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Aerial census of the Icelandic harbour seal (*Phoca vitulina*) population in 2016: Population estimate, trends and current status / *Landselstalning 2016: Stofnstærðarmat, sveiflur og ástand stofns*

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Harbour seals hauling-out at Sigríðarstaðaós estuary on the South-Eastern Vatnsnes Peninsula, North-West Iceland. Picture: Jóhann Garðar Þorbjörnsson.
Landselir liggja í látri við Sigríðastaðaós á suð-austanverðu Vatnsnesi, norðvesturlandi Íslands. Mynd: Jóhann Garðar Þorbjörnsson

Haf- og vatnarannsóknir

Marine and Freshwater Research in Iceland

HAFRANNSÓKNASTOFNUN
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Titill: Aerial census of the Icelandic harbour seal (*Phoca vitulina*) population in 2016: Population estimate, trends and current status / *Landselstalning 2016: Stofnstærðarmat, sveiflur og ástand stofns*		
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Ágrip:

Til þess að fylgjast með stöðu og breytingum í íslenska landselsstofninum er mikilvægt að framkvæma regluleg stofnstærðarmöt. Á Íslandi hófst framkvæmd slíkra mata árið 1980, og hafa þau gefið til kynna fækkun í íslenska landselsstofninum. Í þessu verkefni fór fram ellefta stofnstærðarmat landsela síðan 1980, með það að markmiði að meta núverandi stofnstærð, kanna sveiflur og verndunarstöðu landsselsstofnsins. Landselir voru taldir á allri strandlengju landsins úr Cessna 207 yfirþekju og voru samtals 3.383 selir taldir. Áætluð stofnstærð gaf 7.652 seli. Niðurstöður gefa til kynna að fækkun hafi átt sér stað í stofni landsela á Íslandi. Stofninn er nú 77% minni en þegar hann var fyrst metinn árið 1980 og 32% minni en árið 2011, þegar stofnstærðarmat yfir alla strandlengju landsins var síðast framkvæmt. Samkvæmt stjórnunarmarkmiðum íslenska landselsstofnisns skal halda stofninum í 12.000 selum en niðurstöður okkar gefa til kynna að hann sé nú um 36% minni en sem því nemur. Stofninn væri nú skilgreindur sem "Endangered" skv. verndarflokkun International Union for the Conservation of Nature (IUCN), og "Critical" samkvæmt verndarflokkun Working Group on Harp and Hooded seals (WGHARP). Þó lítið sé vitað um mögulega orsakaþætti þessarar fækkunar er líklegt að meðafli í fiskveiðum og beinar selveiðar geti hoggið djúp skörð í stofninn. Sökum þess að mikil fækkun virðist nú eiga sér stað er sérstaklega mikilvægt að meta mögulega orsakaþætti í nákominni framtíð.

Lykilorð:

Landselur, selir, stofnstærðarmat, phoca vitulina, harbour seal

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Töfluskrá

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Abstract

Regular harbour seal population censuses are important so that knowledge of the population status and trends can be obtained. In Iceland, aerial population censuses have been conducted from 1980, and have revealed a declining trend 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 11th time. Further, we examined the population trends and the conservation status of the population. Harbour seals were counted from a Cessna 207 airplane, resulting in a total number of 3,383 individuals. An estimated population size was acquired by applying correction factors, yielding a total population of 7,652 animals. The 2016 census indicated a continuing decline in the harbour seal population. The estimated population size was 77% smaller than when first estimated in 1980, and 32% smaller than in 2011, when the last complete population census was undertaken. In addition, the estimate was 36% lower than a government issued management objective for the minimum population size of harbour seals in Iceland. According to criteria used by the International Union for Conservation of Nature and Natural Resources (IUCN), the conservation status of the population should be considered as “Endangered” and according to the criteria put forward by the ICES Working Group on Harp and Hooded Seals (WGHARP) it should be considered as “Critical”. Although factors contributing to the observed population decline are poorly understood, by-catch and direct-hunts are likely population limiting factors. Given a recent population decline, it is pressing that mortality by direct and indirect seal removal, and other potential factors, are further assessed in the future.

Útdráttur:

Landselstalning 2016: Stofnstærðarmat, sveiflur og ástand stofns

Til þess að fylgjast með stöðu og breytingum í íslenska landselsstofninum er mikilvægt að framkvæma regluleg stofnstærðarmöt. Á Íslandi hófst framkvæmd slíkra mata árið 1980, og hafa þau gefið til kynna fækkun í íslenska landselsstofninum. Í þessu verkefni fór fram ellefta stofnstærðarmat landsela síðan 1980, með það að markmiði að meta núverandi stofnstærð, kanna sveiflur og verndunarstöðu landsselsstofnsins. Landselir voru taldir á allri strandlengju landsins úr Cessna 207 yfirþekju og voru samtals 3.383 selir taldir. Áætluð stofnstærð gaf 7.652 seli. Niðurstöður gefa til kynna að fækkun hafi átt sér stað í stofni landsela á Íslandi. Stofninn er nú 77% minni en þegar hann var fyrst metinn árið 1980 og 32% minni en árið 2011, þegar stofnstærðarmat yfir alla strandlengju landsins var síðast framkvæmt. Samkvæmt stjórnunarmarkmiðum íslenska landselsstofnisns skal halda stofninum í 12.000 selum en niðurstöður okkar gefa til kynna að hann sé nú um 36% minni en sem því nemur. Stofninn væri nú skilgreindur sem "Endangered" skv. verndarflokkun International Union for the Conservation of Nature (IUCN), og "Critical" samkvæmt verndarflokkun Working Group on Harp and Hooded seals (WGHARP). Þó lítið sé vitað um mögulega orsakaþætti þessarar fækkunar er líklegt að meðafli í fiskveiðum og beinar selveiðar geti hoggið djúp skörð í stofninn. Sökum þess að mikil fækkun virðist nú eiga sér stað er sérstaklega mikilvægt að meta mögulega orsakaþætti í nákominni framtíð.

1. Introduction

Harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*) are the only pinniped species that breed in Iceland. Harbour seals are economically valuable in the context of Iceland´s growing wildlife watching industry (Granquist and Nilsson 2016), but have also been perceived as a nuisance for fisheries (Ólafsdóttir 2001; Hauksson 2005; Mcclelland 2007; Marine Research Institute 2015). As such, information pertaining to the harbour seal population size and trends is important.

1.1 Previous trends in the Icelandic harbour seal population

Aerial population censuses for Icelandic harbour seals have been conducted since 1980, when the population was estimated to be around 33,000 animals (Hauksson and Einarsson 2010). Since 1980, ten complete coast censuses have been conducted at irregular intervals. For each successive census, the harbour seal population size has exhibited a declining trend. In 2006, Icelandic authorities put forward a management objective regarding the Icelandic harbour seal population stating that the population should not decrease below 12,000 animals and if that occurs, actions should be taken to balance the population and minimize further declines (NAMMCO 2006). During the most recent complete census, in 2011, a total of 4,983 harbour seals were counted in Iceland, which when correction factors were applied provided an estimate of 11-12,000 animals (Granquist et al. 2011; NAMMCO CSWG 2016). In 2014, a partial census was conducted, with only the largest harbour seal haul-out sites surveyed. At these selected sites, the census indicated an annual decline of 28.55% in the period from 2011-2014 (Granquist et al. 2014). The numbers from the censuses of 2011 and 2014 suggest that the Icelandic harbour seal population has approached the minimal population size presented in the management objective. This underlined the need for a new full census survey.

1.2 Seal removals

Harbour seals are widely distributed throughout the Northern Hemisphere, breeding in both the North Pacific and North Atlantic Oceans. Numerous factors are thought to contribute to fluctuations in harbour seal populations, such as prey availability, environmental changes, disease, hunting and by-catch (Granquist et al. 2014, Lowry 2016). In Iceland, it is unknown how these factors can affect the harbour seal population, although hunting and by-catch have been suggested as population limiting factors (Hauksson and Einarsson 2010; Granquist et al. 2011).

