelandic grounds by nationality, during the years 1950 - 2016.

3.2. The Icelandic fishery

First recorded fishing trials for *Nephrops* in Icelandic waters date back to the summer of 1939 off the Reykjanes peninsula (Stafnes and Selvogur) and Vestmannaeyjar (Vestman Islands). Reportedly two small trawling boats (22 and 26 GRT) were involved in this experiment. Although there were some good hauls of *Nephrops* made (Vigfússon, 1980), the overall trials were only partially successful and only some 2.9 tonnes of de-shelled tails were conserved (canned) (Björnsson, 1980). Another *Nephrops* trials began in the year 1951 on a 20 GRT trawling boat with a 70 - 80 HP engine, mainly in the area off Selvogur on the Reykjanes peninsula, SW Iceland. The fishery almost immediately turned out quite successful, reportedly with good catches of *Nephrops* and minimal by-catch of demersal fish. Despite relatively good prospects and additional boats partaking during the next years, these trials were discontinued

in 1954 due to market difficulties and limited financial backing from banking authorities (Björnsson, 1980). However, according to some rather limited fishery statistics for these early *Nephrops* trials, maximum landings of Norway lobster amounted to 115 tonnes in the year 1953 (Anon., 1954). Since 1958 landings from Icelandic boats have been regularly reported. That year 728 tonnes of whole *Nephrops* were landed, mostly exported as frozen lobster tails to the USA. The fishery expanded rapidly in the next few years reaching an historical record of 5.550 tonnes already in 1963 with CPUE of some 88 kg/hour (Fig. 3). Following this rapid expansion, the fishery experienced its first decline with landings decreasing to less than 2.500 tonnes in 1968, accompanied by increasing fishing effort and a fall in CPUE to 30 kg/hour. Decreasing CPUE as well as stock assessments done later in 1976 (Eiríksson, 1976) (see section 4), are strongly indicative of much to high fishing pressure on these largely virgin grounds in 1963 - 1966, but the concurring decrease in sea temperatures in the latter half of the 1960s (Stefánsson, 1972, Eiríksson, 2009) is thought have accentuated the very low catch rates experienced especially in 1968. Thus, the calamitous *Nephrops* season is partly attributed to

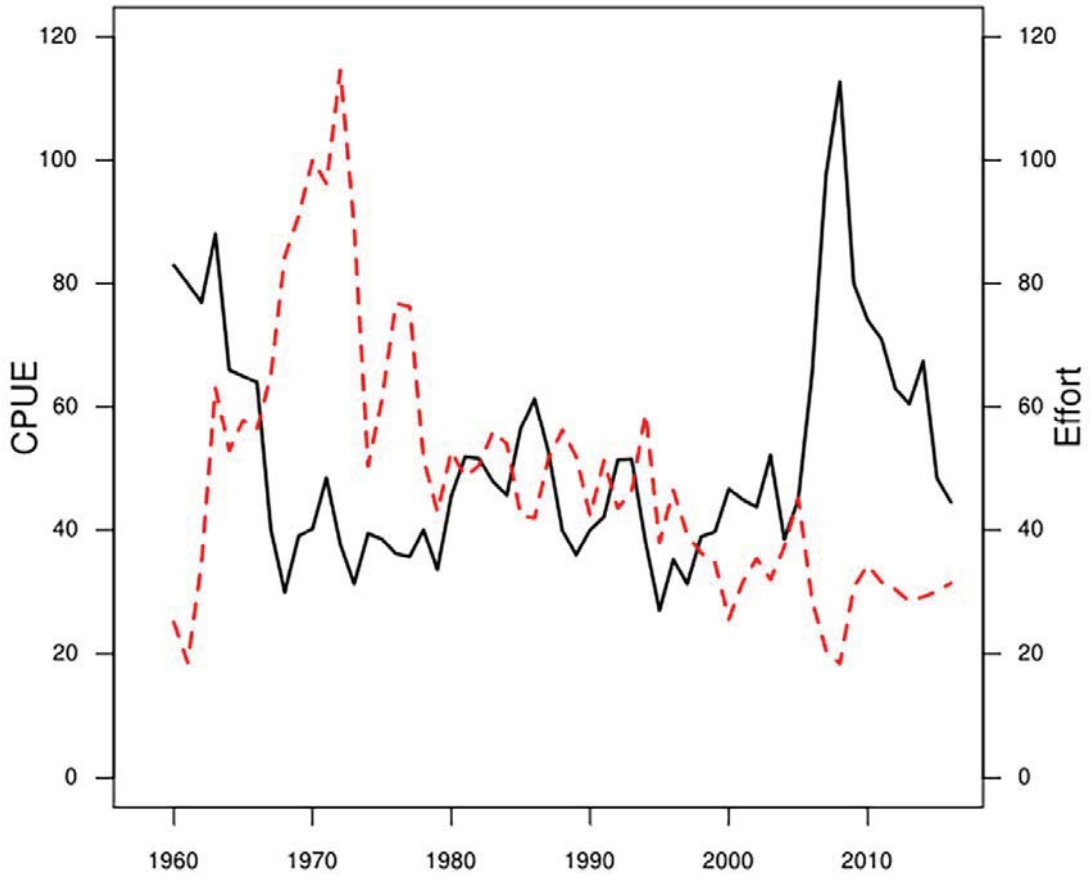

Figure 3. Standardized CPUE (black line) and effort (red dotted line) of *Nephrops* from all fishing grounds during the years 1960 - 2016.

an unusual influx of Arctic drift-ice from the cold East-Icelandic current, resulting in very sub-normal sea temperatures that most likely resulted in lesser availability of *Nephrops* associated

with their burrowing behaviour (Chapman, 1980). This was especially pronounced on the more easterly grounds at SE Iceland (Eiríksson, 1970a).

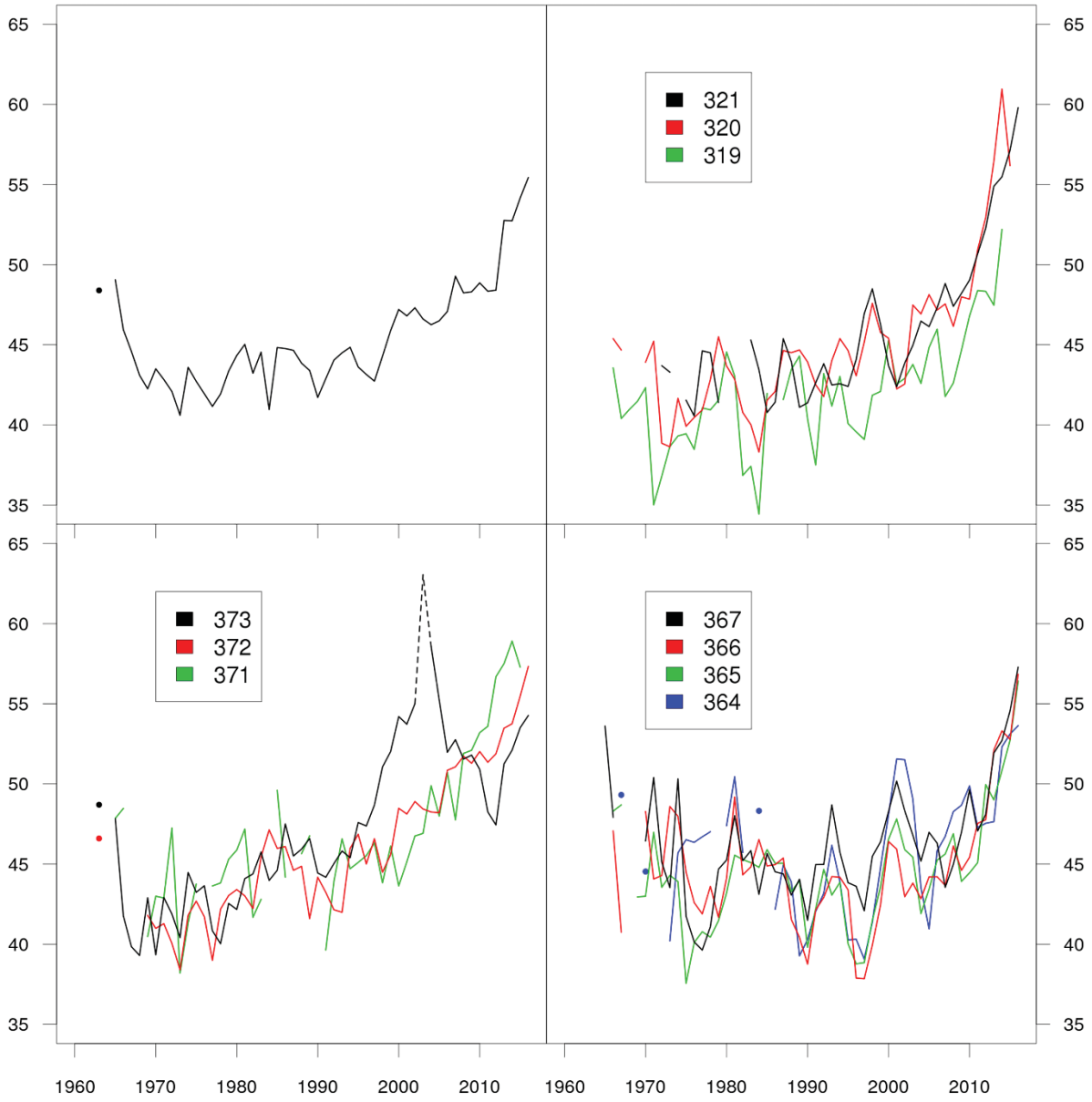

Figure 4. Average CL (mm) of male *Nephrops* from the years 1963 and 1965 - 2016 (denoted by a line or dot if not continuous). Upper left is the average of all areas, while other graphs refers to fishery rectangles (See fig. 1). A minimum of 140 measurement was chosen as a threshold for individual year/rectangle. In rectangle 373, few sampled animals in 2003 (264) compared to last decades are denoted by a broken line.

