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The Icelandic harbour seal (*Phoca vitulina*): Population estimate in 2020, summary of trends and the current status

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Ágrip

Til að vakta stöðu og breytingar á íslenska landselsstofninum og til þess að geta byggt stjórnunaraðgerðir á vísindalegri þekkingu er reglulegt mat á stofnstærð hans grundvallaratriði. Slíkt mat var fyrst gert árið 1980 og hefur verið gert reglulega síðan þá. Árið 2020 voru talningar framkvæmdar með markmiði að meta stærð íslenska landselsstofnsins og þróun stofnstærðarinnar. Heildarfjöldi taldra sela var 4.559 dýr, og áætluð stofnstærð eftir beitingu leiðréttingarstuðuls var 10.319 (CI 95%= 6.733-13.906). Stofninn er nú 69% minni en þegar hann var fyrst metinn árið 1980. Samkvæmt stjórnunarmarkmiðum fyrir íslenska landselsstofninn skal halda stofninum í 12.000 selum en niðurstöður sýna hann 14% undir þeim fjölda. Núverandi mat er rúmum 9% hærra en árið 2018 þegar stofnmat fyrir alla strandlengju landsins var gert síðast. Mat á þróun stofnstærðar bendir til þess að stofnin sé að sveiflast í kringum lágmarksstofnstærð.

Í ljósi viðkvæmrar stöðu landselsstofnsins við strendur Íslands er brýnt að meta og bregðast við þeim þáttum sem mögulega hafa áhrif á stærð stofnsins, svo sem beinar og óbeinar selveiðar, umhverfisbreytingar, aðgengi að mikilvægum fæðutegundum, ásamt truflun vegna athafnir manna. Einnig er mikilvægt að vakta stofnvistfræðilega þætti, svo sem kópaframleiðslu og frjósemi.

Abstract

To monitor fluctuations in the harbour seal population and to facilitate evidence-based management, regular population censuses are an important foundation. In Iceland, censuses of the harbour seal population have been conducted regularly since 1980. In the summer of 2020, an aerial census was conducted with the aim of estimating the size of the Icelandic harbour seal population and to examine recent trends. The total number of observed seals was 4,559 individuals, which yielded an estimated population size of 10,319 (CI 95%= 6,733-13,906) animals. This estimate is 14% below the governmentally issued

management objective for the minimum population size of harbour seals in Iceland of 12,000 animals. The estimated population size was roughly 9% larger than in 2018, when the last complete population census was conducted, but 69% smaller than when first estimated in 1980. Trend analyses indicate that the population is currently fluctuating around a stable minimum level. Considering the sensitive conservation status of the Icelandic harbour seal population, it is necessary to assess and sustainably manage factors affecting the status of the population, such as direct and indirect seal removals, environmental changes, changes in prey availability and anthropogenic impacts. In addition, increased monitoring of population demographic factors is urgent.

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

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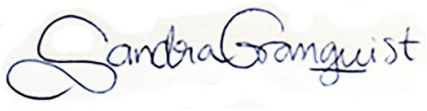	

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1. Introduction

The Icelandic harbour seal population has been monitored rather regularly since 1980, when the first complete aerial census was carried out. The population was estimated to be 33,327 animals in 1980 (Hauksson and Einarsson 2010), however, trend analysis based on previous complete surveys has shown a declining trend in the harbour seal population since 1980. Most of the decline occurred between 1980 and 1990, when the population decreased by about half. Thereafter, the population decrease continued at a slower rate. The Icelandic government introduced a management objective in 2006, 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 (oral statement, NAMMCO 2006). The estimated population size in 2006 was close to the issued management objective. However, the population estimate prior to 2006, conducted in 2003, and all the population estimates following the 2006 estimate have been below the threshold of 12,000 animals. A partial census carried out in 2014, where only the largest harbour seal haul-out sites were surveyed, indicated an annual decline of 28.55% in the period from 2011–2014 (Granquist et al. 2014). This decline was confirmed in the census in 2016, when the population size was estimated to be 7,700 animals (Þorbjörnsson et al. 2017). The last full census on the Icelandic harbour seal population was carried out in 2018 and resulted in an estimated population size of 9434 animals, which is 71.69% smaller than when the population was first estimated in 1980, and 21.38% below the set threshold of 12,000 animals.

The aim of the present census was to estimate the size of the Icelandic harbour seal population for the 13th time, and to examine ongoing general and local trends in the population size. Sufficient knowledge on the status of the population is an important foundation to facilitate evidence-based management of the Icelandic harbour seal population. Such knowledge is also a crucial base for other research undertaken on the Icelandic seal population.

2. Methods

2.1. Aerial survey

The aerial survey was conducted between 27 July and 24 August 2020, to coincide with the moulting season of Icelandic harbour seals. Previous studies have suggested that the peak of the moulting season of the Icelandic harbour seal population occurs between the end of July and the end of August (Granquist and Hauksson 2016a). The entire coastline of Iceland was surveyed from a small airplane. All the coastline was covered at least once, while some important haul-out areas (Vatnsnes, Heggstaðanes, Sigríðastaðaós and part of South Iceland) were covered twice.

Previous research has shown that several factors, beside time of the year, may affect haul-out patterns of harbour seals, such as weather and tidal state. One of the most important

factors to consider is the tidal cycle, since seals haul-out to a higher extent during low tide, while foraging mainly occurs during high tide (Schneider and Payne 1983, Thompson and Miller 1990, Granquist and Hauksson 2016a). The weather factors that may affect haul-out behaviour are precipitation (Pauli and Terhune 1987, Grellier et al. 1996), wind speed and wind direction (Brasseur et al. 1996, Simpkins et al. 2003), temperature (Pauli and Terhune 1987, Granquist and Hauksson 2016) and cloud cover (Pauli and Terhune 1987, Grellier et al. 1996). To minimise the effects of these factors, the weather and tidal conditions when the flights were carried out were standardized in the following way. All flights were conducted in clear weather without precipitation, with wind <10 m/s and +/- 3 h from low tide. During the survey, the observer was seated in the front of the airplane with a good view to be able to detect and count all smaller groups (<30 seals) of harbour seals and to photograph larger groups (>30 seals) through an open window. A Canon 5DS full-frame digital camera mounted with a Canon 70-200 mm f/2.8L II USM lens with image stabilization was used to photograph the seal groups. The camera was equipped with a Global Positioning System (GPS), which assigns positional coordinates to each image. If grey seals were spotted during the survey, they were also recorded.

2.2 Photographic and statistical analysis

When photographs were available, the number of harbour seals in the images was counted by two individuals separately, and if the results differed between observers, the average number was used for the area. For smaller groups (<30 seals) the direct count value was used. In the areas that were covered twice the average of the two observations was used. To facilitate an exact site comparison to results from previous censuses, the definitions of sub-areas and counting areas were identical to those used in previous censuses (Hauksson 2010). That is, the coastline is divided into seven sub-areas (Figure1) and each sub-area is divided into several counting areas (in total for the whole coast= 98 counting areas, see Table 3-9).

