HELCOM core indicator report
December 2015

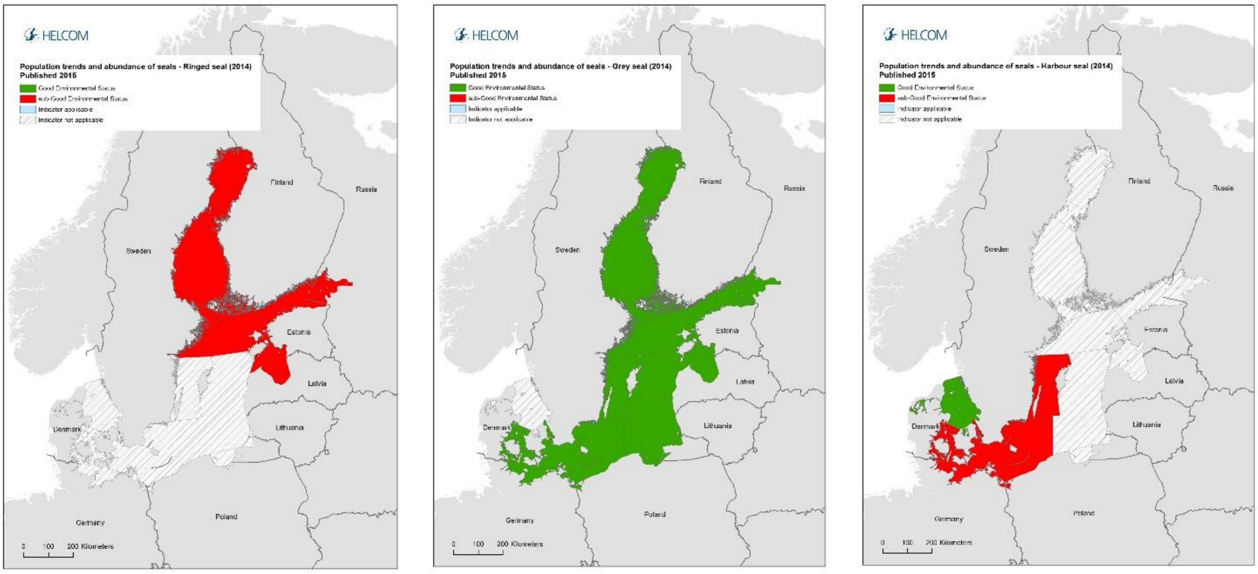
Population trends and abundance of seals

Key Message

This core indicator evaluates the status of the marine environment based on population trends and abundance of the three species of seal that occur in the Baltic Sea. Good Environmental Status (GES) is achieved when the abundance of seals in each management unit is at least 10,000 individuals and the species specific growth rate is achieved.

The status evaluation is presented separately for the three seal species. The grey seal in the Baltic proper is evaluated as a single unit, whereas the Kattegat grey seals are evaluated separately. The status of ringed seals is evaluated for two management units and harbour seals for four units. The evaluation of abundance of seals is based on data from 2014.

Ringed Seal | Grey seal | Harbour seal



Key message figure 1: Status assessment results based on evaluation of the indicator 'population trends and abundance of seals'. The assessment is carried out using Scale 2 HELCOM assessment units (defined in the HELCOM Monitoring and Assessment Strategy Annex 4). Click to enlarge.

Grey seals occur in the entire Baltic Sea except for the Kattegat where the species has not been breeding since the 1930s except for a few observations from recent years. Grey seals achieve GES with regard to population growth rate in the entire Baltic Sea when evaluated as one single population. The abundance of grey seals also achieves GES.

Ringed seals occur in the Bothnian Bay (which is considered one management unit) and in the Gulf of Finland, Archipelago Sea, Gulf of Riga and Estonian coastal waters (which is considered a second management unit). The ringed seal population growth rate is considerably below GES (sub-GES) in both units. The size of subpopulations in the Gulf of Finland and Gulf of Riga are stable or declining. The size of the population achieves GES only in the Bothnian Bay.

Harbour seals are confined to the Kalmarsund, Southern Baltic Sea, the Kattegat and Limfjord, which are all considered separate management units. The Kattegat and Limfjord subpopulations may be approaching carrying capacity since the annual growth rates are levelling off. As no decline exceeding 10% has been detected over the last 10-year period, these subpopulations have achieved GES with regard to population growth rate. However, more information is needed for Limfjord on the connectivity of this stock with the Wadden Sea population. The harbour seal population in the southern Baltic Sea is growing at 9.1% per year, and is considered to achieve GES, while evaluation of abundance of ringed seals is not applicable here. The growth rate of the Kalmarsund population (9%) achieves GES, but the population size is well below GES (sub-GES).

Confidence of the indicator evaluation is considered to be high for all seal species in the applicable assessment units, except for harbour seals in the Limfjord.

The indicator is applicable in the waters of all the countries bordering the Baltic Sea since the indicator includes all species of seal that occur in the Baltic Sea and at least one of the species occurs in all HELCOM assessment units.

Relevance of the core indicator

The population trends and abundance of seals signal changes in the number of marine top predators in the Baltic Sea. Being top predators of the marine ecosystem, marine mammals are good indicators of the state of food webs, levels of hazardous substances and direct human disturbance.

Distributions of different species during feeding and annual migrations encompass the entire Baltic Sea although no terrestrial haul-out sites occur in Germany, Latvia and Lithuania.

Policy relevance of the core indicator

	BSAP segment and objectives	MSFD Descriptor and criteria
Primary link	Biodiversity • Viable populations of species	D1 Biodiversity 1.3. Population condition
Secondary link	Biodiversity: • Thriving and balanced communities of plants and animals Hazardous Substances • Healthy wildlife	D1 Biodiversity 1.1 Species distribution (range, pattern, covered area) 1.2 Population size (abundance, biomass) D4 Food-web 4.1. Productivity of key species or trophic groups 4.3 Abundance/distribution of key trophic groups/species D8 Contaminants 8.2. Effects of contaminants
Other relevant legislation: In some Contracting Parties also EU Water Framework Directive – Chemical quality, Habitats Directive		

Cite this indicator

HELCOM (2015) Population trends and abundance of seals. HELCOM core indicator report. Online. [Date Viewed], [Web link].

Download full indicator report

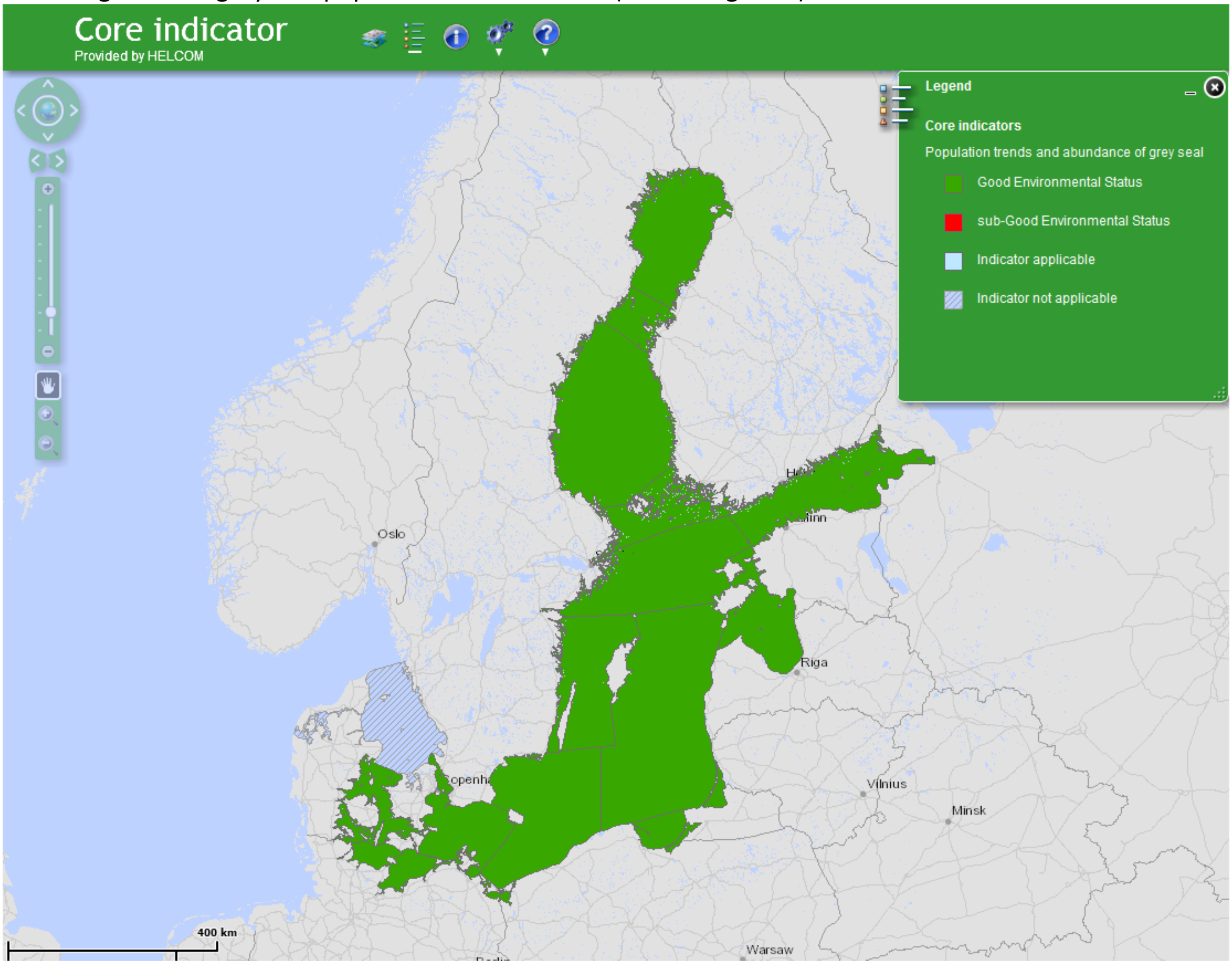
Core indicator report – web-based version December 2015 (pdf)

