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Abstract

Regular harbour seal (*Phoca vitulina*) population censuses are necessary to understand the status of the population and to monitor trends in the population size. In Iceland, aerial population censuses have been conducted since 1980, and have revealed a decline in the Icelandic harbour seal population. In this project, we conducted an aerial census with the aim of estimating the population size of Icelandic harbour seals for the 12th time and to examine population trends. In total, 4,168 (CI 95% = 6,149-12,726) seals were observed, which after correction factors had been applied, resulted in an estimated population size of 9,434 animals. The estimated population size was 72% smaller than when first estimated in 1980, but about 23% larger than in 2016 when the last complete population census was conducted. The current estimate is 21% below the governmentally issued management objective for the minimum population size of harbour seals in Iceland (12,000 animals). Most of the observed decrease in the population occurred between the years 1980 and 1989. When examining recent changes in the size of the population based on estimates in the current period (2011-2018) no significant trend was detected, indicating that the population currently seems to fluctuate around a stable minimum stock level. Due to the sensitive conservation status of the Icelandic harbour seal population, it is urgent to assess factors affecting the status of the population, such as mortality by direct and indirect seal removals, climate change and prey availability. In addition, increased monitoring of population demographic factors is urgent.

Ágrip

Mikilvægt er að framkvæma reglulega stofnmöt, til þess að vakta stöðu og breytingar á íslenska landselsstofninum. Á Íslandi hófst framkvæmd slíkra mata árið 1980, og hafa þau gefið til kynna fækkun í íslenska landselsstofninum. Í þessu verkefni voru landselir taldir úr lofti, með það að markmiði að meta stofnstærð í tólfta skiptið, ásamt því að kanna sveiflur

í stofninum. Samtals voru 4.168 landselir taldir og áætluð stofnstærð eftir að leiðréttingarstuðli hafði verið beitt var 9.434 (CI 95% = 6.149-12.726) selir. Stofninn er nú 72% minni en þegar hann var fyrst metinn árið 1980, en 23% stærri en árið 2016 þegar stofnstærðarmat fyrir alla strandlengju landsins var síðast framkvæmt. Samkvæmt stjórnunarmarkmiðum fyrir íslenska landselsstofninn skal halda stofninum í 12.000 selum en niðurstöður okkar gefa til kynna að hann sé nú um 21% minni en sem því nemur. Mesta fækkunin í stofninum átti sér stað frá árinu 1980 til ársins 1989. Þegar nýlegar stofnstærðarbreytingar voru kannaðar byggt á nýjustu stofnmötum fyrir landsel (2011-2018), komu engar marktækar breytingar í ljós, sem bendir til að landselsstofnin sé að sveiflast í kringum lágmarksstofnstærð. Í ljósi viðkvæmar stöðu landselsstofnsins við Íslands sem strendur, er brýnt, í náinni framtíð, að meta þá þætti sem mögulega hafa áhrif á stöðu stofnsins, svo sem meðafla í fiskveiðum, beinar selveiðar, umhverfisbreytingar og aðgang að mikilvægum bráðartegundum. Einnig er mikilvægt að vakta stofnvistfræðilega þætti, svo sem kópaframleiðsla og frjósemi.

Lykilorð: *Landselur, selir, stofnstærðarmat, phoca vitulina, harbour seal*

Undirskrift verkefnisstjóra:	**Undirskrift forstöðumanns sviðs:**
	

Table of contents

Figures

Tables

1. Introduction

Two pinniped species breed in Iceland: harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*). Aerial censuses for the Icelandic harbour seal population have been conducted since 1980, when the population was estimated to be around 33,000 animals (Hauksson and Einarsson 2010). Since then, the population has been monitored rather regularly and in total, eleven censuses covering the whole coastline have been completed. Trend analysis based on complete surveys show a declining trend in the harbour seal population since 1980. In 2006, a management objective was introduced by the Icelandic authorities stating that the harbour seal population should not decrease below 12,000 animals and if that occurs, actions should be taken to balance the population and prevent further declines (NAMMCO 2006). In the census of 2006 and the following census of 2011, the population size was close to the objective minimum population size. In a partial census carried out in 2014, with only the largest harbour seal haul-out sites surveyed, the results indicated an annual decline of 28.55% in the period from 2011-2014 (Granquist et al. 2014). This decline was confirmed during the most recent complete census from 2016, when the population size was estimated to be 7,700 animals (Þorbjörnsson et al. 2017). The numbers from the 2014 and 2016 censuses suggested that the Icelandic harbour seal population had decreased below the minimal population size presented in the management objective.

The aim of the present census was to estimate the size of the Icelandic harbour seal population for the 12th time, and to monitor ongoing population trends. Examining changes in population sizes and monitoring of general and local trends, is important to obtain sufficient knowledge of the status of the population and to facilitate sustainable management of the Icelandic harbour seal population. Such knowledge is also a crucial base for other research undertaken on the Icelandic seal populations.

2. Methods

2.1. Aerial surveys

The census was conducted between 25 July and 24 August to coincide with the peak of the moulting season of harbour seals in Iceland (Granquist and Hauksson 2016a). The survey was conducted from a small airplane and the whole coastline of Iceland was covered at least once. Vatnsnes and part of the south coast were covered twice. To standardize conditions, all sites were surveyed in clear weather with wind <10 m/s and +/- three hours from low tide.

During the survey, the main observer, being responsible for detecting and counting all visible animals, was seated in the front of the airplane. The assistant observer was seated in the rear, counting smaller groups (<30 seals) and photographing larger groups (>30 seals), using a Canon 5DS full-frame digital camera mounted with a Canon 70-200 mm f/2.8L II USM lens. The camera was equipped with a Global Position System (GPS), which assigns each image positional coordinates, and a camera lens with image stabilisation. During the analysis, when photographs were available, the number of harbour seals in the images was used for the area concerned. For smaller groups (<30 seals) the direct count value was used. In cases when direct counts were obtained by both the assistant and main observer, the values were compared, and the higher value was used if the values differed. To facilitate an exact comparison to results from previous censuses, the definition of haul-out sites and areas were identical to those used in previous censuses (Figure 1, Table 4-10) (Hauksson 2010).

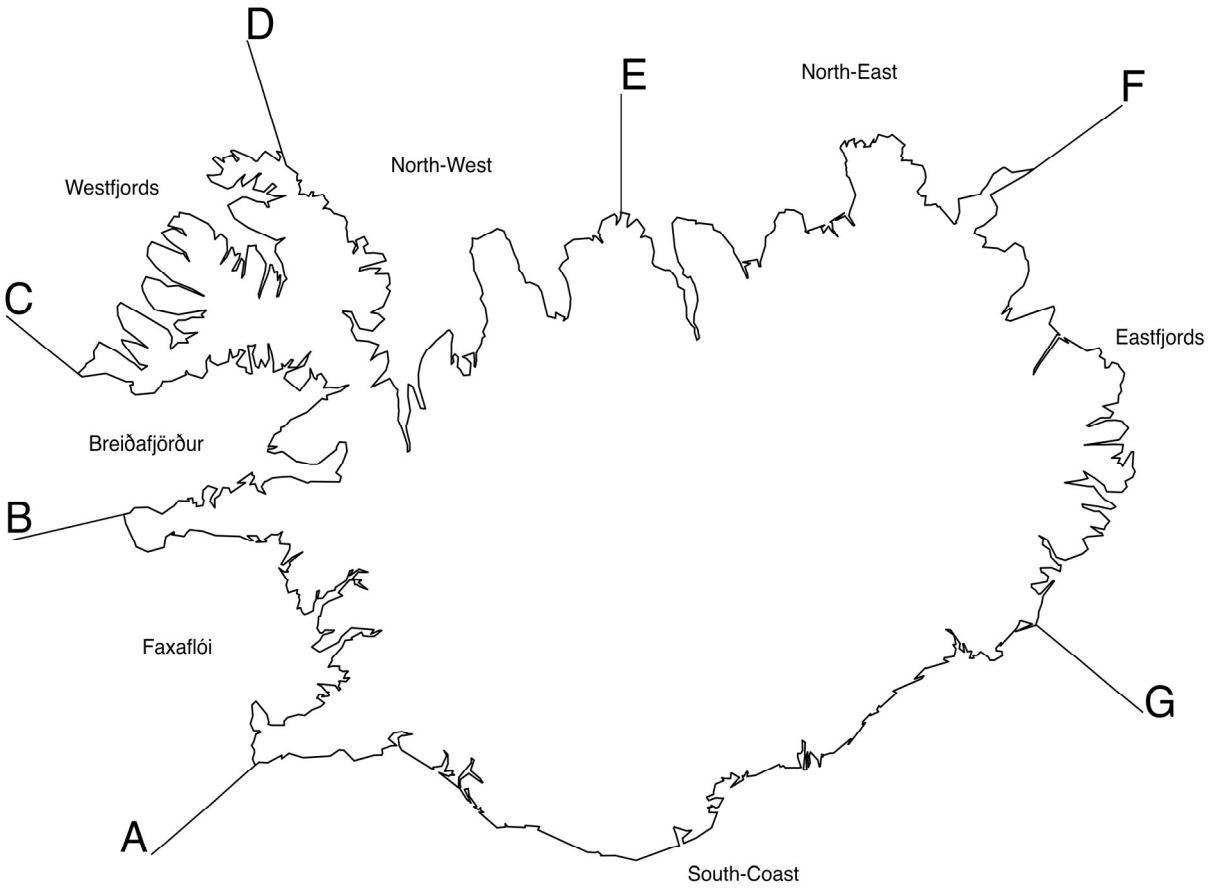

Figure 1. The Icelandic coastline divided into sub-areas; A – B: Faxaflói, B – C: Breiðafjörður, C – D: Westfjords, D – E: Northwest, E – F: Northeast, F – G: Eastfjords and G – A: South coast.

