Radioactive substances

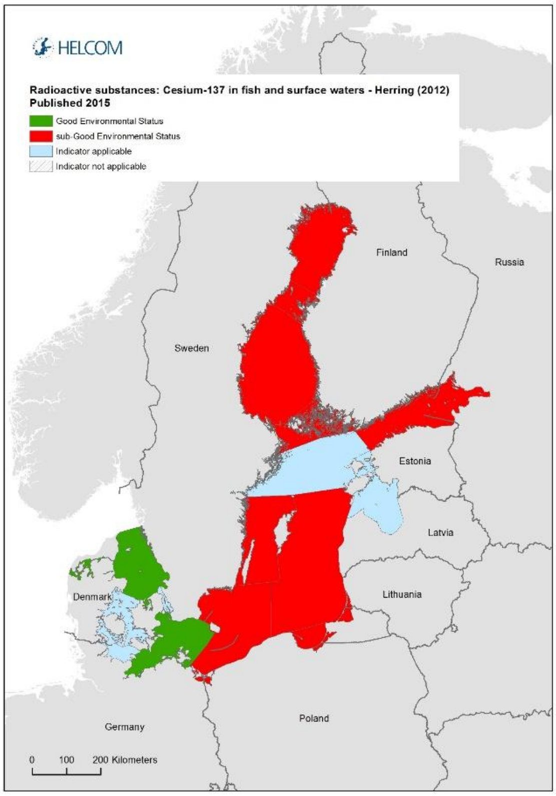
- Cesium-137 (^{137}Cs) in fish and surface waters

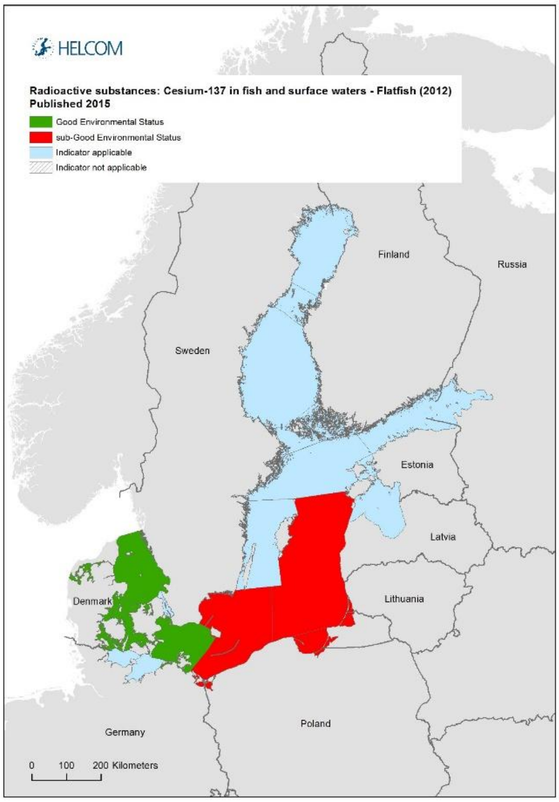
Key message

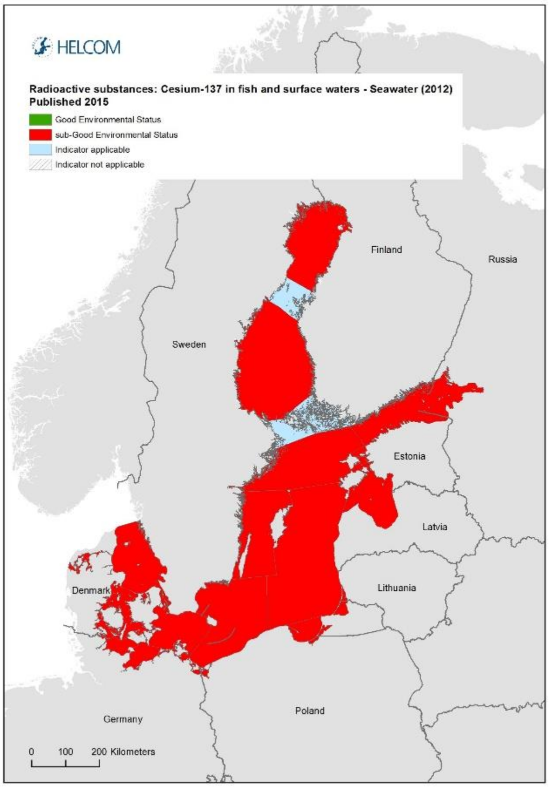
In general, the activity concentrations of radioactive isotope cesium 137 (^{137}Cs) in herring, flatfish, and surface waters are still above the pre-Chernobyl levels which constitute the boundary for Good Environmental Status (GES).

The indicator presents an evaluation using 2012 data. For herring, GES is only achieved in the Arkona Basin and sub-basins west of Arkona Sea (Kiel Bay and Kattegat). For flatfish, GES is not achieved in Eastern Gotland Basin, Gdańsk Basin and Bornholm Basin, while ^{137}Cs concentrations below the GES-boundary were found in Arkona Basin, Kiel Bay and Kattegat. For surface waters, GES is not achieved in any of the HELCOM sub-basins.

Time series analyses show that the ^{137}Cs activity concentrations in herring flatfish and surface waters in the Baltic Sea basins are decreasing and approaching pre-Chernobyl levels. It is expected that GES in the Baltic Sea may be reached by about year 2020. The confidence of the indicator status evaluation is considered to be high.