Extended core indicator report – outcome of CORESET II project (pdf)

Results and Confidence

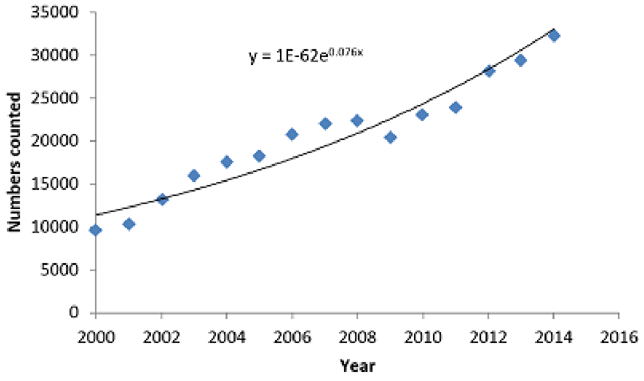
Grey seal

The grey seal population abundance and population growth rate parameters exceed the GES boundary, indicating that the grey seal population achieved GES (Results figure 1).



Results figure 1. Baltic grey seals achieved GES both with regard to population growth rate and abundance, which is considerably beyond the limit reference level of 10,000. Grey seals in the Kattegat do not form a functional population because of low numbers (less than 100) and irregular and low pupping rate.

For the grey seal a time series of data from 2000 and onwards is used to estimate the population growth rate and its confidence limits (Results figure 2). The annual population growth rate over the period was 7.9%. A Bayesian analysis shows a >80% support for a growth rate value ≥7%. Earlier data from the Swedish monitoring programme indicate that the grey seal population has been growing at a rate of about 8% per year from the early 1990s in the Baltic Sea (Stenman et al. 2005; Hårding et al. 2007). The population has thus achieved GES according to the growth rate parameter, and as 32,000 animals were counted in 2014 the population size is also well above the minimum viable population size (i.e. limit reference level (LRL) of 10,000 individuals).

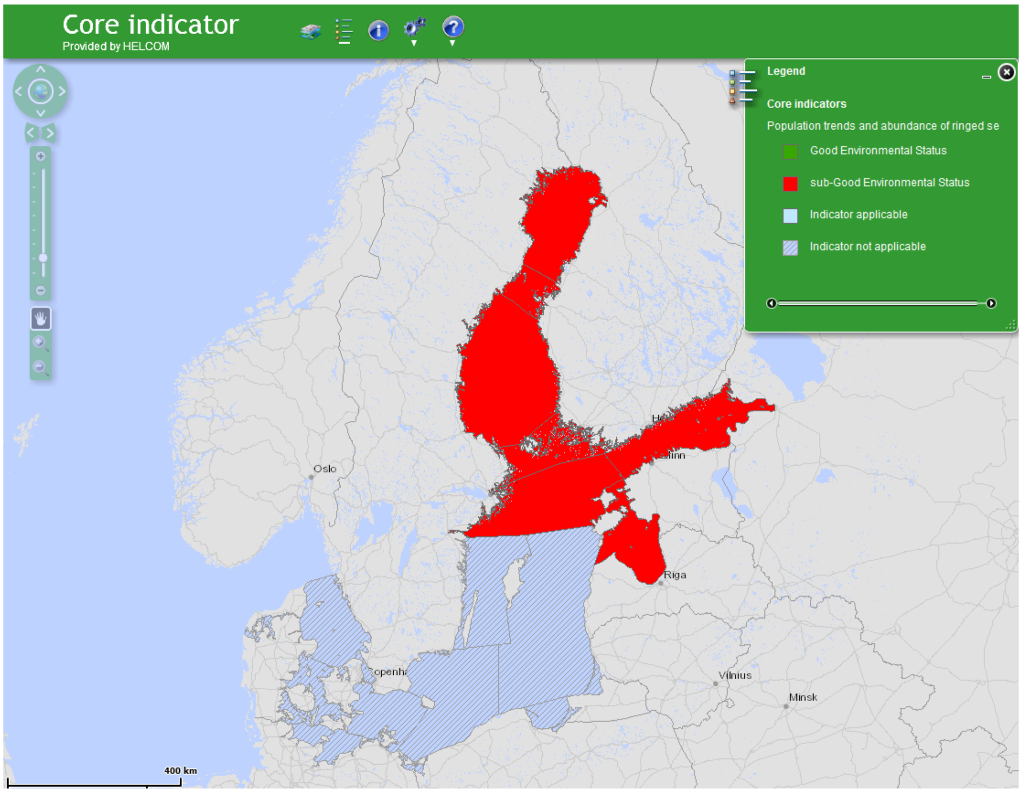


Results figure 2. Counted numbers of Baltic grey seals showed an annual rate of increase at 7.9% over the period 2000-2014 and 80% support for a rate ≥7%.

Grey seals in the Kattegat amount to approximately 100 animals, of which a majority are found at Læsø, Anholt, Hesselø, and Varberg, although single animals are seen all along the Swedish west coast. The grey seals here come both from the Baltic Sea and the Atlantic populations, and pupping occurs irregularly on Læsø but also other sites (Härkönen et al. 2007).

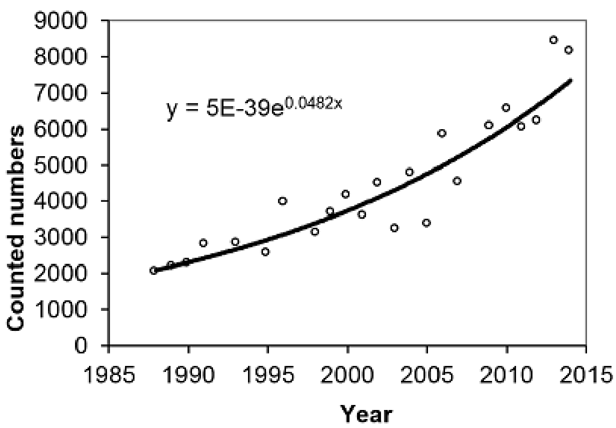
Ringed seal

The ringed seal population reflects a sub-GES status due to the fact that the population growth rate is below the GES boundary (Results figure 3).



Results figure 3. Ringed seals in the two management units (1 - the Bothnian Bay and 2 - the southern unit encompassing the Archipelago Sea, the Gulf of Finland and the Gulf of Riga including Estonian coastal waters) do not achieve GES.

The ringed seal population in the Bothnian Bay has been increasing at a rate of a 4.8% per year since 1988 (Hårding & Härkönen 1999; Karlsson et al. 2008), which is less than half the intrinsic capacity and below the GES boundary of 7% (Results figure 4; Karlsson et al. 2008). Counted numbers of seals in the Bothnian Bay exceeded 8,000 in 2014, which indicates a true population size in the area exceeding the minimum viable size at 10,000 animals, since the haul-out fraction during surveys is approximately 70%. A Bayesian analysis shows that observed data do not support ringed seals having reached the GES boundary of 7% population growth rate. This implies that ringed seals in the Bothnian Bay management unit have only reached GES for population size but not for growth rate.