***1. mynd*.** Skipting strandlengju 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.

2.2 Statistical analysis

The size of the Icelandic harbour seal population in 2018 was estimated based on the total number of observed animals, which was corrected for submerged animals and animals missed by the observer by applying a correction factor of 2.26 (SD=0.41). To generate the estimated population size, the total number of observed animals was multiplied by 10,000 normally distributed correction factors. This yielded 10,000 normally distributed population estimates, of which the average was used as the estimate for the population size for the year 2018. The 95% Confidence Interval (95% CI) was calculated for the distribution of the 10,000 population estimates. For comparative purposes, the correction factor was identical to the one used in all previous harbour seal censuses since 2006 (Hauksson and Einarsson 2010).

Recent changes in abundance and trends in the Icelandic harbour seal population were examined by using results from the most recent censuses; 2011 (Granquist et al 2011), 2014 (a partial census, Granquist et al 2014), 2016 (Þórbjörnsson et al. 2017) and 2018. The period of 2011-2018 was then compared to trends in the previous period of 1980-2006 (Hauksson 2010).

The changes in the population were examined in two ways. Firstly, the following equations were used to calculate the total change in population size between the estimate of 2018 and previous estimates (Table 1), as well as the total change between the years 2011 and 2018 in the various coastal areas and specific haul-out sites (Table 2 - 9):

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

$$R_{est} = \frac{\ln\left(\frac{Nlast}{Nfirst}\right)}{\Delta T}$$

Linear percent change (Δ) was calculated as:

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

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

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

N_{last}: The most recent value.

N_{first}: The earlier value, which N_{last} is compared to.

ΔT: Total time interval (in years) of which a change is examined ($T_{last} - T_{first}$).

Secondly, recent trends (2011-2018) in the abundance of harbour seals at individual haul-out sites, coastal areas and the whole coast of Iceland was assessed by applying linear regression

models on *ln* transformed counts. In case of zeros values, 0.49 was added before performing the linear regression on *ln*(counts). The same method was used in the trend analysis for the previous period (1980-2006) published by Hauksson (2010) and hence, a direct comparison of these results was possible. The probability of a population estimate being lower than the previous estimate was calculated with the normal cumulative distribution (CDF) (Sokal & Rohlf 1997). All analysis was conducted in RStudio (RStudio. Version 3.3.1. 2016).

3. Results

3.1 Estimated population size

The total number of observed harbour seals on the entire Icelandic coastline, based on direct and photographic counts, was 4,168. Multiplication of the number of observed seals with 10,000 normally distributed correction factors, yielded an estimated total population size of 9,434 (SD = 1,678; CI 95% = 6,149-12,726) harbour seals (Figure 2).

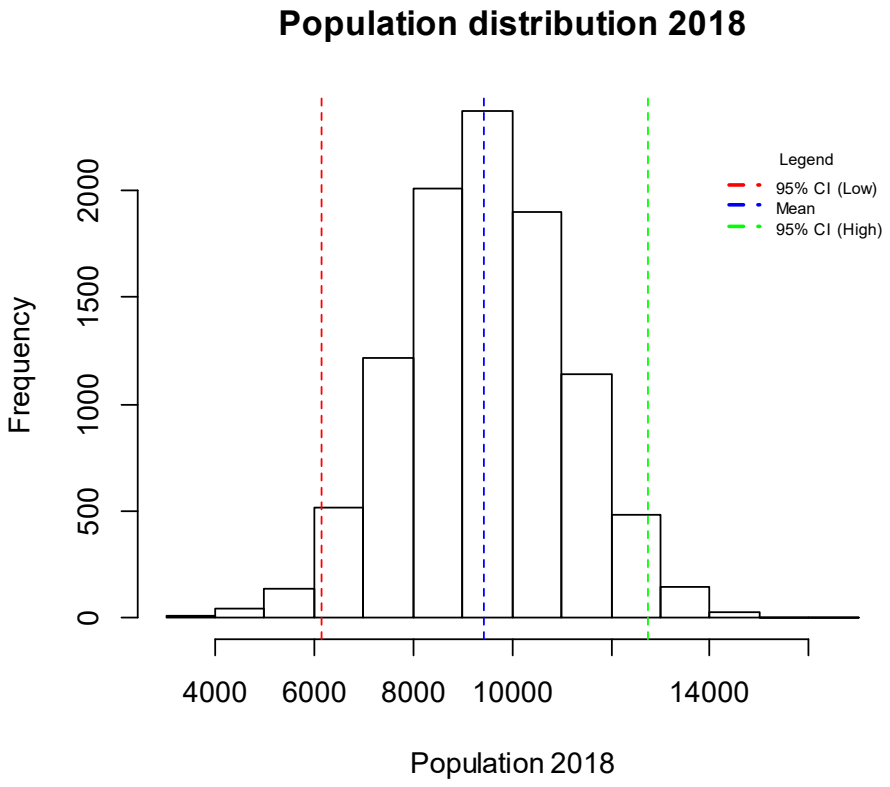

Figure 2. A normal distribution showing the number of counted harbour seals on the whole coast of Iceland, multiplied by 10,000 normally distributed correction factors. The mean value (blue line) and the 95% confidence intervals (red line= 95% CI low and green line= 95% CI high) are shown. The estimated population size in 2018 is based on the mean value of 9,434 seals.

2. mynd. Normaldreifing sem sýnir fjöldi talinna landsela á strandlengju Íslands eftir margföldun með 10,000 normaldreifðum leiðréttingarstuðlum. Meðalgildið (blá lína) og 95% öryggismörk (rauð lína=95% neðri öryggismörk og græn lína=95% efri öryggismörk) eru sýnd. Stofnstærðarmat landselsstofnsins árið 2018 byggir á meðaltali dreifingarinnar sem er 9,434 selir.

3.2 Population trends 1980 - 2018

Changes between 2018 and previously conducted population estimates are presented in Table 1. The temporal population trends show that the total decline from 1980 to 2018 is 71.69% and the annual discrete time per capita growth rate (λ) during this period was -3.27%. A linear regression model indicated a significant decline between 1980 and 2018 of 3% annually (R_{est} = -0.032 (SE= 0.004); R^2_{ad} = 0.83, p < 0.001) (Figure 3). An increase of 23.29% was observed since the survey of 2016, corresponding to an annual discrete time per capita growth rate of 11.04%. Based on the 2018 population distribution, there is a 94% chance that the population size is below the threshold value of 12,000 animals (Table 1), which is suggested as the minimum population size in the management objective put forward by Icelandic authorities (NAMMCO 2006).

The main decline in the Icelandic harbour seal population occurred during the period 1980 to 2006, when the total decline was significant; R_{est} = -0.042 (SE = 0.01), p>0.001. However, no significant decline occurred during the period 2011 to 2018; -0.035 (SE = 0.04), ns.

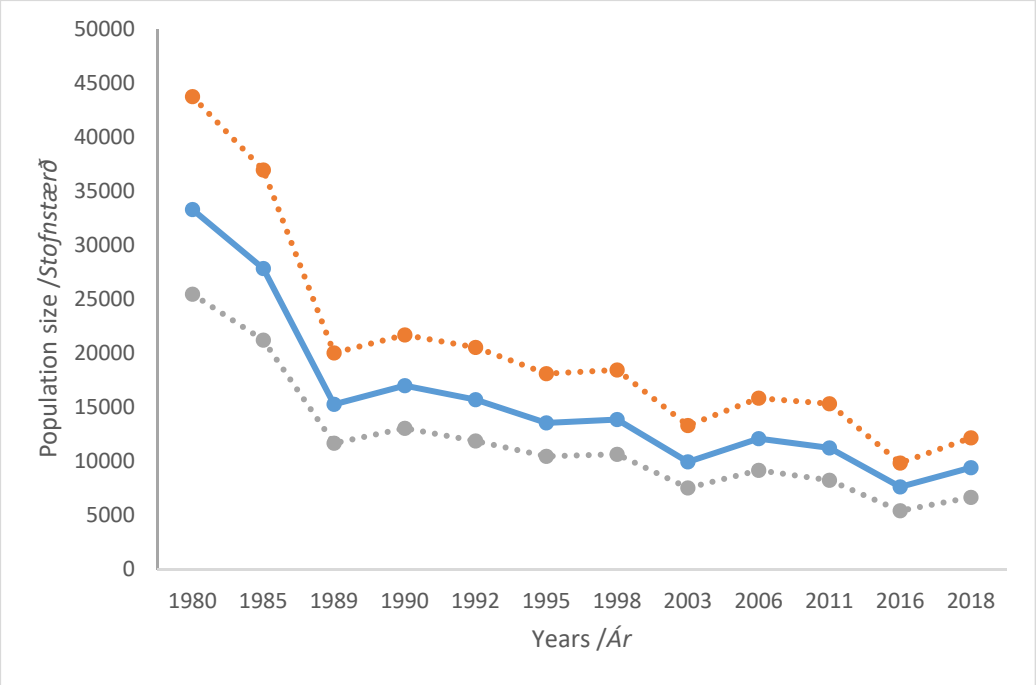

Figure 3. Trends in the Icelandic harbour seal population from 1980 to 2018. The mean values (solid blue line) are the estimated population size for respective years. The 90% confidence intervals indicated with dotted lines (90% CI low = grey line and 90% CI high = orange line).