No quota or compulsory registration system pertaining to seal hunting has yet been established in Iceland. Members of the Seal Farmers Union who traditionally hunt harbour seals to utilize the meat or skin can voluntarily report catches to the union. Other seal hunting data is obtained by the

Marine and Freshwater Research Institute by directly contacting hunters (Granquist and Hauksson 2016a).

Traditionally, harbour seals were hunted for consumption or for their skins, but today hunting for subsistence has declined in Iceland and the fur trade has ceased (Marine Research Institute 2016). Between 1982 and 1995 a bounty system for harbour seals was in place to prevent spread of the seal worm (*Pseudoterranova decipiens*) to the economically important Atlantic cod, since harbour seals act as intermediate hosts for this parasite (Ólafsdóttir 2001; Mcclelland 2007). Recently, hunting has mainly occurred in estuaries of salmonid rivers with the aim to reduce the potential effect that harbour seal predation is believed to have on salmon, trout and charr populations. In 2015, a total catch of 159 seals were reported and 82% of these seals were hunted around salmon angling river estuaries. However, recent scientific studies suggest that salmon, trout and charr are not important prey in the diet of harbour seals in Iceland (Granquist 2016; Granquist and Hauksson 2016b).

In addition to hunting, by-catch may also affect the Icelandic seal populations (Hauksson and Einarsson. 2010). According to Icelandic law, all by-caught animals should be reported to authorities, although it is speculated that only a proportion of by-caught seals get reported (Ólafsdóttir 2010).

1.3 Objective

To obtain successful management of the Icelandic harbour seal population, it is important to regularly monitor population trends. The objective of the present census was to estimate the Icelandic harbour seal population for the 11th time, based on a complete coast aerial count, and to monitor ongoing population trends.

2. Methods

2.1. Aerial surveys

In the present census, the whole coastline of Iceland was covered a single time in a Cessna 207 airplane, between the 26th of July and the 2nd of September 2016. This period was chosen to coincide with the peak of the harbour seal moulting season in Iceland (Granquist and Hauksson 2016c). Small groups (<30 seals) and individual seals were counted via direct count by observers in the airplane. Larger groups (>30 seals) 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 and +/- three hours from low tide.

To obtain an exact comparison to results from previous censuses, the definition of haul-out sites and areas were identical to definitions used in previous censuses (Figure 1) (Hauksson 2010).

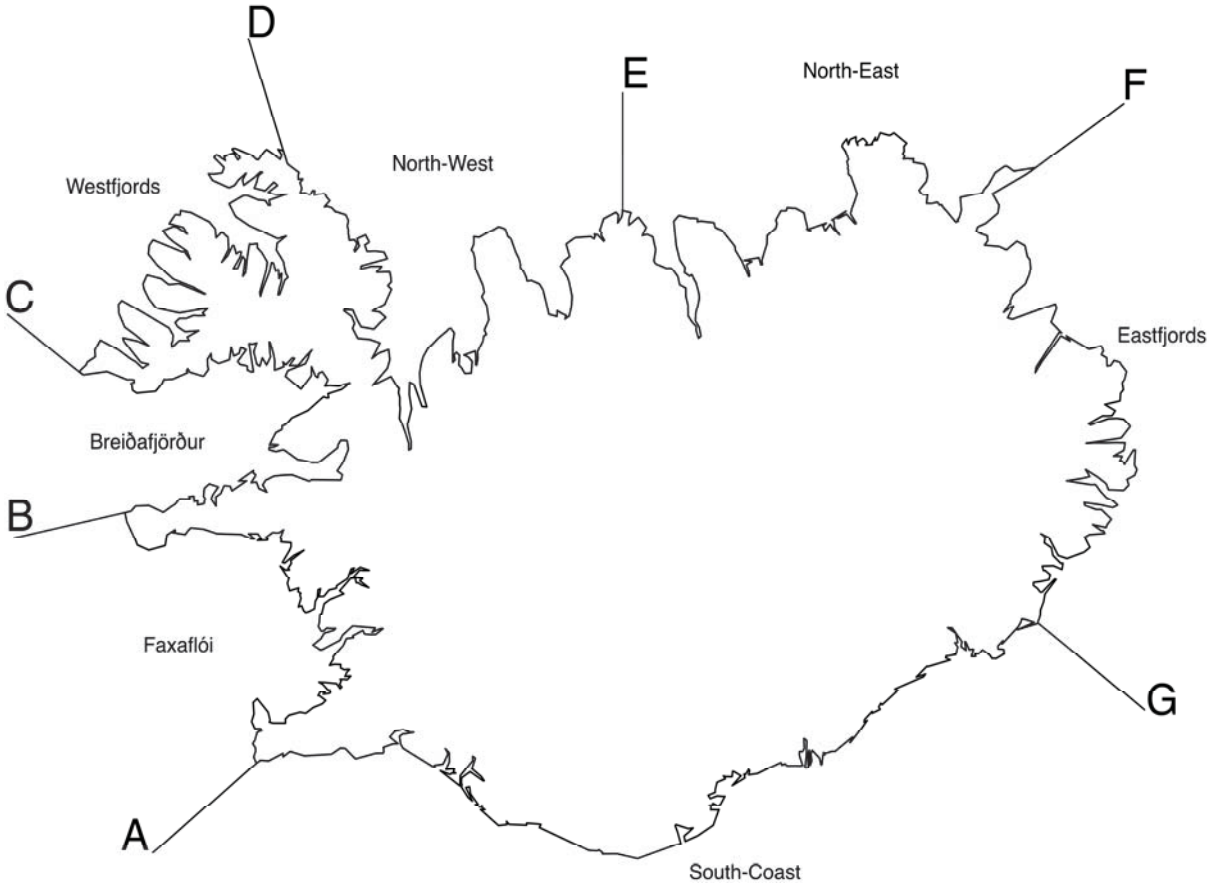

Figure 1. A map of Iceland with separate sections of the country labeled. The area from A (Reykjanestá) to B (Öndverðanes) is defined as Faxaflói, area B (Öndverðarnes) to C (Bjargtangar) is defined as Breiðafjörður, area C (Bjargtangar) to D (Hornbjarg) is defined as the Westfjords, area D (Hornbjarg) to E (Siglunes) is defined as the North-West, area E (Siglunes) to F (Fontur) is defined as the North-East, area F (Fontur) to G (Eystrahorn) is defined as the Eastfjords and area G (Eystrahorn) to A (Reykjanestá) is defined as the South-Coast.

***Mynd 1**. Kort af Íslandi með mismunandi svæðum landsins merkt inn. Svæði frá A (Reykjanestá) til B (Öndverðanes) er skilgreint sem Faxaflói, Svæði B Öndverðanes til C Bjargtangar er skilgreint sem Breiðafjörður, svæði C (Bjargtangar) til D (Hornbjarg) er skilgreint sem Vestfirðir, svæði D (Hornbjarg) til E (Siglunes) er skilgreint sem Norðvesturland, svæði E (Siglunes) til F (Fontur) er skilgreint sem Norðausturland, svæði F (Fontur) til G (Eystrahorn) er skilgreint sem Austfirðir og svæði G (Eystrahorn) til A) (Reykjanestá) er skilgreint sem Suðurströnd.*

2.2. Numerical analysis

When values had been obtained through direct counts by both the assistant and main observer, the higher value was used. When photographs had been taken, the number of seals in the photographs was counted by two individual observers. The resulting mean of these two counts was used for that area.