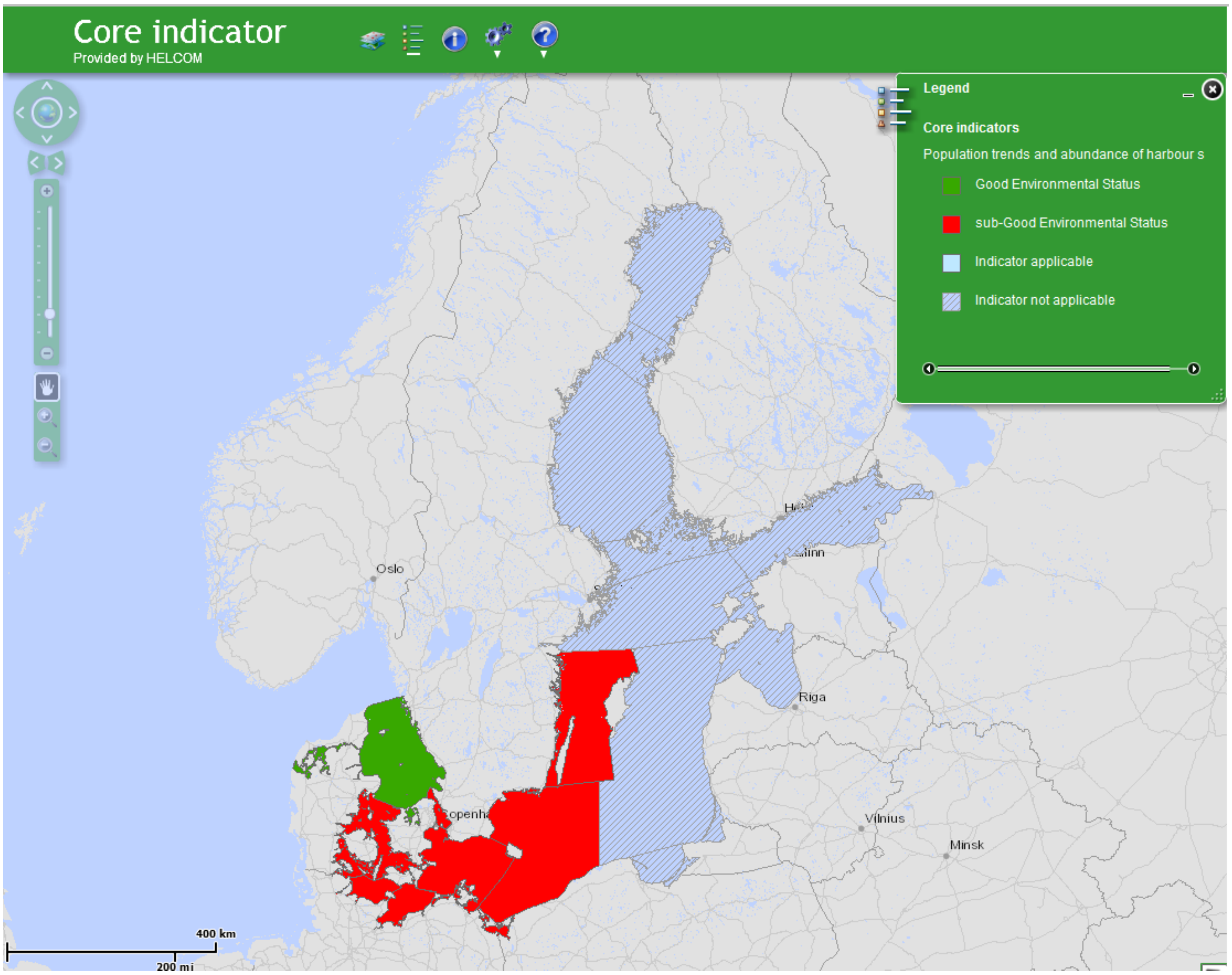


Results figure 4. Counted numbers of ringed seals in the Bothnian Bay 1988-2014. The annual growth rate was 4.8% which is well below the GES boundary of 7%. The analysis shows no support for a growth rate ≥7%.

In the southern breeding areas of the ringed seals (i.e. Gulf of Riga, Gulf of Finland and Archipelago Sea) improving trends have not been observed (Karlsson et al. 2008; M. Jussi pers. com; Ahola pers com.). The ringed seal population in the Gulf of Finland is decreasing, amounting to about 100 animals (M. Verevkin pers. com), and considered to indicate a very alarming status. The Baltic ringed seal is listed as Vulnerable by the International Union for Conservation of Nature, IUCN. Thus, the low population growth rates in all subpopulations show that the Baltic ringed seal does not achieve GES.

Harbour seal

The harbour seal population in the Kattegat reflects GES through both the abundance and the population growth rate parameters, while the populations in the Kalmarsund and Southern Baltic Sea do not achieve GES for either parameter (Results figure 5).

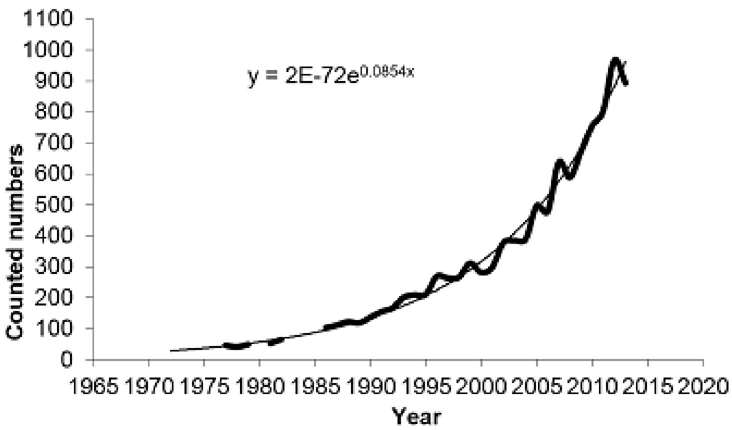


Results figure 5. Harbour seals occur in three management units, where the subpopulations in the Kalmarsund and the Southern Baltic don't achieve GES because of their low numbers (approximately 1,000 in both cases), although the growth rate in both cases does not deviate from the GES boundary value of 8% in a Bayesian analysis.

Kalmarsund

The harbour seal population in Kalmarsund is genetically divergent from adjacent harbour seal populations (Goodman et al. 1998) and experienced a severe bottle-neck in the 1970s when only some 30 seals were counted. Long-term isolation and low numbers have resulted in low genetic variation in this population (Härkönen et al. 2006). The population has increased annually by 9% since 1975 and counted numbers amounted to about 1,000 seals in 2014 (Results figure 6). See also Härkönen & Isakson (2011).

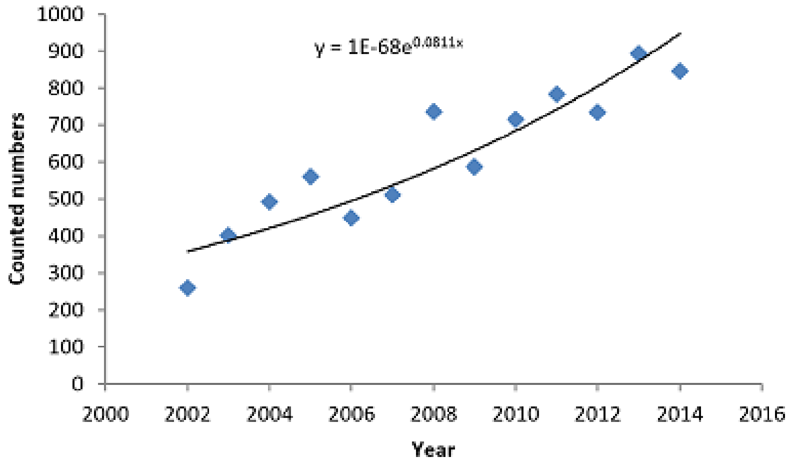
A Bayesian analysis of the trend in abundance shows that there is less than 80% support for a growth rate of 9%, and the current population size is well below the LRL of 10,000 individuals, which is why this population does not achieve GES.



Results figure 6. Changes in abundance of the Kalmarsund population of harbour seals since 1975. There is 80% support for a growth rate ≥8.4%, which is just below the GES boundary of 9%. The total number of individuals (approximately 1,000 animals) is well below the LRL of 10,000, which means that this population does not achieve GES.

The Southern Baltic Sea

Harbour seals in the Southern Baltic Sea area experienced a mass mortality caused by a Phocine Distemper virus (PDV) epidemic in 2002 which is why the growth rate is analyzed over a period starting after this event. The average annual rate of increase up to 2014 was 8.4% (Results figure 7). There is less than 80% support for a growth rate ≥9%. The abundance of seals is also well below the set LRL. However, it is genetically connected to the Kattegat population and should in this context be treated as a part of the larger unit, which would result in GES with regard to the LRL, but not the growth rate.



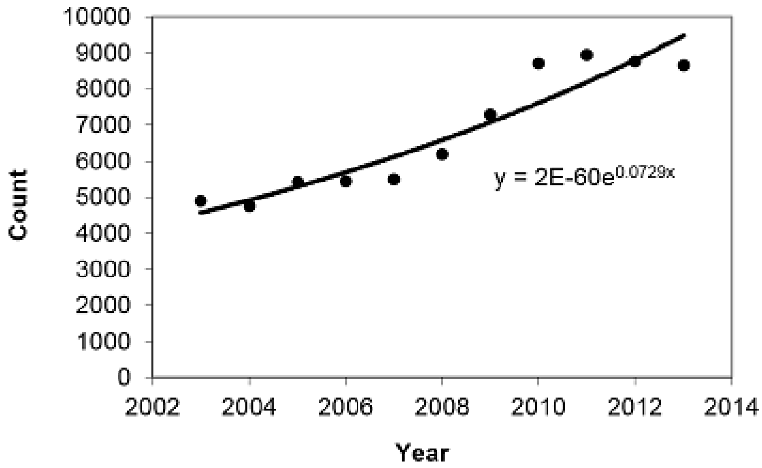
Results figure 7. The growth rate in the Southwestern Baltic harbour seal population was 8.4% over the period 2002-2014. There is 80% support for a growth rate ≥7.1%, which is below the GES boundary of 9%.

