Reproductive biology of a new invader, brown shrimp *Crangon crangon* (L), in Iceland

Helena Puro

Faculty of Life and Environmental Sciences
Engineering and Natural Sciences
University of Iceland
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15 ECTS undergraduate research project of
Baccalaureus Scientiarum degree in biology

Supervisiors
Prof. Guðrún Marteinsdóttir
Jónas Páll Jónasson

Faculty of Life and Environmental Sciences
Engineering and Natural Sciences
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Æxlunarferlar nýs landnema, sandrækju *Crangon crangon* (L) við Ísland

Helena Puro

15 eininga ritgerð sem er hluti af
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Líf- og umhverfisvísindadeild
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Háskóli Íslands
Sturugötu 7
101 Reykjavík

Sími: 525 4000

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Yrirlýsing

Hér með lýsi ég því yfir að riterð þessi er samin af mér og að hún hefur hvorki að hluta til né í heild verið lögð fram áður til hærri prófgráðu.

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Helena Puro

Abstract

Aspects of the reproductive biology of brown shrimp *Crangon crangon* were studied in Helguvík bay, southwest Iceland over a period of twelve months. *C. crangon* is a new invader in Iceland with first record in 2003. The life cycle and reproductive behaviour of *C. crangon* is not fully understood and even less is known about the Icelandic population. This paper tries to highlight the reproductive biology with comparison to other shrimp populations in Northern Atlantic. Size, fecundity, reproductive output, size-at-maturity and seasonal fluctuations were studied. A total 1060 shrimps from August 2009 to July 2010 were length and weight measured and sex was identified. Fecundity and reproductive output was determined for 30 shrimps and a comparison was done with the previous study of the same Helguvík population (2010). Sex ratio was highly variable between months and within size classes but generally females were more numerous and dominating in biggest size classes. No correlation was found between female size and fecundity or reproductive output which differs from other studies done on brown shrimp.

Keywords: *Crangon crangon*, brown shrimp, reproductive biology, fecundity, reproductive output, invasive species, Iceland

Úrdráttur

Kannaðir voru æxlunarferlar sandrækju (*Crangon crangon)* frá Helguvík á Álftanesi. Sandrækjan er nýr landnemi á Íslandi en hennar varð fyrst vart árið 2003. Almennt eru lífs- og æxlunarferlar sandrækju frekar illa þekktir og enn minna er vitað um þá hér á landi. Í þessari ritgerð voru bornir saman æxlunarferlar sandrækju á Íslandi við aðra stofna í Norður – Atlantshafi. Stærð, frjósemi, hlutfall eggja af þyngd kvendýra og stærð við kynþroska var metin eftir mánuðum. Í heildina voru 1060 rækjur kyngreindar, lengdar og þyngdar mældar frá águst 2009 til júlí 2010. Frjósemi og hlutfall eggja af þyngd kvendýra var metið fyrir 30 rækjur og borið saman við eldri mælingar frá sama stað. Kynhlutfall var mjög breytilegt milli mánaða sem og stærðarflokka og voru stærri rækjurnar að jafnaði kvenkyns. Ekki var marktækt samband á milli stærðar og frjósemis eða hlutfalls eggja af þyngd kvendýra og er það frábrugðið öðrum rannsóknum.

Lykilorð: *Crangon crangon*, sandrækja, æxlunarferlar, frjósemi, ágeng tegund, Ísland

Acknowledgements

I address my acknowledgements to Prof. Guðrún Marteinsdóttir and the Marice lab at the University of Iceland for the support and help which I got during this project. For assistance, support, help and critical reading I want especially thank Jónas Páll Jónasson. I want to mention and thank Svarar Örn Guðmundsson for assistance and Janus Hansen for critical reading.

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1 Introduction

Recent climate change has affected biodiversity both in positive and negative ways (Mainka and Howard 2010). One of the most obvious consequences to warming climate is the expansion in distribution of many terrestrial and marine species (Miglietta and Lessios 2009). In the marine habitats, warming of the oceans, particularly in the higher latitudes have lead to both expansions of local species ranges as well as invasion of species into new areas. Marine invasions are classified as silent invasions compared to terrestrial ones due to difficulties to recognize new species by humans (Miglietta and Lessios 2009). Changes have often already happened when the invasive species is first recognized (Mainka and Howard 2010). Globalisation has consequently increased trade and shipping traffic and ballast waters are the main vectors for human induced marine invasion. The effects of invasive species have been shown to be ecologically and economically effects (Miglietta and Lessios 2009, Mainka and Howard 2010).

The brown shrimp *Crangon crangon* (Decapoda, Crangonidae) is a new species in Icelandic waters. It was first recorded in 2003 and is thought to originate from colonization that occurred between 2001 and 2003. Its previous absence is rather strange because it exists widely in east Atlantic Arctic waters in rocky shore habitats in Norway similar to those in Iceland (Gunnarsson 2007, Ingólfsson 2006). Distribution before invasion to Iceland indicates that climate change with increased sea temperatures is not a reason for the invasion. Introduction with ballast water was believed to be the only realistic reason for the brown shrimp invasion (Gunnarsson 2007). Both alone and especially together with effects of climate change, invasions can be a large and injurious problem in marine ecosystems (Mainka and Howard 2010). Depending on conditions at Icelandic coastal areas when invasion occurred we could expect to see effects on native species even leading to extinction or overtaking of an empty niches (Mainka and Howard 2010).

C. crangon plays an important role both in the marine ecosystem and for humans. It is a predator of benthic animals, living on a soft substratum of sand or mud in temperate coastal waters with strong tidal effect (Oh and Hartnoll 2004, Lloyd and Yonge 1947). It is an important food source for cod (*Gadus morhua*) and whiting (*Merlangius* *merlangus*) which have remarkable commercial values and variations in shrimp stock size can immediate affect fish yields (Siegel *et al.* 2008). It is also an important catch species for humans and in some areas it sustains a very important and traditional autumn fishery (del Norte-Campos and Temming 1998, Temming and Damm 2002). European fisheries had from 1950 to 1994 a mean brown shrimp harvest of 39,762 tonnes annually (Oh and Hartnoll 2004).

C. crangon has a planktonic larval stage which last around five weeks depending on temperature (Lloyd and Yonge 1947). Temperature is the most important factor affecting growth rate and therefore growth rate is highest during summer months (Del Norte-Campos and Temming 1998). Growth rate was similar for both sexes during the first year but after that, females grew more rapidly (Lloyd and Yonge 1947). Females also live longer and grow to be larger than males (Lloyd and Yonge 1947, Siegel *et al.* 2008). Females can be up to five years old with an extreme length of 80 mm but only a few females survive the fourth winter and approximately shrimps live about 3 years (Lloyd and Yonge 1947, del Norte-Campos and Temming 1998). Females moult into egg-carrying condition when sexual maturity is reached during second year. They normally carry eggs in spring and summer when they are about 50 mm long (Lloyd and Yonge 1947) but shorter egg carrying females can be found in spring (Siegel *et al* 2008). Males reach maturity at around 30 mm length (Lloyd and Yonge 1947). After copulation small females immediately lay the eggs on the carrying setae but among larger females it can be up to 48 hours later. Females burrow themselves into substratum to escape enemies. Burrowing behaviour is apparent for whole shrimp population and they leave the protection of substratum only in darkness. Eggs are carried about four weeks in mid-summer and thirteen weeks in the winter, until they hatch. There is a resting period during October and November when usually no egg-carrying females are found (Lloyd and Yonge 1947). Temming and Damm (2002) found that the function for resting period is to produce eggs and prepare for the winter brood (Temming and Damm 2002). The main breeding season extends over much of the year, from January to June with two distinct spawning peaks and consequently two broods, winter (January-June) and summer (July-September) brood of which winter brood is considered as the main brood (Oh and Hartnoll 2004). Long breeding season and continuous reproductive activity within it is a common pattern among many ovoviviparous marine invertebrates (Oh and Hartnoll 2004, Boddeke 1982, Guðmundsson 2010). Proportion of mature females and size composition of the whole stock is highly variable within and between years (Oh and Hartnoll 2004, Guðmundsson 2010). However, proportion of mature females is size-dependent. Males are predominating in smaller size classes (Siegel *et al.* 2008). Females are more numerous and dominating except during, October, December, January and February (Oh and Hartnoll 2004). *C. crangon* is reported to be facultative protandric hermaphrodite, i.e. it can sometimes change sex; some experiments found sex change and other did not so experiments and discussion are conflicting and controversial (Shatte and Saborowski 2006). *C. crangon* is euryhaline and can withstand a wide range of temperatures. The capability to withstand low salinities reaches its limits when low salinity is combined with low temperature (Lloyd and Yonge 1947, Boddeke 1976). Seasonal migrations have been reported to be cyclic. Emigration seaward during autumn/winter and immigration back towards the beach during spring following the cyclic temperature pattern (Lloyd and Yonge 1947, Boddeke 1976, del Norte-Campos and Temming 1998, Temming and Damm 2002) but there may be differences between males and females (Siegel *et al* 2004).