The frequency of different haul-out group sizes was assessed out of all direct counts. To estimate the population size of Icelandic harbour seals, the total number of counted animals was multiplied by 10,000 normally distributed correction factors with a mean of 2.26 and SD of 0.41, to obtain 10,000 normally distributed population estimates. The correction factors utilized were identical to those used in previous harbour seal censuses since 2006 for comparative purposes (Hauksson and Einarsson 2010). The 95% confidence interval (CI) was calculated for the population distribution by computing the 2.5 and 97.5 percentiles of the distribution. The following equations were then used to calculate the total population trends in the period between 1980 and 2016, and at all haul- out sites in the period between 2011 and 2016:

- The estimated annual growth rate (r_{est}) was calculated as (Mills 2012)

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

- Linear percent change was calculated as

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

- Geometric growth rate (λ) was calculated as (Mills 2012):

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

Nlast: The most recent value

Nfirst: The earlier value

ΔT: Total duration of survey

λ: Geometric growth rate

In addition to the above, a linear regression model was used to assess the trend in the population size between 1980-2016 and in the number of counted animals at sites that were surveyed in 2011, 2014 and 2016. For this, the population sizes and number of counted animals were *log* transformed. All analysis was conducted in Microsoft Excel for Mac (Microsoft Corporation. Version 14.3.0. 2011) and RStudio (RStudio. Version 3.3.1. 2016).

3. Results

3.1 Harbour seal population on the Icelandic coastline

The total number of hauled-out harbour seals counted on the entire Icelandic coastline, based on direct and photographic counts, was 3,383. By multiplying this value with 10,000 normally distributed correction factors, a normal population distribution with mean 7,652 (SD: 1.341) was acquired. This yielded an estimated total population size of 7,652 animals (CI: 95% low: 4.995; 95% high: 10.310) in 2016 (figure 2).

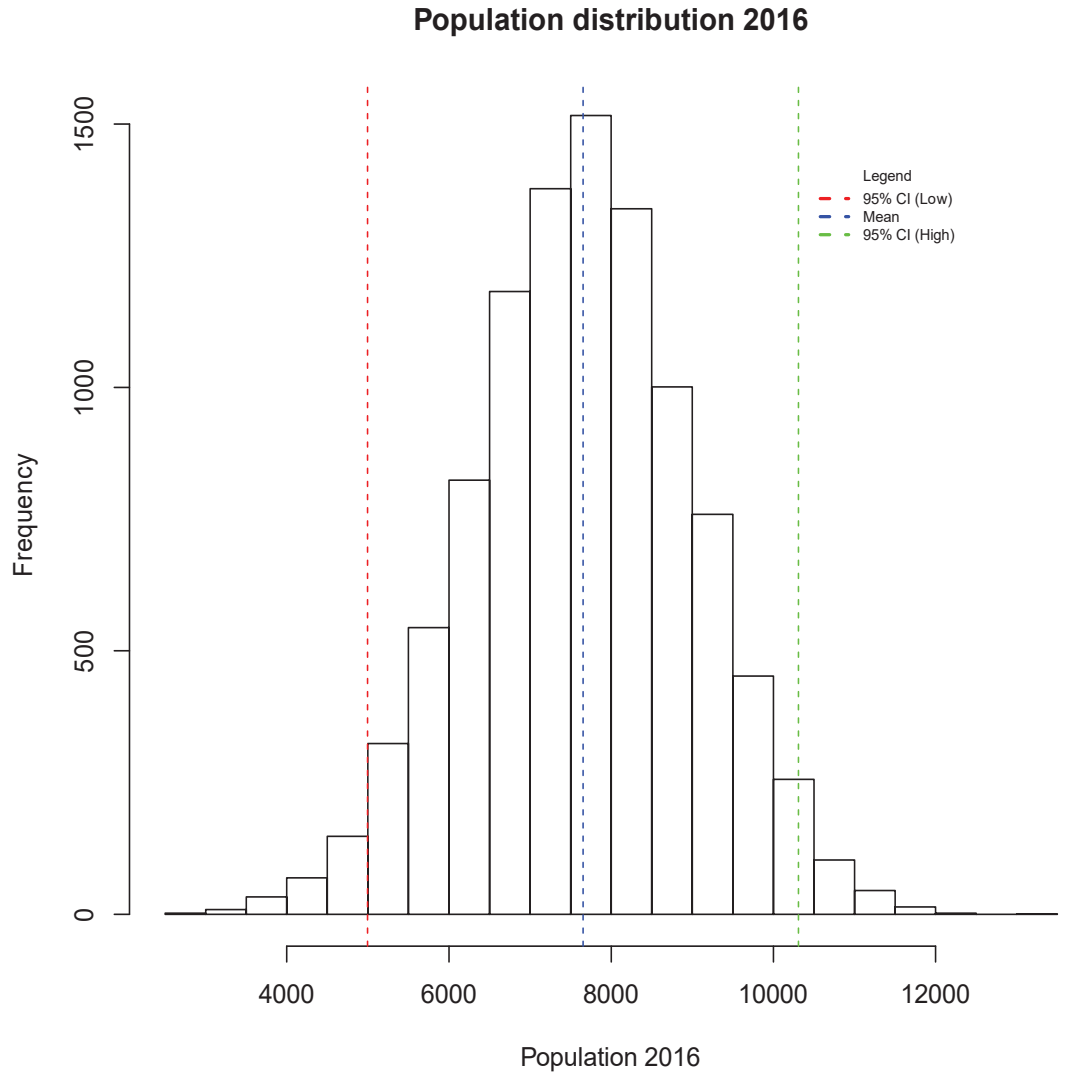

Figure 2. A normal distribution showing the number of counted seals on the whole coastline of Iceland, multiplied by 10.000 normally distributed correction factors. The mean value (blue line) and the 95% confidence intervals (95% CI low (red line)) and (95% CI high (green line)), are shown. The estimated population 2016 is the mean value, 7.652.

Mynd 2. *Normaldreifing sem sýnir fjölda talinna sela á strandlengju Íslands, margfaldaðan með 10.000 normaldreifðum leiðréttingarstuðlum. Meðalgildið (blá lína) og 95% öryggismörk (95% CI low (rauð lína) og 95% CI high (græn lína) eru sýnd. Stofnstærðarmat landsselstofnsins árið 2016 byggir á meðaltali dreifingarinnar, 7652.*

The average seal group size was 10.49 (SD=17.36) animals. The most common group size of seals was 2-4 animals (36.60% of the groups) and 8.68% of the groups contained more than 30 seals (table 1).

Table 1. The frequency and percentage of various group sizes of harbour seals counted with direct counts from airplane.

Tafla 1*. Fjöldi og hlutfall ýmissa hópastærða landsela sem taldir voru með beinum talningum úr flugvél*

#Seals	Frequency	Percentage (%)
1	46	17,36
2-4	97	36,6
5-9	47	17,74
10-29	52	19,62
>30	23	8,68

3.2 Population trends 1980-2016

A linear regression model indicated that from 1980 to 2016 a significant decline of 4% annually (R^2=0.68; p=0.001) has occurred in the Icelandic harbour seal population (figure 3).

Based on the 2016 population distribution, there is a 99.99% chance that the population size is below the threshold value of 12,000 animals (P=90%), which was presented in the management objectives by Icelandic authorities as a preferred minimum population size (NAMMCO 2006). The temporal population trends show that the total recorded decline from 1980 to 2016 is 77.04% while the annual geometric growth rate is -4.00%. Trends compared to other years are presented in table 2.

