Monitoring trends in the abundance of harbour seals *(Phoca vitulina)* in Icelandic waters

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ABSTRACT

Harbours seal (*Phoca vitulina)* numbers along the coast of Iceland were monitored by aerial survey in the period 1980-2006. Trends in the abundance of the harbour seal population on the whole coast and in coastal regions of Iceland waters were estimated using ANCOVA on the survey counts, corrected for the influence of several covariates. Harbour seals were found in every coastal area, but were most abundant in Faxaflói, Breiðafjörður and on the northwest coast in the beginning of this study. Harbour seal numbers declined significantly at a rate of r_{est} = -0.04 (SE 0.005) yr^{-1} during this period. Decline was highest in Faxaflói and at the south coast (≅7%), while the east coast experienced a significant but lesser (≅1%) decline. Other coastal areas did not show significant trends. The northwest coast was the richest harbour seal area in Iceland in 2006. In Icelandic waters seals are commercially harvested, and unreported but probably high numbers of harbour seals are killed intentionally by shooting and accidentally in fishing gear each year. These factors likely contributed to the overall observed decline in seal numbers.

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INTRODUCTION

An understanding of population status of the Icelandic harbour seal (*Phoca vitulina vitulina*) is a fundamental requisite for its effective management and conservation. The current catches are low (104 harbour seals were caught in year 2007) but were much higher in the past (in the 1970's the annual catch was about 6,000 (MRI 2008)). The exploitation of the stock and the unreported but possibly high numbers of harbour seals killed intentionally by shooting and accidentally in fishing gear each year (Hauksson and Einarsson 2010) makes it highly relevant to monitor harbour seal abundance on a regular basis. In addition, current and accurate information on trends in abundance is needed to understand the role of the population in ecosystem dynamics, its potential interactions with fisheries, the impacts of global climate change, and other anthropogenic changes caused in habitat (Small *et al.* 2003).

In Iceland harbour seals inhabit coastal waters all around the country (Fig. 1). There are 2 types of haulout sites, rocks (Fig. 2) and sandbanks (Fig. 3), which can be at the exposed coast or inside sheltered river estuaries, frequently glacial rivers. Hardly any data on trends of total numbers are available prior to 1980 and no aerial surveys covering the entire coastline were undertaken. Arnþór Garðarsson (unpublished) counted harbour seals from an aircraft on part of the Icelandic coast in the summers of 1973 and 1977. He found 2,500; 632 and 3,568 harbour seals in Faxaflói, Vestfjörðum and the northwest - northeast coasts respectively (cited in Einarsson 1978). Pálsson (1976) carried out aerial counts of harbour seals on the south coast of Iceland in 1976 and observed 5,800 animals. There have also been other opportunistic counts of harbour seals at specific locations for studying haulout behaviour and seasonal distribution (Hauksson 1985, 1986, 1992a, 1993 and unpublished).

Harbour seals in Icelandic waters have been exploited as far back as at the time of the first settlements. Catch statistics are available until the late 19th century, showing high catches of mainly pups for skins, which were exported (Hauksson and Einarsson 2010). In the period 1982-1989 a bounty was paid for catching harbour seals off the coast, which increased noticeably the mortality of harbour seals of all age classes (Hauksson 1992b). Hauksson and Einarsson (2010) speculate that in the 19th and early 20th centuries the population size of the Icelandic harbour seal was much larger (about 60,000) than in 2006 (about 12,000), and that the decline in the population may have started as early as 1970.

Regular monitoring of the Icelandic harbour seal population only started recently. The first aerial survey which covered the whole coast was carried out in 1980 (Hauksson 1986). In this paper I present estimates of trend in harbour seal abundance on 98 haulout sites around Iceland, as well as trend in the coastal areas and finally the overall trend on the whole coast, based on the aerial surveys performed in the period 1980-2006.

MATERIALS AND METHODS

Aerial surveys

Beginning in 1980 the whole coast of Iceland, except the island Grimsey far off the north coast (Fig. 1), and the island of Hvalbakur far off the southeast coast (about 64°36´N, 13°17’ W, outside the area shown on Fig. 1) was usually surveyed in the period late July- early September. Grimsey and Hvalbakur are known to be inhabited by only few harbour seals, and are situated far from the main coast, outside the flying capacity of the single-engine aircraft

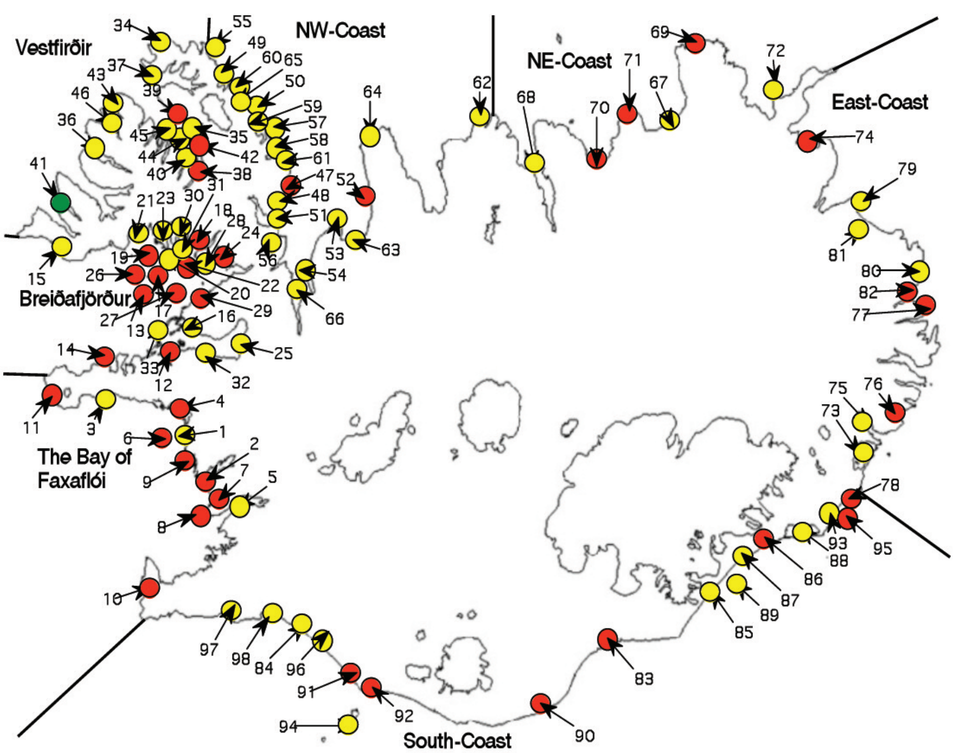

Fig. 1. *Distribution of haulout sites of the harbour seal (*Phoca vitulina*), on the coast of Iceland. For names of haulout sites see Appendix 1. Grímsey is a small island located just north of the "NE-Coast" text on the figure.*