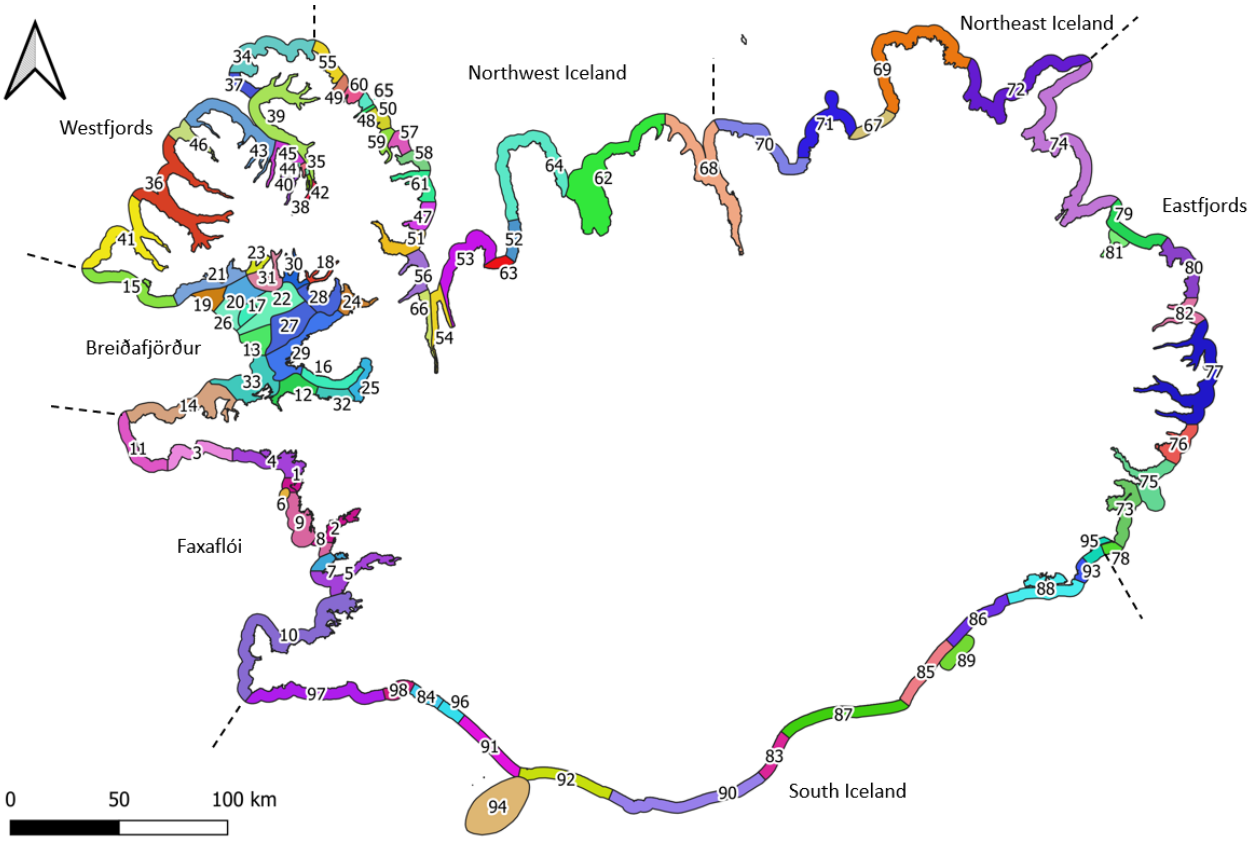

Figure 1. The seven sub-areas of the Icelandic coastline: Faxaflói, Breiðafjörður, Westfjords, Northwest Iceland, Northeast Iceland, Eastfjords and South Iceland. The 98 counting area are indicated with their respective numbers (see Table 3-9).

1. mynd. Strandlengja Íslands skipt í sjö undirsvæði. Faxaflói, Breiðafjörður, Vestfirðir, Norðvesturland, Norðausturland, Austfirðir og Suðurland. Talningarsvæði 1-98 eru sýnd með viðeigandi númer (sjá Töflu 3-9).

The estimate of the Icelandic harbour seal population in 2020 was based on the total number of observed animals, corrected for submerged animals and animals missed by the observer, by applying a correction factor of 2.26 (SD=0.41) (see Hauksson and Einarsson 2010). To generate the estimated population size, the total number of observed animals was bootstrapped by normally distributed correction factors (10,000 resamples). A 95% Confidence Interval (95% CI) was then estimated as the 2.5 and 97.5 percentiles of the bootstrapped distribution.

Changes in the population size between 2020 and all previous estimates were examined by applying the following equations (Table 1):

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):

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

Where N_{last} was the most recent value; N_{first} was the earlier value which N_{last} was compared to; ΔT was the total time interval (in years) in which a change is examined ($T_{last} - T_{first}$).

A linear regression model on *ln* transformed numbers was applied to examine the population trend based on all previous population estimates (1980–2020). Secondly, the recent trend (2011-2020) based on estimates from the censuses in 2011 (Granquist et al 2011), 2014 (a partial census, Granquist et al 2014), 2016 (Þórbjörnsson et al. 2017), 2018 (Granquist and Hauksson 2019) and the current census (2020) was calculated. Further, linear regression models on *ln* transformed counts were applied to estimate recent local trends in the seven different sub-areas (Figure 1, Table 2) and in the counting areas when possible (Tables 3–9). In case of zero values, which occurred some years in specific counting areas, 0.49 was added before performing the linear regression on *ln*(counts). The period of 2011–2020 was then compared to trends in the previous period of 1980–2006, (published by Hauksson 2010).

Normal cumulative distribution (CDF) (Sokal and Rohlf 1997) was used to calculate the probability of a population estimate being lower than previous estimates. All analysis was carried out in R 3.3.1 (R Core Team 2021).

3. Results

3.1 Estimated population size

The number of observed harbour seals was in total 4558.5 seals, which after application of the correction factor resulted in a population size of 10,319 (SD=1830.0; CI 95%= 6,733-13,906) animals (Figure 2). Based on the estimate of the population size for 2020, there is an 82% chance that the population is below the threshold value of 12,000 animals suggested in the management objective (Table 1) put forward by Icelandic authorities as a threshold value for the minimum population size (oral statement, NAMMCO 2006).