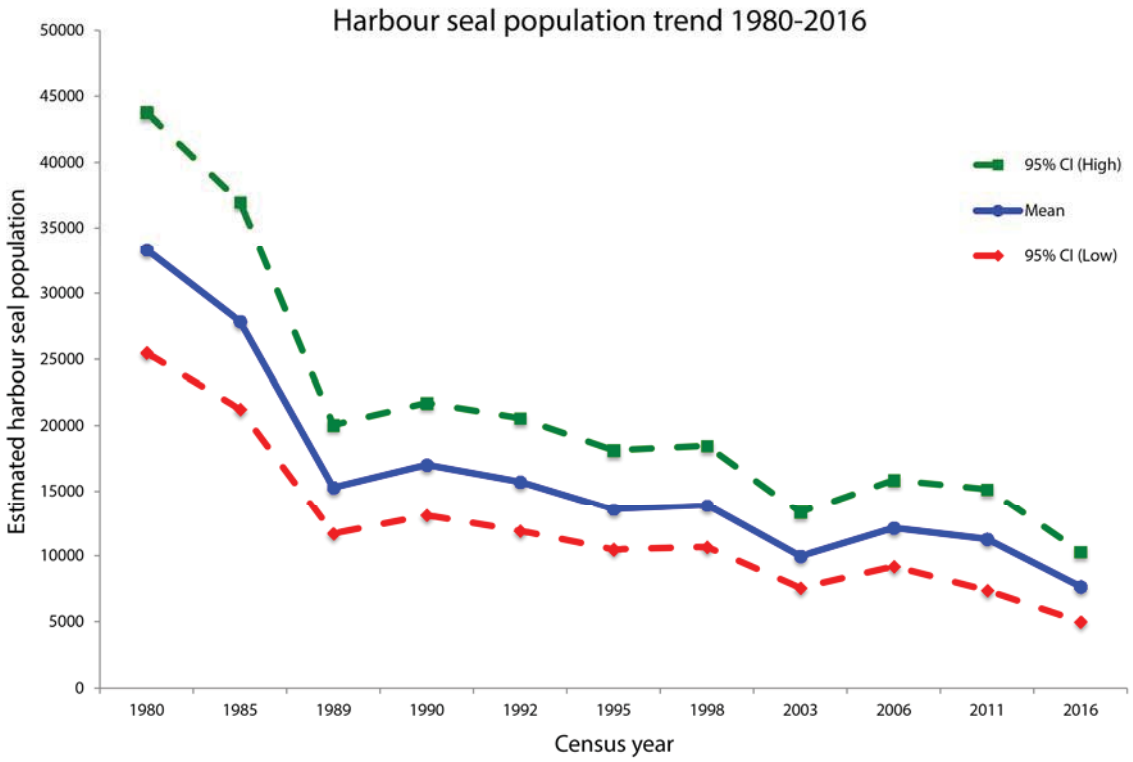

Figure 3. The trend in the Icelandic harbour seal population from 1980 to 2016. The mean values (blue) and the 95% confidence intervals (((95% CI low (red line)) and ((95% CI high (green line))) are shown.

***Mynd 3**. Sveiflur íslenska landselsstofnsins frá árinu 1980 til 2016. Meðalgildi stofnstærðar (blá lína) ásamt 95% öryffismörkum intervals (((95% CI low (rauð lína)) and ((95% CI high (græn lína))) eru sýnd.*

Table 2. Population estimates from 1980 til 2016 and the minimum population size stated in the management objectives by Icelandic authorities (M.o.). The probability of the 2016 population estimate being lower than previous estimates is shown ($P(pop_{2016}<pop_{yr.X})$ in addition to the annual growth rate (R_{est}), the total percent change (Δ (%)) and annual geometric growth rate (λ (%)) from the relevant year compared to the 2016 population.

***Tafla 2**. Stofnstærðarmöt frá 1980 til 2016 og lægsta stofnstærð landsela sem er tiltekinn í stórnunarviðmiðum íslenskra stjórnvalda (M.o.). Líkur þess að stofnstærðin árið 2016 sé lægri en fyrri stofnstærðarmöt eru sýndar ($P(pop2016<popyrX)$ ásamt árlegum vaxtahraða (R_{est}) , hlutfallslegri breytingu (Δ (%)) og árlegum geometrískum vaxtahraða (λ (%)) frá viðeigandi ári sem borið er saman við stofnstærð ársins 2016.*

Survey year	Est. pop.	$P(pop_{2016}<pop_{yearX})$	R_{est}	Δ (%)	λ (%)
1980	33.327	100%	-0,04	-77,04	-4,00
1985	27.871	100%	-0,04	-72,54	-4,08
1989	15.298	100%	-0,03	-49,98	-2,53
1990	17.026	100%	-0,03	-55,06	-3,03
1992	15.731	100%	-0,03	-51,36	-2,96
1995	13.578	99,99%	-0,03	-43,64	-2,69
1998	13.887	99,99%	-0,03	-44,90	-3,26
2003	9.972	96,20%	-0,02	-23,27	-2,02
2006	12.122	99,99%	-0,05	-36,88	-4,50
2011	11.272	99,69%	-0,08	-32,11	-7,45
2016	7.652	-	-	-	-
M.o.	12.000	99,99%	-	-	-

3.3. Counted individuals at haul-out sites

The highest number of harbour seals was found at the West fjords (n=685) and the lowest in North-Eastern Iceland (n=89.5) (table 3). When looking at the trend in counted animals, the highest decline was observed in North-Western Iceland (-57.87%) while the only area in the country that experienced an increase was Faxaflói (0.27%) (table 3).

Table 3. Number of counted animals at different areas in Iceland from the full census in 2011, the partial census in 2014 and the full census in 2016. The change in number of counted animals from 2011-2016 (Δn), total percent change (Δ%), annual geometric growth rate (λ (%)), and annual growth rate (R_{est}) is shown for each area.

***Tafla 3**. Fjöldi talinna einstaklinga á mismunandi svæðum innan Íslands frá flugtalningu árið 2011, flugtalningu sem tók til hluta strandlengju Íslands árið 2014 og flugtalningu árið 2016. Breyting í fjölda talinna einstaklinga frá 2011 til 2016 (Δn), heildar hlutfallsbreyting (Δ%), árlegur geómetrískur vaxtahraði (λ (%)), og árlegur vaxtahraði (R_{est}) er tiltekið fyrir hvert svæði.*

Area	2011	2014	2016	Δn	Δ (%)	λ (%)	R_{est}
Faxaflói	554,5	34	556	-1,5	0,27	0,05	0,00
Breiðafjörður	621	132	463	158	-25,44	-5,70	-0,06
Westfjords	796,5	337	685	111,5	-14,00	-2,97	-0,03
North-West	1461,5	478	615,75	845,75	-57,87	-15,88	-0,17
North-East	209	-	89,5	119,5	-57,18	-15,60	-0,17
East-fjords	530,5	-	527,5	3	-0,57	-0,11	0,00
South-coast	709	66	445,5	263,5	-37,17	-8,87	-0,09

3.3.1 Faxaflói

The largest haul outs in Faxaflói were in the areas of Haffjörður and Mýrar with 271 and 60 counted seals respectively. The 2011-2016 trend in this area shows that most sites have experienced an increase in the number of seals counted. The greatest proportional increase occurred in the bay of Búðavík (500%; 2011: 6 seals, 2016: 36 seals). The greatest proportional decline occurred in the estuary of Akraós (-54.69%; 2011: 64 seals, 2016: 29 seals), except for the site Melar, where one seal was counted in 2011 and none in 2016 (-100%) (table 4).

Table 4. The number of counted individuals at all Faxaflói haul-outs (#:haul-out number) from 2011-2016 and the resulting trend demonstrated with the annual growth rate (R_{est}), percent change (Δ (%)), and the annual geometric growth rate (λ (%)). In 2014, only a partial census was conducted, resulting in data absence from some haul-outs in that year. A linear regression was conducted for the haul out sites that were surveyed in 2011, 2014 and 2016, showing the resulting adjusted R^2, log(n) slope coefficient (log(n) s.c.) and standard error (SE). When R^2 is negative it indicates that the line of best fit is worse suited to fit the model than a horizontal line.

