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# THE ICELANDIC HARBOUR SEAL (*PHOCA VITULINA)* POPULATION: TRENDS OVER 40 YEARS (1980–2020) AND CURRENT THREATS TO THE POPULATION

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## ABSTRACT

Regular harbour seal (*Phoca vitulina*) population censuses are necessary to monitor fluctuations in the population size and to inform seal management. In this paper, the status of the Icelandic harbour seal population is presented, along with trends in the population over a 40-year period. In total, 13 full aerial censuses were carried out during the moulting season (July-August) between 1980 and 2020. The most recent census from 2020 yielded an estimate of 10,319 (CI 95%= 6,733-13,906) animals, indicating that the population is 69.04% smaller than when systematic monitoring of the population commenced in 1980 (33,327 seals). The observed decrease puts the population on the national red list for threatened populations. Trend analyses indicate that most of the decline occurred during the first decade, when the population decreased about 50% concurrently with large human-induced removals of harbour seals. After that point, the population decline slowed down but continued, and currently the population seems to fluctuate around a stable minimum level. The sensitive conservation status of the population underlines the need to assess and sustainably manage current threats to the population, including human-induced removals, anthropogenic disturbance, and various environmental factors such as contaminants, climate change and fluctuation in prey availability. Furthermore, it is urgent to continue regular censuses and to increase monitoring of population demographic factors.

*Keywords: harbour seal, phoca vitulina, population estimate, census, Iceland, population trend, marine mammals*

## INTRODUCTION

In order to facilitate and inform evidence-based management of seal populations, it's crucial to regularly assess population status and monitor population dynamics over time. Knowledge of spatial abundance and fluctuations in populations is also important for understanding their role in the ecosystem and provides a fundamental foundation for other seal research. Two seal species breed in Iceland: the harbour seal (*Phoca vitulina*) and the grey seal (*Halichoerus grypus*). In Iceland, harbour seals and grey seals are often observed to haul out together, although in general grey seals haul out in more remote areas. The Icelandic harbour seal population is distributed around the entire country and haul out in two types of habitats: rocky coast/skerries and sand banks, which are located either along exposed coastlines or within more sheltered river mouths (Hauksson, 2010). Some haul-out sites can hold large groups of up to several hundred seals, especially on the sandbanks of glacial rivers. However previous research has suggested that around 70% of the Icelandic harbour seal population haul out in smaller groups of 1-9 seals during the moulting season when the population census is carried out (Þorbjörnsson, Hauksson, Sigurðsson & Granquist, 2016).

The Icelandic harbour seal population is genetically distinct from other harbour seal populations (Liu et al., 2022). Systematic monitoring of the population commenced in 1980, when the population was estimated to be 33,327 animals. Since then, the population has experienced a dramatic decline, which has put the population on the national red list for threatened populations as endangered (Icelandic Institute of Natural History, 2020). Very little is known about the abundance of harbour seals in Iceland prior to the first estimate in 1980, apart from some opportunistic local counts (Hauksson, 2010). However, Hauksson & Einarson (2010) suggested by back calculating the population size based on data from skin exports that the population could have been considerably higher in the beginning of the 20th century, or about 60,000 animals. This implies that the decline may have started well before 1980. In 2006, the Icelandic government put forward a management objective for the Icelandic harbour seal population for the first time. The management objective stated that the population should not decrease below 12,000 animals and if that occurs, actions to prevent further declines should be taken.

Many factors have the potential to affect abundance of harbour seal populations. These include human-induced removals (hunting, culling and bycatch in fishing gear), anthropogenic disturbance (e.g. due to touristic activities, underwater noise and man-made structures) and various environmental factors including contaminants, climate change and fluctuation in prey availability (Granquist, Hauksson, & Stefánsson, 2014; Lowry, 2016). However, knowledge about the extent of different risks is scarce for Icelandic conditions.

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Table 1: Timing and coverage of the harbour seal censuses conducted around Iceland between 1980 and 2020. ([1]Hauksson, 2010; [2]Hauksson & Einarsson, 2010; [3]Granquist et al., 2011; [4]Granquist et al., 2014; [5]Þórbjörnsson et al., 2017; [6]Granquist & Hauksson, 2019; [7]Granquist, 2021a), estimated population sizes (Est. pop.) for respective year from 1980 to 2020, the probability of the most recent population estimate (from 2020) being lower than previous estimates P(pop2020<popyearX), exponential growth rate ($R_{est}$), with linear percent change (Δ (%)) and discrete time per capita growth rate (λ (%)) for each year compared to 2020.