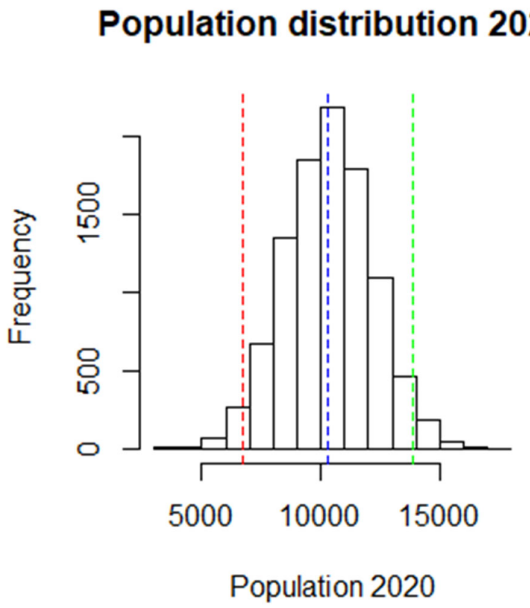

Figure 2. A normal distribution of the estimated number of harbour seals on the coast of Iceland in 2020 of 10,319 seals (mean value; blue line) and the 95% confidence interval (red and green lines).

2. mynd. *Normaldreifing yfir mat á fjölda landsela á strandlengju Íslands árið 2020 upp á 10,319 seli (meðaltalsgildi; blá lína) ásamt 95% öryggismörkum (rauð og græn lína).*

3.2 Population trends 1980–2020

The temporal population trend from 1980 to 2020 shows a total decline of 69.04%. During this period, the annual discrete time per capita growth rate (λ) was -2.89% (Table 1). A linear regression model revealed a significant decline of 3% annually between 1980 and 2020 (R_{est} = -0.03 (SE= 0.004); R^2_{ad} = 0.77, RSE=0.20, p < 0.001). When compared to the census of 2018, an increase of 9.38% was observed, which corresponds to an annual discrete time per capita growth rate of 4.59% (Table 1).

As indicated in Figure 3, the main decline in the Icelandic harbour seal population occurred during the period of 1980 to 1990, however the decline continued after that point at a slower rate. The negative trend between 1980 and 2006 was significant; R_{est} = -0.04 (SE = 0.01), p>0.001 (Hauksson, 2010), while no significant trend was detected for the period 2011 to 2020; R_{est} =-0.01 (SE = 0.03), nonsignificant (ns).

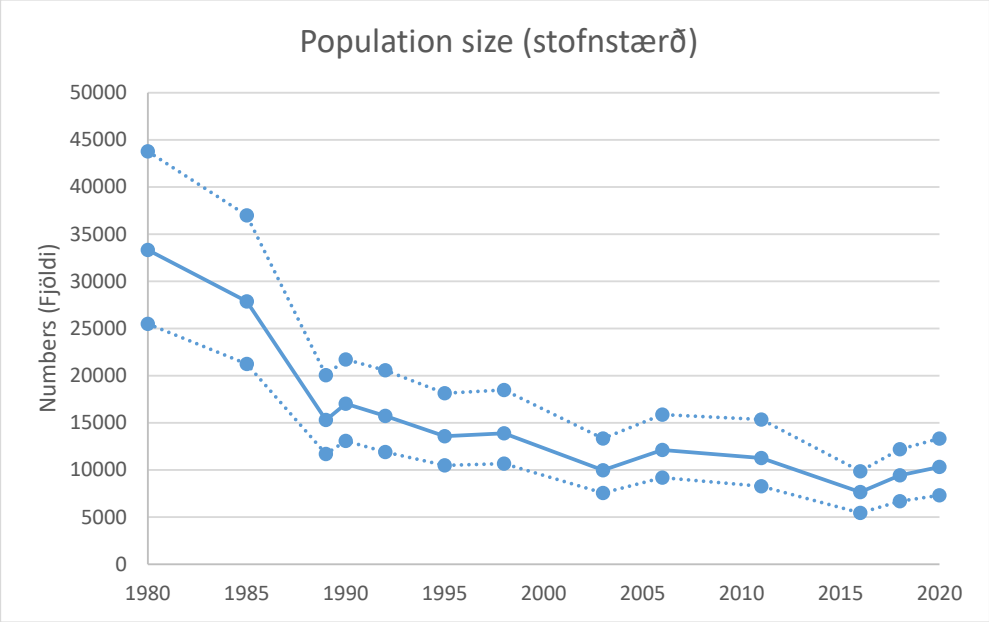

Figure 3. Changes in the Icelandic harbour seal population size from 1980–2020 (solid blue line) and the 90% confidence intervals (dotted line).

3. mynd. *Breytingar í stærð íslenska landselsstofnsins á árunum 1980 til 2020 (heil lína) ásamt 90% öryggismörk (brotnar línur).*

Table 1. Estimated population size from 1980 to 2020 and the governmentally issued management objective (M.o). The probability of the current population size being lower than previous estimates $P_{(pop2020<popyearX)}$. Exponential growth rate (R_{est}), with the linear percent change (Δ (%)) and annual discrete time per capita growth rate (λ (%)) from the relevant year compared to 2020.

Tafla 1. *Áætluð stofnstærð landsels við Ísland tímabilið 1980–2020, ásamt stjórnunarmarkmið stjórnvalda (M.o.). Líkur þess að núverandi stofnstærðin sé minni en árin á undan ($P_{(pop2020<popyearX)}$) með veldisvaxtarstuðull (R_{est}), prósentu breyting (Δ (%)) og ársvöxtur λ (%), miðað við ár 2020.*

Survey year	Est. pop.	$P(pop_{2020}<pop_{yearX})$	R_{est}	Δ (%)	λ (%)
1980	33,327[1]	100%	-0.03	-69.04%	-2.89%
1985	27,871[1]	100%	-0.03	-62.98%	-2.80%
1989	15,298[1]	100%	-0.01	-32.55%	-1.26%
1990	17,026[1]	100%	-0.02	-39.39%	-1.66%
1992	15,731[1]	100%	-0.02	-34.40%	-1.49%
1995	13,578[1]	96%	-0.01	-24.00%	-1.09%
1998	13,887[1]	97%	-0.01	-25.69%	-1.34%
2003	9,972[1]	42%	0.002	3.48%	0.20%
2006	12,122[1]	84%	-0.01	-14.87%	-1.14%
2011	11,272[2]	70%	-0.01	-8.45%	-0.98%
2016	7,652[3]	7%	0.08	34.85%	7.76%
2018	9,434[4]	31%	0.05	9.38%	4.59%
2020	10,319	-			
M.o.	12,000	82%			

[1]Hauksson 2010, [2]Granquist et al. 2011, [3]Þorbjörnsson et al. 2016, [4]Granquist and Hauksson 2019

3.3. Trends in the seven coastal sub-areas and in the individual counting areas

The highest number of harbour seals in 2020 was found in Northwest Iceland (907 seals), followed by the Eastfjords (861 seals) and the Westfjords (814 seals), while the lowest number of harbour seals was found in Northeast Iceland (138 seals). A higher number of seals were observed in all sub-areas in 2020 compared to 2018, except for South Iceland. Breiðafjörður had similar numbers of seals both years. When trend estimates based on the most recent population estimates (2011–2020) were calculated, significant trends were not found for any of the seven sub-areas. Nevertheless, during the period 1980–2006, a negative significant trend was found for three of the seven areas: Faxaflói, Eastfjords and South Iceland (Hauksson, 2010) (Table 2).