Following the low yield of the 1968 season, landings rose again with both increased effort and catch rates, reaching the second peak in the *Nephrops* fishery of almost 4.700 tonnes and CPUE of 48 kg/hour in 1971. This high sustained effort and landings in 1969 - 1973 most inevitably led to a decrease in stock density, reflected in low CPUEs of some 30 - 40 kg/hour, as well as record low mean carapace length between 41 - 42 mm CL (Fig. 4) and very high proportion of females (up to 25 - 35%) during the season of May-August for most of the 1970s (Eiríksson,

2014). It must be noted that in addition to the effects of fishing effort in 1969 - 1973, the small size of *Nephrops* and high proportion of the naturally smaller-bodied females was intensified by overall good recruitment in the 1970s and particularly large year-classes in the early part of the decade (Eiríksson, 1982a, 1992; Anon., 1989).

The adverse development in the early 1970s, when some 185 vessels partaking in the fishery, reaching over 200 GRT in size with up to 600 HP engines (Anon., 1973), landings were most certainly exceeding sustainability of the stock. The aftermath of this high fishing intensity, reflected in falling catch rates, mean size of animals and increasing female ratios, led to the introduction of more stringent regulations. Thus in 1973 and 1974, landings were limited to a TAC of 3000 and 2000 tonnes, respectively and the maximum size of vessels decreased to 100 GRT and 400 HP engines. These protective measures stabilized the fishery to a certain extent although CPUE and mean size remained low partly due to the relatively good recruitment in the 1970s as previously mentioned. However, somewhat unexpectedly in 1979, landings fell to their lowest level since the beginning of the fishery or only 1.440 tonnes. The drop in landings was most pronounced at SE Iceland, from around 1.370 tonnes in 1978 to only 300 tonnes in 1979. Moreover CPUE in SE Iceland fell from 48 kg/hour to 34 kg/hour (see further in section 3.3.3). The 1979 decline in the *Nephrops* fishery is mostly associated with an unusually strong influx of the cold East-Icelandic current to southeastern waters in the spring and early summer (Eiríksson, 1980: Malmberg, 1983), somewhat reminiscent of the year 1968 in the same area as previously mentioned.

During most of the 1980s, *Nephrops* landings remained rather stable and in accordance with annual TAC recommendations (Fig. 5), averaging about 2.400 tonnes per year. In addition, CPUE increased to 50 - 60 kg/hour accompanied by rising mean size of animals (males 44 - 45 mm CL, see fig. 4) and lowering sex ratio of females (10 - 15%) in catches. This was largely the result of increasing biomass from above average year-classes of the early 1970s (Eiríksson, 1992). By the late 1980s, however, landings fell to 1.700 tonnes in 1990 accompanied by declining CPUE to 35 - 40 kg/hour as well as smaller mean size and higher ratio of females (Eiríksson, 2014).

In the early years of the 1990s the fishery experienced a periodic rise in landings to almost 2.400 tonnes in 1993 as well as an average catch rate of over 50 kg/hour, mostly the result of relatively good recruitment from year-classes of the mid-1980s (estimated mainly 1984 and 1985 year-classes). However, this good recruitment seemed to be generally confined to areas at SE Iceland that led to very high and localized fishing intensity. Therefore landings there rose to 1.400 - 1.500 tonnes during the seasons of 1991 - 1993 accompanied by an average CPUE of over 60 kg/hour. In the aftermath of these high landings and effort, catches declined to an historical low in 1995, at 1.000 tonnes and CPUE of only 28 kg/hour.

In addition to the effects of preceding exploitation rates, the fishery in 1995 showed clear indications of weaker year-classes from the late 1980s (*e.g*. Anon., 2012). Moreover, the fishery was intercepted by a three week general strike by fishermen during the first weeks of the *Nephrops* season in late May - early June, but as a rule catch rates are June, but as a rule

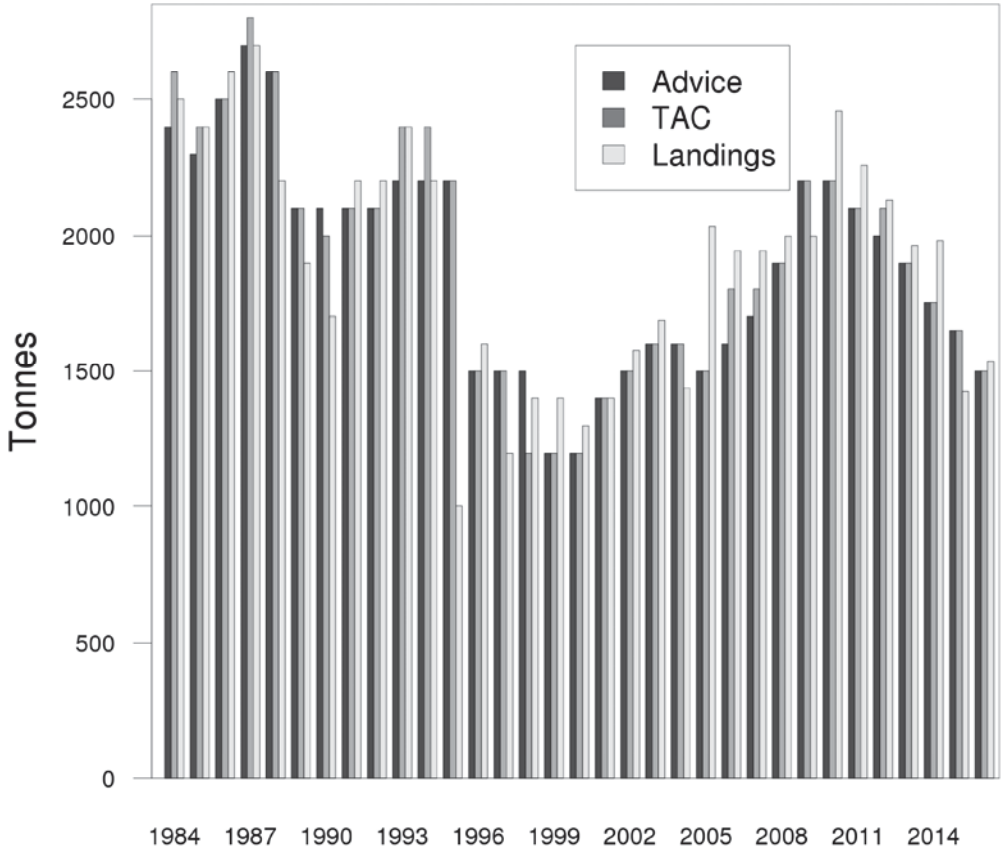

Figure 5. Advice, total allowable catch (TAC) and landings from the years 1984 to 2016. From 1992 it refers to the quota year, September of the previous year to end of August.

catch rates are highest in the springtime during spring blooming (Eiríksson, 2014). Due to the downward stock trends and low catch rates, TAC recommendations as well as the national TACs were diminished drastically in the latter half of the 1990s, down to 1.500 tonnes in the quota years 1995/1996 - 1997/1998 and 1.200 tonnes in the quota years 1998/99-1999/00, probably paving the way for a gradual increase in average CPUE up to over 45 kg/hour in the year 2000.

