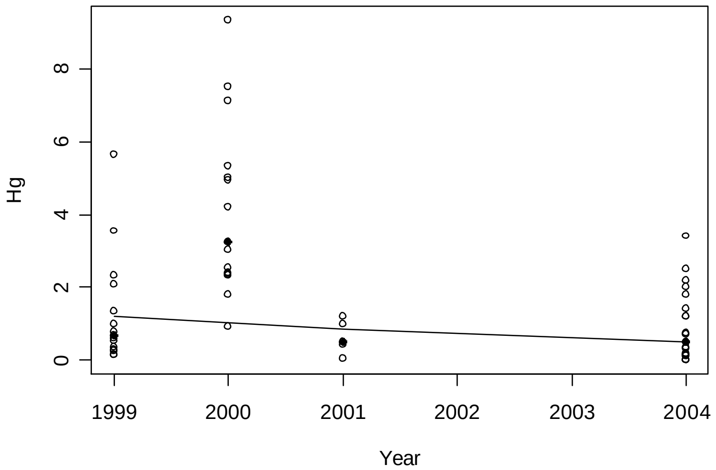
Statistical analyses of timeseries

by Maria Dam and Frank Rigét



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The picture on the front is Figure 2 in this text.

DANCEA
Danish Cooperation for Environment in the Arctic
Ministry of the Environment

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Foreword

The monitoring of contaminants like heavy metals and persistent organic pollutants in various environmental samples in the Faroe Islands began in its current version in 1996. Prior to this time, the monitoring had been focussed on fish for the export market and was not dedicated to describe the environmental status as such. In 2006 it was decided to take a closer look at the monitoring data that had been acquired to date, with a special emphasis on depicting the predicting power of the monitoring series. Most focus was on the time series established as part of the Arctic Monitoring and Assessment Programme, AMAP, of the Faroe Islands run by the Food, Veterinary and Environmental Agency, but also data series originating from before the AMAP monitoring began are included.

The present report is a write-up of the findings of these analyses, that began with a two day workshop in April 2006.

Introduction

The “time-series” of the Faroe Island AMAP monitoring programme for the heavy metals and persistent organic pollutants monitoring in the terrestrial, freshwater and marine compartments are given in Table 1. The bold v´s represent samples that will be analysed in the present project during 2006.

Table 1 AMAP time series Faroe Islands. Bold v´s are part of the proposed "AMAP 2005 filling the gaps" project.

	Initial target ferquency (yr-1)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Pilot whales*	1			v		v	v	v	**v**	**v**	**v**	
Black guillemot**												
eggs	1					v	v	v	**v**		v	
liver	1		v						v			**v**
feather	0.2		v						**v**			**v**
Arctic char***	1				(v)		v	v	**v**		v	
Sheep	1			v		v		v				**v**
Sculpin	1					v	v	v	**v**		v	
Hare	1			v		v		v			**v**	

* Pilot whales sampled in 1997 were analysed individually in a project funded by Arktisk Miljø Program Projekt 123/001-0068 "Kviksølv og PCB i grindehval; hvad er ekstremværdierne"in addition to the samples analysed as part of the AMAP core program. In total, samples of approx. 450 Pilot whales were taken in 1997, most of which were analysed in pooled samples on funding by the Faroes Governm.
** Fulmar was originally selected as the indicator species representing seabirds, not least because it may present an important route for human exposure. The international desire to include black guillemots in the AMAP program, made us exclude fulmars to the "benefit" of black guillemot in 1999. Black guillemot egg sampling was not successful in 2003. It is uncertain whether a yearly sampling can be supported by the populations in the two samples areas thus sampling every second year will be tested.
*** Arctic char was sampled for the first time in 1998, and then in Leynavatn and Heygardalsvatn. Neither of these sampling sites proved to be ideal, and sampling was initiated in the Lake. In 1997, brown trout were analysed as part of the AMAP program, but this species was later substituted by Arctic char.

Recently, it was decided to have a closer look at the time-series that could reasonably be treated as a series of comparable data for at least three years.
With this criteria, the following species were analysed;

- Pilot whales (juvenile, adult females and adult males)
- black guillemot eggs
- sculpin

and, of scientific interest, the longest time-series from the Faroe Islands, that of mercury in cod was analysed as well although monitoring of cod has not been part of the AMAP Faroe Islands Core program.

For these species, the task was to analyse the predicting power represented in the Faroese AMAP time-series presently available, where the power may be described as the probability of a time series to actually pick up a change that has occurred. Or, for a given monitoring series the equation may be turned around and used to calculate the number of years necessary to detect a given yearly change with a certain degree of probability (i.e. the power).

The power of a given time-series depends on

- o the level of significance demanded (a significance level of 5% is often used)
- o number of years for which there are data
- o residual standard error (a measure of the total variation i.e. within-year variation plus random between-year variation)
- o rate of change (slope, say 5% per year)

The method described by Nicholson and Fryer [1] demands that the data are normally distributed, which to a large extent may be achieved by taking the $\log_e$ of the measured data. However, allowing also for not normally distributed data (also denoted log-normal data) and for data which are dependent on individual parameters like age or length as is the case for mercury in fish, and a certain between-year random variation, a modified method for linear trends is used [2,3]. The linear trend applies to the logarithm of the annual medians if log-normal data as is often the case with pollutant concentrations or annual means if the data are normally distributed. If the dataset contains outliers and/or pollutants concentrations reported as being below the detection limit, the median approach is preferable. Such a linear trend, which could be called log-linear, is consistent with the same relative yearly increase (or decrease) of for instance 5 %.