| Census year | Counting period | Coverage | Est. pop. | P | $R_{est}$ | Δ (%) | λ (%) |
|---|---|---|---|---|---|---|---|
| 1980[1,2] | 11-22 August | The whole coast | 33.327 | 100% | -0.03 | -69.04% | -2.89% |
| 1985[1,2] | 20 July-4 August | The whole coast | 27.871 | 100% | -0.03 | -62.98% | -2.80% |
| 1988[1,2] | 7 July-23 August | Partial coverage | - | - | - | - | - |
| 1989[1,2] | 8 May-21 September | The whole coast* | 15.298 | 100% | -0.01 | -32.55% | -1.26% |
| 1990[1,2] | 11 August-28 September | The whole coast** | 17.026 | 100% | -0.02 | -39.39% | -1.66% |
| 1992[1,2] | 4 August-4 September | The whole coast | 15.731 | 100% | -0.02 | -34.40% | -1.49% |
| 1995[1,2] | 9 August- 13 September | The whole coast | 13.578 | 96% | -0.01 | -24.00% | -1.09% |
| 1998[1,2] | 8 August-2 September | The whole coast | 13.887 | 97% | -0.01 | -25.69% | -1.34% |
| 2003[1,2] | 28 July-22 August | The whole coast | 9.972 | 42% | 0.002 | 3.48% | 0.20% |
| 2006[1,2] | 9-25 August | The whole coast | 12.122 | 84% | -0.01 | -14.87% | -1.14% |
| 2011[3] | 14 July- 15 September | The whole coast covered 3 times | 11.272 | 70% | -0.01 | -8.45% | -0.98% |
| 2014[4] | 28 August- 2 September | Partial coverage | - | - | - | - | - |
| 2016[5] | 26 July- 2 September | The whole coast | 7.652 | 7% | 0.08 | 34.85% | 7.76% |
| 2018[6] | 25 July- 24 August | The whole coast | 9.434 | 31% | 0.05 | 9.38% | 4.59% |
| 2020[7] | 27 July- 24 August | The whole coast | 10.319 | - | | | |

** Northwest and South coast covered 4 times; ** Completion of survey delayed due to weather conditions.*

In this paper, the current status of the Icelandic harbour seal population is presented, along with trends in the population over a period of 40 years, from 1980 when regular censuses commenced until 2020. Hauksson (2010) investigated general and local trends in the population between 1980 and 2006, however in the current paper it was of special interest to investigate recent trends and changes that have occurred in the population since the management objective was enacted in 2006. In light of the results, potential current threats to the population are discussed and evaluated.

## METHODOLOGY

### Aerial surveys

Systematic aerial surveys, where animals hauling out on land are counted either directly or from photographs, is a frequently used method to estimate harbour seal population sizes (Bjørge, Øien & Fagerheim, 2007; Teilman, Riegert and Härkönen, 2010; Thompson, Duck & Lonergan, 2010). To obtain the most reliable estimates, it is important to consider factors affecting the likelihood of seals hauling out, such as time of year and environmental factors, and to standardize the timing of the census accordingly. Harbour seals aggregate on haul-out sites during the pupping period to give birth and during the moulting period, since being on land elevates the temperature of the skin, which leads to faster moulting (Granquist & Hauksson, 2016a; Ling, 1970; Paterson et al., 2012; Reder et al., 2003). Harbour seal population estimates are commonly conducted during either of these biologically important periods (Mogren et al., 2010), since it ensures counting the greatest proportion of the population. The environmental factors that should be considered in terms of harbour seal haul out behaviour are tidal state and weather conditions. Many studies have shown that tide height and time to low tide affect the haul-out pattern of harbour seals, with a higher number of seals hauling out during low tide (Granquist & Hauksson 2016a; Schneider & Payne, 1983; Thompson & Miller, 1990). Several meteorological factors can also affect harbour seal haul out patterns and should be considered, including precipitation (Grellier, Thompson, Corpe, 1996; Pauli & Terhune, 1987; Simpkins, Withrow, Cesarone, & Boveng, 2003), wind speed and direction (Brasseur, Creuwels, vd Werf, & Reijnders, 1996; Simpkins et al., 2003), temperature (Brasseur et al., 1996; Pauli & Terhune, 1987; Reder et al., 2003; Simpkins et al., 2003) and fog/cloud coverage (Grellier et al., 1996; Pauli & Terhune 1987).