From the onset of current assessment method in 1978 $F_{0.1}$ was set at 0.21. Due to small yearclasses from 1986 - 1989 and periodically higher F than recommended in the early 1990s the target F was lowered to 0.15 for the quota year of 1997/1998 (Anon., 2007), a level enforced since then. In the 2000s, the fishery started to reap the benefit of the low effort management strategy, with TAC recommendations increasing from 1.200 tonnes in the quota

year 1999/00 to 2200 tonnes in quota years 2008/09 and 2009/10. During the period 2000 - 2004 landings were largely in accordance with annual recommendations and national TAC, however surpassing those substantially in the quota years 2004/05 - 2010/11, reaching about 2.500 tonnes in 2009/10. Concomitantly with increasing landings in the latter half of the 2000s, fishing effort declined by some 50% from the year 2005 to 2007 - 2008 and catch rates (single rigged gear) rose from an average of 45 kg/hour in 2005 to an historical high of 100 - 110 kg/hour in 2007 - 2008, nevertheless decreasing annually from 80 kg/hour in 2009 down to 63 kg/hour in 2012 and further decreased to 45 kg/hour in 2016. Moreover, mean size of *Nephrops* in catches continued to rise in the 2000s to over 48 mm CL for males in the latter half of the decade (Fig. 4) and proportion of females in the catch fell drastically to only 5 - 10 %, both showing figures resembling those of the early years of the fishery in the first half of the 1960s (Eiríksson, 2014). There was a continuous increase in the mean size from 2010 - 2016 reaching 55 mm CL in 2016, a level more than 5 mm larger than in the early years of the fishery.

A twofold rise in CPUE, even threefold in certain areas, most certainly cannot be ascribed exclusively to increasing stock abundance and must therefore have coincided at least with greater availability of *Nephrops* for one reason or another. In retrospect, however, the sudden changes that were observed in some important fisheries parameters in 2007 - 2008, such as fishing effort, changing fishing pattern by areas and increasing availability of larger animals, most certainly did pose some difficult questions concerning stock assessments as will be discussed later. In addition, the decreasing annual CPUE following the historical high catch rates of 2007 and 2008 can probably be attributed to landings exceeding recommendations as well as suspected unusually high unreported catches of *Nephrops* in recent years. However, low recruitment rates are apparent in many areas and may have played a considerable role in this respect.

3.3. Landings and CPUE by areas

Sigurðsson (1965) described the first years of the *Nephrops* fishery, 1960 - 1962, following the introduction of logbooks in 1960 and Skúladóttir (1965) detailed similar data on landings, effort and CPUE by areas in 1960 - 1964. In addition, Eiríksson (1970a) related the trends in landings, effort and CPUE during the decade 1960 - 1969, in which some drastic decline was observed in CPUE, both by areas and overall. Total landings of *Nephrops* in Icelandic waters for Iceland and other nations since 1951 has been published annually by the Marine and Freshwater Research Institute (MFRI), Reykjavík since 1978 and annual CPUE by areas (SW, S, SE) have also been listed since 1988 (e.g. Anon., 2012).

The following description of landings and CPUE is largely detailed by fishery rectangles pertaining to the south-western, southern and south-eastern waters of Iceland (Fig. 1).

3.3.1. South-western areas

In the early years of the *Nephrops* fishery the most rapid expansion occurred on the grounds of Eldeyjarbanki, Reykjanesgrunn and Selvogsleir off the Reykjanes peninsula (fishery rectangles 373, 372, 371) (Fig. 1), reaching over 1.100 tonnes already in 1960, almost 2.000 tonnes in 1962 and peaking in 1963 at around 4.000 tonnes whereof 3.200 tonnes were taken in rectangle 373 (Fig. 6). This development of the fishery coincided with very high catch rates of some 90 - 100 kg/hour that can be explained by the utilization of largely virgin areas at that time. However, the clear effects of overexploitation became clear in the following years with landings dropping to around 1.100 tonnes in 1967 and most markedly in the Eldeyjarbanki area (rectangle 373), although remaining at an average of 1.250 tonnes until 1972 due to good recruitment of year-classes from the early 1960s (see section 4.2). On the other hand CPUE stayed low at less than 40 kg/hour in 1967 - 1972 apart from a temporary increase in 1971. The great level of landings during the decade 1962 - 1972, however, resulted in high sustained fishing mortality rates averaging at around F = 0.3 (Eiríksson, 1979). In the next three decades from 1974 - 2006 the south-western fishery was largely identified with much lower catches than in the 1960s and early 1970s, averaging less than 400 tonnes a year and ranging from 700 tonnes in 1980 to only 100 tonnes in 2000. Moreover, CPUE remained extremely low for most of the period 1973 - 2005, 25 - 35 kg/hour, apart from the 1980s when they averaged between 40 - 45 kg/hour. As discussed later this periodic rise in catch rates can be partly explained by increased recruitment of larger *Nephrops* of year classes from the early 1970s. In retrospect, the 1970s were also typified by small mean size of animals (Fig. 4) and a very high proportion of females in the catch due to the combined effect of high exploitation rates and relatively good recruitment from year classes of the early 1970s (Eiríksson, 2014).

The development of the *Nephrops* fishery in those main areas at SW Iceland during the period 1998 to 2005 stands out as being historically different to any other previously experienced at Iceland (Fig. 6). Annual landings were lower than formerly observed or only some 100 to 200 tonnes per annum and historically low CPUEs were experienced, averaging 25 kg/hour a year with a seasonal low of only 17 kg/hour in 2004. In addition, *Nephrops* surveys from the period 1998 - 2005 resembled the fishery trends with overall low indices. In May 2006, however, the annual *Nephrops* trawl survey revealed good catches of *Nephrops* off SW Iceland, especially in fishery rectangle 373 (Anon., 2007). Although *Nephrops* vessels were notified, many had to leave the area relatively soon due to large by-catch of cod surpassing their quota allowance. Despite those limitations, the total landings at SW Iceland rose to 300 tonnes in 2006 and CPUE to 48 kg/hour.

In regard to the notable changes observed in CPUE, landings and survey indices in 2006, the continuation in the forthcoming years did not come altogether as a surprise although the magnitude of the increase in CPUE, especially those in rectangles 373 and 372 of around 95 kg/hour in 2007 and the resultant south-western area landings of 1.200 tonnes were not easily foreseen. Moreover, the extremely high catch ratio of large male *Nephrops*, 50 - 70 mm

carapace length (estimated at some 10 to 15+ years of age), had neither been apparent as recruiting juveniles in catch and survey samples nor had led to increasing landings (Fig. 4).

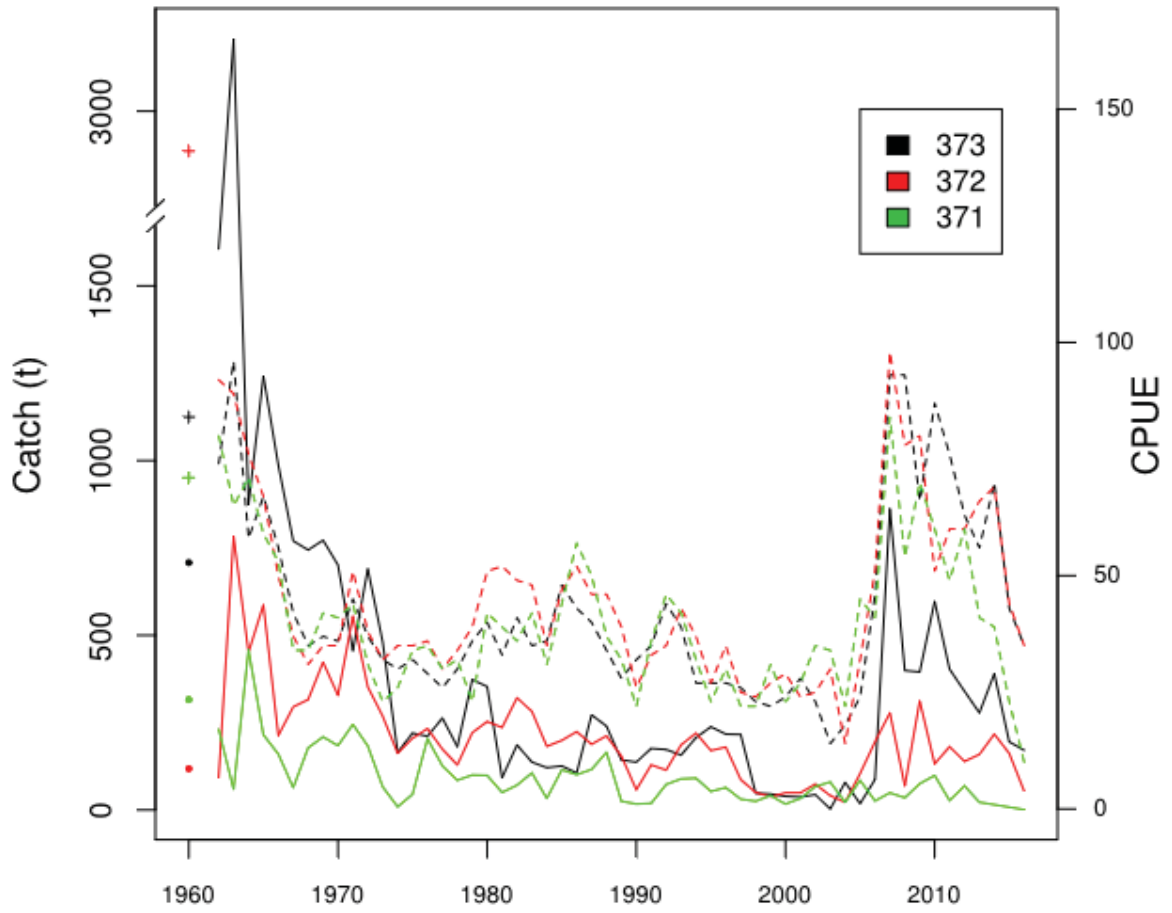

Figure 6. Catches (solid lines, and point symbol) and standardized CPUE (dotted lines and plus symbol) of *Nephrops* from rectangles 371 - 373 (See fig. 1 for locations) during the years 1960 - 2016 (data is missing from 1961). Note broken y-axis.