The main objective of this study is to increase our knowledge on the biology and ecology of the *C. crangon* in Iceland. Emphasis will be on estimation and description of fecundity, reproductive behaviour and population dynamics while at the same time we aim to compare the Icelandic population with other populations in Northern hemisphere. A little research has hitherto been done about the *C. crangon* in Iceland (Guðmundsson 2010). The study was performed within the perspective that brown shrimp is a relatively new species in Icelandic coasts.

2 Materials and methods

2.1 Sampling

Shrimps were sampled at the beach in Helguvik bay, Alftanes (64º05’52 N, 22º01’57 W), Iceland, between August 2009 and July 2010. Samples were taken twice a month in summer months May-September and once a month during winter months October-April. Sampling was done with a beam trawl which is 1 m wide and 5.5 m long. Mesh size was 5.5 mm in the cod end and 8 mm in the main body. Sampling was carried out during the low tide at 0.5-1m depth by towing the trawl by two persons in South-North direction in first and third tow and North-South in second tow. Average towing speed was 35 m/min and it was aimed to keep as constant as possible. Weather influenced sampling in some days and instead of three, two tows were taken due to severe or hazard conditions. Shrimps were counted and length measured, fixed in formalin for at least 48 hours and then transferred to ethanol for storage.

2.2 Sample analysis

One hundred individuals of each sample were examined. Total length (TL) was measured with propulsion measure to nearest 0.01 millimetres between the anterior tip of the carapace (rostum) and tip of the telson and weighted to the nearest 0.01 g. All individuals were measured if less than 100 existed; January 2010 had 35, March 2010 74 and April 2010 52 individuals, respectively. Sexes were determined under a stereo microscope by looking at external sexual characteristics i.e. the two first pairs of pleopods and their endopodites. Endopodite in the first pleopod is minor, spine-like and bent in males whereas in females it is flat and bigger (Figure 1) (Shatte and Saborowski 2006). The size of endopodite of the second pair of pleopods is similar in both sexes but males are equipped with appendix masculina, one kind of protuberance (Figure 1) (Lloyd and Yonge 1947, Shatte and Saborowski 2006). Female endopodites grow in length and female development stage was determined by looking at these endopodites in first pair of pleopods (Lloyd and Yonge 1947). Females were divided into four different developmental stages, from A to D depending of length and form of endopodites in first pair of pleopods (Figure 2). Shrimps less than 20.00 mm were treated as juveniles and sex was not defined because endopodites in the first pair of pleopods are equal-sized and difficult to separate (Lloyd and Yonge 1947).

2.3 Fecundity and reproductive output

A total of 30 pregnant females with eggs were used in the fecundity analysis and calculations of reproductive outputs. Eggs were carefully removed from the setae using fine forceps and a subsample of 200-400 eggs, depending on brood size, were counted under a binocular microscope. After drying at 60°C for 48 h, the dry weight of subsample, the remaining were measured to nearest 0.001 milligram and the female body to nearest 0.01 gram.

Fecundity was derived from the number of eggs the female is carrying. Total amount of eggs per female was calculated from the weight of eggs in subsample related to total weight of sample, by equation 1:

Fecundity = (total weight of sample / weight of subsample) * number of eggs in subsample [1]

Reproductive output, RO, per female was calculated according to Oh and Hartnoll (2004) but no difference between eyed and non-eyed eggs was done:

RO = total dry weight of the brood / dry weight of female [2]

Comparative analysis of fecundity and reproductive output was done with the data from Guðmundsson's (2010), i.e. samples from May-September 2008 from same population at Helguvík bay. Logistic regression was used to estimate the proportion of mature females at length.

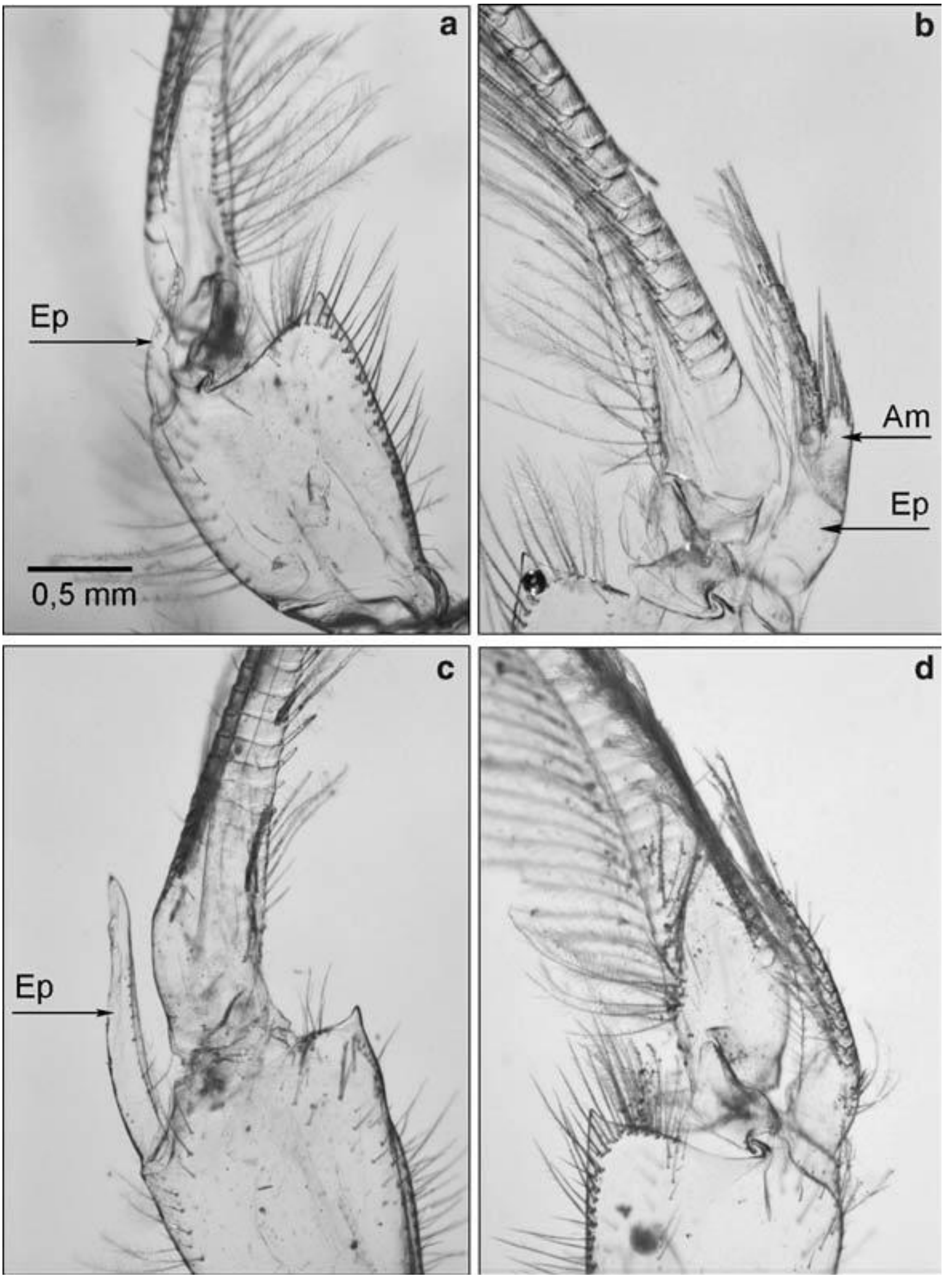

Figure 1. External sexual characteristics of brown shrimp which are used to determine the sex. First pleopod (a) and second pleopod with appendix masculina (b) of a male, and first (c) and second (d) pleopods of a female. Ep= endopodite, Am= appendix masculina. (Shatte and Saborowski 2006)