Table 2. Number of counted animals in each sub-area from censuses in the period 2011–2020. Trends in abundance of harbour seals for the periods 1980–2006 (Hauksson 2010) and 2011–2020, described by exponential growth rate (R_{est} (SE; standard error and significance level[a]). Adjusted coefficient of determination (R_{ad}^2) and residual standard error (RSE) are shown for the recent trends.

Tafla 2. *Fjöldi taldra landsela á mismunandi svæðum á tímabilinu 2011–2020. Árlegur veldisvöxtur fjölda landsela fyrir tímabilunum 1980–2006 (Hauksson 2010), og 2011–2020 (R_{est} (SE; staðalskekkja og marktækni[a])). Aðhvarfsgreiningarstuðull (R_{ad}^2) og staðalskekkja leifa aðhvarfsgreiningarinnar (RSE) er sýnt fyrir seinna tímabilið.*

Coastal sub-area	2011	2016	2018	2020	R_{est} (SE)$^{p\text{-value}}$ 1980-2006	R_{est} (SE)$^{p\text{-value}}$ 2011-2020	R_{ad}^2	RSE
Faxaflói	554.5	556	325	602	-0.07 (0.01)*	-0.01 (0.05)^{ns}	-0.45	0.34
Breiðafjörður	621	463	489	495	-0.06 (0.01)^{ns}	-0.03 (0.01)^{ns}	0.45	0.10
Westfjords	796.5	685	683	813.5	-0.02 (0.01)^{ns}	-0.003 (0.02)^{ns}	-0.47	0.12
Northwest Iceland	1461.5	615.75	867	906.5	-0.02 (0.01)^{ns}	-0.06 (0.05)^{ns}	0.05	0.35
Northeast Iceland	209	89.5	96	138	-0.04 (0.01)^{ns}	-0.06 (0.06)^{ns}	0.04	0.38
Eastfjords	530.5	530	624	860.5	-0.01 (0.01)*	0.05 (0.03)^{ns}	0.44	0.17
South Iceland	709	443.5	1084	743	-0.07 (0.01)*	0.02 (0.07)^{ns}	-0.41	0.43

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

In the following sub-chapters (3.3.1-3.3.7) changes observed in each of the counting areas in the seven different coastal sub-areas will be presented.

3.3.1 Faxaflói

The counting areas with the highest numbers in Faxaflói were Haffjörður and Hvalfjörður, with 155 and 115 seals respectively. The numbers in Hvalfjörður were about three times higher than what has been observed over the last ten years. No significant overall trend was observed for any of the counting areas in the period 2011–2018, while in the previous period (1980–2006), significant negative trends were observed for most of the counting areas in Faxaflói and for the sub-areas as a whole (Table 3).

Table 3. Number of observed animals in each counting area (see Fig. 1) in Faxaflói from censuses in the period 2011–2020. Trends in abundance of harbour seals for the periods 1980–2006 (Hauksson 2010) and 2011–2020, described by exponential growth rate (R_{est} (SE; standard error and p-value[a]).

Tafla 3. *Fjöldi taldra landsela á mismunandi talningarsvæðum (sjá 1. mynd) í Faxaflóa á tímabilinu 2011–2020. Árlegur veldisvöxtur í fjölda landsela fyrir tímabilunum 1980–2006 (Hauksson 2010), og 2011–2020 (R_{est} (SE; staðalskekkja og p-gildii[a])).*

#	Counting area	2011	2014	2016	2018	2020	R_{est} (SE)$^{p\text{-value}}$ 1980-2006	R_{est} (SE) $^{p\text{-value}}$ 2011-2020
1	**Akraós**	64	19	29	86	71	-0.06 (0.03)^{ns}	0.06 (0.10)^{ns}
2	**Borgarfjörður**	31	NA	40.5	18	57	-0.10 (0.05)*	0.03 (0.09)^{ns}
3	**Búðavík**	6	NA	36	22	65	0.03 (0.07)^{ns}	0.24 (0.08)^{ns}
4	**Haffjörður**	339	15	271	72	155	-0.05 (0.02)*	-0.02 (0.21)^{ns}
5	**Hvalfjörður**	35	NA	37.5	31	115	-0.04 (0.02)^{ns}	0.10 (0.09)^{ns}
6	**Hvalseyjar**	7	NA	4	29	2	-0.17 (0.03)*	-0.05 (0.21)^{ns}
7	**Leirárvogur**	24	NA	42	1	7	-0.06 (0.02)*	-0.23 (0.26)^{ns}
8	**Melar**	1	NA	0	7	12	-0.20 (0.04)*	0.29 (0.19)^{ns}
9	**Mýrar**	29.5	NA	60	47	87	-0.14 (0.03)*	0.11 (0.04)^{ns}
10	**Hafnarósar**	15.5	NA	32	10	31	-0.07 (0.02)*	0.04 (0.10)^{ns}
11	**W-Snæfellsnes**	2.5	NA	4	2	0	-0.12 (0.02)*	-0.15 (0.13)^{ns}
	Faxaflói, total	554.5	NA	556	325	602	-0.07 (0.01)*	-0.01 (0.05)^{ns}

[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 (Granquist et al 2014).

3.3.2 Breiðafjörður

The counting areas with the highest numbers in Breiðafjörður were, as in previous censuses, Lækjarskógarfjörur (159 seals) and Bæjarvaðall (130 seals). A big increase was observed in Skarðsströnd, where 31 seals were observed in 2020, while only 0-4 seals have been observed in censuses over the previous 10-year period. No significant trends were found for any of the counting areas over the recent years, while in the previous period (1980–2006) there was a significant negative trend in half of the counting areas in Breiðafjörður (Table 4, Figure 1).

Table 4. Number of observed animals in each counting area (see Fig. 1) in Breiðafjörður from censuses in the period 2011–2020. Trends in abundance of harbour seals for the periods 1980–2006 (Hauksson 2010) and 2011–2020, described by exponential growth rate (R_{est} (SE; standard error and p-value[a]).