3. mynd. Breytingar í stærð íslenska landselsstofnsins á árunum 1980 til 2018. Meðalgildið er áætluð stofnstærð og punktalínurnar sýna 90% öryggismörk (90% neðra öryggismörk = grá lína og 90% efri öryggismörk = appelsínugul lína).

Table 1. Estimated population sizes of the Icelandic harbour seal from 1980 to 2018, the probability of the 2018 population estimate being lower than previous estimates $P_{(pop2018<popyearX)}$, exponential growth rate (R_{est}), with the linear percent change (Δ (%)) and discrete time per capita growth rate (λ (%)) from the relevant year compared to 2018.

Tafla 1. *Stofnstærð landsels við Ísland tímabilið 1980-2018 (Est. Pop), líkur þess að stofnstærðin árið 2018 sé minni en árin á undan ($P_{(pop2018<popyearX)}$), veldisvaxtarstuðull (R_{est}), prósentvís breyting (Δ (%)) og ársvöxtur λ (%), miðað við ár 2018.*

Survey year	Est. pop.	$P_{(pop2018<popyearX)}$	R_{est}	Δ (%)	λ (%)
1980	33,327	100%	-0.03	-71.69%	-3.27%
1985	27,871	100%	-0.03	-66.15%	-3.23%
1989	15,298	100%	-0.02	-38.33%	-1.65%
1990	17,026	100%	-0.02	-44.59%	-2.09%
1992	15,731	100%	-0.02	-40.03%	-1.95%
1995	13,578	99%	-0.02	-30.52%	-1.57%
1998	13,887	100%	-0.02	-32.07%	-1.91%
2003	9,972	63%	0.00	-5.40%	-0.37%
2006	12,122	95%	-0.02	-22.17%	-2.07%
2011	11,272	86%	-0.03	-16.31%	-2.51%
2016	7,652	14%	0.10	23.29%	11.04%
2018	9,434	-	-	-	-
Management objective	12,000	94%	-	-	-

3.3. Trends at the different haul-out sites

The highest number of harbour seals in 2018 was found at the South coast (1,084 seals), followed by Northwest coast (867 seals), while the lowest number of harbour seals was found in North-Eastern Iceland (96 seals) (Table 2). To investigate changes in different haul-out sites, trends based on the most recent censuses (2011, 2014 (a partial census), 2016 and 2018) were compared to trends in the previous period of 1980-2006. During the period 2011 to 2018, a numerical decrease was observed in all geographical areas, except for the Eastfjords and the South coast where an increase was observed. The highest decline was observed in Northeastern Iceland (54.07%) and the area with the highest increase was the South coast (52.89%). However, linear regression revealed no significant trend for any of the areas. On the other hand, during the previous period of 1980 to 2006, a significant negative trend was observed for Faxaflói, Eastfjords and the South coast. The main changes since the last survey in 2016 were the observed increases in the South coast, the Northwest coast and in the Eastfjords, while a decrease was observed in Faxaflói. Other areas had a similar number in 2018 and in 2016. (Table 2).

Table 2. Trends in abundance of harbour seals for the period 1980-2006 (Hauksson 2010), described by exponential growth rate (R_{est}), standard error (SE) and significance level[a]. Number of counted animals from censuses in the period 2011-2018. The total change between the years 2011 and 2018 calculated as Mills (2012): exponential growth rate (R_{est}^{Mills}), linear percent change (Δ (%)) and time per capita growth (λ (%)). Total trends for the period 2011-2018 calculated by linear regression models on ln transformed counts: adjusted coefficient of determination (R_{ad}^2), annual growth rate (R_{est}), standard error (SE), significance[a] and residual standard error (RSE).

Tafla 2. *Árlegur veldisvöxtur fjölda landsela fyrir tímabilið 1980-2006 (R_{est} (SE; staðalfrávik og marktækni[a])) (Hauksson 2010). Fjöldi taldra landsela tímabilið 2011-2018. Breyting á milli árana 2011 og 2018 reiknuð með aðferð Mills (2012): veldisvaxtarstuðull (R_{est}^{Mills}), prósentvís breyting (Δ) og ársvöxtur (λ). Heildarbreyting á timabilinu 2011-2018 metið með línulegri aðhvarfsgreiningu: Aðhvarfsgreiningarstuðull (R_{ad}^2), veldisvaxtrastuðull (R_{est} (SE), marktækni[a]) og staðalfrávík leifa aðhvarfsgreiningarinnar (RSE).*

	R_{est} (SE)^{significance}	Total count			R_{est}^{Mills}	Δ (%)	λ (%)	R_{ad}^2	R_{est} (SE)^{significance}	RSE
Coastal area	**1980-2006**	**2011**	**2016**	**2018**	**2011 vs. 2018**				**2011 - 2018**	
Faxaflói	-0.07 (0.01)*	554.5	556	325	-0.076	-41.39%	-7.35%	0.03	-0.062 (0.060)^{ns}	0.300
Breiðafjörður	-0.06 (0.01)^{ns}	621	463	489	-0.034	-21.26%	-3.36%	0.61	-0.039 (0.019)^{ns}	0.097
Westfjords	-0.02 (0.01)^{ns}	796.5	685	683	-0.022	-14.25%	-2.17%	0.86	-0.024 (0.006)^{ns}	0.032
North west	-0.02 (0.01)^{ns}	1461.5	615.75	867	-0.075	-40.68%	-7.19%	0.20	-0.094 (0.076)^{ns}	0.390
North east	-0.04 (0.01)^{ns}	209	89.5	96	-0.111	-54.07%	-10.52%	0.76	-0.122 (0.046)^{ns}	0.232
Eastfjords	-0.01 (0.01)*	530.5	527.5	624	0.023	17.62%	2.35%	-0.01	0.018 (0.019)^{ns}	0.096
South coast	-0.07 (0.01)*	709	445.5	1084	0.061	52.89%	6.25%	-0.87	0.031 (0.119)^{ns}	0.609

[a]Significance levels: ns = not significant, * significant at the 5%, ** 1 % and *** 0.1%, levels respectively

3.3.1 Faxaflói

The largest haul-outs in Faxaflói in 2018 were Akraós and Haffjörður where 86 and 72 seals were observed respectively. No significant overall trend was observed for the period 2011-2018, but the number of observed seals decreased from 554.5 to 325 seals during the period. In the previous period (1980-2006), a significant negative trend was observed. When the eleven haul-out sites in Faxaflói were analysed separately, there was no significant trend for any of the sites between 2011 and 2018, while a negative trend was observed in all haul-out sites except for Akraós, Búðavík and Hvalfjörður in the previous period (1980-2006). Compared with the previous survey of 2016, there was a large decrease in Haffjörður where only 72 seals were observed in 2018 compared to 271 seals in 2016. Further, the number of observed seals in Leirárvogur declined from 42 in 2016 to only 1 in 2018. On the other hand, the number of observed seals increased in Hvalseyjar from 4 in 2016 to 29 in 2018 (Table 3).

Table 3. Trends in abundance of harbour seals for the period 1980-2006 in Faxaflói (Hauksson 2010) described by exponential growth rate (R_{est}), standard error (SE) and significance level[a]. Number of counted animals from censuses in the period 2011-2018. The total change between the years 2011 and 2018 calculated as Mills (2012): exponential growth rate (R_{est}^{Mills}), linear percent change (Δ (%)) and time per capita growth (λ (%)). Total trends for the period 2011-2018 calculated by linear regression models on ln transformed counts: adjusted coefficient of determination (R_{ad}^2), annual growth rate (R_{est}), standard error (SE), significance[a] and residual standard error (RSE).

