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Potential ecological effects of the Red King Crab *(Paralithodes camtschaticus)* as a newly invasive species in Iceland.

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Yfirlýsingar

„Ég lýsi því yfir að ég ein er höfundur þessa verkefnis og að það er afrakstur eigin rannsókna."

Lára Hrönn Pétursdóttir

„Það staðfestist að verkefni þetta fullnægir að mínum dómi kröfum til prófs í námskeiðinu LOK1226

Hreiðar Þór Valtýsson

Birgir Örn Smárason

Samantekt

Kónga krabbi (Kk) hefur dreift sér gífurlega í Rússlandi og Noregi og líklegt er að hann dreifi sér enn frekar, jafnvel til Íslands. Þetta verkefni fjallar hvaða vistfræðilegu áhrif Kk á ný svæði hafa komið fram og hver þau gætu mögulega verið á Íslandi.

Áhrif Kk eru misjöfn eftir því hvar hann velur sér að setjast að. Í Noregi eru áhrifin meiri en í Rússlandi vegna mismunandi botnslags og dýpis. Áhrifanna gætir helst í breytingu í botndýralífi á mjúkum botni sem og slakari gæða botnlaganna. Kk nærist á botnliggjandi hrognum annarra tegunda og er einnig talinn éta fæðu annarra mikilvægra nytjategunda. Svo virðist sem áhrifin séu að mildast í Noregi líkt og gerðist í Rússlandi eftir þónokkurn tíma þar sem krabbinn var að aðlagast nýju svæði.

Erfitt er að spá fyrir hvernig og hvar Kk gæti birst við Ísland og hver áhrif hans gætu orðið hér við land en augljóst þykir að þau yrðu misjöfn eftir svæðum. Áhrifin gætu orðið meiri í upphafi og mildast eftir að krabbinn hefur komið sér fyrir. Kk er bæði álitinn verðmæt nytjategund og skaðvaldur í lífríkinu á hafsbotni.

Lykilorð: Konga krabbi, nýbúi, umhverfisáhrif, viðhorf.

Þakkarorð

Takk allir – fyrir að láta þetta ganga!

Sérstaklega þú…þú veist hver þú ert...

Seattle, 3. ágúst 2015

Lára Hrönn Pétursdóttir

Summary

The Red King Crab (RKC) has spread immensely in Russia and Norway and will likely spread farther, even to Iceland. This thesis tries to explain the ecological impact it has had as an alien species and what impact it could have in Icelandic waters.

Research has shown the effects of RKC are different depending on the areas it chooses to settle in. The RKC feeds on bottom laying fish eggs and is also considered a competitor for prey of other commercially important ses. In Norway the effects have been more severe than in Russia because of different ocean topography. The effects mainly show in changes in soft bottom benthic environments. However it seems the ecological effects of the RKC are reducing in Norway as they did in Russia after the RKC's period of "trial and error" while settling.

It is difficult to tell to how and where the RKC could migrate to in Iceland and what the affect would be on the Icelandic ocean flora. It is obvious that it would be different depending on settling areas. The effects could be severe to begin with but reduce as the RKC settles. The RKC is considered both a valuable commercial species and an alien species with the hazards associated with that.

Key words: Red King Crab, alien invasive species, ecological affect, attitude.

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1. Introduction

The Red King Crab (RKC) is native to the North Pacific (Stevens & Lovrich, 2014). Its native distribution is along the coast of Korea, Japan, Russia, Alaska and Canada (Jörgensen et.al. 2005). Russian scientists, to create a new resource for commercial fisheries, intentionally introduced it to the Barents Sea. Larvae, juveniles and adults were transferred from areas in the Northern Pacific to western Kamchatka peninsula in southern Russian Barents Sea over the period 1961-1969. It took about ten years for the RKC to become an established species there (Orlov & Ivanov, 1978). The following decades the RKC also spread to Norwegian waters, became an established species there and continues spreading westward (Oug et.al. , 2010). In 1994 RKC fishing in Norway for research purposes was allowed and in 2002 commercial fishing begun (Sundet, 2012). There were and still are mixed feelings towards the RKC in Norway where it is both seen as a valuable fishing resource and as an unwanted alien but in Russia it is looked upon as “a blessing” for the fishing industry (Sundet J. H., 2014). There are concerns that the RKC is spreading more in the North Atlantic. These concerns are partly related to ecological changes and consequences of the arrival of such a beast to vulnerable Arctic benthic flora (Christiansen et.al., 2015).

It is likely that the RKC will appear in Icelandic waters and if it does, the Icelandic government has to be ready and decide how to respond for there are known examples where the crab has spread fast (Sundet J. H., 2014). So far the only confirmed RKC finding reported in Icelandic water was by the crew of Sigurður Ólafsson SF44 who caught the crab in a lobster troll on Breiðamerkurdýpi south of Iceland in the end of April 2014. The question remains how it got there (RÚV, 2014; Gíslason, 2015).

In Norway, there are loud voices of the harmfulness of the RKC. These voices have been heard in Iceland and are beginning to form some opinions. The question arises if the RKC is so bad. In that sense how did the diverse marine life in Alaska thrive with such an amount of RKC in its water?

The thesis purpose is to shed some light on what ecological affect the arrival of the RKC has had in the past as invading alien species and explore how it could affect other invaded areas like Iceland. Social factors and people’s presumption of its potential arrival will be reviewed.

This thesis will attempt to answer the following questions:

Would the Red King Crab thrive in the waters of Iceland?

How could the Red King Crab affect the ecosystem?

Would allowing the Red King Crab spread and grow around the coast of Iceland and maintaining the stock be a feasible option?

What do the people of Iceland think of newly invasive marine species?

2. Materials and methods

Research on the Red King Crab in both the Barents Sea and the Bering Sea were used. To get further information and insights The Kodiak Fisheries Research Center (KFRC) and The Institute of Marine Research in Norway were contacted. To get an idea of the spreading of the RKC the Marine Research Institutes of Faroe Island, England, Scotland, Ireland, Sweden and Finland were contacted. Sailors in those areas were reached out to through Facebook.

Jewett's and Onuf's (1988) Habitat Sustainability Index (HIS) model for the RKC, built on several research projects on the matter from the years 1960-1985, was used to assess if the RKC would be successful in Icelandic waters. The HSI was used as a basis for emphasizing each variable (V1-V9) and compare to Icelandic waters and surroundings with some updates by recent research. Different variables apply to different life stages where the requirements of the RKC differ considerably according to them. Because of that, separate models were developed for larval, young-of-the-year juveniles, age 1-4 juvenile (subadult) and through adult life stages.

The online application Kwiksurveys was used for a survey and to analyze the results. The self-selective survey was promoted through social media and sent with email. Therefor the sample is limited to the website members and there are some evidence that self-selected samples of Internet-based surveys may systematically differ from samples drawn from the general populations with other sampling procedures (Khazaal, et.al., 2014). In this case it may be argued that social media in Iceland is a good way to reach out. As of April 2013 81.7% of Icelandic people use Facebook and Twitter (Hagstofan, 2014) and the way to promote and influence the general public is often done through social media and electronic news.

3. The Red King Crab

3.1 Ecology

Behavior contributes largely to the success of invasive species. Certain behaviors are particularly relevant including feeding, predator avoidance, habitat, movements, the ability to learn and to reproduce (Weis, 2010).

3.1.1 External appearance

The Red King Crab (*Paralithodes camtschaticus* (Tilesius, 1815)) is a decapod and one of the most widely distributed and best known of all King Crabs. This species is what most people imagine when they think about King Crabs. They are among the world's largest arthropods and the largest of the King Crabs (Jörgensen & Spiridonov, 2013; ADF&G n.d.). In Alaska the RKC female has been found as big as 4.8 kg and the male 10.9 kg (Stevens & Lovrich, 2014; ADF&G, n.d.) and their carapace length (CL) can reach up to 220 mm (Gollasch, 2006). The RKC color ranges from dark red/reddish brown to burgundy. It is covered with a strong calcified exoskeleton with spines that provides some protection (Ocean Animal Ency-clopedia, n.d.; Cunningham et.al. 1992). The carapace is split into four regions: two lateral, the front area and the upper posterior region (Jörgensen L. L., 2013). The upper posterior region usually has three pairs of spines (Donaldson & Byersdorfer, 2005). The RKC have distinctive abdomens or tails that are fan-shaped and tucked underneath the rear of the shell (ADF&G, n.d.) and the rostrum is a single upwards bended spine (Donaldson & Byersdorfer, 2005). They have ten legs; the first pair has claws where the right claw is usually the largest on the adults, next three pairs are walking legs and the fifth pair are small and specialized to use during mating where females use them to clean their embryos and males use them to transfer sperm. The male and female RKC have abdominal flaps, the male has a narrow one and the female has a wide one that covers most of the underside (ADF&G, n.d.).

Figure 1: Red King Crab in Alaska (www.flickr.com - amanda)

3.1.2. Habitat and Life Cycle

The Red King Crab passes through two distinct stages: a short pelagic stage that lasts for 2-3 months, divided in 4 zoeal stages (Jörgensen L. L., 2013) and a long benthic stage that can last for 15-20 years (Jewett & Onuf, 1988; Sundet J. H., 2014).

3.1.2.1 Larvae

Time of hatch within a region does not necessarily happen simultaneously and there are known examples where they can vary by as much as 4-6 weeks (Armstong et.al., 1981; Stevens, 2014). This is most likely due to environmental conditions, mainly temperature (Powell & Nickerson, 1965; Christiansen et.al., 2015; Stevens, 2014). Below 4°C starvation is likely to occur because of little algae growth (Raven & Geider, 1988; Eppley, 1972). High survival and acceptable development time is reported to be between 5-10°C (Jewett & Onuf, 1988; Larsen, 1996) and survival decreases as temperature increases above 10°C, likely because of to much molting stress (Jewett & Onuf, 1988).

Preliminary results from a Norwegian study show that the RKC spawns early there where larval release starts in February, peak in April and settle on the sea floor around June (Michelsen, 2014). Larvae may be transported considerable distances by currents and it is very important for their survival that they are transported to favorable habitats (Pedersen et.al., 2006). In Alaska larvae were thought to be able to transport over 200 km (Armstong et.al., 1981). It depends on oceanographic factors and the environment where the juveniles end up and if they are successful or not (Jewett & Onuf, 1988). Larval settlement occurs in shallower waters (<20 meters) (Gollasch, 2006; Marukawa, 1933) where juvenile crabs stay throughout the year (Sundet, 2014).

3.1.2.2 Juvenile

The juvenile RKC pass through three phases based on their needs for shelter, food, protection from predation and reproduction (Stevens, 2014):

- First phase (<18 months of age): Solitary juvenile crabs seek shelter from randomly searching predators among highly complex bottom layer with protective niches of rock crevices, kelp patches, fouling organism, boulders, gravel and shell debris with attached epifauna (Stevens, 2014; Jewett & Onuf, 1988). Post larvae avoid the seafloor with epibenthic predators such as hermit crabs and juvenile halibut. Structurally complex habitats are better for protection from predators and food sources for later stages (Stevens, 2014). In some places juveniles can be found under rocks in intertidal but that is not always the case (Stevens & Lovrich, 2014).
- Second phase (lasts 3-6 months): Exploratory phase where they head out from their initial habitats for greater feeding opportunities (Stevens & Jewett, 2014; Jewett & Onuf, 1988). They remain solitary (Gollasch, 2006), still in hard bottom layer

(substrata) or in close contact with other larger organisms such as sea stars (Stevens, 2014; Gollasch, 2006). They generally remain in shallow water along the coastline in 20-50 meters depth (Powell & Nickerson, 1965). In the Barents Sea (Cape Khairyuzovo coastline) they mainly live along hydroids, sponges, and bryozoans (Jewett & Onuf, 1988).

- Third phase (from about 2 years till sexual maturity or beyond): Grouping behavior is seen (Gollasch, 2006). The crabs frequently form highly structured pods of mixed sexes and similar aged crabs in shallower waters (<50 meters) (Stevens, 2014; Jewett & Onuf, 1988). Around 4 years old they begin their onshore-offshore migration to depths of more than 200 meters with the adults but not being sexually mature, which happens around the age 5-6, they are called sub adults (Jewett & Onuf, 1988).

Like all decapods the RKC molts because the exoskeleton does not expand (Ocean Animal Encyclopedia, n.d.). The juvenile crabs molt 16-19 times during the first three years and after that they normally molt once a year (Jewett & Onuf, 1988). The new exoskeleton can be soft for some time, leaving the crab vulnerable to predation (Ocean Animal Encyclopedia, n.d.).

3.1.2.3 Adult

The adult RKC migrate to shallow waters (10-30 meters) early in spring for mating, molting and breeding (Powell & Nickerson, 1965; Jörgensen L. L., 2013). They are often found where kelp occurs (Powell & Nickerson, 1965) where it might offer them protection during molting and mating (Jewett & Onuf, 1988).

After spawning, during summer and autumn, they gradually return to deeper waters for feeding where they spend the winter at depths below 200 meters (Gollasch, 2006; Jewett & Onuf, 1988; Jörgensen & Spiridonov, 2013). There the RKC aggregates according to size, life history group or sex (Jörgensen L. L., 2013). They prefer soft bottom like mud, silt, or sand in deeper offshore areas where they occupy open seafloor habitats with less diverse assortment of prey (Jewett & Onuf, 1988; Stevens & Jewett, 2014). Adult crabs, with leg span of up to 1.4 meters, are fast and can travel 3-13 km daily. An RKC has been known to travel 426 km in a year (Gollasch, 2006).

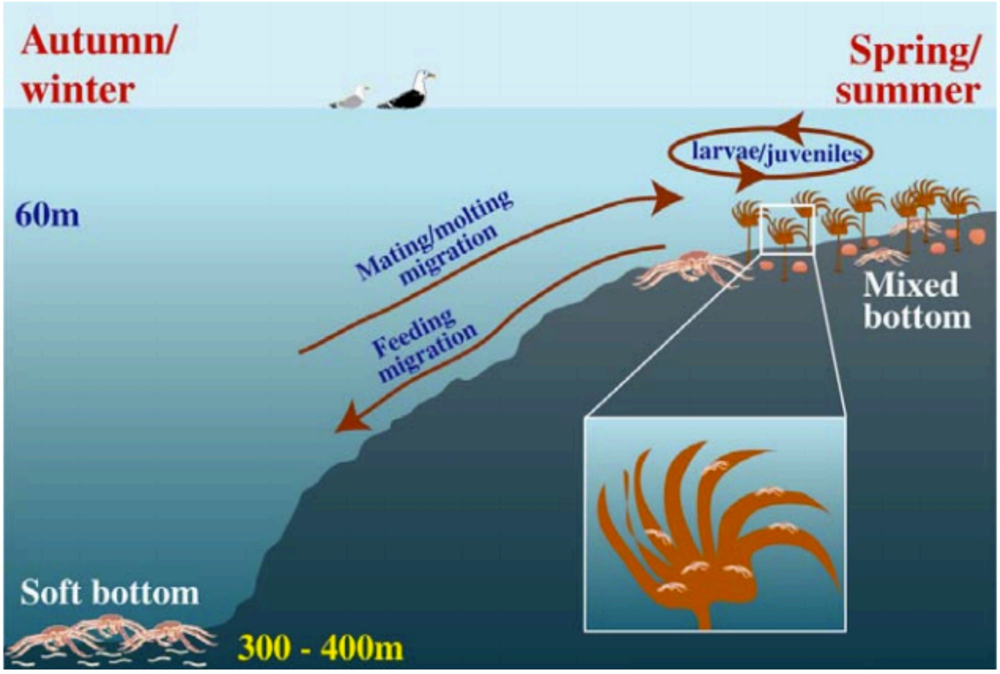

Figure 2: Migrating pattern and habitat of the Red King Crab (Jörgensen L. L., 2013)

3.1.3 Temperature and Salinity

Laboratory thermal behavior test show that adult Red King Crab, irrespective of body size, maturation stage and nutritional state select temperatures within the <1 to 4°C temperature zone, preferably 2.5 to 3.5°C and avoids temperatures >4°C (Christiansen et.al., 2015). The NOAA summer trawl data shows that in nature RKC can be found in water temperatures ranging from -1.8°C to 12.8°C in the Bearing Sea (Stevens & Lovrich, 2014). Depending on location, the mean summer temperatures in the Barents Sea ranges from 3.2 to 5.5°C (Stevens & Lovrich, 2014) and there they are found within a temperature range of -0.8°C to 8.5°C. When spawning in April-May both males and females remain within 0°C to 2°C temperature range but split up in August-September where males are found at 4°C to 9°C and females 5°C to 7°C (Pinchukov & Sundet, 2011). This shows that the RKC has a wide tolerance of temperature.

Larvae survival is high within a range of salinities >20 ppt. and a range of temperatures from 6°C to 15°C (Stevens, 2014). With higher temperatures juveniles experience more frequent molting (Jewett & Onuf, 1988) growth rate increases and the crabs eat more (Stevens & Jewett, 2014; Jewett & Onuf, 1988) but it is not affected by salinity (Jewett & Onuf, 1988). Crabs in colder regions grow more slowly and require more time to reach sexual maturity (Stevens & Jewett, 2014). Laboratory research show that larval survival is quite high up to about 14°C and up to 50% in temperatures up to about 20°C. Larvae that were accustomed to 4°C and 8°C survived well in subzero temperature but the ones acclimated at 14°C were less viable close to freezing point (Sparboe, unpubl.). This indicates a wide potential for spread in the Northeast Atlantic, both southward and northward (Sundet J. H., 2014).

Even though the RKC has a lot to gain to be in higher temperatures it seems as salinity in the lower range has more to do with the adult crab excluding areas than temperatures. A good example is from the coastal waters off Nome in Alaska where adult RKC are present when the salinity is around 34 ppt. but the temperature is as low as -1.8°C but they are absent when salinity is 22 to 24.5 ppt. and the temperature is more desirable or 8.5°C to 11°C (Jewett & Onuf, 1988; Hood, o.fl., 1974; Rusanowski et.al. 1987). Salinity range from 26 to 34 ppt. is indicated as an optimal range for larvae, juveniles and adults with larvae mostly in 30 to 32 ppt. and Juveniles to age 3 from 26 to 32 ppt. (Jewett & Onuf, 1988).

3.1.4 Food and Feeding

The adult Red King Crab is an omnivorous predator (Gollasch, 2006) with a vide variety of prey, depending on availability (Stevens & Jewett, 2014; Jewett & Onuf, 1988). The RKC is an active feeder on benthic fauna and feeds especially in deep soft-bottom environments (Oug et.al., 2010). Jörgensen & Spiridonov (2013) show results and conclusions from a Norwegian-Russian Workshop held in Tromsö in 2010 in the report "Effect of the King- and Snow crab on Barents Sea Benthos" that is made from several research done in the Barents Sea. A gathering on information of different food consumptions between different stages show that juveniles (0-4 years) who live in shallow water of 5-40 meters were found to have detritus, sponge, algae and sea urchins in the stomach independent of area and season. Adults were shown to have mostly echinoderms, bivalves, polychaetes and fish carrion (Jörgensen & Spiridonov, 2013). If living on a similar area same sized crabs, both males and females, consume similar diets (Stevens & Jewett, 2014). Before that, pelagic larvae consume both phytoplankton and zooplankton (Gollasch, 2006; Bright, 1967).

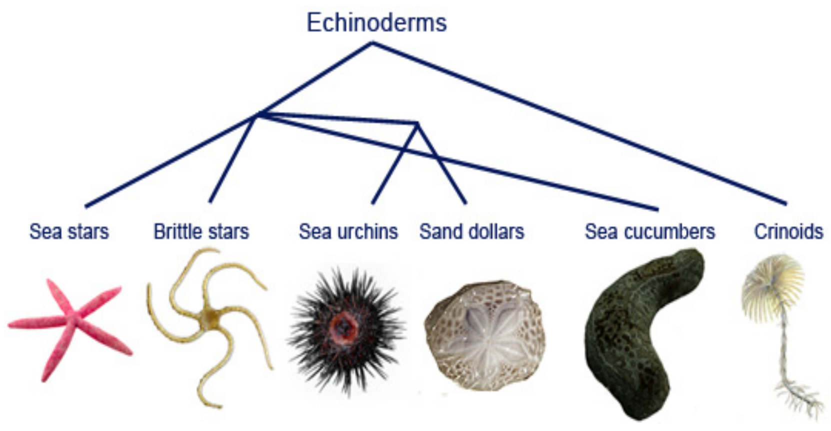

Figure 3: The different groups of echinoderms (www.mesa.edu.au)

The crab is a new species in the Barents Sea and the feeding behavior and model is still very flexible and will probably change over time (Jörgensen & Spiridonov, 2013). Recent feeding studies in the Barents Sea show that the sea star (*Ctenodiscus crispatus)* and the bivalve (*Bathyarca glacialis)* are preferred by the Red King Crab and should be used as indicator species in impact studies. In both Russian and Norwegian areas abundant and widely distributed species within asteroids, ophiuroids and bivalves also work well as indicators (Jörgensen & Spiridonov, 2013).

3.1.5 Predation

In Alaska fishing grounds the Red King Crab is the prey of Pacific cod (*Gadus macrocephalus*), Pacific halibut (*Hippoglossus stenolepis*) and yellowfin sole (*Limanda aspera*) (Jewett & Onuf, 1988). The Red King Crab in the Bering Sea is consumed by large Pacific cod (>60 cm) during the month of May in the soft-shell condition (Livingston, 1988), assumingly females, 11 cm in carapace length, because they start molting in the end of April through May (Stevens & Swiney, 2007). The cod should not have severe affect on the stock compared to research of stomach content of the Pacific cod in the Bering Sea in the years 1981, 1984, and 1985 where it is estimated to have consumed 3.8%, 2.8% and 1.4% of the female red king crab stock (Livingston, 1988).

Daly et. al. (2013) identified predators and predation susceptibility of the RKC with carapace width of 1.75-4.08 mm in Alaskan waters with underwater video cameras in July and September 2011. Identified predators were hermit crabs (*Pagurus* spp), Alaskan ronquil (*Bathymaster caeruleofasciatus*)*,* Arctic shanny (*Sticheus punctatus)*, northern rock sole (*Lepidopsetta polyxystra)* and kelp greenling (*Hexagrammos decagrammus)* (Daly, Eckert, & Timothy, 2013).

