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Útselstalning 2017: Stofnstærðarmat, sveiflur og ástand stofns

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Abstract

A grey seal census was conducted by aerial survey during the pupping period of 2017. Pups were counted three to five times in the main grey seal pupping areas. In addition, areas where grey seal pups have occasionally been observed were surveyed once. The peak of the pupping period varied from 2 October (Frameyjar in Breiðafjörður) to 24 October (Strandir). Based on the estimated pup production (1452; 95% CI= 1385-1529), the total grey seal population size was estimated to be 6269 (95% CI= 5375-7181) animals. Breiðafjörður was the most important pupping area in Iceland, with a total of 845 (CI 95%= 807-887) pups, corresponding to 58% of the total estimated pup production in 2017. Other important pupping areas were the northwest coast (Strandir and Skagafjörður) and the south coast (Öræfi and the island Surtsey). The population was approximately 32% smaller than when the first census was conducted in 1982 with an approximate total exponential growth rate (r_{est}) of -0.01. The population estimate for 2017 corresponds to an increase of 49% since the last census in 2012. However, trend analysis for the period 2005–2017 revealed no statistically significant trend for the total population size since the current population size is close to the estimated population size of 2008/9 and slightly larger than the estimate of 2005. In 2017 the population size was larger than the governmental management objective for the size of the grey seal population of 4100 animals. However, according to the Icelandic red list for threatened populations, which is based on criteria put forward by IUCN, the grey seal population should, at its current level, be considered as “Vulnerable”.

Ágrip

Stærð íslenska útselsstofnsins var metin út frá kópatalningum úr lofti haustið 2017. Flogið var þrisvar til fimm sinnum yfir mikilvægustu kæpingarsvæðin. Á kæpingarsvæðum þar sem venjulega hafa verið fáir eða engir kópar var aðeins talið einu sinni. Kæping náði hámarki á tímabilinu 2. (Frameyjar í Breiðafirði) til 24. október (Strandir). Samkvæmt áætluðum heildarfjölda kópa haustið 2017 (1452; 95% CI= 1385-1529) var heildarstofnstærð útsels 6269 (95% CI= 5375-7181) dýr. Breiðafjörður var sem áður langmikilvægasta kæpingarsvæðið, en þar fæddust alls 845 (95% CI=807-887) kópar, eða 58% af heildarfjölda kópaframleiðslunnar haustið 2017. Önnur mikilvæg kæpingarsvæði voru Strandir og Skagafjörður á Norðurlandi Vestra, ásamt Surtsey og Öræfum á Suðurlandi. Stofnstærð útsels er um 32% minni en við fyrstu talningu 1982 og í heild hefur því veldisvöxtur verið -0.01 á tímabilinu 1982 til 2017. Stofn útsels 2017 var 49% stærri en hann var þegar stofnmat var síðast framkvæmt árið 2012, en heildarbreytingar á stofnstærð milli 2005 og 2017 er þó ekki tölfræðilega marktækar, þar sem stofnstærðin 2017 er svipuð því sem var árið 2008/9 og aðeins meiri en árið 2005. Stofnstærðin árið 2017 er yfir viðmiðunarmörkum stjórnvalda, sem eru 4100 dýr. Hafa ber í huga að á válista íslenskra spendýra sem er metinn samkvæmt viðmiðum Alþjóðlegu náttúruverndarsamtakanna (IUCN) lendir íslenski útselsstofninn í áhættuflokknum „Í nokkurri hættu" (Vulnerable).

Lykilorð: *Útselur, selir, stofnstærðarmat, Halichoerus grypus, grey seal*

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Myndskrá

Figure 3. Estimated population sizes of Icelandic grey seal from 1982 to 2017, with 95% CI. The population sizes for 1982-2002 were estimated based on one pup count (older method, see Methodology section). The red broken line indicates the management objective of Icelandic authorities for the grey seal (4100 animals). /*Stofnstærðir útsels 1982 til 2017 með 95% öryggismörk. Stofnstærðir 1982-2002 voru metnar með eldri aðferð sem byggðist á einni flugtalningu á hverjum kæpingarstað að hausti (sjá aðferðakafla um mun á eldri og nýrri aðferð). Rauða brotna línan sýnir viðmiðunarmörk stjórnvalda fyrir útselsstofninn á Íslandi (4100 dýr)* 12

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1. Introduction

Data describing the status of the Icelandic grey seal (*Halichoerus grypus*) population is necessary for advice on conservation and management including the regulation of hunting and is the foundation for other research on grey seal ecology in Iceland. The first aerial survey aiming at estimation of the size of the Icelandic grey seal population was conducted in 1982 and resulted in a population estimate of 9200 animals. Since then, aerial surveys have been conducted rather regularly (ten surveys in total). The population was largest in 1990 (10600 animals) but has decreased substantially since then. In 2012, when the population was last surveyed, it was estimated at 4200 (95% CI= 3400 – 5000) animals, following an estimated annual decrease of 5% (90% CI= 4%-6%) over the previous seven years (Hauksson et al. 2014; Georgsdóttir 2018 et al.).

1.1 Factors affecting the status of the grey seal population and current knowledge

Like other wild populations, fluctuations in the size of the grey seal populations is affected by a combination of many factors. Anthropogenic removals often have severe effects on populations, but variations in the environment, for example due to climate change which in turn may affect prey availability and weather parameters, may also influence the status of seal populations. Other factors that should also be mentioned are human disturbance, environmental toxins, predation and diseases, although knowledge of possible effects due to those factors on the status of the Icelandic grey seal population is scarce.

Anthropogenic seal removals—including culling of seals, traditional hunt for utilization of seal products and bycatch of seals in fishing gear—is an important factor to consider when managing seal populations. Traditionally, grey seals were mainly hunted at pupping sites in October and the meat and fur were subsequently utilized as important resources. However, the traditional grey seal hunt has sharply declined in recent years. In 1982, the Research Committee for Biological Seafood Quality (RCBSQ) introduced a bounty system for grey seals in Icelandic waters. The aim of introducing the system was to reduce the occurrence of roundworm (also named cod worm and seal worm) in commercial fish. A high proportion of caught cod were at the time infected by the parasite, of which seals are the final host (Ólafsdóttir 2001). Although other factors probably also contributed to the observed decline in the grey seal population, culling due to the bounty system is likely to have played an important role. Currently, accurate data of the extent of human removals due to culling and traditional hunt is uncertain due to the absence of an obligatory reporting system for seal hunting in Iceland. Today, the largest source of mortality for the Icelandic grey seal population is considered entanglements in nets/fishing gears, leading to the drowning of seals (bycatch). Data indicate that the lumpsucker-fishery is responsible for the largest proportion of bycaught

grey seals, although bycatch also occurs in other types of fishing gear, such as cod gillnets. The total number of bycaught grey seals is currently somewhat uncertain and improvement in the recordings is urgent (Marine and Freshwater Research Institute 2018).