In Iceland, the surveys were conducted during the moulting period, which occurs between the end of July and the beginning of August. Previous research suggest that the moulting period represents a peak in the proportion of seals hauled out and hence is the optimal timing to conduct the aerial survey in Iceland (Granquist & Hauksson, 2016a). The survey period had to be extended into September some years due to unfavourable weather conditions (Table 1). Further, to increase the significance of the population estimate and minimise the effects of environmental factors, conditions were standardized in the following way: all flights were conducted over a period of three hours before low tide until three hours after low tide and only in clear weather with good visibility, without precipitation and when the windspeed was below 10 m/s.

In total, 13 full surveys have been conducted between 1980 and 2020, where the entire coast was covered at least once during the survey period. Teilman et al. (2010) suggested that to optimize harbour seal censuses, up to three counts would be desirable. However, this was seldom possible here due to cost-

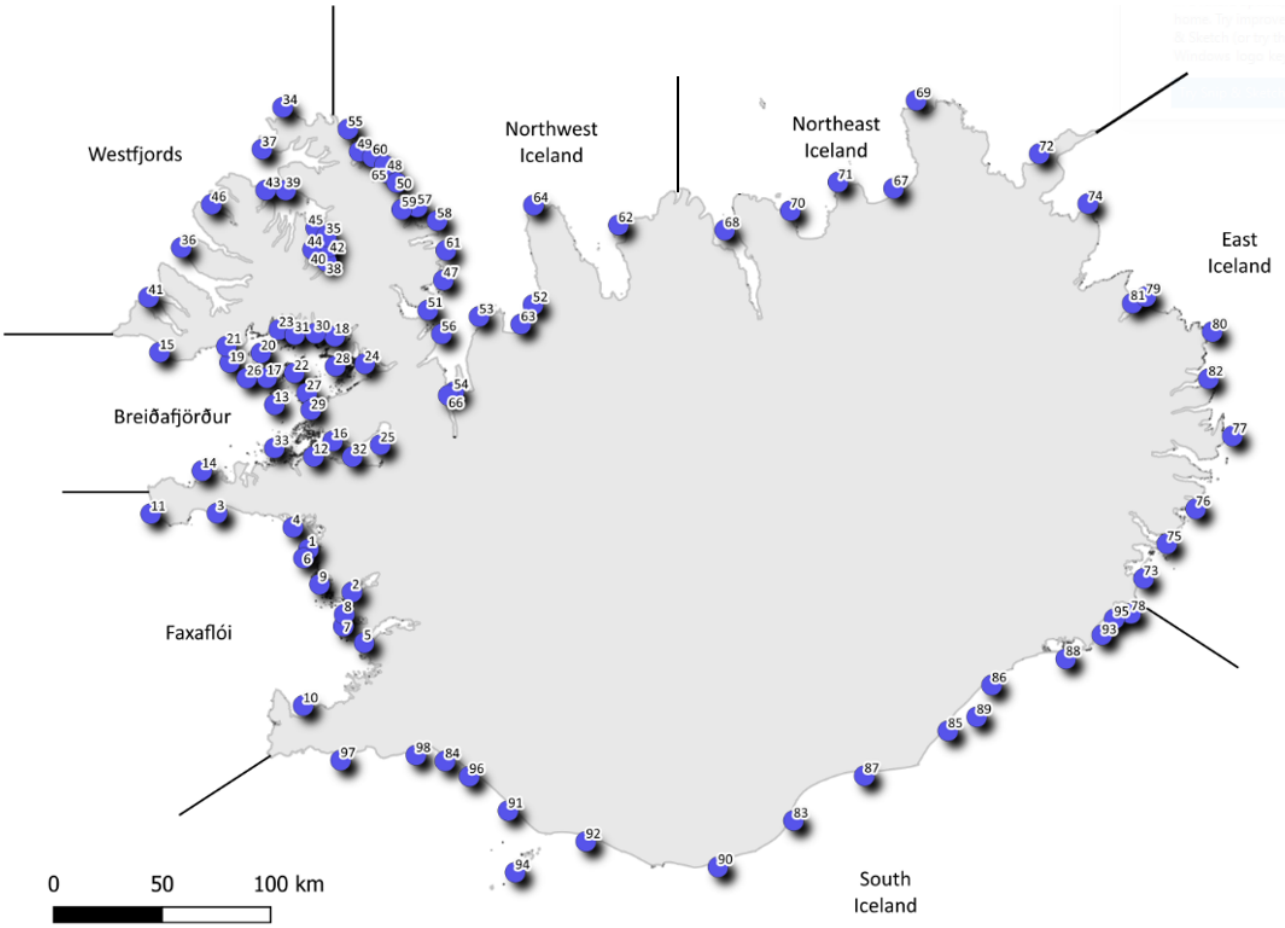


Figure 1: The seven coastal sub-areas of Iceland: Faxaflói, Breiðafjörður, Westfjords, Northwest Iceland, Northeast Iceland, East Iceland and South Iceland. The 98 counting areas are indicated by circles (the circles refer to the middle of each counting area and do not represent the exact placement of individual haul-out sites since counting areas often consist of several haul-out sites). Names and trends for the counting areas can be found in Supplementary Table 1.