Many different studies show that there is not a one single predator that appears to target the RKC as a primary prey. Mortality amongst the RKC appears to be spread throughout many different species but cannibalism may also be an important factor. These predations mainly occur before the crab reaches maturity, after that there are few species that threaten it, except humans (Stevens & Jewett, 2014).

3.1.6 Habitat Suitability Index (HSI)

To narrow down the specific requirements the Red King Crab has on certain stages in its life Jewett and Onuf (1988) gather conclusions from several researches and made the Habitat Sustainability Index (HSI). It describes how well an area fulfills the requirements of the

RKC to settle and live a good life. The HSI could be a useful tool to speculate where the RKC would most likely settle in new areas. Therefore it has been updated with the new research done in newly invaded Barents Sea that was described in earlier chapters.

The index is divided by 9 different variables dependent on life stages. The output value of each variable is between 0.0 and 1.0, higher index meaning a more suitable habitat (Jewett & Onuf, 1988).

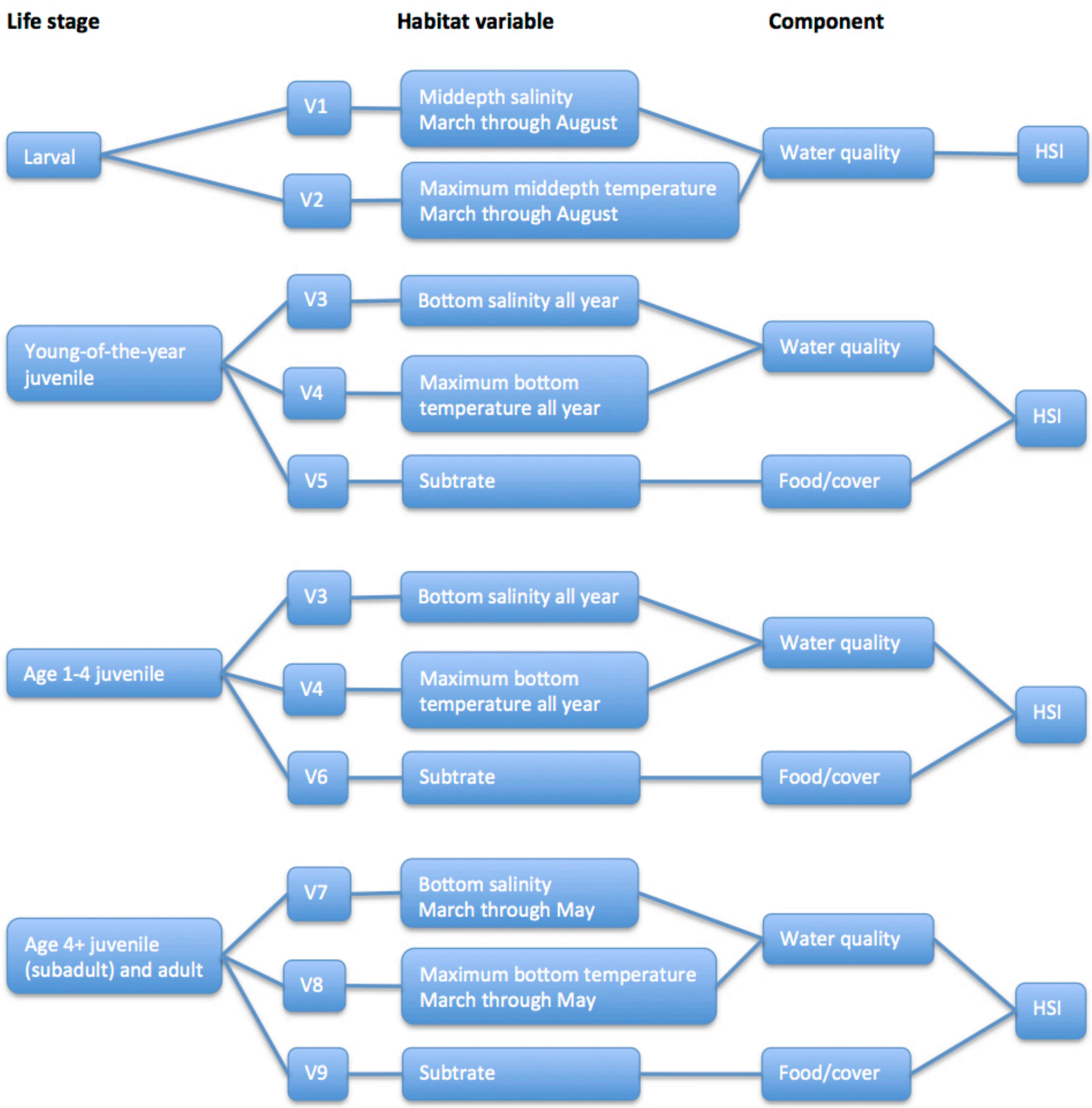

Figure 4: Different variables for different life stages (Jewett & Onuf, 1988)

3.1.6.1 Larval life stage

Pelagic larvae of the RKC are dependent on conditions in the water column and because of that the HSI has only a water quality component. The Salinity during the larval period from March through August can range quite broadly (Jewett & Onuf, 1988) and the larvae have been reported to survive in salinity as low as 20 ppt (Stevens, 2014). For any successful development the salinity needs to be in the optimal range for at least half of the larval development time or >45 days.

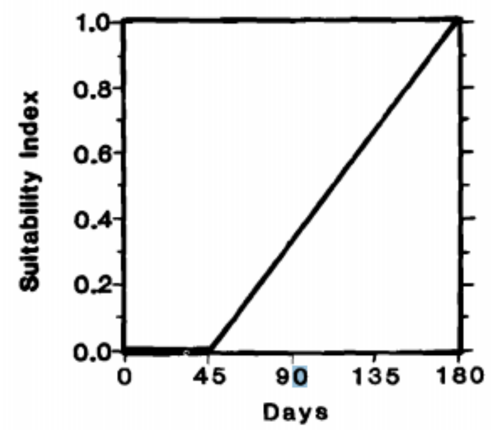

Figure 5: Number of days in optimum salinity

- V1 – Middepth salinity March through August
  - Number of days above 45 in salinity of 26-34 ppt.
  -
- V2 – Maximum middepth temperature March through August.
  - <4°C – Larvae will probably starve but if not, development will take long and predation will be severe.
  - <7°C – Survival is high and developmental time is intermediate (Jewett & Onuf, 1988; Larsen, 1996; Stevens, 2014).
  - <10°C – Survival is high and development time high (Jewett & Onuf, 1988; Stevens, 2014).
  - Between 10-20°C – Development time will become shorter and fewer larvae will survive to the point that none will complete development to the point that none are successful at 20°C.

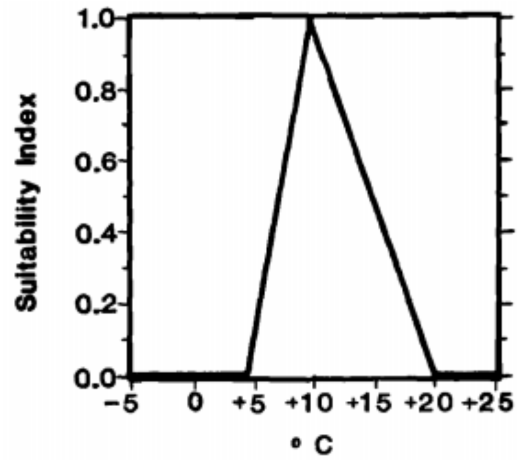

Figure 6: Desirable temperature range

3.1.6.2 Young-of-the-year and young juvenile (Age 1-4) life stages

The same water quality components as in earlier stages but more demand for longer periods in optimal salinity.

- V3 – Bottom salinity all year
  - Number of months in salinity of 26-34 ppt.

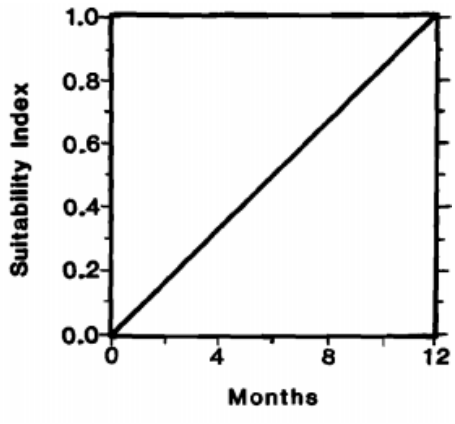

Figure 7: Number of months in optimum salinity

- V4 – Maximum bottom temperature all year
  - High molting success at 5-10°C (Rice, Brodersen, & Arasmith, 1985)
  - Preferred temperatures 3-6°C (Hansen, 2002)
  - Tolerated temperatures 0-15°C (Jewett & Onuf, 1988)

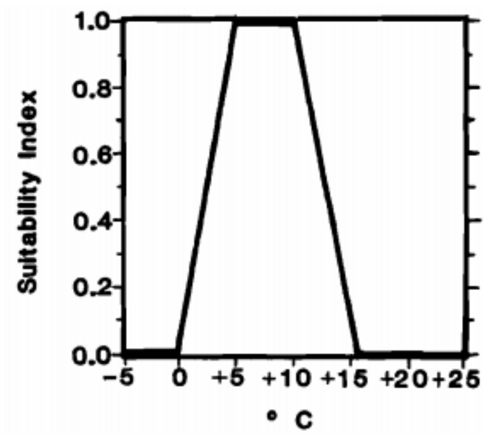

Figure 8: Desirable temperature

There are different index values for same substrate between age groups because of different suitability between life stages. Older crabs have less need for cover that allows them to exploit alternative food resources on different substrate.

- V5 – Substrate
  1. Bare bedrock
  2. Bare rocks, gravel, shell
  3. Bedrock, rocks, gravel, shell with sessile epifauna/flora
  4. Substrate with sessile epifauna/flora adjacent to soft bottom areas
  5. Soft bottom – sand, mud

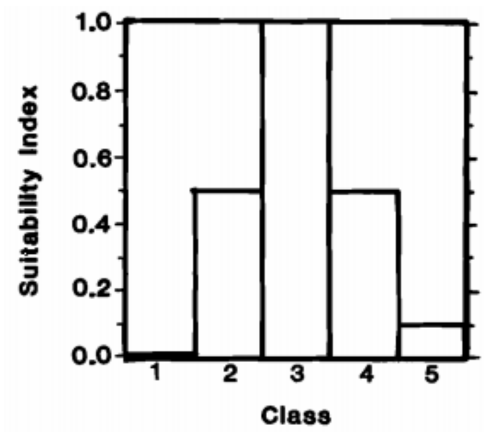

Figure 9: Substrate class

- V6 – Substrate
    1. Bare bedrock
    2. Bare rocks, gravel, shell
    3. Bedrock, rocks, gravel, shell with sessile epifauna/flora
    4. Substrate with sessile epifauna/flora adjacent to soft bottom areas
    5. Soft bottom – sand, mud

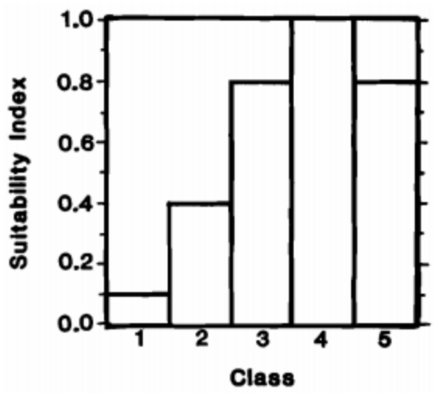

Figure 10: Substrate class

3.1.6.3 Sub adult (Age 4+) and adult life stages

- V7 – Bottom salinity March through May
    - Number of days in salinity of 26-34 ppt

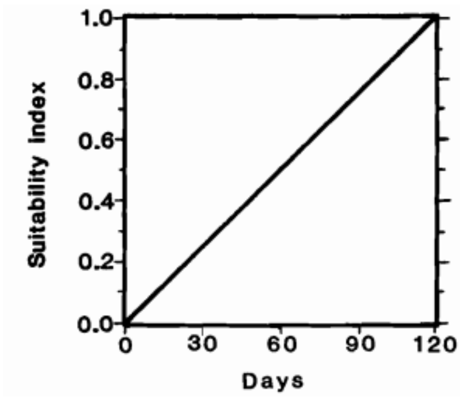

Figure 11: Number of days in optimum salinity

- V8 – Maximum bottom temperature March through May
    - Optimal 2-7°C (Jewett & Onuf, 1988)
- Conflicts because of recent research:
    - Selects <1-4°C and avoids >4°C (Christiansen et.al., 2015)
    - Considered lower by Pinchukov & Sundet (2011) when spawning in April-May or 0°C to 2°C

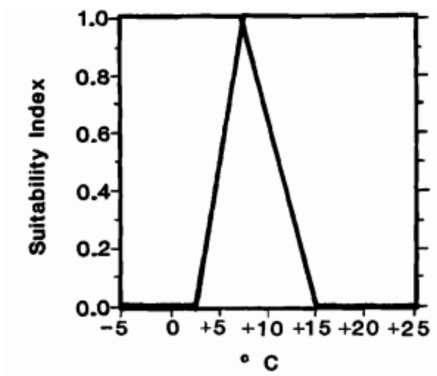

Figure 12: Desired temperature range

V9 – Substrate

1. Bare bedrock
2. Bare rocks, gravel, shell
3. Bedrock, rocks, gravel, shell with sessile epifauna/flora
4. Substrate with sessile epifauna/flora adjacent to soft bottom areas
5. Soft bottom – sand, mud

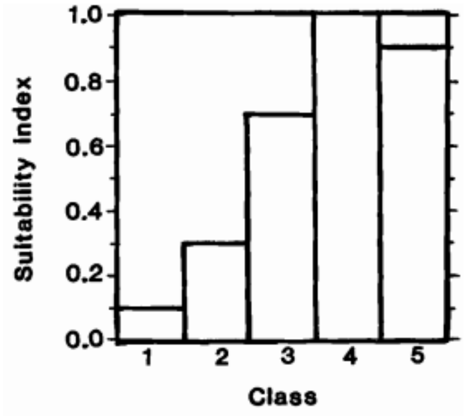

Figure 13: Substrate class

3.2 Red King Crab in the Barents Sea

Since the introduction of the Red King Crab to the Russian part of the Barents Sea research has been done to evaluate the impact it has had on the area. Even though the areas are adjacent the impact varies heavily.

The RKC is spreading from the coastline and offshore in a north- and westward direction in Norwegian waters and east- and northward direction in Russian waters (Jörgensen L. L., 2013). The general transport of the pelagic crab larvae is by currents towards the east (Pedersen et.al., 2006) but the RKC continuously migrates westward from Russia along the coast of Norway. They have been found south of Bergen, most likely transplanted there by vessels on their route back from seasonal fisheries in eastern Finnmark (Pedersen et.al., 2006; Sundet J. H., 2014). From the late 1990s an exponential

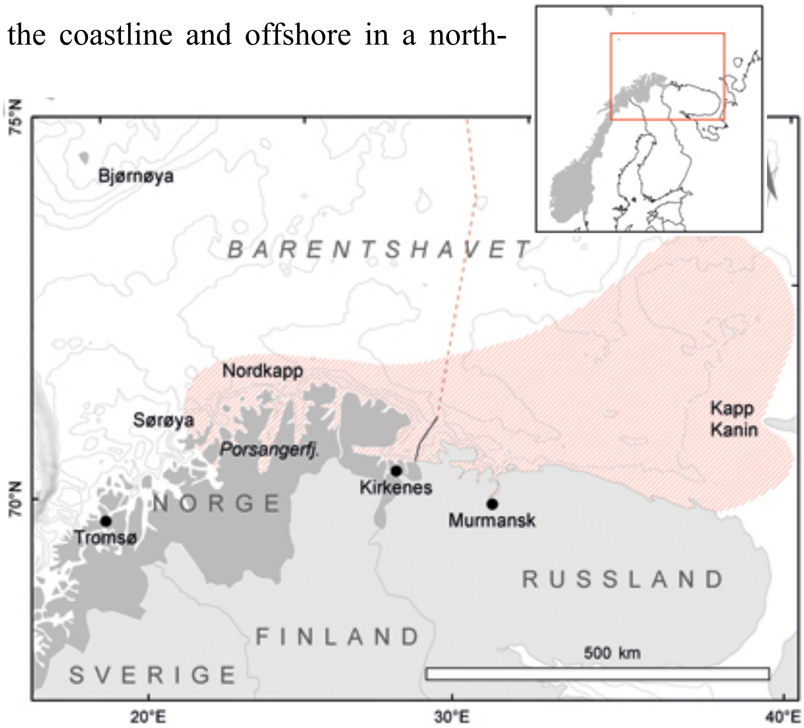

Figure 14: Approximate distribution of Red King Crab in the Barents Sea 2011 (Institute of Marine Research Norway)

growth in legal RKC male stock in Norway (137 mm carapace length (CL) (Hjelset, 2013)) reached its maximum level in 2003-2004 with the dispersal rate of about 25 km/year (Sundet J. H., 2014).

A recent unpublished study by Sundet and Nilssen (2014) describes a general trend among adult male and female RKC in recently invaded area in Norwegian waters. All crabs occupied deep areas during late autumn and winter but movements up and down were observed regardless of season. It seemed to them that the RKC adapts the same seasonal movement behavior as in its native areas after a period of "trial and error" (Sundet J. H., 2014). This correlates with the "adaptive flexibility hypothesis" that predicts that behavioral flexibility and diversity of behaviors observed in an invasive population will be high during the initial stage of introduction into a new environment and then declines during the establishment and the growth of a founding population due to social learning of successful behavioral variants (Wright et.al., 2010).

3.2.1 Ecological impact in Norway and Russia

Since the Red King Crab was introduced to the waters of Russia and Norway several research have been done on the impact it has had as an alien species. In 2013 results and conclusions where published from the Norwegian-Russian Workshop in Tromsö from the year 2010 on the effect from the king- and snow crab on Barents Sea benthos. The studies show different results in effect on species diversity and biomass in king crab areas in Norway and Russia. The affects of the crab on the benthos appear to be more severe in Norwegian waters, categorized as serious (Oug et.al., 2010) compared to coastal areas on the Russian side where the effects are categorized as moderate (Anisimova et.al., 2005). The benthic communities and environmental conditions are almost the same but the near coastal areas are not the same. In Russia there are almost no large fjords or inlets. The bottom slopes gradually as far as 40-50 nautical miles from the coastline where it reaches depths of about 250 meters, therefore the crabs performs seasonal migration far from the coast to reach deep water but the immature crab stock remains in shallow areas year round. In Norway however there are several large fjords where depths reaches down to 300 meters or more within the fjords. Therefore migration is believed to be more limited and predation pressure constant. This may lead to higher concentrations of RKC in Norwegian coastal waters than in Russian waters that lead to larger impact on the benthic fauna (Sundet J. H., 2014; Jörgensen & Spiridonov, 2013).

Shallow areas with hard bottoms may be more resistant to RKC impact but it is difficult to detect. These areas have higher biomass and productivity and the predation pressure from adult king crabs differ throughout the year (about 3-4 months) while juveniles predate year-round. Effects of the RKC are more noticeable in soft bottom areas. In waters 100 meters and deeper the species composition has changed according to the foraging of the RKC where the most abundant prey decreases but other benthic fauna often increases. (Jörgensen & Spiridonov, 2013).

3.2.1.1 Norway

The invasion phase of the RKC in Norway can give an idea of how fast the crab can spread. The first reported king crab in Norwegian waters was in 1976 in the inner part of Varanger fjord. Bycatches of RKC became more frequent in the 1980s but usually single or in small numbers. In 1992 fisherman in South Varangerfjord started to get them by hundreds and the crab quickly became a menace to them, destroying nets and in worst cases stopping gill net fishing on traditional fishing grounds (Kuzmin & Olsen, 1994). Figure 15 describes findings of the RKC in Norway and clearly describes the speed of distribution (Sundet J. H., 2014).

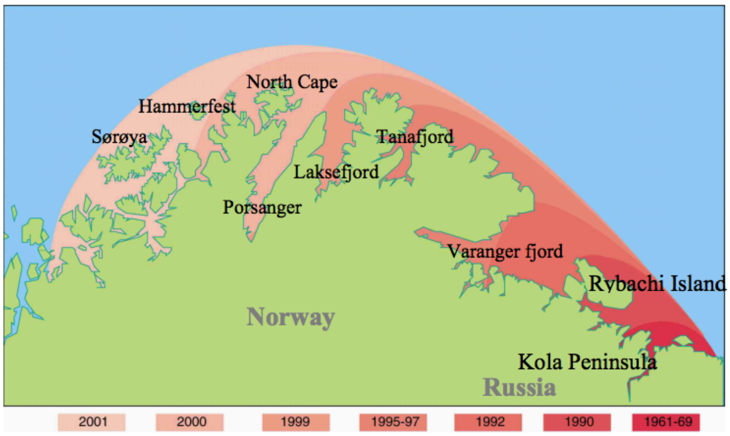

Figure 15: Findings of Red King Crab in Norway (Jörgensen L. L., 2013)

Soft bottom epifauna and infauna have become markedly reduced in areas invaded by the crab but there have been fewer changes in shallow hard bottom areas (Oug, 2014: Jörgensen & Spiridonov, 2013). In Bokkfjord epi- and infaula mean density at depths >200 meters had decline by 70-90%, mostly larger echinoderms and mollusks, and the mud star *Ctenodiscus crispatus* (Oug et.al., 2010). In Varanger area close to the Russian borders a six times reduction of the benthic community biomass (sea stars, sea urchins, brittle stars and bivalves) has accrued. There has been a significant reduction in polychactes, echinoderms and bivalves but increase in myriochele sp. and small bivalves (Jörgensen & Spiridonov, 2013). Soft bottom epi- and infauna in Varangerfjord clearly demonstrate a reduction in composition and biomass since the crab was introduced 20 years earlier (Oug et.al., 2010).

Studied were carried out in Varanger fjord in the years 2007-2009 and again in 2012 and compared to data from 1994. In 2012 the composition of the fauna was mostly the same as in 2007-2009 and in some locations some species of polychaetes had increased, showing a moderate improvement (Oug et.al., 2014). Recent studies show that there is a moderate improvement of the fauna in deep fjords of northern Norway. This is most likely due to an overexploitation of the food resources when the RKC first invaded the fjords but recently there has been an adjustment between the RKC and its prey in the fjords (Oug et.al., 2014).