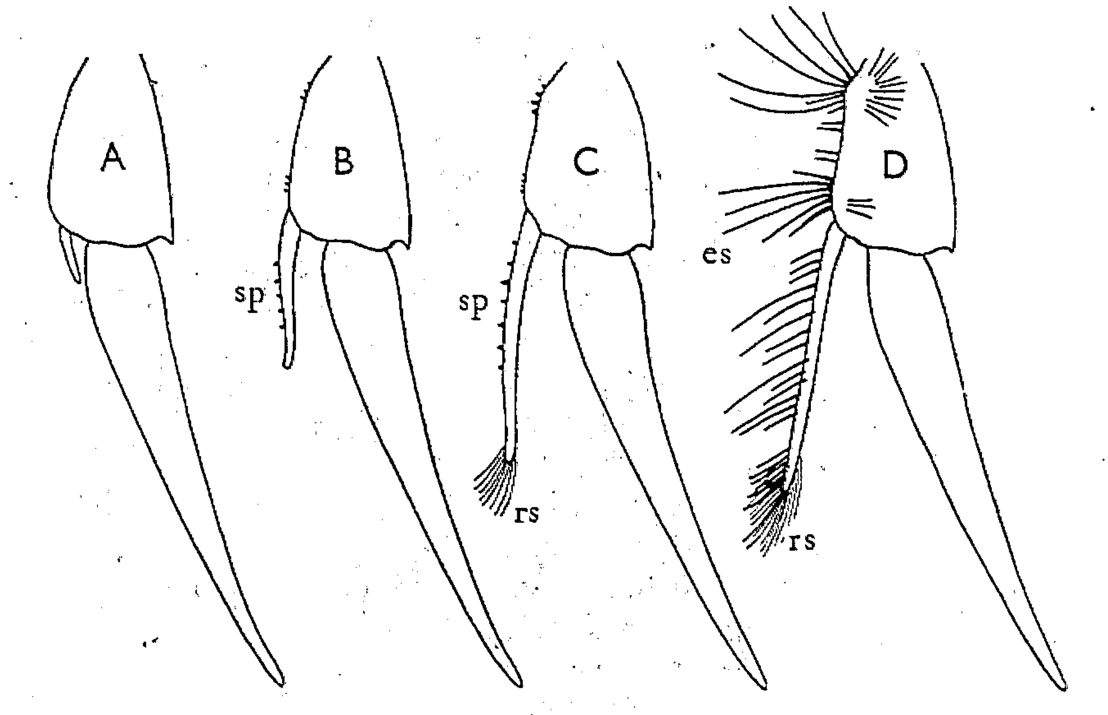

Figure 2 Female endopodite development in first pair of pleopods in animals of length A 16 mm, B 46 mm, C 50 mm, D 50 mm. Sketches are in same size to emphasize relative increase in size of the endopodite. Maturity is reached at a length of about 50 mm. Females in development stage D, in "egg-carrying stage", nearly always carry eggs in their setae (Lloyd and Yonge 1947).

3 Results

3.1 Size distribution

Fluctuations in the Helguvík shrimp population are commonly observed; e.g. size, sex ratio, size-at-maturity (here observed only for summer brood), spawning period and brood size tend to fluctuate within a year. Length distribution during the 12-months study fluctuated between 10.77 mm and 62.79 mm (n=1060) with mean length 29.58 mm and median 28.73 mm (Table 1). Shortest length was observed in August when the number of juveniles was highest (Figure 4). Shrimps tend to be both longer and heavier in summer when growing rates are highest and food supply is not limiting. When shrimps are growing they will moult. During summer the moulting occurs more frequently than during winter (Lloyd and Yonge 1947) and because shrimps are longer they are also heavier in summer since high correlation in length-weight relationship. The December sample differed from this seasonal trend with parallel mean length and wet weight as observed in summer months. Weight ranged between 0.01 g and 3.67 g with mean weight of 0.42 g (Table 1). The December sample makes an exception also with respect to minimum wet weight. A strong correlation was found between length and weight ($p<0.05$).

Table 1. Length and weight distribution of C. crangon between August 2009 and July 2010 in Helguvík.

Month	Min length (mm)	Max length (mm)	Mean length (mm)	Min wet weight (g)	Max wet weight (g)	Mean wet weight (g)	N
August	10.77	55.82	27.4	0.01	2.35	0.391	100
September	11.59	50.9	23.89	0.01	1.63	0.202	100
October	13.72	47.69	23.51	0.01	1.34	0.178	100
November	11.77	55.35	25.95	0.01	2	0.236	100
December	16.84	44.57	30.18	0.05	1.04	0.357	100
January	15.22	33.68	24.87	0.03	0.53	0.215	35
February	11.89	42.06	24	0.02	0.81	0.206	100
March	14.6	54.96	29.47	0.04	2.12	0.355	74
April	17.12	43.16	30.26	0.06	1.38	0.399	52
May	16.4	54.9	35.95	0.06	2.42	0.619	100
June	25.73	62.79	36.73	0.2	3.67	0.744	100
July	15.99	56.6	39.88	0.05	2.99	0.982	100

3.2 Sex distribution

There were 516 females, of which 49 were egg carrying, 420 males and 124 juveniles. Females were more abundant in bigger size-classes and nearly all of the large shrimps were females. Therefore, the difference in size between the sexes was significant ($p<0.05$). None egg carrying females were found during October-March and only two in September and one in April respectively. Sex ratio varied substantially; in August >70 % and in May <40 % of the population were females. Females were generally more numerous and dominating except in February, May and July (Figure 3 and 4). Two peaks of juveniles were visible, in August and February (Figure 4), which indicates the recruitment pulses of winter and summer brood.

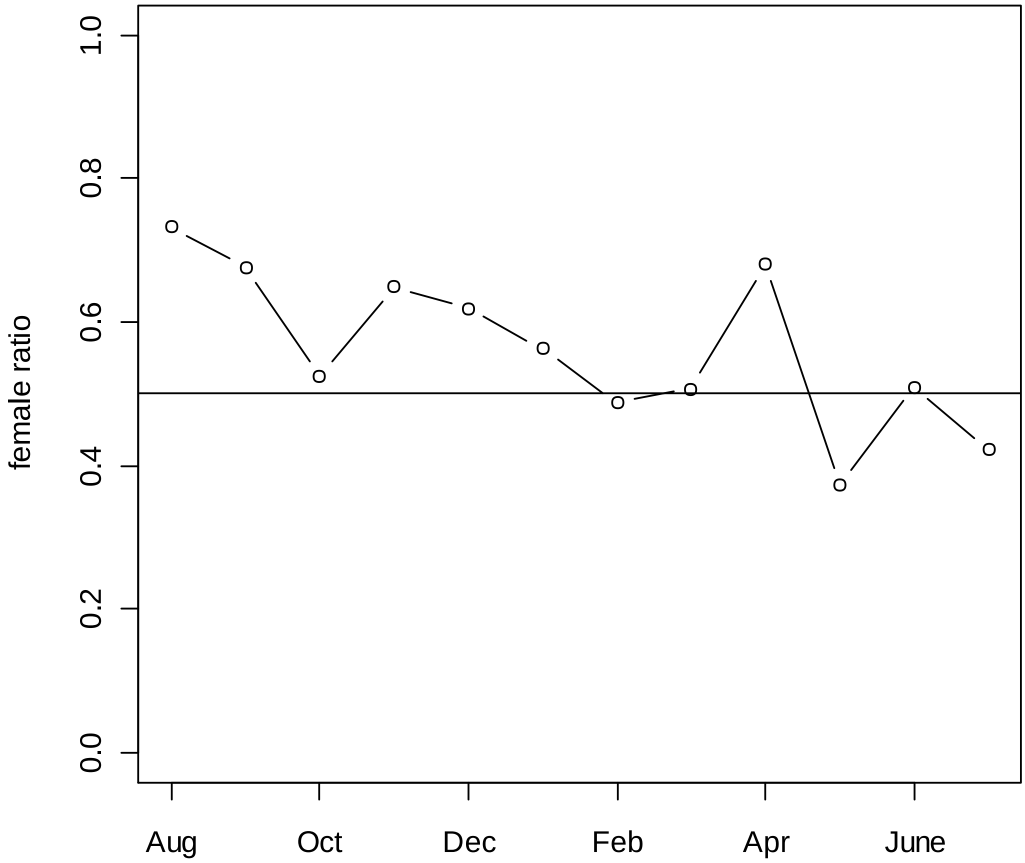

Figure 3. Monthly variation of C. crangon sex ratio during 12 months study in August 2009-July 2010. The line represents equal sex ratio.

