

Radioactive substances

- Caesium-137 in fish and surface waters

Authors

HELCOM Monitoring of Radioactive Substances Expert Group

Corresponding authors:

Jürgen Herrmann, BSH - Federal Maritime and Hydrographic Agency, Germany

Günter Kanisch, vTI - Johann Heinrich von Thünen-Institute, Germany

Sven P. Nielsen - Risoe National Laboratory for Sustainable Energy, DTU, Denmark

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Key messages

- 🤔 The ¹³⁷Cs activity concentrations in herring, flatfish and surface waters are still above the pre-Chernobyl levels.
- 😬 Overall, the ¹³⁷Cs activity concentrations in herring flatfish and surface waters in the Baltic Sea basins are approaching pre-Chernobyl levels.
- 😊 Radioactive fallout over the Baltic Sea from the Fukushima accident in Japan in March 2011 is very small and may not be detectable in seawater and fish. The corresponding radiological risks are estimated to be negligible.

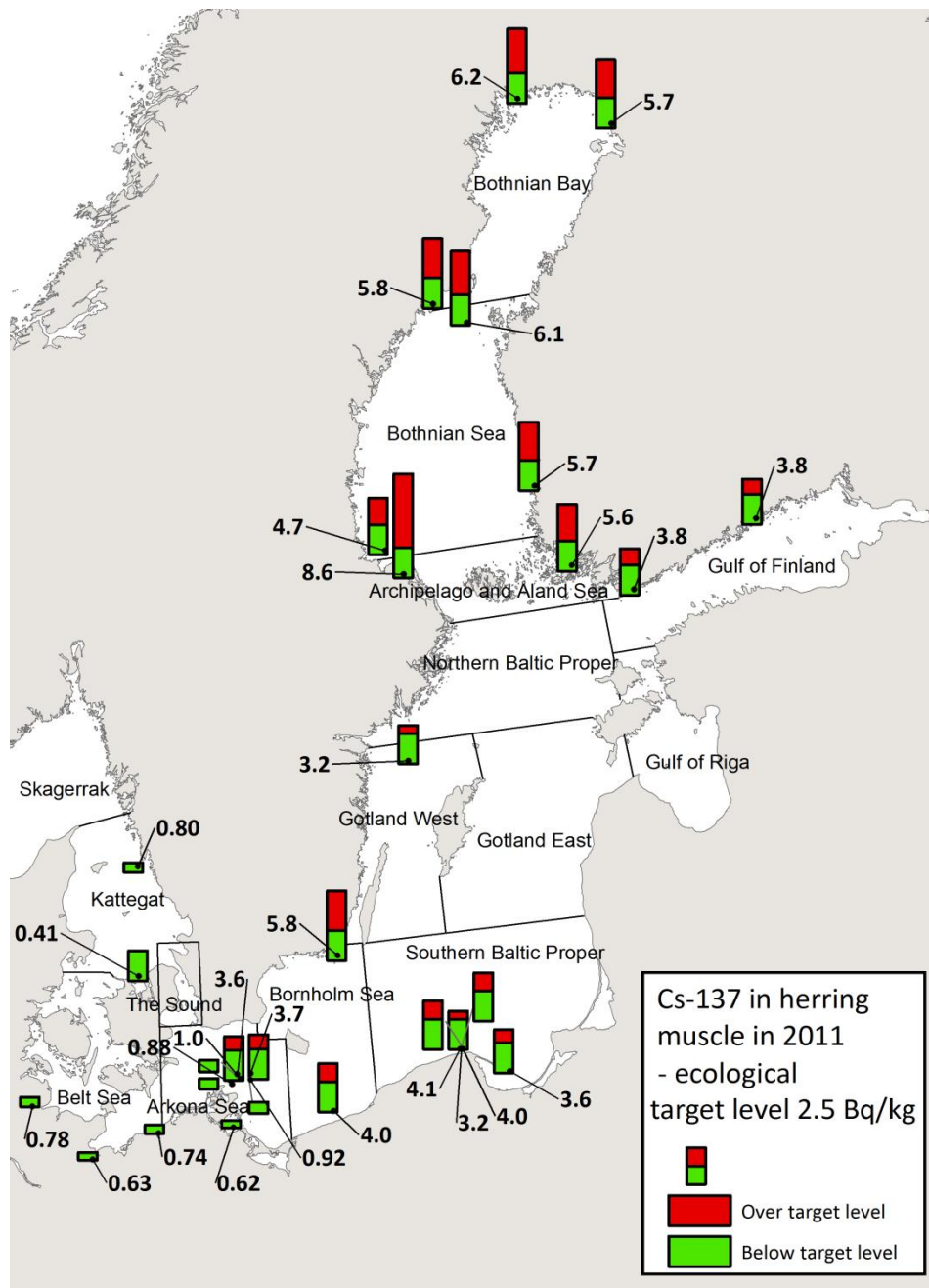


Figure 1. ¹³⁷Cs concentrations (in Bq/kg) in herring muscle in 2011. Ecological target values have been calculated as averages of pre-Chernobyl (1984–1985) concentrations.