***Table 4**. Fjöldi talinna einstaklinga á öllum látrum Faxaflóa (#:látursnúmer) frá 2011-2016 ásamt sveiflum sem sýndar eru með árlegum vaxtahraða (Rest), hlutfallslegri breytingu (Δ (%)) og árlegum geómetrískum vaxtahraða (λ (%)). Árið 2014 fór fram talning sem tók aðeins til hluta strandlengju Íslands, sem gerir það að verkum að gögn frá árinu 2014 eru ekki til staðar fyrir öll látur. Línuleg aðhvarfsgreining var gerð á þeim látrum þar sem talið var árin 2011, 2014 og 2016 og sýnir hún R^2, hallatölu (log(n) s.c.) og staðalfrávik (SE). Þegar R2 sýnir neikvætt gildi táknar það að besta lína greiningarinnar fellur verr að greiningunni heldur en lárétt lína.*

Faxaflói

								Linear Regression		
#	Haul-out site	2011	2014	2016	R_{est}	Δ (%)	λ (%)	R^2	log(n) s.c.	SE
1	Akraós	64	19	29	-0,16	-54,69	-14,64	0,05	-0,18	0,17
2	Borgarfjörður	31	-	40,5	0,05	30,65	5,49	-	-	-
3	Búðavík	6	-	36	0,36	500,00	43,10	-	-	-
4	Haffjörður	339	15	271	-0,04	-20,06	-4,38	-0,94	-0,12	0,68
5	Hvalfjörður	35	-	37,5	0,01	7,14	1,39	-	-	-
6	Hvalseyjar	7	-	4	-0,11	-42,86	-10,59	-	-	-
7	Leirárvogur	24	-	42	0,11	75,00	11,84	-	-	-
8	Melar	1	-	0	-	-100,00	-	-	-	-
9	Mýrar	29,5	-	60	0,14	103,39	15,26	-	-	-
10	Hafnarósar	15,5	-	32	0,14	106,45	15,60	-	-	-
11	W - Snæfellsnes	2,5	-	4	0,09	60,00	9,86	-	-	-
	Total	554,5	34	556	0,00	0,27	0,05	-	-	-

3.3.2 Breiðafjörður

In Breiðafjörður, the number of counted seals was highest on the shore of Lækjarskógarfjörur (267 seals) and in the estuary of Bæjarvaðall (112 seals) (table 5). The 2011-2016 trend showed that most sites experienced declines with the greatest proportional decline recorded in the fjord Kerlingafjörður (-100%; 2011: 20 seals, 2016: 0 seals). The greatest proportional increase occurred in islands of Rauðseyjar (500%; 2011: 2 seals, 2016: 12 seals) (table 5).

Table 5. The number of counted individuals at all Breiðafjörður haul-outs (#: haul-out number) from 2011-2016 and the resulting trend demonstrated with annual growth rate (R_{est}), percent change (Δ (%)), and annual geometric growth rate (λ (%)). In 2014, only a partial census was conducted, resulting in data absence from some haul-outs in that year. A linear regression was conducted for the haul out sites that were surveyed in 2011, 2014 and 2016, showing the resulting adjusted R^2 and log(n) slope coefficient (log(n) s.c.) and standard error (SE). When R^2 is negative it indicates that the line of best fit is worse suited to fit the model than a horizontal line.

Tafla 5. *Fjöldi talinna einstaklinga á öllum látrum Breiðafjarðar (#:látursnúmer) frá 2011-2016 ásamt sveiflum sem sýndar eru með árlegum vaxtahraða (R_{est}), hlutfallslegri breytingu (Δ (%)) og árlegum geómetrískum vaxtahraða (λ (%)). Árið 2014 fór fram talning sem tók aðeins til hluta strandlengju Íslands, sem gerir það að verkum að gögn frá árinu 2014 eru ekki til staðar fyrir öll látur. Línuleg aðhvarfsgreining var gerð á þeim látrum þar sem talið var árin 2011, 2014 og 2016 og sýnir hún R^2, hallatölu (log(n) s.c.) og staðalfrávik (SE). Þegar R^2 sýnir neikvætt gildi táknar það að besta lína greiningarinnar fellur verr að greiningunni heldur en lárétt lína.*

Breiðafjörður

									Linear regression	
#	Haul-out site	2011	2014	2016	R_{est}	Δ (%)	λ (%)	R^2	log(n) s.c.	SE
12	Álftafjörður	0	-	11	-	-	-	-	-	-
13	Bjarneyjar	8,5	-	10	0,03	17,65	3,30	-	-	-
14	Eyrarfjall	22	-	2	-0,48	-90,91	-38,10	-	-	-
15	Bæjarvaðall	176	75	112	-0,09	-36,36	-8,64	-0,22	-0,11	0,13
16	Fellströnd	64,5	-	10	-0,37	-84,50	-31,12	-	-	-
19	Hagadrápssker and Flögur	0	-	1	-	-	-	-	-	-
20	Hergilseyjar and Sandeyjarhólmi	12,5	-	1	-0,51	-92,00	-39,66	-	-	-
21	Hjarðarnes	5,5	-	3	-0,12	-45,45	-11,42	-	-	-
22	Svefneyjar	9	-	12	0,06	33,33	5,92	-	-	-
23	Kerlingarfjörður	20	-	0	-	-100,00		-	-	-
24	Króksfjarðarnes	9,5	-	1	-0,45	-89,47	-36,25	-	-	-
25	Lækjarskógarfjörur	181	57	267	0,08	47,51	8,09	-0,97	0,04	0,32
26	Drápsker	12	-	3	-0,28	-75,00	-24,21	-	-	-
27	Rauðseyjar	2	-	12	0,36	500,00	43,10	-	-	-
28	Reykhólalönd	21	-	3	-0,39	-85,71	-32,24	-	-	-
29	Skarðströnd	3,5	-	1	-0,25	-71,43	-22,16	-	-	-
30	Skálanes	2,5	-	1	-0,18	-60,00	-16,74	-	-	-
31	Skálmarnes	2,5	-	9	0,26	260,00	29,20	-	-	-
32	Skógarströnd	14	-	1	-0,53	-92,86	-41,01	-	-	-
33	Þórsnes and islands	55	-	3	-0,58	-94,55	-44,11	-	-	-
	Total	621	132	463	-0,06	-25,44	-5,70	-	-	-

3.3.3 Westfjords

There are many large haul-out sites in the West fjords and in six of the sites ≥80 seals were found; Reykjanes, Borgarey, Ögurnes, Mjóifjörður, Vogasker and Laugaból. The largest site was on the tip of Reykjanes (106 seals) and the smallest in the bay Aðalvík (3 seals). The largest proportional decline was observed in Aðalvík (-80%; 2011: 15 seals, 2016: 3 seals) and the greatest proportional increase in the fjord Mjóifjörður (647.83%; 2011: 11.5 seals, 2016: 86 seals) (table 6).

Table 6. The number of counted individuals at all Westfjords haul-outs (#: haul-out number) from 2011-2016 and the resulting trend demonstrated with annual growth rate (R_{est}), percent change (Δ (%)), and annual geometric growth rate (λ (%)). In 2014, only a partial census was conducted, resulting in data absence from some haul-outs in that year. A linear regression was conducted for the haul out sites that were surveyed in 2011, 2014 and 2016, showing the resulting adjusted R^2 and log(n) slope coefficient (log(n) s.c.) and standard error (SE). When R^2 is negative it indicates that the line of best fit is worse suited to fit the model than a horizontal line.

***Tafla 6**. Fjöldi talinna einstaklinga á öllum látrum Vestfjarða (#:látursnúmer) frá 2011-2016 ásamt sveiflum sem sýndar eru með árlegum vaxtahraða (R_{est}), hlutfallslegri breytingu (Δ (%)) og árlegum geómetrískum vaxtahraða (λ (%)). Árið 2014 fór fram talning sem tók aðeins til hluta strandlengju Íslands, sem gerir það að verkum að gögn frá árinu 2014 eru ekki til staðar fyrir öll látur. Línuleg aðhvarfsgreining var gerð á þeim látrum þar sem talið var árin 2011, 2014 og 2016 og sýnir hún R^2, hallatölu (log(n) s.c.) og staðalfrávik (SE). Þegar R^2 sýnir neikvætt gildi táknar það að besta lína greiningarinnar fellur verr að greiningunni heldur en lárétt lína.*

Westfjords

									Linear regression	
#	Haul-out site	2011	2014	2016	R_{est}	Δ (%)	λ (%)	R^2	log(n) s.c.	SE
34	Aðalvík	15	-	3	-0,32	-80,00	-27,52	-	-	
35	Borgarey	82	46	92,5	0,02	12,80	2,44	-1,00	0,01	0,15
36	Laugaból	52	28	77,5	0,08	49,04	8,31	-0,84	0,06	0,2
38	Vogasker	90	-	80	-0,02	-11,11	-2,33	-	-	-
39	Jökulfirðir	14	-	64	0,30	357,14	35,52	-	-	-
40	Mjóifjörður	11,5	55	86	0,40	647,83	49,54	0,92	0,41	0,08
41	Patreksfj.-Tálknafj.	0	0	10	-	-	-	-	-	-
42	Reykjanes	206	56	106	-0,13	-48,54	-12,44	-0,27	-0,16	0,21
44	Vatnsfjarðarnes	177	47	71,5	-0,18	-59,60	-16,58	0,12	-0,20	0,18
45	Ögurnes	149	83	88,5	-0,10	-40,60	-9,89	0,53	-0,11	0,06
46	Önundarfjörður	0	-	6	-	-	-	-	-	-
	Total	796,5	315	685	-0,03	-14,00	-2,97	-	-	-

3.3.4 Northwest

The largest haul-out sites were found on Vatnsnes (179.5) and in the estuary Sigríðarstaðaós (82.5). Most sites have experienced declines, with the greatest proportional decline having occurred in the bay of Skjaldarbjarnarvík (-100%; 2011: 32.5 seals, 2016: 0 seals) and the greatest proportional increase in the fjord of Furufjörður (581.25%; 2011: 8, 2016: 54.5) (table 7).