used for the survey. A total of 98 haulout sites were distinguished on the coast (Fig. 1). Both harbour seals and grey seals (*Halichoerus grypus*) were counted from the airplane. In Icelandic waters harbour seals and grey seals haul-out in separate groups and the 2 species were rarely seen together on the same haulout site. Many of the haulout sites on the coast have also been visited by foot, car and/or boat and studied more thoroughly with strong binoculars (25x, D = 50 mm), or more recently by taking images with a digital camera equipped with a 1,000 mm telescopic zoom lens. Such observations also indicate that there is little mix of grey and harbour seals at the same haulout sites. A very small haulout site was usually combined with another larger site close by, for reducing zero counts in the analyses.

The first aerial survey was undertaken in 1980 and then repeated in 1985. Since that year a triennial survey plan was put into operation, counting always in late July, August and early September (moulting and early breeding period of the Icelandic harbour seal). In an experiment in 1989 the author attempted to find the best month to do the counting, by flying surveys over the northwest and south coast in May, June, July and August/September. In a total of 35 haulout sites, maximum numbers of harbour seals were

Fig. 2. *The rocky shore habitat of the Icelandic harbour seal (*Phoca vitulina*). The picture was taken from the air of the tip of Vatnsnes (a part of site no. 53 on Fig.1) (Photo: Erlingur Hauksson)*

Fig. 3. *The sandy-shore habitat of the Icelandic harbour seal (*Phoca vitulina*). The picture was taken from the air in Sigríðastaðaós (part of site no. 63 on Fig. 1) (Photo: Erlingur Hauksson)*

observed 14 times in August/September, 11 times in May, 6 times in July and 4 times in June (Hauksson 1992a). However, the observations of maximum counts occurred at different months (from May to July) for different locations even for close locations or within the same site (Hauksson 1993). At site 15 and 38, for example, both at the West Fjords, the maximum corrected counts occurred respectively in July and in June (Hauksson unpublished).

Successful surveys were performed in the years 1980, 1985, 1989, 1990, 1992, 1995, 1998, 2003 and 2006. Usually, each site was covered once during each year of survey, with few exceptions in some coastal areas (Table 1). Poor weather usually prevented counting on a few sites each year at the first attempt. Those sites were revisited later if seal density was expected to be high or otherwise excluded from the analyses.

Seals were counted from Cessna Skyhawk single-engine, high winged aircraft, at an altitude of 50-150 m. Surveys were usually conducted within a 6 hour interval around the lowest tide as suggested by Fancher and Alcorn (1982), in good weather, and stopped in case of fog, heavy rain or unfavourably strong winds (> 4 Beaufort scale). After locating haulout sites, the pilots half circled the site and observers visually counted all seals hauled-out, with a handheld counter, including those seen in the water closest to the haulouts, from the side windows front and aft. The observers also photographed sites with >30 seals, using 35 mm colour slide film (ASA 400), using a camera shutter speed at least 1/500 and a 70-150 mm zoom lens. After 1998 a digital still camera, Cyber-shot 5.0 mega pixels with 10x precision digital zoom , using the highest image quality (2560 x 1920), was employed.

The total number of seals and time of the day were recorded during counting and the weather in the area was noted down in a log book, hence hours to lowest water, tide height (m) and tidal status (spring tide – ebb tide, tidal state in Reykjavik in meters as the base) at each site

Table 1. Characteristics of aerial surveys flown on the coast of Iceland, 1980 – 2006.

Survey no	Survey year	Counting period	Number of days days counting with hours flown in parentheses	Remarks
1	1980	11 - 22 August	10 (67)	The whole coast
2	1985	20 July - 4 August	12 (≅ 70)	The whole coast
3	1988	7 July - 23 August	6 (≅ 50)	Partial count due to bad weather. Covered Breidafiord, Strandir, Skagafjörður and the south coast
4	1989	8 May - 21 September	19 (≅ 120)	The whole coast. Northwest coast and south coast surveyed 4 times, in May, June, July and August or September
5	1990	11 August - 28 September	13 (≅ 80)	The whole coast. Survey was difficult due to bad weather and finished in late September
6	1992	4 August - 4 September	9 (≅ 60)	The whole coast
7	1995	9 August - 13 September	11 (≅ 70)	The whole coast
8	1998	8 August - 2 September	10 (≅ 60)	The whole coast
9	2003	28 July - 22 August	13 (72)	The whole coast
10	2006	9 - 25 August	10 (87)	The whole coast

could be estimated from the Tide Tables (Icelandic Coast Guard 1980, 1985, 1988, 1989, 1990, 1992, 1995, 1998, 2003, 2006) and hours to solar noon for each site were estimated from a solar calendar for selected sites in Iceland, published in an almanac (Hið íslenska þjóðvinafélag 1980, 1985, 1988, 1989, 1990, 1992, 1995, 1998, 2003, 2006). Hours and minutes were decimalised before analysis.

In the laboratory seals were counted on slides projected on a white surface or by viewing the slides using a dissecting microscope. The digital images were viewed on a computer screen and in the case of densely packed seal groups each seal was marked with a red dot and tallied using the image analysis application SigmaScan Pro 5.0 SPSS Science™.

Trend analysis

The distribution of the total counts (C) of harbour seals turned out to be closest to a negative binomial distribution, of all the various discrete distributions tested (Chi-square test statistic = 130.62 df = 106 $P = 0.052$). Counts were therefore transformed using $\log_e(C + 1)$, before analysis, the 1 being added because of zero counts in some sites during some years. The transformed data can be used to estimate of the population exponential growth coefficient (r_{est}) for each seal group (haulout site), coastal areas and the whole coast. Before selecting the exponential model other models were tried, such as inverse exponential, hyperbolic and quadratic, reverse logistic and square. The other transformations applied to the counts, such as $(C+0.5)^{1/2}$, $1/(C+1)$ and $\log_e((C+1)/\text{-}(2000-(C+1))$, gave a worse fit to a normal-curve, when inspected with a Q-Q plot.