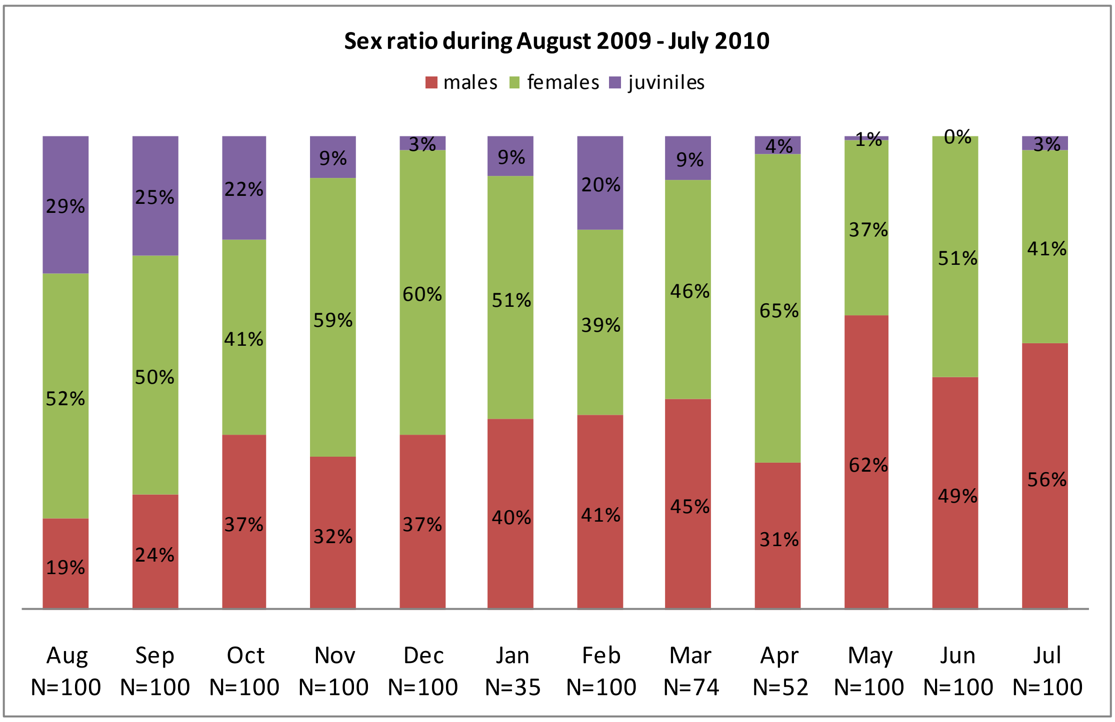

Figure 4. Seasonal changes in the ratio of female, male and juvenile shrimps.

In general, ratio of females varied with size and season (Figures 5 and 6). Four size classes were used to see the female frequency distribution per size (Figure 5). The ratio of females was approximately 0.75 at 20 mm and it gradually decreases to 0.5 at 35 mm but increased again and was 1.0 at 50 mm. When the data was split into size classes, the large size classes (50 mm+) consisted nearly solely of females, except in May (Table 2). Shrimps over 50 mm were numerous in July and August and in May, June and July shrimps 40-50 mm were most common. Enormous fluctuations in the two biggest size classes by month (27%-100%) can be explained by low number of individuals (Table 2.) In the smallest size class (20-30 mm) a downward trend in female ratio was from 75 % in August to 56% in October, and the same trend concern 30-40 mm size class starting from 81 % in August. In contrast, the ratio in the smallest size class increased from February to May. The female ratio fitted to total length varied as well between seasons (Figure 6). In spring males were dominant in the population at lengths around 35 mm (~70 %). In winter and autumn their highest ratio was around 0.5 but around 28 mm winter and 35 mm in autumn, respectively (Figure 6).

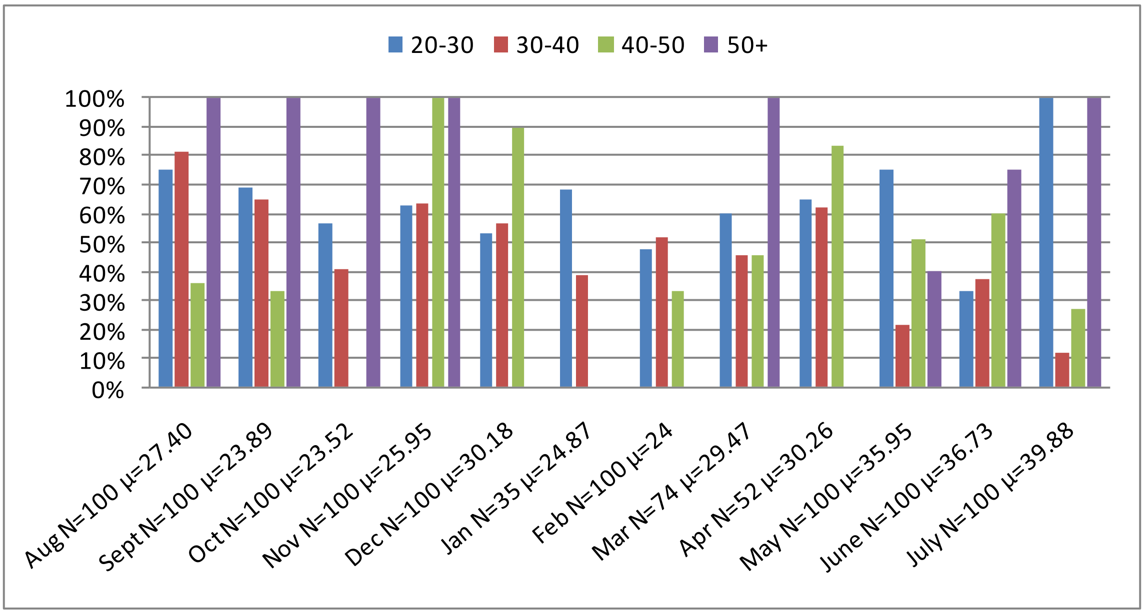

Figure 5. Monthly female C. crangon frequency distribution per size classes with mean length. See appendix table 2.

Table 2. Number of females and males in each size class. Appendix to figure 5.