In hindsight, however, some indefinite indications of improving recruitment may have been noticed in surveys in some odd years but were not followed up in the fishery. Although catch rates continued relatively high in those southwestern rectangles, landings decreased to around 600 tonnes in 2011 and CUPE to 50 - 79 kg/hour within the three rectangles. The large size of *Nephrops* in the latter part of the 2000s and a very low ratio of females resembled those of the early years of the fishery at the beginning of the 1960s (Fig. 4). The CPUE decreased gradually between 2012 - 2016 to 35 kg/hour, in rectangles 373 and 372, with reduction in landings. The same was evident in rectangle 371 and less then 10 tonnes were landed in 2015 - 2016 and CPUE reached an all time low. The mean size of males in rectangle 373 decreased from the peak of 2003 (note small sample size from that year) until 2012. Small recruitment pulse was evident in rectangle 373 (as well as in 323 directly south of 373) during 2012 - 2015 (Anon., 2015), but since 2012 the mean size has increased to 54 mm CL in 2016. In rectangle

371 and 372 the mean size has been increasing almost constantly from the year 2000 to 2016, from 45 to 57 mm CL (Fig. 4).

The northernmost fishing areas at SW Iceland, Jökuldjúp in Faxaflói (rectangles 423 and 473) (Fig. 1) have only periodically been of importance in the Icelandic *Nephrops* fishery, although Sæmundsson (1937) included these grounds as being one of major areas for *Nephrops* as by-catch in the bottom trawl fishery in the early 20th century. The first records of fishing in this area date back to only some 25 tonnes taken in 1962, but the expansion of the fishery was very rapid up to a historical high of 600 - 700 tonnes in 1963 and 1964. However, landings fell to 100 tonnes already in 1966 and CPUE dropped from 80 kg/hour in 1962 to 50 kg/hour in 1966 (Fig. 7), much in line with the fishery trends observed in the nearby Eldeyjarbanki (rectangle 373).

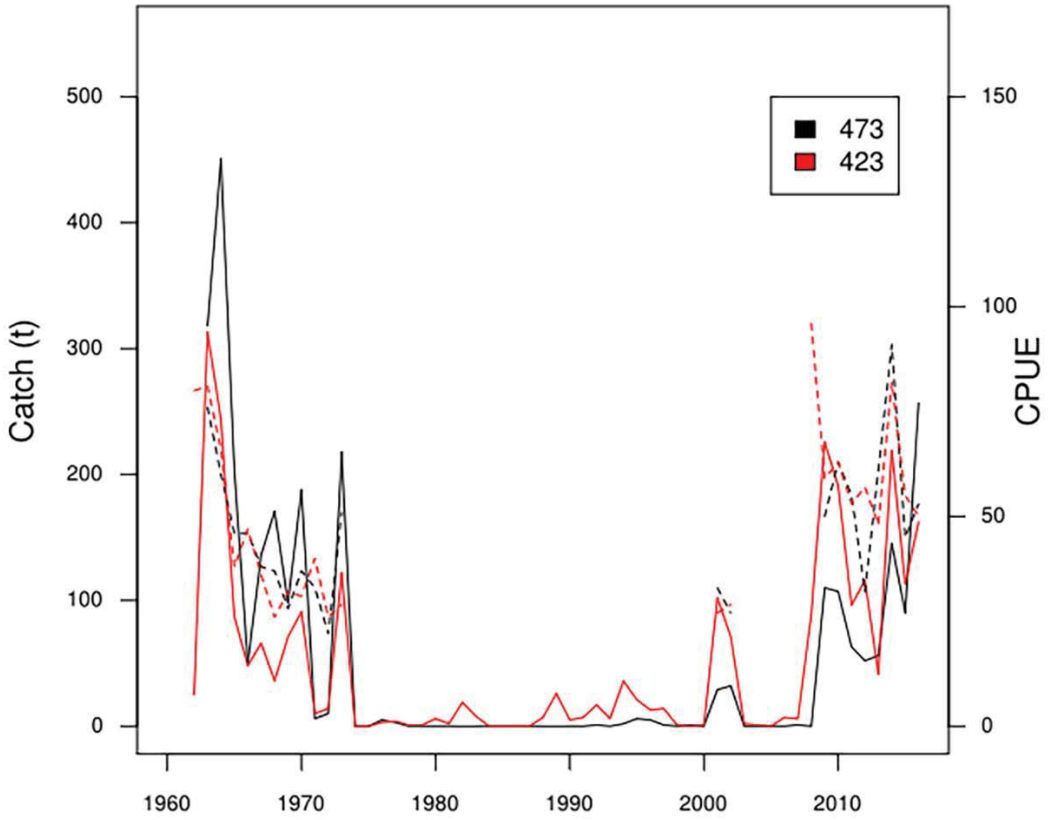

Figure 7. Catches (solid lines) and standardized CPUE (dotted lines) of *Nephrops* from rectangles 472 - 473 (See fig. 1 for locations) during the years 1962 - 2016).

Although landings rose periodically to 200 - 300 tonnes in 1967 - 1970 and again in 1973, CPUE fell consecutively to only 22 - 26 kg/hour in 1971 - 1972, however rising up to 50 kg/hour in rectangle 473 in 1973 with increasing landings from that year (Fig. 7).

During almost 35 years, 1974 to 2007, *Nephrops* landings from rectangles 423-473 remained minimal, amounting to only 0 - 30 tonnes annually, apart from the years 2001 and 2002 when they rose to just over 100 tonnes. Although resembling to a certain extent those decades of overall small landings in other areas at SW Iceland there may have been additional factors to that of low catch rates such as long term closure of the inner Faxaflói for trawling and seining from the early 1970s to the early 2000s that included part of the *Nephrops* grounds. Moreover, these most north-western areas have always been renowned for best average catch rates in late summer or autumn by which time the total allowable catch (TAC) had most often been reached. In the 2000s the *Nephrops* fishing season was extended from the typical May - August period for decades to an April - September (November) season of the last few years. This provided more opportunity for a successful autumn fishery, possibly paving the way for increasing effort in the area. Landings rose to 90 tonnes in 2008 and over or around 300 tonnes in 2009 - 2010 (Fig 7.). The landings have fluctuated during 2011 - 2016, but reached over 400 tonnes in 2016. At the same time, CPUE has followed the peaks in the fisheries fluctuating from 30 - 50 kg/hour reaching 90 kg/hour in rectangle 423 in 2008 and above 80 kg/hour in both rectangles in 2014.

A trial *Nephrops* creel fishery was carried out in 1989 - 1991, largely in the closure area of Faxaflói described above. Landings reached over 30 tonnes in 1990 with an average CPUE of 0.3 kg/creel haul and a maximum of 0.4 kg/creel haul in September that year (Anon., 1992a). Although these catch rates compared favourably with those experienced in other *Nephrops* creel fisheries the trial fishery was discontinued in the spring of 1991, partly due to weakness of ropes and thus loss of creels. Evidently the equipment had to be strengthened for the heavy seas and deeper waters of Icelandic *Nephrops* grounds. Despite this partly successful pioneering work only limited trials have been carried out in recent years.