An estimate of population trend in time based on counts must account for the variation in those counts that results from both real changes in population abundance and factors that affect the proportion of the population visible during surveys (Small *et al.* 2003). Rather than assume that a constant proportion of seals was visible, and thus observed during each survey, the counts were modelled as functions of covariates that were assumed to affect visibility of the harbour seals (Small *et al.* 2003, Frost *et al.* 1999, Boveng *et al.* 2003). Therefore the analysis incorporates the following covariates: date of survey (1-365), tide height, hours to solar noon, hours to lowest water and the tidal status, wind force using the Beaufort scale (0 -12) and whether raining or not during surveying (present = 1 absent = 0), as well as the quadratic terms of these covariates except haulout sites and rain which were categorical variables in the model. The aim of including such covariates into statistical models was to increase the accuracy of trend estimates, by adjusting the survey counts for the effects of the covariates (Hauksson 1985, Hauksson 1986, Olesiuk *et al.* 1990, Thompson and Harwood 1990, Hauksson 1992a, Hauksson 1993, Frost *et al.* 1999, Boveng *et al.* 2003, Small *et al.* 2003).

The transformed counts were analysed with a General Linear Model (GLM). The initial full model incorporated all covariates including the continuous covariate survey year (transformed into years since 1979), their 2-level interactions and the covariates' quadratic terms. Three level interactions were not included because the data did not support them and high order interactions occur rarely (van Belle 2002). The analysis was performed at the haulout site level, with a stepwise backward selection procedures for selecting significant covariates to use in the final model. There was a problem with multicollinearity in the full model (*i.e.* predictors measuring essentially the same quantity). The covariates tidal state and hours to lowest water were significantly correlated with each other and with tide height (Table 2) and by excluding these highly correlated covariates and the interaction terms rain×tidal status, rain×tide height and tidal status×tide height, the problem of collinearity was solved (see Hocking 2003). The final model, after the stepwise backward exclusion, included years (*YR*), hours to solar noon *(HSN)*, wind (*W*), tide height *(TH)*, $[day]^2$, $[HSN]^2$, $[TH]^2$, $[W]^2$ and haulout sites (Table 3). None of the 2 level interactions were then significant.

For estimating adjusted counts from the original survey counts ($Y = \log_e(C+1)$), the $[day]^2$ term was excluded. Examination of the raw data showed that this quadratic relationship was probably mainly caused by

Table 2. Pearson correlation coefficient between covariates
(n = 845, *, ** and *** significant at the 0.05, 0.01 and 0.001 level respectively)

	Year	Day of year	Hours to solar noon	Wind	Rain lowest	Hours to status water	Tidal height	Tidal
Year	1	.	.	.	.	.	.	.
Day of year	0.069*	1	.	.	.	.	.	.
Hours to solar noon	0.039	0.054	1	.	.	.	.	.
Wind	-0.051	-0.051	0.181***	1	.	.	.	.
Rain	-0.028	-0.008	0.061*	-0.004	1	.	.	.
Hours to lowest water	-0.108***	0.010	0.100**	-0.063*	-0.041	1	.	.
Tidal status	-0.027	0.008	0.036	-0.081**	-0.009	0.400***	1	.
Tide height	-0.027	-0.058*	0.138***	-0.037	-0.019	0.341***	0.701***	1

Table 3. Results from GLM-analyses of "treatment effects" on $\log_e$ (total number of harbour seals *(Phoca vitulina)* seen +1). All effects were continuous except rain (0 not and 1 raining) and haulout sites (numbered from 1 to 98), which were categorical effects in the analyses (*, ** and *** significant at the 0.05, 0.01 and 0.001 level respectively)

Effect	Coefficient	SE	F-value
Year	-0.057	0.004	213.258***
Hours to solar noon (*HSN*)	0.029	0.015	3.649
Wind (*W*)	0.220	0.113	3.806
Tide height (*TH*)	-0.705	0.165	18.180***
$(Day)^2$	-0.000	0.000	3.975*
HSN^2	-0.010	0.003	8.735**
TH^2	0.166	0.061	7.464**
W^2	-0.046	0.020	5.418*
Site no.	.	.	17.317***

Table 4. Factors of the quadratic terms $Y = k_1X + k_2X^2$ (with (SE) and [95% CI]), for hours to solar noon, wind and tide height, and the range of the conversion factors used (with "95% CI" in parentheses)

Covariates	K_1 (SE) [95% CI]	K_2 (SE) [95% CI]	Range of conversion factors (95% CI)
Hours to solar noon	0.024 (0.024) [-0.023 – 0.071]	-0.012 (0.005) [-0.022 - -0.001]	1-1.2 (1-1.4)
Wind	0.425 (0.180) [0.072 – 0.778]	-0.080 (0.031) [-0.142 - -0.018]	1-1.5 (1-3.0)
Tide height	-0.640 (0.255) [-1.139 – -0.140]	0.130 (0.097) [-0.060 - 0.320]	1-2.75 (1-3.8)