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[1] Nicholson M.D. and R.J. Fryer. 1992. The Statistical Power of Monitoring Programmes. Mar. Poll. Bull. 24, 146-149

[2] Fryer, R.J. and Nicholson, M.D., 1993. The power of a contaminant monitoring programme to detect linear trends and incidents. ICES J. Mar. Sci. 50, 161-168.

[3] Nicholson M.D., R. Fryer and J.R.Larsen. 1998. A Robust Method for Analysing Contaminant Trend Monitoring Data. Techniques in Marine Environmental Sciences. ICES.

Shorthorn sculpin

The four years of sculpin liver PCB data were analysed looking at the individual congeners, CB 138, 153, 156, 170 and 180 where CB 153 may serve as a good example because it is the single congener invariably occurring in highest concentration in these samples as in many others. The concentration of CB 153 in the individuals samples are shown in Figure 1 together with a regression line derived from a log-linear regression of annual median values (black dots). The within-year variation in these samples was calculated to be 0.470. The slope of the regression line was -0.187 (or -18.7%), but with a p = 0.384 the fit of the measured data to this linear decrease is not significant. The residual standard error (RSE) was 0.663. In the analyses of time-trends in congeners done first, that of CB 138 (not shown), the slope of the non-significant regression line was -17.7 % (p=0,362) implying that there was a substantial decrease in CB 138 concentration from year to year in the sculpin population. Assuming this decrease was real and assuming a similar total variation the number of years necessary to statistically detect such a trend can be calculated. With a power of 80% and with the usual significance level of 5%, it is found that such monitoring must be performed annually for 11 years. An almost 20% yearly change may be regarded as unrealistic in a scenario where the driver of the change could be regulation of release as international conventions and protocols aims to install, and thus a 5% annual change may be more realistic. Using similar calculations as above, it is found that in order to obtain a 80% power of detecting such a change in CB 153 (p=5%), the monitoring must persist for more than 20 years!

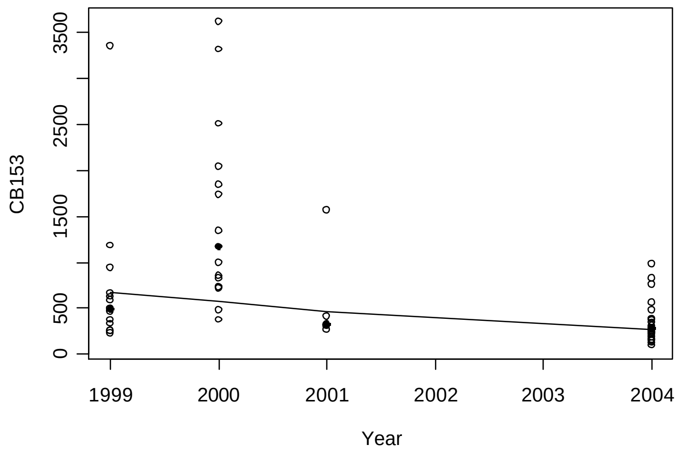

Figure 1 The time-trend for PCB as CB 153 in sculpin liver is shown. The concentration of CB 153 is given in ng/g LW.

Similarly, mercury concentrations in sculpin livers were treated in the same manner, and the results were rather similar as for PCB. As with the various PCB congeners, the tendency of the mercury in sculpin livers were one of decreasing concentration (Figure 2) but testing of the measured data to this tendency line showed that the relation was not significant (p=0.576) and that in order to obtain a 80% power for a

17.7% annual decrease in Hg for this monitoring series, the annual monitoring would have to be done for 16 years.
Note that the present calculations include data for both pooled and individually analysed fish samples, where the samples in a given pool were represented by one figure only. Fish length has not been taken into account and concentrations reported as being below detection limit of x, has been replaced by x (this is not likely to influence the calculations anyway as they are median-based). The method described by Nicholson *et al.*, 1998 otherwise suggest that pooled data are represented as individual data in the analyses (such that if you have a pool of five fish with a concentration c_i, the data should be treated as being five equal concentrations c_i).

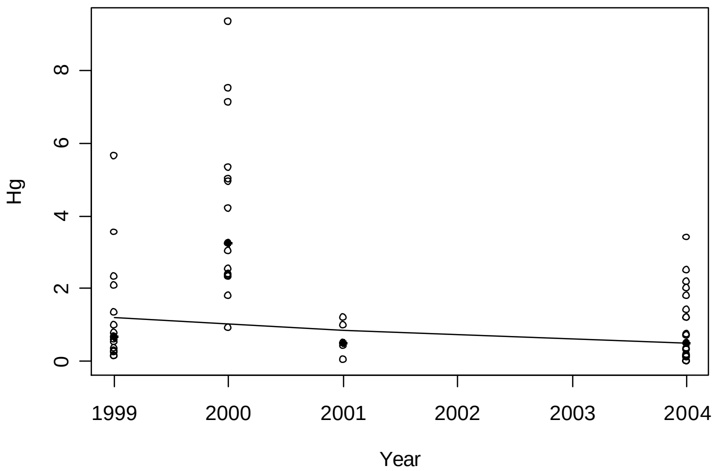

Figure 2 Mercury in sculpin liver is shown for the four years where data is presently available. The concentration of mercury is given in mg/kg dw. The slope of the regression line is -17.5% (p=0.576), RSE = 0.987.