Relevance of the core indicator

The radionuclide cesium (^{137}Cs) is the greatest contributor to the level of artificial radionuclides in the Baltic Sea, where the level of ^{137}Cs contamination is still higher than in any other of the world oceans. The main source of ^{137}Cs deposited in the Baltic Sea stems from the accident at the Chernobyl nuclear power plant in 1986. The ^{137}Cs was introduced into the Baltic seawater by atmospheric deposition and, to a lesser extent, through riverine input. This anthropogenically introduced ^{137}Cs then bioaccumulated in marine flora and fauna and has eventually been deposited in the marine sediments. Therefore ^{137}Cs activity concentrations are the key factors in an assessment of the radiological hazard to marine organisms and humans (Nielsen et al. 1999). Both are highly interconnected as the dominating exposure pathway of humans from man-made radioactivity in the Baltic Sea is related to the ingestion of ^{137}Cs in fish.

Policy relevance of the core indicator

	BSAP **Segment and Objective**	**MSFD** **Descriptors and Criteria**
Primary link	Hazardous substances • Radioactivity at pre-Chernobyl level	D8: Concentrations of contaminants are at levels not giving rise to pollution effects 8.1. Concentration of contaminants
Secondary link		D9: Contaminants in fish and other seafood for human consumption do not exceed levels established by Community legislation or other relevant standards. 9.1. Levels, number and frequency of contaminants

According the HELCOM Baltic Sea Action Plan - BSAP (HELCOM 2007), the agreed goal of HELCOM is a Baltic Sea undisturbed by hazardous substances. The goal of Good Environmental Status (GES) is described by four ecological objectives:

- Concentrations of hazardous substances close to natural levels,
- All fish safe to eat,
- Healthy wildlife,
- Artificial radioactivity at pre-Chernobyl level.

These ecological objectives were also used as operational indicators with targets, reflecting good ecological and environmental status of the Baltic marine environment according to Marine Strategy Framework Directive – MSFD (Anon 2008).

Cite this indicator

HELCOM [2015]. [Title]. HELCOM Core Indicator Report. Online. [Date Viewed], [Web link].

Indicator concept

Good Environmental Status

The Good Environmental Status (GES) is expressed as a boundary for radioactivity and is based on reference conditions. GES is achieved when the **activity concentration of the radionuclides is below 2.5 Bq kg^{-1} for herring, 2.9 Bq kg^{-1} for flounder and plaice and 15 Bq m^{-3} for seawater** which corresponds to pre-Chernobyl levels, in other words the levels before 1984. According to the BSAP the main goal on hazardous substances is a Baltic Sea undisturbed by hazardous substances and one of the ecological objectives defining GES within hazardous substances segment is 'radioactivity at pre-Chernobyl level'.

The activity concentration of the radionuclide cesium-137 (^{137}Cs) is evaluated in herring, flatfish and seawater and evaluated against the GES-boundary. Currently, no internationally accepted criteria for the assessment of GES in fish exist. There are only upper levels available in the literature, where fish will suffer from doses of radioactive substances (e. g. ICRP, 2008). Therefore, GES boundaries for ^{137}Cs concentrations in sea water, sediments and biota have been set at pre-Chernobyl levels. The GES-boundaries are averages based on monitoring measurements from 1984-1985 from the HELCOM MORS database. The confidence is considered to be high, as there are numerous observations from pre-Chernobyl time even if the length of this time series is short (1984-1985).

Anthropogenic pressures linked to the indicator

	General	MSFD Annex III, Table 2
Strong link		Contamination by hazardous substances - introduction of radio nuclides
Weak link		

The total collective dose of radiation from ^{137}Cs in the Baltic Sea is estimated at 2600 manSv of which about two thirds (1700 manSv) originate from the Chernobyl fallout, about one quarter (650 manSv) from the fallout from nuclear weapons testing, about 8 % (200 manSv) from the European reprocessing facilities, and about 0.04 % (1 manSv) from the nuclear installations bordering the Baltic Sea area.

Dose rates and doses from natural radioactivity has been dominating except for the year 1986 where the individual dose rates from Chernobyl fallout in some regions of the Baltic Sea approached those from natural radioactivity.

Since 1950 the maximum annual equivalent dose to individuals from any critical group in the Baltic Sea area due to ^{137}Cs is estimated at 0.2 mSv y^{-1}.This value is lower than the doses the humans receive from natural radionuclides in foodstuffs, which are e.g. 0.215- 0.521 mSv in Germany (BfS, 2014), and much lower than the dose limit of 1 mSv y^{-1} set for the exposure of members of the public in the IAEA International Basic Safety Standards (IAEA 1996). Considering the uncertainties involved in the assessment, it is unlikely that any individual has been exposed from marine pathways at a level above this dose limit. Doses to man due to liquid discharges from nuclear power plants in the Baltic Sea area are estimated at or below the levels mentioned in the Basic Safety Standards to be of no regulatory concern (individual dose rate of 10 µSv y^{-1} and collective dose of 1 manSv). It should be noted that the assumptions made throughout the assessment were chosen to be realistic and not conservative. Consequently, this also applies to the estimated radiation doses to man.

Assessment protocol

The Pre-Chernobyl values used to derive the GES-boundary have been calculated from the data in the MORS database. The data used was collected between 1984 and 1985 for ^{137}Cs concentrations in herring, flatfish (plaice and flounder) and surface waters. The mean pre-Chernobyl ^{137}Cs concentrations have been used as GES values.

Relevant assessment units are HELCOM sub-basins. GES values are uniform across all Baltic Sea assessment units due to uniform distribution of pre-Chernobyl radiation levels caused by atmospheric fallout from nuclear weapons testing. The mean value for all samples in the assessment unit is calculated and evaluated against the GES-boundary.