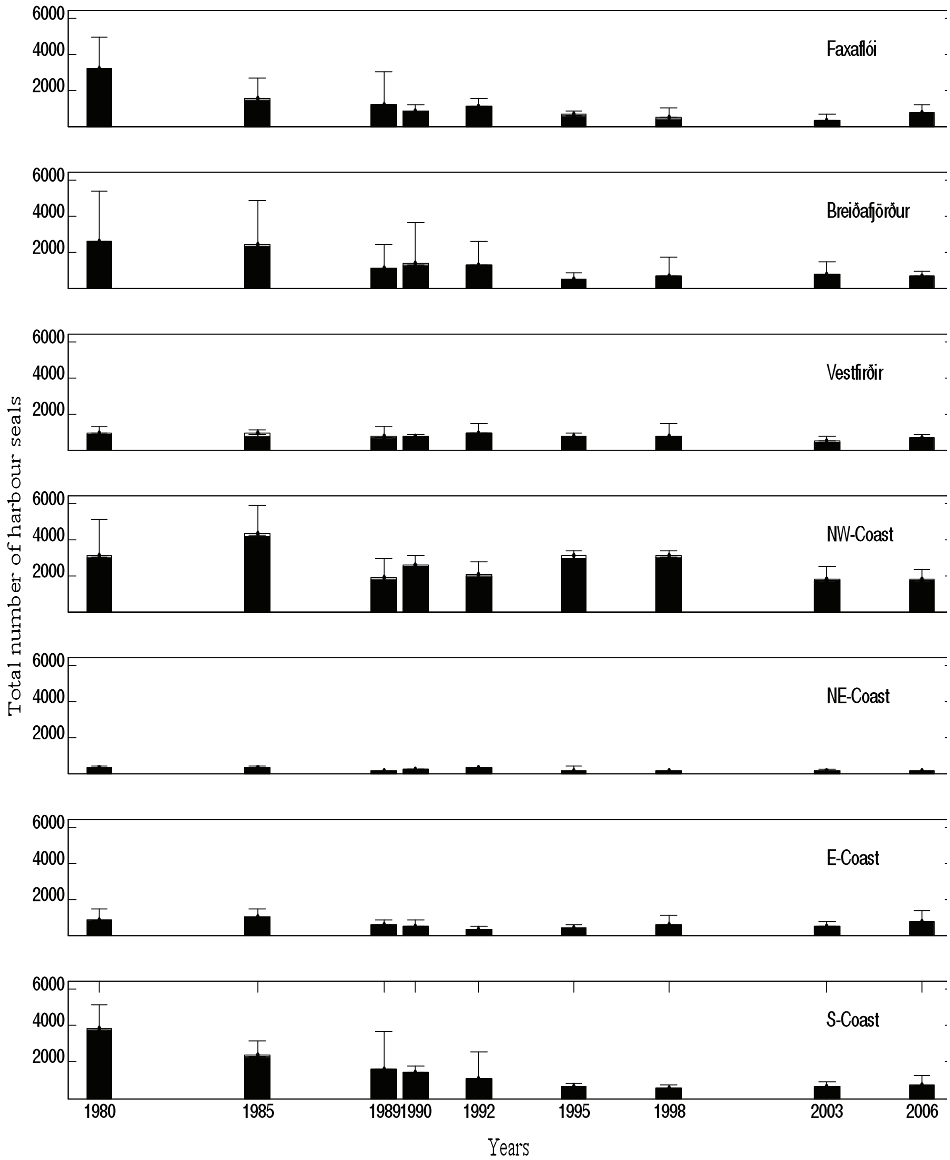

***Fig. 4.** Total number of harbour seals* (Phoca vitulina*) counted (black bars) in the aerial surveys and the adjusted counts (black + white bars), with 95% CI values for the adjusted counts (error-bars), for each coastal area and survey year in the period 1980-2006.*

counting being performed on a few sites earlier than July in 1989 (Table 1). The significance was also low (*P* = 0.047), and the linear term of day was not significant. The raw counts from the period July-September did not substantiate this quadratic trend of logarithmically transformed counts and survey day. Bayesian regression was performed on the data using the following model with diffuse priors for estimation:

(1)

$$Y = a + b[YR] + c[HSN] + d[W] + e[TH] + f[HSN]^2 + g[W]^2 + h[TH]^2;$$

Bayesian regression was used to estimate the coefficients, their SE and 95% CI with presumably less bias than if a least-squared model was used, because least-square models assume that error terms are normal random variables. Bayesian methods have also been proposed for discrete outcome data which are over-dispersed by Congdon (2003).

The original counts were adjusted with 95% CI, by using conversion factors for *HSN, W* and TH. The reference point for solar noon was 0.0 hours from solar noon each day 0.0 meters for tide height and the conversion factor was set to 1.0 for wind force less than and equal to 4 in Beaufort Scale. These reference points were chosen after studying the raw survey data by smoothing with the LOESS method using 75% of data points in the span. For back-calculating logarithmically transformed counts, the antilog was taken, 1 subtracted and the upper 95% CI calculated (Elliott 1971). In the calculations for the adjusted data presented in Figures 4 and 5 the lower 95% CI was sat the same as the counts from the aerial surveys on each site in each survey year.

For inspecting trends in counts (C) in interval (x_i) between survey years (t_i) the r_{est} was estimated as $\log_e(C_{t+1}/C_t)/x_i$, where $x_i = (t_{i+1} - t_i)^{1/2}$ (Mills 2007).

Statistical analyses were performed with SYSTAT 11®, Systat Software Incorporated.

RESULTS

The model

Significant correlation was found between many covariates (Table 2). The initial model with all the covariates and their second power terms, with $\log_e(C+1)$ as the dependent variable, had N equal to 844 and multiple R^2 equal to 0.74. The influence of years from 1979, wind and W^2, HSN^2, tide height, TH^2 and the category haulout site were significantly different from zero ($P <$ 0.05 in Table 3). The final model incorporated years from 1979, hours to solar noon, HSN^2, wind, W^2, tide height, TH^2 and haulout site had $N = 844$, multiple $R^2 = 0.73$ and was significant ($P < 0.001$). Counts from site no. 3 in survey year 1980 and site no. 63 in survey year 1992 (Fig. 1), had large leverage and were probably outliers. These sites had zero counts in these years, but some or numerous harbour seals were observed there in the other survey years. These two counts were not excluded from the analyses and probably did not influence the overall results much, however these zero counts could have caused the no significant trends observed at the sites no. 3 and 63 (Fig. 1 and Appendix 1).

The trend to hours to solar noon, wind force and tide height, were quadratic $Y = k_1X + k_2X^2$ and $\Delta Y/\Delta X = k_1 + k_2 2X$, where k_1 and k_2, for

Table 5. Trend estimate (r_{est}) of adjusted counts of harbour seals *(Phoca vitulina)*, in the periods between aerial surveys, in each coastal area of Iceland and the whole coast (Fig. 1). Standard error in parentheses and *, ** and *** significant at the 0.05, 0.01 and 0.001 level respectively.