In a study by Hauksson and Bogason (1997), sandeels were found to be important prey for young and female grey seals, especially off the south coast. It is unclear how the drastic decline that occurred in the sandeel population at the south coast of Iceland in the summer of 2005 (Lilliendahl et al. 2013) influenced the Icelandic grey seal population. It should however be noted that grey seals are usually considered as generalist predators choosing prey species readily available to them and hence, a decline in one prey species may not be likely to have severe effects on a population level. The diet study mentioned above (Hauksson and Bogason 1997) confirmed diverse diet of grey seals around Iceland but recent studies of the diet of grey seals in Iceland is lacking.

Very little is known about diseases in pinnipeds in Iceland. No big pinniped epidemic due to viruses have been observed around Iceland. The Phocine distemper virus, which previously has caused massive epidemies in European waters leading to mortality in pinniped populations (Duignan et al. 2014) has not been found to kill grey seals on the coast of Iceland. Ecotoxins have, in some cases, been observed to severely affect pinniped populations. In the Baltic grey seal population, ecotoxins were suggested to have contributed to a decline from 90 thousand to 20 thousand animals in the 1960s and 1970s (Harding et al. 2007). Information about ecotoxins in Icelandic grey seals has been totally lacking, however research investigating occurrence of per- and polyfluoroalkyl substances (PFASs) and new brominated flame retardants is currently ongoing. Another aspect which has often been ignored in Icelandic population studies, mainly due to lack of knowledge on the subject, is the effects of species, such as orcas (*Orcinus orca*), preying on grey seals. However, anecdotal observations of such predation exsists (Samarra et al. 2018).

1.2 Management objective and current status

In 2005 the Icelandic government introduced a management objective stating that the grey seal population should be maintained near 4100 animals (NAMMCO 2006). In 2018, a national red list for threatened mammal populations in Iceland was published (Icelandic Institute of Natural History 2018). The red list is based on criteria defined by IUCN and despite the grey seal being considered as „Least concern“ on an international level, the Icelandic population was defined as “Endangered” based on the most recent estimate available at the time (from 2012). The reason for this is the severe long-term population size reduction.

By reason of the critical grey seal population status and due to the previously observed decline in the population, it was considered important to evaluate the current status of the population

and to increase the frequency of censuses. The aim of this study was to estimate the size of the Icelandic grey seal population for the 11th time and to define the peak of the pupping season in the different areas to assist in the planning of future censuses. The census was, as in previous estimates, carried out by aerial survey during the pupping period, and the estimated pup production subsequently extrapolated to the total size of the grey seal population.

2. Methods

2.1 Methodology

Grey seal censuses can be conducted either during the moulting period (which is done in the Baltic, see Harding et al., 2007) or during the pupping period (which is done in the UK, see Duck and Thompson 2007), since the grey seals are more abundant on land during these periods (Bonner 1972; Hauksson and Ólafsdóttir 2004). Ever since regular censuses of the Icelandic grey seal population commenced in 1982, the surveys have been conducted during the pupping period in the autumn and the population size estimated based on pup production. The reason behind choosing the pupping period rather than conducting the survey during the moult, is that historical data on positions of large breeding sites on different geographical areas around the coast of Iceland existed. These were old descriptions of positions where pups were clubbed for meat in the autumn (Kristjánsson 1980). However, positions of moulting groups, in the spring and early summer were less well known in Iceland.

In the past (before 2005), the grey seal population estimate was obtained by counting once at each pupping site and subsequently applying correction factors (Hauksson 2007a). However, in 2005, an attempt was made to improve the significance of the results by applying a new method aiming at surveying pupping sites four times (see Duck and Thompson 2007). This method has been used in every survey since then; 2005, 2008/2009 and 2012 (Hauksson 2007a; Hauksson 2010; Hauksson et al. 2014). Each fly-over is expensive and after the fourth, precision increases progressively less (Duck & Thompson 2007; Hauksson 2010). Hence, five or more fly-overs would likely be inadvisable due to the excessive cost.

2.2 Aerial surveys in 2017

The 2017 census was conducted by aerial survey between 30 September and 12 November. The coast of Iceland was divided into seven areas (Figure 1) where 22 pupping sites have been identified. To obtain an exact comparison to results from previous censuses, the definition of pupping sites and geographic areas were identical to definitions used in previous censuses

(Table 1, Figure 1) (Hauksson et al. 2014), as far as was possible due to logistics. An attempt was made to conduct four counts in all important pupping areas. However due to inclement weather conditions, conducting four fly-overs of the entire coastline during the period was impossible. All the largest breeding sites were surveyed at least three times. Four passes were achieved in Faxaflói, in most breeding sites in Breiðafjörður, on the island of Málmey in Skagafjörður and on the island of Surtsey off the south coast. Areas where few pups have been observed in previous surveys were surveyed only once. These areas were Hrollaugseyjar and Tvísker on the south coast, the coasts of the Westfjords and northeastern Iceland (Table 1).

Small groups (<30 seals) and individual seals were counted directly by observers in the airplane. Larger groups were photographed, using a Canon 5ds full-frame digital camera mounted with a Canon 70-200 mm f/2.8L II USM lens with image stabilisation. During the survey, the main observer was seated in the front of the airplane, being responsible for counting all visible animals while the assistant observer was seated in the rear, counting smaller groups and photographing the larger groups. To standardize conditions, all sites were surveyed in clear weather with wind < 10 m/s. Information about pup catch which the Marine and Freshwater Research Institute received from seal hunters was taken into consideration in the analysis and corrected for to obtain the total number of the pup production.