There are suggestions that the crab removes organisms of deep-burrowing bivalves, worms and larger sized resident fauna, that perform important functions of oxidizing the sediment and that results in reduced sediment habitat quality (Jörgensen & Spiridonov, 2013; Oug et.al., 2010). Overall the crab may be the cause of reduced functional diversity that may have implications for ecosystem function, production and responses to other environmental stressors. In some locations there are signs of the crab enhancing particle mixing and oxygenations of the surface sediments by walking, digging and scooping behavior but unlikely that the crab's behavior will keep up with epifaunal mixing. It is hard to tell to what extend an area will be effected where it seems that it is not certain that the crab feeds on the species that play the key roles in the benthos so the ecological consequences of the faunal reductions may differ locally (Oug et.al., 2010).

There are no signs of any impacts of parasites the crab might bring and it has been questioned if the crab has brought new diseases to areas of introduction. No observations of any new diseases in the crab environment in Norwegian waters have been made so far but investigations have not been pursued (Sundet J. H., 2014).

3.2.1.2 Russia

Overall the impact of the crab on the bottom communities of the Russian part of the Barents Sea is not as great as expected from a large generalist predator as the RKC. That is explained with a distributed predation pressure among various groups of organisms that prevents elimination of particular species (Britayev et.al., 2010). Changes in the order of species domination within the benthic community occurred in the Russian part of the Barents Sea (Anisimova et.al., 2005). Polychaeta increased while other groups of "preferred prey species" of the Red King Crab declined: Large visible sea stars, brittle stars and bivalves. Calcareous algae (*Lithotamnium* sp.), clams (*Ciliatocardium ciliatum* and *Astarte crenata)* and Icelandic schallops (*Chlamys islandica)* were no longer dominant but the importance of barnacles (*Balanus balanus and B. crenatus)* had increased. The bivalve species had decreased from 24 to 16 and only 12 were re found (Jörgensen & Spiridonov, 2013). Because of high predation pressure the crab has moved from shallow to deeper waters from 2001 to 2009 and the impact of crabs is different between areas (Jörgensen & Spiridonov, 2013).

Since the crab was introduced in Russia there has been a measurable decrease of soft bottom community diversity, species richness, density and biomass of bivalves. The diversity of hard-bottom communities has remained stable, except for sea urchins that decreased likely due to the crab's predations on smaller urchins (Britayev et.al., 2010).

3.2.1.3 Other concerns

There are studies that show the RKC feeding on row, therefore fish stocks that spawn eggs attached to the bottom have become a concern, especially in Norway (Sundet & Nilssen, 2000).

In Russia during the main capelin-spawning season RKC has been found invading spawning areas and large amount of capelin eggs have been encountered in crab stomachs. Large amount doesn't necessarily mean a big portion of the over all amount of eggs though. The highest frequency of occurrence of fish eggs in the crab stomachs was noted in 2001. That year it was calculated that the RKC consumed 0.03% of eggs laid by capelin in the Russian part of the Barents Sea and that is considered insignificant (Anisimova et.al., 2005). In northern Norway the capelin egg consumption by th RKC was approximately 0.03% and 2.23% in 2005 and 2006 and that was not considered as a threat to the recruitment of capelin. The RKC damages eggs and may cause eggs to drift away from spawning sites and there for the total egg loss is higher. The RKC was found to feed more frequently on post spawn capelin than eggs (Mikkelsen & Pedersen, Invasive red king crabs feed on both capelin and their eggs, 2014).

The RKC could potentially have a negative effect on lumpfish eggs because of consumption and spillage (Michelsen, 2011). RKC prefer scallops or sea urchins and do not actively feed on lumpfish eggs. Smaller crabs (300-1020g) tend to choose lumpfish eggs but it is not their preferred food (Mikkelsen & Pedersen, 2012).

The lumpfish enters the coastal area for mating and breeding. The female lumpfish lays its eggs at a location chosen by the male, then the male fertilizes them and protects them until they have hatched. It is a challenging and important job where the male provides oxygen rich water and protects them from predators (Þorsteinsson, 1996). Small juvenile RKC stay in shallow waters the whole year around, adult crabs enter shallow waters during spring to spawn and stay there for a more limited time. They could both pose a threat to the lumpfish egg where juvenile and adult crabs overlap with the spawning lumpfish in time and space, making the predation chances higher. It is not certain how well the male lumpfish manages to guard the eggs from the juvenile crabs (Michelsen, 2011) but there are records that show that it is unsuccessful against the adult crab. In addition to feeding on the eggs the RKC destroys and spills other eggs while feeding and leaves them exposed to other predators, therefore predation is higher than consumption (Mikkelsen & Pedersen, 2012).

The Icelandic scallop is declining in areas with RKC, both in the Bering Sea and the Barents Sea (Falk-Petersen et.al., 2011). The RKC has the potential to substantially reduce the abundance of scallops such as the Icelandic scallop (Jörgensen L. L., 2005; Anisimova et.al., 2005). Larger RKC have bigger effects on scallop beds where there is a positive correlation between the amount of scallops consumed and the size of the crab (Jörgensen L. L., 2005; Michelsen, 2011). The larger RKC open scallops of all sizes and they open them faster than the smaller ones (Michelsen, 2011). They are only present in shallower waters where the scallop is found in spring and summer and therefore the effects lasts for a short period of time. The small RKC prey on scallops but seem to prefer sea urchins and sea stars (Jörgensen L. L., 2005). The smaller RKC stay in shallow water for five years therefore predation due to them is steady (Michelsen, 2011). The potential impact of the RKC on native assemblages associated with the commercial scallop *C. islandica* should be of significant concern (Jörgensen L. L., 2005).

Like the haddock the RKC feeds on echinoderms, mollusks and worms and could therefor be a food competition between those two species. Long-term analysis of haddock feeding in the period of the RKC low abundance (1971-1977) and of its increased abundance (1995-2002) was made. It did not show any effect of the food competition from the side of the RKC on the haddock feeding (Anisimova et.al., 2005).

3.3. Icelandic marine environment

Researchers have not precisely predicted if or when the Red King Crab will spread more in the Barents Sea and further into the Atlantic. There are speculations that it will spread further north in the Barents Sea and it has already started spreading south along the coast of Norway (Jörgensen & Nilssen, 2011; Sundet J. H., 2014).

If the RKC manages to migrate to Icelandic waters, the big question is if it can survive and flourish. To shed light on that question the Icelandic waters and coastal conditions can be evaluated.

3.3.1 The Coastal Area of Iceland

The Icelandic fisheries jurisdiction is 758,000 km^2 and there of the coastal water (<200 meters) is 115,000 km^2 (Jónsson, 2010). The environmental conditions in the ocean around Iceland are considered unstable because of the country's location at a confluence of warm and cold ocean currents. Iceland lies at the crossing of the Central Atlantic Ridge and Greenland-Iceland-Scotland Ridge (MRI, 2015). The parts of these ridges that reach out from Iceland are called Greenland-Iceland Ridge and Reykjanes Ridge in the west and Jan Mayen and Iceland-Faroe Ridge to the east of Iceland. The Reykjanes Ridge is the part of the Atlantic Ridge that extends about 300-400 nautical miles southwest into the North Atlantic and separates depths of 2,000-3,000 meters on each side. The Iceland-Faroe Ridge is a part of the Greenland-Iceland-Scotland ridge that reaches to the southeast towards the Faroe Islands and separates depths of more than 2,000 meters on both sides. It is a natural boundary between relatively warm Northeast Atlantic water and cold subarctic water masses. Depths between Iceland and the Faroes are less than 300 meters outside the continental shelf areas. These ridges separate the oceans around Iceland; the Irminger Sea to the west, the Iceland Sea to the north, the Norwegian Sea to the east, and the Iceland Basin of the North Atlantic to the south (Figure 17) (Malmberg, 2004).

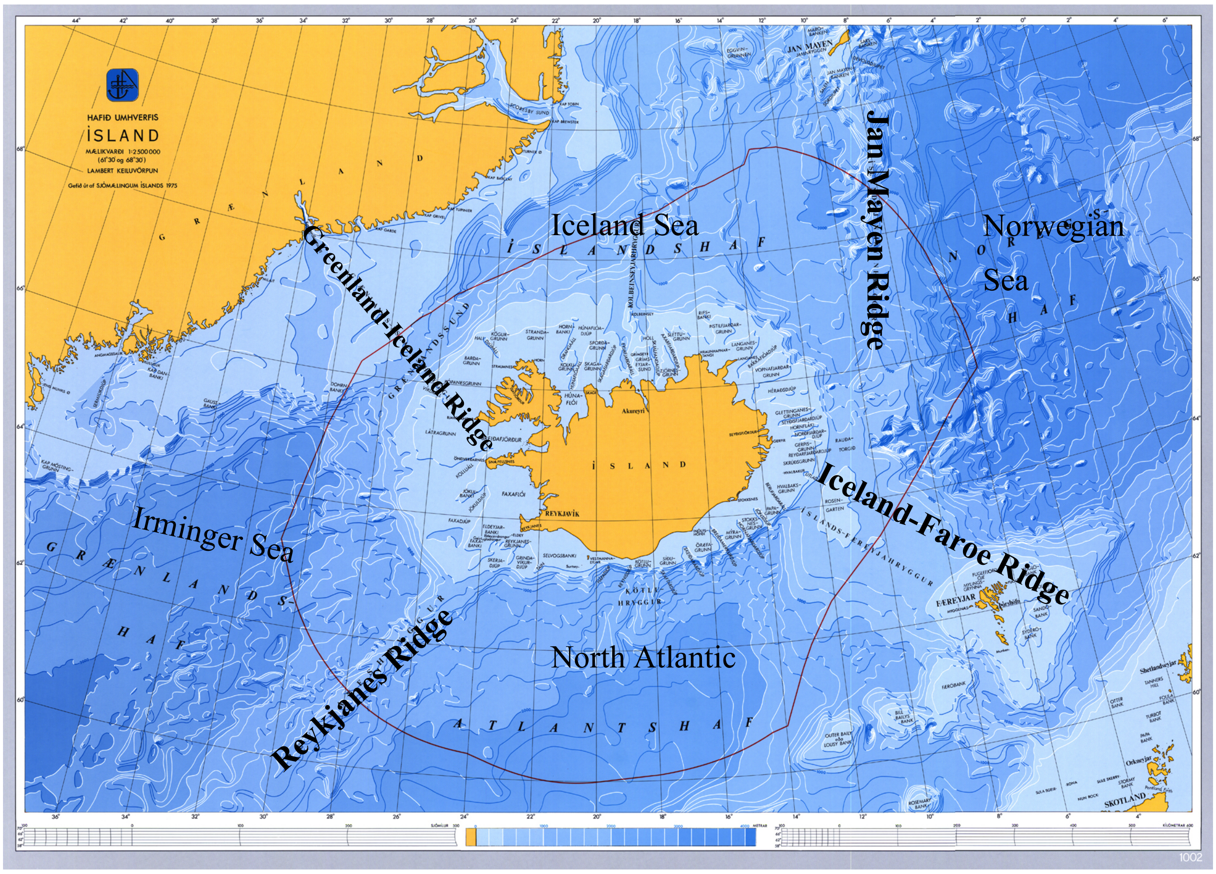

Figure 16: Iceland's Topography (Icelandic Coast Guard)

Except for the south coast, many bays and fjords of various shapes and sizes indent the coastline. They typically have steep sides and flat bottoms filled with sediments. The fjords deepen gradually when approaching the open shelf where depths are generally 100-200 meters (Jónsson, 2010). The southern shores of Iceland are smooth and sandy made by sedimentation brought by the many glacier fed rivers. (Malmberg, 2004). The shelf is the broadest off the west and North coast where it extends over 100 km. The shelf is narrowest off the south coast, or down to 20 km wide (Jónsson, 2010). The continental shelf breaks at about 200 meters depth to a steep canyon embedded continental slope down to 1,000 meters depth at the foot of the continental terrace. From there the depths increase slowly into the Iceland Basin to 2,000-3,000 meters (Malmberg, 2004).

3.3.2 Temperature and Salinity in the Waters of Iceland

Cold and warm ocean currents meet in the seas off Iceland and nutrient-rich seawater rises to the surface from the deep and provides favorable conditions for the foundation of a flourishing marine life. It creates living conditions for substantial amount of zoo- and phytoplankton, rich and diverse benthic communities, and high-yielding fishing grounds. Benthic algae grow in narrow coastal belt and the growth reaches down to a depth of about 50 meters, deeper if the sea is clear and there is sufficient sunlight. There are some 260 species of benthic algae known around Iceland. Planktonic algae occupy the upper layers of the sea but no overview exists of the number of species in the area (Ministry for the Environment and Natural Resources, 2009).

The Greenland-Iceland-Scotland ridge has a great impact on the spread of water masses around Iceland. It limits the mixing of warmer waters south of the country and the cold deep sea north of the country. The ridge affects the upper layer of the sea in the sense that warmer Atlantic water is dominant south of the country but cooler waters north of the country where it mixes with the cooler water from the north, the Polar water (Marine Research Institute Iceland, 2015). The warm Atlantic water mass is several hundred meters thick and very homogeneous. It is about 10°C when it approaches Iceland and the salinity is about 35.2 ppt. This water mass begins south of the country and flows westward as the Irminger Current, then north along the west coast where it divides and a small branch continues northwards onto the north Icelandic shelf as the North Icelandic Irminger Current. It continues eastwards and looses its characteristics at the northeast corner of Iceland. On this route it cools down to 4-5°C at the North Icelandic shelf, the salinity decreases and at the same place it has dropped to about 35 ppt. The Polar water originates in the Arctic Ocean, is relatively fresh ($S \leq 34.5$) and very cold ($T \leq 0°C$). It cools down and decreases the salinity in the water off the northern coast of Iceland. Low salinity coastal water mass then circulates clockwise around Iceland in spring and summer, caused by freshwater run off (Jónsson, 2010). Most of the deep water in the Iceland Sea is deep water from the Norwegian Sea, caused by cooling and sinking of North Atlantic drift waters. These water masses are rather cold ($T < -0.5°C$) and the salinity is very stable at around 34.9 ppt. The deep waters south of Iceland do not go through much seasonal changes but the deep waters north of Iceland are colder and have less salt during winter (Jónsson, 2010).

The salinity in the top layers in the ocean around Iceland ranges from 24.5 to 35.25 ppt. with the exception of fresh water masses mixing in certain places. The salinity is the highest off the south coast, due to the warm Atlantic water, and reaches north of the West fjords. South of Iceland the water is about 5-6°C during winter and reaches up to an average 10-11°C in August.

The salinity is lower north of Iceland due to the Polar water (Jónsson, 2010). North of the country it goes down to 1-3°C during winter and up to 7-9°C in August. The water is the coldest east of the country where it is about 2°C during winter but rarely reaches 7°C during summer. The temperature changes more closer to the coast where it goes from -1°C during winter to more than 12°C during summer (Marine research institute, e.d.)

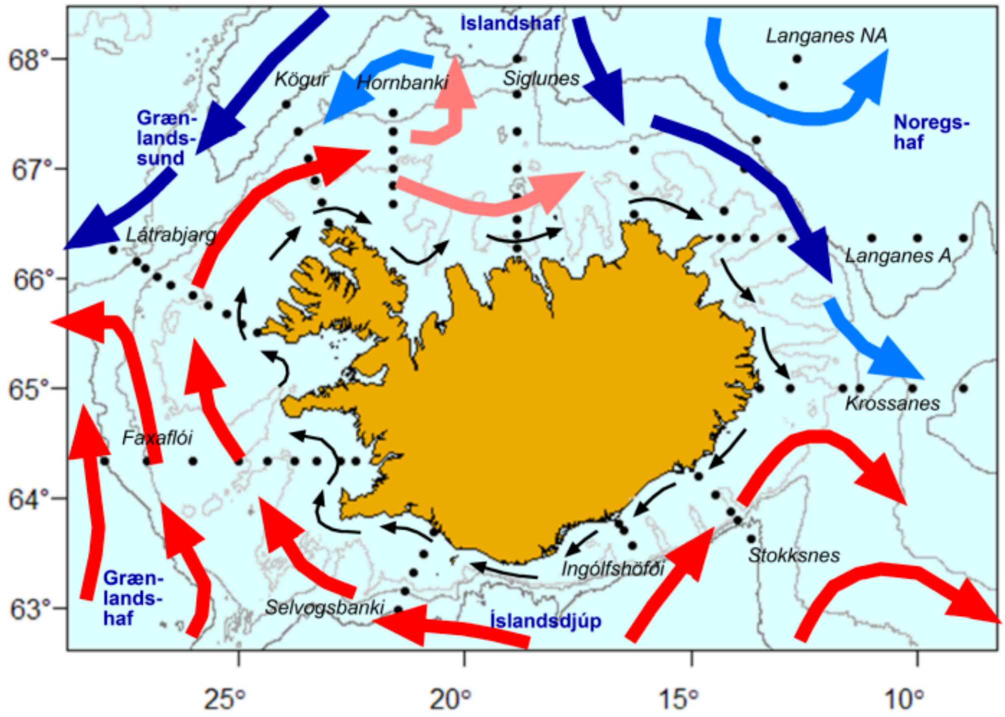

Figure 17: Cold and warm ocean currents around Iceland (MRI)

3.4. Species possibly affected

The Red King Crab can alter benthic ecosystems and reduce biodiversity but the affect of the RKC differs between locations and the long term effects are unknown.

3.4.1 Benthic Invertebrates as prey

Since 1992 the BIOICE (Benthic Invertebrates of Icelandic Waters) project has been researching the composition of species in the seas around Iceland. The project has collected more than 2,000 benthic fauna species with around 845 new discoveries near Iceland and 46 that were unknown anywhere in the world (Ministry for the Environment and Natural Resources, 2009). The Icelandic benthic flora includes species of sea stars, mussels, sea urchin, sponges, bivalves, polychaete and ophiuroids (Valtýsson, 2010; MRI, n.d.) and those have all been described as prey for the RKC.

Based on research from Norway and Russia, the following commercially important species could be affected if the RKC settles in Iceland.

3.4.1.1 The Icelandic scallop (Chlamys islandica)

The Icelandic scallop *(Chlamys islandica)* can be found all around Iceland except off of the south coast. It is mainly found on soft bottoms with small rocks and gravel (MRI, 2010) and more common in strong currents (Wiborg, 1963). It has been found at the depth of 2-300 meters but is usually found at around 20-50 meters (MRI, 2010). An ongoing ban was enforced on Icelandic scallop fishing in 2012 because the stock had collapsed due to an infection and excessive fishing. The Icelandic scallop population seems to be growing but is still not in good shape. The main fishing grounds were in Breiðafjörður bay but also in Faxaflói bay, east of The West fjords and in Húnaflói bay (MRI, 2014). There are hopes that the Icelandic scallop will recover and become commercially important species again.

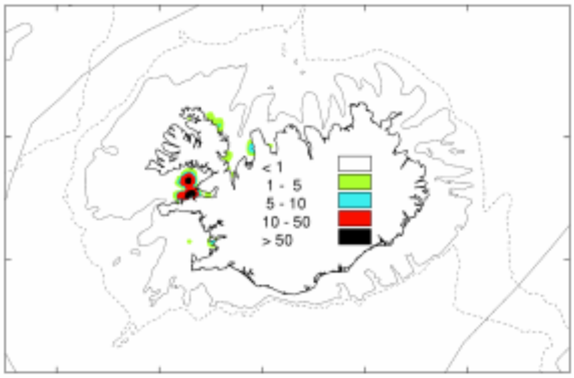

Figure 18: Iceland scallop fishing grounds in 1995-2003 (MRI)

3.4.1.2 Sea Urchin

There are two main types of sea urchin around Iceland, the green urchin (*Strongylocentrotus droebachiensis)* and the common sea urchin (*Echinus esculentus)*. They can be found all around Iceland but are less common along the south coast (Sea Life Base, n.d.). The green urchin has been harvested around Iceland since 1993, mainly in Breiðafjörður bay but also in Húnaflói bay and Eyjafjörður bay (MRI, 2014). The sea urchin can be found from the intertidal zone down to 1,200 meters (Buitron, 2003). It feeds on a wide variety of food and often feeds on fallen blades of kelp. If there are large amounts of sea urchin they start eating the kelp alive and become a big threat to kelp and can wipe it out, leaving a desert behind them (Valtýsson, 2010)

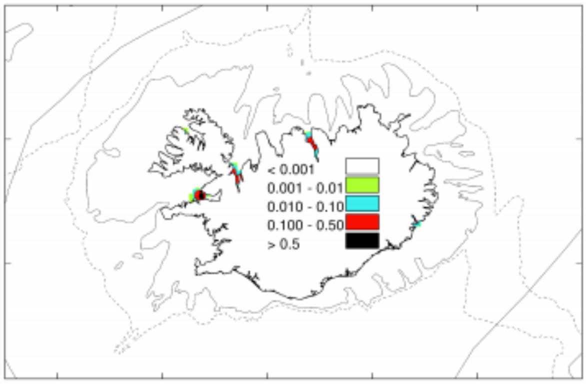

Figure 19: Sea urchin fishing grounds in 1995-2014

3.4.2 Other prey

Russian and Norwegian research have described the RKC feeding on bottom laying eggs. This behavior can be a cause for concerns for following species in Icelandic waters.

3.4.2.1 Fish egg

Capelin (*Mallotus villosus)* mainly spawns by the south coast, in Faxaflói bay and Breiðafjörður bay at 10-100 meters depth. The spawning season is late February towards the end of March/beginning of April. Like other pelagic fish it spawns at the ocean bottom (MRI, 2010). In that sense other pelagic fish species that spawn in Icelandic waters like herring *(Clupea harengus)* could be under threat if the RKC arrives in Iceland.

The lumpfish *(Cyclopterus lumpus)* can be found all around Iceland and is harvested, mainly for the female row. It migrates towards the shore to spawn late winter to early spring (MRI, n.d). Similar as in Norway the lumpfish eggs could be under threat from the RKC.

The small sandeel (*Ammodytes tobianus*) stock has been declining in Icelandic waters. It is an important part of the diet of many fish, seals and birds in the Northern Sea. Many species of sea birds have had problems bringing up their young ones due to lack of sandeel (Bogason & Lilliendahl, 2009). Because the sandeel spawns sticky eggs in sand or gravel in the coastal waters within 100 meters of depth (Froese & Luna, e.d.) they could be a prey for the RKC.

3.4.3 Food competitors

The RKC is not the only marine species that feeds on abovementioned prey. Below are some of the species that could be affected by competition for food from the RKC.