The high concentrations of both PCB and Hg in the 2000 samples and even in some 1999 samples could indicate that these have been sampled closer to a local pollution source. The sampling of sculpin has been done in Kaldbaksfjord (Figure 3) with the entire fjord regarded as a potential sampling area. In the 2000 sampling however, a larger proportion of the samples were taken near the village Kaldbak, and it appears that it is these fish that have the high mercury concentrations. Concentrations of PCB are also high as already mentioned in these 2000 samples, but the concentrations of Hg and CB 153 are not high in the same individuals (and Hg and CB153 not significantly correlated neither in the 1999 nor the 2000 samples) and inspection of the sampling sites of the individual samples do not indicate a co-occurrence of PCB and Hg, but would indicate that the samples taken at Sund would have a tendency towards higher PCB levels.

It does appear thus, that there are local variations in pollution level when pollutants as mercury and PCB are considered. Later analyses of sediment samples in a transect from this fjord have however, not supported the assumption of elevated PCB levels at Sund but instead elevated PCB levels has been found in the foot of the fjord in Kaldbaksbotnur[4]. Mercury was analysed in these sediments as well. The sampling did not include sediments from the littoral in Kaldbak but samples from the fjord bottom

[4] Hoydal, K. and Dam, M. 2005. AMAP Faroe Islands Heavy metals and POPs core programme 2004. Food-v Veterinary and Environmental Agency, Report no 2005:2, Torshavn, Faroe Islands. pp 74.

off Kaldbak did not support assumed elevated mercury abundance near the village. Instead, rather even mercury concentrations were found along the transect, though, if the organic material content of the sediments is taken into consideration, the highest relative mercury concentration was found in the foot of the fjord.

Because of the lack of coherence between the sediment data and the sculpin data, and also the lack of correlation of sculpin pollutants data to the other parameters that are known as confounders in such analyses, it is not possible to be specific about the reason for the variability between and within-years with the data at hand.

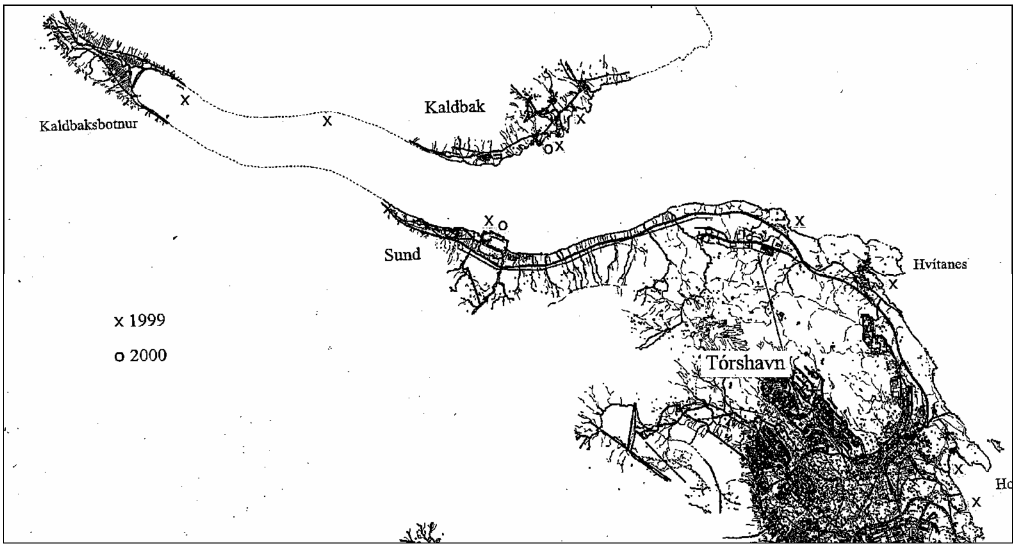

Figure 3 Shorthorn sculpin sampling sites in Kaldbaksfjord.

Black guillemot eggs

Black guillemot eggs are sampled from two locations Skúvoy and Koltur. It has been chosen to treat the samples from these two localities as one, because statistical test have not indicated that they are significantly different (for Hg; t-test on separate years, $0.21 < p < 0.93$) In Figure 4 the egg mercury concentration are shown along with a regression line with a slope equivalent to a yearly increase of 3.1%. The trend is however far from significant ($p=0.661$) and it was calculated that this monitoring must be kept up for a total of 19 years in order to reach the 80% power for this particular yearly change and monitoring series.