and weather factors. In Iceland, poor weather conditions (strong wind or fog) are a common and substantial challenge when carrying out aerial surveys. However, in 2011, three overflights were done over the whole coastline and in 1989 the whole coastline was covered once during the main survey period and the Northwest coast and South coast of Iceland were covered once per month between May and September that year. In other surveys, some important counting areas were covered twice to increase the reliability of the surveys. In addition to the 13 full surveys, partial surveys were carried out in 1988 and 2014 Table 1 shows the timing and success of harbour seal censuses in Iceland.

The coastline is divided into seven coastal sub-areas (Figure 1) and each sub-area is divided into several counting areas (in total for the whole coast= 98 counting areas, see Figure 1 and Supplementary Table 1), each of which can include several haul-out sites. To enable exact site comparison between censuses, the geographical area definition of coastal sub-areas and counting areas has been identical throughout all survey years (Hauksson, 2010).

All surveys were conducted from small airplanes, with one or two observers on board. Smaller groups (<30 seals) were counted directly, and larger groups (>30 seals) were photographed through an open window. In the first surveys a 35 mm colour slide film (ASA 400) with a camera shutter speed minimum 1/500 and a 70-150 mm zoom lens was used. From 1998, a digital still camera, Cyber shot 5.0 megapixels with 10x precision digital zoom was used (Hauksson, 2010). From 2011, a Canon 5DS full-frame digital camera was used, equipped with a Canon 70-200 mm f/2.8L II USM lens with image stabilization and fitted with a Global Positioning System (GPS), which assigns geographic coordinates to each image (Granquist, 2021a).

**Analysis**

Following the aerial surveys, analysis of photographs and direct counts was carried out. For smaller groups (<30 seals) the direct count value was used. In the earlier surveys, photographic slides were projected on a white surface or analysed by viewing slides in a microscope. Digital photos from the latter surveys were viewed and analysed on computer screens. The photographic images were usually analysed by a single observer, but on a few occasions up to three separate observers analysed all the images. In cases where more than one observer analysed images, care was taken to ensure inter-observer reliability (agreement between observers >95% and the average number of seals used). When counting areas were covered more than once, the average of the observations was used.

The population estimates were based on the total number of observed animals each survey year, corrected for animals in the population that are not hauling out during the survey and are missed by the observer, by applying a correction factor of 2.26 (SD=0.41) (see;Hauksson & Einarsson, 2010). To generate the estimated population size, the total number of observed animals was multiplied by 10,000 normally distributed correction factors with the stated parameter estimate of 2.26 (SD=0.41), and the average was chosen to represent the population estimate. The presented population sizes thus refer to an estimated number of 0+ animals (adults and pups of the year).

To assess the current status of the population, changes in the population size between the most recent estimate (from 2020) and previous estimates (Granquist, 2021a) were assessed by applying the following equations:

Estimated exponential growth rate ($R_{est}$) was calculated as described in 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: $\lambda = \exp(R_{est})$ ,

where $N_{last}$ was the most recent value, $N_{first}$ was the earlier value which $N_{last}$ was compared to and ΔT was the total time interval (in years) of which a change is examined ($T_{last} - T_{first}$) (see Mills, 2012). Normal cumulative distribution (CDF) (Sokal & Rohlf, 1997) was used to calculate the probability of the most recent population estimate being lower than estimates from previous years.

A linear regression model on ln transformed numbers was applied to estimate trends based on all population estimates (1980–2020). In addition, trends for periods of particular interest were estimated (earlier period 1980-2006 compared to the recent period 2011-2020) for the whole coastline, as well as locally for the seven coastal sub-areas and the 98 different counting areas. All analysis was carried out in RStudio (Rstudio. Version 3.3.1. 2016).