Periods	Faxaflói	Breiðafjörður	Vestfirðir	NW coast	NE coast	E coast	S coast	The whole coast
1980-1985	-0.33	-0.05	0.00	0.15	-0.07	0.12	-0.22	-0.06
1985-1989	-0.14	-0.38	-0.11	-0.42	-0.55	-0.29	-0.18	-0.29
1989-1990	-0.36	0.21	0.01	0.31	0.93	-0.17	-0.13	0.06
1990-1992	0.22	-0.06	0.16	-0.15	0.11	-0.26	-0.18	-0.05
1992-1995	-0.34	-0.50	-0.12	0.23	-0.26	0.14	-0.34	-0.08
1995-1998	-0.17	0.16	0.01	-0.00	-0.16	0.16	-0.02	0.01
1998-2003	-0.14	0.03	-0.23	-0.25	0.05	-0.05	0.03	-0.14
2003-2006	0.46	-0.04	0.24	0.00	-0.29	0.24	0.09	0.10
1980-2006	-0.07 (0.01)*	-0.06 (0.01)^{ns}	-0.02 (0.01)^{ns}	-0.02 (0.01)^{ns}	-0.04 (0.01)^{ns}	-0.01 (0.01)*	-0.07 (0.01)*	-0.04 (0.01)***

hours to solar noon were 0.024 and -0.012, for wind 0.425 and -0.080, and for tide height -0.640 and 0.130, respectively (Table 4). The range of conversion factors after taken the antiloge were 1-1.2 , 1-1.5 and 1-2.75 for hours to solar noon, wind and tide height respectively (Table 4).

Temporal trends

Results from the Bayesian linear regression (Appendix 1, see Fig. 1 for the location of the sites) showed that the highest significant trend upwards in the adjusted counts of harbour seals (r_{est} = 0.07, 95% CI 0.02 - 0.13) was on site no. 41 (Patreksfjörður-Tálknafjörður), in the coastal area of Vestfirðir. The highest significant decline in harbour seal numbers (r_{est} = -0.20, 95% CI -0.31 to -0.09) was in Bjarneyjar, in the coastal area of Breiðafjörður (site no. 13).

All sites in the Faxaflói exhibited declines, except site no. 3 (Búðahraun and Búðavík) which showed a non significant increase, and sites no. 1 and 5 which had non-significant declines. The highest significant decline was observed at Melar, (r_{est} = -0.20, 95% CI -0.28 to -0.12) (site no. 8). In Breiðafjörður no sites had a significant increase in seal numbers, however many exhibited significant declining trends, with the greatest decline occurring in Bjarneyjar. In Vestfirðir, there was a significant increase in the Patreksfjörður-Tálknafjörður area, and some significant declines, the highest one on site no. 39, Langadalsströnd-Snæfjallaströnd, (r_{est} = -0.09, 95% CI -0.17 to -0.003). On the northwest coast there were no significant increases in harbour seal numbers and most sites showed no significant trend. There was a significant decline (r_{est} = -0.09 95% CI -0.14 to -0.04) at Asparvik-Veiðileysuffjörður (site no. 47). On the northeast coast no haulout site exhibited a significant increasing trend, but significant declining trends were observed on sites no. 69, 70 and 71 (Melrakkaslétta, Skjálfandafljót and Tjörnes respectively). On the east coast no significant increases were observed, however significant declines were observed at many sites,the highest on site no. 78 (Eystrahorn) with r_{est} = -0.14 (95% CI -0.21 to -0.08). No haulout sites showed a significant upward trend on the south coast, but many of them had significant declines, with the highest occurring on Landeyjarsandur, site no. 91 (r_{est} = -0.19 95% CI -0.28 to -0.10).

Table 5 shows the trend in seal numbers by region subdivided into different time periods. Overall the highest number of seals was usually seen on the northwest coast and the lowest numbers on the northeast coast (Fig. 4). The greatest reduction in the total adjusted number of seals over the period occurred in the bay of Faxaflói and the south coast, both with a regional rate of decrease of -0.07 (Table 5). Significant declines were also observed on the east coast but not in other coastal areas (Table 5). At Faxaflói the trend was negative in most periods, except in 1990-1992 and the period 2003-2006. In the coastal area Breiðafjörður, r_{est} was negative in all years except 1989-1990 and the period 1995-2003. In the coastal area Vestfirðir, r_{est} was negative or very close to zero except in the periods 1990-1992 and 2003-2006. On the northwest coast $r_{est}$was not consistently positive or negative. On the northeast coast r_{est}-was usually negative or close to zero except the period 1989-1992. On the east coast r_{est} was usually negative before 1992, but later positive or close to zero. On the south coast r_{est} was negative until 1998 and positive or close to zero after that.

A total of 14,459 harbour seals were counted in the first survey in 1980. In the last survey in 2006 only 5,358 were counted, representing an observed trend in uncorrected counts of -0.04 (SE 0.005) from the ANCOVA. Adjusted counts showed the same trend, with the same slope of -0.04 (SE 0.005). Before 1989 r_{est} was negative or close to zero, and also after 1990 until the period 2003-2006 when r_{est} was positive (Table 5 and Fig. 5).

DISCUSSION

Considerations regarding survey timing

There were some practical reasons for counting harbour seals in late July-August in Icelandic waters, even though there was some evidence that maximum haulout numbers might occur in June and July, at least at some sites. Low flying is prohibited over the areas where eider-ducks (*Somateria mollissima*) nest and this restriction lasts to the end of June in the west and north western areas and early July in the north eastern areas in Iceland. Nest sites of eider-ducks and haulout sites for harbour seals very often occur in close proximity to one another. It is not feasible to start the surveys in September in Iceland due to frequent inclement weather. In addition, in August the harbour seal pups have grown in size and are more easily spotted than earlier. The maximum breeding of the Icelandic harbour seal occurs in early June, while moulting and some mating occur in August (Hauksson 2006). It is therefore not known whether counting in August results in higher or lower counts than if surveys were flown earlier or later. It has also been observed in British waters and elsewhere that harbour seals may choose different haulouts seasonally (Terhune and Almon 1983, Thompson 1988, Thompson *et al.* 1989). Counting at the same time of year in each survey should provide a useful index of abundance (Eberhardt *et al.* 1979), unless there are long term changes in the seasonality of pupping or moulting.

Consideration regarding the model used

Wind (W) was not a useful covariate in the initial model describing haulout behaviour, but $W2$ was significant ($P = 0.01$). The effect of the wind on the haulout behaviour of harbour seals was rather complex, with evidence of a maximum in the number hauling out at wind force 3 to 4. Moderate wind probably does not affect haulout behaviour, however, the animals may seek shelter from winds at the haulout site. As a result, they may be easier to count in a gentle and moderate breeze than in calm weather, because they are more clustered in sheltered areas, rather than spread out as observed under calm conditions. In strong wind, on the other hand, wind turbulence makes it more difficult to count and observe the seals from the airplane, which may result in negatively biased counts. Generally, survey flights were conducted at winds of force 5 or less, on the assumption that there might be no influence of wind on the seal counts at wind force less than 5, but a sharply increasing influence at higher wind speeds. In practice some flights were carried out in stronger winds, and this was accounted for in the final model by not correcting for wind unless it was of force 5 or higher.