Table 1. Overview of number of counts and survey dates in the different geographical areas, around Iceland in 2017. ***Tafla 1.*** *Yfirlit fyrir flugtalningar, talningardagar og fjöldi flugferða yfir strandsvæðin, haustið 2017.*

Area	1st fly-over	2d fly-over	3d fly-over	4th fly-over	5th fly-over
Faxaflói					
Faxaflói	28 Sep	5 Oct	16 Oct	1 Nov	-
Northwest					
Strandir	1 Oct	8 Oct	1 Nov	-	-
Ófeigsfjörður	1 Oct	8 Oct	21 Oct	-	-
Vatnsnes and Heggstaðanes	1 Oct	8 Oct	21 Oct	-	-
Skagi	1 Oct	8 Oct	21 Oct	-	-
Skagafjörður	1 Oct	8 Oct	21 Oct	7 Nov	-
Westfjords					
Westfjords	30 Sep				
South coast					
Þjórsá	3 Oct	15 Oct	12 Nov	-	-
Surtsey	3 Oct	15 Oct	25 Oct	12 Nov	-
Hrollaugseyjar and Tvísker	15 Oct	-	-	-	-
Öræfi	3 Oct	15 Oct	25 Oct	-	-
Vigur	3 Oct	15 Oct	25 Oct	-	-
Eastfjords					
Papey and Berufjörður	3 Oct	15 Oct	25 Oct	-	-
Northeast					
Northeast	10 Oct	-	-	-	-
Breiðafjörður					
Suðureyjar	28 Sep	5 Oct	16 Oct	-	-
Reykjanes	29 Sep	5 Oct	16 Oct	-	-
Bjarneyjar	28 Sep	5 Oct	21 Oct	1 Nov	-
Rúfeyjar	28 Sep	5 Oct	16 Oct	1 Nov	-
Skálmanes	28 Sep	29.sep	8 Oct	16 Oct	21 Oct[1]
Svefneyjar,Skáleyjar and Hvallátrar	29 Sep	5 Oct	21 Oct	1 Nov	-
Vestureyjar	30 Sep	8 Oct	21 Oct	1 Nov	-
Frameyjar	29 Sep	5 Oct	16 Oct	1 Nov	-

[1] Not the same area as October 16.

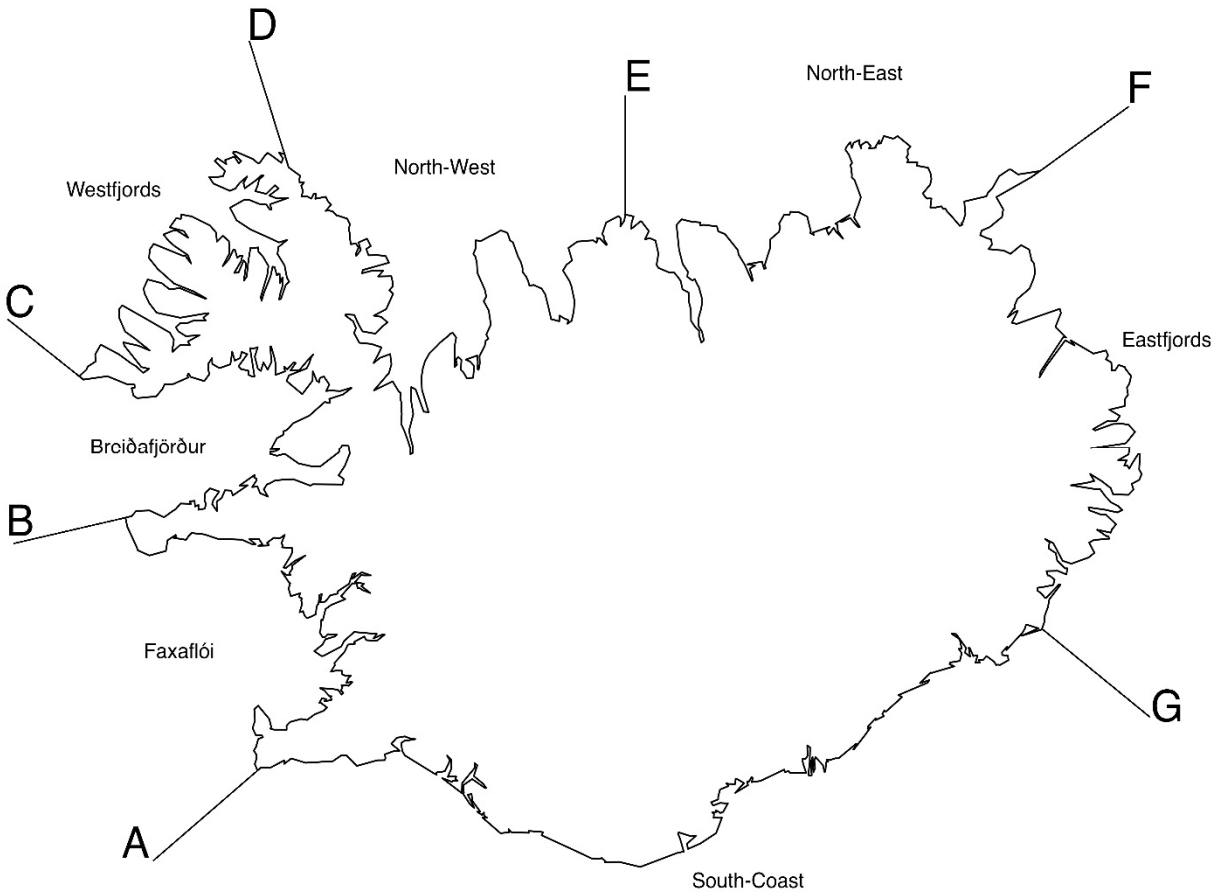

Figure 1. A map of Iceland with the different sections of the country labelled. The area from A (Reykjanestá) to B (Öndverðarnes) is defined as Faxaflói. The area from B (Öndverðarnes) to C (Bjargtangar) is defined as Breiðafjörður. The area from C (Bjargtangar) to D (Hornbjarg) is defined as Westfjords. The area from D (Hornbjarg) to E (Siglunes) is defined as Northwest. The area from E (Siglunes) to F (Fontur) is defined as Northeast. The area from F (Fontur) to G (Eystra horn) is defined as Eastfjords. The area from G (Eystra horn) to A (Reykjanestá) is defined as South coast. ***Mynd 1.*** *Skipting stranda Íslands í undirsvæði. A – B Faxaflói, B – C Breiðafjörður, C – D Vestfirðir, D – E Norðvesturland, E – F Norðausturland, F – G Austfirðir og G – A Suðurland.*

2.3 Statistical analysis

2.3.1 Defining peak of pupping period and calculating total pup production from direct counts

Newborn grey seal pups are very local and can be assumed to stay on the pupping site until they are 15-30 days old, when they have finished moulting their white lanugo fur. During the survey, the number of pups were recorded for each fly-over. To estimate the number of pups that were still present at the site during the repeated fly-overs (non-moulted pups which had not left the area yet), and the number of the pups that had been born since the previous fly-over, a normal density function was applied. The assumptions made were the following: a) pups which are < 15 days old are all still present at the breeding site, b) half of the 22-day-old pups have left the pupping site, and c) all pups > 30 days old have left the pupping site. These

data are assumed to follow a normal density distribution with a mean of 22 days and standard deviation of about 3 days (Bowen et al. 2003; Hauksson 2010).