Table 7. The number of counted individuals at all North- West haul-outs (#haul-out number) from 2011-2016 and the resulting trend demonstrated with annual growth rate (R_{est}), percent change (Δ (%)), and annual geometric growth rate (λ (%)). In 2014, only a partial census was conducted, resulting in data absence from some haul-outs in that year. A linear regression was conducted for the haul out sites that were surveyed in 2011, 2014 and 2016, showing the resulting adjusted R^2 and log(n) slope coefficient (log(n) s.c.) and standard error (SE). When R^2 is negative it indicates that the line of best fit is worse suited to fit the model than a horizontal line.

***Tafla 7**. Fjöldi talinna einstaklinga á öllum látrum Norðvesturlands (#:látursnúmer) frá 2011-2016 ásamt sveiflum sem sýndar eru með árlegum vaxtahraða (R_{est}), hlutfallslegri breytingu (Δ (%)) og árlegum geómetrískum vaxtahraða (λ (%)). Árið 2014 fór fram talning sem tók aðeins til hluta strandlengju Íslands, sem gerir það að verkum að gögn frá árinu 2014 eru ekki til staðar fyrir öll látur. Línuleg aðhvarfsgreining var gerð á þeim látrum þar sem talið var árin 2011, 2014 og 2016 og sýnir hún R^2, hallatölu (log(n) s.c.) og staðalfrávik (SE). Þegar R^2 sýnir neikvætt gildi táknar það að besta lína greiningarinnar fellur verr að greiningunni heldur en lárétt lína.*

North west coast

									Linear Regression	
#	Haul-out site	2011	2014	2016	R_{est}	Δ (%)	λ (%)	R^2	log(n) Slope s.c.	SE
47	Eyjar	14	8	1	-0,53	-92,86	-41,01	0,64	-0,50 (0,23)	0,23
48	Bjarnarfjörður	5	5	2	-0,18	-60,00	-16,74	0,29	-0,17 (0,13)	0,13
49	Furufjörður	8	-	54,5	0,38	581,25	46,78	-	-	-
50	Drangar-Drangavík-Bjarnavík	37,5	33	22,5	-0,10	-40,00	-9,71	0,70	-0,10 (0,04)	0,04
51	Drangsnes	0	-	11	-	-	-	-	-	-
52	Eyjarey	20	-	-	-	-	-	-	-	-
53	Vatnsnes	556,5	76	179,5	-0,23	-67,74	-20,25	-0,14	-0,26 (0,30)	0,3
54	Heggstaðarnes	43	60	11,25	-0,27	-73,84	-23,52	-0,08	-0,24 (0,26)	0,26
56	Kollafjörður	53	16	44	-0,04	-16,98	-3,65	-0,87	-0,07 (0,25)	0,25
57	Munaðarnenssker	3,5	13	5,5	0,09	57,14	9,46	-0,60	0,12 (0,24)	0,24
58	Litla Ávík	24	35	54	0,16	125,00	17,61	0,95	0,16 (0,02)	0,02
59	Ófeigsfjörður	75	55	35	-0,15	-53,33	-14,14	0,90	-0,15 (0,03)	0,03
60	Reykjarfjarðarsker	49,5	23	41,5	-0,04	-16,16	-3,46	-0,78	-0,05 (0,15)	0,15
61	South-Reykjafjörður	0	-	7	-	-	-	-	-	-
63	Sigríðarstaðaós	211,5	88	82,5	-0,19	-60,99	-17,16	0,77	-0,20 (0,07)	0,07
64	Skagi	110	-	52,5	-0,15	-52,27	-13,75	-	-	-
65	Skjaldarbjarnarvík	32,5	-	0	-	-100,00	-	-	-	-
66	V-Hrútafjörður	218,5	66	12	-0,58	-94,51	-44,03	0,91	-0,57 (0,12)	0,12
	Total	1461,5	478	615,75	-0,17	-57,87	-15,88	-	-	-

3.3.5 Northeast

The highest number of seals was counted in the estuary Bakkahlaup (53 seals), while no seals were counted in the fjords Eyjafjörður and Þistilfjörður. Most sites experienced declines from 2011-2016 with the greatest proportional declines at Þistilfjörður (-100%; 2011: 7 seals, 2016: 0) and Eyjafjörður (-100%; 2011: 2 seals, 2016: 0 seals). The greatest proportional increase occurred in the estuary of the glacial river Skjálfandafljót (-110%; 2011: 15 seals, 2016: 31.5 seals) (Table 8).

Table 8. The number of counted individuals at all North-East haul-outs (#: haul-out number) from 2011-2016 and the resulting trend demonstrated with annual growth rate (R_{est}), percent change (Δ (%)), and annual geometric growth rate (λ (%)). In the partial census of 2014 seals were not counted in this area.

***Tafla 8**. Fjöldi talinna einstaklinga í öllum látrum á Norðurlandi eystra (#:látursnúmer) frá 2011-2016 ásamt sveiflum sem sýndar eru með árlegum vaxtahraða (R_{est}), hlutfallslegri breytingu (Δ (%)) og árlegum geómetrískum vaxtahraða (λ (%)). Árið 2014 fóru talningar ekki fram á Norðurlandi Eystra.*

North east coast

#	Haul-out site	2011	2014	2016	R_{est}	Δ (%)	λ (%)
67	Bakkahlaup	164	-	53	-0,23	-67,68	-20,22
68	Eyjafjörður	2	-	0	-	-100,00	-
69	Melrakkaslétta	21	-	5	-0,29	-76,19	-24,95
70	Skjálfandafljót	15	-	31,5	0,15	110,00	16,00
72	Þistilfjörður	7	-	0	-	-100,00	-
	Total	209	-	89,5	-0,17	-57,18	-15,60

3.3.6 Eastfjords

The largest haul-outs were in the estuary of Jökla and Lagarfljót (243 seals) and in the fjord Álftafjörður (130.5 seals). The 2011-2016 trend shows the greatest proportional decline in the islands of the bay Breiðdalsvík (-100%; 2011: 9 seals, 2016: 0 seals) while the greatest proportional increase occurred in the fjord of Berufjörður (80%; 2011: 40 seals, 2016: 72 seals) (table 9).

Table 9. The number of counted individuals at all Eastfjords haul-outs (#: haulout number) from 2011-2016 and the resulting trend demonstrated with annual growth rate (R_{est}), percent change (Δ (%)), and annual geometric growth rate (λ (%)). In the partial census of 2014 seals were not counted in this area.