The effect of wind and other meteorological factors on the haulout behaviour of harbour seals has been studied and sometimes strong influence has been observed. Tidal state, cloud cover and disturbances were shown by Schneider and Payne (1983) to play a part in explaining the haulout behaviour of harbour seals in Massachusetts, U.S.A. In other areas rain, disturbances and heavy seas have been shown to have influence (Pauli and Terhune 1987, Patterson and Acevedo-Gutiérrez 2008). Harbour seals on Sable island haul out more in sunny weather than when it is raining (Godsell 1988). Date, time of day, tidal status and temperature all significantly influenced the

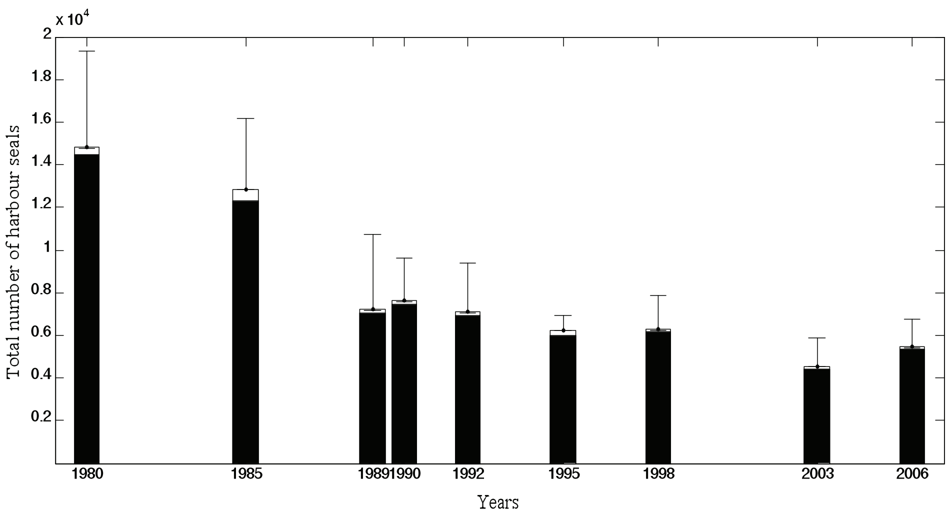

***Fig. 5.** Total number of harbour seals (*Phoca vitulina*) counted (black bars) in the aerial surveys and the adjusted counts (black + white bars), with 95% CI values for the adjusted counts (errorbars), for the whole coast of Iceland in the period 1980 – 2006.*

number of harbour seals hauling out on the shores of Svalbard (Reder *et al.* 2003). Often meteorological factors operate jointly, for example low temperatures and windy weather combining to create excessive wind chill, discouraging seals from hauling out (Boulva and McLaren 1979). Hours to lowest tide has been shown to influence the number of seals hauled on many sites on the Icelandic coast (Hauksson 1985, Hauksson 1992a), as elsewhere (Olesiuk *et al.* 1990, Pauli and Terhune 1987, Pitcher and McAllister 1981, Schneider and Payne 1983, Yochem *et al.* 1987, Reder *et al.* 2003). The time to low water and tide height has been shown to influence considerably the haulout behaviour of harbour seals in Alaska (Small *et al.* 2003, Boveng *et al.* 2003) as well as in Norway and the Wadden Sea (Bjørge *et al.* 1995, Nørgaard *et al.* 1992). The underlying reason for this influence of the tides on the haulout behaviour of the harbour seal must be its need to rest on dry land for its general well being while maintaining access to the sea (Brasseur *et al.* 1996). Therefore, the effect of the tides should be included in the model.

The effect of covariates

Some of the covariates used in the model are not independent. The covariates related to tidal state are correlated by definition. The flights were carried out during daylight, at low water as close to low tide as practically possible, in calm weather when it was not raining. This could explain why some other covariates were correlated as observed (Table 2). Using all of them in the final model would therefore not be very meaningful. Hours to solar noon was also correlated with hours to low water and tide height (Table 2), probably because counting was performed in good daylight during low tide, not during the evening or at night. The 3 variables relating to the tides, hours to low water, tide height and tidal status could potentially measure different aspects of the tide's influence on the seal counts, if it had been possible to set up an experimental plan to study the influence of each of these covariates separately. Specifically tide height, at the time of a count, could affect the number of seals hauled out because the space available at many sites is directly related to tide height. Additionally, because of daily changes in the height of lowest tide at the same site in relation to tidal status, the amount of available haulout substrate could differ substantially, as suggested by Small *et al.* (2003). Tide height should describe best the size of the area available for the seals to haul out on, on each location. Therefore, it is most meaningful to use tide height in the model rather than hours to lowest water or tidal status.

The potential area to haul out on could also play a part. A logarithmic relationship was found between the area of islands and rocks and the maximum number of harbour seals hauling out there by Krieber and Barrette (1984), with larger areas having proportionally fewer seals hauling out, thus with less harbour seal densities. Tide height would determine the available area to haul-out on rocks and islands, however less so in the estuaries and the river mouths where tides are usually delayed and reduced in amplitude by constrictions in the outlet to the sea. There was probably available space to haul out on regardless of the tidal status. This could not be accounted for in the surveys, because information about tides at many haulout sites in Iceland, especially in glacier river mouths, was limited. However it is commonly experienced that the highest water levels occur in the evenings, especially during warm weather, because the rivers have greater flow during the day due to glacial melt.