3.4.3.1 The Norway lobster (Nephrops norvegicus)

The Norway lobster *(Nephrops norvegicus)* is found and fished mainly around the southern coast of Iceland at the depths of around 110-300 meters (MRI, n.d.). The lobster stock has been decreasing (Hafro, 2015). The arrival of the RKC could make it more difficult for the stock to regrow in areas where there might be

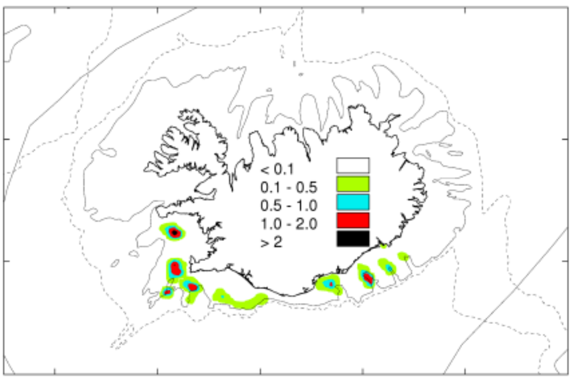

Figure 20: Norwegian lobster fishing grounds in 2014

competition between those two species for food. The lobster feeds on crustaceans, mollusks, polychaetes and echinoderms like the RKC (BIOTIC, n.d.; MRI, n.d.). No research was found on the interaction of the Norwegian lobster and the RKC nor the affect it could have on it because there is no known overlaps in their distribution areas (FAO, e.d.; Sundet J. H., 2015).

Other possible food competitors are mainly the haddock (*Melanogrammus aeglefinus)*, the long rough dab (*Hippoglossoides platessoides),* the plaice (*Pleuronectes platessa)*, and starry ray (*Raja radiate)* but there is no evidence that the RKC has had negative effects on those species so far (Sherstneva, 2013).

3.5 Establishing a baseline opinion of an RKC invasion

Conventional risk assessment is applicable when there is a good basis for predicting the likelihood of harm and the extent of the consequences but that is not the case with the Red King Crab. Natural sciences have a clear role to play in establishing the ecological knowledge base but uncertainty calls for integration of social science research in the management process (Falk-Petersen, 2012). Ecosystem-based management (EBM) is an approach that examines more than one aspect of exploitation of a species and could be helpful in this case. It recognizes ecological systems as a whole with the human as part of it. This approach calls for constant scientific input and a flow of information between management, scientist and society (Agardy et.al., 2011). It creates a common platform for discussing the range of services the ecosystem provides and exploring trade–offs between these, that science helps evaluate (Falk-Petersen, 2012). Scientists should avoid making managing decisions for society but further more inform so society can make these decisions (Agardy et.al., 2011). Crab fishing is not a big commercial fishery in Iceland and the presence of large crabs in big amounts is a fairly new thing there. To form a base line for the common knowledge, perception, and opinions on an invasive alien crab species in Iceland an online survey was conducted. The results can be used to gauge the attitude towards crabs and other invasive fish species. It can also be used to see how people value the potential of new valuable commercial species versus changes in the ecosystem and how informed they are about the changes a crab could bring.

The survey is in Appendix I and its raw results in Appendix II.

3.5.1 Survey results analysis

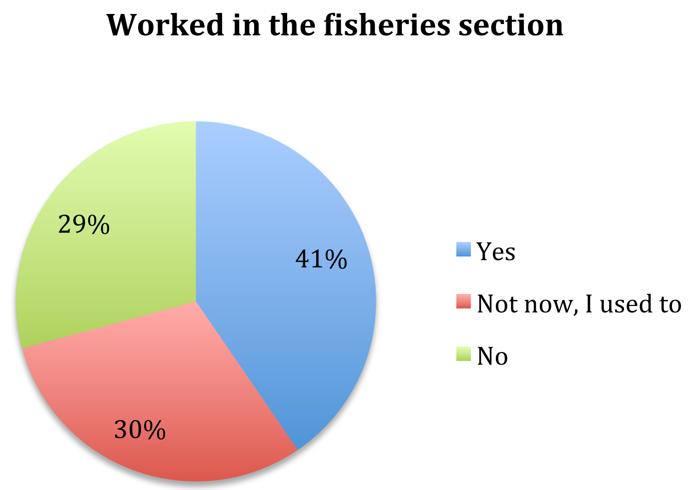

Figure 21: Percentage of respondent who work or used to work in the fisheries section

There were 109 people who answered the survey from 1st of July to 10th of July 2015. The respondents ranged from 21-80 years old, with the majority being 31-60 years old or 71%. The majority of the respondents were male or 66% compared to 34% female. Many more people declined to answer the survey because felt that they didn't have the knowledge to do so. The demographic therefore leaned heavily towards people from the fishing industry as question nr. 16: "Do you work in the fisheries industry" shows where 41% said yes and 30% used to work in the fisheries industry, in total 71% of the respondents.

Most of the respondants lived in or near the capital Reykjavík or 47%. The biggest group after that were people from West Iceland or 18% and remaining parts of the country ranged from 3-7%.

More than half of the respondents had a university degree or 57%. There was also a big group of people with "other" educations or 24% and most of them had a degree from the School of Navigation or a Mareen engineering degree.

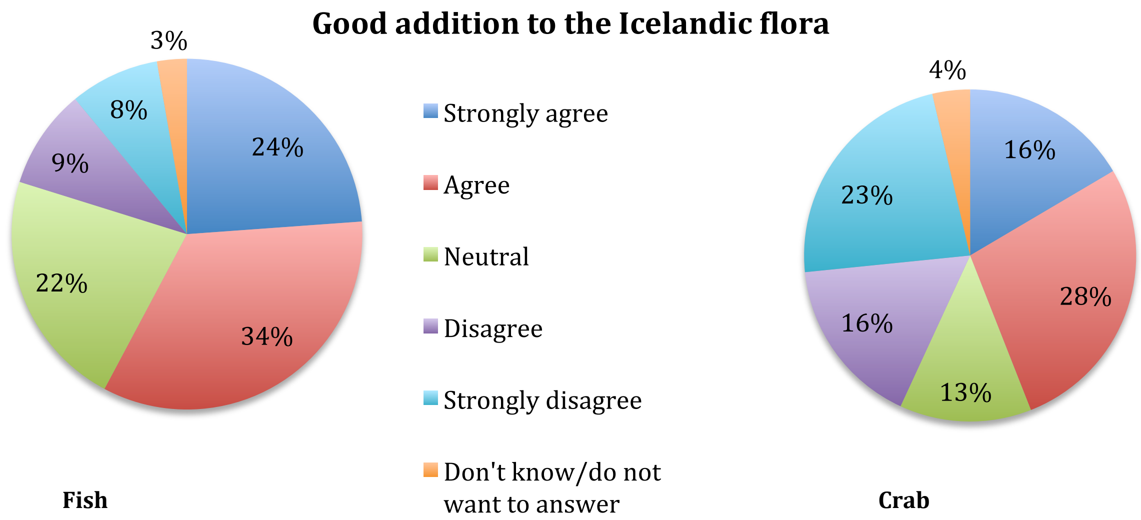

Figure 22: Percentage of respondent who agree/disagree that (to the left) alien species of fish or (to the right) alien species of crab were a good addition to the Icelandic marine flora

Minority of the survey's respondents were opposed to new species of fish entering the Icelandic waters where 8% strongly disagreed and 9% disagreed that they were a good addition to the Icelandic flora. In the case of new species of crabs in the Icelandic waters 23% strongly disagreed and 16% disagreed that they were a good addition to the Icelandic flora. Respondents consider alien crab to be worse than alien fish for the Icelandic flora. The majority of respondents thought felt crab was a good addition or 44% compared to 39% who thought it was bad.

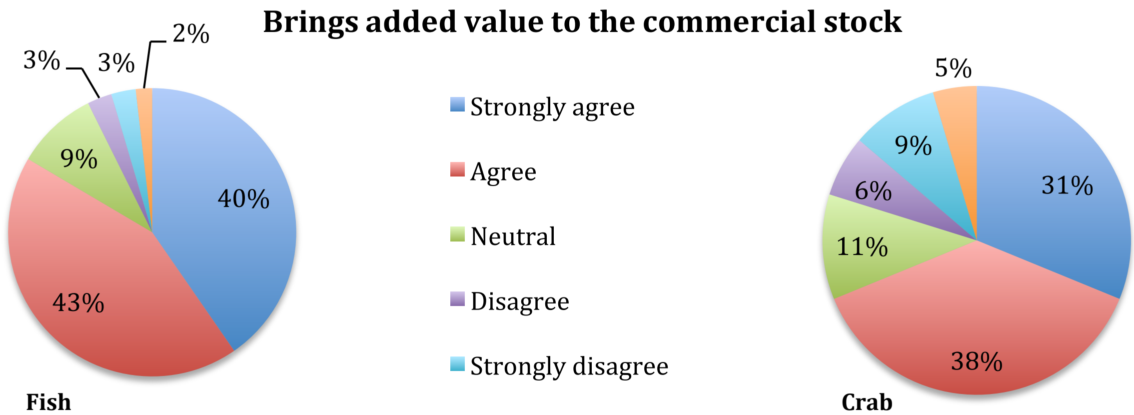

Figure 23: Percentage of respondent who agree/disagree that alien species of fish or crab brings added value to the Icelandic commercial stock

When asking about fish being an added value to the commercial stock 40% strongly agreed and 43% agreed but when asking about the crabs being an added value to the commercial stock 31% strongly agreed and 38% agreed. Respondents thought more of the commercial value of new fish species than new crab species.

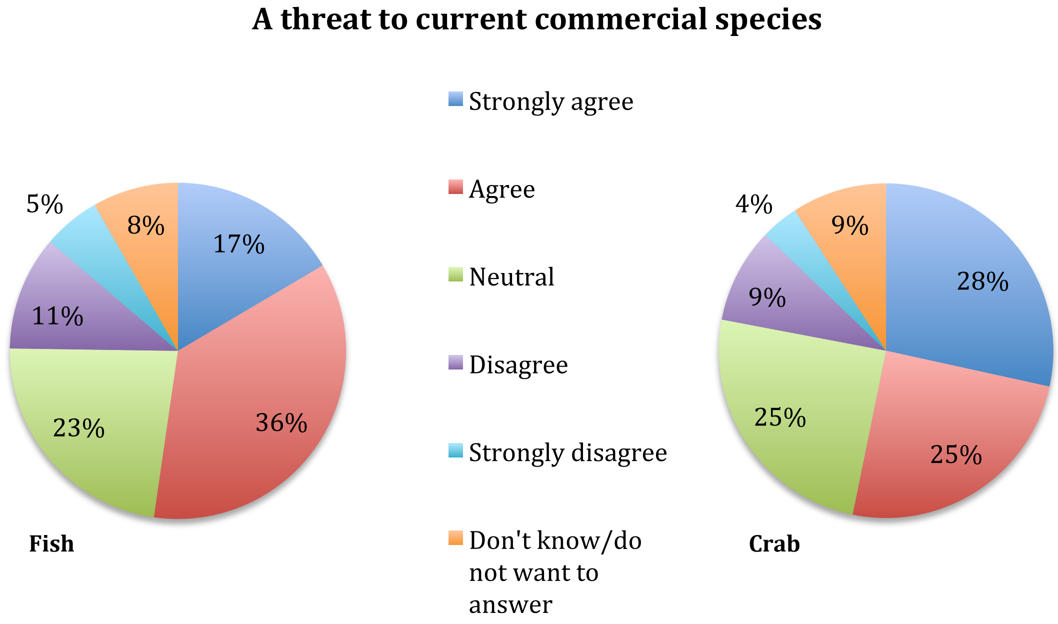

Figure 24: Percentage of respondent who agree/disagree that alien species of fish or crab are a threat to current commercial species

Respondents thought that new fish species and new crab species were a threat to current commercial species. Again the crab was considered worse where respondents felt more strongly to it being a threat. Respondents gave similar answers to the question if new fish and crab species disrupted the balance in the ecosystem or +/- 1% from the question about them being a threat for commercial species.

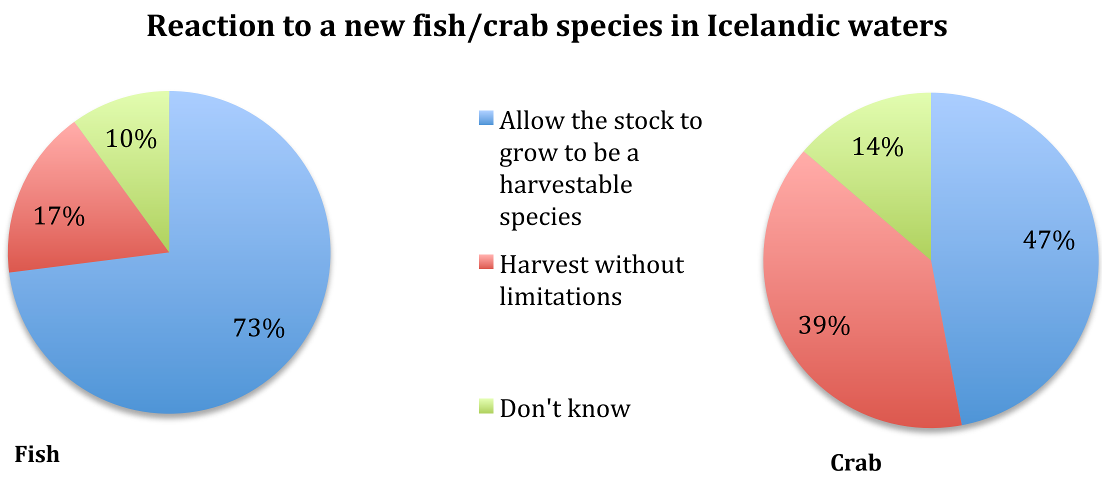

Figure 25: Reaction to a new fish/crab species in Icelandic waters

It was most obvious that respondents consider crab a bigger threat than fish in the question if a new stock should be allowed to grow to be a harvestable species 47% agreed with crabs but 73% agreed with fish. 39% thought that new crab species should be harvested without limit to try to keep the stock from growing too much compared to 17% regarding new fish species. The rest did not know.

The majority of the respondent thought that it was very important for Iceland to do its own marine research or 74% thought it was very important and 17% thought it was important. Fewer respondents thought it was important to consider foreign studies or 35% thought it was very important and 27% important.

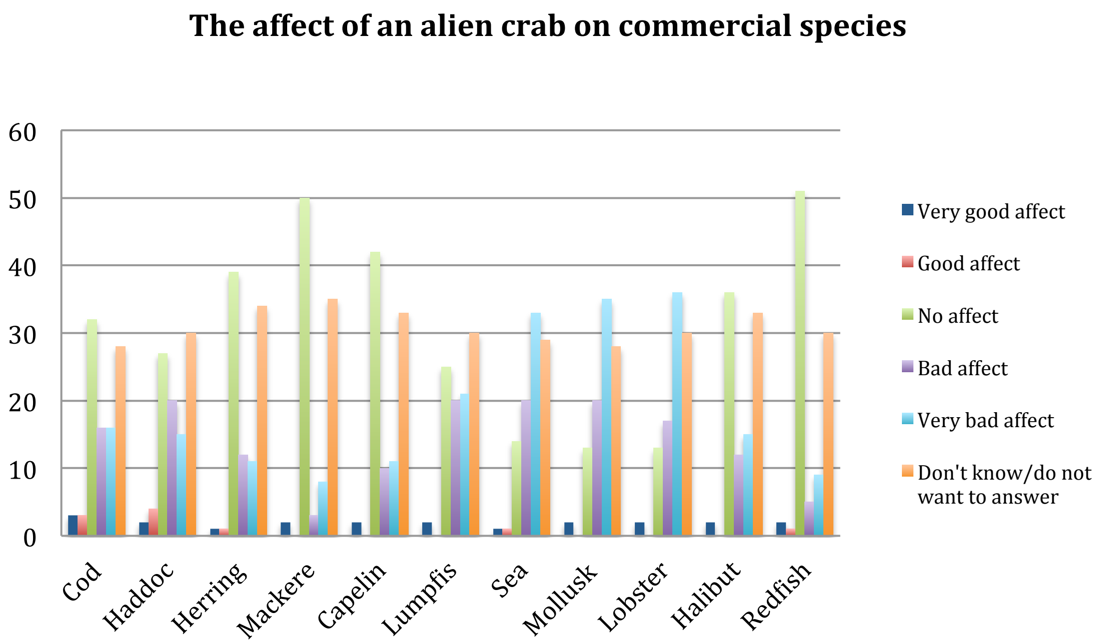

Figure 26: What respondent think the affect of an alien crab will be on different commercial species

Over all respondents thought that the crab didn't have any affect or that they didn't know the affect on certain commercial species but the ones they were most worried about were the lumpfish, sea urchin, mollusk and lobster. Some thought it would have a bad affect on cod, haddock and herring.

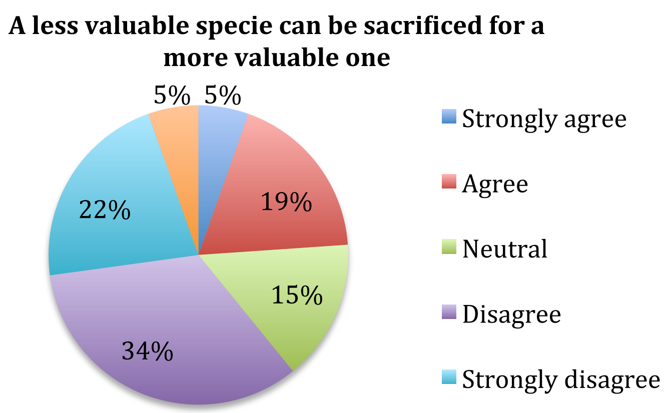

Figure 27: Percentage of respondent who agree/disagree that a less valuable species can be sacrificed for a more valuable one

Only 24% of respondent thought that it was acceptable to sacrifice less valuable species for more valuable species where 5% strongly agreed and 19% agreed, 15% were neutral. 62% of respondent thought that changes in the ocean fauna was not acceptable even if it was for valuable species where 34% disagreed and 22% strongly disagreed. 51% of respondents did not agree with the idea of uncertainty in the meaning that if it is unsure if a commercial species harms the ecology it should not be allowed to grow to a harvestable amount.

Most respondent thought that harvesting of new species should be first and foremost in the benefit of all Icelanders and leaning more towards the benefit of smaller communities and smaller fisheries operators. Respondent did favor the entrepreneur who would be the first to harvest the species where 61% thought it should be in their benefit.

Around 70% of the respondent would consider buying crabmeat in restaurants, markets and fish stores.

The media outlets that respondents considered most reliable were by far the television news on the national television as well as the national radio but also mbl.is. The most widely used social and news media were mbl.is, visir.is, Facebook, the news on the Icelandic national television and radio. Respondents also rated the media by trust by giving them 1 to 5 stars. The most trusted media was the news on the Icelandic national television. The news on the Icelandic national radio and mbl.is also got quite high scores. Where respondents were mostly from the fishing industry online media like sax.is, kvotinn.is, fiskifrettir.is, huninn.is and skip.is were mentioned. This question was asked to get the sense of what media would be good to inform people of research on new harvestable species in the waters of Iceland.

Respondents were given an option to give written replies and those who did, mostly talked about crabs being terrible for the environment. It was clear that some respondents had heard about the crab in Norway and what affects it has had there. Respondents talked about this being a project for scientists and that they did not have a clue. Many respondents talked about the crab eating row and some talked about it eating the cod's juvenile. Answers like the crab destroying benthic environments, eating mollusk, being a food competitor and leaving the shallower waters as a desert were given although some did talk about the nature finding a way to coexist with new species. It was interesting to see how accurate many answers were but usually they were related to Norwegian research and concerns.

4. Summary and discussion

There is little doubt that the Red King Crab will extend the distribution we see today but it is not possible to draw conclusions on further spread than is evident (Sundet J. H., 2014). The RKC could continue spreading and reach Iceland, probably by the Iceland-Faroe Ridge and enter the southeast coast where the conditions for it are good. RKC larvae could be brought either by currents or transported in ballast water. The latter is a fairly real scenario especially with increased traffic around the Barents Sea and Northern Norway (Jörgensen & Nilssen, 2011).

Would the Red King Crab thrive in the waters of Iceland?

When compared to the HSI model (see chapter 3.1.6) the RKC could live a good life in Iceland's favorable physical and biological marine conditions. Temperature and salinity is in a good range for all of its maturity stages. The ocean floor topography of Iceland gives the RKC man habitat options. It can choose from sand, rock or lava, flat and steep environments, with different stages of currents. The most likely areas seem to be the southeast but also south and west of Iceland. The waters northeast and east of Iceland are colder (MRI, 2015) so it is possible that the RKC would prefer the waters south and west of Iceland. The RKC is able to occupy a wide range of habitats throughout its lifetime being very mobile and having a generalist diet (Falk-Petersen et.al., 2011). Therefore it is difficult to predict exactly where it would settle and no reason to exclude any area.

If it would travel the Iceland-Faroe Ridge a likely scenario is that it would begin to settle south east of Iceland, then spread west along the South coast, north along the West coast and east along the North coast with larvae being transported by currents. If larvae would be transported by ballast it would depend on where it would be discharged and where the currents would take it from there.

The fjords in Iceland typically have steep sides and flat bottoms filled with sediment but they are not as deep as in Norway, therefore they might not be an ideal settling area for the adult RKC. The RKC predation would most likely spread further out the fjords to the open shelf where the fjords deepen gradually and depths are generally 100-200 meters (Jónsson, Topography, 2010). West of Iceland would be a good spot for the RKC where it has a large shelf to spread the adult predation and juveniles have a wide selection of hard bottoms both in shallower waters in Faxaflói bay and Breiðafjörður bay. It should be noted that these are only speculations and far from being a comprehensive list of possible scenarios.

A period of trial and error can be expected of the RKC while settling. The RKC often starts at high density in limited areas. In the later phases of its settling the RKC's density could reduce and predation pressure is spread over larger areas. That has happened in Russia and is starting to happen in Norway (Sundet J.H., 2014; Wright et.al., 2010: Oug et. al., 2014; Jörgensen & Spiridonov, 2013).