Kattegat and the Danish Straits

This harbour seal population in Kattegat and the Danish Straits experienced two dramatic mass mortality events when more than 50% of the population died in 1988 and about 30% in 2002 (Härkönen et al. 2006). Both epidemics were caused by PDV. Unusually large numbers also died in 2007, but the reason for this mortality remains unclear (Härkönen et al 2007). In the spring of 2014, some seals appearing to show signs of pneumonia, and Avian influenza H10N7 were isolated from seals in Sweden and Denmark, but also the North Sea coast (Zohari et al. 2014). Population surveys in August 2014 showed lower numbers at all seal localities, suggesting a total mortality of approximately 10%. Since we evaluate the population growth rate between major epidemics the data used here encompasses the period 2003-2013.

The rate of increase between the two PDV epidemics was close to 12% per year as in the adjacent North Sea populations (Good environmental status table 1). This high annual increase is close to the intrinsic rate of increase in harbour seals (Härkönen et al. 2002).

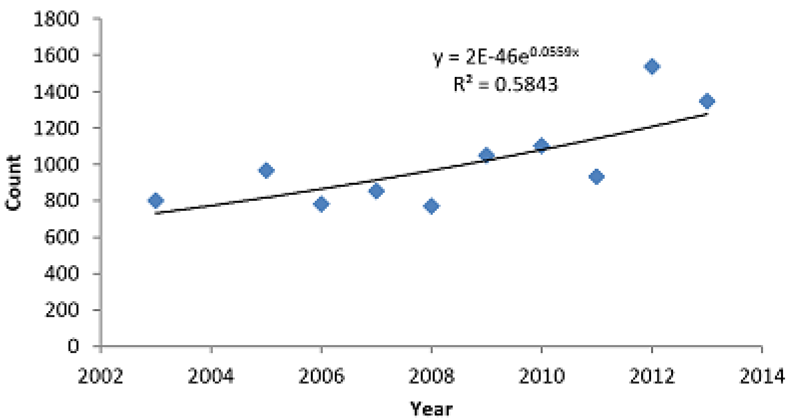
The annual population growth rate was close to 12% per year until 2010, but data suggest that it is levelling off, which could be caused by density dependent effects. It is thus unclear if the population has reached the carrying capacity of the system. Additional surveys are needed to establish such mechanisms. However, the increase over the period 2002-2013 at 7.5% is significantly lower than the 12% increase during earlier exponential growth (Results figure 8). Bayesian analysis shows 80% support for a growth rate ≥6.7% for the period after 2002, which is below the GES boundary of 9%.



Results figure 8. The harbour seal population in the Kattegat (including the Danish Straits) shows signs of stabilizing. No increase is seen during the four last years, but Power analyses suggest that a significant change in growth rate can only be detected after seven years.

Limfjord

The size of the Limfjord harbour seal population appears to have been fluctuating around 1,000 individuals since the early 1990s and appears to have reached its carrying capacity, although an annual increase at 5.6% is suggested by surveys from 2003-2013 (Results figure 9). However, genetic analysis indicates that the seals in the fjord originate from two different populations, (1) the population originally inhabiting the fjord and (2) seals from the Wadden Sea (Olsen et al. 2014). It is not known to what extent the seals from the Wadden Sea use the fjord for other purposes than hauling out and to which extent they interbreed with the native seal population. A proper assessment of the Limfjord harbour seals is contingent on clarification of these issues. Consequently, the status of the Limfjord population is uncertain since immigration may link it to the expanding Wadden Sea population.



Results figure 9. The harbour seal population in the Limfjord showed a 5.6% annual increase, and has been fluctuating around 1,000 seals for 25 years. Immigration from the Wadden Sea link it to the latter population, which is why the status of this population is uncertain.

Confidence of the indicator status evaluation

The confidence of the indicator evaluation is considered to be high for all species in all assessment units, except for harbour seals in the Limfjord. The confidence is generally deemed high as many observations are available from all years in all the relevant assessment units, with no clear temporal or spatial bias.

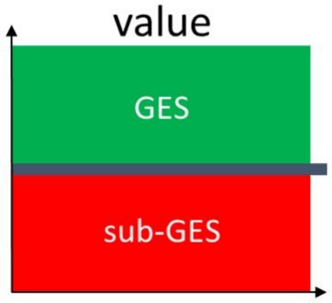
Annual surveys are carried out for all species and management units except for ringed seals in the Gulf of Riga and Estonian coastal waters. Here new methodology is underway since moulting counts on ice are not feasible under ice free conditions.

Compared to anticipated signals in the seal population trends, monitoring activities are currently carried out at a high spatial and temporal frequency. Historical data on population sizes of seals in all management units are available. The main pressures affecting seals, such as by-catches, diminishing ice fields and effects of contaminants are well known on a qualitative level, but more work is needed to quantify those pressures. Dedicated studies are needed to quantify by-catches on a regular basis, and it is not known why the nutritive condition of Baltic grey seals shows a negative trend. Furthermore, the low fertility rate in ringed seals is not fully understood.

Survey data is available for harbour seals in the Kattegat since 1979, 1972 in the Kalmarsund, 1990 in Southwestern Baltic, since 1988 for ringed seals in the Bothnian Bay and since 2000 for grey seals in the entire Baltic Sea. For grey seals there are data from Sweden also two decades before this time. Ringed seal data in the southern management unit is scarce. Sufficient data collected in the appropriate moulting periods coupled with the well-known population ecology processes, rates the confidence of the indicator evaluation as high. Although data is scarce in the southern management unit of ringed seals, this subpopulation is clearly below GES and hence the evaluation of the populations against the set GES boundaries is deemed to be reliable.

Good Environmental Status

Good environmental status (GES) for the population trends and abundance of seals in the Baltic Sea is determined by comparing population data with GES boundaries that have been defined based on concepts developed for conservation of seals, in particular the HELCOM Recommendation 27/28-2 'Conservation of seals in the Baltic Sea area'.



Good environmental status figure 1. GES is achieved when the population growth rate trend and abundance of seals are above the GES boundary.

GES is achieved for abundance of seals in a management unit if the population is above the Limit Reference Level (LRL) with a steady increasing trend towards the Target Reference Level (TRL), where TRL is the level where the growth rate starts to level off and the population asymptotically approaches the current carrying capacity level.

HELCOM set an LRL of 10,000 individuals for grey seals, ringed seals and harbour seals in each of their management units respectively, which is the minimum abundance for a species to achieve the GES boundary.

The growth rate aspect of the GES boundary is set separately for populations at- and below the TRL:

- For populations at TRL, GES is defined as 'No decline in population size or pup production exceeding 10% occurred over a period up to 10 years'
- For populations below TRL, GES is defined as 3% below the maximum rate of increase for seal species, i.e. 7% annual rate of increase for grey seals and ringed seals and 9% for harbour seals.

The concept for defining a GES boundary for the population size of seals is derived from the general management principle in the HELCOM Recommendation 27/28-2, which states that the population size is to be managed with the long-term objective of allowing seal populations to recover towards carrying capacity. Thus, the GES boundary for abundance of a seal species is achieved when the limit reference level (LRL) is reached in the management unit and the population grows steadily (at least with 3% below the maximum rate of increase for seal species, i.e 7% annual rate of increase for grey seals and ringed seals and 9% for harbour seals when below TRL).

The limit reference level corresponds to the safe biological level and minimum viable population size. HELCOM has set a LRL of 10,000 individuals for grey seals, ringed seals and harbour seals in each of their management units, respectively, understanding that the haul-out fraction during moult surveys is 70%. The LRL of 10,000 implies a population with approximately 5,000 adult seals (and thus 2 500 adult female seals).

LRL has been calculated based on estimates of minimum viable population sizes of each seal species based on different extinction risk levels (1, 3, 5 and 10%). The LRL is applicable to Baltic ringed seals, grey seals and harbour seals in the Kalmarsund corresponding to management units defined in HELCOM Rec. 27/28-2. Although other management units of harbour seals (Southern Baltic Sea, Kattegat and the Limfjord) show distinct genetic differences, these populations are affected by immigration/emigration, which is why LRL is not applicable in these units and population sizes of adjacent stocks are included in the evaluation of the LRL.

The approach used for defining the GES boundary for population trends is based on the principles of the HELCOM Recommendation 27/28-2 as the population is to increase until it reaches carrying capacity. The GES concept also follows principles applied in Ecological Quality Objectives (EcoQOs) that were developed for marine mammals in the North Sea by the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention). This core indicator is similar to the EcoQO element of the same name used in the ICES and OSPAR frameworks, with the distinction that the two latter EcoQOs include 'No decline in population size or pup production exceeding 10% over a period up to 10 years' for populations 'minimally affected by anthropogenic impacts'. This condition is, however, also deemed appropriate for this core indicator when seal populations are close to natural abundances, i.e. close to carrying capacity.

The OSPAR and ICES frameworks provide some guidance also for populations far below 'natural' or 'pristine' abundances. Applying the term 'anthropogenic influence is minimal' would imply that a population should grow close to its intrinsic rate of increase when not affected by human activities. The theoretical base for this measure is outlined below and compared with empirical data from seal populations.