The peak of the pupping period for each site was determined by defining the peak of the statistical distribution which best fitted the observed birthdays of pups. Various statistical distributions (normal, Weibull, gamma, log-normal, logistic and log-logistic) were fitted and the one best suited for each pupping site chosen (the one with the lowest log-likelihood value). A higher number of fly-overs facilitate a more accurate fit of the distributions, as well as improving the likelihood that the observed number of pups represents the actual total pup production. A minimum of two fly-overs is required to apply the statistical method, three fly-overs yield more accurate results, but four is the preferable number of flights, taking cost into consideration (see above). To minimize the possibility of a bias caused by pups being born outside of the survey period—born either after the last fly-over or born so long before the first fly-over that they had moulted and left—and hence missed, the probable number of pups missed was estimated based on the applied distribution and added to obtain the total pup production of each site.

2.3.2 Estimating total population size

Correction factors for undercounting (pups that are at the pupping site but missed by the observers) and for a natural mortality (estimated to 2% by Hauksson 2007a) were combined into one conversion factor (***q***) of 1.08 (95% CI= 1.07-1.10) (Hauksson 2007a) and applied to the estimated pup production. The estimated total pup production was used as an index for the population size of grey seals by assuming that the ratio between pup production and the total number of grey seals (one year old and older) was 4 (3-5), as applied by Hauksson (2007a). After applying the correction factor ***q***, and an extrapolation of 4 (3-5) times the pup production, the distribution of 1.000.000 population sizes was calculated to yield an average population size for the grey seal population. A 95% confidence interval (95 % CI) for the population was obtained by computing the 2.5 and 97.5 percentiles of the distribution.

2.3.3 Trends between years in pup production and changes in specific areas

The following equations were used to calculate changes in pup production for different geographical areas, and in total population size for the period between 2005 and 2017:

The estimated exponential growth rate (r_{est}) was calculated as Mills (2012):

$$\frac{\ln(\frac{Nlast}{Nfirst})}{\Delta T}$$

Linear percent change was calculated as:

$$\frac{(Nlast - Nfirst)}{Nfirst} * 100$$

Discrete-time per capita growth rate (λ) was calculated as Mills (2012):

$$\lambda = exp(r_{est})$$

Nlast: The most recent value

Nfirst: The earlier value, which Nlast is compared to

Δ*T: Total duration of survey*

To assess trends in the population size and pup production, a resistant regression was used (*rlm* and method = "MM") from the *MASS* package in R (Venables and Ripley 2002). Due to the different methods to estimate population sizes, trends (r_s) were calculated separately for the previous method (used 1982-2002) and the updated method (2005-2017). Pup counts were *ln* transformed before performing the resistant regression. *Rlm* was used to assess both the overall trend in total pup production, and the separate trends in the seven different geographical areas (according to Figure 1). In addition, for some of the geographical areas, it was possible to estimate trends in individual breeding sites of specific interest.

To estimate the improvement obtained with the updated method for estimating grey seal population size based on four counts compared to the previous method based on one count, a piecewise regression analysis was applied (Crawley 2013). The population sizes for the years 2004 and 2005 was extrapolated with both regressions' lines (from the old and new method) and the ratio of results from the new and old method calculated for those years. All analysis was conducted in ***R*** with *RStudio* (RStudio. Version 3.3.1. 2016).

3. Results

3.1 Pup production and peak of pupping period

The results from the aerial survey (Table 2) showed that the estimated peak of pupping varied from the 2 to the 24 October. The total pup production was 1452 (1385-1529). Breiðafjörður was the most important area for pupping, with a total of 845 pups, which corresponds to 58% of the total pup production. The most important pupping sites in Breiðafjörður were the islands Frameyjar, Rúfeyjar and Vestureyjar. Other important breeding areas were Strandir and Skagafjörður (Málmey and Þórðarhöfði) in Northwest Iceland and the island of Surtsey and the sandy shores of Öræfi on the south coast. Breiðarfjörður, Strandir, Skagafjörður, Surtsey and Öræfi were responsible for 92% of the pup production in 2017.

Table 2. Number of estimated pups for each area during the pupping period in 2017 (95% CI). The estimated peak date for the pupping period for each site (SD days), type of distribution that best described the observed pupping process, number of survey flights (N), proportion of observed pups of the estimated total pup production and log likelihood values for the distributions fitting the data best.

Tafla 2. *Áætlaður kópafjöldi á hverju strandsvæði haustið 2017 (95% öryggismörk). Hámarksdagur kæpingar á hverjum stað (meðalfrávik í dögum), gerð tölfræðidreifingar sem best lýsti kópagögnum, fjöldi yfirfluga vegna talninga (N), hlutfall kópa sem sást í talningum af áætluðum fjölda kópa sem fæddist haustið 2017, "log likelihood" gildi dreifingarinnar sem best lýsti gögnunum.*

[1]The numbers have not been corrected for the coefficient ***q*** (which corrects for animals not seen by the observers and takes natural mortality into account). [2]Corrected for pup hunt.

Area	Total number of pups (95% CI)[1]	Peak of pupping period (SD days)	Best fitted distribution	N	% seen	Log-likelihood
Faxaflói	37 (34-41)	23 Oct (± 2 days)	Weibull (53.43; 5.62)	4	86.49 (78.00-94.12)	-119.96
Total	**37 (34-41)**					
Breiðafjörður						
Suðureyjar	10 (9-11)	14 Oct (±2 days)	Weibull(43.98;8.36)	3	60.00 (54.5-66.7)	-19.64
Frameyjar	426 (412 – 441)	2 Oct (± 1 day)	Log-logistic(32.45;7.05)	4	75.59 (73.02-78.16)	-1160.91
Rúfeyjar	141(135-147)	7 Oct (± 1days)	Lognormal(3.62; 0.25)	4	86.52 (82.99-90.37)	-446.48
Skálmarnes and surroundings	10	(-)	To few pups	5		
Skáleyjar, Svefneyjar and surrounding	25(22-28)	4 Oct (±1 days)	Lognormal(3.53; 0.22)	4	80.00 (71.43-90.91)	-68,35
Reykjanes and surrounding	49(45-53)[2]	3 Oct (±1 days)	Lognormal(3.51; 0.18)	3	79.59 (73.58-86.67)	-125.31
Vestureyjar	157 (150-166)	14 Oct (±1days)	Weibull(44.24;4.49)	4	77.70 (73.49-81.33)	-457.26
Bjarneyjar	27 (24-31)	20 Oct (±1 days)	Weibull(49.92;9.74)	4	77.78 (67.74-87.50)	-70.38
Total	**845 (807-887)[2]**					
Westfjords	0	(-)	No pups	1		
Total	**0**					
Northwest						
Strandir	140 (135-151)	24 Oct (±1 days)	Weibull(54.84;4.50)	3	80.00 (74.17-83.00)	-447.82
Ófeigsfjörður and Ófeigsfjarðarsker	6 (-)	(-)	To few pups	3		
Vatnsnes and Heggstaðanes	3 (-)	(-)	To few pups	3		
Skagi and surrounding	2 (-)	(-)	To few pups	3		
Skagafjörður (Málmey and Þorðarhöfði)	111(105-116)	16 Oct (± 1 days)	Lognormal(3.83;0.27)	4	86.49 (82.76-91.43)	-379.22
Total	**262 (251-278)**					
Northeast	4 (-)	(-)	Only one count	1		(-)
Total	**4 (-)**					
Eastfjords (Papey)	37 (33-41)	21 Oct (±1 days)	Weibull(51.34; 8.55)	3	83.78 (75.61-93.93)	-104.06
Total	**37 (33-41)**					
South coast						
Þjórsá	3	(-)	To few pups	3		
Surtsey	134 (126-140)	12 Oct(±1 days)	Lognormal(3.74;0.35)	4	76.12 (72.86-80.95)	-419.82
Öræfi	99 (97-102)	5 Oct (±1 days)	Normal(35.71;7.23)	3	73.74 (71.57-75.26)	-248.02
Hrollaugseyjar and Tvísker	5 (-)	(-)	Only one count	1		(-)
Vigur	26 (25-28)	8 Oct (±1 day)	Normal(38.40;5.97)	3	76.92 (71.43-80.00)	-64.11
Total	**267 (256-278)**					
Whole coast	**1452 (1385-1529)[1,2]**					