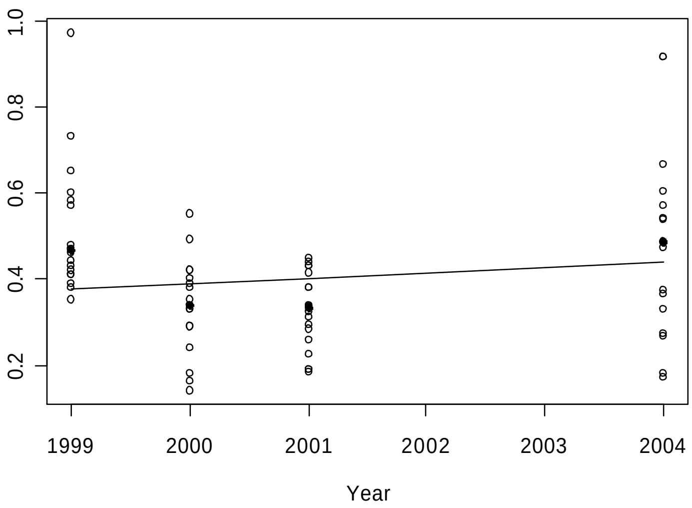

Figure 4 Mercury in black guillemot eggs from Skúvoy and Koltur are shown, in mg/kg ww. The slope of the non-significant regression line shown is 3.1% ($p=0.661$), with RSE = 0.987.

Arctic char

Samples of Arctic char have been taken from the lake á Mýranar since 2000, and these samples are representatives of a freshwater compartment only meaning that these fish have no access to the sea. As with sculpin, the fish has been analysed in both pooled samples and in single fish samples, and in the analyses no distinction was done among these. The Arctic char muscle mercury concentrations are plotted against the sampling year in Figure 5. A regression line representing an annual mercury increase of 10.3% is shown but the trend indicated is not significant (p=0.409) but it may be (with 80% probability) after a succession of 5 years of annual monitoring.

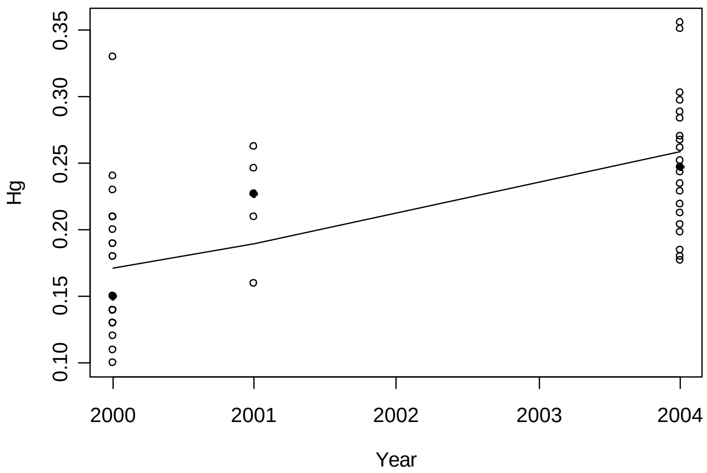

Figure 5 Mercury in Arctic char muscle, given as mg/kg ww. The slope of the non-significant regression line is 10.3% (p=0.409) with RSE = 0.051.

Atlantic cod

Beginning in the mid ninety seventies, mercury has been monitored in salt fish for the export marked. In the early nineties this monitoring discontinued and was replaced by monitoring for the purpose of following the background pollution level in accordance to the OSPAR convention using adapted JAMP guidelines. Monitoring for food safety may be most rationally done on fish as marketed whereas monitoring for spatial and temporal trend purposes demand strict choice of sampling locality and fish size and may be done on tissues that are less utilized as food. Therefore, when combining such data from various monitoring series, a larger scatter stemming from less parameter control may result. In Figure 6 all cod mercury data are given, and a linear regression line is shown along with a non-linear fitted curve. The non-linear fitted curve is constructed as a running mean of three consecutive years as in Fryer and Nicholson, 1993. The linear regression line has a significant negative slope equivalent to an annual decrease in mercury concentrations of 4%. This apparent decrease may however be an artefact stemming from an overweight of large fish in the early years which from experience would indeed tilt the curve in this direction.

In order to separate out the effect of fish length from that of a possible change in mercury input, the fish data were split in large and small fish using a cut-off of 73 cm fork length. This is in accordance with the gist in the method of Nicholson et al., 1998, though not the same (they use floating cut-offs determined as the median fish length for each year). In Figure 7 the small cod data are plotted along with linear and non-linear regression lines. The significant negative slope seen when all fish were combined in Figure 6, is now no longer significant though the tendency towards decreasing cod mercury concentrations remains, though now with a somewhat smaller slope. The 3-years running average smoother did not described the trend statistically better than the log-linear regression (p=0.121).

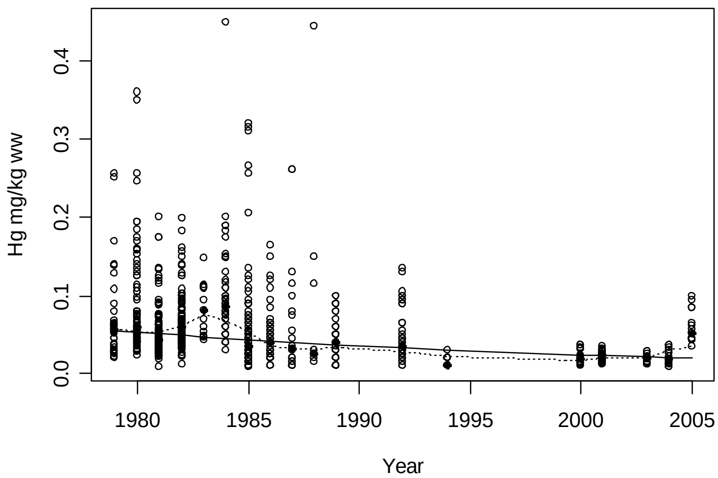

Figure 6 Mercury, as mg/kg ww, in Atlantic cod muscle from the Faroe shelf is shown along with a significant linear regression line with a slope of -4.0% (p=0.005). The dotted line represents a fitted non-linear line.