Relevance of the indicator

Policy Relevance

Radioactivity at pre-Chernobyl level is one of the ecological objectives within hazardous substances segment of the HELCOM Baltic Sea Action Plan (BSAP; HELCOM 2007). HELCOM Monitoring of Radioactive Substances (MORS) Expert Group has been working to implement the Helsinki Convention on matters related to the monitoring and assessment of radioactive substances in the Baltic Sea. This work is based on HELCOM Recommendation 26/3 Monitoring of Radioactive Substances, and aims to evaluate progress towards the ecological objective *Radioactivity at pre-Chernobyl level* which has now been defined as the GES-boundary for this indicator. The work of HELCOM MORS also supports the implementation of the Euratom Treaty, of which all EU Member States are signatories. The Euratom Treaty requires actions in relation to monitoring and effects of discharges on neighbouring states.

Two of the eleven MSFD descriptors relate to hazardous substances and their aims are: D8 - Concentrations of contaminants are at levels not giving rise to pollution effects and D9 - Contaminants in fish and other seafood for human consumption do not exceed levels established by Community legislation or other relevant standards.

Role of ^{137}Cs concentration in fish and seawater in the ecosystem

The development and use of nuclear power for military and peaceful purposes have resulted in the production of a number of man-made radioactive substances and their release into the environment. For example, even the routine operations of nuclear power plants cause small controlled discharges of radioactive substances, but accidents at nuclear power plants can release considerable amounts of radioactivity into the environment. Artificial radionuclides of particular concern to man and the environment and ^{137}Cs is formed by nuclear fission.

A worldwide study on marine radioactivity has shown that the Baltic Sea has the highest average ^{137}Cs levels in surface water compared to other marine areas of the world (IAEA, 2005). Therefore, including radioactivity in the assessment of the status of the environment in the Baltic Sea region is considered to be of relevance. Radioactive fallout from the Chernobyl accident in 1986 is the dominating source for ^{137}Cs in the Baltic Sea.

^{137}Cs is the radionuclide of anthropogenic origin. ^{137}Cs reaching the Baltic Sea waters from different sources (atmospheric fallout, river discharges, controlled liquid and gaseous discharges from working nuclear facilities) become distributed within other compartments of the marine environment. It can be bioaccumulated in marine floral and faunal organisms, which are the most important components of the ecosystem, because of their function and environmental status, and due to their potential importance for humans. The harmful effects of ^{137}Cs on marine organisms are related to the emission of ionizing radiation, which can lead to internal damage, i.e. the effects are observed at the cellular level.

It is difficult to establish unequivocally which ^{137}Cs concentrations can be considered as harmless because of the complexity of reactions of individual organisms to its effects, especially in the presence of other hazardous substances the effects of radionuclides could be intensified (synergetic effects).

Levels of radionuclides in marine biota are linked to the corresponding levels in seawater and sediments, via accumulation through food chains. Anthropogenic radionuclides, including ^{137}Cs, entering seawater with atmospheric fallout and discharged in riverine outflow can be bioaccumulated and/or adsorbed on suspended particulate matter (composed mainly by plankton and mineral particles), which accumulates in bottom sediments. Radionuclides can also be accumulated by higher flora and fauna organisms.

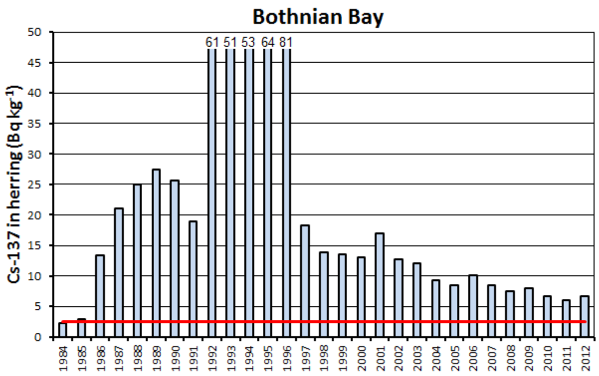
The complexity of food chains increases with the trophic level of the species considered. Fish are mainly exposed to radionucleids and accumulate them through their food sources, not from water. Predators such as cod and pike, have shown the highest ^{137}Cs levels, but there was some delay in reaching their maximum values after 1986, when compared to the trends in seawater. In the long-term, ^{137}Cs time trends in biota closely follow the trends in seawater (Zalewska and Suplińska 2013). Taking into account the present concentration levels in the biota in the Baltic Sea, no effects on animal health by ^{137}Cs are expected as the lowest effect levels observed in fish are more than three orders of magnitude higher compared to the measured doses to these animals (according to ICRP, 2008).

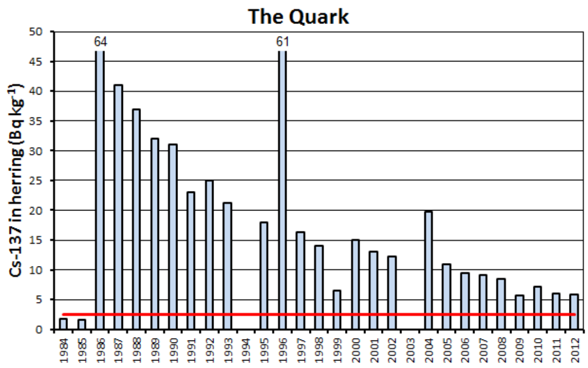
Ingestion of ^{137}Cs with fish is the dominating exposure pathway of humans to man-made radioactivity in the Baltic Sea. Therefore, ^{137}Cs concentrations in herring, plaice and flounder can be suitable as indicators for man-made radioactivity in the Baltic Sea. Internationally recommended maximal permitted concentrations of ^{137}Cs in foodstuff are in the range 100–1250 Bq/kg (EU, 2012 and EC, 2010).