Tafla 4. *Fjöldi taldra landsela á mismunandi talningarsvæðum (sjá 1. mynd) í Breiðafirði á tímabilinu 2011–2020. Árlegur veldisvöxtur í fjölda landsela fyrir tímabilunum 1980–2006 (Hauksson 2010), og 2011–2020 (R_{est} (SE; staðalskekkja og p-gildi[a]).*

#	Counting area	2011	2014	2016	2018	2020	R_{est} (SE) p-value 1980-2006	R_{est} (SE) p-value 2011-2020
12	**Álftafjörður**	0	NA	11	0	11	-0.11 (0.02)*	NA
13	**Bjarneyjar**	8,5	NA	10	4	1	-0.20 (0.05)*	-0.21 (0.12)ns
14	**Brimilsvellir**	22	NA	2	4	2	-0.13 (0.02)*	-0.25 (0.10)ns
15	**Bæjarvaðall**	176	75	112	160	130	-0.02 (0.02)ns	-0.00 (0.06)ns
16	**Fellsströnd**	64.5	NA	10	85	65	0.09 (0.03)ns	0.02 (0.18)ns
17	**Flateyjarlönd**	0	NA	0	2	0	-0.15 (0.04)*	NA
18	**Grónes/Hallsteinsnes**	0	NA	0	12	0	-0.10 (0.04)*	NA
19	**Hagadrápssker and Flögur**	0	NA	1	17	2	-0.17 (0.04)*	0.25 (0.22)ns
20	**Hergilseyjar and Sandeyjarhólmi**	12.5	NA	1	5	5	-0.12 (0.07)ns	-0.10 (0.18)ns
21	**Hjarðarnes**	5.5	NA	3	4	8	0.04 (0.06)ns	0.02 (0.08)ns
22	**Svefneyjar**	9	NA	12	8	18	-0.12 (0.02)*	0.05 (0.06)ns
23	**Kerlingarfjörður**	20	NA	0	2	3	-0.06 (0.04)ns	-0.23 (0.23)ns
24	**Króksfjarðarnes**	9.5	NA	1	2	3	-0.06 (0.02)*	-0.15 (0.14)ns
25	**Lækjarskógarfjörur**	181	57	267	114	159	0.03 (0.02)ns	0.01 (0.10)ns
26	**Drápsker**	12	NA	3	3	0	-0.10 (0.04)*	-0.31 (0.09)ns
27	**Rauðseyjar**	2	NA	12	18	15	-0.14 (0.03)*	0.25 (0.07)ns
28	**Reykhólalönd**	21	NA	3	15	2	-0.06 (0.03)ns	-0.20 (0.16)ns
29	**Skarðströnd**	3.5	NA	1	0	31	-0.17 (0.08)*	0.11 (0.32)ns
30	**Skálanes**	2.5	NA	1	0	0	-0.05 (0.03)ns	NA
31	**Skálmarnes**	2.5	NA	9	12	8	-0.07 (0.05)ns	0.15 (0.07)ns
32	**Skógarströnd**	14	NA	1	0	2	-0.15 (0.08)ns	-0.28 (0.18)ns
33	**Þórsnes and islands**	55	NA	3	22	30	-0.02 (0.05)ns	-0.07 (0.23)ns
	Breiðafjörður, total	621	NA	463	489	495	-0.06 (0.01)ns	-0.03 (0.01)ns

[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 (Granquist et al 2014).

3.3.3 Westfjords

Several large haul-out areas are found in the Westfjords. The highest number of seals in the Westfjords in 2020 was found in Ögurnes (153 seals), followed by Borgarey, Vogasker and Laugaból. In 2018, the highest number was observed in Reykjanes (137 seals), but only 44 seals were observed there in 2020. No significant trends were found for any of the counting areas in the Westfjords in the recent period (2011–2020). In the previous period (1980–2006), a significant negative trend was observed in three of the counting areas (Vogasker, Jökulfirðir and Reykjanes) (Table 5, Figure 1).

Table 5. Number of observed animals in each counting area (see Fig. 1) in the Westfjords from censuses in the period 2011–2020. Trends in abundance of harbour seals for the periods 1980–2006 (Hauksson 2010) and 2011–2020, described by exponential growth rate (R_{est} (SE; standard error and p-value[a]).

Tafla 5. *Fjöldi taldra landsela á mismunandi talningarsvæðum (sjá 1. mynd) á Vestfjörðum á tímabilinu 2011-2020. Árlegur veldisvöxtur í fjölda landsela fyrir tímabilunum 1980–2006 (Hauksson 2010), og 2011–2020 (R_{est} (SE; staðalskekkja og p-gildi[a]).*.

	Counting area	2011	2014	2016	2018	2020	R_{est} (SE) p-value 1980-2006	R_{est} (SE) p-value 2011-2020
34	**Aðalvík**	15	NA	3	0	23	-0.03 (0.04)^{ns}	-0.09 (0.31)^{ns}
35	**Borgarey**	82	46	92.5	109	126	-0.07 (0.04)^{ns}	0.07 (0.05)^{ns}
36	**Laugaból**	52	28	77.5	100	118.5	-0.01 (0.04)^{ns}	0.13 (0.06)^{ns}
37	**Grænahlíð**	0	NA	0	0	0	-0.05 (0.06)^{ns}	NA
38	**Vogasker**	90	NA	80	46	123	-0.08 (0.02)*	5.88e^{-04} (7.51e^{-02})^{ns}
39	**Jökulfirðir**	14	NA	64	5	52	-0.09 (0.04)*	0.06 (0.21)^{ns}
40	**Mjóifjörður**	11.5	55	86	118	87	-0.01 (0.02)^{ns}	0.23 (0.08)^{ns}
41	**Patreksfjörður-Tálknafjörður**	0	0	10	0	8	0.07 (0.03)^{ns}	NA
42	**Reykjanes**	206	56	106	137	44	-0.05 (0.02)*	-0.11 (0.09)^{ns}
43	**Súgandafjörður**	0	NA	0	0	22	-0.05 (0.07)^{ns}	NA
44	**Vatnsfjarðarnes**	177	47	71.5	91	48	0.02 (0.03)^{ns}	-0.10 (0.07)^{ns}
45	**Ögurnes**	149	83	88,5	77	153	0.02 (0.02)^{ns}	-0.01 (0.06)^{ns}
46	**Önundarfjörður**	0	NA	6	0	9	-0.06 (0.04)^{ns}	NA
	Westfjords, total	796.5	NA	685	683	813.5	-0.02 (0.01)^{ns}	-0.003 (0.02)^{ns}

[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 (Granquist et al 2014).

3.3.4 Northwest Iceland

Currently, the most important counting area in Northwest Iceland is Vatnsnes and in 2020 240 seals were observed there, which made Vatnsnes the only area in Northwest Iceland with over 100 observed seals in 2020. However, notably in 2011, 557 seals were observed in Vatnsnes. Vatnsnes was in 2020 followed by Sigríðarstaðaós (81 seals), West-Hrútafjörður (79) and Skagi (79). When individual counting areas were analysed, a significant negative trend over the period 2011–2020 was found for the counting area Drangar/Drangavik/Bjarnavík (p = 0.022), while a positive trend was found for Drangsnes (p= 0.02) (Table 6, Figure 1).