Some research on crabs has been done around the coast of Iceland but experienced crab fishermen consider those possibly inadequate due to wrong equipment used, the fishing methods and the bait used. It is a strong possibility that there are already species of crabs in the deep ocean of Iceland (Fehst, 2015). The Marine Research Institutes of Faroe Island, England, Scotland, Ireland, Sweden and Finland were contacted but findings of the RKC had not been reported there. Fishermen in those areas were reached out to through Facebook but there were no cases of RKC reported there either. Some did reach out with pictures of other crabs they had caught but most turned out to be stone crabs (*Lithodes maja).* This could also be due to the same reasons listed before where the RKC is unlikely to be caught in traditional fisheries or with inadequate fishing gear unless it is in extreme and concentrated amounts like in Norway.

What effect could the Red King Crab have on the ecosystem?

There is no direct evidence of RKC's harm on the ecosystem in whole but it is obvious that it can have a severe affect on benthic fauna. It is less clear how that affects the whole ecosystem and other species and it is difficult to predict what the affect would be in the long run in a new area.

The crab being an active predator on benthic fauna has mainly described the RKC's impact. Hard bottom communities are less affected but soft bottom communities show lack in diversity, biomass, species richness, density, structure and functional diversity because of the RKC's predation that have in many cases led to worsening sediment conditions. The RKC main source of food could be a species that does not play a key role in the benthos that would result in less impact (Oug et.al., 2010). The RKC is also considered a possible competitor with other crabs, benthic fish and predatory echinoderms and a predator in bottom laying fish eggs.

The effects of the RKC can be different between settling areas (Oug et.al., 2010; Anisimova et.al., 2005) and research show that the intensity of predation depends on the bottoms topography where it is better to have shelves with more spread impact than narrow fjords and canyons where the crab accumulates (Sundet J. H., 2014; Jörgensen & Spiridonov, 2013).

The affect of the RKC in Iceland could be a decrease in benthic diversity and sediment quality especially if the RKC would be in high concentrations in narrow areas. Fjords where sea urchins are harvested and scallops are recovering could be more sensitive for the RKC invasion than other areas. The RKC might have consequences on populations for some fish species that lay eggs on the seabed. It is a possible competitor for prays with commercially important species like the Icelandic lobster, haddock, halibut and other benthic fish. In the RKC early stages it could become a pray for other fish like big cod and halibut.

Would letting the Red King Crab spread and grow around the coast of Iceland and maintain the stock be a feasible option?

The RKC is both an alien species and a commercially valuable species so the answer is not simple. The RKC in Norway is very controversial and the regulations around it have changed almost annually since 2007. Keeping the RKC stock sustainable was crucial for the survival of some of the fishing plants and even some of the villages in eastern Finnmark. It also improved the way of life for many fishermen and their family in the area. In Russia the RKC is less controversial and more considered as commercially valuable specie. In Alaska it has the same reputation as in Russia and there the emphasis is on increasing the stock (Sundet J. H., 2014). The RKC population has thresholds and when they are crossed the stock can quickly increase or decrease and therefore decisions have to be made as soon as the RKC shows up (Falk-Petersen, 2012).

If it would migrate to Iceland an ecological approach to the management would be an interesting option, dividing the invasive area into smaller ecological areas and include the social part in the management. Some areas could be more sensitive to crab invasion than others and that should be recognized. Some areas are in need of a good addition to the community and would welcome the RKC as a valuable commercial species. Scientific results and information should be distributed to relevant people. In each divided area people could be reached out to through local media and with local informative meetings and nationally through media such as the national television news, national radio news and online media.

What do the people of Iceland think of a newly invasive crab species?

It is safe to say that the majority of the survey respondents are concerned about the resources of the Icelandic waters. Whether it reflects the opinion of the Icelandic nation is uncertain. The respondents want to ensure the safety of the Icelandic marine flora but at the same time the respondents saw the opportunities in commercially exploitable species that they want fairly divided. Respondents were surprisingly aware of the threat alien species might bring and also the value it could bring. That could be explained by the fact that the majority of respondents were from the fisheries sector and likely well informed on the matter. The survey results show that some people believe that a new crab species might destroy the ecosystem around Iceland but in general more people would want it to become sustainable and harvest it for commercial purposes than not.

5. Conclusions

The arrival of the Red King Crab to new fishing grounds could be considered good or bad and like for many things in nature, there are no critical evidence of which one it is. As an alien invasive species in the Barents Sea it has undeniably caused changes, moderate to severe depending on location. In the Russian part of the Barents Sea the RKC migration behavior has changed in the way that the RKC migrates farther and therefore spreads its predation. Effects of the RKC in the Russian part are considered moderate. In Norway the crab has been more concentrated in smaller areas but recent studies show that the predation is starting to spread like it has in Russia. The period of trial and error might be coming to an end with a healthy distribution of the RKC in Norway just around the corner. Nature might be taking control.

Despite that, the RKC does affect soft bottom benthic communities and the long-term affect is unknown. Nations have to be prepared and have the infrastructure to make a decision on what to do soon after arrival of alien species like the RKC. Using an ecosystem based management method could be good to implement both because of the lack of information on the RKC affect on ecosystems and because of the public's interest and concerns. It might also benefit the benthic community and the nation to divide areas in separate ecosystems with separate management goals. With such a social media savvy nation like Iceland it should be simple to inform it on research status, get input on trade-off factors and involve it in the decision making.

It is unlikely that the Red King Crab can be wiped out in newly invaded areas to protect the benthic fauna and given the fact that it is a valuable commercial species it is well worth considering adding it to the list of the marine products of Iceland if it migrates there.

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Nýjar tegundir á Íslandsmiðum

1) Hversu sammála eða ósammála ertu eftirfarandi fullyrðingum um nýjar tegundir af **fiskum** í fiskveiðilögsögu Íslands?						
	Sammála	Fremur sammála	Hvorki né	Fremur ósammála	Ósammála	Veit ekki/ vil ekki svara
Þær eru kærkomin viðbót við lífríki sjávar						
Þær færa ný sóknartækifæri						
Af þeim stafar hætta við núverandi nytjastofna						
Þær raska jafnvægi í lífríki lögsögunnar						
Þær færa þjóðarbúinu tekjur						

2) Hversu sammála eða ósammála ertu eftirfarandi fullyrðingum um nýjar tegundir **krabba** í fiskveiðilögsögu Íslands?						
	Sammála	Fremur sammála	Hvorki né	Fremur ósammála	Ósammála	Veit ekki/ vil ekki svara
Þær eru kærkomin viðbót við lífríki sjávar						
Þær færa ný sóknartækifæri						
Af þeim stafar hætta við núverandi nytjastofna						
Þær raska jafnvægi í lífríki lögsögunnar						
Þær færa þjóðarbúinu tekjur						

3) Hver telur þú að viðbrögð Íslendinga eigi að vera við komu nýrra **fiskitegunda**?	
Leyfa stofninum að vaxa og stunda sjálfbærar veiðar (þá eru veiðar takmarkaðar og reynt að viðhalda stofninum í ákveðinni stærð)	
Veiða ótakmarkað svo stofninn nái ekki að stækka	
Veit ekki	
Önnur viðbrögð, hver?	

4) Hver telur þú viðbrögð Íslendinga eigi að vera við komu nýrra **krabbategunda**?	
Leyfa stofninum að vaxa og stunda sjálfbærar veiðar (þá eru veiðar takmarkaðar og reynt að viðhalda stofninum í ákveðinni stærð)	
Veiða ótakmarkað svo stofninn nái ekki að stækka	
Veit ekki	
Önnur viðbrögð, hver?	

5) Hversu mikilvægt eða léttvægt þykir þér eftirfarandi við ákvörðun Íslendinga um meðhöndlun nýrra **fiski- eða krabbastofna**?						
	Mikilvægt	Fremur mikilvægt	Í meðallagi	Fremur léttvægt	Léttvægt	Veit ekki/ vil ekki svara
Að Ísland geri eigin rannsóknir						
Að Ísland fari eftir rannsóknum annarra þjóða						

Nýjar krabbategundir á Íslandsmiðum

6) Telur þú að tilkoma nýrrar **krabbategundar** geti haft góð eða slæm áhrif á eftirfarandi nytjastofna?						
	Góð áhrif	Fremur góð áhrif	Engin áhrif	Fremur slæm áhrif	Slæm áhrif	Veit ekki/ vil ekki svara
Þorsk						
Ýsu						
Síld						
Makríl						
Loðnu						
Grásleppu						
Ígulker						
Skelfisk						
Humar						
Lúðu						
Karfa						

7) Getur þú útskýrt nánar hver þú telur að áhrifin verði?

Verðmæti

8) Hversu sammála eða ósammála ertu eftirfarandi fullyrðingum?						
	Sammála	Fremur sammála	Hvorki né	Fremur ósammála	Ósammála	Veit ekki/ vil ekki svara
Fórna má verðminni nytjastofnum fyrir verðmeiri nytjastofna						
Breytingar á lífríki sjávar eru í lagi ef það						
Ekki er vitað hvort verðmæt nytjategund veldur lífríki sjávar skaða. Henni skal samt viðhalda fyrir fjárhagslegan ágóða						

9) Hversu sammála eða ósammála ertu eftirfarandi fullyrðingum?						
	Sammála	Fremur sammála	Hvorki né	Fremur ósammála	Ósammála	Veit ekki/ vil ekki svara
Nýting á nýjum tegundum á að vera hagur stærri útgerða						
Nýting á nýjum tegundum á að vera hagur smærri útgerða						
Nýting á nýjum tegundum á að vera hagur stærri samfélaga						
Nýting á nýjum tegundum á að vera hagur minni samfélaga						
Nýting á nýjum tegundum á að vera hagur allra landsmanna						
Nýting á nýjum tegundum á að vera hagur þess sem hefur frumkvæði til þess að veiða þær						

10) Hversu sammála eða ósammála ertu eftirfarandi fullyrðingu?						
	Sammála	Fremur sammála	Hvorki né	Fremur ósammála	Ósammála	Veit ekki/ vil ekki svara
Ég get hugsað mér að kaupa krabbakjöt á veitingastaði						
Ég get hugsað mér að kaupa krabbakjöt í matvöruverslun						
Ég get hugsað mér að kaupa krabbakjöt í fiskbúð						
Ég get ekki hugsað mér að kaupa krabbakjöt						

11) Annað sem þú vilt koma á framfæri?

Almennar upplýsingar

12) Hvort ertu kona eða karl?	
Kona	
Karl	

13) Hversu gömul/gamall ert þú?	
15 ára eða yngri	
16-20 ára	
21-30 ára	
31-40 ára	
41-50 ára	
51-60 ára	
61-70 ára	
71-80 ára	
81-90 ára	
91-100 ára	
101 ára eða eldri	

14) Menntun	
Grunnskólapróf	
Stúdentspróf	
Háskólapróf	
Annað, hvað?	

15) Hvar býrð þú?	
Höfuðborgarsvæðinu	
Reykjanes	
Vesturlandi	
Vestfjörðum	
Norðurlandi	
Austurlandi	
Suðurlandi	
Erlendis	

16) Vinnur þú við sjávarútveg?	
Já	
Ekki núna, en ég hef unnið við sjávarútveg	
Nei	

17) Hvaða fróðleiks-/fréttamiðla notar þú?				
	Aldrei	Sjaldan	Stundum	Oft
Mbl.is				
Visir.is				
Pressan.is				
Sjónvarpsfréttir RÚV				
Sjónvarpsfréttir Stöðvar 2				
Facebook				
Fréttablaðið				
Morgunblaðið				
DV				
Útvarpsfréttir rásar 1 og 2				
Útvarpsfréttir Bylgjunnar				
Kjarninn.is				
Eyjan.is				
Stundin.is				

18) Vinsamlegast gefðu eftirfarandi fróðleiks- og fréttaveitum stjörnur eftir trausti, þ.e. 5 stjörnur fyrir mesta traustið og 1 stjörnu fyrir minnsta.
Ef þú notar ekki eða þekkir ekki fróðleiks-/fréttaveituna, vinsamlegast slepptu því að gefa henni stjörnu.

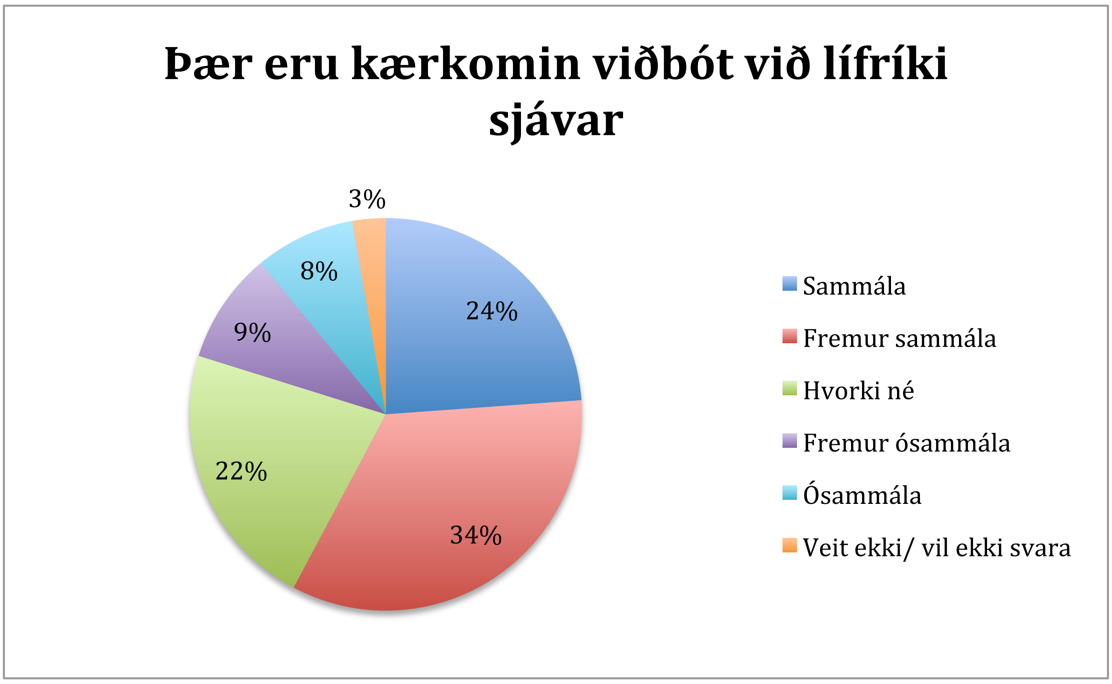
mbl.is					
visir.is					
Pressan.is					
Sjónvarpsfréttir RÚV					
Sjónvarpsfréttir Stöðvar 2					
Facebook					
Fréttablaðið					
DV					
Morgunblaðið					
Útvarpsfréttir Rásar 1 og 2					
Útvarpsfréttir Bylgjunnar					
Kjarninn.is					
Stundin.is					
Eyjan.is					

19) Er annar fróðleiks- eða fréttamiðill sem er ekki nefndur hér að ofan og þú kýst frekar?

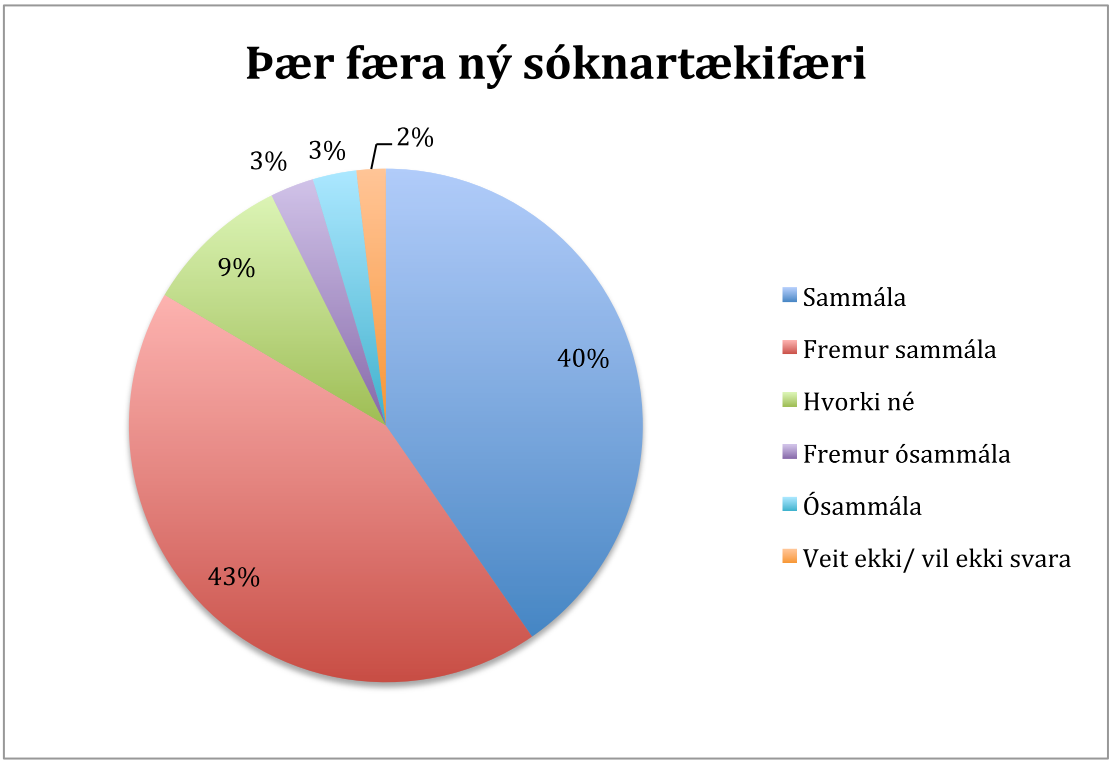
Appendix II – Survey results

1. Nýjar tegundir af fiskum í lögsögu Íslands

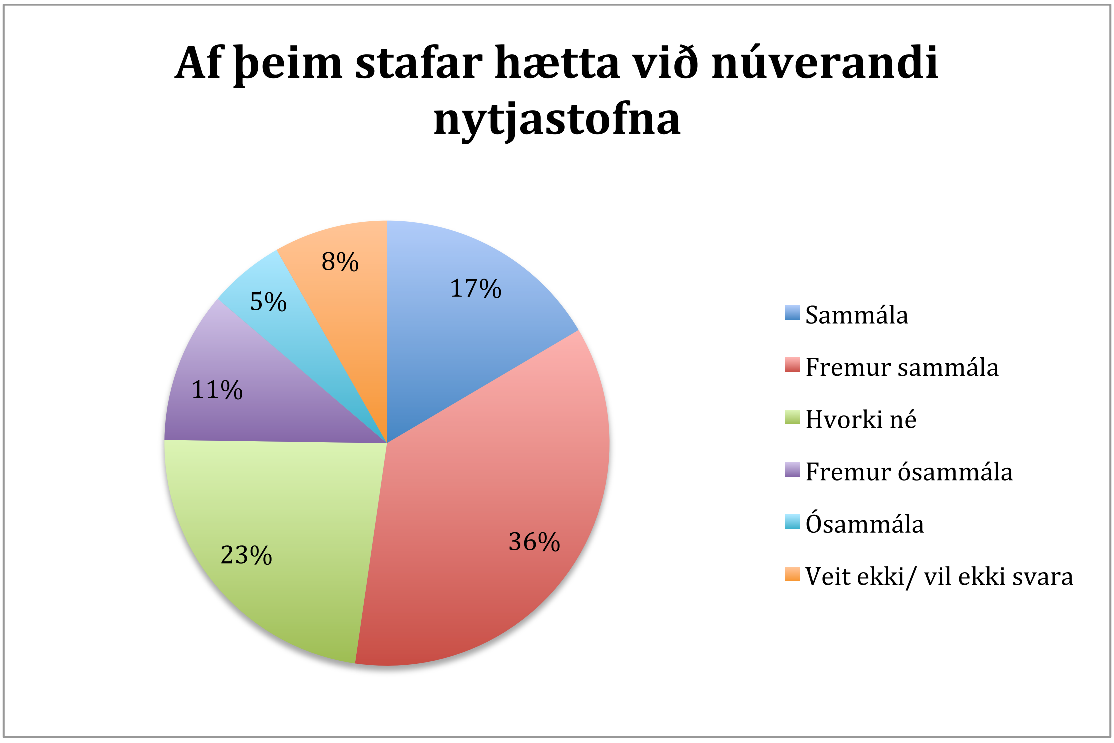
Question 1 a)



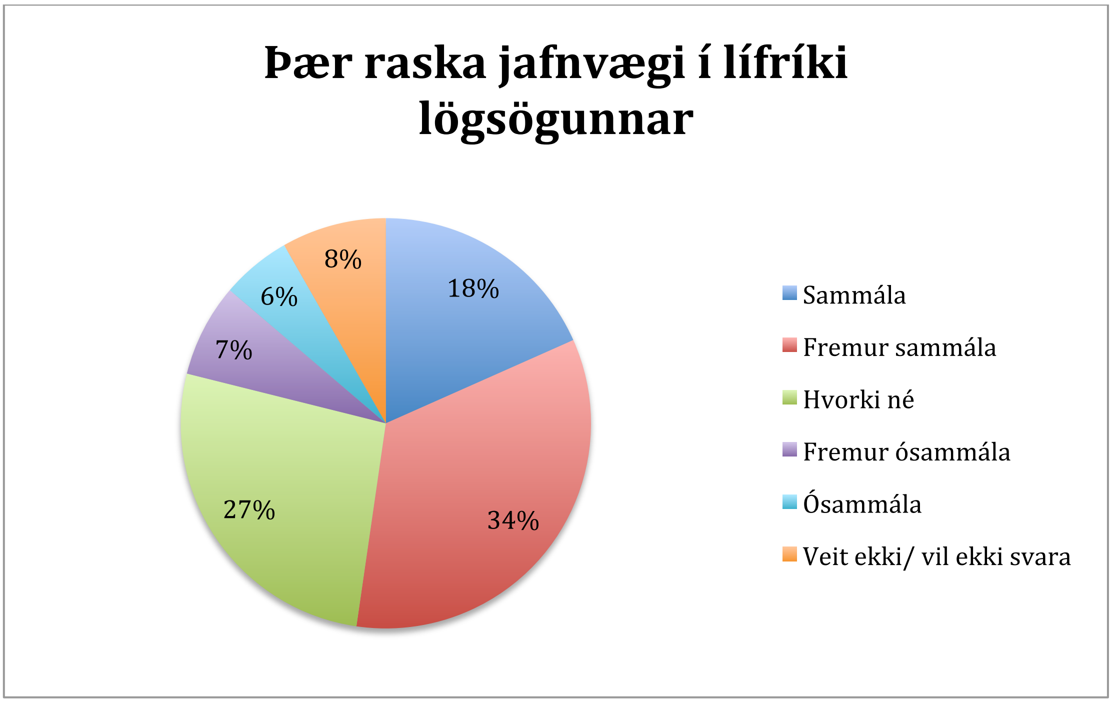
Question 1 b)