3.3.2. Southern areas

The fishing grounds SA - SW of Vestmannaeyjar (fishery rectangles 319, 320) included those surveyed in the early fishing trials of the 1940s and 1950s and among the first areas utilized from 1958 onwards in the commercial *Nephrops* fishery along with the grounds off Reykjanes peninsula mentioned previously (Fig. 1). Selvogsbanki further westwards (rectangle 321) became an important fishing ground a little later. Landings had already reached 700 tonnes by 1960, levelling at around 600 tonnes in 1962 - 1963 but falling to only some 250 tonnes in 1964 (Fig. 8). In the coming years, however, landings rose rapidly to a historical high level of around 1.400 - 1.450 tonnes in 1971 - 1972. Following this temporary peak, the catch fell to around 500 tonnes in 1973 - 1974 and remained at 550 - 600 tonnes annually for the 1970s and 1980s, apart from a temporary decline to less than 300 tonnes in 1978 and peaks of over 700 tonnes in 1983 - 1984 and 950 tonnes in 1988. During the 1990s and 2000s average landings were around 470 tonnes a year, some 100 tonnes below the overall average for the period 1960 to

2011. However, fluctuations in catches were notable, peaking at 950 tonnes in 2005 and dropping temporarily to only 50 tonnes in 2007. This historically low catch for the Vestmannaeyjar - Selvogsbanki area was distinctly related to the dramatic increase in the fishery at SW Iceland from 300 tonnes in 2006 to 1.200 tonnes in 2007 described earlier. From 2012 - 2016 there has been continuous decline in landings from 440 tonnes to sole 50 tonnes in 2016.

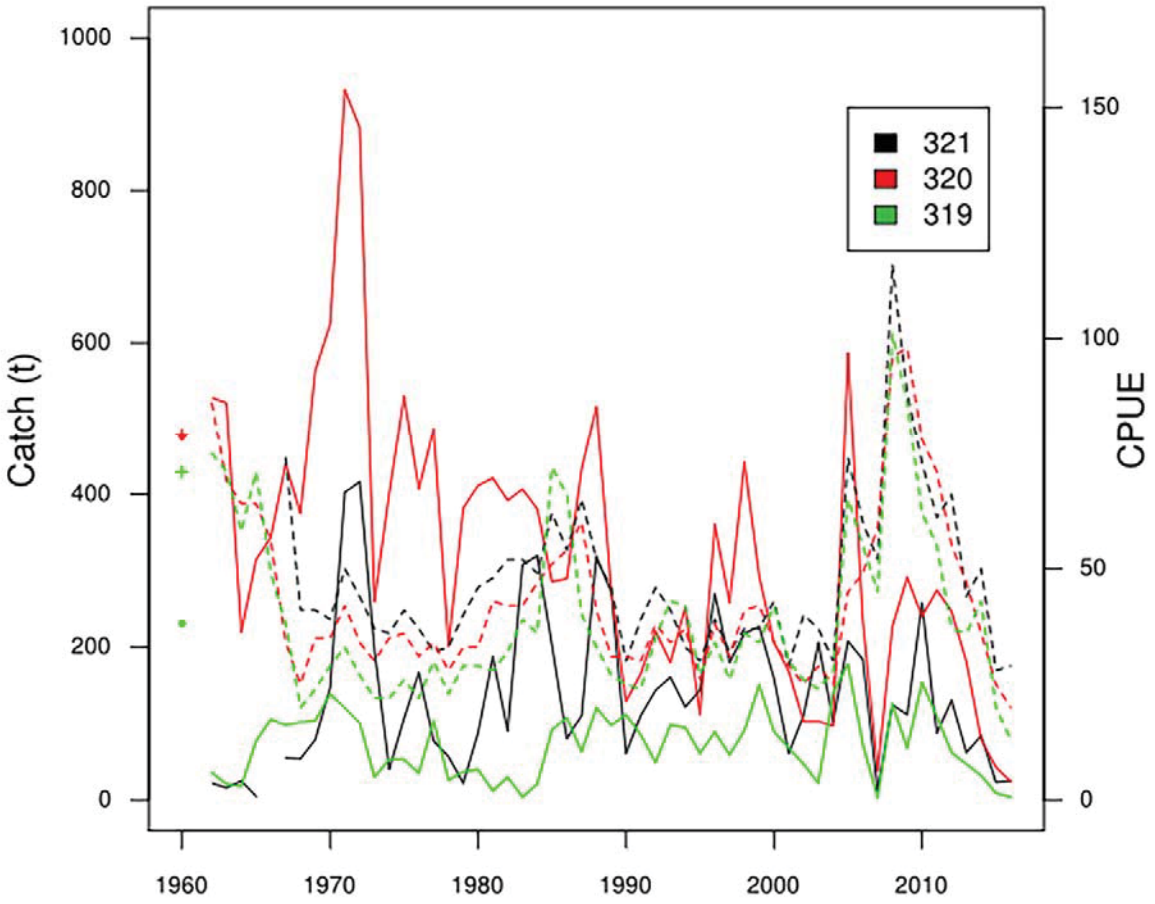

Figure 8. Catches (solid lines, and point symbol) and standardized CPUE (dotted lines and plus symbol) of *Nephrops* from rectangles 319 - 321 (See fig. 1 for locations) during the years 1960 - 2016 (data is missing for 1961).

CPUE in those southern rectangles decreased in the 1960s from 75 - 85 kg/hour in 1960 and 1962 to only around 25 kg/hour in 1968 but recovered again to an average of 43 kg/hour in 1971 (Fig. 8). This periodical rise in CPUE, concurring with record landings in 1971 - 1972 was largely related to increased recruitment from year classes of the early 1960s. CPUE continued low for most of the 1970s or between 30 - 35 kg/hour, increasing to an average of over 40 kg/hour in the 1980s with a peaks around 50 - 70 kg/hour in 1985 - 1987. Following this temporary peak, that was partly due to year classes from the early 1970s, CPUE decreased again to relatively low catch rates of 30 - 40 kg/hour during the 1990s and early 2000s. In the latter half of the 2000s, however, CPUE rose from only 25 kg/hour in 2004 to around 50

kg/hour in 2005 and a very high of 100 kg/hour in 2008 - 2009, although declining again to 35 - 45 kg/hour in 2013. The CPUE continued to decrease and was at all time lowest levels around 20 kg/hour in 2016 concurrently with decreasing landings.

Mean carapace length of catches showed a decreasing trend in the early years of the fishery in the 1960s and remained low until the latter half of the 1970s (Fig. 4). In the 1980s and 1990s mean size of *Nephrops* varied considerably followed by increasing carapace length in the 2000s due to year classes from the mid 1990s and no apparent recent influx of juveniles. The peak in landings observed in 2005 can also be related to this recruitment of year classes from the mid-1990s as well as additional effort from *Nephrops* vessels from Southeast Iceland that had previously only fished for *Nephrops* in south-eastern waters. From 2011 - 2016 there has been a continuous increase in mean length and apparently no evident recruitment (Anon., 2015). As such, the mean length reached an unprecedented size of 60 mm CL in rectangles 321 and 320 in 2015 and 2016, respectively.

3.3.3. South-eastern areas

The Icelandic *Nephrops* fishery was implemented somewhat later at SE Iceland than elsewhere although Belgian trawlers had been fishing in south-eastern waters since 1950. Reportedly, however, Icelandic fishers caught about 200 tonnes in 1960 after which landings fell to less than 100 tonnes in 1962. The most important fishing areas from the beginning have been those located in the deeps of Skaftárdjúp, Skeiðarárdjúp, Breiðamerkurdjúp and upper Hornafjarðardjúp (rectangles 367, 366, 365) (Fig. 1).

The development of the fishery was rapid following 1962 or up to over 1.400 tonnes in 1966, especially in the two major rectangles of 367 and 365, although declining promptly to less than 400 tonnes in 1968 (Fig. 9). The main reason for this decrease in landings is considered to be the influence of colder waters of the East Icelandic current, including an influx of drift ice reaching as far west as Breiðamerkurdjúp in late winter and spring (Stefánsson, 1972), thus likely affecting *Nephrops* availability and CPUE. Little is known how *Nephrops* react to such a cold spell and if that extends the period they stay in their burrows as could be suspected by lower CPUE. However, it has to be kept in mind that with increasing effort up to 1966, CPUE decreased from over 80 kg/hour in 1964 to less than 60 kg/hour in 1967 and only 30 kg/hour in 1968 giving an additional indication of the effect of high prolonged fishing effort. Sharp increase in CPUE during the next fishing season of 1969 is an indicator that the cold spell didn't cause mass mortalities on those grounds. The influence of fishing has been substantiated later, by no prolonged records of average seasonal catch rates over 60 kg/hour for four decades, or until in the 2000s (Fig. 9).