Tafla 3. *Árlegur veldisvöxtur fjölda landsela fyrir tímabilið 1980-2006, í látrum í Faxaflóa (R_{est} (SE; staðalfrávik og marktækni[a])). Fjöldi taldra landsela tímabilið 2011-2018. Breyting á milli árana 2011 og 2018 reiknuð með aðferð Mills (2012): veldisvaxtarstuðull (R_{est}^{Mills}), prósentvís breyting (Δ) og ársvöxtur (λ). Heildarbreytingar á timabilinu 2011-2018 metið með línulegri aðhvarfsgreiningu: Aðhvarfsgreiningarstuðull (R_{ad}^2), veldisvaxtrastuðull (R_{est} (SE), marktækni[a]) og staðalfrávik leifa aðhvarfsgreiningarinnar (RSE).*

		R_{est} (SE)[significance]	Total count				R_{est}^{Mills}	Δ (%)	λ (%)	R_{ad}^2	R_{est} (SE)[significance]	RSE
	Haul-out site	**1980-2006**	**2011**	**2014[b]**	**2016**	**2018**	**2011 vs. 2018**				**2011 - 2018**	
1	**Akraós**	-0.057 (0.03)^{ns}	64	19	29	86	0.042	34.38%	4.31%	-0.47	0.033 (0.16)^{ns}	0.845
2	**Borgarfjörður**	-0.104 (0.05)*	31	NA	40.5	18	-0.078	-41.94%	-7.47%	-0.58	-0.052 (0.102)^{ns}	0.52
3	**Búðavík**	0.026 (0.07)^{ns}	6	NA	36	22	0.186	266.67%	20.40%	0.453	0.219 (0.134)^{ns}	0.685
4	**Haffjörður**	-0.053 (0.02)*	339	15	271	72	-0.221	-78.76%	-19.86%	-0.42	-0.111 (0.331)^{ns}	1.712
5	**Hvalfjörður**	-0.039 (0.02)^{ns}	35	NA	37.5	31	-0.017	-11.43%	-1.72%	-0.639	-0.011 (0.024)^{ns}	0.123
6	**Hvalseyjar**	-0.173 (0.03)*	7	NA	4	29	0.203	314.29%	22.51%	-0.494	0.142 (0.245)^{ns}	1.248
7	**Leirárvogur**	-0.060 (0.02)*	24	NA	42	1	-0.454	-95.83%	-36.49%	-0.238	-0.345 (0.440)^{ns}	2.243
8	**Melar**	-0.198 (0.04)*	1	NA	0	7	0.278	600.00%	32.05%	-0.456	0.198 (0.324)^{ns}	1.651
9	**Mýrar**	-0.143 (0.03)*	29.5	NA	60	47	0.067	59.32%	6.88%	0.313	0.081 (0.059)^{ns}	0.299
10	**Hafnarósar**	-0.070 (0.02)*	15.5	NA	32	10	-0.063	-35.48%	-6.07%	-0.961	-0.023 (0.161)^{ns}	0.823
11	**W-Snæfellsnes**	-0.122 (0.02)*	2.5	NA	4	2	-0.032	-20.00%	-3.14%	-0.988	-0.008 (0.098)^{ns}	0.499
	Faxaflói total	**-0.07 (0.01)***	554.5		556	325	-0.076	-41.39%	-7.35%	0.03	-0.062 (0.06)^{ns}	0.30

[a]Significance levels: ns = not significant, * significant at the 5%, ** 1 % and *** 0.1%, levels respectively

[b]The 2014 census was only partial, so no total numbers are available.

3.3.2 Breiðafjörður

The two largest haul-outs in Breiðafjörður in 2018 were Bæjarvaðall (160 seals) and Lækjarskógarfjörur (114 seals). No significant overall trend was observed in either of the two periods 1980-2006 or 2011-2018. When analysing the haul-out sites individually, the only site with a significant trend in the period 2011 to 2018 was Skarðsströnd where a negative trend was observed due to a decrease from 3.5 seals in 2011 no observed seals in 2018. However, during the previous period there was a significant negative trend in half of the haul-out sites in Breiðafjörður. Compared with the census in 2016, there was a clear decrease at Lækjarskógarfjörur where 267 seals were observed in 2016 compared to 114 seals in 2018. However, a clear increase was observed at Fellsströnd, where 10 seals were observed in 2016 compared to 85 seals in 2018, and in Bæjarvaðall, where 112 seals were observed in 2016 and

160 seals in 2018. An increase was also observed in Þórsnes and surrounding islands from 3 seals in 2016 to 22 seals now (Table 4).

Table 4. Trends in abundance of harbour seals for the period 1980-2006 in Breiðafjörður (Hauksson 2010) described by exponential growth rate (R_{est}), standard error (SE) and significance level[a]. Number of counted animals from censuses in the period 2011-2018. The total change between the years 2011 and 2018 calculated as Mills (2012): exponential growth rate (R_{est}^{Mills}), linear percent change (Δ (%)) and time per capita growth (λ (%)). Total trends for the period 2011-2018 calculated by linear regression models on ln transformed counts: adjusted coefficient of determination (R_{ad}^2), annual growth rate (R_{est}), standard error (SE), significance[a] and residual standard error (RSE).

Tafla 4. *Árlegur veldisvöxtur fjölda landsela fyrir tímabilið 1980-2006, í látrum í Breiðafirði (R_{est} (SE; staðalfrávik og marktækni[a])). Fjöldi taldra landsela tímabilið 2011-2018. Breyting á milli árana 2011 og 2018 reiknuð með aðferð Mills (2012): veldisvaxtarstuðull (R_{est}^{Mills}), prósentvís breyting (Δ) og ársvöxtur (λ). Heildarbreytingar á timabilinu 2011-2018 metið með línulegri aðhvarfsgreiningu: Aðhvarfsgreiningarstuðull (R_{ad}^2), veldisvaxtrastuðull (R_{est} (SE), marktækni[a]) og staðalfrávik leifa aðhvarfsgreiningarinnar (RSE).*

		R_{est} (SE)^{significance}	Total count				R_{est}^{Mills}	Δ (%)	λ (%)	R_{ad}^2	R_{est} (SE)^{significance}	RSE
	Haul-out site	**1980-2006**	**2011**	**2014[b]**	**2016**	**2018**	**2011 vs. 2018**			**2011 - 2018**		
12	**Álftafjörður**	-0.114 (0.02)*	0	NA	11	0	NA	NA	NA	NA	NA	NA
13	**Bjarneyjar**	-0.199 (0.05)*	8.5	NA	10	4	-0.108	-52.94%	-10.21%	-0.291	-0.081 (0.109)ns	0.556
14	**Brimilsvellir**	-0.126 (0.02)*	22	NA	2	4	-0.244	-81.82%	-21.61%	0.425	-0.289 (0.184)ns	0.935
15	**Bæjarvaðall**	-0.021 (0.02)ns	176	75	112	160	-0.014	-9.09%	-1.35%	-0.493	-0.009 (0.092)ns	0.474
16	**Fellsströnd**	0.088 (0.03)ns	64.5	NA	10	85	0.039	31.78%	4.02%	-0.97	-0.040 (0.320)ns	1.634
17	**Flateyjarlönd**	-0.150 (0.04)*	0	NA	0	2	NA	NA	NA	NA	NA	NA
18	**Grónes/Hallsteinsnes**	-0.097 (0.04)*	0	NA	0	12	NA	NA	NA	NA	NA	NA
19	**Hagadrápssker/Flögur**	-0.168 (0.04)*	0	NA	1	17	NA	NA	NA	NA	NA	NA
20	**Hergilseyjar and Sandeyjarhólmi**	-0.119 (0.07)ns	12.5	NA	1	5	-0.131	-60.00%	-12.27%	-0.346	-0.203 (0.291)ns	1.483
21	**Hjarðarnes**	0.036 (0.06)ns	5.5	NA	3	4	-0.045	-27.27%	-4.45%	0.02	-0.060 (0.059)ns	0.300
22	**Svefneyjar**	-0.116 (0.02)*	9	NA	12	8	-0.017	-11.11%	-1.67%	-1	-0.003 (0.058)ns	0.295
23	**Kerlingarfjörður**	-0.064 (0.04)ns	20	NA	0	2	-0.329	-90.00%	-28.03%	0.244	-0.408 (0.318)ns	1.62
24	**Króksfjarðarnes**	-0.061 (0.02)*	9.5	NA	1	2	-0.223	-78.95%	-19.96%	0.388	-0.266 (0.177)ns	0.902
25	**Lækjarskógarfjörur**	0.025 (0.02)ns	181	57	267	114	-0.066	-37.02%	-6.39%	-0.499	-0.006 (0.157)ns	0.813
26	**Drápsker**	-0.104 (0.04)*	12	NA	3	3	-0.198	-75.00%	-17.97%	0.846	-0.213 (0.062)ns	0.314
27	**Rauðseyjar**	-0.141 (0.03)*	2	NA	12	18	0.314	800.00%	36.87%	0.977	0.322 (0.346)ns	0.176
28	**Reykhólalönd**	-0.056 (0.03)ns	21	NA	3	15	-0.048	-28.57%	-4.69%	-0.689	-0.114 (0.265)ns	1.352
29	**Skarðströnd**	-0.165 (0.08)*	3.5	NA	1	0	NA	-100.00%	NA	0.988	-0.273 (0.021)*	0.109
30	**Skálanes**	-0.045 (0.03)ns	2.5	NA	1	0	NA	-100.00%	NA	0.948	-0.221 (0.0363)ns	0.185
31	**Skálmarnes**	-0.065 (0.05)ns	2.5	NA	9	12	0.224	380.00%	25.12%	0.977	0.230 (0.025)ns	0.127
32	**Skógarströnd**	-0.148 (0.08)ns	14	NA	1	0	NA	-100.00%	NA	0.986	-0.486 (0.040)ns	0.205
33	**Þórsnes and islands**	-0.019 (0.05)ns	55	NA	3	22	-0.131	-60.00%	-12.27%	-0.443	-0.218 (0.350)ns	1.787
	Breiðafjörður total	-0.06 (0.01)ns	621		463	489	-0.034	-21.26%	-3.36%	0.611	-0.039 (0.019)ns	0.097

[a]Significance levels: ns = not significant, * significant at the 5%, ** 1 % and *** 0.1%, levels respectively

[b]The 2014 census was only partial, so no total numbers are available.