***Tafla 9**. Fjöldi talinna einstaklinga á öllum látrum Austfjarða(#:látursnúmer) frá 2011-2016 ásamt sveiflum sem sýndar eru með árlegum vaxtahraða (R_{est}), hlutfallslegri breytingu (Δ (%)) og árlegum geómetrískum vaxtahraða (λ (%)). Árið 2014 fóru talningar ekki fram á Austfjörðurm*

Eastfjords

#	Haul-out site	2011	2014	2016	R_{est}	Δ (%)	λ (%)
73	Álftafjörður	118,5	-	130,5	0,02	10,13	1,94793474
74	Bakkaflói	2	-	2	0,00	0,00	0
75	Berufjörður	40	-	72	0,12	80,00	12,4746113
76	Breiðdalsvík	9	-	0	-	-100,00	-
77	Dalatangi	27	-	1	-0,66	-96,30	-48,271814
79	Héraðsflói	71,5	-	72,5	0,00	1,40	0,27816842
80	Húsavík	14	-	7	-0,14	-50,00	-12,944944
81	Jökla	248,5	-	243	0,00	-2,21	-0,4466277
	Total	530,5	-	528	0,00	-0,47	-0,0944289

3.3.7 South-coast

The largest haul-out on the south coast was the glacial river estuary Fjallsárós (219.5 seals). There were numerous haul-out sites with no seals; at the estuary Skaftárós, on the shore of Landeyjarsandur, in the estuary Papós, on the islands of Vestmannaeyjar and the island Vígur í Lóni. The 2011-2016 trend exhibits the greatest decline at Skaftárós where 90.5 seals were found in 2011 but none in 2016. However, the greatest proportional increase was found in the fjord Hornafjörður (375%: 2011: 6 seals, 2016: 28.5 seals) and on the shore of Selvogur (375%; 2011: 4 seals, 2016: 19 seals) (table 10).

Table 10. The number of counted individuals at all South-coast haul-outs (#: haul-out number) from 2011-2016 and the resulting trend demonstrated with annual growth rate (R_{est}), percent change (Δ (%)), and annual geometric growth rate (λ (%)). In 2014, only a partial census was conducted, resulting in data absence from some haul-outs in that year. A linear regression was conducted for the haul out sites that were surveyed in 2011, 2014 and 2016, showing the resulting adjusted R^2 and log(n) slope coefficient (log(n) s.c.) and standard error (SE). When R^2 is negative it indicates that the line of best fit is worse suited to fit the model than a horizontal line.

***Tafla 10.**. Fjöldi talinna einstaklinga á öllum látrum Suðurstrandar (#:látursnúmer) frá 2011-2016 ásamt sveiflum sem sýndar eru með árlegum vaxtahraða (R_{est}), hlutfallslegri breytingu (Δ (%)) og árlegum geómetrískum vaxtahraða (λ (%)). Árið 2014 fór fram talning sem tók aðeins til hluta strandlengju Íslands, sem gerir það að verkum að gögn frá árinu 2014 eru ekki til staðar fyrir öll látur. Línuleg aðhvarfsgreining var gerð á þeim látrum þar sem talið var árin 2011, 2014 og 2016 og sýnir hún R^2), hallatölu (log(n) s.c.) og staðalfrávik (SE). Þegar R^2 sýnir neikvætt gildi táknar það að besta lína greiningarinnar fellur verr að greiningunni heldur en lárétt lína.*

South coast

									Linear Regression	
#	Haul-out site	2011	2014	2016	R_{est}	Δ (%)	λ (%)	R^2	log(n) s.c.	SE
78	Eystrahorn	0	-	2	-	-	-	-	-	-
83	Skaftarós	90,5	-	0	-	-100,00	-	-	-	-
84	Eyrarbakki/Stokkseyri	6	-	11	0,12	83,33	12,89	-	-	-
85	Fjallsárós	219,5	-	219,5	0,00	0,00	0,00	-	-	-
86	Hestgerðislón	12	-	8,5	-0,07	-29,17	-6,66	-	-	-
87	Öræfi	164,5	-	48	-0,25	-70,82	-21,83	-	-	-
88	Hornafjörður	6	-	28,5	0,31	375,00	36,56	-	-	-
89	Hrollaugseyjar-Tvísker	0	-	4	-	0,00	-	-	-	-
90	Kúðafljót	95,5	39	87	-0,02	-8,90	-1,85	-0,91	-0,04	0,19
91	Landeyjarsandur	1	-	0	-	-100,00	-	-	-	-
92	Markarfljót	14,5	7	5	-0,21	-65,52	-19,18	0,98	-0,22	0,02
93	Papós and skerries	12,5	-	0	-	-100,00	-	-	-	-
94	Vestmannaeyjar	2	-	0	-	-100,00	-	-	-	-
95	Vigur í Lóni	7,5	-	0	-	-100,00	-	-	-	-
96	Þjórsá	62	10	9	-0,39	-85,48	-32,02	0,75	-0,40	0,15
97	Selvogur	4	-	19	0,31	375,00	36,56	-	-	-
98	Ölfusá	11,5	10	4	-0,21	-65,22	-19,04	0,51	-0,20	0,11
	Total	709	66	445,5	-0,09	-37,17	-8,87	-	-	-

4. Discussions

4.1. Population trends and dynamics

Globally, the current statuses of harbour seal populations vary, with some regions experiencing declines while populations in other areas are increasing (Lowry 2016). We report a decline in the Icelandic harbour seal population. We counted 3,383 harbour seals during the 2016 aerial census, which suggests a total population of 7,652 harbour seals. The 2016 population estimate is 77.04% smaller than when first estimated in 1980, and 32.11% smaller than in 2011, when the last population census was undertaken. As stated by Icelandic authorities in the management objective for the Icelandic harbour seal population, action needs to be taken to balance the population and minimize further declines if the population falls appreciably below a threshold of 12,000 animals (P=90%), (NAMMCO 2006). As the results presented in this report demonstrate a 99.99% probability that the population has now reached this threshold, and is 36.23% below the management objective of 12,000 animals, actions to minimize further declines should be considered.

With the exception of the bay Faxaflói and the East Fjords, where the number of harbour seals has remained stable, a decline appears to be occurring in all regions of Iceland. The greatest decline (57.87%) was observed in the North-West area of Iceland and the haul-out sites that mostly account for this are in the western area of the fjord Hrútafjörður, on the tip of Skagi and Vatnsnes and in the estuary of Sigríðarstaðaós. Given that Vatnsnes and Sigríðarstaðaós have been marketed prominently as seal watching locations, the decline at these sites is of particular concern for the seal-watching industry. However, tourism can also affect harbour seal behaviour and cause changes in distribution (Granquist and Sigurjónsdóttir 2014). If tourism related disturbance is an issue harbour seals could be dispersing to haul-out sites that are less disturbed, causing a decline in haul-outs at the seal watching locations of Vatnsnes and Sigríðarstaðaós. However, further studies are required to understand such effects of tourism on harbour seals.

4.1.1 Conservation status of the Icelandic harbour seal population

Globally, a number of different methods are used for pinniped population management. When knowledge on important parameters is scarce, precautionary approaches are often used, where conservation measures can be implemented despite the lack of certain information. An example of such a method is the criteria to assess the conservation status of pinniped populations developed by the NAMMCO/ICES/NAFO working group on harp and hooded seals (WGHARP). The WGHARP bases its conservation status assessment on a reference level, identified as the highest population level observed. A precautionary level is reached when the population has declined to 70% of the reference level, and a critical level is reached when the population has declined to 30% of the reference level. In cases when

populations are below the precautionary level but above the critical level, they should be considered as a conservation concern, while populations that fall below the critical level should be considered to be in danger of serious harm (NAMMCO CSWG 2016). If the conservation status of the Icelandic harbour seal population is assessed using the WGHARP criteria, the first population estimate, conducted in 1980, which is the largest estimated population size should be used as a reference level (33,000 animals). According to the criteria, a population size of 12,000 animals which has been recommended by Icelandic authorities as a preferred minimum population size (NAMMCO 2006) would fall within the cautionary zone, only slightly above the critical level of approximately 10,000 individuals. The current status of the population 7,652 seals would fall below the critical level (P=95.83%).