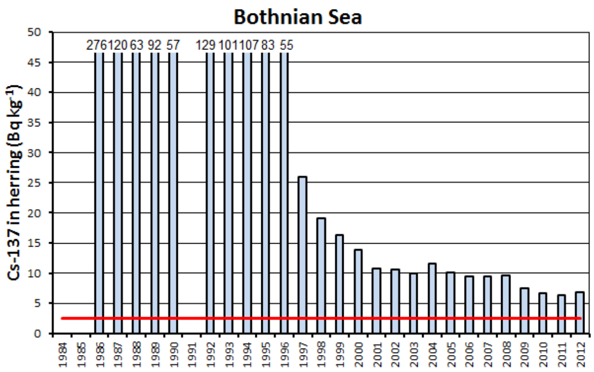
Results and confidence

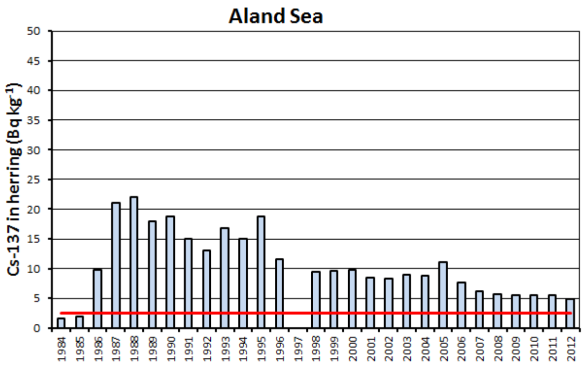
Good Environmental Status (GES) for ^{137}Cs in herring, is not achieved in most of the HELCOM sub-basins, except for the Arkona Basin and sub-basins west to Arkona Sea (Kiel Bay and Kattegat). For flatfish, GES is not achieved in the Eastern Gotland Basin, Gdańsk Basin and Bornholm Basin, while ^{137}Cs concentrations below the GES-boundary were found in the Arkona Basin, Kiel Bay and the Kattegat. For surface seawaters, GES is not achieved in any of the HELCOM sub-basins. If a one-out-all-out-approach is used for the entire Baltic Sea for the three parameters, then GES is not achieved.

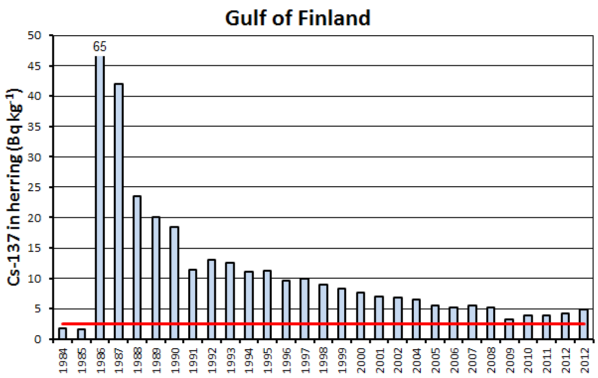
In Figures 1-3 annual mean values of fish and seawater in each sub-basin since 1984 are compared to GES. The activity concentrations of ^{137}Cs are approaching the pre-Chernobyl levels in all matrices and it is expected that the GES status in the Baltic Sea may be reached by about year 2020.