Table 6. Number of observed animals in each counting area (see Fig. 1) in Northwest from censuses in the period 2011–2020. Trends in abundance of harbour seals for the periods 1980–2006 (Hauksson 2010) and 2011–2020, described by exponential growth rate (R_{est} (SE; standard error and p-value[a]).

Tafla 6. *Fjöldi taldra landsela á mismunandi talningarsvæðum (sjá 1. mynd) á norðurlandi vestra á tímabilinu 2011–2020. Árlegur veldisvöxtur í fjölda landsela fyrir tímabilunum1980–2006 (Hauksson 2010), og 2011–2020 (R_{est} (SE; staðaskekkja og p-gildi[a]).*

#	Counting area	2011	2014	2016	2018	2020	R_{est} (SE) p-value 1980-2006	R_{est} (SE) p-value 2011-2020
47	**Eyjar**	14	8	1	36	20	-0.09 (0.02)*	0.08 (0.22)ns
48	**Suður Bjarnarfjörður**	5	5	2	17	11	-0.02 (0.04)ns	0.12 (0.12)ns
49	**Furufjörður**	8	NA	54.5	16	18	-0.04 (0.03)ns	0.08 (0.13)ns
50	**Drangar/Drangavík/Bjarnavík**	37.5	33	22.5	15	17	-0.03 (0.02)ns	-0.11 (0.02)*
51	**Drangsnes**	0	NA	11	20	31	0.04 (0.02)ns	0.48 (0.07)*
52	**Eyjarey**	20	NA	0	12	0	-0.06 (0.02)*	NA
53	**Vatnsnes**	556.5	76	179.5	256	239.5	-0.02 (0.03)ns	-0.04 (0.12)ns
54	**Heggstaðanes**	43	60	11.25	62	68	-0.01 (0.03)ns	0.04 (0.12)
55	**Horn - Straumnes**	0	NA	0	0	6	0.01 (0.08)ns	NA
56	**Kollafjörður**	53	16	44	74	58	-0.02 (0.02)ns	0.07 (0.09)ns
57	**Munaðarnessker**	3.5	13	5.5	22	9	0.04 (0.05)ns	0.01 (0.05)ns
58	**Litla Ávík**	24	35	54	37	25	-0.03 (0.04)ns	0.01 (0.05) ns
59	**Ófeigsfjörður**	75	55	35	60	65	-0.04 (0.04)ns	-0.01 (0.05)ns
60	**Reykjarfjarðarsker**	49.5	23	41.5	0	60	-0.04 (0.05)ns	-0.01 (0.05)ns
61	**Suður Reykjafjörður**	0	NA	7	0	11	-0.03 (0.04)ns	NA
62	**Siglufjörður**	0	NA	0	0	16	-0.06 (0.04)ns	NA
63	**Sigríðarstaðaós**	211.5	88	82.5	86	81	-0.004 (0.10)ns	-0.10 (0.04)ns
64	**Skagi**	110	NA	52.5	48	79	-0.04 (0.02)ns	-0.06 (0.06)ns
65	**Skjaldarbjarnarvík**	32.5	NA	0	6	13	-0.02 (0.05)ns	-0.12 (0.32)ns
66	**Vestur Hrútafjörður**	218.5	66	12	100	79	-0.02 (0.03)ns	-0.09 (0.17)ns
	Northwest, total	1461.5	NA	615.75	867	906.5	-0.02 (0.01)ns	-0.06 (0.05)ns

[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 (Granquist et al 2014).

3.3.5 Northeast Iceland

Few seals have generally been observed in Northeast Iceland, except for in Bakkahlaup (87 seals in 2020) and in Skjálfandafljót (49 seals). A significant increase was found in Skjálfandafljót for the period between 2011 and 2020 (p = 0.004), from 15 seals in 2011 to 49 seals in 2020. No significant trends were found for the other counting areas in the northeast during this period. In the earlier period (1980-2006), significant negative trends were observed for Melrakkaslétta, Skjálfandafljót and Tjörnes (Table 7, Figure 1).

Table 7. Number of observed animals in each counting area (see Fig. 1) in Northeast from censuses in the period 2011–2020. Trends in abundance of harbour seals for the periods 1980–2006 (Hauksson 2010) and 2011–2020, described by exponential growth rate (R_{est} (SE; standard error and p-value[a]).

Tafla 7. *Fjöldi taldra landsela á mismunandi talningarsvæðum (sjá 1. mynd) á norðausturlandi á tímabilinu 2011–2020. Árlegur veldisvöxtur í fjölda landsela fyrir tímabilunum 1980–2006 (Hauksson 2010), og 2011–2020 (R_{est} (SE; staðalskekkja og p-gildi[a]).*

#	Counting area	2011	2016	2018	2020	R_{est} (SE) p-value 1980-2006	R_{est} (SE) p-value 2011-2020
67	**Bakkahlaup**	164	53	50	87	-0.02 (0.02)^{ns}	-0.09 (0.08)^{ns}
68	**Eyjafjörður**	2	0	0	1	0.03 (0.04)^{ns}	NA
69	**Melrakkaslétta**	21	5	4	0	-0.07 (0.03)*	-0.37 (0.11)^{ns}
70	**Skjálfandafljót**	15	31.5	37	49	-0.06 (0.02)*	1.30e^{-01} (8.36e^{-03})**
71	**Tjörnes**	0	0	1	0	-0.13 (0.05)*	NA
72	**Þistilfjörður**	7	0	4	1	0.03 (0.09)^{ns}	-0.17 (0.19)^{ns}
	Northeast, total	209	89.5	96	138	-0.04 (0.01)^{ns}	-0.06 (0.06)^{ns}

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

3.3.6 Eastfjords

There are two large haul-out areas in the Eastfjords: Álftafjörður and Jökla. In 2020, these two areas had higher numbers than any other counting area in Iceland, with 389 and 356 seals respectively. Interestingly, numbers in the counting area Álftafjörður (including Hamarsfjörður and Kjöggur), had increased to 389 seals from ~130 seals in 2016 and 2018. In the period 1980–2006, a negative significant trend was observed in five out of the ten counting areas in the Eastfjords, as well as for the whole area in total. However, no significant trend was observed for any of the counting areas in the latter period (between 2011 and 2020) (Table 8, Figure 1).

Table 8. Number of observed animals in each counting-area (see Fig. 1) in the Eastfjords from censuses in the period 2011–2020. Trends in abundance of harbour seals for the period 1980–2006 (Hauksson 2010) and the period 2011–2020, described by exponential growth rate (R_{est} (SE; standard error and p-value[a]).