3.2 Trends in pup production in different geographical areas

The pup production was higher in all areas in 2017 compared to 2012 when the last survey was conducted, except for the northwest coast where a decrease of 18.6% was observed. The largest numerical increase was observed in Breiðafjörður, where the pup production increased from 525 to 845. The pup production on the south coast doubled between these years. In the Eastfjords, one pup was observed in 2012, while the pup production was 37 in 2017 (Table 3).

When the pup production of year 2017 is compared with year 2005, the greatest increase was observed in the Eastfjords where the exponential growth rate (r_{est}) was 0.17. In Breiðafjörður and on the south coast, the increase was moderate; r_{est} = 0.02. Declines in pup production were observed in northwest and northeast Iceland, where r_{est} was -0.05 and -0.03 respectively. The biggest decrease in numbers was observed in northwest Iceland, where the number had declined by 209 pups during the period (Table 3). In the geographical areas where it was possible to do trend analyses (Resistant regression, *rlm*) for the period 2005–2017 (see Appendix), the only area where a significant trend had occurred was in northwest Iceland (p= 0.004) due to a significant decline in Strandir (see below). An indication of a negative (non-significant) trend already started in the earlier period of 1982–2002; r_s= -0.003 (p=*ns*: not significant). *Rlm* also showed a significant declining trend between 1982 and 2002 in Faxaflói (r_s= -0.19, p = 0.01), however, this trend did not continue between 2005 and 2017. On the south coast, a significant downward trend -0.08 (p = 0.02), was also observed in the earlier period, however this trend did not continue in the later period. For some of the geographical areas, it was possible to estimate trends in individual pupping sites in the period 2005–2017. Strandir was the only pupping site where a significant change had occurred (r_s = -0.07, p < 0.001). A marginal decline was found for Skálmarnes (r_s = -0.16, p = 0.08), in comparison to a non-significant increasing trend in the earlier period of 1982–2002 (r_s= 0.02, p = ns). Frameyjar combined with Rúfeyjar showed indications for a slight negative trend in pup production (r_s= -0.05, p = ns) in the earlier period but an increasing pup production in the later period, although these changes were non-significant. In Öræfi, a significant downward trend was observed in the earlier period, -0.10 (p = 0.001), however, that trend did not continue in the later period (Appendix).

Table 3. Pup production in the different geographical areas for the years 2005-2017. Change in pup production 2005-2017 (*Δn*), total percent change (*Δ(%)*), discrete time per capita growth rate (*λ*) and the exponential growth rate (r_{est}), are shown for each coastal area.

Tafla 3. *Kópafjöldi á strandsvæðum árin 2005 til 2017. Breyting kópafjölda árið 2005 miðað við árið 2017 (Δn), prósentvís breyting (Δ(%)), meðalársvöxtur (λ) og veldisvöxtur (r_{est}).*

	Pup production				Period 2005 - 2017			
Area	**2005**	**2008/9**	**2012**	**2017**	**Δn**	**Δ (%)**	**λ**	**r_{est}**
Faxaflói	40	18	12	37	-3	-7.5	0.994	-0.006
Breiðafjörður	645	859	525	845	200	31.0	1.023	0.022
Westfjords	2	0	0	0	-2	-100	-	-
Northwest	471	424	322	262	-209	-44.4	0.952	-0.049
Northeast	6	0	0	4	-2	-33.3	0.967	-0.034
Eastfjords	5	13	1	37	32	640.0	1.182	0.167
South coast	223	225	133	267	44	19.7	1.015	0.015

3.3 Estimated population size and trends

The estimated population size was 6269 (95% CI= 5375-7181) (Figure 2, 3, 4). The current population size is 49% larger than the last census in 2012 and 32% smaller than when the first census was conducted in 1982 with a total exponential growth rate of -0.01 between 1982 and 2017 (Table 4). The population is now of similar size as in 2008/9 and somewhat bigger compared with the population size in 2005.

Trend analyses (*rlm*) for the total pup production in the period 2005–2017, showed no significant trend during the period (p = 0.54). The 2017 population exceeds the current management objective (4100 animals) for the Icelandic grey seal population; the calculated probability of the population being smaller than 4100 is negligible ($p = 3.79\ 10^{-05}$) (Figure 2, 3, 4).

Results from the Piecewise regression analysis when the old method of only one count was compared with the new method when multiple counts are used showed that the new method gave about 11 % (9% for year 2004 – 13% for year 2005) higher average population size. This suggests that estimates obtained by the old one-count method (from 1982–2002) can be multiplied by 1.11 (1.09–1.13) to increase their comparability to the updated method (from 2005–2017).

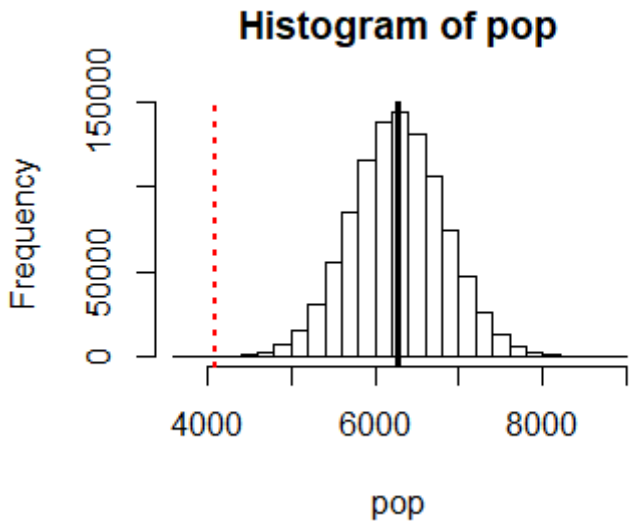

Figure 2. Distribution of the population sizes of Icelandic grey seal for the year of 2017, when calculated 1.000.000 times (bootstrapping) using pup data and correction coefficients. The bold line corresponds to the average population size of 6269 animals. The red line corresponds to a population size of 4100 animals (the management objective for the population size set by Icelandic authorities).