Approach for defining the GES boundary for growth rate for populations close to carrying capacity (target reference level)

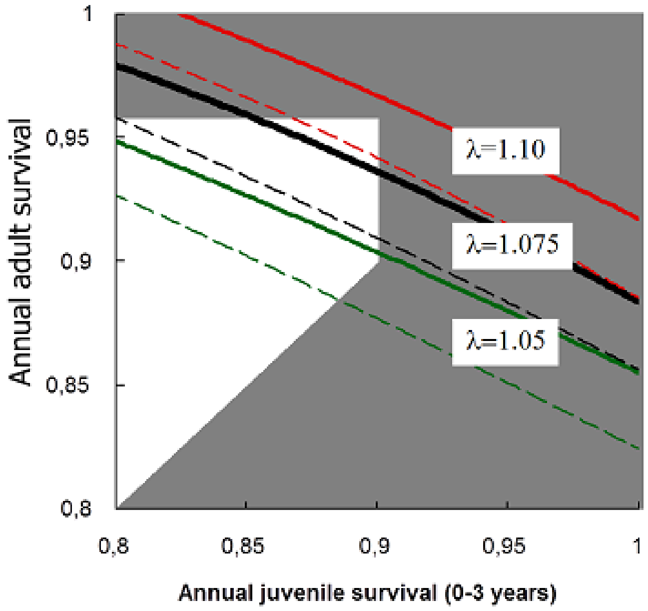
All growing populations will eventually be affected by density dependent factors (such as decreased availability of food and lack of haul-out sites) and the population size will stabilize at the carrying capacity of the ecosystem. Population sizes of marine mammals can be expected to fluctuate around the carrying capacity due to annual changes in food abundance and other external factors (Svensson et al. 2011). In this situation, the ICES and OSPAR frameworks proposed that GES is achieved when there is 'No decline in population size or pup production exceeding 10% occurred over a period up to 10 years'. The same level is used in the Baltic Sea for the purposes of this core indicator.

Approach for defining the GES boundary for growth rate for populations below carrying capacity

Long-term maximum growth rates in seals

The maximum rate of population growth is limited by several factors in grey seals and ringed seals. Females have at most one pup a year, of which 48% are female pups, and first parturition occurs at about 5.5 years of age. It is also evident that not all adult females bear a pup each year, especially not young females (Bäcklin 2011). Of females older than six years, 95.5% ovulate each year (NRM database, Bäcklin et al.), and not all of them will complete a successful pregnancy. An additional limitation for the population growth rate is given by the survival of adults. In most seal species, the highest measures of adult survival are about

0.95-0.96, and for grey seals the best estimate available is 0.935 (Harwood & Prime 1978). An additional constraint is the observation that pup and sub-adult survival is always found to be lower and more variable compared to adult survival in all studied species of seals (Boulva & McLaren 1979; Härkönen et al. 2002).



Good environmental status figure 2. Biological constraints delimit the maximum possible rate of increase in populations of grey and ringed seals. The shaded area denotes unlikely combinations of adult and juvenile survival rates. Any given point along the 6 lines shows a combination of adult survival and juvenile survival that produces a given growth rate (λ). The two uppermost lines are for λ=1.10, the two lines in the middle for λ=1.075, and the lowest two lines show combinations that result in λ=1.05. The stippled lines show combinations of adult and juvenile survival rates given that the mean annual pupping rate is 0.95. The bold full lines show the possible combinations given that the pupping rate is 0.75.

These biological constraints impose an upper ceiling of possible rates of long-term population growth for any seal species and can be found by manipulations of the life history matrix (Caswell 2001; Härkönen et al. 2002). Good environmental status figure 2 illustrates how fertility and mortality rates known for grey and ringed seals can combine to produce different long-term population growth rates. It is found that growth rates exceeding 10% (λ= 1.10) per year are unlikely in healthy grey seal populations (top stippled line in Good environmental status figure 2). Reported values exceeding 10% should be treated sceptically since they imply unrealistic fecundity and longevity rates. Such high growth rates can only occur temporally, and can be caused by e.g. transient age structure effects (Härkönen et al. 1999; Caswell 2001), but are also to be expected in populations influenced by considerable immigration.

The upper limit of individual reproductive rate is reflected at the population level, and gives an upper theoretical limit for the rate of population increase (Good environmental status figure 2). The mean values of fecundity and mortality will always be lower than the theoretical maximum, also for populations which live under favourable conditions. Chance events such as failed fertilization or early abortions reduce annual pregnancy rates, and in samples of reasonable sizes, mean pregnancy rates (or rather annual ovulation rates) rarely reach 0.96 (Boulva & McLaren 1979; Bigg 1969; Härkönen & Heide-Jørgensen 1990).

Another factor that will decrease mean pregnancy rates is senescence and pathological changes in the reproductive organs (Härkönen & Heide-Jørgensen 1990). Further, environmental factors reduce fecundity and survival rates. The impact from extrinsic factors may occur with different frequency and amplitude. Environmental pollution and high burdens of parasites can decrease population-specific long-term averages of fecundity and survival (Bergman 1999), while epizootic outbreaks and excessive hunting have the capacity to drastically reduce population numbers on a more short-term basis (Dietz et al. 1989; Harding & Härkönen 1999; Härkönen et al. 2006). Fluctuations in food supply and availability of breeding grounds can cause an energetic stress that affect survival and fecundity. The type of variation in fecundity and survival rates will determine the structure of a population. In a population with a constant rate of increase (thus no temporal variability), the age- and sex-structures quickly reach stable distributions, where the frequencies of individuals at each age class are constant. Populations with low juvenile survival typically have steeper age distributions compared to populations with higher juvenile survival rates (Caswell 2001). Skewed age structure can cause a temporal flux in the population growth rate.

Harbour seals mature about one year earlier than grey seals and ringed seals, which is why maximum rate of increase in this species is 12-13% per year (Härkönen et al. 2002).

Empirical evidence

With few exceptions, most populations of seals have been severely depleted by hunting during the 20th century. Detailed historical hunting records for pinnipeds are available for the Saimaa ringed seal, Baltic ringed seal, Baltic grey seal and the harbour seal in the Wadden Sea, Kattegat and the Skagerrak. Analyses of these hunting records have documented collapses in all populations, which were depleted to about 5-10% of pristine abundances before protective measures were taken (Heide-Jørgensen & Härkönen 1988; Kokko et al. 1999; Harding & Härkönen 1999). After hunting was banned and protected areas were designated, most populations started to increase exponentially.

Harbour seal populations in the Kattegat and outside the Baltic increased by about 12% per year between epizootics in 1988 and 2002 (Olsen et al. 2010, Teilmann et al. 2010), whereas harbour seals and grey seals in the Baltic showed lower increase compared with exponentially increasing oceanic populations (Wadden Sea Portal). A Bayesian approach (below) is used to evaluate if observed rates of increase close to intrinsic rates are supported. The GES boundary for population growth rate is set to a value 3% lower than the maximum rate of increase.

Good environmental status table 1. Rates of increase in seal populations recovering after over-hunting. Grey seals from the UK, Norway, and Iceland are not included here since they have been consistently hunted over the years. Canadian grey seals have a life history similar to harbour seals.

Species	Area	Annual growth rate	Period	Reference
Harbour seal	Skagerrak	+12%	1978-1987	Heide-Jørgensen & Härkönen (1988)
Harbour seal	Skagerrak	+12%	1989-2001	Härkönen et al. 2002
Harbour seal	Kattegat	+12%	1978-1987	Heide-Jørgensen & Härkönen (1988)
Harbour seal	Kattegat	+12%	1989-2001	Härkönen et al. 2002
Harbour seal	Baltic	+ 9%	1972-2010	Härkönen & Isakson 2011
Harbour seal	Wadden Sea	+12%	1980-1988	Reijnders et al. 1994
Harbour seal	Wadden Sea	+12%	1989-2001	Wadden Sea Portal

Assessment Protocol

This core indicator evaluates whether Good Environmental Status (GES) is achieved by determining the growth rate of the population as well as the population size over a specified time period. The data collected and used in this indicator are based on national aerial surveys described in Galatius et al. (2014).

Each assessment unit is evaluated against two GES boundaries, the GES boundary for population growth rate and the Limit Reference Level (LRL). The status of seals in each management unit only achieve GES if both GES boundaries are met.

Time series of data for each seal species and each management unit are used as input values in Bayesian analyses with uninformative priors, where it is evaluated whether observed data support the set GES value. In this process, 80% support for a growth rate ≥ GES boundary is required. If the unit fails GES, the probability distribution is used to evaluate the confidence of the assessment. The package 'bayesm' in the program R has been used for the analysis. The following is an example of the procedure using survey data on harbour seals in the Southern Baltic Sea over the period 2002-2014:

```
library(bayesm)
year <-
c(2002,2003,2004,2005,2006,2007,2008,2009,2010,20
11,2012,2013,2014)
count <-
c(260,401,494,560,448,511,737,586,715,783,734,893,
845)
y <- log(count)
X <- model.matrix(log(count)~year)
Theta0 <- c(0,0)
A0 <- 0.0000001*diag(2)
nu0 <- 0
sigma0sq <- 0
n.sims <- 5000
Data <- list(y=y,X=X)
Prior <- list(betabar=Theta0, A=A0, nu=nu0,
ssq=sigma0sq)
Mcmc <- list(R=n.sims)
bayesian.reg <- runireg(Data, Prior, Mcmc)
beta.sims <- t(bayesian.reg$betadraw)
sigmasq.sims <- bayesian.reg$sigmasqdraw
apply(beta.sims, 1, quantile, probs = c(0.025, 0.975,
0.05, 0.1, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55,
0.6, 0.65, 0.7, 0.75, 0.8, 0.85, 0.90, 0.95))
```

Which gives the output:

2.50%	0.057402
97.50%	0.104045
5%	0.061368
10%	0.065921
15%	0.069049
20%	0.071529
25%	0.073271
30%	0.074951
35%	0.076557
40%	0.07791
45%	0.079096
50%	0.08053
55%	0.082055
60%	0.08343
65%	0.084957
70%	0.0866
75%	0.088232
80%	0.090172
85%	0.092368
90%	0.095354
95%	0.100053

In this example, there is 80% support for a growth rate ≥0.072 (read at 20%). Thus, the unit does not achieve GES.