Tafla 8. *Fjöldi taldra landsela á mismunandi talningarsvæðum (sjá 1. mynd) á austfjörðum á tímabilinu 2011–2020. Árlegur veldisvöxtur í fjölda landsela fyrir tímabilunum 1980–2006 (Hauksson 2010), og 2011–2020 (R_{est} (SE; staðalskekkja og p-gildi[a]).*

#	Counting area	2011	2016	2018	2020	R_{est} (SE) p-value 1980-2006	R_{est} (SE) p-value 2011-2020
73	**Álftafjörður**	118.5	130.5	133	388.5	-0.04 (0.02)^{ns}	0.10 (0.07)^{ns}
74	**Bakkaflói**	2	2	10	11	-0.07 (0.02)*	0.21 (0.10)^{ns}
75	**Berufjörður**	40	72	99	40	0.06 (0.04)^{ns}	0.03 (0.08)^{ns}
76	**Breiðdalsvík**	9	0	17	27	-0.09 (0.02)*	0.13 (0.32)^{ns}
77	**Dalatangi**	27	1	0	6	-0.10 (0.01)*	-0.26 (0.27)^{ns}
78	**Eystrahorn**	0	2	0	0	-0.14 (0.03)*	NA
79	**Héraðsflói**	71.5	72.5	56	25	-0.01 (0.02)^{ns}	-0.10 (0.06)^{ns}
80	**Húsavík**	14	7	5	7	0.04 (0.07)^{ns}	-0.09 (0.04)^{ns}
81	**Jökla**	248.5	243	303	356	0.02 (0.03)^{ns}	0.04 (0.02) ^{ns}
82	**Loðmundar- Seyðisfjörður**	0	0	1	0	-0.11 (0.04)*	NA
	Eastfjords, total	530.5	530	624	860.5	-0.01 (0.01)*	0.05 (0.03)^{ns}

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

3.3.7 South Iceland

The largest haul-outs in South Iceland were Fjallsárós with 183 seals, followed by Öræfi (158 seals), and Kúðafljót (132 seals). The overall numbers for South Iceland had more than doubled in the last census (from 444 seals in 2016, to 1084 seals in 2018). The total number in the area had decreased again to 743 seals in 2020. Despite Fjallsárós being the counting area with most seals in this sub-area in 2020, that was one of the areas where the number has decreased most since 2018. In the earlier period, significant decreasing trends were observed in six of the 16 counting areas and there was also a negative trend for the area in total. Between 2011 and 2020, significant positive trends were found for Eyrarbakki/Stokkseyri (p = 0.004) and Selvogur (p = 0.001) (Table 9, Figure 1).

Table 9. Number of observed animals in each counting area (see Fig. 1) in South Iceland from censuses in the period 2011–2020. Trends in abundance of harbour seals for the period 1980–2006 (Hauksson 2010) and the period 2011–2020, described by exponential growth rate (R_{est} (SE; standard error and p-value[a]).

Tafla 9. *Fjöldi taldra landsela á mismunandi talningarsvæðum (sjá 1. mynd) á suðurlandi á tímabilinu 2011–2020. Árlegur veldisvöxtur í fjölda landsela fyrir tímabilunum1980–2006 (Hauksson 2010), og 2011–2020 (R_{est} (SE; staðalskekkja og p-gildi[a]).*

#	Counting area	2011	2014	2016	2018	2020	R_{est} (SE) p-value 1980-2006	R_{est} (SE) p-value 2011-2020
83	**Skaftárós**	90.5	NA	0	130	33	-0.11 (0.04)*	-0.04 (0.47)ns
84	**Eyrarbakki/Stokkseyri**	6	NA	11	16	21	-0.03 (0.05)ns	1.40e-01 (8.42e-03)**
85	**Fjallsárós**	219.5	NA	219.5	366	183	-0.07 (0.04)ns	0.01 (0.06)ns
86	**Hestgerðirlón**	12	NA	8.5	16	5	-0.14 (0.05)*	-0.06 (0.08)ns
87	**Öræfi**	164.5	NA	48	280	158	0.02 (0.11)ns	0.02 (0.14)ns
88	**Hornafjörður**	6	NA	28.5	6	44	-0.19 (0.17)ns	0.16 (0.15)ns
89	**Hrollaugseyjar-Tvísker**	0	NA	4	0	2	0.02 (0.06)ns	NA
90	**Kúðafljót**	95.5	39	87	118	132	-0.06 (0.01)*	0.07 (0.07)ns
91	**Landeyjarsandur**	1	NA	0	0	0	-0.19 (0.04)*	NA
92	**Markarfljót**	14.5	7	5	39	20	-0.07 (0.02)*	0.10 (0.12)ns
93	**Papós and skerries**	12.5	NA	0	30	22	-0.07 (0.05)ns	0.10 (0.34)ns
94	**Vestmannaeyjar**	2	NA	0	0	0	-0.09 (0.05)ns	NA
95	**Vígur í lóni**	7.5	NA	0	21	11	-0.15 (0.04)*	0.09 (0.30)ns
96	**Þjórsá**	62	10	9	29	46	-0.01 (0.02)ns	5.55e-04(1.45e-01)ns
97	**Selvogur**	4	NA	19	30	56	-0.05 (0.04)ns	0.29 (0.01)**
98	**Ölfusá**	11.5	10	4	3	10	-0.01 (0.06)ns	-0.07 (0.09)ns
	South Iceland, total	709	NA	443,5	1084	743	**-0.07 (0.01)***	0.02 (0.07)ns

[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 (Granquist et al 2014).

4. Discussion

4.1 Status of the population

On the IUCN Red List of Threatened Species, the global status of harbour seals is considered "least concern", although some regions, including Iceland, have been experiencing population decline (Lowry 2016). In the 2020 Icelandic harbour seal census, a total number of 4,559 animals were observed which yielded an estimated population size of 10,319 (CI 95%= 6,733-13,906) animals after correction factors had been applied. Although the population estimate was 9.38% larger than in 2018 when the last complete population census was conducted, it is 69.04% smaller than the first estimate of 33,327 animals conducted in 1980. The current population size is 14.00% below the government-issued management objective for the minimum population size of harbour seals in Iceland of 12,000 animals (oral statement, NAMMCO 2006). The importance of improving the status of the population should therefore be emphasized. On the Icelandic national red list for threatened populations, the Icelandic harbour seal population is defined as critically endangered based on the estimate from 2018. The current status should be re-evaluated based on the results from 2020, presented in this report. However, the population status is clearly sensitive, which underlines the necessity of further conservation actions.