***Mynd 2**. Dreifing 1.000.000 stofnstærða útsels árið 2017, reiknað út frá kópafjölda og leiðréttingarstuðlum. Feitletraða lóðrétta línan er meðalstofnstærðin 6269 dýr og lóðrétta rauða punktalínan er viðmiðunarmörk stjórnvalda um stofnstærð útsels hér við land.*

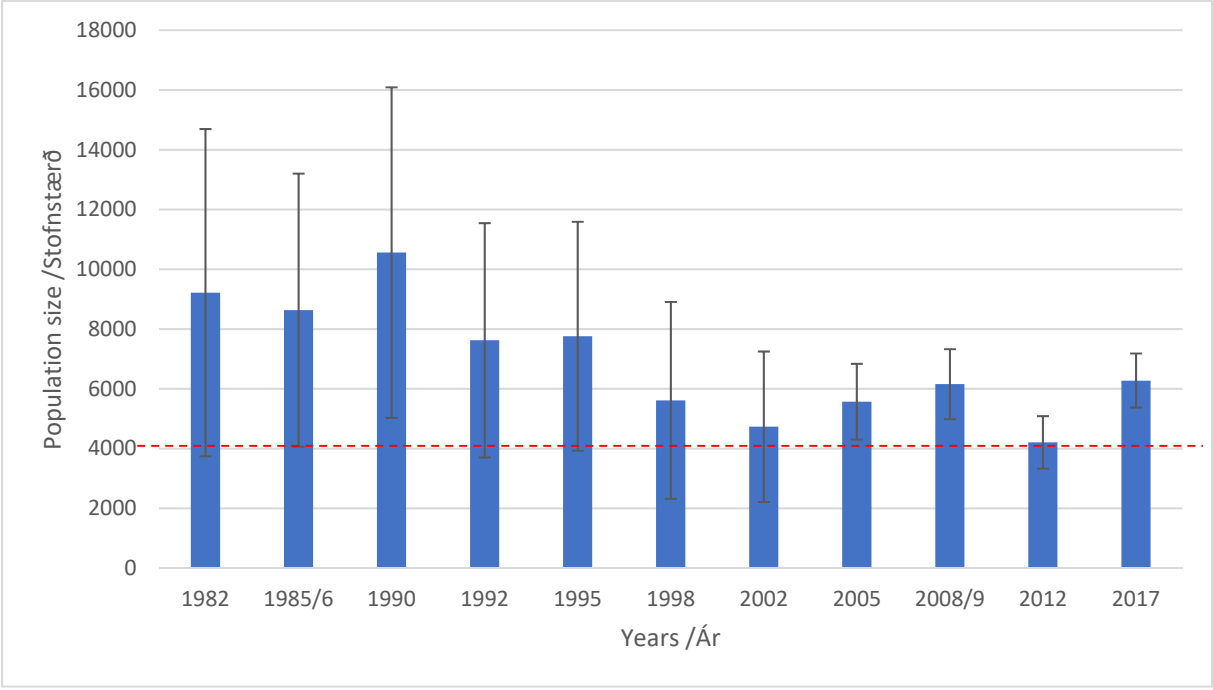

Figure 3. Estimated population sizes of Icelandic grey seal from 1982 to 2017, with 95% CI. The population sizes for 1982-2002 were estimated based on one pup count (older method, see Methodology section). The red broken line indicates the management objective of Icelandic authorities for the grey seal (4100 animals).

***Mynd 3.** Stofnstærðir útsels 1982 til 2017 með 95% ö. m. Stofnstærðir 1982-2002 voru metnar með eldri aðferð sem byggðist á einni flugtalningu á hverjum kæpingarstað að hausti (sjá aðferðakafla um mun á eldri og nýrri aðferð). Rauða brotna línan sýnir viðmiðunarmörk stjórnvalda fyrir útselsstofninn á Íslandi (4100 dýr).*

Table 4. Population estimates for Icelandic grey seal from 1982-2017 (M.o. (management obejective) corresponds to a population size of 4100 animals, the lowest population size recommended by Icelandic authorities), probability of the 2017 population estimate being lower than previous estimates ($P(pop_{2017}<pop_{yr.X})$), exponential growth rate (r_{est}) with the total percent change (*Δ(%)*) and discrete time per capita growth rate (*λ*) from the relevant year compared to 2017.

Tafla 4. *Stofnstærðarmöt útsels árin 1982 til 2017 (viðmiðunarmörk stjórnvalda eru 4100 dýr), líkur þess að stofnstærðarmatið árið 2017 sé lægra en stofnstærðarmöt árin á undan, veldisvöxtur (r_{est}), prósentvís breyting (Δ(%)) og ársvöxtur (λ) miðað við árið 2017.*

[1]The population sizes for 1982-2002 were estimated based on one count (older method, see Methodology section).

Survey year	Est. pop.[1]	$P(pop_{2017}<pop_{yearX})$	r_{est}	Δ (%)	λ
1982	9216	1.00	-0.011	-31.98	0.99
1985/6	8632	1.00	-0.010	-27.38	0.99
1990	10557	1.00	-0.019	-40.62	0.98
1992	7624	1.00	-0.008	-17.78	0.99
1995	7758	1.00	-0.010	-19.19	0.99
1998	5612	0.08	0.0058	11.71	1.005
2002	4731	0.0004	0.019	32.51	1.019
2005	5568	0.064	0.0099	12.59	1.0099
2008/9	6156	0.403	0.0023	1.84	1.00
2012	4206	0.000004	0.080	49.05	1.083
2017	6269	-	-	-	-
M.o.	4100	0.000001			

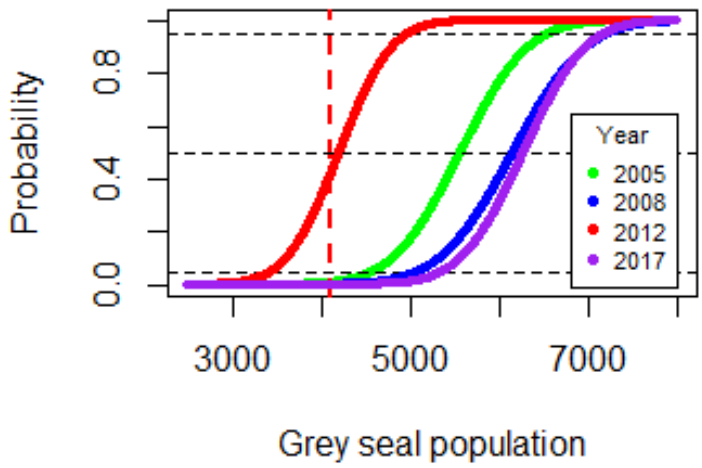

Figure 4. Cumulative distributions for 1.000.000 Icelandic grey seal population sizes for the year of 2005 (green line), 2008 (blue line), 2012 (red line) and 2017 (purple line), calculated from the number of pups (with 95% CI) after corrections for the factor ***q*** and a multiplication with 4 (3 and 5 as lower and upper limits) has been made. The red dashed line shows the population size of 4100 animals (the management objective set by the Icelandic authorities).