	Total number of individuals in each size class			
	20-30	30-40	40-50	50+
August	31	16	14	10
September	52	17	3	2
October	55	22	0	1
November	43	44	3	1
December	32	46	19	0
January	19	13	0	0
February	50	27	3	0
March	20	35	11	1
April	17	21	12	0
May	4	47	43	5
June	3	40	53	4
July	1	17	56	23

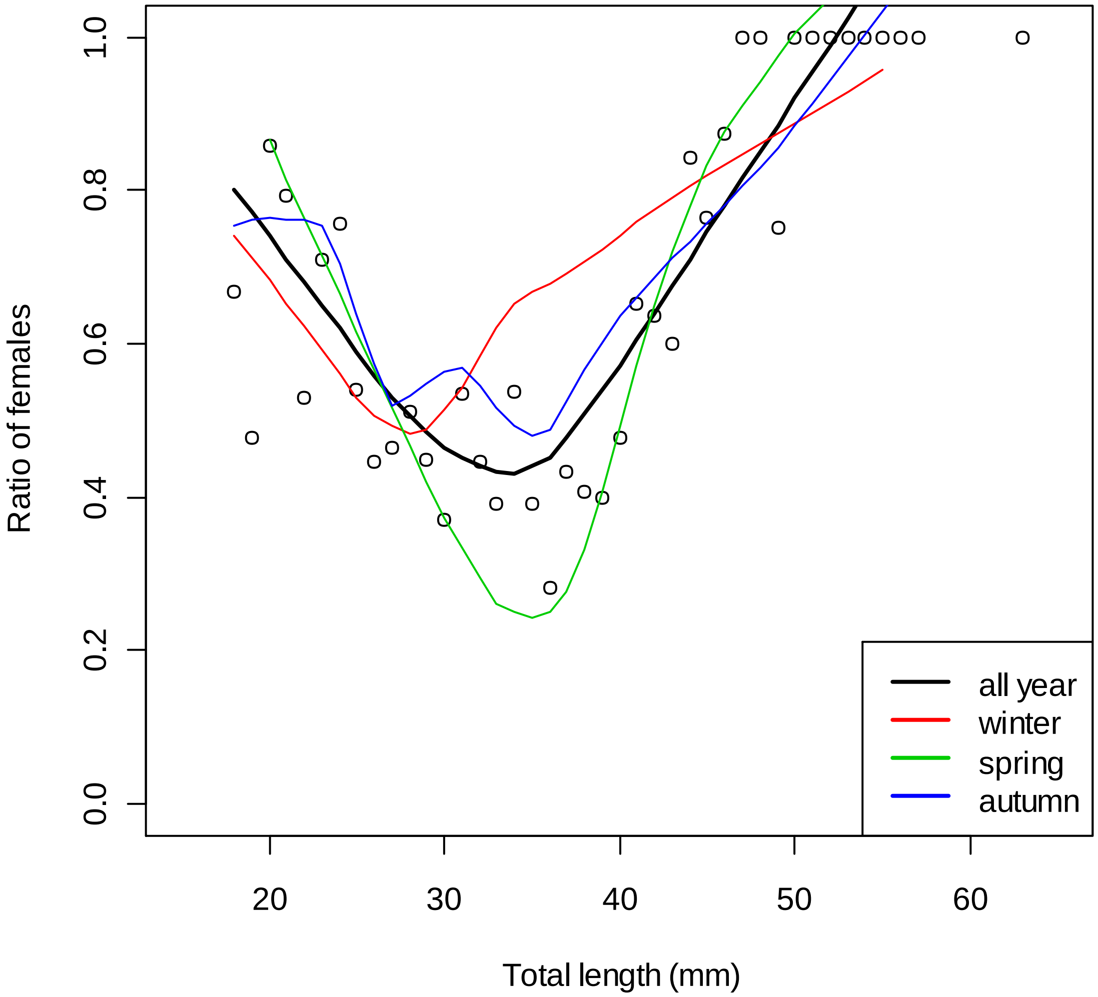

Figure 6. Ratio of females against total length of shrimps. A non-parametric linear regression of female and total length distributed to seasons. Winter months=11,12,1,2,3 Spring=4,5,6,7 and Autumn=8,9,10.

3.3 Fecundity and reproductive output

Mean fecundity was 2187 eggs per female with mean female dry weight of 205 mg. Lowest fecundity was 727 and highest 3792 eggs/female. Mean reproductive output (RO) was 0.15 with minimum of 0.06 and maximum of 0.20. Size at of sexual mature, i.e. egg carrying, females ranged between 39.63 mm and 54.90 mm. The estimated size at 50 % sexual maturity was 47.78 mm (SE 1.08) (Figure 7). Maturity was based on presence of attached eggs and should therefore rather be termed as apparent maturity. Neither fecundity nor reproductive output could be explained with shrimp length (p=0.52 and 0.16) or dry weight (p=0.16 and 0.07, figure 8). Together with Guðmundsson's data from Helguvík bay in summer 2008 mean fecundity was 1899 and mean reproductive output 0.14. When our results and Guðmundsson's results put together, the trend was still the same, with no correlation but higher insignificance (fecundity and length p=0.271 and dry weight p=0.364 and for reproductive output and length p=0.629 and dry weight p=0.353) (Figure 9). However, brood dry weight (total egg batch) was significantly correlated with female dry weight (Figure 10) $p < 0.001$

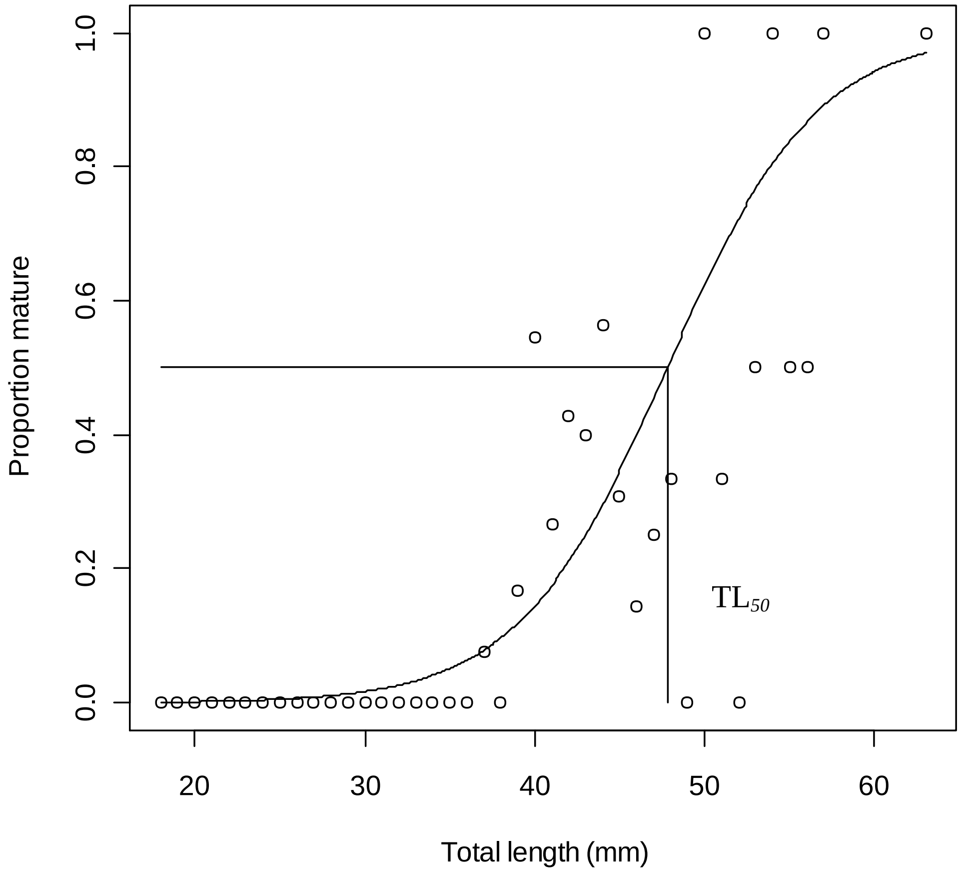

Figure 7. Proportion of egg carrying females fitted to total length. Line represents the length of which 50 % females are mature, TL50=47.78mm.