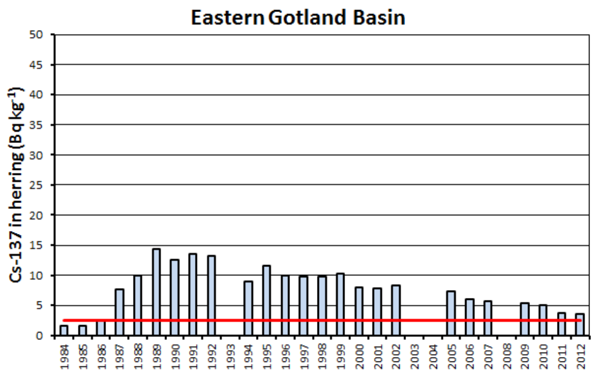












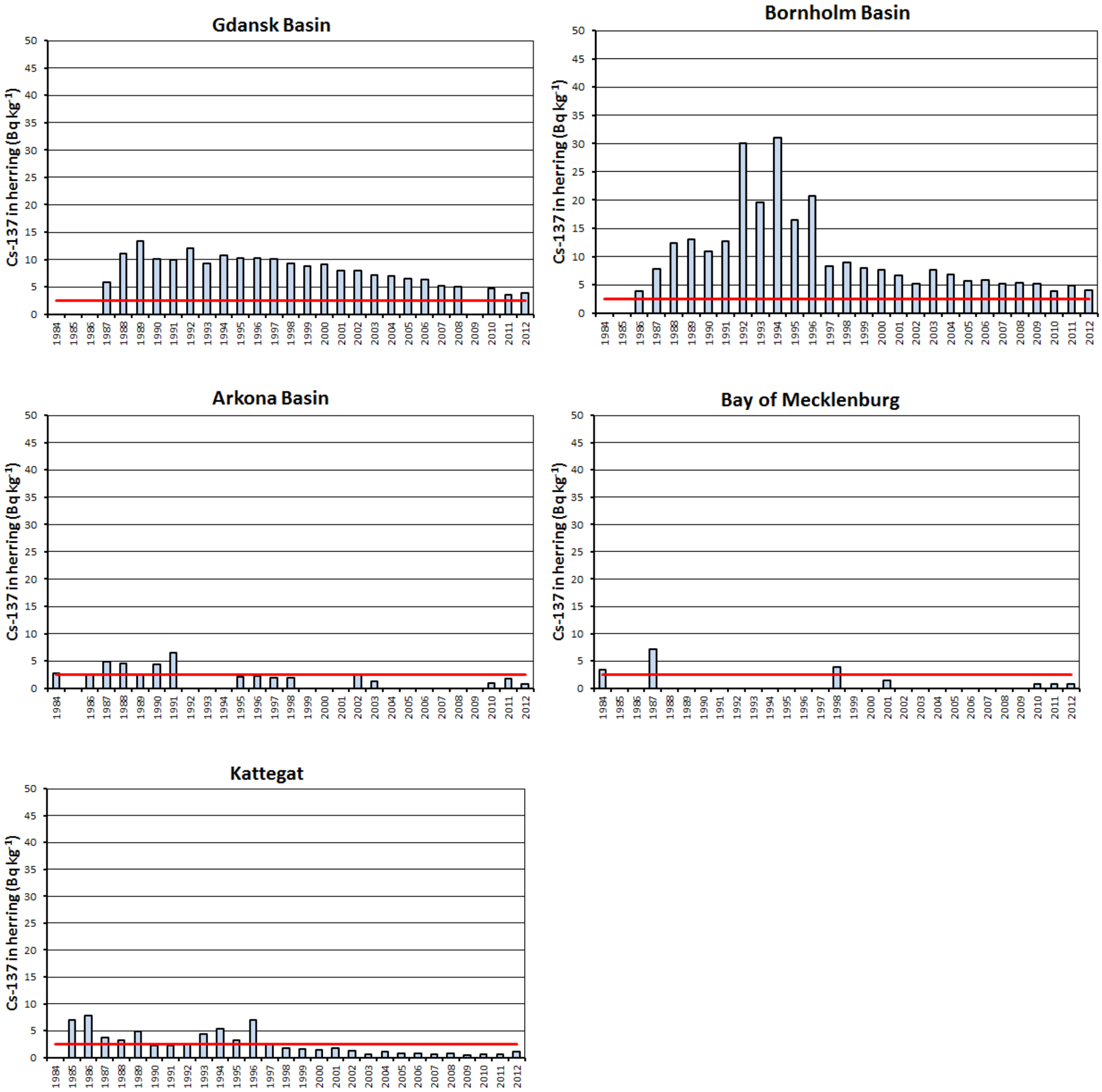


Figure 1. ^{137}**Cs mean concentrations (in Bq kg^{-1}) in herring muscle (fillets or whole fish without head and entrails) in 1984–2012, as annual mean by sub-basin. Red line indicates the GES-boundary (2.5 Bq kg^{-1}) calculated as average of pre-Chernobyl (1984–1985) concentrations.**

Following the Chernobyl accident in 1986 the biota of the Baltic Sea received the most significant contribution to their level of artificial radionuclides, predominantly in the form of ^{137}Cs. ^{137}Cs in fish and seawater reached their maximum values in the late 1980s and early 1990s (Figures 1–3). Since then concentrations of ^{137}Cs in fish and seawater have continued to decrease in all regions of the Baltic Sea. As shown in Figure 1, concentrations of ^{137}Cs in herring muscle are slowly decreasing after the Chernobyl accident in 1986. In 2012, in the western parts of the Baltic Sea, i.e. the Kattegat, the Kiel Bay, the Bay of Mecklenburg and the Arkona Basin (Figure 1a), the mean values were well below the target value of 2.5 Bq kg^{-1} wet weight, which was calculated as average of pre-Chernobyl (1984-1985) concentrations. In the remaining Baltic Sea basins, the target value is still not reached; the concentrations are higher than the pre-Chernobyl level. The highest mean concentration of ^{137}Cs in herring muscle of the level of 7 Bq kg^{-1} wet weight was noted in the Bothnian Bay. In the Quark, the Åland Sea and the Gulf of Finland the concentrations remained at the level of 5 Bq kg^{-1} wet weight while in the Baltic Proper area (Eastern Gotland Basin, Gdańsk Basin and Bornholm Basin) they were close to 4 Bq kg^{-1} wet weight.