Assessment units and management units

This core indicator evaluates the population trends and abundance of seals using HELCOM assessment unit scale 2 (division of the Baltic Sea into 17 sub-basins). The assessment units are defined in the HELCOM Monitoring and Assessment Strategy Annex 4.

The existing management plans for seals operate according to management units that are based on the distribution of seal populations. The management units typically encompass a handful of HELCOM scale 2 assessment units. Evaluations are therefore done by grouping HELCOM assessment units to align with the management units defined for each seal population.

- The Baltic grey seal is a single management unit, although genetic data show spatial structuring (Fietz et al. 2013). Total numbers of counted seals in the entire Baltic during moulting surveys in 2014 was about 32,000. The proportion of the population hauled out during moult has been estimated to about 60-80% (e.g. Hiby et al. 2013). Coordinated aerial surveys encompassing the entire Baltic started in 2000, which is why only data after that year are used in analyses.
- The Baltic ringed seal is distributed in the Gulf of Bothnia on the one hand and Southwestern Archipelago Sea, Gulf of Finland and Gulf of Riga on the other, and is represented by two different management units. This sub-division is justified by ecological data that indicate separate dynamics of the stocks. Since ringed seals from both areas show a high degree of site fidelity, as seen in satellite telemetry data (Härkönen et al. 2008), it is unlikely that extensive migrations occur at current low population numbers, although some individuals can show more extensive movements (Oksanen et al. 2015).
- Harbour seals in the Kalmarsund, Sweden, constitute a separate management unit and is the genetically most divergent of all harbour seal populations in Europe (Goodman 1998). It was founded about 8,000 years ago, and was close to extinction in the 1970s as a consequence of intensive hunting, and possibly also impaired reproduction (Härkönen et al. 2005). The genetic diversity is substantially reduced compared with other harbour seal populations.
- Harbour seals in the southwestern Baltic (Danish Straits, Danish, German, Polish Baltic and the Öresund region including Skåne county in Sweden) should be managed separately as this stock is genetically distinct from adjacent populations of harbour seals (Olsen et al. 2014).
- Harbour seals in the Kattegat are also genetically distinct from adjacent populations (Olsen et al. 2014).
- Harbour seals in the Limfjord form the fourth management unit and is genetically distinct from the Kattegat harbour seals (Olsen et al. 2014).

Relevance of the Indicator

Biodiversity assessment

The status of biodiversity is assessed using several core indicators. Each indicator focuses on one important aspect of the complex issue. In addition to providing an indicator-based evaluation of the population trends and abundance of seals, this indicator will also contribute to the next overall biodiversity assessment to be completed in 2018 along with the other biodiversity core indicators.

Policy relevance

The core indicator on population trends and abundance of Baltic seals addresses the Baltic Sea Action Plan's (BSAP) Biodiversity and nature conservation segment's ecological objective 'Viable populations of species'.

The core indicator is relevant to the following specific BSAP target:

- 'By 2015, improved conservation status of species included in the HELCOM lists of threatened and/or declining species and habitats of the Baltic Sea area, with the final target to reach and ensure favourable conservation status of all species'.

The HELCOM Recommendation 27/28-2 Conservation of seals in the Baltic Sea area outlines the conservation goals of seals agreed on at HELCOM. The recommendation is implemented to reach the BSAP goals. The recommendation conservation goals are used as the basis for defining this indicator's GES boundary.

The core indicator also addresses the following qualitative descriptors of the MSFD for determining good environmental status (European Commission 2008):

Descriptor 1: 'Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climatic conditions' and

Descriptor 4: 'All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity'.

Descriptor 8: 'Concentrations of contaminants are at levels not giving rise to pollution effects'

and the following criteria of the Commission Decision (European Commission 2010):

- Criterion 1.1 (species distribution)
- Criterion 1.2 (population size)
- Criterion 1.3 (population condition)
- Criterion 4.1 (Productivity of key species or trophic groups)
- Criterion 4.3 (abundance/distribution of key trophic species)
- Criterion 8.2 (Effects of contaminants)

Marine mammals were recognized by the MSFD Task Group 1 as a group to be assessed.

In some Contracting Parties, the indicator also has potential relevance for implementation of the EU Water Framework Directive (WFD) and Habitats Directive. The WFD includes status categories for coastal waters as well as environmental and ecological objectives. The EU Habitats Directive (European Commission 1992) specifically states that long-term management objectives should not be influenced by socio-economic considerations, although they may be considered during the implementation of management programmes provided the long-term objectives are not compromised. All seals in Europe are also listed under the EU Habitats Directive Annex II, and member countries are obliged to monitor the status of seal populations

Role of seals in the ecosystem

Being top predators in the Baltic Sea ecosystem, seals are exposed to ecosystem changes in lower trophic levels, but also to variations in climate (length of seasons and ice conditions) and human impacts. These pressures can affect fish stocks, levels of harmful substances as well as direct mortality caused by hunting or by-catch. The vulnerability of seals to these pressures makes them good indicators for measuring the environmental status of ecosystems.

The growth rate of a population is the result of age-specific mortality rates and age-specific fecundity rates. It is therefore a sensitive parameter signalling if mortality or fecundity rates change. Depleted, undisturbed populations are expected to grow by 10% per year (grey and ringed seals) or 12% per year (harbour seals). Significantly lower observed growth rates indicate effects from the environment in form of reduced food availability or impaired health caused by contaminants or diseases. Low growth rates can also be the result of excessive hunting or high levels of by-catches.

All species of marine mammals in the Baltic Sea were severely reduced in the beginning of the 20th century as a result of a coordinated international campaign to exterminate seals. Seal numbers in the Baltic Sea dropped by 80-90% over the period 1920-1945, resulting in extirpation of grey seals in the Kattegat in the 1930s (Heide-Jørgensen & Härkönen 1988) and grey seals and harbour seals along the Polish and German coasts (Harding & Härkönen 1999). Environmental contaminants in the 1960s and 1970s caused infertility in ringed and grey seals, where fertility rates in ringed seals dropped to 17% in the beginning of the 1970s (Helle 1980).

Human pressures linked to the indicator

	General	MSFD Annex III, Table 2
Strong link	The main pressures affecting the abundance and growth rate of Baltic seal populations include hunting, by-catches, and disturbance	Biological disturbance: -selective extraction of species, including incidental non-target catches (e.g. by commercial and recreational fishing)
Weak link	The effects of climate change are a threat to the ringed seal that breeds on sea ice Fishery and food availability	Contamination by hazardous substance: - introduction of synthetic compounds - introduction of non-synthetic substances and compounds

Historically, hunting of seals has been a major human pressure on all the seal species in the Baltic Sea. A coordinated international campaign was initiated in the beginning of the 20th century with the aim of exterminating the seals (Anon. 1895). Bounty systems were introduced in Denmark, Finland and Sweden over the period 1889-1912, and very detailed bounty statistics provide detailed information on the hunting pressure. The original population sizes were about 180,000 for ringed seals, 80,000 for Baltic grey seals and 5,000 for the Kalmarsund population of harbour seals (Harding & Härkönen 1999; Härkönen & Isakson 2011). Similar data from the Kattegat and Skagerrak suggest that populations of harbour seals amounted to more than 17,000 seals in this area (Heide-Jørgensen & Härkönen 1988).

The hunting pressure resulted in extirpation of grey and harbour seals in Germany and Poland in 1912, and grey seals were also extirpated from the Kattegat by the 1930s. Ringed seals declined to about 25,000 seals in the 1940s, whereas grey seals were reduced to about 20,000 (Harding & Härkönen 1999) over the same time period. A similar rate of reduction of harbour seals occurred in the Kalmarsund and the Kattegat (Heide-Jørgensen & Härkönen 1988; Härkönen & Isakson 2011). However, after these heavy reductions, populations appear to have been stable up to the 1960s (Harding & Härkönen 1999).

Then, in the beginning of the 1970s grey seals were observed aborting near full term foetuses, and only 17% of ringed seal females were fertile (Helle 1980). Later investigations showed a linkage to a disease syndrome including reproductive disorder, caused by organochlorine pollution, in both grey seals and ringed seals (Bergman & Olsson 1985). The reduced fertility resulted in population crashes, where numbers of ringed and grey seals dwindled to approximately 3,000 of each species in the beginning of the 1980s (Harding & Härkönen 1999). Increasing numbers of these species were recorded after levels of PCB in biota decreased by the end of the 1980s. Recent samples show that fertility is normal in grey seals, but still impaired in ringed seals (Bäcklin et al. 2011; Bäcklin et al. 2013). The very low numbers of ringed seals in the Gulf of Finland may be caused by impaired female fertility.