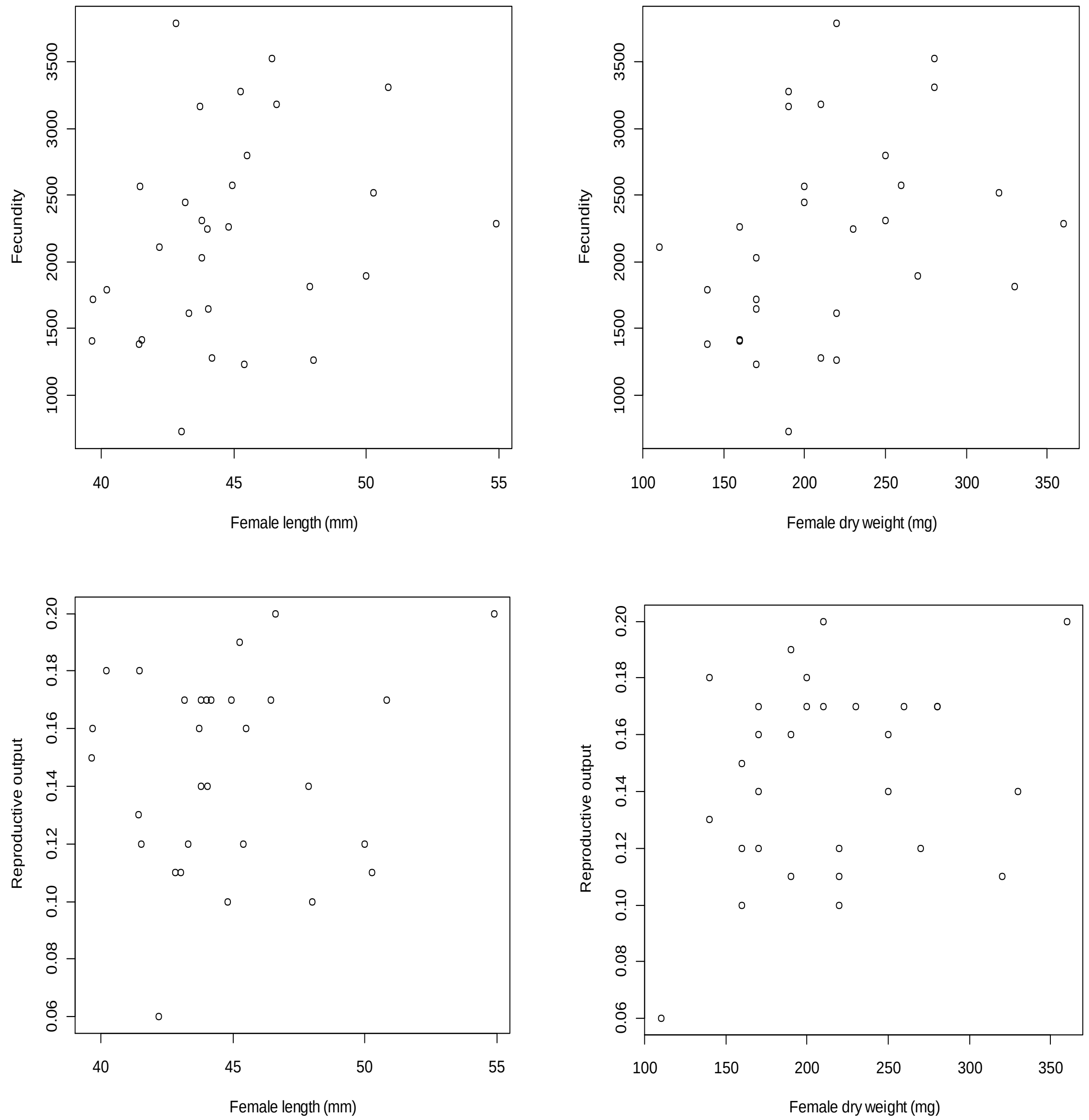

Figure 8. Fecundity related to female length (top left) and female dry weight (top right) and reproductive output related to female length (lower left) and female dry weight (lower right) N=30.

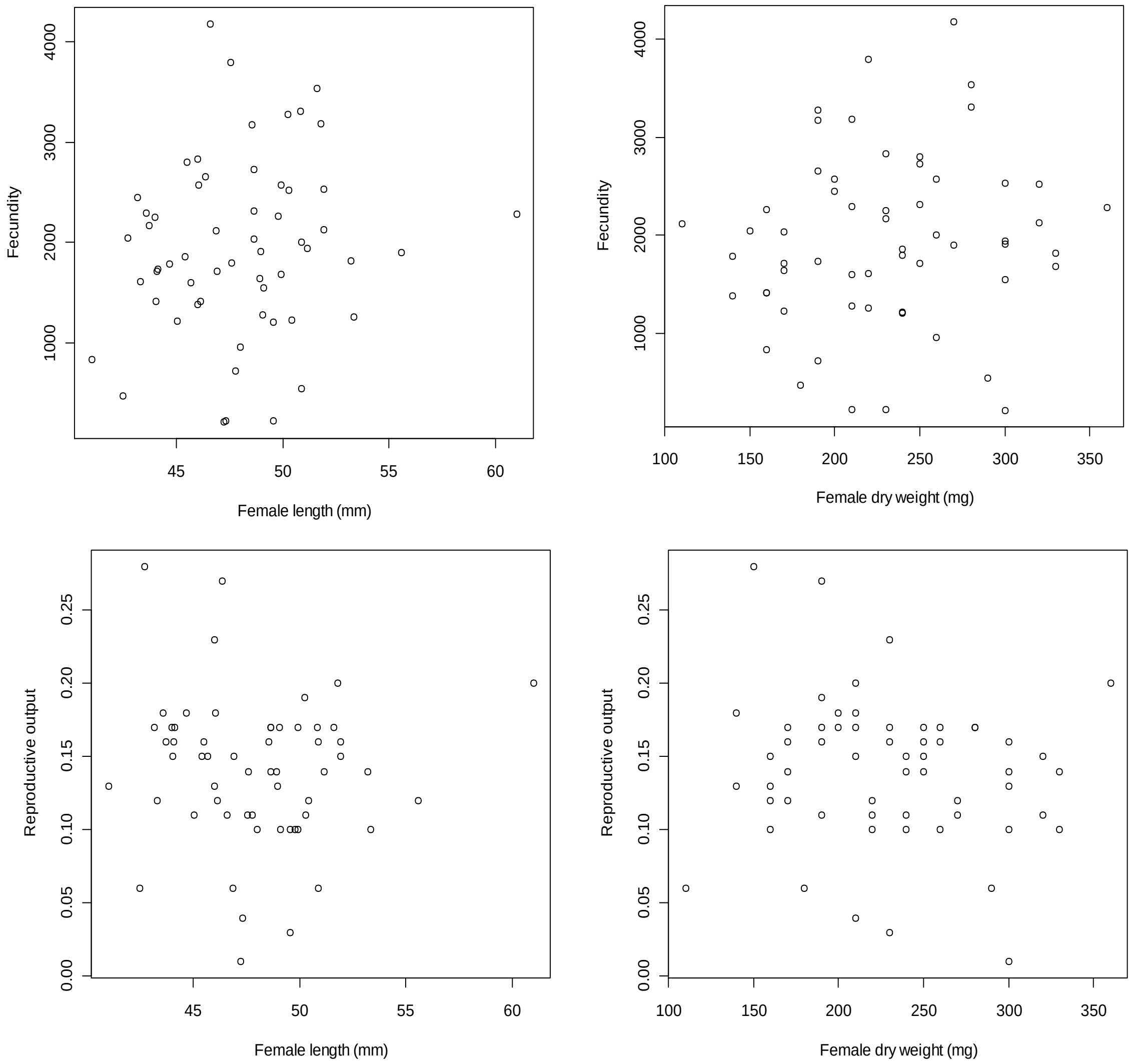

Figure 9. Fecundity (upper) and reproductive output (lower) related to female length (left) and female dry weight (right) relationships plotted together with Gudmundsson's data, N=58.