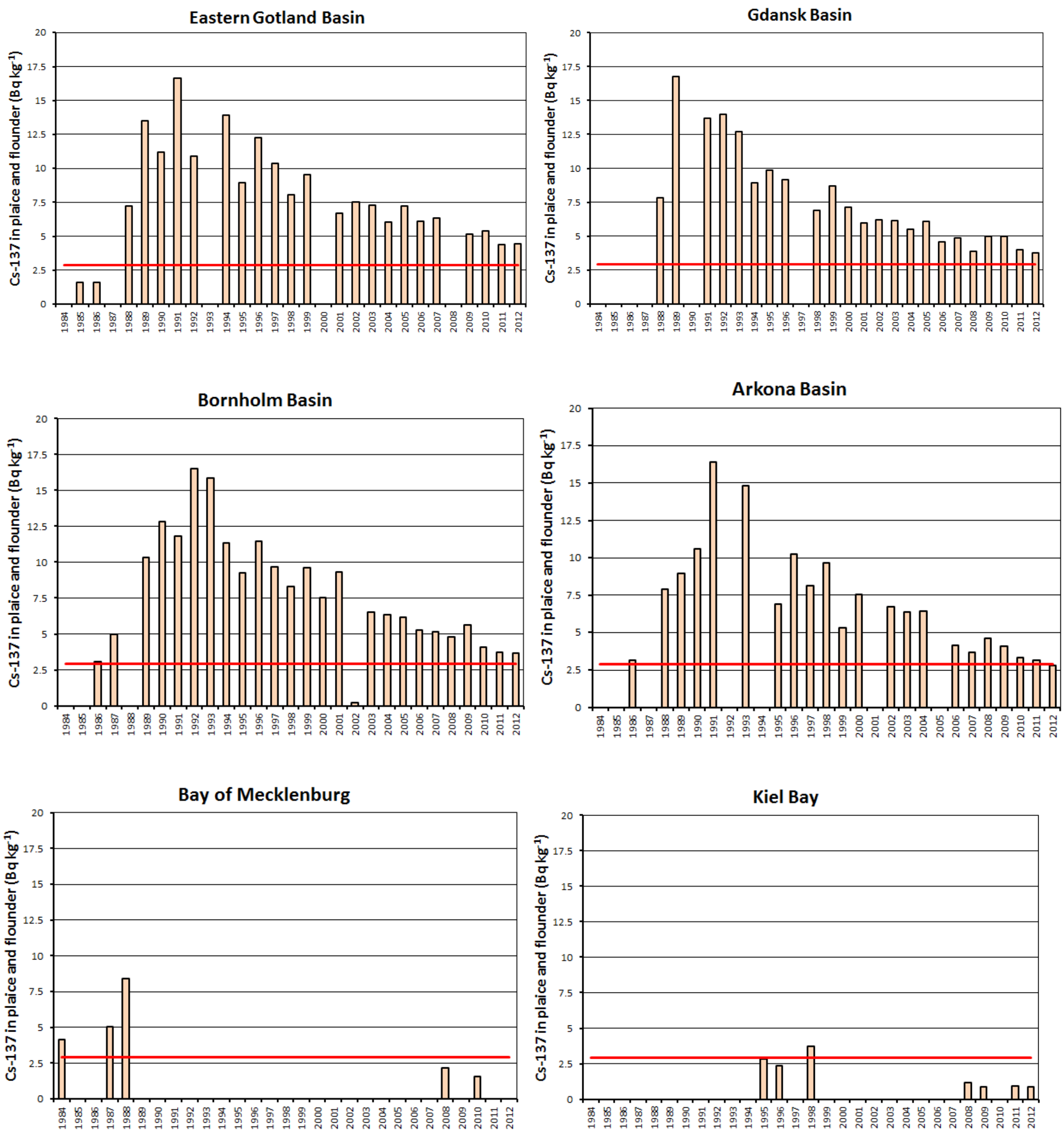
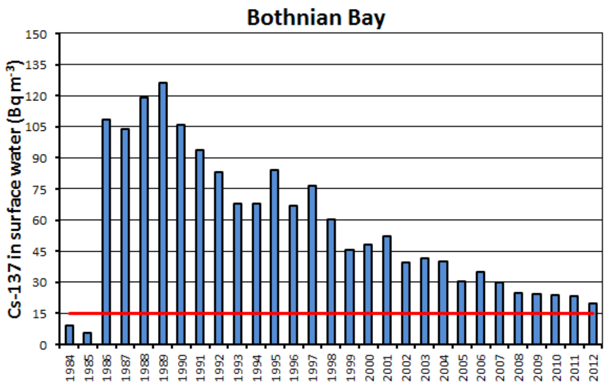
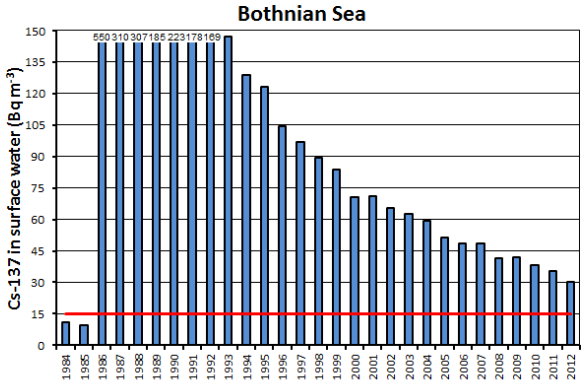


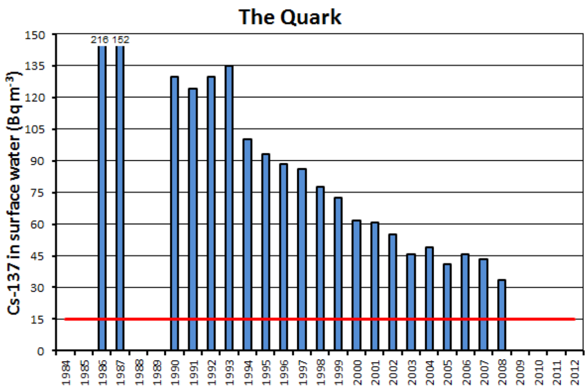
Figure 2. ^{137}Cs concentrations (in Bq kg^{-1}) in plaice and flounder muscle (fillets or whole fish without head and entrails) in 1984–2012, as annual means by sub-basin. Red line indicates the GES-boundary (2.9 Bq kg^{-1}) calculated as average of pre-Chernobyl (1984–1985) concentrations.

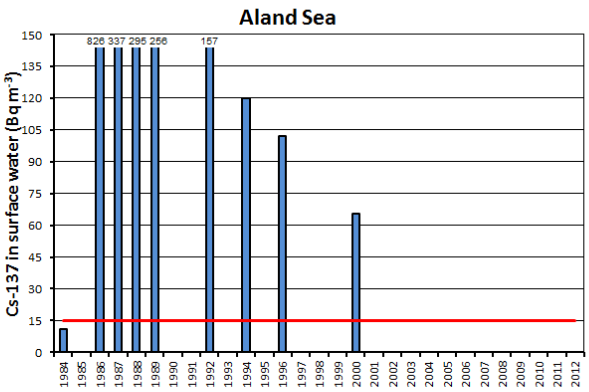
Figure 2 shows the ^{137}Cs time series in the flat fish group, consisting of flounder (*Platichthys flesus*) and plaice (*Pleuronectes platessa*). Samples of fillets/flesh were used for these measurements. In 2012, the mean values of ^{137}Cs concentrations were below 5 Bq kg^{-1} wet weight, they were at the level of 4 Bq kg^{-1} wet weight in the Eastern Gotland Basin and in the Gdańsk Basin and close to the target value, at the level of 3 Bq kg^{-1} wet weight, in the Bornholm Basin. Similarly to herring, the mean ^{137}Cs concentrations in the western parts of the Baltic Sea, i.e. the Kattegat, the Kiel Bay, the

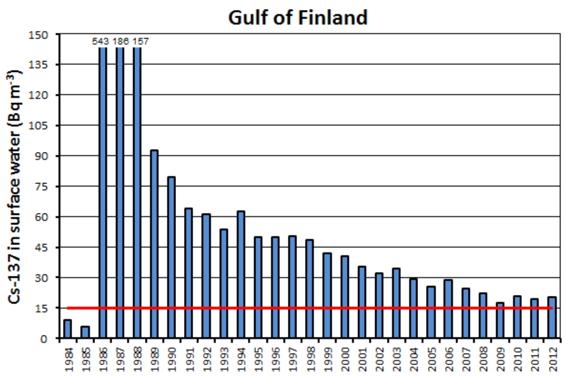
Bay of Mecklenburg and the Arkona Basin, are well below the target value for flatfish, which is 2.9 Bq kg^{-1} wet weight.