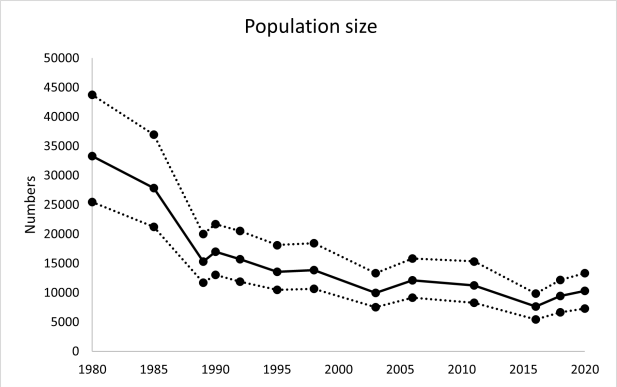


Figure 2: Changes in the Icelandic harbour seal population size from 1980–2020 (solid line) and the 90% confidence intervals (dotted lines).

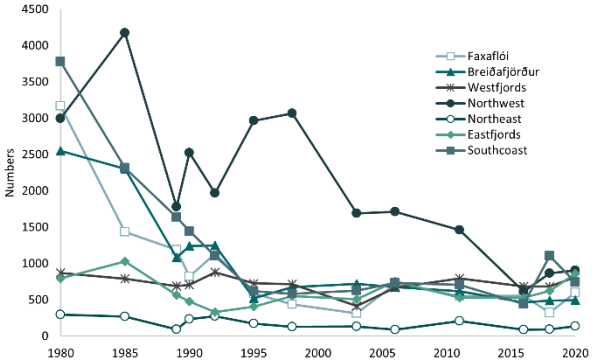


Figure 3: Number of counted animals for each coastal sub-area over the period 1980–2020.

Table 2: Coastal sub-areas and the corresponding counting areas (see Figure1), trends in harbour seal abundance in each coastal sub-area for the periods 1980–2006 (published in Hauksson, 2010) and 2011–2020: exponential growth rate ($R_{est}$), standard error (SE) and p-value (Significance levels: ns = not significant, * significant at the 5%, ** 1 % and *** 0.1%). Adjusted coefficient of determination ($R_2^{ad}$) and residual standard error (RSE) are shown for the latter period.

| | | 1980-2006 | 2011-2020 | | |
|---|---|---|---|---|---|
| **Coastal sub-area** | **Counting areas** | **$R_{est}$ (SE) p-value** | **$R_{est}$(SE) p-value** | **$R^2_{ad}$** | **RSE** |
| Faxaflói | 1-11 | -0.07 (0.01)* | -0.01(0.05) ns | -0.45 | 0.34 |
| Breiðafjörður | 12-33 | -0.06 (0.01)ns | -0.03 (0.01) ns | 0.45 | 0.10 |
| Westfjords | 34-46 | -0.02 (0.01) ns | -0.003 (0.02) ns | -0.47 | 0.12 |
| Northwest Iceland | 47-66 | -0.02 (0.01) ns | -0.06 (0.05) ns | 0.05 | 0.35 |
| Northeast Iceland | 67-72 | -0.04 (0.01) ns | -0.06 (0.06) ns | 0.04 | 0.38 |
| East Iceland | 73-82 | -0.01 (0.01)* | 0.05 (0.03) ns | 0.44 | 0.17 |
| South Iceland | 83-98 | -0.07 (0.01)* | 0.02 (0.07) ns | -0.41 | 0.43 |

## RESULTS

### General population trend and current status

The first full harbour seal census was carried out in 1980 and the population estimate was 33,327 seals. Between 1980 and 1989 the population decreased by around 50% and between 1990 and 2016 the population decrease continued but at a slower rate. In 2016, the estimated population size was 7.652 animals, which is the smallest estimate since censuses commenced (Þórbjörnsson et al., 2017). However, the two most recent estimates, from 2018 (Granquist & Hauksson 2019) and 2020 (Granquist, 2021a), were slightly higher, which might suggest that the decrease has abated (Table 1, Figure 2). The latest population estimate from 2020 is 10,319 (CI 95%= 6,733-13,906) animals, which suggests that the current population is 69.04% smaller than when first estimated in 1980. This corresponds to 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). The 40-year history of harbour seal population estimates was divided into two periods: the recent period (2011-2020) and the earlier period (1980-2006). In the earlier period, a significant negative trend was found; $R_{est}$ = -0.04 (SE = 0.01), p>0.001 (trends published in Hauksson, 2010). In the more recent period between 2011 and 2020 the population was stable at a historical minimum and no significant trend was detected; $R_{est}$ =-0.01 (SE = 0.03), p= 0.716 (Granquist, 2021).