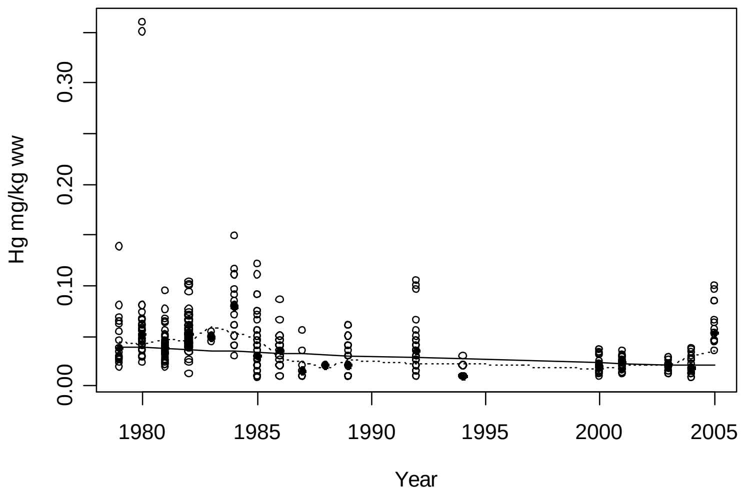

Figure 7 Mercury in Atlantic cod from the Faroe shelf is given as mg/kg ww. Only fish of fork length less than or equal to 73 cm are included in this figure. The linear regression line shown has a slope of -2.7% but is not significant at the 5% level (p=0.065).

Pilot whale

Pilot whales have been the subject of mercury monitoring at irregular periods since 1977. The frequency of whale catch incidents and the number of whales in each kill varies from year to year, and so does the opportunities for sampling. In the following, the muscle mercury data that has been established as part of the AMAP/DANCEA monitoring in the Faroe Islands has been analysed[5]. Data from pre 1997 and pooled samples data from 1997 are available but have not yet been included in the analyses.

Pilot whales accumulate mercury with age, but persistent organic pollutants are depleted in adult females as these are offloaded unto the offspring, and thus a division of the whales in adult males, adult females and immature have been done. Histograms depicting the density of mercury concentration in the three groups are given in Figure 8. As was done with the other monitoring species, the statistical calculations were performed on $\log_e$-transformed data.

The data that has been treated in this calculations stem from Pilot whale catches given in Table 2 Pilot whales included in the calculation for trends in mercury concentration. With one exception, the Sandagerði 2002 data, data on mercury concentration in muscle in these Pilot whales have been established as part of AMAP/DANCEA projects.. In the table, the number of whales analysed from each catch is given, along with the number of adult females, males and immature whales. When mercury concentrations are known, an average Pilot whale school mercury concentration may be calculated based on knowledge of the normal composition of a school in terms of mass equivalents of these three groups of adult and immature whales. The immature group consists of whales of both sexes and sorting into this pool is done according to reproductive activity as inferred from body length and sex, where males are known to be actively reproducing from age 14 years equivalent to 494 cm[6], and similarly, the female is regarded as adult from 8 years old and 375 cm[7].

The whales analysed are from two schools in 1997, 1999 and 2000. The reason for including whales from more than one school is that the concentrations of pollutants vary between schools in a manner that is not related to sampling site in the Faroe Islands. In the 1997 data, the variation between mercury in the two schools was highest, with a mean school mercury concentration in the Leynar school at 1.44 mg/kg and in the Torshavn school at 2.61 mg/kg[8].

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[5] The 2002 data do not belong to this AMAP/DANCEA pool but is included for the sake of enhancing the information output.

[6] Desportes, G., Saboureau, M. and Lacroix, A. (1993). Reproductive maturity and seasonality of male long-finned Pilot whales, off the Faroe Islands. Report International Whaling Commission (Special Issue 14), 233-262.

[7] A.R. Martin & P. Rothery, 1993. "Reproductive parameters of female long-finned Pilot whales (Globicephala melas) around the Faroe Islands", Rep. Int. Whal. Commn (Special issue 14) p. 263.

[8] Dam, M. & Bloch, D. 2000. Screening of mercury and persistent organochlorine pollutants in long-finned Pilot whale (Globicephala melas) in the Faroe Islands. Marine Pollution Bulletin 2000, Vol. 40, 1090 – 1099.

Table 2 Pilot whales included in the calculation for trends in mercury concentration. With one exception, the Sandagerði 2002 data, data on mercury concentration in muscle in these Pilot whales have been established as part of AMAP/DANCEA projects.

Location	Year	Date	N	Adult females	Adult males	Immature
Torshavn	1997	13-11-1997	54	21	11	22
Leynar	1997	02-12-1997	50	31	3	16
Hvalvík	1998	25-11-1998	3 pools	1 pool	1 pool	1 pool
Torshavn	1999	14-03-1999	40	20	11	9
Vestmanna	1999	08-09-1999	22	8	7	7
Hvannasund	2000	31-08-2000	3 pools	1 pool	1 pool	1 pool
Torshavn	2000	09-09-2000	21	11	6	4
Vestmanna	2001	27-06-2001	25	14	5	6
Sandagerði	2002	03-09-2002	41	16	13	12

The 1999 data which also covers two schools do not show the same variability as the 1997 data, a factum that is easily explained by the earlier mentioned non-predictable between school variability, and the fact that the 1997 schools had been pre-screened in pooled samples prior to the selection of these two schools as the subject of further analyses. The Hvannasund 2000 school was analysed in pooled samples only, and is therefore not discussed any further. The statistical method applied has not considered the number of samples represented in a pooled sample datum, but has treated this as being one single data-point. This is easily visible for the 1998 data for instance in Figure 9.