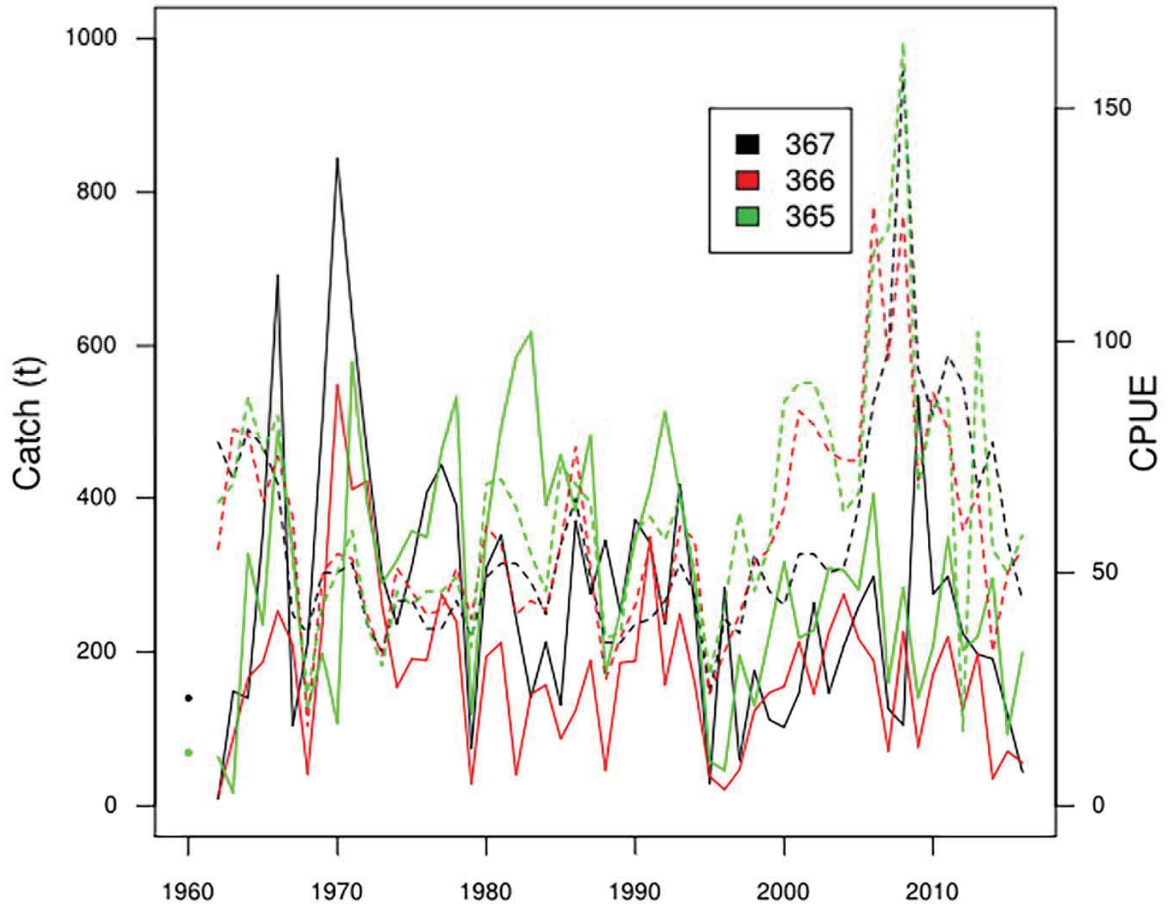

Figure 9. Catches (solid lines, and point symbol) and standardized CPUE (dotted lines) of *Nephrops* from rectangles 365 - 367 (See fig. 1 for locations) during the years 1960 - 2016 (data is missing for 1961).

Following the low season of 1968, landings rose again to a historical high of around 1.500 and 1.600 tonnes in 1970 and 1971, probably reaping the benefits of good recruitment from year classes from the early 1960s, albeit with high fishing mortalities. During the course of the 1970s landings fell to around 700 tonnes in 1974 but rose again to almost 1.200 tonnes in 1977 and 1978 due to good recruitment of year classes from the early 1970s. Owing to the high proportion of relatively young *Nephrops* mean carapace length of males remained at just over 40 mm in the years 1975 - 1978 , decreasing from over 50 mm CL in the early 1960s (Fig. 4). In addition, fishing mortality rates reached heights of around F = 0.38 in 1976 - 1977 as shown later in section 4.2, indicating great overexploitation of a *Nephrops* stock of biennial reproductive nature (Eiríksson, 1970b, 1993, 2014). In 1979, south-eastern waters experienced another spring of extremely low sea temperature (Malmberg, 1983), resembling that of 1968, and landings plummeted to only 200 tonnes.

For most of the 1980s annual landings remained between 800 - 1000 tonnes apart from lower catches of around 600 tonnes in 1985 and 1988 - 1989. In addition, CPUE that had averaged

about 44 kg/hour in the 1970s rose to 50 - 60 kg/hour for most of the 1980s although decreasing periodically to less than 40 kg/hour in 1988 - 1989. In the early 1990s annual landings increased to 900 - 1.100 tonnes and CPUE to around 60 kg/hour in 1990 - 1993, but declined again to record low landings of only 130 tonnes and CPUE of less than 30 kg/hour in 1995. Concerning this unfavourable trend in landings it must be kept in mind that fishing mortality rates had been very high for over a decade from the early 1980s to 1994, averaging around F = 0.3, and apparently only plausible due to relatively good recruitment. There was also a sharp increase in mean lengths, or from 40 mm in 1990 to 46 - 50 mm CL in 1993, although sudden drop in *Nephrops* size occurred during 1995 - 1997 (Fig. 4). Prior to that the mean length had been decreasing for most of the 1980s. In addition to those trends, the 1995 fishing season was partly affected by general strike by fishermen early in the *Nephrops* season in May, normally the best part of the season with highest CPUE rates. Following the 1997 season, the MRI adopted a stricter F_{opt} strategy of F = 0.15, a recommendation policy more in line with value than yield per recruit, first described by Eiríksson (1976) for Icelandic *Nephrops*. This new fishery policy was approved by the Ministry of Fisheries but repeated MRI recommendations concerning issuing separate quotas for south-western and south-eastern waters due to variable recruitment trends by areas (*e.g.* Anon., 2007) were not, however, adopted by the ministry.

Subsequent to 1995, landings rose gradually from 350 tonnes in 1996 to almost 900 tonnes in 2006 but decreased temporally to 350 tonnes in 2007 when the fishery shifted early in the season to the south-western areas as described previously. In 2008 - 2014 annual landings have ranged between 550 - 870 tonnes in those three major fishery rectangles at SE Iceland. In addition, CPUE increased from less than 30 kg/hour in 1995 to 80 - 90 kg/hour for rectangles (365 and 366) in 2000 - 2004, although decreasing periodically to some 50 kg/hour in 2005. Similar to the more western areas discussed previously, CPUE increased at SE Iceland subsequent to 2005 or from 50 kg/hour to a historical high for Icelandic grounds of around 150 kg/hour in 2008 although rapidly decreasing again to about 60 - 90 kg/hour in 2011 - 2012. Due to early onset of the fishing season in the recent decade the bulk of the catch at SE Iceland has been caught in late March - April/May. Unusually low CPUE for rectangles 365 in 2012 and 366 in 2014 are as such not representative for the fisheries, as historically the CPUE is calculated from May - September. When calculated from March to September, the CPUE goes from 16 to 104 kg/hour in 2012 in rectangle 365 and from 33 to 68 kg/hour in 2014 in rectangle 366. The overall trend however, in both catches and CPUE from 2013 - 2016 is downward, as CPUE was 50 - 55 kg/hour in 2016 with 200 tonnes caught during that year. Following high mean lengths in the early 2000s, there was a decline in the mean to around 45 mm CL, mainly because of strong recruitment pulses from latter part of the 1990s (*e.g.* Anon., 2007)**.** Since 2005 there has almost been a continuous rise in mean size and in 2016 the average male had

reached a record size of 54 mm CL in rectangle 364, 56 mm CL in rectangle 365 and 57 mm CL in rectangles 366 and 367.

Somewhat differently, the catch rate in the most westerly area Skeiðarárdjúp (rectangle 367) remained rather similar in the early 2000s at an average of 45 kg/hour, although rising eventually to a similar record high of around 150 kg/hour in the year 2008 (Fig. 9). Although not proven by bottom sedimentology data, a large run-off from a sub-glacial volcanic activity that occurred in the Vatnajökull glacier ice cap in the autumn of 1996 may have affected some *Nephrops* grounds especially those in more shallower waters. Certainly, many *Nephrops* and Danish seine fishers avoided some of these grounds for some years after this sub-glacial run-off and *Nephrops* landings in the seasons 1997 - 2001 were only 40% of the long-term average for that area. This area has also had on average higher mean length than the other areas in the east, with somewhat less but identical fluctuations as in other rectangles (Fig. 4).