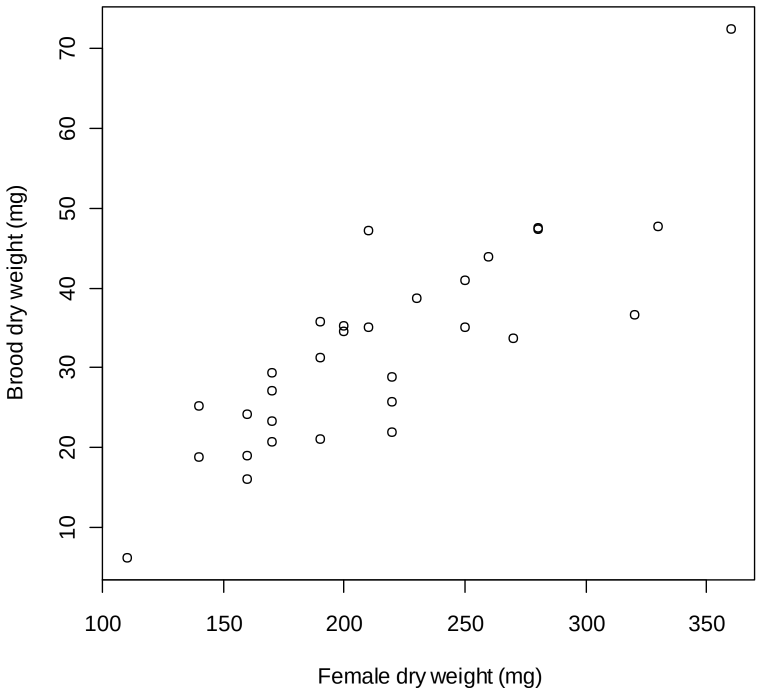

Figure 10. Relationship between brood dry weight and female dry weight, p<0.001, N=30

4 Discussion

Brown shrimp spread to Iceland 2003 and it seems that it has settled down and established itself as a part of the ecosystem (Ingólfsson 2006). In this paper aspects of reproductive biology of *C. crangon* were studied in an effort to document the main features of this population in comparison to older samplings at same locations as well as populations in other areas. Fluctuations in shrimp populations have been reported (e.g. Siegel *et al.* 2008) and observations made in the Helguvík bay are identical to this opinion and variations in the population tend to be normal among *C. crangon* populations.

It is common among shrimps that females tend to exceed males in size (Lloyd and Yonge 1947, Siegel *et al.* 2008). Growth rate is similar for both sexes during the first year but after that, females grow more rapidly (Lloyd and Yonge 1947) and mortality is higher for males (Siegel *et al.* 2008). Our results from Helguvík bay are congruent with this distribution between sexes and size-specific sex ratio that is not an uncommon pattern in shrimp population (Figure 5) (Siegel *et al.* 2008). According to Siegel *et al.* (2008) the proportion of females is size-dependent with a decrease in 30-40 mm size class and an incessant increase in size class 50 mm up to 100 % at 60 mm. Our results match well to this model with lowest proportions of females in 30-40 mm size class and nearly dominance in 50+ size class. Sexual difference in growth rate, mortality and migration habits explain difference why females are nearly dominating in biggest size class (50+): final length of males is lower and they tend to accumulate in the lower half of joint size distribution (Siegel *et al.* 2008). Our results show that females are also dominating in the smallest size class (20-30mm) in August 2009 and July 2010, but in August when recruitment from the winter brood is coming there is numerous juveniles (<20mm) and shrimps which are barely over 20 mm and then males' appendix masculina is not fully developed, so males can therefore easily be classed as females. In July 2010 there were only one single shrimp in size class 20-30 mm. However two obvious trends can be distinguished from the female frequency distribution per size classes: First, female predominance in August 2009 in size class 20-30 mm decreases all the way to October.

Same trend concerns 30-40 mm size class. Secondly, female ratio in smallest size class increases from February to May. The increasing trend could extend up to July but in our data there is too few large shrimps (June: 3, July: 1) to say how long-lasting the growing trend is. Juveniles were excluded from the data which means that declines are caused by increasing amount of males. Similar trend, i.e. decline in female ratio in 30-40 mm size class, have been observed also in other populations (Siegel *et al.* 2008) and is discussed beneath. Decline in female predominance in size class 20-30 mm could be a consequence of different tolerance to salinity or temperature fluctuations related to autumn migration (Boddeke 1976). A reason for the trend could also be temperature and incubation length influence to sex: if e.g. later hatched eggs become males.

Oh and Hartnoll (2004) observed in Irish Sea that females are more numerous and dominating except during, October, December, January and February. In Helguvík bay females are dominating except February, May and July but the trend is similar to Oh and Hartnoll's observations with higher number of males in October-February and female predominance in March-May with a lowering in May (Figure 3). However, the peak in female dominance is in Helguvík bay in August instead of June. When female ratio was fitted to total length and separated by season it is obvious that the proportion of females decreased within 30-40 mm size range and increased close to 100 % at around 50 mm total length in each season (Figure 6). Siegel *et al.* (2008) observed similar seasonal trend in proportion of females with a decline in 30-40 mm size class. As it is known that females grow faster and temperature is the most important factor affecting growth rate these factors lie plausible behind this phenomenon with decline in female predominance in 30-40 mm size class: in spring water start to be warmer and females start to grow faster. Males grow slower spending more time in size range 30-45 and accumulating to this size class and reducing the proportion of females. The effect can still be seen during autumn and winter (Siegel *et al.* 2008)

Reproductive potential of a species is mainly determined by reproductive pattern and Crustaceans represent a wide range of these reproductive patterns. It is generally accepted that brown shrimp has two discrete peaks in spawning within a breeding season with some latitudinal variation (Oh and Hartnoll 2004). The main breeding season is from January to June (Oh and Hartnoll 2004, Lloyd and Yonge 1947, Siegel *et al.* 2008). In Helguvík bay we can see two peaks in juvenile recruitment (Figure 4) that is congruent with previous studies (Oh and Hartnoll 2004, Lloyd and Yonge 1947) Juvenile recruitments in February base on the summer brood and recruitment in August, with a beginning in July, base on the winter brood (Figure 4). Winter brood is the main brood with higher reproductive output values and bigger eggs. Summer brood is smaller and is also called second brood (Oh and Hartnoll 2004, Boddeke 1982). This phenomenon is confirmed to be geographically uniform and assumed to base on fluctuations of water temperature (Boddeke 1982). In Helguvík bay a comparative analysis between winter and summer brood was not achievable due to absence of mature females during winter. Juvenile recruitment from the winter brood, i.e. mass occurrence of juvenile shrimps, is seen in August which is one month later than 2008 (Guðmundsson 2010) and two months later than in the North Sea (Temming and Damm 2002). Variations between latitudes in spawning period have been reported and can be a reason for variations in juvenile recruitment in different populations (Kuipers and Dapper 1984, Oh and Hartnoll 2004). Earlier studies have also described seasonal patterns of occurrence of mature females (Siegel *et al.* 2008). *Crangon crangon* do have a resting period during October and November when no egg carrying females were found, but unlike to previous studies, the absence of egg carrying females lasted from October to March and only one was found in April. It is known that shrimps have a cyclic seasonal migration pattern with seaward emigration in autumn/winter (Lloyd and Yonge 1947, Del Norte-Campos and Temming 1998, Temming and Damm 2002, Siegel *et al* 2008) and particularly egg-carrying females are staying in deeper water during winter. In the same way, eggs are exposed to the same water body as the females carrying them, which is the deeper water (offshore) during winter and shallower (inshore) water during spring and summer (Temming and Damm 2002). Shrimps were sampled at 0.5-1m depth in Helguvík bay and hence can we assume that the plausible reason for absence of egg-carrying females within the main spawning period is a consequence of sampling in too shallow waters. Also Lloyd and Yonge (1947) observed that egg-carrying shrimps occurred only during the spring, March-June, in Severn Estuary and it was believed to depend on seasonal migrations i.e. shrimps migrate to deeper waters in autumn. Migrations are discussed more detailed later on.