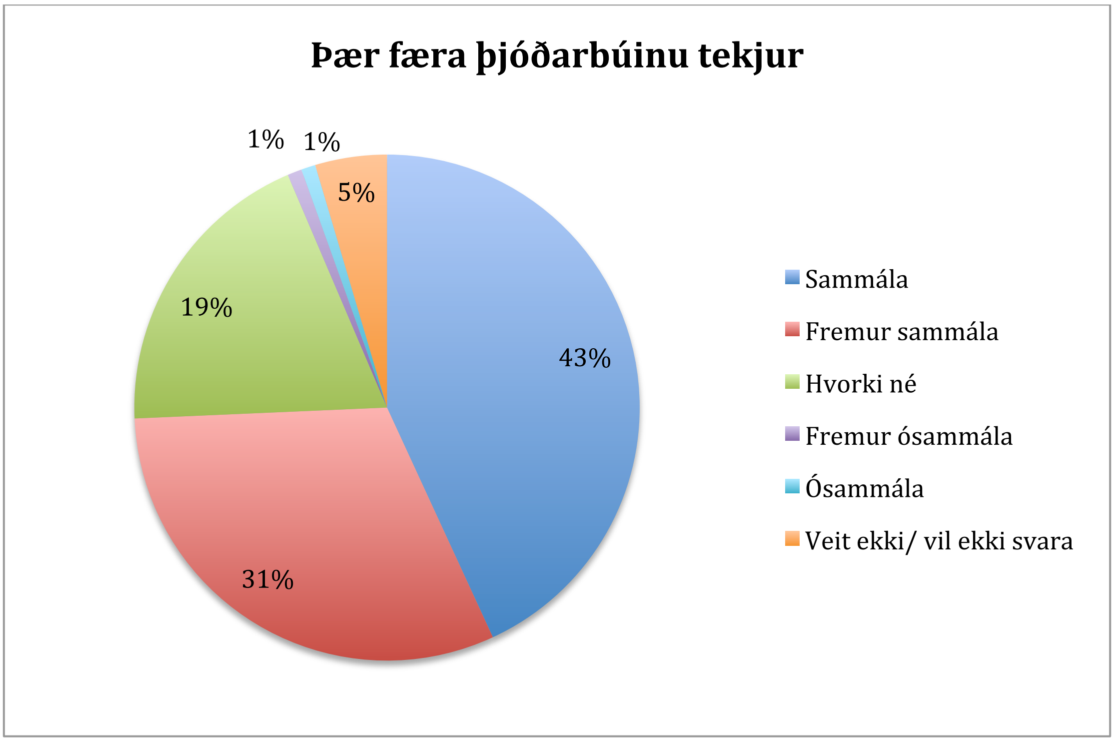
Question 1 c)



Question 1 d)



Question 1 e)

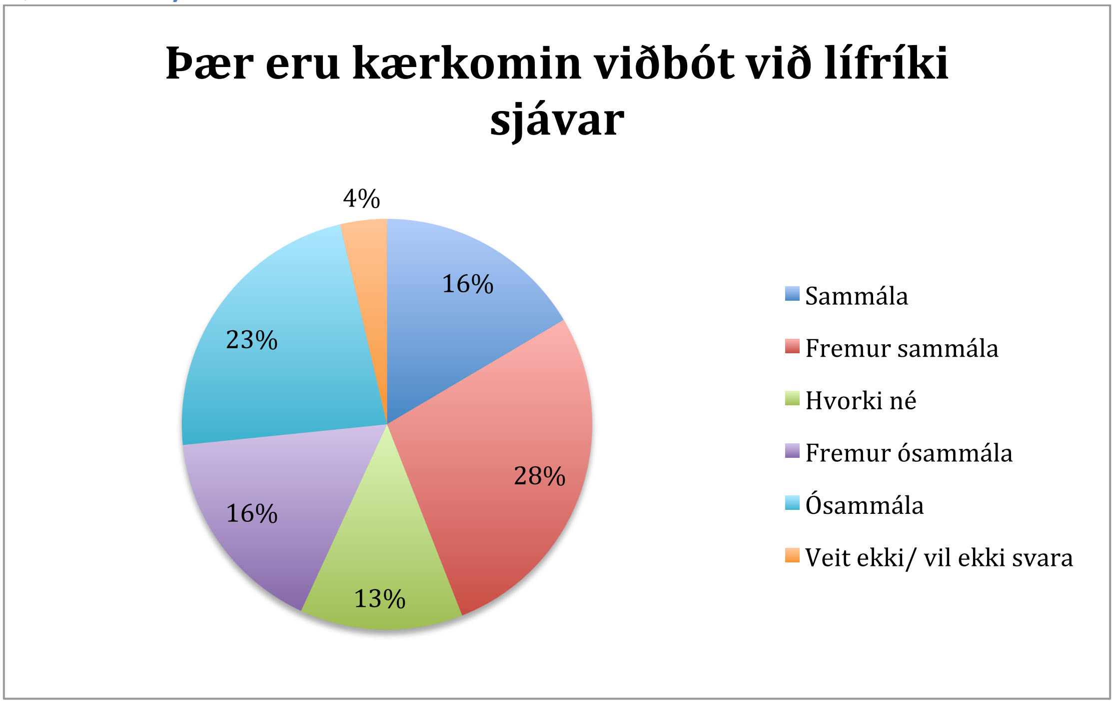


2. Viðbrögð við nýjum fiskitegundum

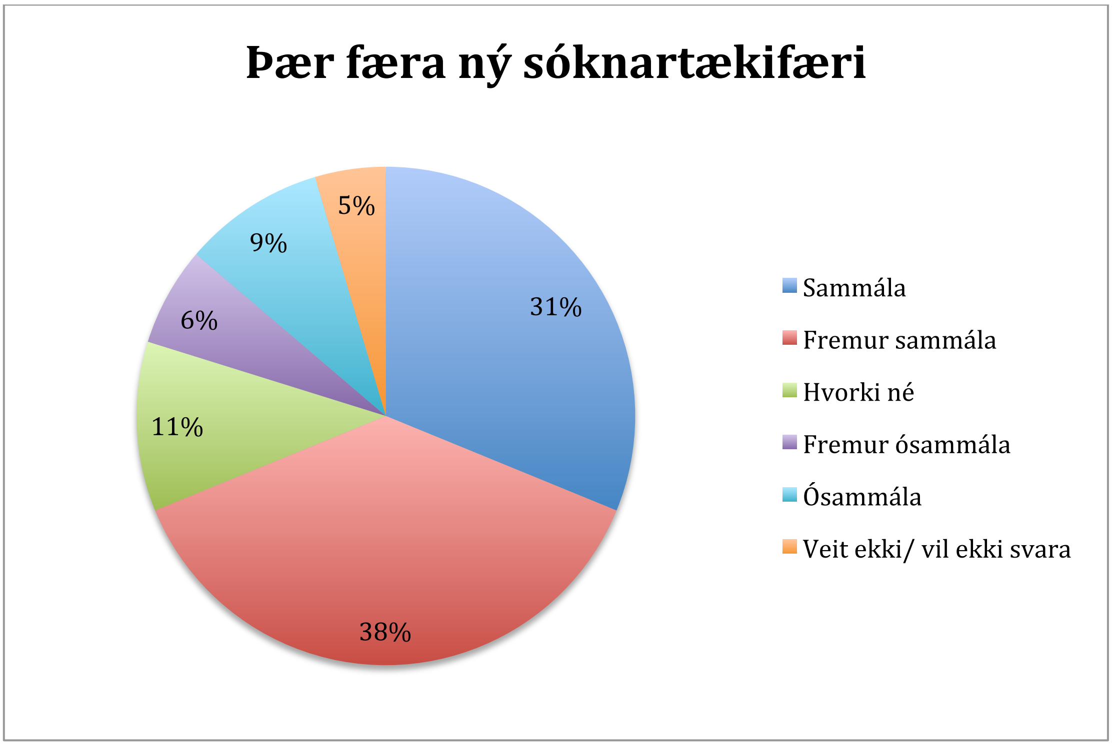
Question 2

3. Nýjar tegundir af kröbbum í lögsögu Íslands

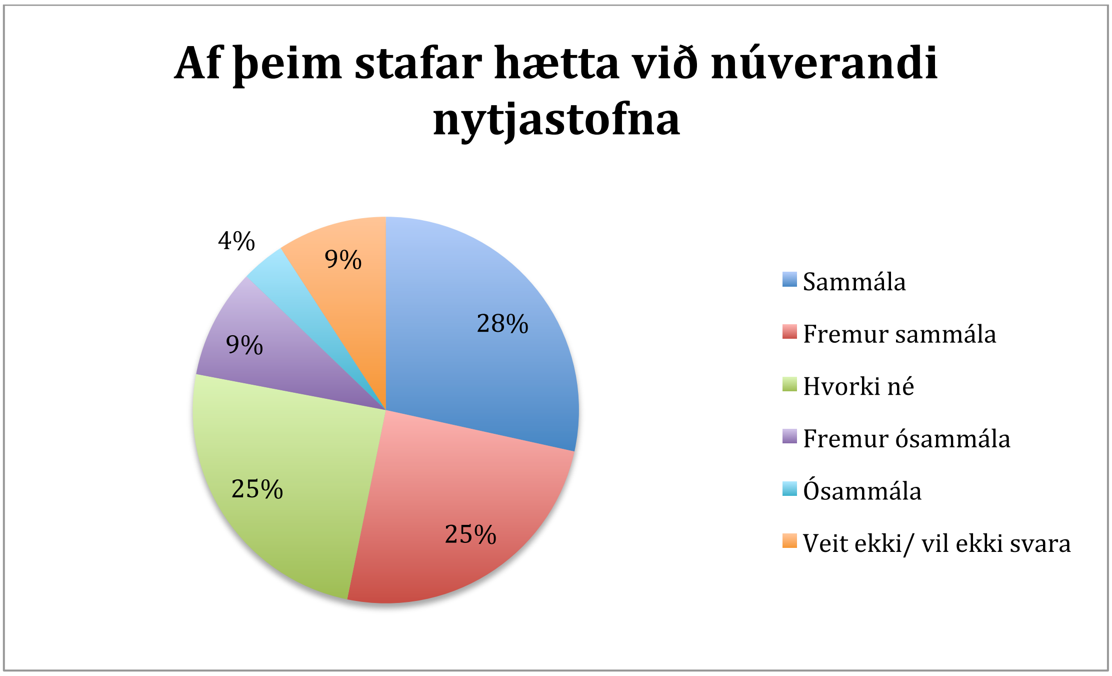
Question 3 a)



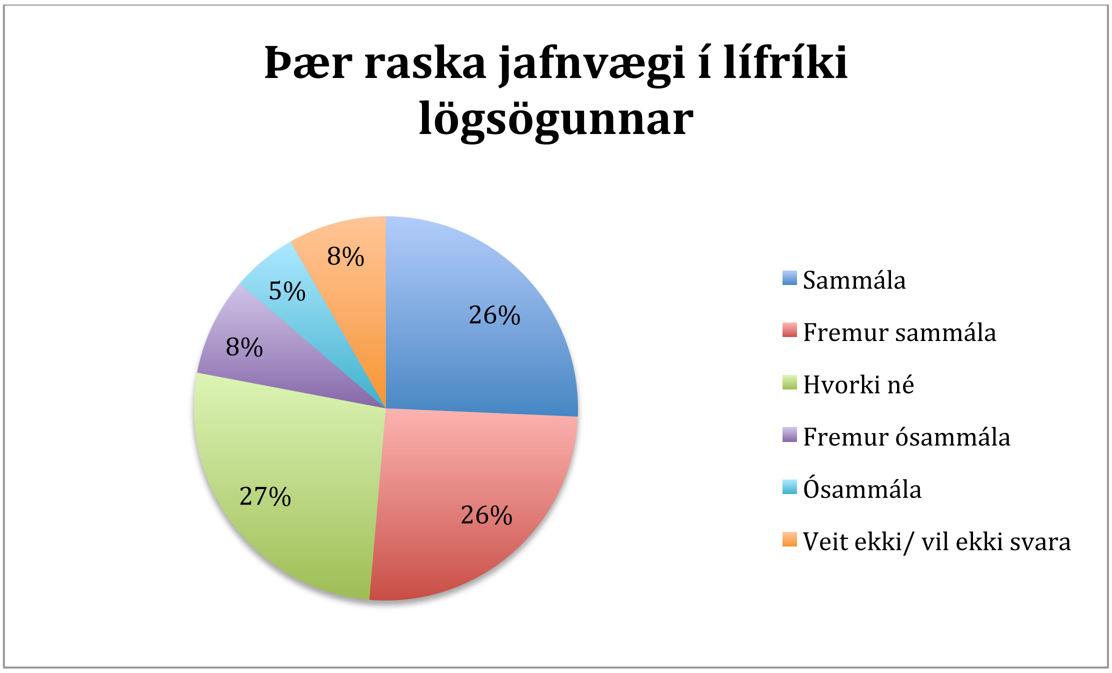
Question 3 b)



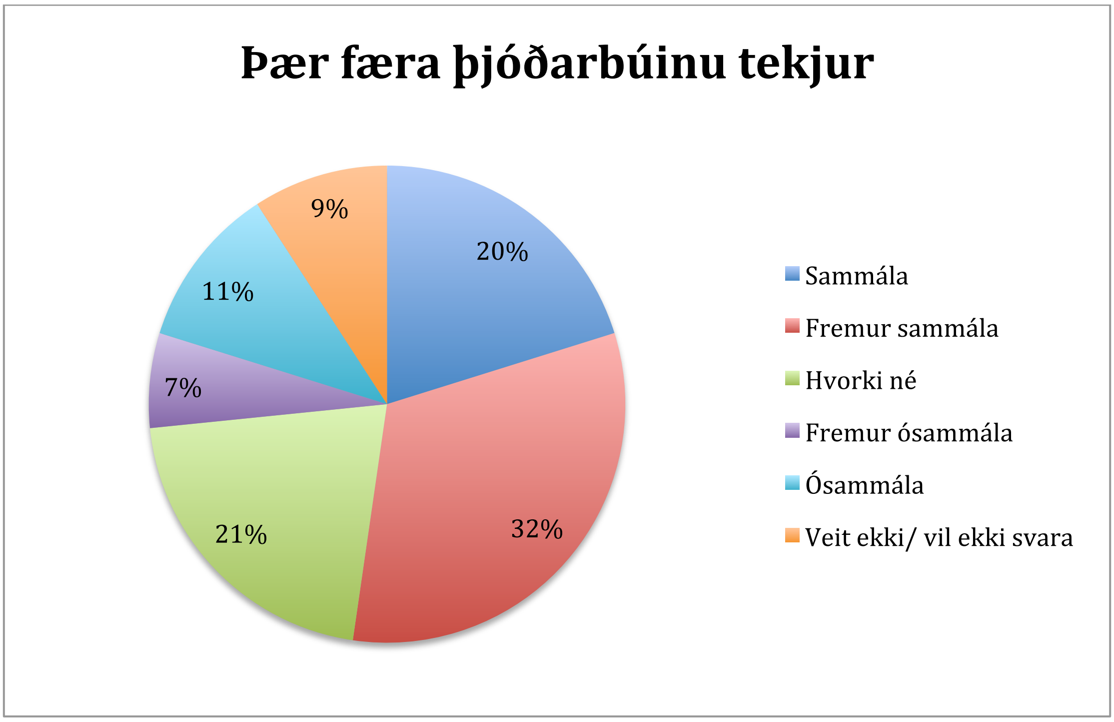
Question 3 c)



Question 3 d)



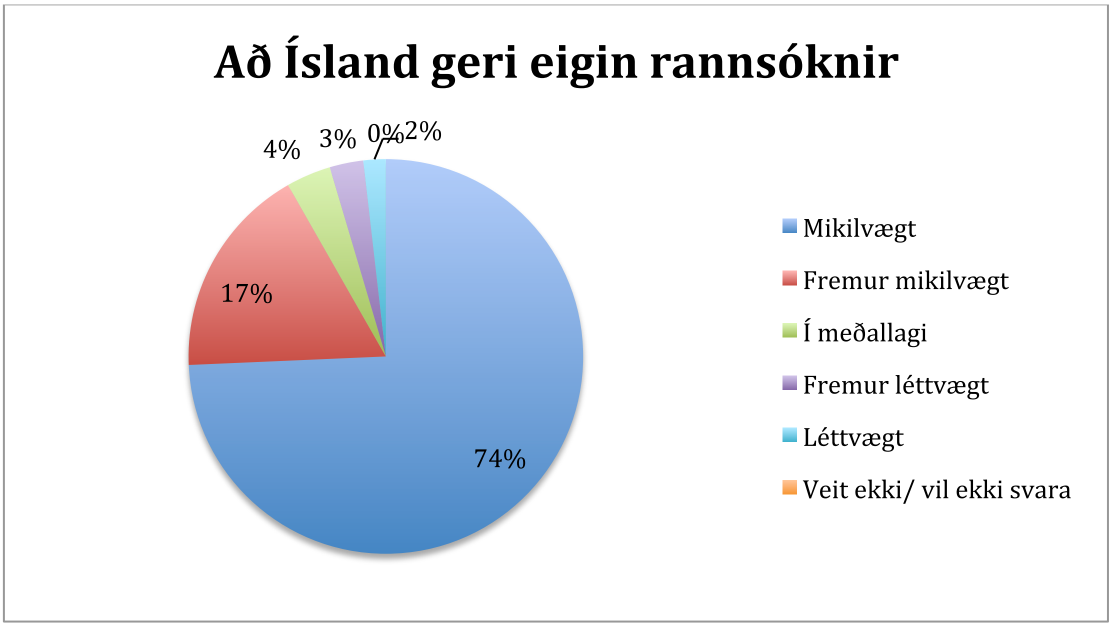
Questino 3 e)



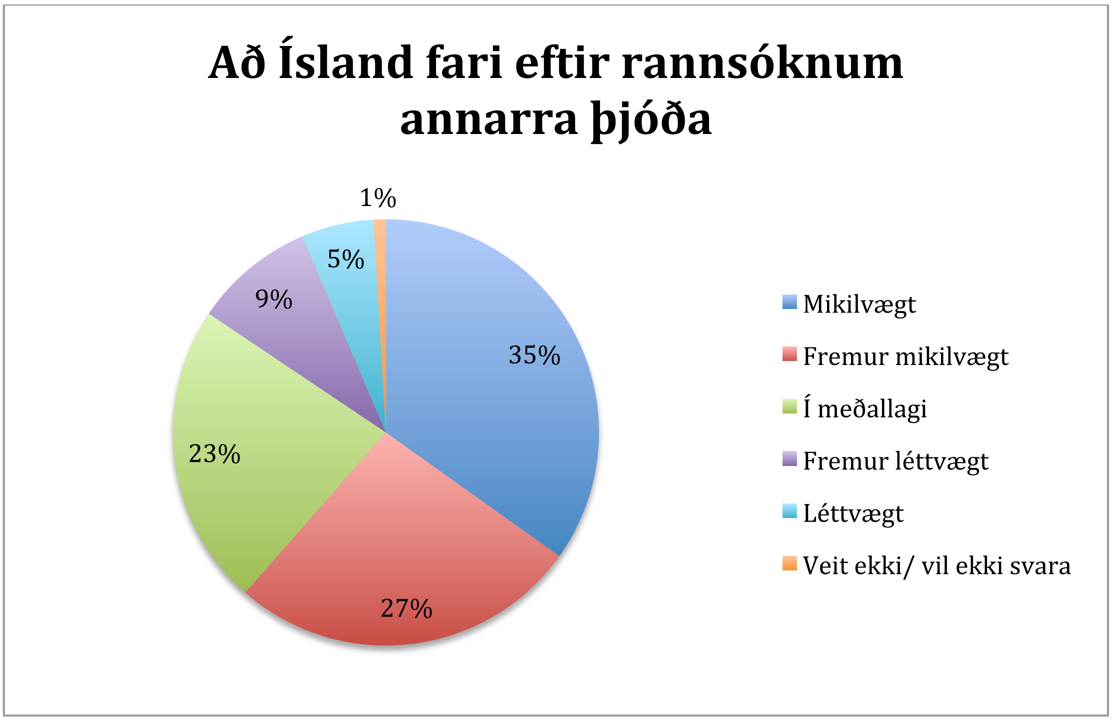
4. Viðbrögð við nýjum krabbategundum

5. Mikilvægi íslenskra og erlendra rannsókna

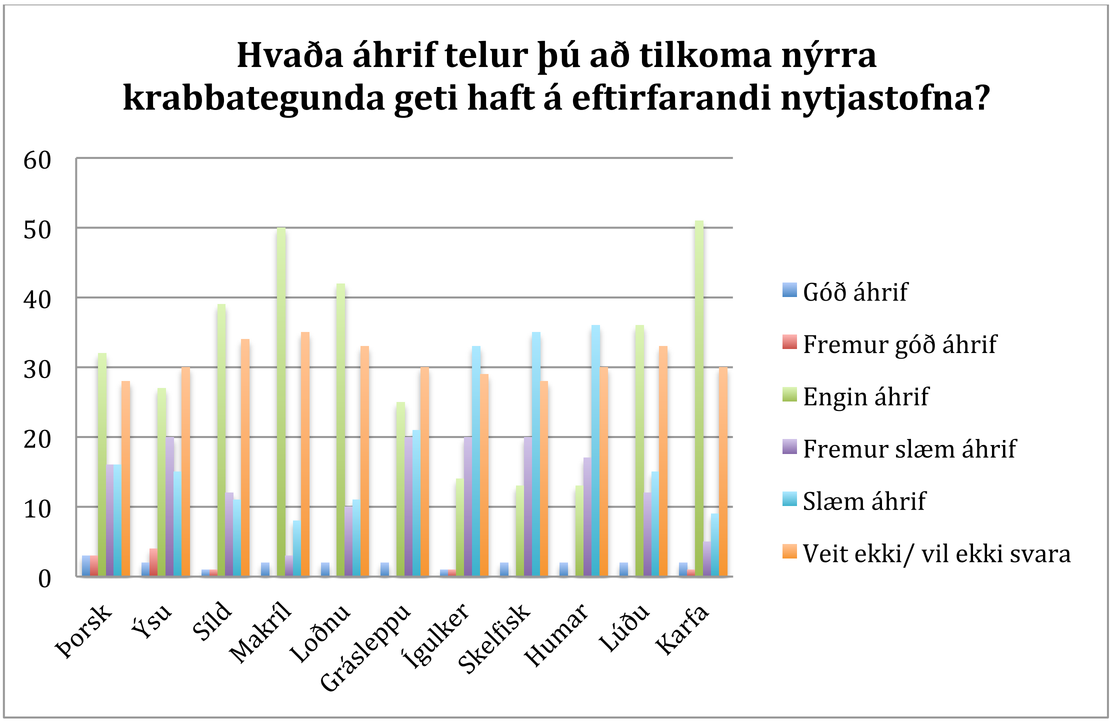
Question 5 a)