Mynd 4. *Tíðnidreifing uppsafnaðra 1.000.000 stofnstærða útsels hér við land, árin 2005 (græn lína), 2008 (blá lína), 2012 (rauð lína) og 2017 (fjólublá lína). Stofnstærðir voru metnar út frá kópafjölda ásamt 95% ö. m. leiðréttum með þætti **q** og margfaldað með 4 (3 og 5 notuð sem neðri og efri mörk). Rauða brotna línan sýnir viðmiðunarmörk stjórnvalda, 4100 dýr.*

4. Discussion and conclusion

4.1 Implications of the results

Based on the estimated pup production in 2017, the population size was 6269 (95% CI= 5375-7181) animals. The current state of the population is 32% smaller than when the size of the grey seal population was estimated for the first time in 1982. The population is larger than the governmental management objective for the size of the grey seal population of 4100 animals. Based on the previous population estimate from 2012, the population was classified as Endangered ("Í hættu") on the Icelandic list for threatened populations, which is based on recognized standards and definitions put forward by IUCN (International Union for Conservation of Nature). The increase in the 2017 population estimate since the 2012 estimate should put the status of the grey seal population as Vulnerable ("Í nokkurri hættu"). This underlines that it must be taken into consideration in management situations that despite the observed increase and the size of the population being somewhat above the management threshold, the population is still considered as vulnerable.

The most important pupping areas were Breiðafjörður, Strandir, Skagafjörður, Surtsey and Öræfi, and together these five areas are responsible for 92% of the pups born in 2017. These areas should therefore be considered as important in a management perspective. Breiðafjörður was by far the most important pupping area in Iceland, with a total of 845 (95% CI= 807-887) pups, corresponding to 58% of the total estimated pup production in 2017. This area has also previously been defined as the most important breeding area for grey seals (Hauksson et al. 2014). It is hence important to note that Breiðafjörður is concurrently the area where the proportionally highest amount of grey seals were bycaught due to lumpsucker fisheries during the period 2014-2017 (Marine and Freshwater Research Institute 2018).

4.2 Trends in pup production in total and locally

Due to the methodological update (multiple fly-over instead of single fly-over), the population estimates made with the updated method might not be directly comparable to the estimates made with the old method. Therefore, a trend analysis was made separately for the period 2005–2017. No statistically significant trend was found for the period in total since the current population estimate is close to the estimated population size in 2008/9 and slightly larger compared with population size in 2005. However, the population estimate for 2017 corresponds to an increase of 49% since the last census in 2012. One possibility for the observed increase since 2012 can be due to worse pup survival that year, which in turn could be due to worse environmental conditions such as weather or prey availability. The higher number of pups in 2017 could also indicate an increase in recruitment of the grey seal

population's breeding stock, which would call for a higher proportion of mature females in 2017 than in 2012. Unstable age distribution of mature females could possibly lead to variance in annual pup production. Such bias could have occurred due to gender differences in survival the first year and/or between years. Annual differences in pup production can also be affected by variable prey availability, weather effects etc. If a high number of females is young and on the verge of being sexually mature, they may not reproduce if food is limited, grow slower and become sexually mature later (Boyd 2000; Bowen et al. 2007; Hauksson 2007b; Hauksson et al. 2014). If a lower pup production occurs in a specific period it leads to biases in population estimates which are based on pup production. However, large fluctuations in pup production have previously been suggested to be rather uncommon (see Bowen et al. 2007). Female grey seals are presumed to give birth to a pup every year after sexual maturation. Such uncertainties underline the necessity of conducting grey seal population estimates more regularly. To obtain good estimates of the noise in the data, annual surveys would be necessary. Further, increased knowledge on parameters regarding grey seal population ecology, such as the age distribution, fecundity and pup survival, would facilitate a better understanding of the status of the Icelandic grey seal population.

When looking at the different coastal areas, the number of observed pups was larger in all areas in 2017 compared to the previous counts from 2012, except for the northwest coast where a decline occurred. When the trend for the whole period 2005-2017 was investigated, the only area where the pup production had changed significantly was the northwest coast where a significant decrease was observed. This indicates that the pup production has been stable in the other areas during this 12-year period. However, the low number of censuses conducted during the period (4 censuses in 12 years) does not provide sufficient information about the noise involved in the counting data.

A marginal decline was found for Skálmarnes (r_s = -0.16, p = 0.08 between 2005 and 2017, while a non-significant increase had been observed in the earlier period 1982–2002 (Appendix). Further, Frameyjar combined with Rúfeyjar showed non-significant indications for the opposite development in pup production: decline in the earlier period and increase in the later period. This may support observations reported by seal farmers in Breiðafjörður that hunting of pups made grey seal females move from Frameyjar towards Skálmarnes in the early period (before 2002) and then back in the later period when pup hunting had declined considerably in Frameyjar. Similarly, it has been suggested by hunters that movement of grey seals has occurred from Hafnir in Skagi to Málmey in Skagafjörður in recent decades and that a movement of the breeding area of grey seals in Öræfi, has occurred westwards, from Svínafellsfjara to Hvalsíki.

4.3 Methodological considerations

Two different methods have been used in estimating pup production. Piecewise regression of data indicates that the newer method, used in 2005 and later gave an 11 % (with limits 9% to 13%) higher average population size than the older method used before year 2005. It suggests that population size estimates from earlier than 2005 should be multiplied with 1.11 to make them more comparable to the newer data, population sizes estimated in 2005 and after. However, in the future these calculations should be repeated after each survey-year, because the new method has much smaller degrees of freedom (has only been used four times) than the old method (seven times). This ratio may therefore not have stabalized yet. As more surveys are conducted, we will better understand the difference between these two methods.