### Local population trends

The severe drop found in the population as a whole during the first 10 years of the monitoring program (1980-1989) was due to a rapid drop in five of the seven coastal sub-areas (Faxaflói, Northwest, Breiðafjörður, South Iceland and East Iceland) (Figure 3). When the earlier period of 1980-2006 is compared with the recent period of 2011-2020 for the seven coastal sub-areas, significant negative trends were found in the earlier period for Faxaflói ($R_{est}$ = -0.07, SE=0.01, p<0.05), East Iceland ($R_{est}$ = -0.01, SE=0.01, p<0.05) and South Iceland ($R_{est}$ = -0.07, SE=0.01, p<0.05), while in the recent period, no significant trends were found for any of the coastal sub-areas (Table 2).

In the first counting year (1980), the highest number of seals was found in South Iceland, however from that point, the decrease was very steep in this coastal sub-area and over a period of 15 years, the number dropped by 84%. Since 1995, the numbers have stayed around a minimum level in South Iceland, except in 2018, when the south coast was the coastal sub-area with the highest number of observed seals. Interestingly, the steep decrease observed for the other large coastal sub-areas during the first five years of the monitoring program, was not observed in Northwest Iceland, where the number of animals instead increased between 1980 and 1985. Then the area experienced some fluctuation in numbers, followed by a rapid decrease. In fact, between 1998 and 2016, Northwest was the single coastal subarea responsible for the continuing negative trend for the total population. However, apart from the very first estimate, population numbers in Northwest Iceland remained the highest of all coastal sub-areas of Iceland until 2016. Breiðafjörður experienced a decrease between 1980 and 1989, however no significant trend was found for the earlier period as a whole, due to a slight increase in this area between 1989 and 1992. The Westfjords, East Iceland and Northeast Iceland have had more stable numbers, and the high levels observed in other coastal sub-areas during the earliest surveys were not observed here. East Iceland has had the lowest number of seals throughout (Figure 3). For the past decade, the number of seals remained relatively stable in all coastal sub-areas. In the most recent censuses (2016–2020), numbers were relatively similar in all areas, apart from in Northeast Iceland, where numbers were substantially lower; e.g. in the most recent census from 2020, the highest number of harbour seals was found in Northwest Iceland (907 seals), followed by the Eastfjords (861 seals) and the Westfjords (814 seals), while the number of harbour seals in Northeast Iceland was 138 seals (Figure 2 and 3).

When investigating the 98 counting areas, 38 areas experienced significant negative trends (p<0.05) between 1980 and 2006. During the latter period, however, only five of the 98 counting areas exhibited significant trends (positive trends in four counting areas and a negative trend in one area, p<0.05) (Supplementary Table 1). In 1980, 20 of the 98 counting areas had over 200 seals (representing 20.4% of the counting areas), and of those, four had more than 500 seals. Only three of the counting areas had over 800 seals of which two areas had over 11000 seals. In 2020, the number of seals had decreased in most counting areas and only three counting areas had over 200 seals, representing 3.06% of the counting areas (Figure 4).

## DISCUSSION

In this paper, the trends in the Icelandic harbour seal population have been investigated and the current status of the population in general and in different local areas explored. The dramatic decrease in the population during the earlier periods of the monitoring program and the fact that the population has not recovered, calls for actions to prevent further decrease. Further, the population size is currently estimated to be 14% under the management objective of 12.000 animals. Since knowledge about the effect of different risk factors for the Icelandic harbour seal population is scarce, it is important to study such threats further. In this section, the current situation and state of the art knowledge regarding factors posing a potential threat to the Icelandic harbour seal populations will be discussed.