Changes in distribution and abundance

Some earlier data on observed numbers of harbour seals are available from some of the coastal areas surveyed (Hauksson 1992a). From these one could speculate about harbour seal abundance prior to 1980, even though these data are not directly comparable to the data from the more recent aerial surveys. In 1973 2,300 harbour seals were counted in Faxaflói and 1,060 in Breiðafjörður (Garðarson unpublished information, cited in Einarsson 1978). This was somewhat lower than the counts obtained by the author in 1980 in the same areas (Fig. 4). From this information, it can probably be deduced that the observed declining trend in Faxaflói in the period of 1980 to 2006 had not started in 1973. In Vestfirðir coastal area, there are available data from a series of seal surveys conducted from boats and land: 632, 1,368, 306, 178, 410, 1,118 and 227, in years 1976, 1977, 1979, 1981, 1982, 1983 and 1984, respectively (Einarsson unpublished information, cited in Hauksson 1992a). As some of these pre 1980 counts were higher than that from the 1980 surveys (Fig. 4), it might indicate that harbour seals were more numerous in Vestfirðir before 1980 than later on. Similarly, the observation of 3,187 seals along the northwest coast in 1977 (Einarsson unpublished information) was higher than seen in the survey in 1980, which could indicate that the seals were also more numerous in this area before 1980 than later on. In the case of the northeast coast, 1 count of 230 is available from1977, which was similar as the value for this area in 1980 (Fig. 4). No earlier data were available for the east coast. Along the south coast, 5,801 harbour seals were counted in 1976 (Pálsson 1976) and 4,102 in 1979 (Einarsson unpublished information). This may indicate that a decline in numbers of harbour seals had already begun in 1976 in this area (Fig. 4). The decline in the Icelandic harbour seal population may therefore already have begun in the 1970's in some areas of Iceland.

Harbour seals were more evenly distributed among coastal areas in 2006 than in 1980 (Fig.4). The observed difference in r_{est} between time periods within and between coastal areas indicates that there might be spatial and temporal differences in the recruitment of harbour seals. At the majority of haulout sites in Faxaflói and Breiðafjörður seal numbers have been declining significantly in the period 1980-2006, but the declines are not as apparent elsewhere. In Faxaflói and Breiðafjörður there was a heavy fishery for lumpsuckers (*Cyclopterus lumpus)* and there was also some shooting of harbour seals for protecting salmon *(Salmo salar)* in salmon rivers estuaries. In the Breiðafjörður area the more exposed haulout sites experienced declines, while the more sheltered ones did not. This may be related to human activity such as the fishery for lumpsuckers. Another non-lethal but potentially disturbing factor in the coastal area of Breiðafjörður was the harvesting of the brown algae *Ascophyllum nodosum*, with Aqua marine weed harvesters floating just off the shoreline. This was practised in the outer part of Breiðafjörður, but not in the sheltered inner area of Breiðafjörður such as inner Hvammsfjörður (sites no. 25 and 32) where there was also little fishery activity for lumpsuckers or codfish. The decline observed on the south coast, where there were no lumpsucker fisheries or brown algae harvesting, is puzzling. However, in this area intensive gill net fisheries for codfish have been practised for years, but it was hardly any by-catch of harbour seals according to the available information. Harbour seals are known to travel long distances from their home range, and could therefore be subject to by-catch or other anthropogenic mortality in other areas. The results from the limited tagging experiments done on harbour seals in Icelandic waters substantiate this (Hauksson and Einarsson 2010). In the period 1982-1989, a bounty-system was in operation, which included harbours seals too (Hauksson 1992b). In these 8 years harbour seal pups and adults were caught in considerable numbers, in Breiðafjörður, at the northwest coast and in Faxaflói. This exploitation may explain the decline observed in these regions until 1990, when harbour seals were excluded from bounty system and only pup-harvest by seal farmers were subsided in the following years. However, the harbour seals groups in these areas have had over 15 years to recover, but that has not happened in any of theses areas.

Monitoring of the Icelandic harbour seal population

Icelandic harbour seals have declined about 63% between 1980 and 2006, a rate of about 4% annually. A continued decline at this rate would in the long run cause extinction of the Icelandic harbour seal population. It is however unlikely that this will happen in the near future. The population declined abruptly in the period 1980-1992 and appears to have been more stable since 1995. The Icelandic harbour seal population is composed of 98 "seal groups" probably with unrestricted dispersal between them (Einarsson 1977), which makes the extinction of the entire population very improbable, particularly since numbers are stable or increasing in some areas.

It would be preferable to monitor the Icelandic harbour seal population by at least triennial surveys in the future, with a least 1 flight to survey each haulout site each survey-year. Multiple flights per site of course increase the cost of the survey and this must be balanced against the need for precision and the power to detect population change.

Given the observed overall decline in Icelandic harbour seals, and the continuing anthropogenic mortality both direct and due to fisheries interactions, the continued monitoring of the population should be a high conservation priority.

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Appendix 1. Number and name of haulout sites of harbour seals *(Phoca vitulina)* on the coast of Iceland, with trend estimates (r_{est}) standard error and 95% CI from a Bayesian regression of $\log_e$ adjusted counts on years from 1979, in the period 1980-2006. For localization of sites see Fig. 1. Trend estimates are significant at the 5% level if 95% CI do not include zero.

Site no.	Trend estimate	Std. Err.	Lower 95%	Upper 95%	Haulout site name
1	-0.057	0.028	-0.114	0.000	Akraós
2	-0.104	0.051	-0.207	-0.002	Borgarfjörður
3	0.026	0.069	-0.113	0.165	Búðahraun and Búðavík
4	-0.053	0.020	-0.093	-0.014	Haffjörður
5	-0.039	0.025	-0.089	0.011	Hvalfjörður
6	-0.173	0.033	-0.239	-0.108	Hvalseyjar
7	-0.060	0.022	-0.104	-0.016	Leirárvogur
8	-0.198	0.039	-0.275	-0.121	Melar
9	-0.143	0.030	-0.202	-0.083	Mýrar
10	-0.070	0.021	-0.113	-0.028	Álftanes, Garðskagi and Hafnarósar
11	-0.122	0.025	-0.173	-0.071	V-Snæfellsnes
12	-0.114	0.019	-0.152	-0.076	Álftafjörður
13	-0.199	0.054	-0.308	-0.090	Bjarneyjar
14	-0.126	0.020	-0.166	-0.086	Brimilsvellir
15	-0.021	0.021	-0.062	0.020	Bæjarvaðall
16	0.008	0.033	-0.058	0.075	Fellsströnd
17	-0.150	0.037	-0.225	-0.076	Flateyjarlönd
18	-0.097	0.045	-0.187	-0.008	Grónes/Hallsteinsnes
19	-0.168	0.038	-0.243	-0.092	Hagadrápssker and Flögur
20	-0.119	0.073	-0.264	0.027	Hergilseyjar, Hrauneyjar
21	0.036	0.058	-0.079	0.152	Hjarðarnes-Vatnsfjörður
22	-0.116	0.023	-0.161	-0.070	Hvallátra, Svefneyja and Skálaeyjalönd
23	-0.064	0.040	-0.145	0.016	Kerlingarfjörður, Litlanes and Kjálkafjörður
24	-0.061	0.024	-0.109	-0.012	Króksfjarðarnes
25	0.025	0.017	-0.009	0.060	Ljárskógar, Lækjarskógarfjörur and Kambsnes
26	-0.104	0.037	-0.179	-0.029	Oddbjarnarsker, Brimsker and Drápsker
27	-0.141	0.028	-0.198	-0.085	Rauðseyjar, Rúfeyjar and Djúpeyjar