3.3.3 Westfjords

The largest haul-out sites in the Westfjord in 2018 were Reykjanes, followed by Mjóifjörður, Borgarey and Laugarból. No significant overall trend was observed in either of the two periods, 1980-2006 and 2011-2018. When analysing the haul-out sites individually, the only site with a significant trend between 2011 and 2018 was Mjóifjörður, where a 39.5% annual increase was observed. In Aðalvík 15 harbour seals were counted in 2011, but no seals were observed in 2018. In the previous period (1980-2006), a significant negative trend was observed in three of the haul-out sites (Vogasker, Jökulfirðir and Reykjanes). In 2016, 64 seals were observed in Jökulfirðir, while only 5 seals were observed in 2018. A large decrease was also observed for Vogasker (from 80 to 46 seals). Increases were observed in Reykjanes, Laugaból and in Mjóifjörður (Table 5).

Table 5. Trends in abundance of harbour seals for the period 1980-2006 in the Westfjords (Hauksson 2010) described by exponential growth rate (R_{est}), standard error (SE) and significance level[a]. Number of counted animals from censuses in the period 2011-2018. The total change between the years 2011 and 2018 calculated as Mills (2012): exponential growth rate (R_{est}^{Mills}), linear percent change (Δ (%)) and time per capita growth (λ (%)). Total trends for the period 2011-2018 calculated by linear regression models on ln transformed counts: adjusted coefficient of determination (R_{ad}^2), annual growth rate (R_{est}), standard error (SE), significance[a] and residual standard error (RSE).

Tafla 5. *Árlegur veldisvöxtur fjölda landsela fyrir tímabilið 1980-2006, í látrum á Vestfjörðum (R_{est} (SE; staðalfrávik og marktækni[a])). Fjöldi taldra landsela tímabilið 2011-2018. Breyting á milli árana 2011 og 2018 reiknuð með aðferð Mills (2012): veldisvaxtarstuðull (R_{est}^{Mills}), prósentvís breyting (Δ) og ársvöxtur (λ). Heildarbreytingar á timabilinu 2011-2018 metið með línulegri aðhvarfsgreiningu: Aðhvarfsgreiningarstuðull (R_{ad}^2), veldisvaxtrastuðull (R_{est} (SE), marktækni[a]) og staðalfrávik leifa aðhvarfsgreiningarinnar (RSE).*

		R_{est} (SE)[significance]	Total count				R_{est}^{Mills}	Δ (%)	λ (%)	R_{ad}^2	R_{est} (SE)[significance]	RSE
	Haul-out site	1980-2006	2011	2014[b]	2016	2018	2011 vs. 2018				2011-2018	
34	Aðalvík	-0.034 (0.04)^{ns}	15	NA	3	0	NA	-100.00%	NA	0.854	-0.454 (0.128)^{ns}	0.65
35	Borgarey	-0.073 (0.04)^{ns}	82	46	92.5	109	0.041	32.93%	4.15%	-0.198	0.056 (0.079)^{ns}	0.51
36	Laugaból	-0.011 (0.04)^{ns}	52	28	77.5	100	0.093	92.31%	9.79%	0.08	0.116 (0.103)^{ns}	0.532
37	Grænahlíð	-0.054 (0.06)^{ns}	0	NA	0	0	NA	NA	NA	NA	NA	NA
38	Vogasker	-0.078 (0.02)*	90	NA	80	46	-0.096	-48.89%	-9.14%	0.36	-0.082 (0.056)^{ns}	0.287
39	Jökulfirðir	-0.088 (0.04)*	14	NA	64	5	-0.147	-64.29%	-13.68%	-0.942	-0.060 (0.351)^{ns}	1.788
40	Mjóifjörður	-0.014 (0.02)^{ns}	11.5	55	86	118	0.333	926.09%	39.46%	0.89	0.333 (0.066)*	0.342
41	Patreksfjörður-Tálknafjörður	0.072 (0.03)^{ns}	0	0	10	0	NA	NA	NA	NA	NA	NA
42	Reykjanes	-0.048 (0.02)*	206	56	106	137	-0.058	-33.50%	-5.66%	-0.413	-0.044 (0.126)^{ns}	0.649
43	Súgandafjörður	-0.045 (0.07)^{ns}	0	NA	0	0	NA	NA	NA	NA	NA	NA
44	Vatnsfjarðarnes	0.019 (0.03)^{ns}	177	47	71.5	91	-0.095	-48.59%	-9.07%	-0.178	-0.086 (0.116)^{ns}	0.602
45	Ögurnes	0.023 (0.02)^{ns}	149	83	88.5	77	-0.094	-48.32%	-9.00%	0.656	-0.088 (0.034)^{ns}	0.176
46	Önundarfjörður	-0.061 (0.04)^{ns}	0	NA	6	0	NA	NA	NA	NA	NA	NA
	Westfjords total	-0.02 (0.01)^{ns}	796.5		685	683	-0.022	-14.25%	-2.17%	0.863	-0.024 (0.006)^{ns}	0.032

[a]Significance levels: ns = not significant, * significant at the 5%, ** 1 % and *** 0.1%, levels respectively

[b]The 2014 census was only partial, so no total numbers are available.

3.3.4 Northwest

In the Northwest region, the largest haul-out sites in 2018 were Vatnsnes, West-Hrútafjörður and Sigríðarstaðaós. In total, the number of seals decreased from 1461.5 seals in 2011 to 867 seals in 2018. However, a linear regression analysis did not reveal a significant overall negative trend for periods 2011-2018. Similaly, no significant trend was detected for the earlier period (1980-2006). When individual sites were analysed, the only significant negative trend over the period 2011-2018 was found for Drangar, Drangavik and Bjarnavík, where the annual decrease was estimated to be 12%. In Vatnsnes, 256 seals were observed in 2018, compared to 556.5 in 2011 and 179.5 in 2016. In Drangsnes, no seals were observed in 2011, while 20 seals were observed in 2018. A large increase between 2011 and 2018 was also observed in Munaðanessker (30% annually, corresponding to 3.5 seals in 2011 and 22 seals in 2018). In Reykjafjarðarsker a decrease was observed between 2016 (41.5) and 2018, when no seals were observed there. In Furufjörður, a higher number of seals was also observed in 2016 (54.5 seals) than in 2018 (16 seals). However, at most haul-out sites in the Northwestern region, a higher number of seals was observed in 2018 than in 2016. For example, in W-Hrútafjörður, 100 seals were observed in 2018, while only 12 seals were observed in 2016. (Table 6).

Table 6. Trends in abundance of harbour seals for the period 1980-2006 in the North west (Hauksson 2010) described by exponential growth rate (R_{est}), standard error (SE) and significance level[a]. Number of counted animals from censuses in the period 2011-2018. The total change between the years 2011 and 2018 calculated as Mills (2012): exponential growth rate (R_{est}^{Mills}), linear percent change (Δ (%)) and time per capita growth (λ (%)). Total trends for the period 2011-2018 calculated by linear regression models on ln transformed counts: adjusted coefficient of determination (R_{ad}^2), annual growth rate (R_{est}), standard error (SE), significance[a] and residual standard error (RSE).