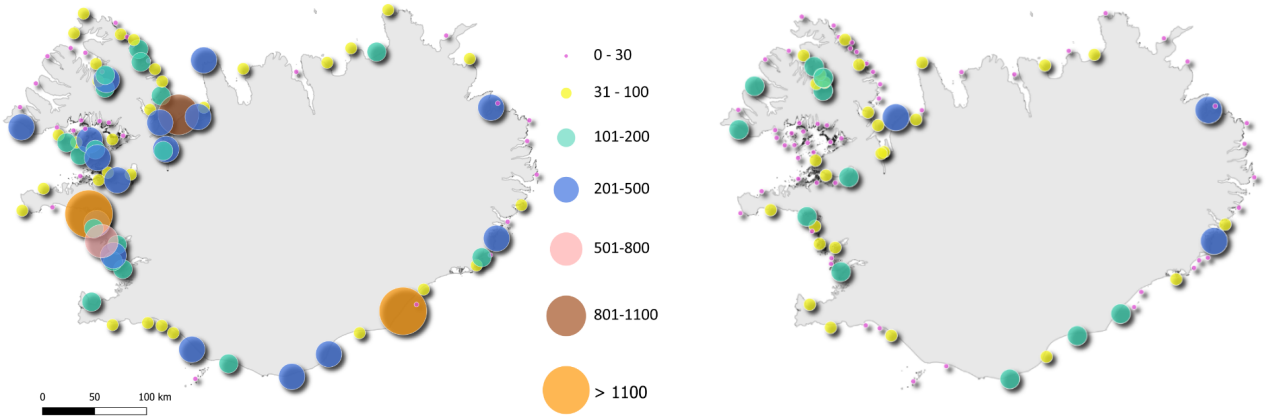


Figure 4: The 98 counting areas are indicated by circles (the circles refer to the middle of each counting area and do not represent the exact placement of individual haul-out sites since counting areas often consist of several haul-out sites). The size of the circles indicates the number of harbour seals in each counting area in the census from 1980 (first census, left) and the census from 2020 (the most recent census, right). Numbers, names and trends for the counting areas can be found in Figure 1 and Supplementary Table 1.

**Human-induced removals: subsistence hunting, culling and bycatch**

Controlling human-induced mortality—including subsistence hunting, culling and bycatch of seals in fishing gear—is often the first measure taken when managing endangered seal populations. Prior to 2019, there was no hunting management system in effect for seal hunting in Iceland. In addition, registration of seal hunting statistics was not compulsory, which complicated population management further, since reliable statistics of human-induced seal mortality is a foundation for management (Granquist & Hauksson, 2016b). In 2019, seal hunting was officially banned in Iceland, though it is possible for landowners to apply for exemptions for traditional utilization of seals (Ministry of industry and innovation, 2019).

Historically, harbour seals were hunted in sealing nets by farmers, as skins, blubber and meat were considered valuable resources. During recent decades, subsistence hunting had decreased to very low numbers and the reasons for human removal of seals had shifted. In the 1980s, a bounty system for harbour seals was initiated with the aim to limit the prevalence of the parasitic worm *Pseudoterranova decipiens* in the flesh of commercially important codfishes. Between 1980 and 1989, the harbour seal population dropped by half, from 33.327 animals to 15.298, which coincides with the temporary high level of culling due to the bounty system. After that point, the culling of harbour seals ceased. In the years prior to the hunting ban, over 80% of the reported seal hunting occurred in the estuaries of economically important salmonid rivers, since there is a common belief that seal predation can affect human salmonid harvest (Granquist & Hauksson 2016c). However, research results suggest that salmon, trout and charr are not important prey for harbour seals hauling out in estuaries in Iceland (Granquist, 2014; Granquist & Hauksson, 2016c; Granquist, Esparza-Salas, Hauksson, Karlsson, & Angerbjörn, 2018).

Despite the fact that seal hunting had decreased to rather low numbers before the hunting ban was enacted, regulating seal hunting is an important step in the work towards the recovery of the Icelandic harbour seal population. Nevertheless, the largest mortality risk by far for harbour seals around Iceland today is considered to be drowning due to bycatch in fishing gear. Seals are mainly by-caught in lumpsucker fisheries, but bycatch also occurs at lower levels in cod gillnet fisheries and demersal trawls. The estimated annual average of harbour seals drowning in the lumpsucker fishery only, over a five-year period (2014-2018), was 1389 (CV=35) harbour seals per year (Marine and Freshwater Research Institute, 2019, 2021). Recently, attempts have been made to reduce seal bycatch around Iceland. Experimental closures have been enacted in marine areas of the lumpsucker fishery where bycatch risks are highest. Further, preliminary experiments have also been made with pingers on fishing gear (audio deterrent devices, ADDs) with the purpose of reducing bycatch (NAMMCO, 2020). Considering the high estimate of harbour seals drowning in fishing gear around Iceland, limiting bycatch is a conservational imperative.

**Anthropogenic disturbance and tourism**

Harbour seals spend a large proportion of their time on land during biologically important periods, such as the pupping, nursing, mating and moulting seasons. During these sensitive periods, pinnipeds are also usually most vulnerable to disturbance (Kovacs & Innes, 1990) and therefore, it's extremely important to take into consideration land based anthropogenic impacts on important haul-out sites when managing seal populations. Actions that can have impacts on haul-out sites include man-made structures, sometimes causing habitat loss and forcing animals to change spatial distribution. Further, anthropogenic disturbance due to human presence in the vicinity of haul-out sites can affect seals. As described above, in Iceland, the harbour seals are commonly rather dispersed and often haul out in small groups around the whole coastline. The Icelandic coast has vast areas free of man-made structures, hence, habitat loss and lack of suitable haul-out sites is not yet considered a problem in Iceland. However, the number of tourists that visit Iceland has exploded during the last decade (Óladóttir, 2018). Visitors mainly come to Iceland to engage in nature-based tourism and even extremely remote areas are now frequently visited by people, including areas with important harbour seal haul-out sites that were, until recently, never visited by people. Further, the interest in seal watching tourism has increased and several places have been developed specifically for that purpose (Aquino, Burns, & Granquist, 2021). Due to the nature of the activity, haul-out sites with high

numbers of seals are often chosen, which means sites that are important for the viability of the population.