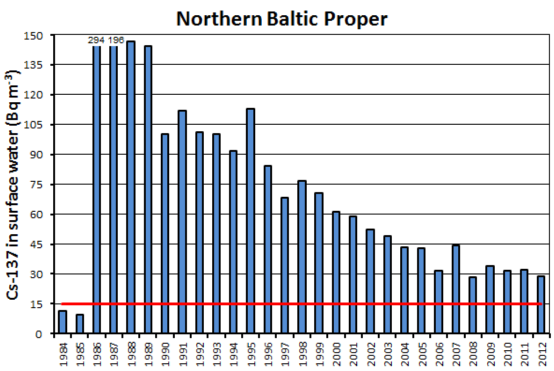


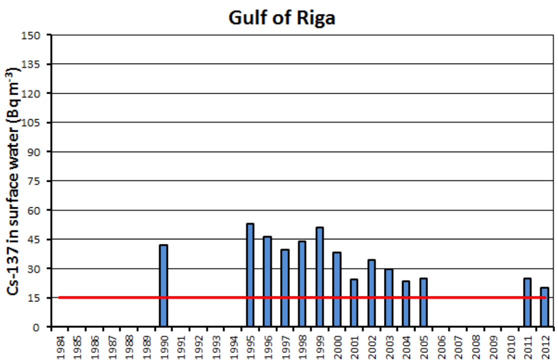


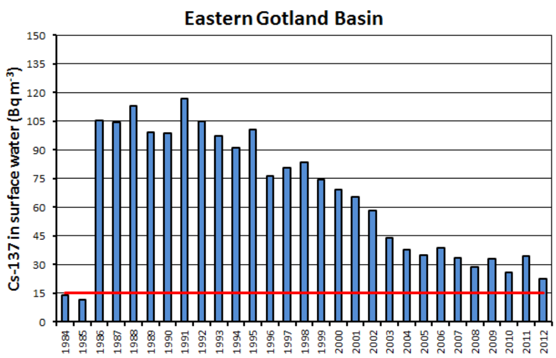












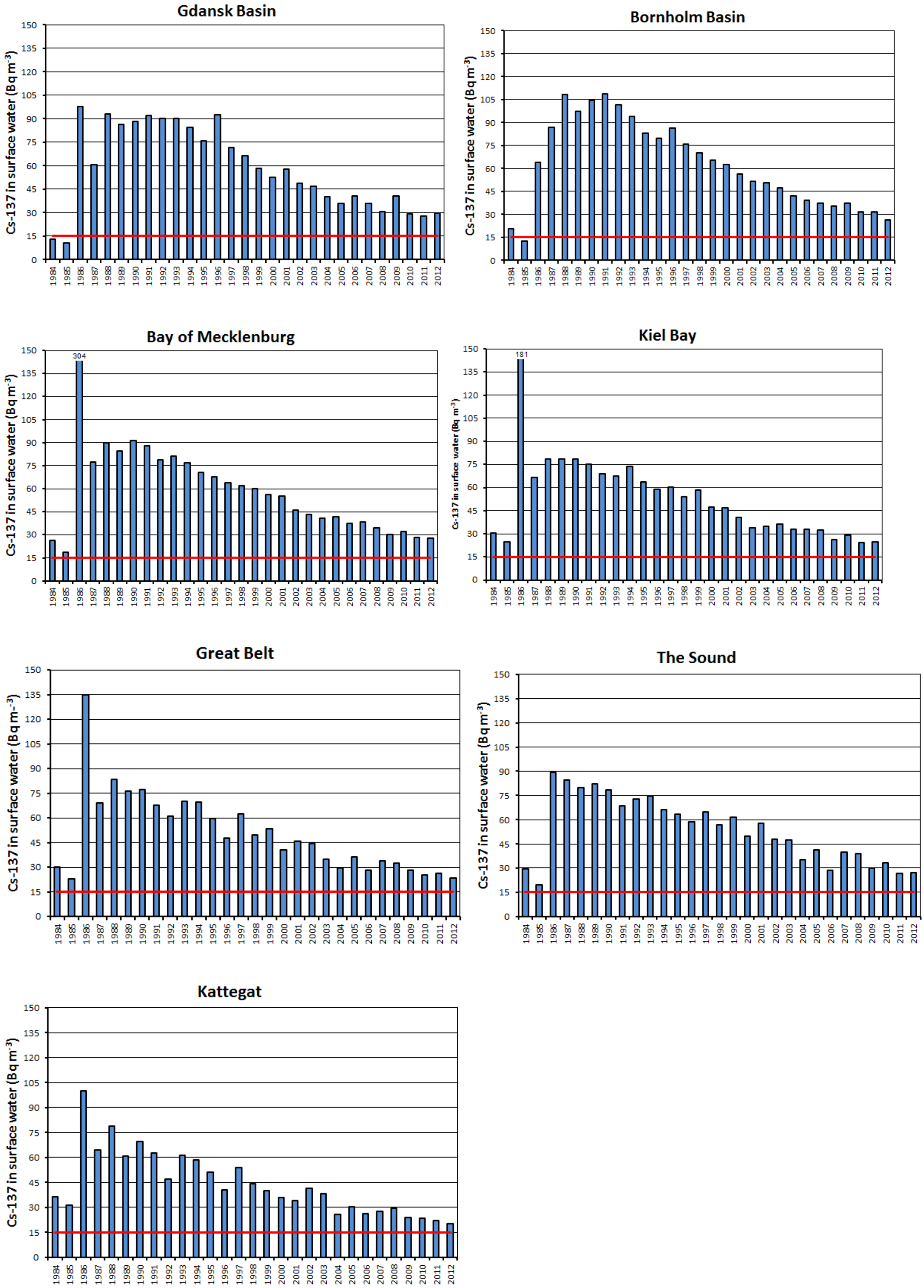


Figure 3. ^{137}Cs concentrations (in Bq m^{-3}) in seawater (sampling depth less than 10 m) in 1984-2012, as annual mean values by basin. Red line indicates the GES-boundary (15 Bq m^{-3}) calculated as average of pre-Chernobyl (1984-1985) concentrations.

In 2012, the concentrations of ^{137}Cs in seawater were significantly uniform (Figure 3) in comparison to the distribution of ^{137}Cs in surface waters after the Chernobyl accident, when in the most contaminated areas (Bothnian Sea and Gulf of Finland) activities exceeding 500 Bq m^{-3} were observed while in the western parts of the Baltic Sea they were close to 100 Bq m^{-3}. In 2012, in the Baltic northern areas i.e. the Bothnian Bay, Bothnian Sea, Gulf of Finland and Gulf of Riga, the mean concentrations were of 20 Bq m^{-3}. Very similar values, in the range of 20 Bq m^{-3} to 25 Bq m^{-3}, were observed in the western regions of the Baltic Sea (Kattegat, Kiel Bay, The Sound, and the Great Belt. Only slightly higher values of 30 Bq m^{-3} were specific of the Arkona Basin, Bay of Mecklenburg, Gdańsk Basin and Bornholm Basin.

Based on the inventory estimates, the effective half-life of ^{137}Cs in Baltic seawater has been 9.6 years during the period 1993–2006. The effective half-life of a radioactive contaminant is the time required for its concentration to decrease by 50% as a result of physical, chemical and biological processes which are specific of each radionuclide and each environment where they may occur. With this decay rate, the ^{137}Cs inventory in the Baltic Sea would reach the pre-Chernobyl levels (250 TBq) by the year 2020, presuming that the effective half-life would remain constant, and no substantial remobilization of ^{137}Cs from sediments should occur. It should be pointed out that the ^{137}Cs input from Fukushima fallout (the Fukushima Daichii disaster took place in 2011) did not result in a significant increase in ^{137}Cs concentration in seawater and biota of the Baltic Sea (Kanisch & Aust, 2013).

Confidence of indicator status evaluation

High

Quality assurance is a fundamental part of radioanalytical procedures, needed to confirm the precision and the long-term repeatability of analyses. The radiochemical procedures and counting techniques used by laboratories are well tested, up-to-date, and similar to those used by laboratories worldwide. Eight intercomparison exercises were organised during the HELCOM MORS-PRO project in the period (1999–2006), including seawater and sediment samples, and their results are also presented in the thematic assessment of radioactivity. The intercomparison exercises confirmed that the data provided by the MORS group are of very good quality and can be considered comparable. Less than five percent of the results were considered outliers.