The trend analysis suggested that the four decades that have passed since regular censuses commenced, can be divided into a period of decline from 1980 to 2006 and a period of stability at a minimal population level from 2006 to 2020. The population decreased rapidly in the first decade of the period (1980–1989). After that, the decline continued but at a slower pace than in the first decade. The partial census carried out at the most important counting areas in 2014, indicated historically low numbers of harbour seals around Iceland, and in the population estimate from 2016 the population was estimated to be 7652 animals, which is the smallest the population has ever been estimated (Granquist et al. 2014, Þórbjörnsson et al. 2017). However, the slight increase observed between 2016 and 2018, has continued between 2018 and 2020, indicating that the steep declining trend did not continue, which suggests that the population is currently fluctuating around a historical minimum population size. Therefore, although significant declines were found for the whole population between 1980 and 2006 and for the sub-areas Faxaflói, Eastfjords and South Iceland during the first period, no significant trend was found for the population in total (whole population), nor for any of the seven coastal sub-areas separately between 2011 and 2020 (Figure 1, Table 2). Further, only five of the 98 counting areas exhibited significant trends in the recent period (positive trend in four areas and negative trend in one area). The absence of detectable trends is most likely due to the drop in numbers in most areas between 2014 and 2018 being balanced by the higher numbers prior to 2014 and the increase of seal numbers in all areas, except South Iceland, between 2018 and 2020. The distribution of harbour seals around the coastal areas of Iceland seems to be rather stable and follows the general national trend. In Iceland, many of the haul-out sites have been occupied almost every survey year, supporting

the earlier findings that harbour seals are loyal to their breeding, resting and moulting-sites, showing strong site fidelity (Yochem et al. 1987, Thompson 1989).

4.2 Factors potentially affecting trends of the Icelandic harbour seal population

There are many factors that may potentially affect trends in the harbour seal populations, such as anthropogenic removals (hunting, culling and bycatch), prey availability, environmental changes, diseases and anthropogenic disturbance (Granquist et al. 2014, Lowry 2016). Many of these relationships are poorly understood and require more research, both internationally and for Icelandic conditions.

In 2019, new regulation regarding seal hunting in Iceland was enacted (Atvinnuvega- og nýsköpunarráðuneytið 2019). Seal hunting was banned, although it is possible for landowners to apply for exemptions to carry out so-called "traditional hunt", referring to utilization of seals by landowners where there had been a tradition of seal hunting and utilization. Prior to the ban, no quota or compulsory registration system pertaining to seal hunting/culling was in effect, which complicated not only hunting management in general, but also data collection on hunting statistics (Granquist and Hauksson 2016b).

Historically in Iceland, harbour seal skin and meat were considered fairly important resources. However, during recent decades this subsistence hunt had declined to very low numbers. Nevertheless, 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 and to limit the abundance of the seal worm (*Pseudoterranova decipiens*). The data presented in the current report shows that the largest decline in the harbour seal population occurred in the first decade (1980–1989), coinciding with the period when seals were culled to a large extent. In recent years prior to the implementation of the hunting ban, over 80% of the reported hunting of harbour seals was due to culling in the estuaries of salmonid rivers. The aim for this hunt was to reduce the potential effect that harbour seal predation was believed to have on the economically valuable salmon, trout and Arctic charr populations (Granquist 2016, Granquist and Hauksson 2016c), despite research results indicating that such hunting was ineffective in terms of increasing human salmonid harvest (Granquist et al. 2016).

While the hunting ban has prohibited culling and direct exploitation without an exemption, the largest mortality risk, by far, for the Icelandic harbour seal population is considered to be drowning in fishing gear. Seal bycatch occurs mainly in the lumpsucker fisheries but also in cod gillnet fisheries and demersal trawls at smaller magnitudes. Data used to quantify the magnitude of affected animals in the lumpsucker fisheries comes from inspectors, who are only able to cover a small proportion of the fishing effort (Marine and Freshwater Research Institute 2019). Increased data collection to facilitate more exact marine mammal bycatch estimates and to generate more information on the animals that get caught is advised.

Environmental changes, including climate change, are likely to affect seal populations in various ways. Currently, knowledge on how factors such as increasing sea temperatures, and

changes in weather and prey availability due to climate change are affecting population trends is scarce. Harbour seals are considered generalist predators, and hence may not be as vulnerable to changes in stocks of particular prey species as specialist predators. However, further research on how variation in prey availability can affect the Icelandic harbour seal population is needed (Granquist 2021).

Periods spent on land are essential for the viability of pinniped populations, especially during biologically important periods such as the pupping, nursing, mating and moulting periods. To facilitate sustainable management for pinniped populations, it's therefore crucial to consider anthropogenic activities at sea and on land at important haul-out sites. This applies not only to implementation of constructions near important haul-out sites, but also human presence in such areas. Due to increasing tourism in Iceland, areas important for harbour seals are frequently visited, including more remote areas. Anthropogenic disturbance can impact seals physiologically and affect their behaviour and distribution, which in turn may reduce fitness, both at an individual and at a population level (Granquist and Sigurjónsdóttir 2014). Therefore, it is important to study and subsequently minimise impacts due to disturbance as part of seal management strategies.

In addition to the human induced factors that can have effects on harbour seal population trends described above, factors pertaining to population identity, population demographics, fecundity and pup production should be considered. There is a pressing need to increase monitoring and knowledge of these components, to facilitate sustainable management of the population.

4.3 Methodological considerations

The estimates presented in this report are all, except for one (2011) based on a single over-flight survey of the entire Icelandic coastline. In 2011, three overflights were possible (Granquist et al. 2011). A single overflight, combined with a low census frequency with sometimes up to several years between censuses, impedes highly accurate population estimates and trend analyses. A higher census frequency combined with three replicates each year has been suggested as a way forward to increase the accuracy of results and to better detect population trends since the method increases statistical power (Teilmann et al. 2010). One overflight presents a potential bias of seals being missed by observers, for example due to local visibility difficulties (such as sunshine or fog). In addition, disturbance can cause seals to temporally move into the water and be totally submerged, which reduces the possibility of detecting the seals from the air. To increase the significance of harbour seal censuses, annual surveys or bi-annual surveys with three replicates are recommended.

The accuracy of the population estimate is partly based on the validity of the correction factor applied to counts in the calculation of an estimate (see Methods). Correction factors have not yet been optimized for Icelandic conditions. However, the correction factor used in the present estimate has been used since 2006 and the current estimate is directly comparable to all estimates made since 2006.

4.4 Future prospective

Despite the slight increase that has been observed in the harbour seal population since 2016, there is an 82% probability that the population remains under the management objective threshold level. Moreover, the population stays on the Icelandic red list for threatened populations. The sensitive conservation status of the Icelandic harbour seal population underlines the need to augment evidence-based seal management in Iceland. For example, it is important to continue regular censuses, but also to increase knowledge regarding what factors affect population trends and how these factors can be regulated. Increased monitoring for more precise assessments of indirect removals (bycatch in fishing gear), is an important step in this work. Further, it is important to note that management of seal populations is not only related to human induced mortality. It is also important to increase research regarding other factors that potentially affect seals both at the individual and population level, many of which are poorly understood. For example, the effects of environmental change, fluctuation in prey availability, and anthropogenic disturbance, such as due to increasing tourism pressure, should be researched thoroughly. Moreover, increased monitoring of population demographic factors such as recruitment to the population (fecundity, pup production and survival) and age distribution in the population is urgent.

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