Another approach to identify the conservation status of populations has been developed by the International Union for Conservation of Nature and Natural Resources (IUCN). Built on different criteria, the IUCN classifies populations into seven categories, ranging from Least Concern to Extinct. A criterion used to define the population status is based on changes in population size over a period of three generations (or 10 years, whichever is longer). In cases when a 50% decline occurs during a period of three generations a population is defined as Vulnerable. If a 70% decline occurs during a period of three generations a population is defined as Endangered and if the decline is 80% the population is defined as is Critically Endangered (IUCN 2012a; IUCN 2012b). Given that the population decline during the last three generations of Icelandic harbour seals (45 years; each generation estimated to be 15 years, IUCN) exceeds 70%, the current population meets the IUCN criteria of Endangered (IUCN 2012b). Therefore, according to the criterion, the Icelandic harbour seal population faces a high risk of extinction in the wild. Although the bulk of the observed decline occurred between 1980 and 1989, the current harbour seal population size is the smallest that has ever been recorded.

4.2 Potential reasons for decline

4.2.1 Culling of harbour seals

The factors contributing to the decline of the Icelandic harbour seal population are poorly understood. Although hunting and by-catch have been mentioned as probable population limiting factors (Granquist et al. 2011), data to quantify the magnitude of affected animals is scarce and unreliable. In 2015, 159 harbour seals were reported to The Marine and Freshwater Research Institute. However, the numbers have been slightly higher in previous years. For example, the average annual hunt between 2012 and 2015 was 230 harbour seals per year (Granquist and Hauksson 2016a). In light of the new population estimate, an annual average removal of 230 seals corresponds to 3% of the population. However, since there is no compulsory reporting system for hunted seals in Iceland, these numbers should probably be considered as a minimum.

4.2.2 By-catch of harbour seals

Based on available data, harbour seals are most frequently by-caught in lumpsucker and cod- gillnet fisheries (Pálsson et al. 2015). Due to insufficient reporting of by-catch of marine mammals and seabirds, alternative methods need to be used to assess the degree of by-catch of these species. For the lumpsucker fishery the assessment is based on observations of by-caught marine mammals reported by inspectors from the Directorate of Fisheries, who board approximately 1% of the lumpsucker fishery trips. The by-catch numbers reported by the inspectors is then extrapolated to correspond to the total number of fishing trips during the season. By using this method, an estimate for by-catch of marine mammals within each lumpsucker fishing area is obtained (Fishing area A= Faxaflói, B= Breiðarfjörður, C= Vestfirðir, D= Húnaflói, E= Norðurland, F= Austurland and G= Suðurland). By-catch in cod gillnet fisheries is based on research fishing trips made by the Marine and Freshwater Research Institute. The numbers of by-caught marine mammals on these trips are extrapolated to match the number of cod gillnet fishing boats in the entire fleet and correction factors are used to account for changes in species availability for each month (Pálsson et al. 2015; NAMMCO CSWG 2016).

In 2015, the estimated number of by-caught harbour seals in lumpsucker nets in fishing areas B,C,D and E (areas that observers covered in 2015) were 1,066 (CV = 1.20) harbour seals in total. Further, an estimated number of 46 (CV = 0.62) harbour seals were caught in cod gill nets in total in 2015. In 2014, when the lumpsucker fishery effort was lower, 160 (CV = 1.8) harbour seals were estimated to have been by-caught in total in the fishing areas A,B,C,D and E (areas that observers covered in 2014). No harbour seals were reported to be by-caught in cod gillnets in 2014 (Guðjón Sigurðsson, in prep.). In 2013, the number of by-caught harbour seals in Icelandic waters was estimated to be 705 animals in total for all fishing gear (Pálsson et al. 2015). Although the error margins for the by-catch estimates are very high due to limited observer coverage, and should be interpreted with caution, these numbers correspond to 2-14.5% of the current harbour seal population size and are largely dependent upon lumpsucker fishery effort.

4.2.3 Environmental factors

Environmental changes are another potential factors that affects the harbour seal population. For example, the northward migration of the sandeel (*Ammodytes marinus*) in Iceland, associated with warming sea temperatures, has triggered large changes in the breeding success, population sizes, distribution and survival of some species of seabirds relying on the sandeel for nutrition (Bogason and Lilliendahl, 2009; Lilliendahl et al., 2013; Vigfusdottir et al., 2013). The sandeel is an important food source for harbour seals (Bogason 1997, Hauksson and

Bogason 1997; Granquist and Hauksson 2016b; Granquist 2016), but harbour seals may not be as vulnerable to changes in the sandeel stocks as some species of seabirds because of the seal's generalist feeding habits. However, the effects of food availability changes on the Icelandic harbour seal population need to be further investigated.

4.3 Methodological considerations

When considering the average size of harbour seal groups, it is clear that harbour seals in Iceland mostly haul-out in groups of less than four animals. This underlines the challenges of surveying harbour seals in Iceland and the need to survey the entire coastline in order to arrive at an accurate population estimate.

The fact that pinniped censuses are based on the number of hauled-out animals presents a number of potential biases since only a portion of the population is hauled-out during any one time. Several factors are known to affect haul-out patterns of harbour seals including weather (Kreiber and Barrette 1984; Watts 1992), tidal cycle (Schneider and Payne 1983; Thompson and Miller 1990; Granquist and Hauksson 2016c), time of day and often annual variations have been described (Stewart 1984; Thompson 1989; Thompson et al. 1989). In this study, the effects of these factors were minimized by limiting survey flights to weather and tidal conditions that fit standardized criteria. However, to compute a population estimate, a correction factor needs to be applied to account for environmental factors, visibility from air and submerged animals. As a result, the population estimate is 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 directly comparable to the estimates made since 2006. Another factor that can impact the results is the photographic image quality, affecting the accuracy in the number of counted seals. Even though high resolution photographic equipment was used in this survey, some photographs were not of optimal quality for reliable counts. This is likely a cause of the photographs being taken through a closed window, resulting in lessened image quality. To minimize this effect in future surveys, airplanes with openable windows should be used.

Recent results presented by Granquist and Hauksson (2016c) indicate that in North-West Iceland, the peak of the harbour seal moulting season takes place between the end of July and early August. During the 2016 census, the counting started in the end of July and continued throughout August. However, as previous harbour seal censuses in Iceland have usually begun in the first week of August, the estimates derived from previous censuses could be underestimated, since the peak of the moulting season could have been missed. In the 2016 census however, some areas had to be surveyed later in the season because of unfavourable weather conditions. This can cause a slight underestimate in the number of animals at these sites,

especially on the south coast from Höfn to Vík. Commencing surveys earlier in July could assist in minimizing these effects in future censuses.

A further limitation is an effect of statistical power. While the present estimate is built on a single survey of the Icelandic coastline, a higher survey frequency with three replicates would provide a more accurate estimate and be better suited to detect population trends as it would increase statistical power (Teilmann et al. 2010). For the 2016 survey, funding was unavailable for this procedure. As of now, a single survey every other year has been deemed to create a sufficient balance of cost and statistical power.

5. Concluding remarks

The Icelandic harbour seal population has declined by 32.11% since 2011 and is currently 77.04% smaller than estimated in the first population census in 1980. The factors contributing to the population decline are poorly understood, although by-catch and hunting are likely to affect the status of the population. According to the estimates presented in this report, the total annual removal (by-catch + culling) would represent 5-17.5% of the current harbour seal population. The potential annual growth has not been investigated for the Icelandic harbour seal population. However, Bjorge and Oien (1999) suggested that the maximum annual growth of the Norwegian harbour seal population was approximately 8%, implying that during years when environmental factors are optimal, human removals (direct catches + by-catches) should not exceed 8% to avoid decreasing the current population (Bjorge and Oien 1999). Hence, if the maximum annual growth of the Icelandic population is expected to be approximately 8%, the combined effect of culling and by-catch may currently affect the population growth negatively, especially during years with high lumpsucker fishing effort. Further, other factors such as effects of climate change, prey availability and anthropogenic disturbance, for example due to tourism, may also contribute and need to be investigated further.

The results from this report confirm that the Icelandic harbour seal population is now 36.23% below the recommended population size of 12,000 animals. Hence, following the governmental management objective for the Icelandic harbour seal population (NAMMCO 2006) actions taken to minimize further decline are recommended.

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