Question 5 b)

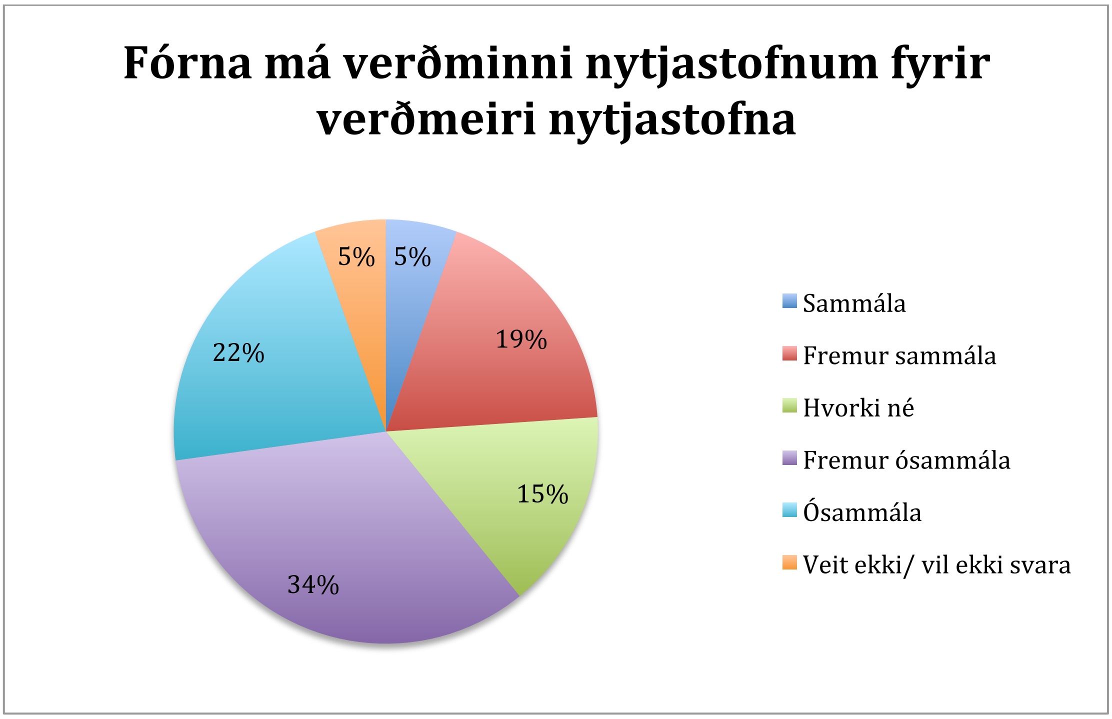


6. Effect on different harvesting species

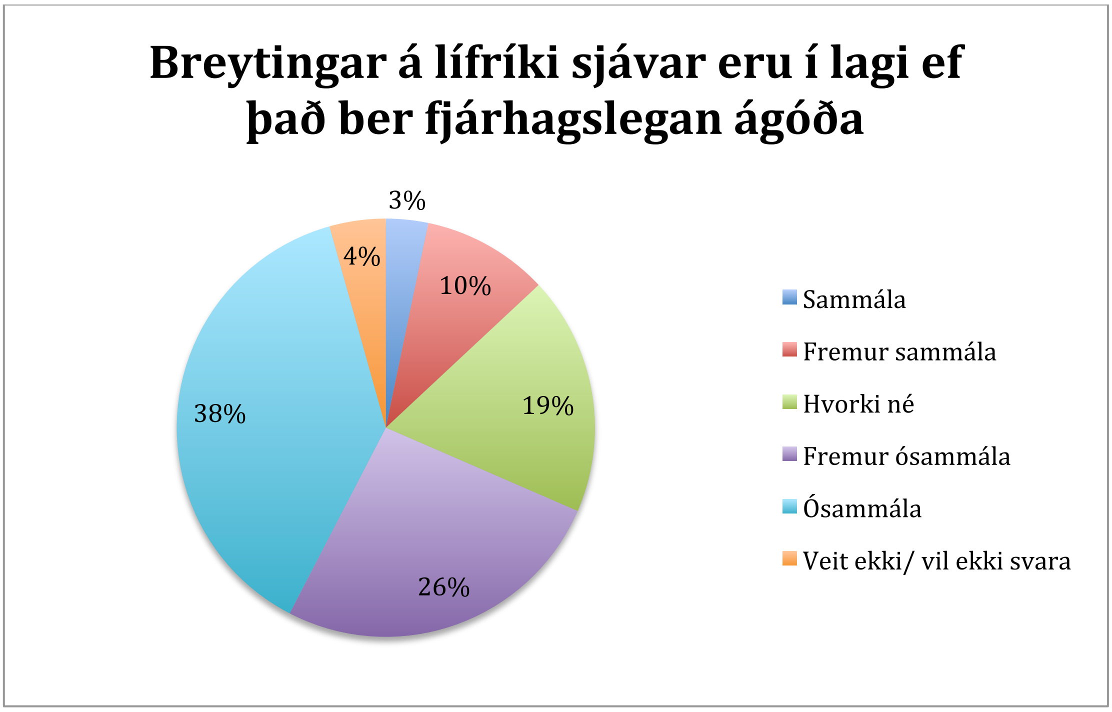


8. Verðmæti nytjastofna

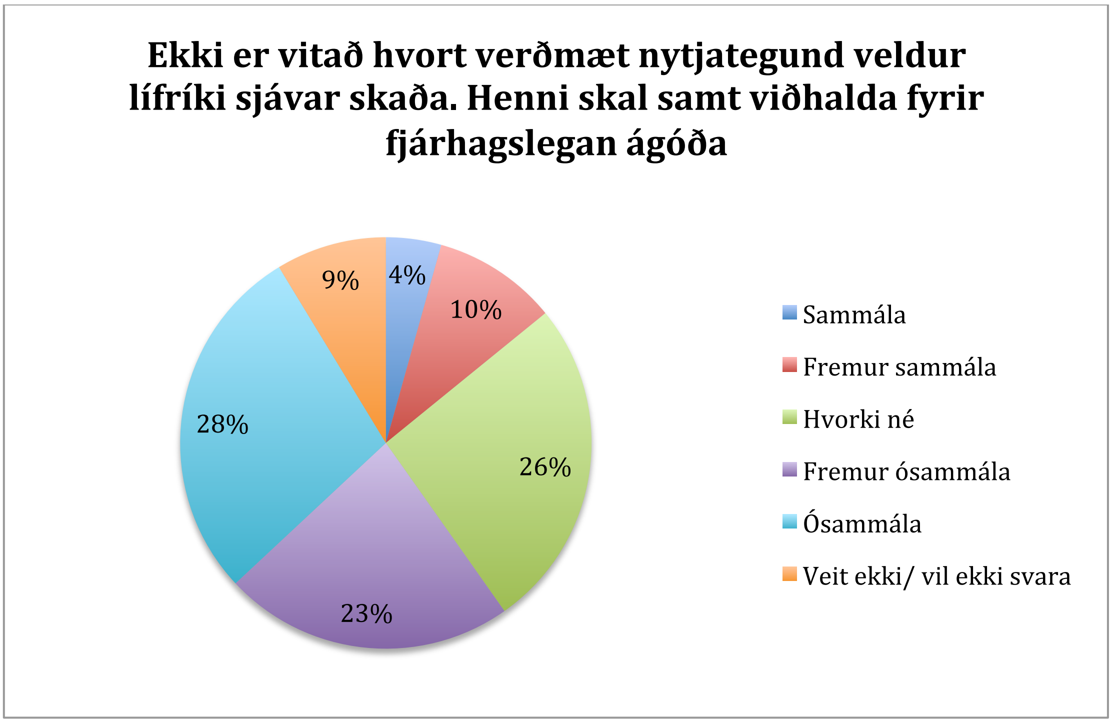
Question 8 a)



Question 8 b)

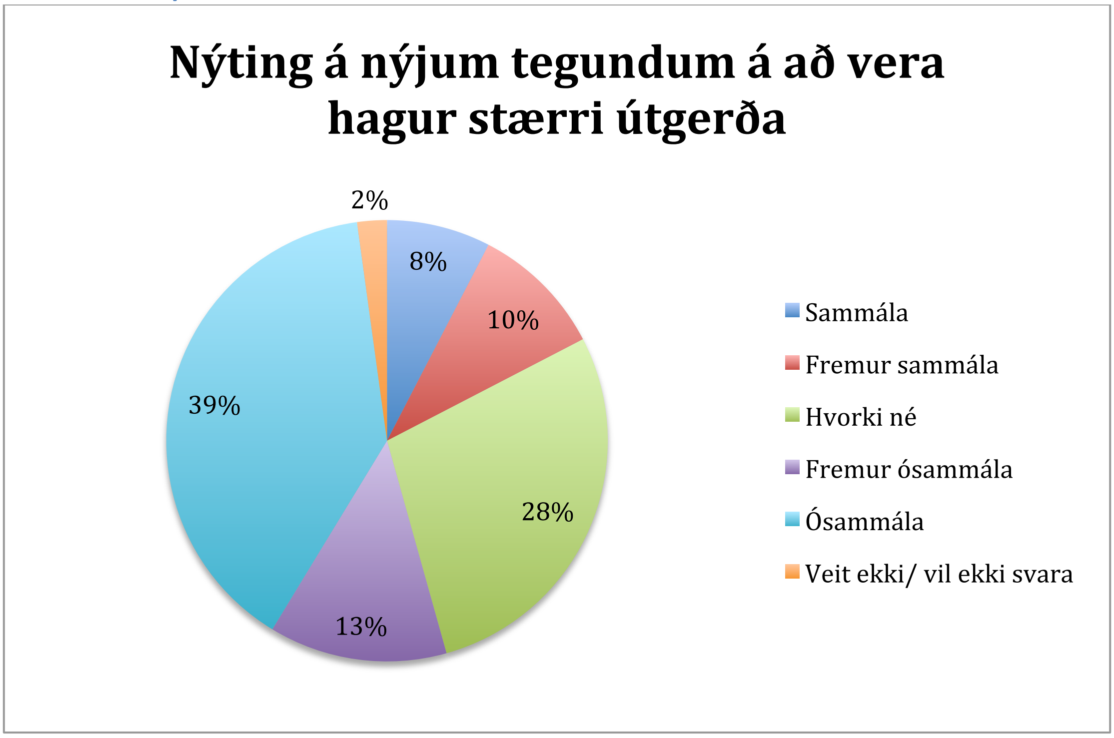


Question 8 c)

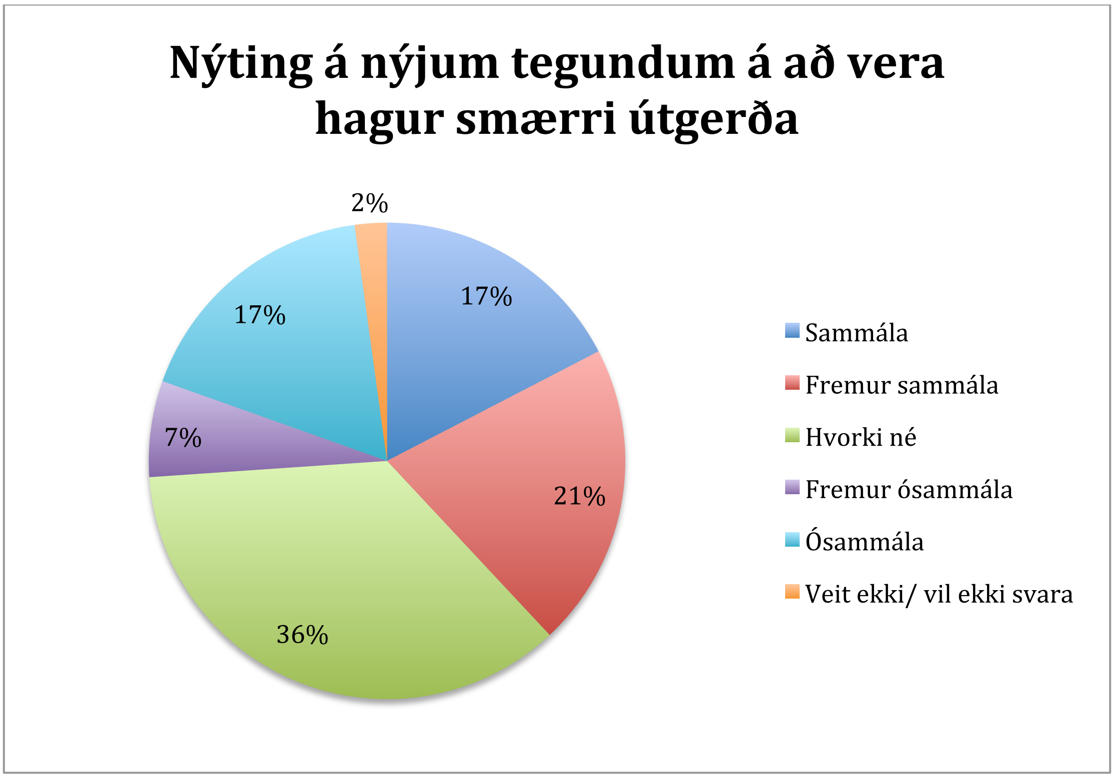


9. Nýting á nýjum tegundum

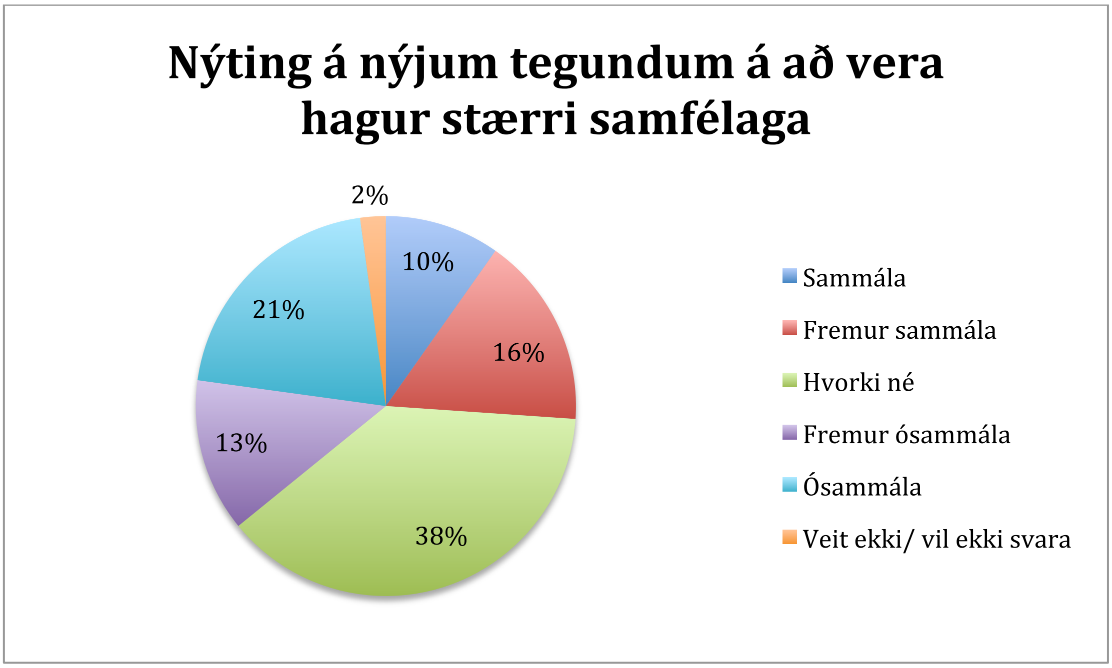
Question 9 a)



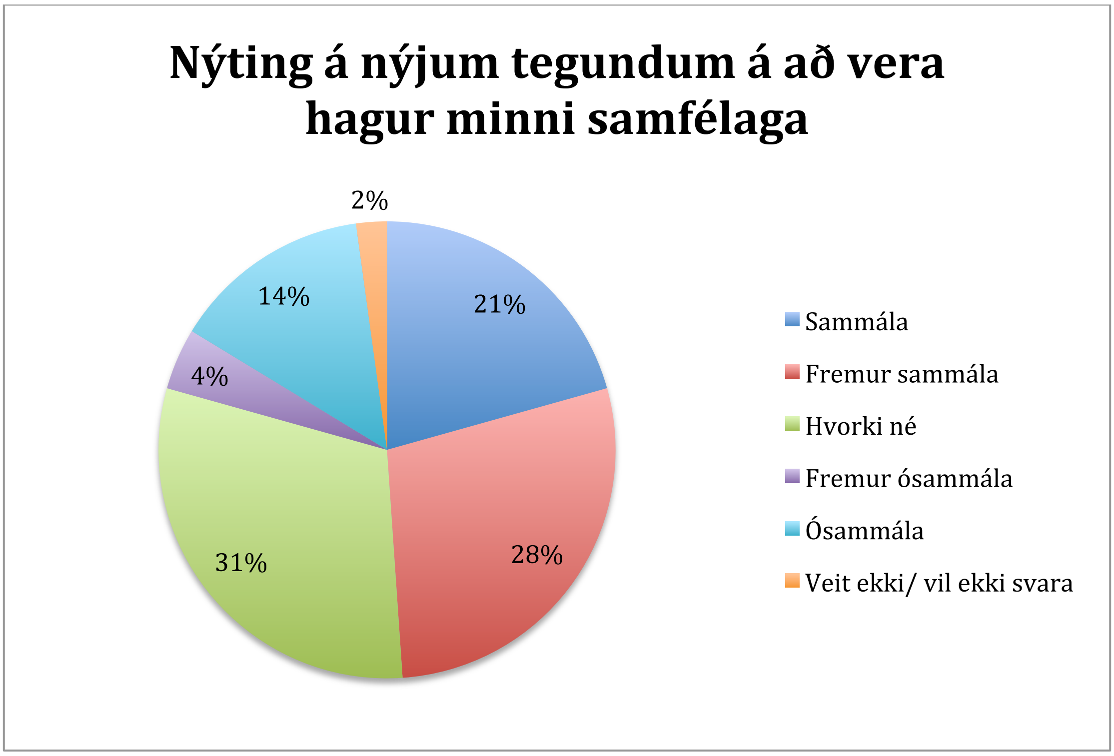
Question 9 b)



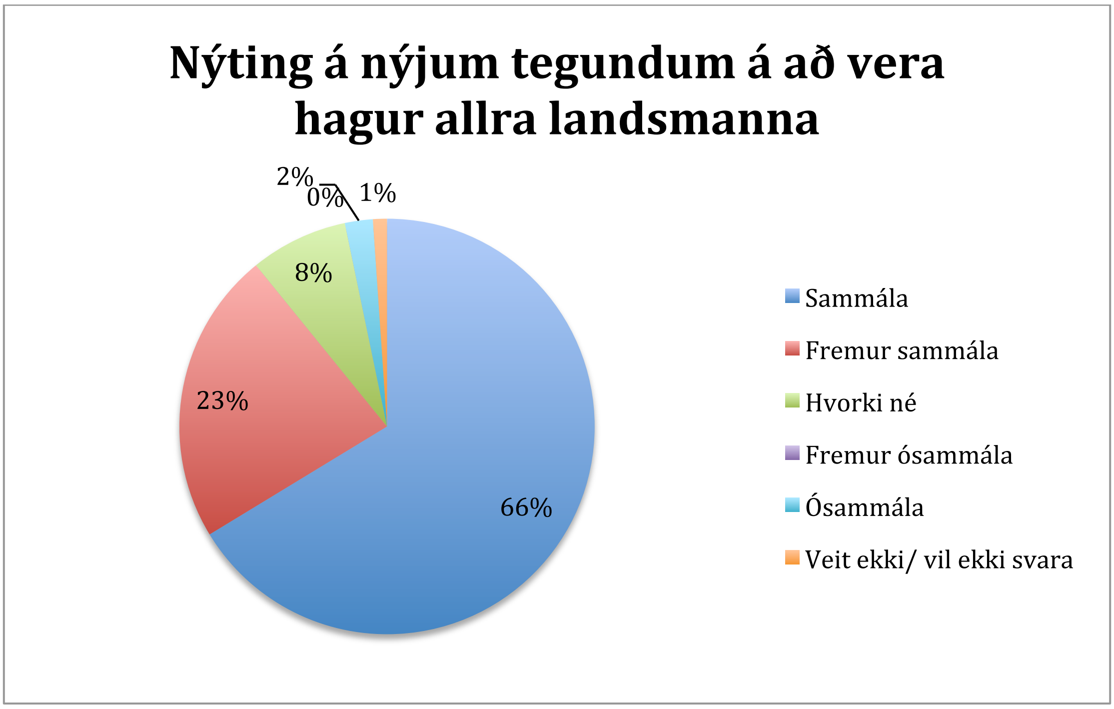
Question 9 c)