It has frequently been reported in the literature that anthropogenic disturbance can impact seals physiologically by causing stress and affecting their behaviour and distribution, which may reduce fitness at the individual and population levels (Cassini, Szteren, & Fernández-Juricic, 2004; Granquist & Sigurjónsdóttir, 2014; Johnson & Lavigne 1999). In Iceland, effects of tourism on the seal population (Clack, 2016; Granquist & Sigurjónsdóttir, 2014) and sustainable seal watching management have been studied (Aquino et al., 2021; Granquist & Nilsson, 2016; Marschall, Granquist, & Burns, 2016). For example, research from important seal watching areas has shown that seals move further away from the seal watching site during periods of high tourism pressure. Furthermore, seals are more vigilant and hence spend less time engaged in necessary behaviours such as resting, when visitors behave in an intense way (Granquist & Sigurjónsdóttir, 2014). However, there is evidence showing that it's possible to reduce disturbance by influencing tourists' behaviour (Granquist & Sigurjónsdóttir, 2014; Marschall et al., 2016), which is an important finding in terms of management (Chauvat, Aquino, & Granquist, 2021; Öqvist, Granquist, Burns, & Angerbjörn, 2017). This implies that it's not only important to take into consideration human-induced removals in management plans, but also to consider the importance of protecting important haul-out sites, especially considering the sensitive conservation status of the Icelandic harbour seal population (Kovacs et al., 2012).

**Environmental changes and contaminants**

Environmental changes, including climate change, have often been found to affect seal populations, especially in the polar regions (Blanchet, Vincent, Womble, Steingass, & Desportes, 2021; Poloczanska et al., 2013). Very little is known about how factors associated with climate change affect harbour seals in Iceland. It has been speculated that warming sea and air temperatures, increased frequency of storms and changes in prey availability may affect the abundance and viability of the Icelandic harbour seal population (Granquist, 2021a).

Environmental contaminants can affect pinnipeds at the population level, for example by affecting the reproductive system and suppressing immune systems, which can lead to population declines (Sonne et al., 2020). Relatively little is known about the effects of contaminants on the Icelandic harbour seal population, although research suggests that in general, the level of many environmental contaminants is low around Iceland, compared to other areas (e.g. Sturludóttir et al., 2013; Ministry for the environment and natural resources, 2021). Some studies on environmental toxins in Icelandic seals exist and most indicate low levels of contaminants compared to other geographical areas (e.g. chlorinated hydrocarbons (Gregory & Cyr, 2002) and PFAS (Span et al., 2020)). However, more research on the effects of environmental factors such as climate change and contaminants is needed to determine the possible effects at the population level.

## CONCLUSIONS AND FUTURE PERSPECTIVES

In the future it's important to continue to research factors that affect the abundance of the Icelandic harbour seal population. The sensitive status of the population, as evidenced by the status on the national red list for threatened populations, and by the fact that the population is fluctuating around a historically minimum population size, implies that the focus should be on minimizing or terminating factors affecting the population negatively. Although high levels of human-induced removals are likely to have highly contributed to the severe decrease in the Icelandic harbour seal population, especially in the first decade of the monitoring program, more research is required to achieve a full understanding regarding the background of the decrease. The information presented in this paper suggests that there are several potential threats to the population, which should be investigated further to facilitate the implementation of solutions. Since the highest mortality risk currently is bycatch in fishing gear, it should be of high conservational priority to establish measures to minimize that risk and to increase monitoring thereof, for more precise bycatch statistics. Moreover, as a foundation for future research it's extremely important to continue to monitor abundance regularly to detect trends, but also to increase knowledge of population demographic factors such as recruitment to the population (fecundity, pup production and survival) and population identity. This will facilitate sustainable and evidence-based management of the Icelandic harbour seal population.

## ADHERENCE TO ANIMAL WELFARE PROTOCOLS

The research presented in this article has been done in accordance with the institutional and national laws and protocols for animal welfare that are applicable in the jurisdictions where the work was conducted.

## AUTHOR CONTRIBUTION STATEMENT

Conceptualisation; Project planning and administration; Data collection; Analysis; Writing: Sandra M. Granquist

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