Tafla 6. *Árlegur veldisvöxtur fjölda landsela fyrir tímabilið 1980-2006, í látrum á Norðvesturlandi (R_{est} (SE; staðalfrávik og marktækni[a])). Fjöldi taldra landsela tímabilið 2011-2018. Breyting á milli árana 2011 og 2018 reiknuð með aðferð Mills (2012): veldisvaxtarstuðull (R_{est}^{Mills}), prósentvís breyting (Δ) og ársvöxtur (λ). Heildarbreytingar á timabilinu 2011-2018 metið með línulegri aðhvarfsgreiningu: Aðhvarfsgreiningarstuðull (R_{ad}^2), veldisvaxtrastuðull (R_{est} (SE), marktækni[a]) og staðalfrávik leifa aðhvarfsgreiningarinnar (RSE).*

		R_{est} (SE)^{significance}	Total count				R_{est}^{Mills}	Δ (%)	λ (%)	R_{ad}^2	R_{est} (SE)^{significance}	RSE
	Haul-out site	1980-2006	2011	2014[b]	2016	2018	2011 vs. 2018				2011 - 2018	
47	Eyjar	-0.087 (0.02)*	14	8	1	36	0.135	157.14%	14.44%	-0.5	0.007 (0.359)ns	1.86
48	South-Bjarnarfjörður	-0.022 (0.04)ns	5	5	2	17	0.175	240.00%	19.10%	-0.31	0.106 (0.194)ns	1.00
49	Furufjörður	-0.037 (0.03)ns	8	NA	54.5	16	0.099	100.00%	10.41%	-0.349	0.154 (0.221)ns	1.13
50	Drangar-Drangavík-Bjarnavík	-0.027 (0.02)ns	37.5	33	22.5	15	-0.131	-60.00%	-12.27%	0.86	-0.13 (0.030)*	0.157
51	Drangsnes	0.039 (0.02)ns	0	NA	11	20	NA	NA	NA	0.967	0.544 (0.071)ns	0.362
52	Eyjarey	-0.057 (0.02)*	20	NA	0	12	-0.073	-40.00%	-7.04%	-0.738	-0.201 (0.517)ns	2.64
53	Vatnsnes	-0.018 (0.03)ns	556.5	76	179.5	256	-0.111	-54.00%	-10.50%	-0.336	-0.091 (0.185)ns	0.955
54	Heggstaðanes	-0.009 (0.03)ns	43	60	11.25	62	0.052	44.19%	5.37%	-0.48	-0.028 (0.189)ns	0.98
55	Horn - Straumnes	0.006 (0.08)ns	0	NA	0	0	NA	NA	NA	NA	NA	NA
56	Kollafjörður	-0.022 (0.02)ns	53	16	44	74	0.048	39.62%	4.88%	-0.368	0.065 (0.149)ns	0.772
57	Munaðarnessker	0.041 (0.05)ns	3.5	13	5.5	22	0.263	528.57%	30.03%	0.34	0.208 (0.130)ns	0.674
58	Litla Ávík	-0.025 (0.04)ns	24	35	54	37	0.062	54.17%	6.38%	0.276	0.080 (0.055)ns	0.282
59	Ófeigsfjörður	-0.041 (0.04)ns	75	55	35	60	-0.032	-20.00%	-3.14%	-0.119	-0.054 (0.065)ns	0.338
60	Reykjarfjarðarsker	-0.035 (0.05)ns	49.5	23	41.5	0	NA	-100.00%	NA	0.347	-0.545 (0.338)ns	1.75
61	South-Reykjafjörður	-0.026 (0.04)ns	0	NA	7	0	NA	NA	NA	NA	NA	NA
62	Siglufjörður	-0.056 (0.04)ns	0	NA	0	0	NA	NA	NA	NA	NA	NA
63	Sigríðarstaðaós	-0.004 (0.10)ns	211.5	88	82.5	86	-0.129	-59.34%	-12.06%	0.576	-0.129 (0.057)ns	0.295
64	Skagi	-0.036 (0.02)ns	110	NA	52.5	48	-0.118	-56.36%	-11.17%	0.934	-0.124 (0.023)ns	0.117
65	Skjaldarbjarnarvík	-0.019 (0.05)ns	32.5	NA	0	6	-0.241	-81.54%	-21.44%	-0.255	-0.356 (0.461)ns	2.35
66	W-Hrútafjörður	-0.023 (0.03)ns	218.5	66	12	100	-0.112	-54.23%	-10.57%	-0.155	-0.197 (0.255)ns	1.32
	North west total	-0.02 (0.01)ns	1461.5		615.75	867	-0.075	-40.68%	-7.19%	0.20	-0.094 (0.076)ns	0.39

[a]Significance levels: ns = not significant, * significant at the 5%, ** 1 % and *** 0.1%, levels respectively

[b]The 2014 census was only partial, so no total numbers are available.

3.3.5 Northeast

The largest haul-out sites in the Northeast in 2018 were Bakkahlaup and Skjálfandafljót with 50 and 37 seals, respectively. The total number of seals in the area decreased from 209 seals in 2011 to 96 seals in 2018, however no significant overall trend was observed in either of the two periods (1980-2006 and 2011-2018). In general, few harbour seals are found in this area. When analysing the haul-out sites individually, significant negative trends were observed in Melrakkaslétta, Skjálfandafljót and Tjörnes during the earlier period, while no significant trends were observed for any of the haul-out sites in the later period. Both Bakkahlaup and Skjálfandafljót had similar numbers in 2018 as in 2016. In 2011, 164 seals were however observed in Bakkahlaup, but only 15 seals in Skjálfandafljót (Table 7).

Table 7. Trends in abundance of harbour seals for the period 1980-2006 in the North east (Hauksson 2010) described by exponential growth rate (R_{est}), standard error (SE) and significance level[a]. Number of counted animals from censuses in the period 2011-2018. The total change between the years 2011 and 2018 calculated as Mills (2012): exponential growth rate (R_{est}^{Mills}), linear percent change (Δ (%)) and time per capita growth (λ (%)). Total trends for the period 2011-2018 calculated by linear regression models on ln transformed counts: adjusted coefficient of determination (R_{ad}^2), annual growth rate (R_{est}), standard error (SE), significance[a] and residual standard error (RSE).

Tafla 7. *Árlegur veldisvöxtur fjölda landsela fyrir tímabilið 1980-2006, í látrum á Norðausturlandi (R_{est} (SE; staðalfrávik og marktækni[a])). Fjöldi taldra landsela tímabilið 2011-2018. Breyting á milli árana 2011 og 2018 reiknuð með aðferð Mills (2012): veldisvaxtarstuðull (R_{est}^{Mills}), prósentvís breyting (Δ) og ársvöxtur (λ). Heildarbreytingar á timabilinu 2011-2018 metið með línulegri aðhvarfsgreiningu: Aðhvarfsgreiningarstuðull (R_{ad}^2), veldisvaxtrastuðull (R_{est} (SE), marktækni[a]) og staðalfrávik leifa aðhvarfsgreiningarinnar (RSE).*

		R_{est} (SE)^{significance}	Total count				R_{est}^{Mills}	Δ (%)	λ (%)	R_{ad}^2	R_{est} (SE)^{significance}	RSE
	Haul-out site	**1980-2006**	**2011**	**2014[b]**	**2016**	**2018**		**2011 vs. 2018**			**2011 - 2018**	
67	**Bakkahlaup**	-0.017 (0.02)^{ns}	164	NA	53	50	-0.170	-69.51%	-15.61%	0.889	-0.181 (0.044)^{ns}	0.223
68	**Eyjafjörður**	0.027 (0.04)^{ns}	2	NA	0	0	NA	-100.00%	NA	NA	NA	NA
69	**Melrakkaslétta**	-0.072 (0.03)*	21	NA	5	4	-0.237	-80.95%	-21.09%	0.951	-0.246 (0.039)^{ns}	0.199
70	**Skjálfandafljót**	-0.063 (0.02)*	15	NA	31.5	37	0.129	146.67%	13.77%	0.974	0.133 (0.0151)^{ns}	0.077
71	**Tjörnes**	-0.131 (0.05)*	0	NA	0	1	NA	NA	NA	NA	NA	NA
72	**Þistilfjörður**	0.033 (0.09)^{ns}	7	NA	0	4	-0.080	-42.86%	-7.68%	-0.629	-0.166 (0.348)^{ns}	1.775
	North east total	-0.04 (0.01)^{ns}	209	NA	89.5	96	-0.111	-54.07%	-10.52%	0.758	-0.122 (0.046)^{ns}	0.232

[a]Significance levels: ns = not significant, * significant at the 5%, ** 1 % and *** 0.1%, levels respectively

[b]The 2014 census was only partial, so no total numbers are available.

3.3.6 Eastfjords

The largest haul-out site in the Eastfjords in 2018 was Jökla with 303 observed seals, followed by Álftafjörður (133 seals) and Berufjörður (99 seals). An overall significant negative trend was observed between 1980 and 2006, while no overall significant trend was observed for the later period 2011 to 2018. When analysing the haul-out sites individually, a significant positive trend was observed for Berufjörður, while a negative trend was observed for Húsavík. The haul-out site Dalatangi had 27 seals in 2011, but zero in year 2018. In the earlier period, a

negative significant trend was observed in five out of the ten haul-out sites in the Eastfjords. The largest numerical change between 2016 and 2018 occurred in Jökla, where the number of observed seals increased from 243 to 303 seals (Table 8).

Table 8. Trends in abundance of harbour seals for the period 1980-2006 in the Eastfjords (Hauksson 2010) described by exponential growth rate (R_{est}), standard error (SE) and significance level[a]. Number of counted animals from censuses in the period 2011-2018. The total change between the years 2011 and 2018 calculated as Mills (2012): exponential growth rate (R_{est}^{Mills}), linear percent change (Δ (%)) and time per capita growth (λ (%)). Total trends for the period 2011-2018 calculated by linear regression models on ln transformed counts: adjusted coefficient of determination (R_{ad}^2), annual growth rate (R_{est}), standard error (SE), significance[a] and residual standard error (RSE).