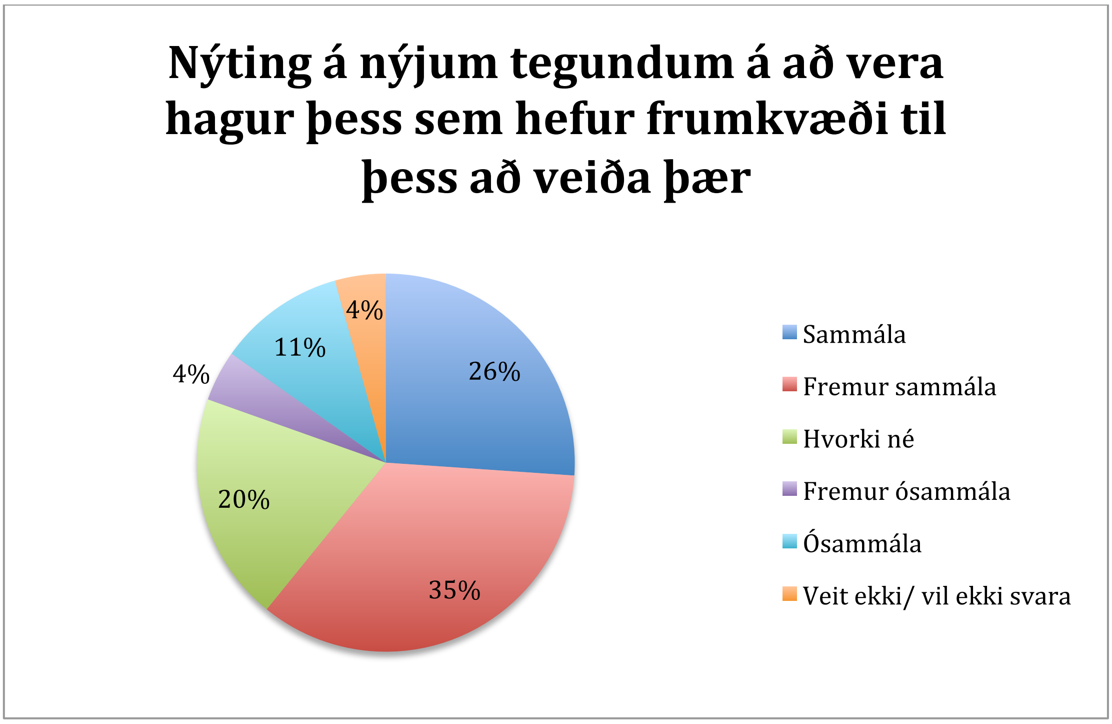
Question 9 d)



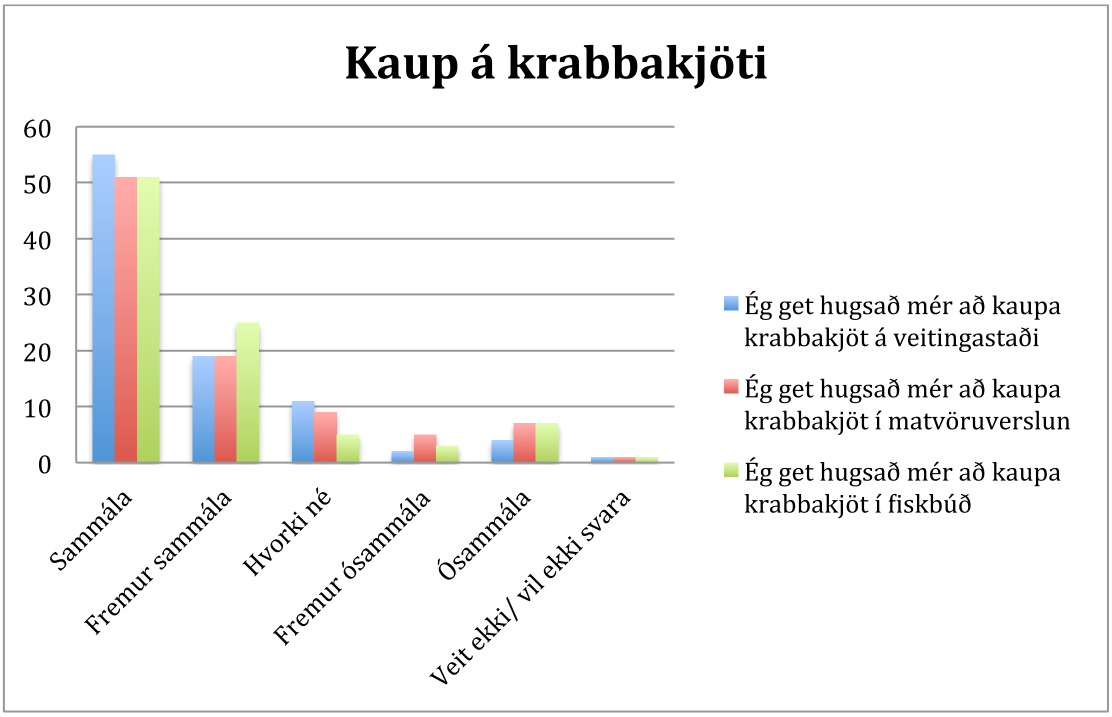
Question 9 e)



Question 9 f)

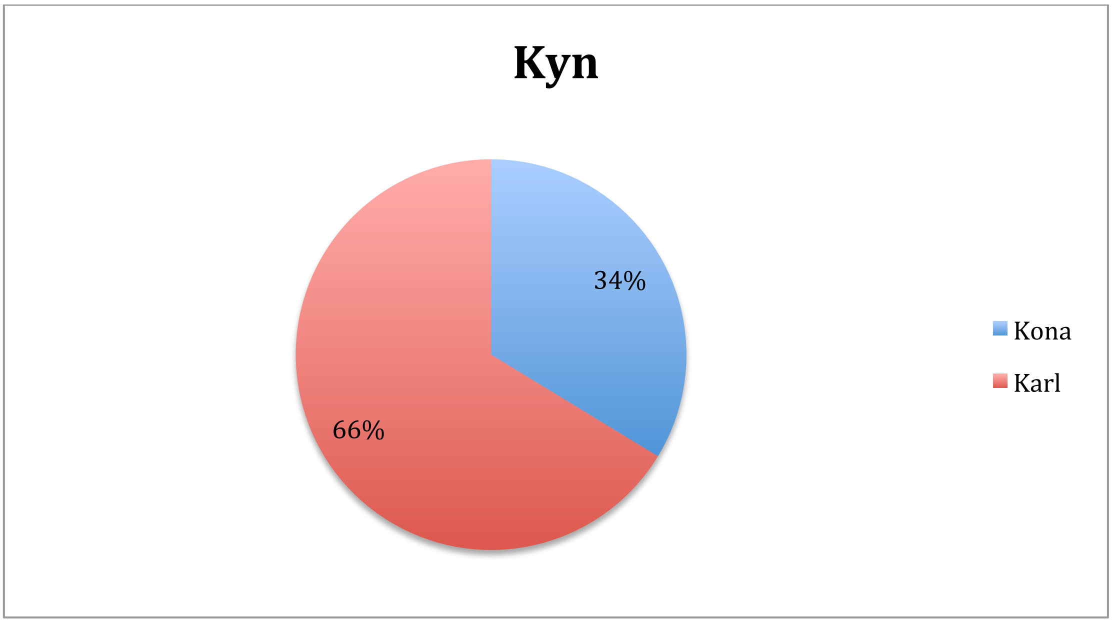


10. Kaup á krabbakjöti

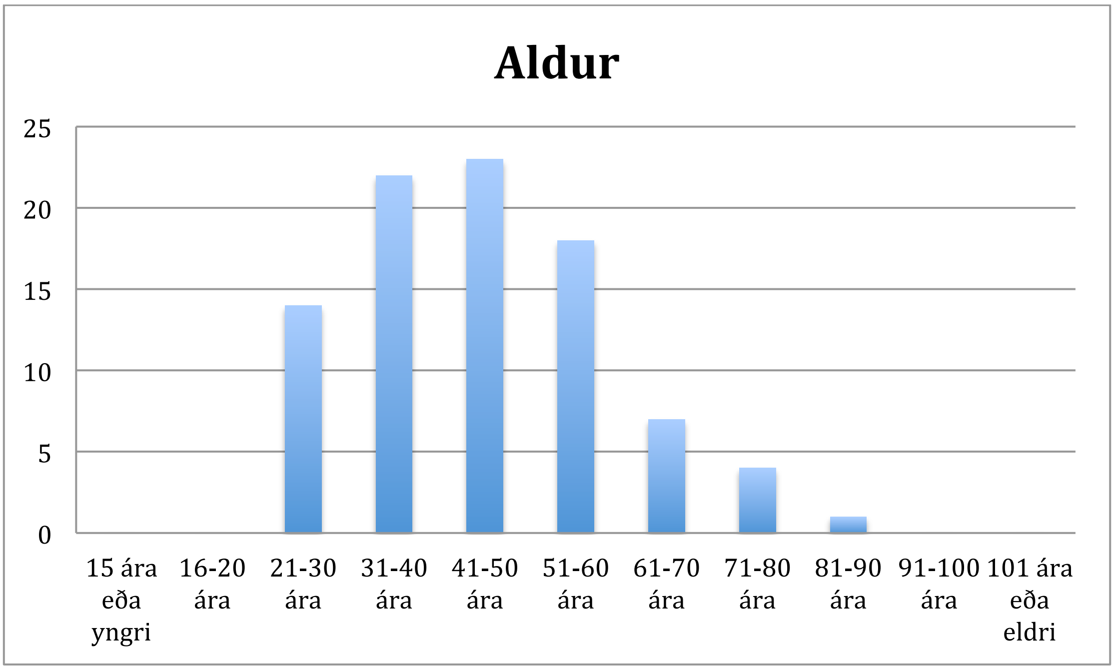


11. Annað

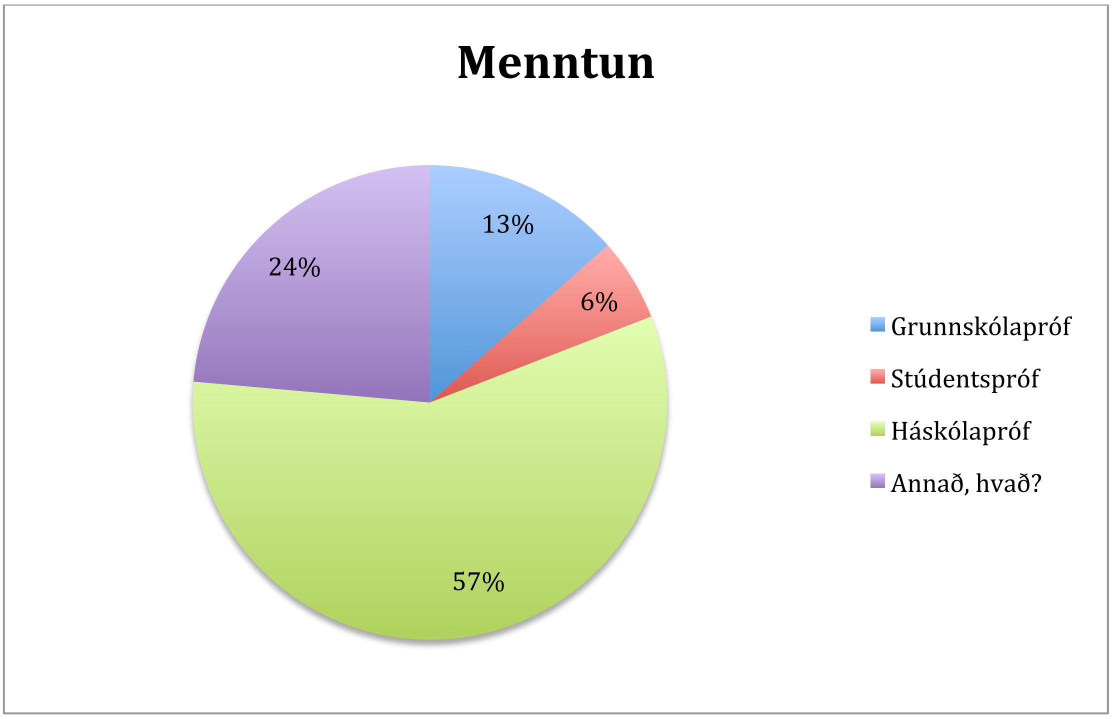
12. Kyn



13. Aldur

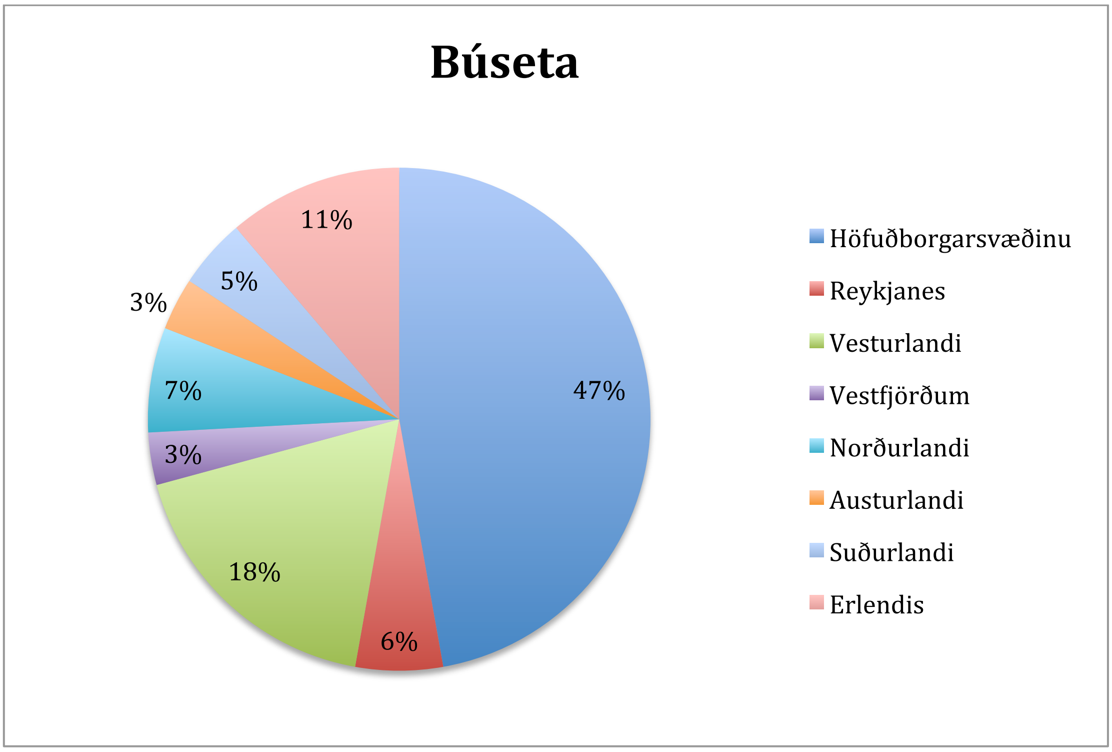


Aldur
25
20
15
10
5
0
15 ára eða yngri
16-20 ára
21-30 ára
31-40 ára
41-50 ára
51-60 ára
61-70 ára
71-80 ára
81-90 ára
91-100 ára
101 ára eða eldri

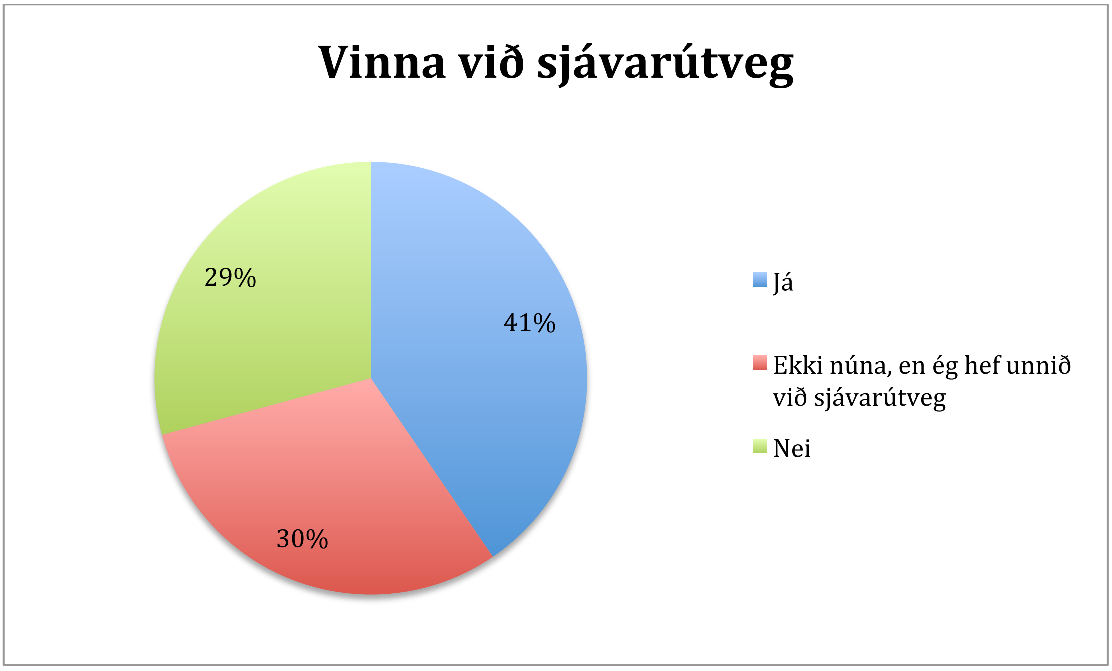


Menntun
13%
6%
57%
24%
Grunnskólapróf
Stúdentspróf
Háskólapróf
Annað, hvað?

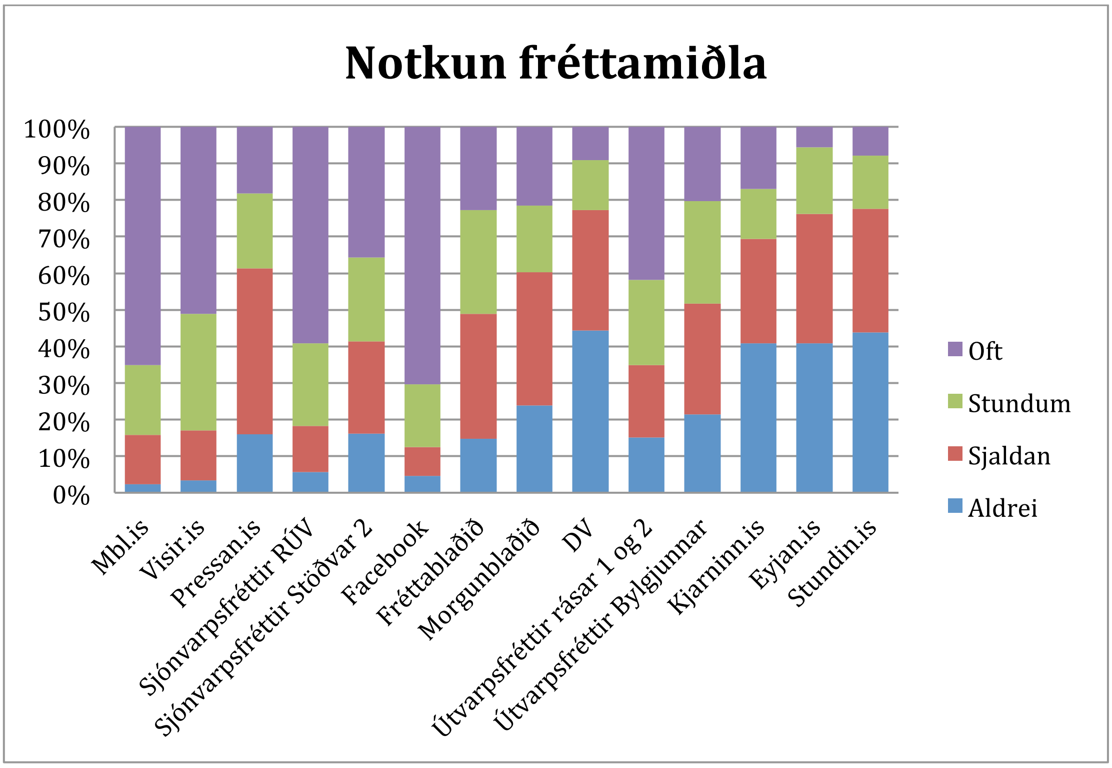
15. Búseta



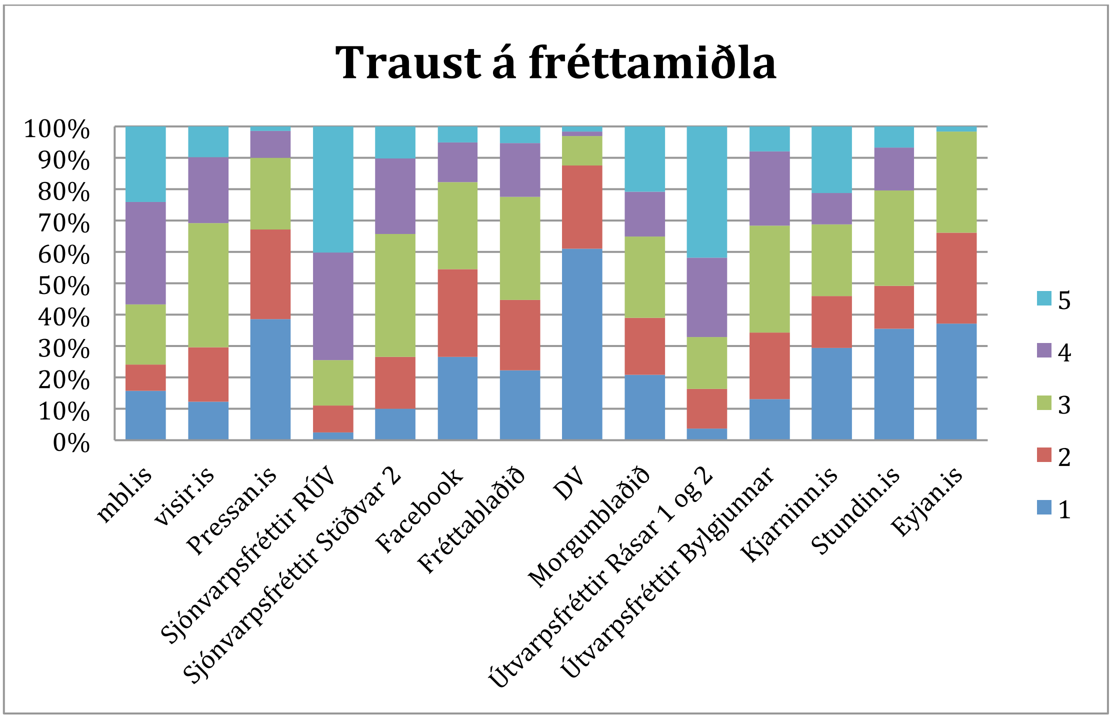
16. Vinnur við sjávarútveg



17. Fréttamiðlar



18. Traust á fréttamiðla



19. Aðrir fréttamiðlar

- Sax.is
- Kvotinn.is
- Fiskifréttir.is
- Huninn.is
- Skip.is