We only surveyed each breeding site a maximum of four times, due to cost in flying. That makes it impossible to describe the breeding process completely. To facilitate increased knowledge on the breeding process it would be preferable to survey a few breeding sites on a daily or weekly basis and use tags to identify each pup born. It is possible that female grey seals could synchronize breeding to tidal states, e.g. spring tide, so the pups would be born high enough on the shore (Bonner 1972). This would result in periodic birthing episodes with multiple birthing tops, which is not taken into consideration in the current methods, where one single top is expected. Another methodological consideration is the timing of the survey. Currently, the timing is based on all existing knowledge. However, rather little knowledge exists regarding annual variation in the timing of breeding and since the population estimate is based on pup production it is crucial that the main pupping period is not missed. Through the years we have gained some insight into when grey seals start giving birth in different areas. Decades ago, the first pups were found in Sviðnur, Breiðafjörður. The birthing commenced earlier in the inner part and later in Vestureyjar, the outer part of Breiðafjörður. Bjarneyjar could sometimes be quite late as could the Hergilseyjar area. Newborns have been observed there in the last survey flights in November. In the current survey it is possible that the first flight in Frameyjar should have been made earlier, because in the first fly-over 2 October numerous pups had already been born.

Dead pups can be flushed into the sea and if they remain on land, they disintegrate quickly and disappear, however the skins of dead pups often get dried out and are traceable. Nevertheless, when visiting grey seal rookeries, dead pups are seldom found, and it is therefore likely that mortality on breeding sites is low. Probably pup mortality increases when the females have left their offspring and they must fend for themselves.

4.4 Factors affecting the status of the Icelandic grey seal population

As discussed in the introduction, several factors are likely to contribute to the status of the Icelandic grey seal population. Due to the absence of a mandatory reporting system, reliable hunting statistics for seals in Iceland is lacking. However, direct contact with hunters indicates that grey seal hunting has decreased during the last decade (Hafrannsóknastofnun 2015). A significant number of grey seals are, on the other hand, bycaught in fishing gear and it is considered the largest source of mortality for the grey seal in recent times. Interestingly, unlike the rather stable status of the Icelandic grey seal population, the Icelandic harbour seal population has recently experienced a severe decrease; a reduction of one third between the year 2012 and 2016 was observed (Þorbjörnsson et al. 2017). A higher total number of direct hunting of harbour seals has been reported during this period, while by-catch in fishing gear, such as lumpsucker gillnets, is estimated to have been high for both species (Marine and Freshwater Research Institute 2018). Further, it could be speculated that in cases where the grey seal population compete with the harbour seal population for prey and space, grey seals would probably have an advantage.

4.5 Conclusions

Monitoring trends and status of the Icelandic grey seal population is necessary for evidence-based advice on management and regulation of hunting. Such knowledge is also the foundation for other research on grey seal ecology in Iceland. The population size of 2017 was estimated to be larger than the estimate from 2012, although no significant trend could be found for the period 2005–2017 indicating that the population can be considered as rather stable at its current level. It must though be considered that despite the population being about 1200 animals larger than the governmental management objective, it is still on the Icelandic red list for threatened species and should per definition be considered as *Vulnerable*. Hence, caution should be advised in terms of management of the population. To facilitate monitoring, improved reporting of bycatch along with the implementation of a mandatory reporting system for seal hunting is suggested. Due to the conservational status of the population, continuing regular population censuses is important, along with research on population ecology.

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7. Appendix

Appendix. Calculated pup production for different breeding sites (95% CI) during the four survey years when the multiple count approach was used (2005-2017). In the years surveyed prior to 2005, only one fly-over was conducted. Information about trend in periods 1982 – 2002 (Hauksson 2007a) and 2005 – 2017 for comparison, in areas and breeding sites where comparison was possible (not too few pups or differences in logistics of surveys), NS = not significant.

Viðauki. *Kópafjöldi (95% ö. m.) á kæpingarstöðum og strandsvæðum 2005 – 2017. Þessi ár var nýju aðferðinni beitt, tímabilið 1982 – 2002 var gömlu aðferðinni beitt og einungis flogið einu sinni yfir hvern kæpingarstað (Hauksson 2007a). Meðalbreyting á ári þessi tvö tímabil er borin saman fyrir kæpingarstaði og strandsvæði þar sem það var mögulegt, ekki og fáir kópar og sambærilegri aðferðafræði beitt.*

Area	2005	2008/9	2012	2017	Trend in period 1982 – 2002 r_s (SE) p	Trend in period 2005 – 2017 r_s(SE) p
Faxaflói	**40 (40-45)**	**18 (18-21)**	**12 (10-13)**	**37 (34-41)**	**-0.19 (0.05) 0.01**	**-0.00 (0.082) NS**
Northwest	**471 (447-506)**	**424 (416-434)**	**322 (279-323)**	**262 (251-278)**	**-0.003 (0.02) NS**	**-0.05 (0.008) 0.01**
Strandir[1]	338 (324-357)	259 (-)	206 (194-222)	140 (135-151)	-	-0.07 (0.002) <0.001
Skagi	54 (50-62)	6 (-)	26 (-)	2 (-)	-0.04 (-) NS	-0.21 (0.140) NS
Skagafjörður	79 (73-87)	159 (151-169)	90 (83-99)	111(105-116)	-	0.01 (0.042) NS
South coast	**223 (218-233)**	**225 (218-236)**	**133 (133-137)**	**267 (256-278)**	**-0.08 (0.02) 0.02**	**0.01 (0.042) NS**
Surtsey	63 (62-66)	88 (87-90)	62 (62-62)	134 (126-140)	0.07 (-) NS	0.05 (0.035) NS
Öræfi	114 (113-115)	86 (-)	62 (62-66)	99 (97-102)	-0.10 (-) 0.001	-0.01 (0.036) NS
Vigur	45 (42-51)	51 (45-60)	8 (8-8)	26 (25-28)	-0.03 (-) NS	-0.08 (0.103) NS
Breiðafjörður	**645 (630-671)**	**859 (836-892)**	**525 (496-553)**	**845 (807-887)**	**-0.02 (0.02) NS**	**0.01 (0.032) NS**
Suðureyjar	9 (-)	4 (-)	1 (-)	10 (9-11)	-0.07 (-) NS	-0.01 (0.148) NS
Skálmarnes[2]	51 (47-59)3	47 (-)3	8 (8-12)	10	0.02 (-) NS	-0.16 (0.071) NS
Frameyjar + Rúfeyjar	418 (-)	599 (583-615)	302 (292-316)	567 (547 -588)	-0.05 (-) NS	0.01 (0.044) NS

[1]Ófeigsfjörður included, [2]Reykjanes included.

HAFRANNSÓKNASTOFNUN

Rannsókna- og ráðgjafarstofnun hafs og vatna