Tafla 8. *Árlegur veldisvöxtur fjölda landsela fyrir tímabilið 1980-2006, í látrum á Austurlandi (R_{est} (SE; staðalfrávik og marktækni[a])). Fjöldi taldra landsela tímabilið 2011-2018. Breyting á milli árana 2011 og 2018 reiknuð með aðferð Mills (2012): veldisvaxtarstuðull (R_{est}^{Mills}), prósentvís breyting (Δ) og ársvöxtur (λ). Heildarbreytingar á timabilinu 2011-2018 metið með línulegri aðhvarfsgreiningu: Aðhvarfsgreiningarstuðull (R_{ad}^2), veldisvaxtrastuðull (R_{est} (SE), marktækni[a]) og staðalfrávik leifa aðhvarfsgreiningarinnar (RSE).*

		R_{est} (SE)[significance]	Total count				R_{est}^{Mills}	Δ (%)	λ (%)	R_{ad}^2	R_{est} (SE)[significance]	RSE
	Haul-out site	**1980-2006**	**2011**	**2014[b]**	**2016**	**2018**	**2011 vs. 2018**				**2011 - 2018**	
73	**Álftafjörður**	-0.043 (0.02)^{ns}	118.5	NA	130.5	133	0.016	12.24%	1.66%	0.968	0.017 (0.002)^{ns}	0.011
74	**Bakkaflói**	-0.071 (0.02)*	2	NA	2	10	0.230	400.00%	25.85%	0.038	0.186 (0.179)^{ns}	0.911
75	**Berufjörður**	0.058 (0.04)^{ns}	40	NA	72	99	0.129	147.50%	13.82%	0.99	0.127 (0.009)*	0.047
76	**Breiðdalsvík**	-0.085 (0.02)*	9	NA	0	17	0.091	88.89%	9.51%	-0.99	-0.038 (0.520)^{ns}	2.651
77	**Dalatangi**	-0.097 (0.01)*	27	NA	1	0	NA	-100.00%	NA	0.972	-0.587 (0.069)^{ns}	0.354
78	**Eystrahorn**	-0.143 (0.03)*	0	NA	2	0	NA	NA	NA	NA	NA	NA
79	**Héraðsflói**	-0.008 (0.02)^{ns}	71.5	NA	72.5	56	-0.035	-21.68%	-3.43%	-0.057	-0.028 (0.029)^{ns}	0.149
80	**Húsavík**	0.044 (0.07)^{ns}	14	NA	7	5	-0.147	-64.29%	-13.68%	0.996	-0.146 (0.007)*	0.034
81	**Jökla**	0.019 (0.03)^{ns}	248.5	NA	243	303	0.028	21.93%	2.87%	-0.146	0.022 (0.026)^{ns}	0.13
82	**Loðmundar-Seyðisfjörður**	-0.111 (0.04)*	0	NA	0	1	NA	NA	NA	NA	NA	NA
	Eastfjords total	**-0.01 (0.01)***	530.5	NA	528	624	0.023	17.62%	2.35%	-0.011	0.018 (0.019)^{ns}	0.096

[a]Significance levels: ns = not significant, * significant at the 5%, ** 1 % and *** 0.1%, levels respectively

[b]The 2014 census was only partial, so no total numbers are available.

3.3.7 South coast

The largest haul-outs on the South coast were Fjallsárós with 366 seals, followed by Öræfi, Skaftárós and Kúðafljót with 280, 130, 118 observed seals respectively. On the South coast, an overall significant negative trend was observed between 1980 and 2006, while no overall significant trend was observed for the later period (2011-2018). The number of observed seals was, however, higher in 2018 (1084 seals) compared to 2011 (709 seals) and 2016 (445.5 seals). When analysing the haul-out sites individually, a significant positive trend was observed for Selvogur between 2011 and 2018. In the earlier period, significant decreasing trends were observed in six of the 16 haul-out sites. Interestingly, in several of the haul-out

sites where colonies were observed in 2018 (Skaftárós, Vigur í Lóni and Papós and skerries) no seals were observed in 2016. Further, in Öræfi and Fjallsárós large increases were observed since the 2016 census (Table 9).

Table 9. Trends in abundance of harbour seals for the period 1980-2006 on the South coast (Hauksson 2010) described by exponential growth rate (R_{est}), standard error (SE) and significance level[a]. Number of counted animals from censuses in the period 2011-2018. The total change between the years 2011 and 2018 calculated as Mills (2012): exponential growth rate (R_{est}^{Mills}), linear percent change (Δ (%)) and time per capita growth (λ (%)). Total trends for the period 2011-2018 calculated by linear regression models on ln transformed counts: adjusted coefficient of determination (R_{ad}^2), annual growth rate (R_{est}), standard error (SE), significance[a] and residual standard error (RSE).

Tafla 9. *Árlegur veldisvöxtur fyrir tímabilið 1980-2006, í látrum á Suðurlandi (R_{est} (SE; staðalfrávik og marktækni[a])). Fjöldi taldra landsela tímabilið 2011-2018. Breyting á milli árana 2011 og 2018 reiknuð með aðferð Mills (2012): veldisvaxtarstuðull (R_{est}^{Mills}), prósentvís breyting (Δ) og ársvöxtur (λ). Heildarbreytingar á timabilinu 2011-2018 metið með línulegri aðhvarfsgreiningu: Aðhvarfsgreiningarstuðull (R_{ad}^2), veldisvaxtrastuðull (R_{est} (SE), marktækni[a]) og staðalfrávik leifa aðhvarfsgreiningarinnar (RSE).*

		R_{est} (SE)^{significance}	Total count				R_{est}^{Mills}	Δ (%)	λ (%)	R_{ad}^2	R_{est} (SE)^{significance}	RSE
	Haul-out site	**1980-2006**	**2011**	**2014[b]**	**2016**	**2018**	**2011 vs. 2018**			**2011 - 2018**		
83	**Skaftárós**	-0.105 (0.04)*	90.5	NA	0	130	0.052	43.65%	5.31%	-0.933	-0.158 (0.848)ns	4.325
84	**Eyrarbakki/Stokkseyri**	-0.030 (0.05)ns	6	NA	11	16	0.140	166.67%	15.04%	0.977	0.136 (0.015)ns	0.075
85	**Fjallsárós**	-0.067 (0.04)ns	219.5	NA	219.5	366	0.073	66.74%	7.58%	0.0385	0.059 (0.057)ns	0.290
86	**Hestgerðirlón**	-0.142 (0.05)*	12	NA	8.5	16	0.041	33.33%	4.20%	-0.897	0.020 (0.086)ns	0.436
87	**Öræfi**	0.019 (0.11)ns	164.5	NA	48	280	0.076	70.21%	7.89%	-0.994	0.014 (0.251)ns	1.28
88	**Hornafjörður**	-0.185 (0.17)ns	6	NA	28.5	6	0.000	0.00%	0.00%	-0.885	0.060 (0.242)ns	1.235
89	**Hrollaugseyjar-Tvísker**	0.017 (0.06)ns	0	NA	4	0	NA	NA	NA	NA	NA	NA
90	**Kúðafljót**	-0.062 (0.01)*	95.5	39	87	118	0.030	23.56%	3.07%	-0.377	0.046 (0.11)ns	0.569
91	**Landeyjarsandur**	-0.192 (0.04)*	1	NA	0	0	NA	-100.00%	NA	NA	NA	NA
92	**Markarfljót**	-0.067 (0.02)*	14.5	7	5	39	0.141	168.97%	15.18%	-0.3665	0.091 (0.206)ns	1.063
93	**Papós and skerries**	-0.065 (0.05)ns	12.5	NA	0	30	0.125	140.00%	13.32%	-0.997	-0.023 (0.598)ns	3.047
94	**Vestmannaeyjar**	-0.093 (0.05)ns	2	NA	0	0	NA	-100.00%	NA	NA	NA	NA
95	**Vígur í lóni**	-0.154 (0.04)*	7.5	NA	0	21	0.147	180.00%	15.85%	-0.998	0.015 (0.535)ns	2.73
96	**Þjórsá**	-0.009 (0.02)ns	62	10	9	29	-0.109	-53.23%	-10.29%	-0.227	-0.131 (0.197)ns	1.019
97	**Selvogur**	-0.054 (0.04)ns	4	NA	19	30	0.288	650.00%	33.35%	0.992	0.292 (0.018)*	0.094
98	**Ölfusá**	-0.011 (0.06)ns	11.5	10	4	3	-0.192	-73.91%	-17.47%	0.816	-0.209 (0.055)ns	0.286
	South coast total	**-0.07 (0.01)***	709		445.5	1084	0.061	52.89%	6.25%	-0.873	0.031 (0.119)ns	0.609

[a]Significance levels: ns = not significant, * significant at the 5%, ** 1 % and *** 0.1%, levels respectively

[b]The 2014 census was only partial, so no total numbers are available.

4. Discussion

4.1 Status of the population and population trends

Globally, the current status of harbour seal populations vary, with some regions experiencing declines while populations in other areas are increasing (Lowry 2016). The census of 2018 revealed a total count of 4,168 harbour seals around the Icelandic coast, which resulted in an estimated population size of 9,434 animals. The estimated population size was 72% smaller than the first estimate from 1980, despite an observed increase of 23% since the last census was undertaken in 2016. The results presented in the current report suggest a 94% probability that the population is below the threshold level of the governmentally issued management objective for a minimum population size of 12,000 animals (NAMMCO 2006). The population estimate reported here is 21% lower than this management objective. The status of the harbour seal population on the Icelandic national redlist should be re-evaluated based on the results presented in this report. It should be underlined that since the population is below the management objective, actions should be taken to improve the conservation status of the population.