Incidental catches of seals in fisheries are known to have substantial effects on the population growth rate in species like the Saimaa and Ladoga ringed seals (Sipilä 2003). The current knowledge on the level of incidental catches of Baltic seal species is limited to a few dedicated studies which suggest that this factor can be substantial. An analysis of reported incidentally caught grey seals showed that approximately 2,000 grey seals are caught annually in the Baltic fisheries (Vanhatalo et al. 2014), but numbers of incidentally caught ringed seals and harbour seals are not known.

Incidentally caught grey seals are significantly leaner compared to hunted seals (Bäcklin et al. 2011), which may suggest that food is a limiting factor for incidentally caught grey seals. It is possible that food limitation is becoming an important factor also for the entire population since data on blubber thickness in Baltic grey seals (also hunted) show a significant decline during the last decade (Bäcklin et al. 2011).

Climate change poses a pressure on species breeding on ice because shorter and warmer winters lead to more restricted areas of suitable ice fields (Meier et al. 2004). This feature alone will severely affect the Baltic ringed seals and the predicted rate of climate warming is likely to cause extirpation of the southern subpopulations (Sundqvist et al. 2012). Grey seals are facultative ice breeders and their breeding success is considerably greater when they breed on ice as compared with land (Jüssi et al. 2008). Consequently, both ringed seals and grey seals are predicted to be negatively affected by a warmer climate.

Most land breeding sites of Baltic seals are protected during critical periods of time, since seals are vulnerable to disturbance during the lactation period. This is especially important for grey seals, where access to undisturbed land breeding sites delimit the expansion of grey seals in the Southern Baltic Sea.

Monitoring Requirements

Monitoring methodology

HELCOM common monitoring relevant for the seal population trends is documented on a general level in the HELCOM Monitoring Manual under the **sub-programme: Seal abundance**.

HELCOM monitoring guidelines for seals were adopted in 2014 and currently all monitoring guidelines are being reviewed for inclusion in the Monitoring Manual.

The three regularly occurring seal species in the Baltic Sea, harbour seal (*Phoca vitulina*), ringed seal (*Pusa hispida*) and grey seal (*Halichoerus grypus*) are monitored at their haul-outs on land during their annual moulting and pupping seasons, with the aim of estimating the abundance and trends (moulting counts) and pup production (pupping counts). Ringed seals are counted during moult on the ice. Where possible, the monitoring is performed using aerial surveys, where the seal haul-outs are photographed during the relevant periods in areas where there is a significant occurrence of seals.

Detailed descriptions of the survey methodology and analysis of results are given in the BALSAM monitoring manual (Galatius et al. 2014).

Current monitoring

The monitoring activities relevant to the indicator that are currently carried out by HELCOM Contracting Parties are described in the HELCOM Monitoring Manual in the Monitoring Concept Table.

Sub-programme: Seal Abundance
Monitoring Concept Table

Current monitoring covers all haul-out sites presently used by seals in the Baltic Sea and is considered to be sufficient to cover the needs of the indicator except for southern ringed seals. See description in the Assessment Requirements of the HELCOM Monitoring Manual.

Description of optimal monitoring

The monitoring strategy is optimal for harbour seals which are surveyed three times annually during the moulting period, and increased effort would not significantly improve results (Teilmann et al. 2010). The same is true for ringed seal surveys on ice in the Bothnian Bay, where a minimum fraction of 13% of the ice area is surveyed. Increasing survey effort would only marginally affect the precision of estimates (Härkönen & Lunneryd 1992). Also the coordinated grey seal surveys would be only marginally improved by increased effort.

However, two management units require modified methodology:

Limfjord harbour seals

The fjord was separated from the North Sea by land until the 1820s and genetic analyses indicate different populations in the eastern and western fjord, with the eastern fjord being predominantly inhabited by the original population of the fjord and the western fjord predominantly inhabited by immigrants from the North Sea / Wadden Sea (Olsen et al. 2014). A study determining the relative abundances of the two populations, the level of interbreeding and the habitat use of seals with genetic signature is necessary for evaluation in this area.

Southern ringed seals

Since ice cover has been diminishing over the past decades, monitoring of ringed seals on ice in the Archipelago Sea, The Gulf of Finland, and Estonian coastal waters including the Gulf or Riga has only been possible during a few years over the past 20 years. However, before the aerial surveys started, ringed seals were counted on land in August, when they returned to the coast after having spent most of the summer foraging at sea (e.g. Härkönen et al. 2008). Such data is available from the Gulf of Finland, where numbers of counted ringed seals amounted to 300 animals in 1992 (Härkönen et al. 1998), whereas only 100 ringed seals were observed in the same area in 2014 (Verevkin pers. com.). Consequently, the method of surveying ringed seals hauled out on rocks in August would be an appropriate alternative method for southern ringed seals.

Data and updating

Access and use

The data and resulting data products (tables, figures and maps) available on the indicator web page can be used freely given that the source is cited. The indicator should be cited as following:

HELCOM (2015) Population trends and abundance of seals. HELCOM core indicator report. Online. [Date Viewed], [Web link].

ISSN: 2343-2543

Metadata

The national survey data is compiled annually by the HELCOM Seal Expert Group. A regional database is under developed and will be hosted at the HELCOM Secretariat.

The first compilations for the database have been completed and an intermediate version of the seal database can be accessed. During 2015-2016 work will continue to operationalize the database. Further metadata will be included at a later stage.

The data collected and used in the indicator are based on national aerial surveys. The survey methodology is described in Galatius et al. (2014). This data covers only haul-out sites and not areas used e.g. as hunting grounds.

Contributors and references

Contributors

Tero Härkönen, Anders Galatius, Karin Hårding, Olle Karlsson, Markus Ahola, Lena Avellan.

Archive

This version of the HELCOM core indicator report was published in December 2015:

Core indicator report – web-based version November 2015 (pdf)

Extended core indicator report – outcome of CORESET II project (pdf)

Older versions of the indicator report are available:

2013 Indicator report (pdf)

References

Anon. (1895) Svensk fiskeritidskrift 1895.

Bäcklin, B.-M., Moraeus, C., Roos, A., Eklöf, E., Lind, Y. (2011) Health and age and sex distributions of Baltic grey seals (*Halichoerus grypus*) collected from bycatch and hunt in the Gulf of Bothnia. ICES Journal of Marine Science 68: 183-188.

Bäcklin, B.-M., Moraeus, C., Kauhala, K., Isomursu, M. (2013) Pregnancy rates of the marine mammals - Particular emphasis on Baltic grey and ringed seals. HELCOM web portal.

Bergman, A., Olsson, M. (1985) Pathology of Baltic grey seal and ringed seal females with special reference to adrenocortical hyperplasia: Is environmental pollution the cause of a widely distributed disease syndrome. Finnish Game Res. 44: 47-62.

Bergman, A. (1999) Health condition of the Baltic grey seal (*Halichoerus grypus*) during two decades. Apmis 107(1-6): 270-282.

Bigg, M.A. (1969) The harbour seal in British Columbia (No. 172). Fisheries Research Board of Canada.

Boulva, J., McLaren, I.A. (1979) Biology of the harbor seal, *Phoca vitulina*, in eastern Canada. Fisheries Research Board of Canada.

Caswell, H. (2001) Matrix population models: Construction, analysis, and interpretation. Second edition. Sinauer, Sunderland. Massachusetts, USA.

Dietz, R., Heide-Jørgensen, M.-P., Härkönen, T. (1989) Mass deaths of harbour seals *Phoca vitulina* in Europe. Ambio 18(5): 258-264.

European Commission (1992) Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (Habitats Directive). Off. J. Eur. Union 206: 7–50.

European Commission (2008) Directive 2008/56/EC of the European Parliament and the Council establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). Off. J. Eur. Union L 164: 19-40.

European Commission (2010) Commission Decision of 1 September 2010 on criteria and methodological standards on good environmental status of marine waters (2010/477/EU). Off. J. Eur. Union L232: 12-24.

Fietz, K., Graves, J.A., Olsen, M.T. (2013) Control Control Control: A Reassessment and Comparison of GenBank and Chromatogram mtDNA Sequence Variation in Baltic Grey Seals (*Halichoerus grypus*). PLoS ONE 8(8): e72853. doi:10.1371/journal.pone.0072853.

Galatius, A., Ahola, M., Härkönen, T., Jüssi, I., Jüssi, M., Karlsson, O., Verevkin, M. (2014) Guidelines for seal abundance monitoring in the HELCOM area 2014. Available at: http://helcom.fi/Documents/Action%20areas/Monitoring%20and%20assessment/Manuals%20and%20Guidelines/Guidelines%20for%20Seal%20Abundance%20Monitoring%20HELCOM%202014.pdf

Goodman, S.J. (1998) Patterns of extensive genetic differentiation and variation among European harbor seals (*Phoca vitulina vitulina*) revealed using microsatellite DNA polymorphisms. Molecular Biology and Evolution 15(2): 104-118.