The *Nephrops* fishery in the most easterly grounds of outer Hornafjarðardjúp and Lónsdjúp (rectangles 364 and 414) (Fig. 10) initiated in the early 1970s or a little later than in those rectangles described above. Although a solitary 100 tonnes were recorded in 1967, landings were negligible until they increased from less than 40 tonnes to almost 300 tonnes in 1971 - 1974 and a further 450 tonnes in 1976. In the late 1970s, however, landings diminished again to only 60 tonnes in the cold year of 1979. Subsequently, *Nephrops* catches rose rapidly to a historical high of almost 500 tonnes in 1982 and landings averaged around 420 tonnes in the period 1982 - 1985, although declining equally fast to only 30 tonnes in 1989. Similar to the more westerly south-eastern grounds landings in the early 1990s rose periodically to around 450 tonnes in 1992 although tapering down again to an average of only some 30 tonnes in the late 1990s.

The trend in CPUE in the 1970s - 1990s resembled that of nearby areas at SE Iceland, averaging around 45 kg/hour in the 1970s but rising to an average of 55 kg/hour in the 1980s. Following a downward trend in late 1980s, CPUE rose temporarily to some 70 - 90 kg/hour in 1992 - 1993 or much in line with high landings of 300 - 440 tonnes in those years but decreased again to an average of some 30 kg/hour in the latter part of the 1990s. This periodical rise in the fishery in the early 1990s can be attributed to good recruitment from year classes estimated from 1984 - 1985 that were particularly abundant at SE Iceland (*e.g.* Anon., 1992b).

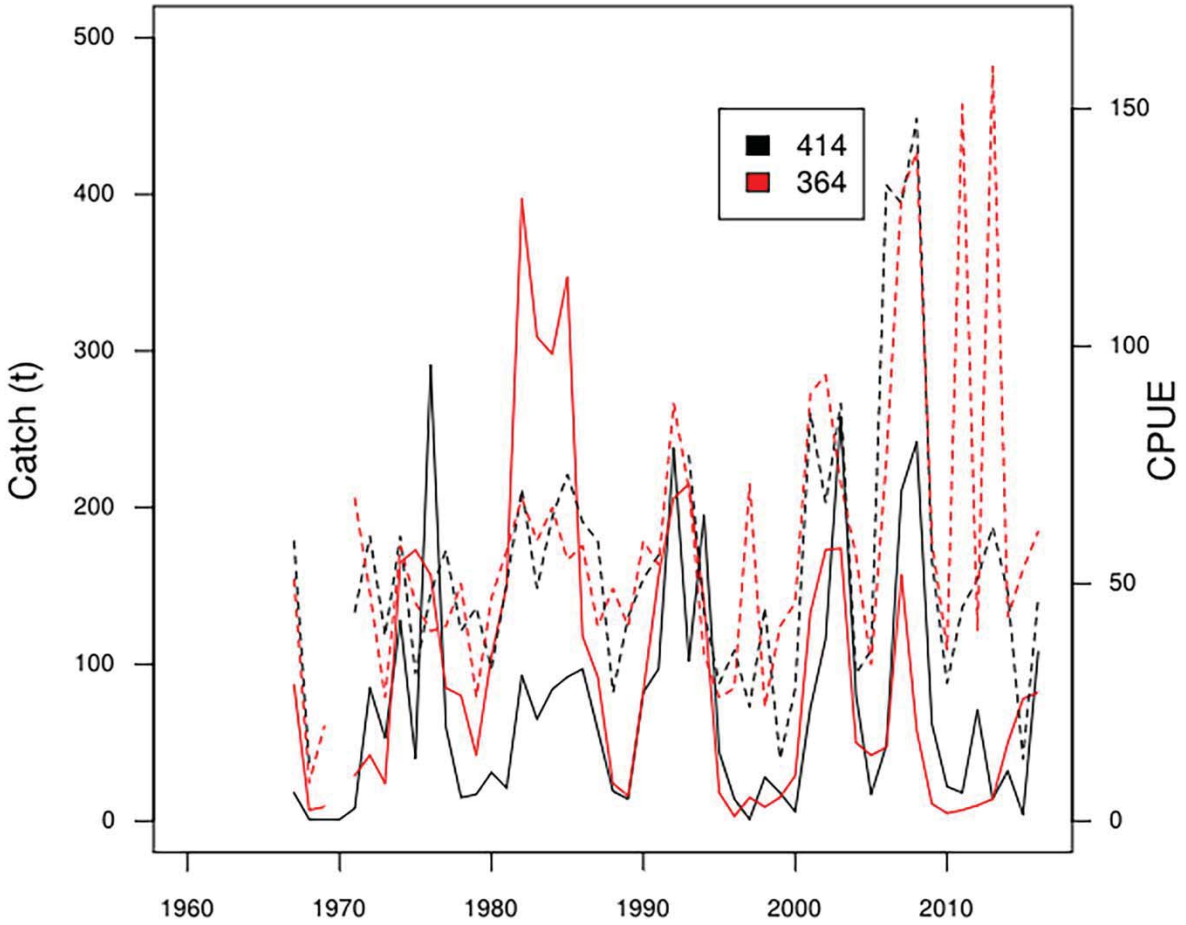

Figure 10. Catches (solid lines) and standardized CPUE (dotted lines) of *Nephrops* from rectangles 364 & 414 (See fig. 1 for locations) during the years 1967 - 2016.

The fishery improved again in the early 2000s with landings rising steeply from only 35 tonnes in year 2000 to 200 - 430 tonnes in 2001 - 2003 with a coinciding average rise in CPUE to 80 - 85 kg/hour due to improved recruitment from year classes from the latter part of the 1990s (*e.g.* Anon., 2007). Still, another decline was experienced in those easternmost fishing rectangles when landings fell to only 60 tonnes and CPUE to around 30 kg/hour in the cold season of 2005 (Temperature < 4 °C at 100 m depth on nearby Stokksnes 2 hydrographic station, for the first time since 1979). However, subsequent to 2005 landings increased repetitively again in those easterly areas to over 300 tonnes and CPUE to a historical high of 120 - 150 kg/hour in 2007 – 2008, although decreasing rapidly again to very low landings of around 30 tonnes in 2011 - 2012. The cactch has been increasing since then with close to 300 tonnes landed in 2016. At the same time there have been rather large fluctuations in CPUE. The fluctuations in mean length in rectangle 364 coincide well with nearby rectangles 365 and 366 (Fig. 4). Thus, the mean male length reached an all time high in 2016 with a mean CL of 54 mm.

The fishery in those eastern-most areas is characterized by extreme periodical pulses in both landings and CPUE (Fig. 10). These are generally more intensified than in other nearby south-eastern areas, particularly concerning the relatively shorter peak and longer low periods in landings and CPUE (Fig. 9). This can be partly explained by the nearby cold-water front of the East Icelandic current that has brought extreme cold water masses, e.g. around 1968, 1979 and 2005 (Stefánsson,1972, Malmberg, 1983, Anon., 2009), but also having its effect on catch rates following strong north-easterly winds in the area, as these areas are less sheltered from that wind direction.

4. STOCK ASSESSMENTS OF ICELANDIC *NEPHROPS*

4.1. Early stock evaluations

Stock assessments of crustaceans have generally been hampered by unreliable data on age, growth and mortality rates, especially so for long-lived species. Consequently, earliest evaluations of stock components of Icelandic *Nephrops* were focused on relationships between catch and effort giving indications of maximum sustainable yield (MSY) by fishing areas (stock units) or the stock as a whole. Unavoidably, such relations based on e.g. average effort for several years (3 - 8) plotted against annual CPUE for the last of the running series of years (Gulland 1961; Skúladóttir, 1967; Eiríksson, 1979) only give a steady state indications of yield by sustained effort. Ideally the number of years chosen for such relations should reverberate number of the most important years for each year-class in the fishery. Thus, Skúladóttir (1967) and Eiríksson (1974) estimated a fishery potential of the Icelandic *Nephrops* stock in the range of 2.900 - 3.500 tonnes annually. These early assessments, being somewhat higher than long-term averages of some 2.400 tonnes annually, are influenced by early virgin stock fishery and a limited number of years fishing history. In addition, average effort calculations depend considerably on the number of years chosen.

Eiríksson (1976, 1979) using a running average effort of 3 years against CPUE in the last year of 3 showed an average catch prediction for rectangle 365 at SE Iceland amounting to some 325 tonnes annually based on catch/effort data from 1964 - 1975. That complies well with the long term average of 317 tonnes in this area for the period 1964 - 2011. Moreover, Eiríksson (1976), included the first cohort analyses on “aged-based” cohort sizes (varying number of CL mm groups depending on size) applied on *Nephrops* stocks described previously in section two.

4.2. Annual stock assessments by age-based VPA

Annual VPA stock assessments were initiated in 1977 (*e.g*, Anon., 1982; Anon., 2015). Such analytical assessments have been carried out with some success in the last four decades. From the beginning of stock assessment in 1977 to 2014, the VPA analysis were run with estimated age classes from 3 to 16 years old. Usually the plus group or 16 years old Nephrops (CL 64 mm +) were few. As mean CL got larger and stock size increased around 2010 the plus group enlargened. As such, the recent assessment has been run with age classes from 3 – 20 years old. In addition, Eiríksson (1999) further indicated that assessments of the stock as a whole gave very similar results as the combined value for the two separate assessments for SW and SE fishing areas during 1992 - 1998, although the two areas had a different stock trend over that period.