As reported, the Icelandic harbour seal population is clearly smaller now than when censuses commenced four decades ago. The trend analysis suggests that the four decades can be divided into a period of decline from 1980 to 2006 and a period of stability at a minimal stock level from 2006 to 2018. In the earlier period (1980-2006), a highly significant decline was observed for the population in total, most of the decline occurring in the first decade of the period (1980-1989). The coastal areas Faxaflói, Eastfjords and South coast all experienced significant declines during the earlier period. When the recent period (2011-2018) was examinated, no significant trend was found for the whole coastline in total (whole population), nor for any of the seven costal areas separately (Figure 1). Overall, historically low numbers were observed in the census of 2016, but already in the partial census of 2014, indications of a severe decrease had been observed (Granquist et al. 2014, Þórbjörnsson et al. 2017). However, due to the observed increase between 2016 and 2018, the declining trend did not seem to continue, which indicates that the population currently seems to fluctuate around a historical minimum stock size. Between the last two censuses in 2016 and 2018 the discrete time per capita growth rate (λ) was estimated at 11.04%. If the high growth rate persists, the Icelandic harbour seal population would reach the management objective of 12 thousand animals in only 3 years.

When local trends in the different haul-out sites were examinated, very few significant trends were observed for the period 2011-2018. No significant trends were found for this period in any of the individual haul-out sites in Faxaflói and the North-east coast. Significant trends

were observed in one haul-out site in Breiðafjörður (decreasing trend in Skarðsströnd), in the Westfjords (increasing trend in Mjóifjörður), in the North-west (decreasing trend in the area Drangar, Drangavík, Bjarnavík) and on the South coast (increasing trend in Selvogur). In the Eastfjords, significant trends were observed in two haul-out sites (decreasing trend in Húsavík and increasing trend in Berufjörður). When figures observed in 2018 were compared to 2016, the largest change occurred on the south coast where the number of observed seals more than doubled. The reason for this is unclear but random disturbance could have caused the seals to move into the water prior to the overflight in 2016, which would reduce the possibility for observers to detect them. Due to increased tourism on the Icelandic coast, human disturbance has the potential to affect the counting results, especially since only one overflight is made in most of the survey areas. Two to three overflights stabilize the results of aerial surveys. Hence, to increase the significance of the results, three overflights in each survey-year (Teilman et al. 2010) is recommended (see section 4.3).

The distribution of harbour seals around the coastal areas of Iceland seems to be rather stable, supporting earlier findings of strong site fidelity of harbour seals (Yochem et al. 1987). The same haul-out sites have been occupied almost every survey-year. This is in accordance with research on the movements of individual harbour seals showing that harbour seals are loyal to their breeding, resting and moulting-sites (Thompson 1989).

4.2 Factors affecting population trends

Factors contributing to the status and wellbeing of the Icelandic harbor seal population are poorly understood, although numerous factors have potential to contribute to fluctuations in the population, such as hunting and bycatch, prey availability, environmental changes, diseases and anthropogenic disturbance (Granquist et al. 2014, Lowry 2016).

4.2.1 Seal removals: hunting, culling and bycatch

Traditionally, harbour seals were considered an important resource and were hunted for consumption or utilization of skins, but today hunting for subsistence has declined to low numbers in Iceland and the fur trade has ceased (Marine Research Institute 2016). In the 1980s, a bounty system for harbour seals was initiated with the purpose of decreasing the seal population to reduce interactions with the fishing industry as well as to prevent spreading of the sealworm (*Pseudoterranova decipiens*) of which harbour seals are the final host. The parasite can end up in the flesh of fish, mainly in the economically important Atlantic cod, and thereby reduce the value of the fish (Ólafsdóttir 2001; Mcclelland 2007). Recently, the main direct removal of harbour seals is culling in the estuaries of salmonid rivers, where the aim is to reduce the potential effect that harbour seal predation is believed to have on the economically valuable salmon, trout and charr populations (Granquist 2016; Granquist and

Hauksson 2016b). No quota or compulsory registration system pertaining to seal hunting/culling has yet been established in Iceland. The lack of such a system complicates hunting management and data collection on hunting statistics (Granquist and Hauksson 2016c).

The data presented in the current report shows that the largest decline in the harbour seal population occurred in the early period (1980-2006), especially in the beginning, coinciding with the period when seals were hunted and culled to a larger extent than in recent years. Although direct exploitation (hunting and culling) has largely decreased in the latter period (2011-2018), a large mortality risk caused by human activities is bycatch in fishing gear (Þorbjörnsson et al. 2017, Marine and Freshwater Research Institute 2018), mainly in the lumpsucker and cod gillnet fisheries. According to Icelandic law, all by-caught marine mammals and birds should be reported to authorities. However, recently published data suggests that only a portion of by-caught seals are reported by the industry (Ólafsdóttir 2010, Marine and Freshwater Research Institute 2018). Although hunting and bycatch have been mentioned as potential population limiting factors (Granquist et al. 2011), data to quantify the magnitude of affected animals is scarce and improved data collection to better understand anthoroplogical effects on marine populations is advised.

4.2.2 Other factors

Little is known about how environmental changes—such as increased sea temperature and variations in, for example, prey availability—affects population trends. Although harbour seals are considered generalist predators, and hence may not be as vulnerable to changes in stocks of particular prey species as specialist predators, the effects of variation in prey availability on the Icelandic harbour seal population need to be further investigated.

Increasing tourism in Iceland has led to an increase in people visiting remote areas, which can possibly disturb harbour seals during sensitive periods such as the moulting and breeding periods. It is well known that anthropogenic disturbance, for example due to seal watching activities, can have an impact on seals physiologically, as well as affect their behaviour and distribution, which in turn may reduce the fitness of the seals, both at an individual and at a population level (see for example Granquist and Sigurjónsdóttir 2014). Such effects should be kept in mind when managing seal populations in Iceland.

In addition to the factors described above, which have the potential to affect population trends directly, there is a pressing need to increase knowledge of factors pertaining to stock identity, population demographics, as well as components indirectly affecting fecundity and pup survival. Very scarce knowledge on these subjects exists for the Icelandic harbour seal population, which complicates population management.

4.3 Methodological considerations

A limitation to the methods used when estimating the Icelandic harbour seal population size is that the estimate is built on a single aerial survey of the Icelandic coastline, which impedes highly accurate population estimates and trend analyses. Due to varios reasons, seals might be overseen by observers during an overflight, for example due to unexpected temporal local visuability difficulties (such as sunshine or fog) which may ultimately bias the population estimate. Disturbance, for example anthropogenic disturbance due to the increase in the Icelandic tourism industry, can also cause seals to temporally move into the water and be totally submerged, which reduces the possibility to detect the seals from air. A higher survey frequency with three replicates each time would provide more accurate results and be better suited to detect population trends because of increased statistical power (Teilmann et al. 2010). For all conducted harbour seal censuses except the census in 2011, funding has been unavailable for this procedure. The current monitoring schedule, involving only one overflight of the coastline every other year, has been deemed to facilitate a sufficient balance of cost and statistical power. To increase the significance of our results, annual surveys or bi-annual surveys with three replicates is recommended.

The fact that pinniped censuses are based on the number of hauled-out animals presents a potential bias since a portion of the population can be submerged during the time of the overflight. Several factors that are known to affect haul-out patterns of harbour seals including the weather (Kreiber and Barrette 1984, Watts 1992), tidal cycle (Schneider and Payne 1983, Thompson and Miller 1990, Granquist and Hauksson 2016a), time of day and often annual variations have been described (Stewart 1984, Thompson 1989, Thompson et al. 1989, Granquist and Hauksson 2016a). To minimise the effects of these factors, the survey flight is only conducted in standardized weather and tidal conditions (see methods). Further, to compute a population estimate, a correction factor was applied to account for environmental factors, visibility from air and submerged animals. The population estimate is hence in part based on the validity of the correction factor used. Correction factors have not yet been optimized for Icelandic conditions, but since the same correction factors have been used since 2006, the current estimate is as comparable to all estimates made since 2006 as currently is possible. Further consideration should be made to develop correction factors based on Icelandic conditions.

4.4 Future prospective

The poor understanding of factors affecting the population trends, combined with the sensitive conservation status of the Icelandic harbour seal population, calls for further assessment of mortality by direct and indirect removals. However, management of the

harbour seal population is not only related to removals. An important aspect is increased research regarding anthropogenic disturbace and assessment of the need for the establishment of protected areas with absence of disturbance encompassing important haul-out sites. A few of the important haul-out sites are remote and already difficult to access, except by helicopter. Such places already form natural seal sanctuary sites. Further, we recommend future research regarding factors affecting population fluctuations, such as climate change and variation in prey availability. Moreover, increased monitoring of population demographic factors, pup production, pup survival, fecundity and age distribution in the population is urgent.

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