In Table 3, the summary statistics for the muscle mercury concentration in the Pilot whales for the various years are given. The number of whales analysed from each group mirror to some extent the frequency of occurrence of the various group in a school, so that the largest number of whales analysed are those belonging to the group of adult females, and the lowest number in the group of adult males. It is also obvious that the largest mercury concentrations are found among the adults and that the lowest variability is found among the adult males (depicted both as standard deviation and relative standard deviation).

The data for the three groups are plotted in Figure 9 to Figure 11 with linear trend lines calculated as a constant relative change each year (thus in effect a log-linear trend) and a non-linear curve calculated as a three year running mean. It is apparent that neither of these fitted curves with negative slopes for the adult whales and positive for the immature, depict significant trends. The highest between year variability as indicated both by the magnitude of p and by the RSE is found among the adults and the lowest among the immature. The annual variability is also high among the adult females (Table 3) though in relative terms it is even higher in the immature.

Table 3 Summary statistics for the muscle mercury data in Pilot whale. AF=adult females, AM =adult males, I =immature of both sexes. The mercury concentrations are given as mg/kg ww.

	N			Mean mercury			Standard dev.			Relative std.dev		
	AF	AM	I	AF	AM	I	AF	AM	I	AF	AM	I
1997	52	10	38	2.37	2.94	1.58	1.09	1.34	0.95	46%	45%	61%
1998	1pool	1pool	1pool	3.62	3.37	1.25	na	na	na	na	na	na
1999	28	18	16	1.74	1.94	1.50	0.74	0.60	0.68	43%	31%	46%
2000	11	6	4	1.86	2.00	1.13	0.54	0.17	0.33	29%	9%	29%
2001	14	5	6	1.82	1.98	1.40	0.43	0.17	0.63	24%	8%	45%
2002	16	13	12	3.18	3.18	1.27	1.62	0.65	0.71	51%	20%	56%
Sum/ mean*	**121**	**52**	**76**	**2.43**	**2.57**	**1.35**	**0.88**	**0.59**	**0.66**	**38%**	**23%**	**47%**

* The 1998 and 2000 pool samples left out in the calculations.

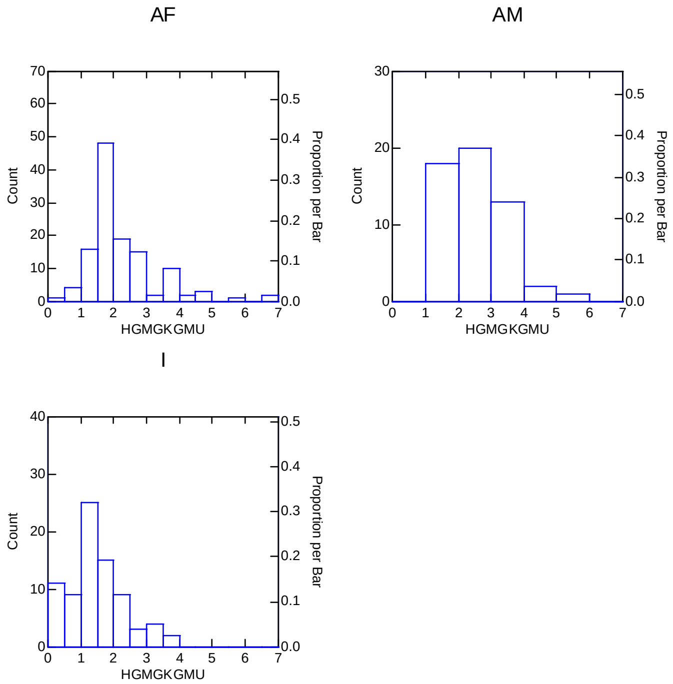

Figure 8 Histograms showing muscle mercury concentration in Pilot whale in the period 1997-2002. The whales have been split in three groups of adult females (AF), adult males (AM) and immature of both sexes (I).

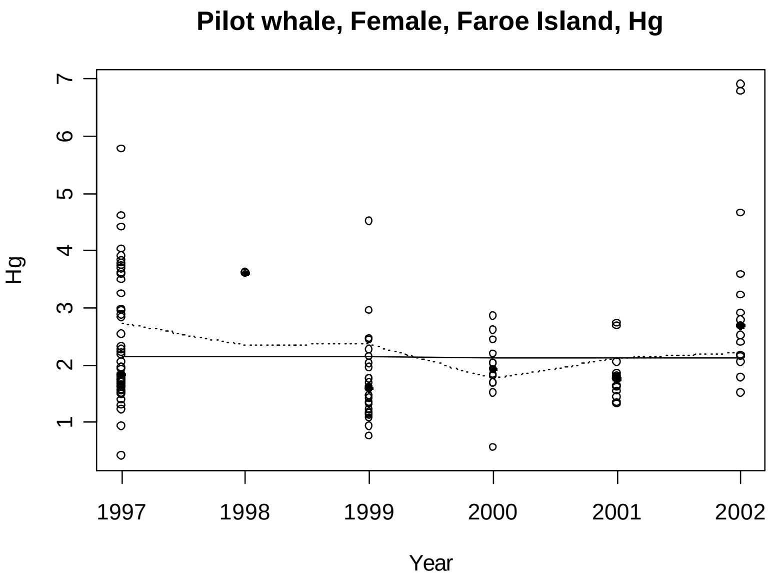

Figure 9 Adult female Pilot whale muscle mercury concentrations are given along with a line depicting linear regression with a slope -0.3% (p= 0.98, RSE 0.348) and a non-linear running mean curve.