28	-0.056	0.033	-0.121	0.009	Reykhólalönd and surroundings
29	-0.165	0.060	-0.285	-0.046	Skarðsströnd, Fagurey and Langey
30	-0.045	0.034	-0.112	0.023	Skálanes
31	-0.065	0.047	-0.159	0.028	Skálmarnes-Kvígindisfjörður
32	-0.148	0.078	-0.304	0.008	Skógarströnd and islands
33	-0.019	0.048	-0.116	0.078	Þórsnes and islands
34	-0.034	0.036	-0.106	0.038	Aðalvík-Hornvík
35	-0.073	0.041	-0.155	0.008	Borgarey
36	-0.011	0.035	-0.081	0.058	Dýrafjörður
37	-0.054	0.055	-0.165	0.056	Grænahlíð
38	-0.078	0.016	-0.109	-0.046	Ísafjörður
39	-0.088	0.043	-0.173	-0.003	Langadalsströnd-Snæfjallaströnd
40	-0.014	0.015	-0.045	0.017	Mjóifjörður
41	0.072	0.030	0.012	0.133	Patreksfjörður-Tálknafjörður
42	-0.048	0.014	-0.076	-0.019	Reykjafjörður Ísafjarðardjúp
43	-0.045	0.071	-0.186	0.096	Súgandafjörður
44	0.019	0.033	-0.047	0.085	Vatnsfjörður
45	0.023	0.017	-0.010	0.056	Ögurnes
46	-0.061	0.040	-0.140	0.018	Önundarfjörður
47	-0.087	0.025	-0.136	-0.037	Asparvík-Veiðileysufjörður
48	-0.022	0.044	-0.110	0.066	South-Bjarnarfjörður
49	-0.037	0.026	-0.089	0.016	Bolungavík-Furufjörður
50	-0.027	0.021	-0.069	0.014	Drangar-Drangavík
51	0.039	0.024	-0.010	0.088	Drangsnes
52	-0.057	0.024	-0.105	-0.010	Eyjarey
53	-0.018	0.030	-0.078	0.042	Vatnsnes (*e.g.* Fáskrúð, Hindisvík and Selland)
54	-0.009	0.027	-0.062	0.045	Heggstaðanes
55	0.006	0.079	-0.152	0.163	Horn-Straumnes
56	-0.022	0.018	-0.058	0.013	Kollafjörður
57	0.041	0.047	-0.054	0.136	Munaðarnes
58	-0.025	0.040	-0.106	0.056	Norðurfjörður/Trékyllisvík
59	-0.041	0.038	-0.118	0.036	Ófeigsfjörður-Eyvindarfjörður
60	-0.035	0.051	-0.135	0.066	Reykjafjörður-Þaralátursfjörður
61	-0.026	0.039	-0.103	0.051	South-Reykjafjörður
62	-0.056	0.041	-0.138	0.025	Siglufjörður
63	-0.004	0.098	-0.199	0.191	Sigríðastaðaós, Bjargós and Húnaós
64	-0.036	0.021	-0.078	0.005	Skagi
65	-0.019	0.050	-0.119	0.081	Skjaldarbjarnarvík
66	-0.023	0.034	-0.091	0.045	West-Hrútafjörður
67	-0.017	0.021	-0.058	0.024	Bakkahlaup
68	0.027	0.041	-0.056	0.109	Eyjafjörður
69	-0.072	0.029	-0.131	-0.013	Melrakkaslétta
70	-0.063	0.016	-0.095	-0.031	Skjálfandafljót
71	-0.131	0.052	-0.234	-0.028	Tjörnes
72	0.033	0.094	-0.154	0.221	Þistilfjörður
73	-0.043	0.023	-0.089	0.004	Álftafjörður-Hamarsfjörður

74	-0.071	0.021	-0.113	-0.029	Bakkaflói
75	0.058	0.035	-0.013	0.128	Berufjörður
76	-0.085	0.023	-0.131	-0.039	Breiðdalsvík
77	-0.097	0.014	-0.125	-0.069	Dalatangi
78	-0.143	0.032	-0.206	-0.079	Eystrahorn
79	-0.008	0.021	-0.049	0.033	Héraðsflói
80	0.044	0.072	-0.099	0.187	Húsavík
81	0.019	0.027	-0.035	0.073	Jökulsá á Dal-Lagarfljót
82	-0.111	0.043	-0.197	-0.025	Loðmundarfjörður-Seyðisfjörður
83	-0.105	0.035	-0.174	-0.036	Eldvatn-Skaftárós
84	-0.030	0.049	-0.128	0.068	Eyrarbakka-Stokkseyrarfjara
85	-0.067	0.044	-0.156	0.021	Fjallsárós
86	-0.142	0.049	-0.240	-0.044	Hestgerðislón
87	0.019	0.105	-0.188	0.225	Hnappavallaós-Ölduós
88	-0.185	0.174	-0.505	0.134	Hornafjörður-Skarðsfjörður
89	0.017	0.061	-0.106	0.139	Hrollaugseyjar-Tvísker
90	-0.062	0.014	-0.090	-0.034	Kúðafljót
91	-0.192	0.045	-0.283	-0.102	Landeyjarsandur
92	-0.067	0.023	-0.113	-0.020	Markarfljót
93	-0.065	0.047	-0.159	0.029	Papós with skerries and islands
94	-0.093	0.050	-0.194	0.008	Vestmannaeyjar
95	-0.154	0.042	-0.238	-0.070	Vigur
96	-0.009	0.017	-0.043	0.025	Þjórsá
97	-0.054	0.035	-0.125	0.016	Þórkötlustaðir-Selvogur
98	-0.011	0.057	-0.124	0.102	Ölfusá

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