During the first decade of the assessment series which started in 1963, the estimated biomass diminished considerably during a period of high catches and increasing fishing mortality that reached a record level of 0.48 in 1972 (Fig. 11). Recruitment was high in historical perspectives during the first decade, especially in 1966 - 1977 (yearclasses from 1961 - 1962). The biomass increased again from 1974 to 1980 as catches were considerable lower and the strong yearclasses from 1970 - 1974 become more prominent in the catch. Between 1981 - 1990 the catches were stable around 2.400 tonnes, recruitment rather low and with fishing mortality around 0.3. That resulted in slowly declining biomass through that decade, the stock reaching a minimum of 12.400 tonnes in 1988. At the start of the 1990's the fishing mortality was still relatively high with catches over 2.000 tonnes (Fig. 11).

As described in chapter 3.3.3 a stricter F_{opt} strategy was adopted in 1997. In the following years two good yearclasses from 1990 and 1992 and later a spell of good recruitment from 1996 to 2001 entered the fishery. With firmer management measures catches gradually increased reaching around 2.500 tonnes in 2009 and 2010. The estimated biomass reached over 25.000 tonnes between 2006 and 2008, close to estimates of a nearly virgin stock. High CPUE on all grounds during the same period have been described in earlier chapters. The fishing mortality has consequently been relatively low since 1997. Although it is has increased a little in recent years, it is still at a lower level than before the reduction in F_{opt} . However, the biomass has decreased sharply from 2009 to an all time low of 10.400 tonnes in 2016. The decline was mainly driven by recruitment failure, as yearclasses since 2005 have all been smaller than any previously measured yearclass and have reached a level never seen in this stock. At the same time there has been a reduction in catches and the average CL has reached an all time high (Fig. 4). The biomass of 10+ *Nephrops* also reached an record high in 2009 and in 2016 despite reduction in the total biomass, abundance of large animals was still above the long term average (Fig. 11).

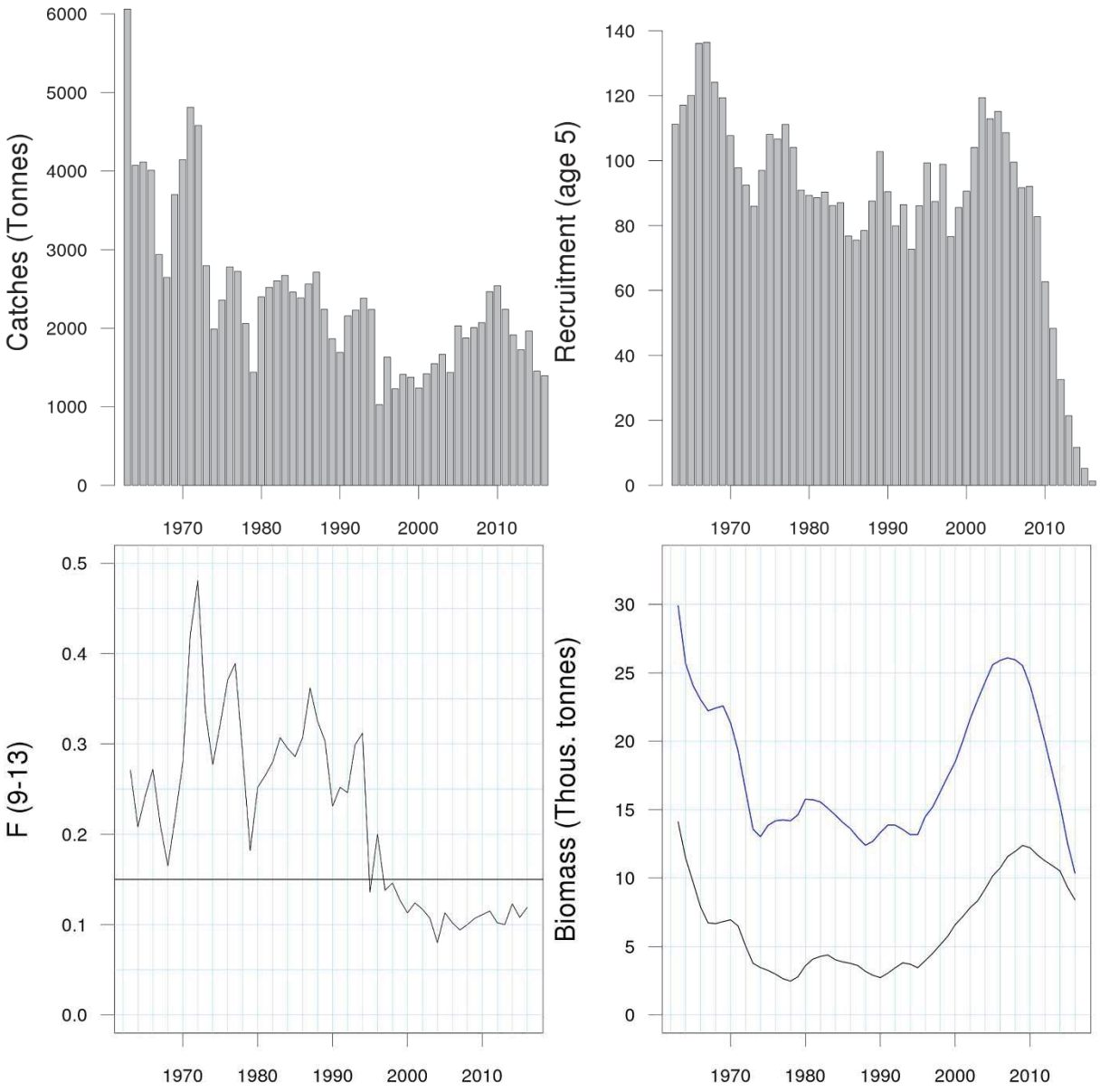

Figure 11. Catches, recruitment at age 5, fishing mortality and indices of fishable (6 years and older, blue line) and large category (10 years and older, black line) biomass.

In hindsight relatively large overestimates of total biomass were experienced during the period 1985 - 1989. This divergence in assessments can be firstly related to a great increase in CPUE in the early 1980s with CPUE remaining relatively high until 1988 leading to underestimates of F values. Moreover, these high catch rates were later ascribed to high availability compared to biomass estimates as indicated by the regression of annual CPUE and biomass in 1971 - 1991 where CPUE values for 1985 - 1987 showed great positive deviation from the regression (Eiríksson, 1992). Conversely, annual stock size estimates later turned out to be considerately underestimated during the decade 1996 - 2006. For some reason or another, very low catch rates were experienced during this period, in particular at SW Iceland where landings averaged

129 tonnes in 1998 - 2004 and CPUE averaged only some 25 kg/hour. Yet in the following years landings at SW Iceland rose to 1.200 tonnes in 2007, their highest level since 1972 and CPUE increased to a record high of 93 kg/hour. This turning point in the south-western fishery cannot be explained by recent improvement in recruitment since average weight of male *Nephrops* at SW Iceland amounted to over 100 g or an estimated age of some 10+ years. Therefore somewhat inexplicitly, *Nephrops* had apparently evaded the trawl fishery as well as surveys to a large extent for over a decade. In continuation overall CPUE reached a record high of over 110 kg/hour in 2009 and decreased after that to some 60 kg/hour in 2013.

Variations in stock trends can best be described by varying recruitment, in particular for remote areas, although fishing intensity and possibly growth must also be important. On the other hand, small scale assessments may not be all that necessary except possibly by using underwater photography of *Nephrops* burrows (Tuck *et al*., 1997).

5. CONCLUSION

Nephrops has now been fished in Icelandic waters for more than six decades . The fishery has behaved like many others with an initial phase of low catches, although mainly of foreign origin followed with a rapid increase of domestic landings. After it reached a peak value of 6.062 tonnes in 1963, the catches remained high during that decade (1960 - 1970) with a relatively high fishing mortality. That period was also characterized by increasing effort and reduction in CPUE, but also by an cold spell that led to less availability of *Nephrops* at the SE areas areas during 1967 - 1968. In the next two decades (1970 - 1990) catches were regulated, but fishing mortality remained relatively high which led to an overall decrease in biomass. More stringent management also led to a build up of biomass during 1990 - 2010 and an increase in average sizes of animals. Pulses in recruitment have caused many short term fluctuations witnessed in the stock, but from 2005 all yearclasses have been very small leading to a sharp decline in biomass and all an time low abundance in 2016.

6. ACKNOWLEDGMENTS

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