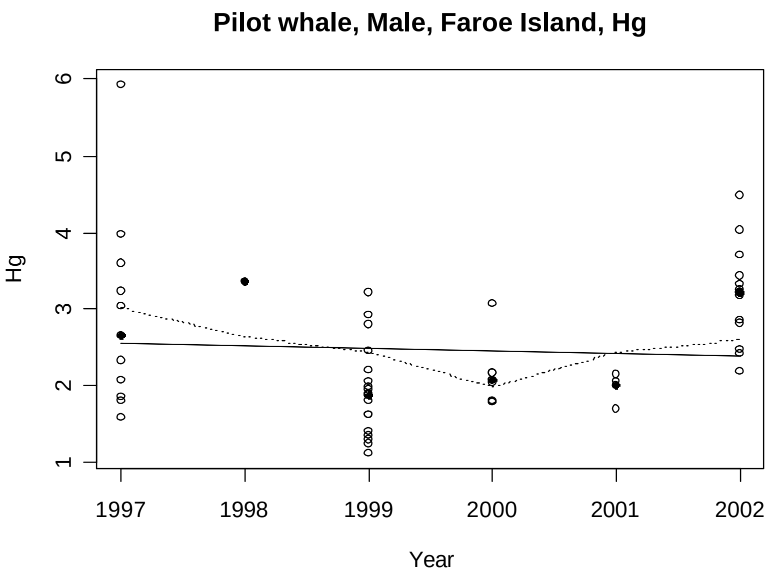

Figure 10 Adult male Pilot whale muscle mercury concentrations are given along with a line depicting linear regression with slope -1.5 % (p= 0.84, RSE 0.284) and a non-linear running mean curve.

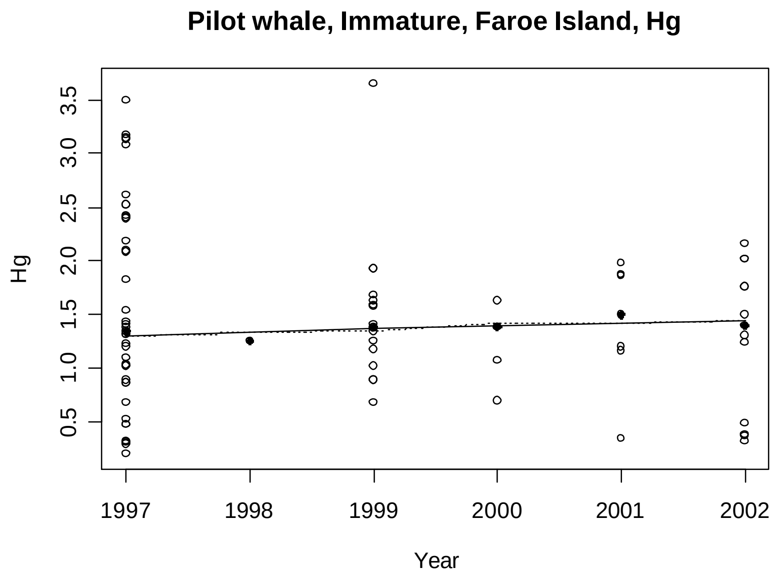

Figure 11 Immature Pilot whale muscle mercury concentrations (mg/kg ww) are shown with a linear regression line slope 2.1% (p=0.15, RSE = 0.048) and a non-linear running mean curve.

How many years until predicting power is achieved?

The question of whether and when a particular monitoring series will be providing answers on temporal trends with an acceptable degree of statistical significance is an important one, and this ability is described as the power of the monitoring series. As noted above, the power increases with the number of years the monitoring has been running, it increases with the number of samples analysed every year and it decreases with within-year and between-year variance. The between-year variance may in part be random variance, whereas the within-year variance may be seen as more directly related to the biological aspects of the species in the particular monitoring series. The biological aspects of variance would then be a common term encompassing age, gender, food choice, foraging area, individual metabolism etc. part of which are sought eliminated through narrow criteria in the sampling plan. The increase in statistical power gained in this manner is however, at the expense of the ability of the output data to answer the basic question of "what is the ambient pollutant level?" in this particular species realising that a narrow selection from the population may not be well suited to answer that question.

Among the species Pilot whale, Black guillemot eggs, sculpin, Arctic char and cod it is immediately evident that the most narrow range of variability in foraging area would be found for the Arctic char who is confined to a small lake, and the largest for the Pilot whale who roams large areas of the eastern North Atlantic. Shorthorn sculpin is known also to be a stationary species in the fjords and the Black guillemot are stationary in the Faroe Islands though potentially foraging over a much larger area than the sculpin. Cod is also foraging over a wide area, though this population stays on the Faroe shelf. The extent of the potential foraging areas is just one of many parameters, and comparing the calculated within-year variation of the species (Table 4) it is evident that a restricted foraging range in no way secures a low individual variability. This is exemplified very well with sculpin, which has a within-year variation almost ten times higher than cod.