Monitoring requirements

Monitoring methodology

Monitoring methodology including methods, frequency and stations is described in detail in MORS Guidelines (HELCOM Recommendation 26/3).

Over ten laboratories from the nine countries bordering Baltic Sea have contributed to the monitoring programmes of Baltic Sea by analyzing radionuclides in marine samples. The various analytical methods used in the different laboratories are summarized the HELCOM thematic assessment: Radioactivity in the Baltic Sea, 1999–2006 (HELCOM 2009).

Description of optimal monitoring

The current annual sampling of biota and seawater is considered an adequate frequency for the core indicator. The monitoring of biota in each sub-basin depends also on the availability of certain species during the time of monitoring cruises; this cannot be secured at all times.

Gaps in monitoring in relation to new sub-basins:

^{137}Cs in seawater is sampled in all HELCOM sub-basins except for the Quark and the Åland Sea.

Currently, the coverage of ^{137}Cs in herring extends to most of the HELCOM sub-basins. There are no samples from the Northern Baltic Proper, Gulf of Riga, The Sound, and Great Belt. Also, the Northern part of Eastern Gotland Basin is not covered by annual samplings.

^{137}Cs in flatfish is sampled in the most relevant Southern Baltic Sea sub-basins only.

Current monitoring

Stations are described in detail in MORS Guidelines (HELCOM Recommendation 26/3) and in HELCOM MORE map service.

Description of data and up-dating

Metadata

Data source: HELCOM MORS Database.

Description of data: Herring and seawater data cover most of the Baltic Sea, but flatfish covers only southern parts of the Baltic. For time series maps (Figures 2-4), data from the year 2012 was used. The data are based on ^{137}Cs concentrations in a) herring (*Clupea harengus L.*), b) flounder (*Platichthys flesus L.*) and plaice (*Pleuronectes platessa L.*) and c) surface seawater (samples 0–10 m). Analyses have been done either in round fish (without head and entrails) or filets (herring), and for plaice and flounder from filets, only. Concentrations (Bq kg^{-1}) have been calculated per wet weight of the samples. Seawater concentrations (Bq m^{-3}) have been analyzed in surface (0–10 m) water samples. Data of each matrix (herring, plaice and flounder and sea water) have been averaged by basin and by year.
The data is collected by national authorities and reported annually to the HELCOM MORS Database. In addition to national quality assurance procedures, manual quality assurance is applied to the reported data and data entries are verified annually by the HELCOM MORS Expert Group.

Publications and archive

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Archive

2013 Indicator report (pdf)

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