Fecundity is a phenotypic characteristic and a measure of the reproductive fitness of Crustacean species and directly effected by natural selection. It is influenced by several environmental factors and its variation among species may make species coexistence possible (Bilgin and Samsun 2006). Fecundity and reproductive output were calculated for summer brood. Fecundity in Helguvík bay ranged between 727 and 3792 eggs/female which is narrower range than summer 2008 (range: 214-4177) (Guðmundsson 2010) and wider range than Bilgin and Samsun (2006) observed (range: 910-3630). Mean fecundities were parallel to Black Sea but not summer 2008 (1687 in Helguvík summer 2008, 2187 in August 2009-July 2010 and 2297 in Black Sea). Mean reproductive output was 0.15 which is higher than observed in 2008 (RO= 0.13, Guðmundsson 2010). Fluctuations in brood size is typical for *C. crangon* and hence it is question about annual fluctuations. Size at sexual maturity was also determined to be 47.78 mm total length that is lower than in brown shrimp population in North Sea and Irish Sea which had length-at-maturity 62.0 mm in winter and 55.4 mm in spring and 55.9 mm respectively but Lloyd and Yonge (1947) observed that size-at-maturity varies greatly with the locality. Lowest size-at-maturity has been observed in Norway's colder waters to be 36 mm (Lloyd and Yonge 1947: Wollebaek 1908). Temperature is the most important factor explaining variations in growth rates and certainly makes an influence thus it was not tested. Also we used only apparent mature females i.e. egg carrying females or females with attached eggs in setae, which can influence the length at maturity hence eggs are not laid immediately after copulation among larger shrimps and they are mature before eggs are visible. Gonadal examination would give more detailed information about sexual maturity. Proportion of mature females and size composition tend to vary substantially but there is no link between these i.e. differences in size composition of the stock is not responsible for the changes in proportion of mature females. (Siegel *et al.* 2008) Relationship between female size and fecundity or reproductive output was not found thus previous studies have reported that there is a highly significant positive linear correlation (Bilgin and Samsun 2006, Oh and Hartnoll 2004). The relationship was even more negligible together with Guðmundsson's data from summer 2008 in Helguvík (Figures 8 and 9). In our data it can be seen that heavier females tend to have heavier brood but the trend is not enough uniform to show significant relationship with our sample (n=30). Sex of the 30 studied egg-carrying females had eyed eggs and theirs brood were remarkable heavier than those of non-eyed. However, a highly significant correlation (p=0.001) was found between female dry weight and brood dry weight that matches excellent to Oh and Hartnoll's (2004) data from Irish Sea (p=0.001). Mismatch between previous studies and our results in female size and fecundity can be a consequence of totally different sampling sizes and lack of information from winter brood. We had 523 females of which 30 were used in fecundity analysis but Oh and

Hartnoll (2004) had 2831 females of which 546 were sexually mature. Significant results could be reached with wider range of data.

Seasonal migrations are dealt to two distinct periods: autumn and spring migrations. Autumn migration is also called autumn-winter (Boddeke 1976) and winter migration (Lloyd and Yonge 1947). Reasons for seasonal migrations are salinity and relative differences in temperature (Boddeke 1976, Lloyd and Yonge 1947). When waters start to be warmer in spring shrimps migrate inshore from deeper waters and autumn migration takes place usually in October when sea water has passed its annual temperature maximum (Boddeke 1976). The same migration pattern is also connected to life cycle. Larvae are transported to shallow areas where they grow up and make a peak in recruitment in July/August (Boddeke 1976). Then young shrimps move offshore to deeper waters in the autumn and do not reappear until the following summer (Lloyd and Yonge 1947). A peak in juvenile recruitment in February can regardless be seen and it is confirmed that it is especially egg-carrying females are staying in deeper water during winter (Temming and Damm 2002). Autumn migration is classified as the most important migration that brings sexually mature shrimps outside from shallow tidal flat dominated areas (Boddeke 1976). Temming and Damm (2002) reported that particularly egg-carrying females are staying in deeper waters during winter. This phenomenon which was also observed in Helguvík bay can be a consequence of higher temperature fluctuations sensitiveness among sexually mature shrimps (Boddeke 1976). Densities in Helguvík bay (Guðmndsson 2010) follows seasonal migrating pattern with higher densities in summer than in winter. Migrating tendency have been examined (Boddeke 1976) and it was found that tendency to migrate is more related to individual differences in physiological condition than to size or sex. Fishing and severity of winter effects the initiation of spring migration. Both migrations effectively redistribute the shrimp stock (Boddeke 1976).

Cod´s (*Gadus morhua*) main food in Iceland is benthic invertebrates, including a northern shrimp, *Pandalus borealis* (Magnusson and Pálsson 1991). Thus northern shrimp and brown shrimp are totally different species both belong to same Caridea – infraorder. Since brown shrimp has established its place in the Icelandic coast ecosystem, we could expect to see that it will be a part of cod´s food during the time because it belongs to cod´s diet in elsewhere in Europe (Siegel *et al.* 2008). Cod research is carried on at Marice lab in University of Iceland and regular stomach examinations of cod could give an answer. Sampling in deeper waters during winter would offer information about winter brood and migrations and benefit the study of fecundity and reproduction. Ovarian and egg examinations would benefit further the study. Without egg-carrying females from winter brood and complete maturity knowledge it is difficult to complete the study of reproductive pattern. Hence temperature is the most affecting factor in growth and migrations it is interesting to see how far away *C. crangon* will invasive. In this case Iceland is an ideal place for distributional studies because continuous difference in water temperatures between South- and North-Iceland.

5 References

Bilgin, S. and Samsun, O. 2006. Fecundity and Egg Size of Three Species, *Crangon crangon*, *Palaemon adspersus,* and *Palaemon elegans* (Crustacea: Decapoda: Caridea), off Sinop Peninsula (Turkey) in the Black Sea. Turkish Journal of Zoology 30, 413-421.

Boddeke, R. 1982. The occurrence of winter and summer eggs in the brown shrimp (*Crangon crangon*) and the pattern of recruitment. Netherlans Journal of Sea Reseach 16: 151-162.

Boddeke, R. 1976. The seasonal migration of the brown shrimp *Crangon crangon*. Netherlands Journal of Sea Research 10 (1): 103-130.

Del Norte-Campos, A. and Temming. A.,1998. Population dynamics of the brown shrimp *Crangon crangon* L., in shallow areas of the German Wadden Sea. Fisheries Management and Ecology, 5, 303-322.

Guðmundsson, S. 2010. Population dynamics of the brown shrimp, *Crangon crangon* (L.) at Helguvík bay, Iceland. BS ritgerð, University of Iceland, 1-29.

Gunnarsson, B., Ásgeirsson, Þ. Ingólfsson, A. 2007. The rapid colonization by *Crangon crangon* (Linnaeus, 1758) (Eucarida, Caridea, Crangonidae) of Icelandic coastal waters. Crustaceana 80 (6): 747-753.

Ingólfsson, A. 2006. The intertidal seashore of Iceland and its animal communities. The Zoology of Iceland I, 7: 1-85

Kuipers B, and Dapper R. 1984. Nursery function of Wadden Sea tidal flats for the brown shrimp *Crangon crangon*. Mar. Ecol Prog Ser 17:171-181

Lloyd, A. and Yonge C. 1947. The biology of *Crangon vulgaris* L. in the Bristol Channel and Severn Estuary. Journal of the Marine Biological Association of the United Kingdom, 26 (4): 626-661.

Magnússon, K. and Pálsson Ò. 1991. The predatory impact of cod on shrimps in Icelandic waters. ICES. Shellfish Committee K:31

Mainka, S. and Howard, W.2010. Climate change and invasive species: double jeopardy. Integrative Zoology; 5: 102-111.

Miglietta, M. and Lessios, H. 2009. A silent invasion. Biol invasions 11: 825-834.

Oh, C.-W. and Hartnoll, R. 2004. Reproductive biology of common shrimp *Crangon crangon* (Decapoda: Crangonidae) in the central Irish Sea. Marine Biology 144: 303-316.

Shatte, J. and Saborowski, R. 2006. Change of external characteristics during consecutive moults in *Crangon crangon* L. Helgol Mar Res 60: 70-73.

Siegel, V., Damm, U., and Naudecker T. 2008. Sex-ratio, seasonality and long-term variation in maturation and spawning of the brown shrimp *Crangon crangon* (L.) in the German Bight (North Sea). Helgol Mar Res 62: 339-349.

Temming, A. and Damm, U. 2002. Life cycle of *Crangon crangon* in the North Sea: a simulation of the timing of recruitment as a function of the seasonal temperature signal. Fisheries Oceanography 11:1, 45-5