Based on the analyses of predicting power of the various monitoring series of the species in the Faroe Island AMAP core program (Table 4), it is apparent that the muscle mercury monitoring in Arctic char and young (immature) Pilot whale have a higher potential of actually returning a significant trend within a decade of monitoring, than does the Black guillemot eggs and the older Pilot whales. The worst prospects of being able to detect trends are offered by the Atlantic cod and Shorthorn sculpin monitoring series. The cod series are however so old, that a significant trend may appear shortly if proper data-sorting and adjustment is done, for instance by ascertaining the inferred fork length from a fish fillet or a salt fish flake.

Table 4 The within year variation, and the years of annual monitoring necessary to detect an annual change of 5% in the mercury concentration with a significance of 5% and a power of 80% is shown. The species given are regarded as pillars in the Faroe Islands AMAP core program except the cod which in recent years has formed part of the OSPAR CEMP monitoring. The pre 1995 cod monitoring was done as a requirement for salt fish export.

Species	Pilot whale adult females	Pilot whale adult males	Pilot whale immature	Sculpin liver	Black guille-mot eggs	Arctic char muscle	Cod, small muscle	Cod, all muscle
within-year variance, s^2 *	0.170	0.081	0.458	2.09	0.127	0.061	0.248	0.388
random between-year variation, t^2 **	0.114	0.073	ca 0	0.825	0.046	ca 0	0.237	0.201
Years	18	16	6	> 20	14	6	>20	>20
RSE	0.348	0.284	0.048	0.987	0.230	0.051	0.493	0.458
N mean	24	11	15	14	18	17	39	44

* Variance, s^2, from ANOVA output tables.
** The random between-year variation was calculated using RSE and s^2.

The cod monitoring series is rather inhomogeneous because the monitoring method has changed over time. If however, only recent data (since 1994) for fish of fork length of max. 60 cm is analysed, the within-year variance is halved (to 0.121) whereas the between-year variance remains approx the same (at 4.362). With a residual standard error, RSE, from the linear regression of 0.363, this implies that the monitoring still needs to be done every year for 19 years until an imaginary slope of 5% change per year is significant ($p<0,05$ and power 80%).

How does the number of samples influence the predicting power?

As was noted above, the predicting power is dependent on the total variability in a monitoring series, which is a sum of the random between-year variance and the within-year variance divided by the number of individual samples in each year.

Where, for a given monitoring series with a given linear change, the power may be written as a function of $1/ ?^{2}$
where
$?^{2} = t^{2} + s^{2}/N$
or
total variation = random between-year variation + within-year variation/ number of ind. samples

The random between-year variation is the variance that remains after the change stemming from an actual change in pollutant level has been subtracted by the method described by Fryer and Nicholson[2], and the total variation is the squared RSE output of the linear regression analyses.

An underlying assumption is that the change in pollutant level can be described as a log-linear trend, thus that the change every year may be described by a constant percentage.

The basic question in elucidating the effect of N on power is to determine when the term within-year variance (s^{2}/N) in the total variance term becomes small in comparison to the random between-year-variance (t^{2}). The presently analysed monitoring series are all except for the cod, of very short duration, and thus the statistical analyses are very uncertain. It appears however, that overall, Table 4, the within-year variance is of similar magnitude as the between-year-variance, and thus that increasing the number of N will not improve the power very much. In these instances the most increase in power will be from continuing the monitoring for more years.

The within-year variance in the sculpin appears to be unreasonably high. To overcome this high variance, a refinement of the data by dividing the fish into categories of large and small fish may be attempted, but in this particular instance, such refinement will not be achieved because there is no close correlation between pollutant and fish length in these samples. Also, studies of mercury and PCB in sediments from Kaldbakfjord have not provided support for an assumed local pollution influence, and thus the conclusion with the limited data at hand, is that this data series may not be well suited to detect possible time-trends in “background” pollution levels.

An exception is seen with the immature Pilot whales, where the within-year variance is substantially larger that the between-year-variance, and thus in this series in particular, one might contemplate increasing the number and yearly samples, and at the same time take measures to narrow the within-year variance by reducing the variability that stems from variations in whale age as approximated by the length (as age is not routinely determined). There has so far been little focus on the immature whales, as these do not pose as major vectors for mercury transfer to the human population due to their relatively low mercury concentration and the relative modest mass contribution from this group in an average Pilot whale catch[9] amounting to on average 32%. There is ample data however, to support an assumption that the immature may form a major route of POP transfer as these normally contain POPs concentrations in-between that of adult females and that in adult males. Thus all in all, both in terms of monitoring for detecting trends as in terms of monitoring to keep track on the human exposure to pollutants, immature pilot whale monitoring is pertinent.

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[9] Bloch, D., Desportes, G., Mouritsen , R., Skaaning , S. & Stefansson E., 1993. An introduction to studies of the ecology and status of the Long-finned Pilot whale (*Globicephala melas*) off the Faroe Islands, 1986 – 1988. Report International Whaling Commission (Special Issue 14), 1-33.