Harding, K.C., Härkönen, T.J. (1999) Development in the Baltic grey seal *(Halichoerus grypus)* and ringed seal *(Phoca hispida)* populations during the 20th century. Ambio 28: 619-627.

Harding, K.C., Härkönen, T., Helander, B., Karlsson, O. (2007) Status of Baltic grey seals: Population assessment and risk analysis. NAMMCO Scientific Publications 6: 33-56.

Härkönen, T., Heide-Jørgensen, M.-P. (1990) Density and distribution of the ringed seal in the Bothnian Bay. Holarctic Ecology 13(2): 122-129.

Härkönen, T., Lunneryd, S.G. (1992) Estimating abundance of ringed seals in the Bothnian Bay. Ambio 21: 497-510.

Härkönen, T., Stenman, O., Jüssi, M., Jüssi, I., Sagitov, R., Verevkin, M. (1998**)** Population size and distribution of the Baltic ringed seal (*Phoca hispida botnica*). In: Ringed Seals (*Phoca hispida*) in the North Atlantic. Edited by C. Lydersen and M.P. Heide-Jørgensen. NAMMCO Scientific Publications 1: 167-180.

Härkönen, T., Harding, K.C., Goodman, S., Johannesson, K. (2005) Colonization history of the Baltic harbor seals: Integrating archaeological, behavioural and genetic data. Marine Mammal Science 21: 695-716.

Härkönen, T., Dietz, R., Reijnders, P., Teilmann, J., Harding, K., Hall, A., Brasseur, S., Siebert, U., Goodman, S., Jepson, P., Dau Rasmussen, T., Thompson, P. (2006) A review of the 1988 and 2002 phocine distemper virus epidemics in European harbour seals. Diseases of Aquatic Organisms 68: 115-130.

Härkönen, T., Brasseur, S., Teilmann, J., Vincent, C., Dietz, R., Reijnders, P., Abt, K. (2007) Status of grey seals along mainland Europe, from the Baltic to France. NAMMCO Scientific Publications 6: 57-68.

Härkönen, T., Harding, K., Rasmussen, T.D., Teilmann, J., Dietz, R. (2007) Age- and Sex-specific Mortality Patterns in an Emerging Wildlife Epidemic: the Phocine Distemper in European Harbour Seals. PLoS ONE 2(9): e887. doi: 10.1371/journal.pone.0000887.

Harkonen, T., Bäcklin, B.-M., Barrett, T., Anders Bergman, A., Corteyn, M., Dietz, R., Harding, K., Malmsten, J., Roos, A., Teilmann, T. (2008) Mass mortality in harbour seals and harbour porpoises caused by an unknown pathogen. The Veterinary Record 162: 555-556.

Harkonen, T., Jüssi, M., Jüssi, I., Verevkin, M., Dmitrieva, L., Helle, E., Sagitov, R., Harding, K.C. (2008) Seasonal activity budget of adult Baltic ringed seals (*Phoca hispida botnica*). PLoS ONE 3(4): e2006.doi:10.1371/journal.pone.0002006.

Harkonen, T., Isakson, E. (2011) Historical and current status of harbour seals in the Baltic proper. NAMMCO Scientific Publications 8: 71-76.

Harwood, J., Prime, J.H. (1978) Some factors affecting the size of British grey seal populations. Journal of Applied Ecology: 401-411.

Heide-Jørgensen, M.-P., Härkönen, T. (1988) Rebuilding seal stocks in the Kattegat-Skagerrak. Marine Mammal Science 4(3): 231-246.

Helle, E. (1980) Lowered reproductive capacity in female ringed seals (*Pusa hispida*) in the Bothnian Bay, northern Baltic Sea, with special reference to uterine occlusions. Annales Zoologica Fennici 17: 147-158.

Hiby, L. et al. (2013) Estimates of the size of the Baltic grey seal population based on photo-identification data. NAMMCO Scientific Publications [S.l.] 6: 163-175. Oct. 2013. ISSN 2309-2491. Available at: <http://septentrio.uit.no/index.php/NAMMCOSP/article/view/2731>. doi:http://dx.doi.org/10.7557/3.2731.

Jüssi, M., Härkönen, T., Jüssi, I., Helle, E. (2008) Decreasing ice coverage will reduce the reproductive success of Baltic grey seal (*Halichoerus grypus)* females. Ambio 37: 80–85.

Karlsson, O., Härkönen, T., Bäcklin, B.-M. (2008) Populationer på tillväxt. Havet 2008: 91-92.

Kokko, H., Helle, E.J., Ranta, E., Sipilä, T. (1999) Backcasting population sizes of ringed and grey seals in the Baltic and Lake Saimaa during the 20th century. Annales Zoologici Fennici 36: 65-73.

Meier, H.E.M., Döscher, R., Halkka, A. (2004) Simulated distributions of Baltic Sea-ice in the warming climate and consequences for the winter habitat of the Baltic Ringed Seal. Ambio 33: 249–256.

Olsen, M.T., Andersen, S.M., Teilmann, J., Dietz, R., Harkonen, T. (2010) Status of the harbour seal in Southern Scandinavia. NAMMCO Scientific Publications 8: 77-94.

Olsen, M. T., Wesley Andersen, L., Dietz, R., Teilmann, J., Harkonen, T., Siegismund, H.R. (2014) Integrating genetic data and population viability analyses for the identification of harbour seal (*Phoca vitulina*) populations and management units. Molecular Ecology 23: 815-831

Teilmann, J., Riget, F., Harkonen, T. (2010) Optimising survey design in Scandinavian harbour seals: Population trend as an ecological quality element. ICES Journal of Marine Science 67: 952–958.

Sipilä, T. (2003) Conservation biology of Saimaa ringed seal (Phoca hispida saimensis) with reference to other European seal populations. PhD Thesis. Available at: http://ethesis.helsinki.fi/julkaisut/mat/ekolo/vk/sipila/conserva.pdf?q=phoca.

Stenman, O., Halkka, A., Helle, E., Keränen, S., Nummelin, J., Soikkeli, M., ... Tanskanen, A. (2005) Numbers and occurrence of grey seals in the Finnish sea area in the years 1970-2004. In Symposium on Biology and Management of Seals in the Baltic area. Kala-ja riistaraportteja nro 346: 58-61.

Svensson, C.J., Hansson, A**.,** Harkonen, T., Harding, K. (2011) Detecting density dependence in growing seal populations. Ambio (2011) 40: 52–59. DOI 10.1007/s13280-010-0091-7.

Sundqvist, L., Harkonen, T., Svensson, C.J., Harding, K.C. (2012) Linking climate trends to population dynamics in the Baltic ringed seal - Impacts of historical and future winter temperatures. Ambio. DOI 10.1007/s13280-012-0334-x.

Vanhatalo, J., Vetemaa, M., Herrero, A., Aho, T., Tiilikainen, R. (2014) By-Catch of Grey Seals (*Halichoerus grypus*) in Baltic Fisheries—A Bayesian Analysis of Interview Survey. PLoS ONE 9(11): e113836. doi:10.1371/journal.pone.0113836.

Zohari, S., Neimanis, A., Härkönen, T., Moraeus, C., Valarcher, J.F. (2014) Avian influenza A(H10N7) virus involvement in mass mortality of harbour seals (*Phoca vitulina*) in Sweden, March through October 2014. Euro Surveill. 2014; 19(46):pii=20967. Available at: http://www.eurosurveillance.org/ViewArticle.aspx?ArticleId=20967.

Additional relevant publications

Harding, K.C., Härkönen, T., Caswell, H. (2002) The 2002 European seal plague: epidemiology and population consequences. Ecology Letters 5: 727-732.

Harding, K.C., Härkönen, T., Pineda, J. (2003) Estimating quasi-extinction risk of European harbour seals: a reply to Lonergan and Harwood. Ecology Letters 6: 894-897.

Härkönen, T., Harding, K.C. (2001) Spatial structure of harbour seal populations and the implications thereof. Can. J. Zool. 79: 2115-2127.

Harkonen, T., Harding, K.C. (2011) Predicting recurrent PDV epidemics in European harbour seals. NAMMCO Scientific Publications 8: 275-284.

Heide-Jørgensen, M.-P., Härkönen, T. (1992) Epizootiology of seal disease. J. Appl. Ecol. 29: 99-107.

Heide-Jørgensen, M.-P., Härkönen, T., Dietz R., Thompson, P. (1992) Retrospective of the 1988 European seal epizootic. Diseases of Aquatic Organisms 13: 37-62.

Mortensen, P., Bergman, A., Bignert, A., Hansen, H.J., Härkönen, T., Olsson, M. (1992) Prevalence of skull lesions in harbour seals *Phoca vitulina* in Swedish and Danish museum collections during the period 1835-1988. Ambio 21: 520-524.

Palo, J.U., Mäkinen, H.S., Helle, E., Stenman, O., Väinölä, R. (2001) Microsatellite variation in ringed seals (*Phoca hispida*): genetic structure and history of the Baltic Sea population. Heredity 86: 609–617. doi: 10.1046/j.1365-2540.2001.00859.x.

HELCOM core indicator report, ISSN 2343-2543