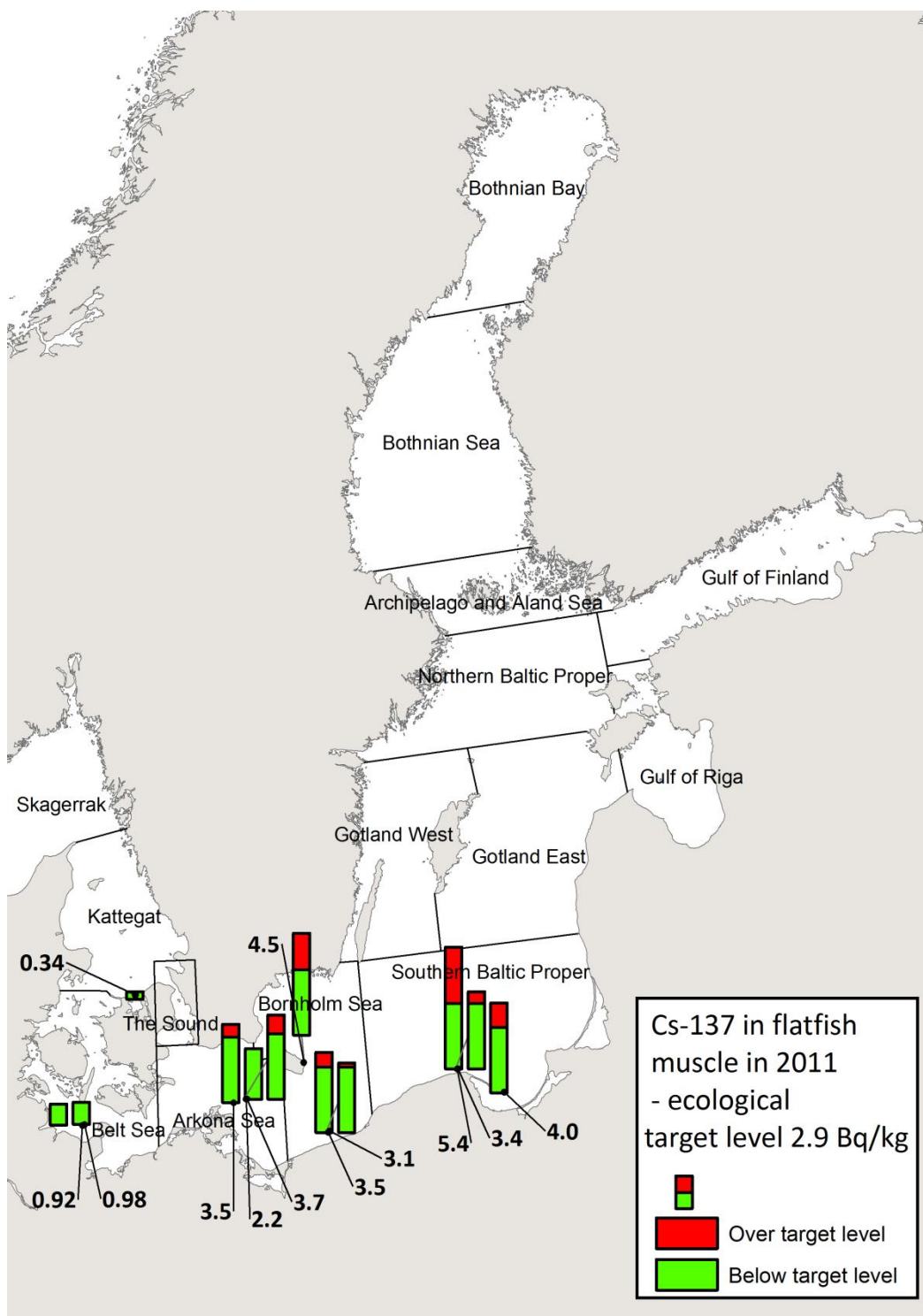


Figure 2. ¹³⁷Cs concentrations (in Bq/kg) in plaice and flounder muscle in 2011. Ecological target values have been calculated as average of pre-Chernobyl (1984–1985) concentrations.



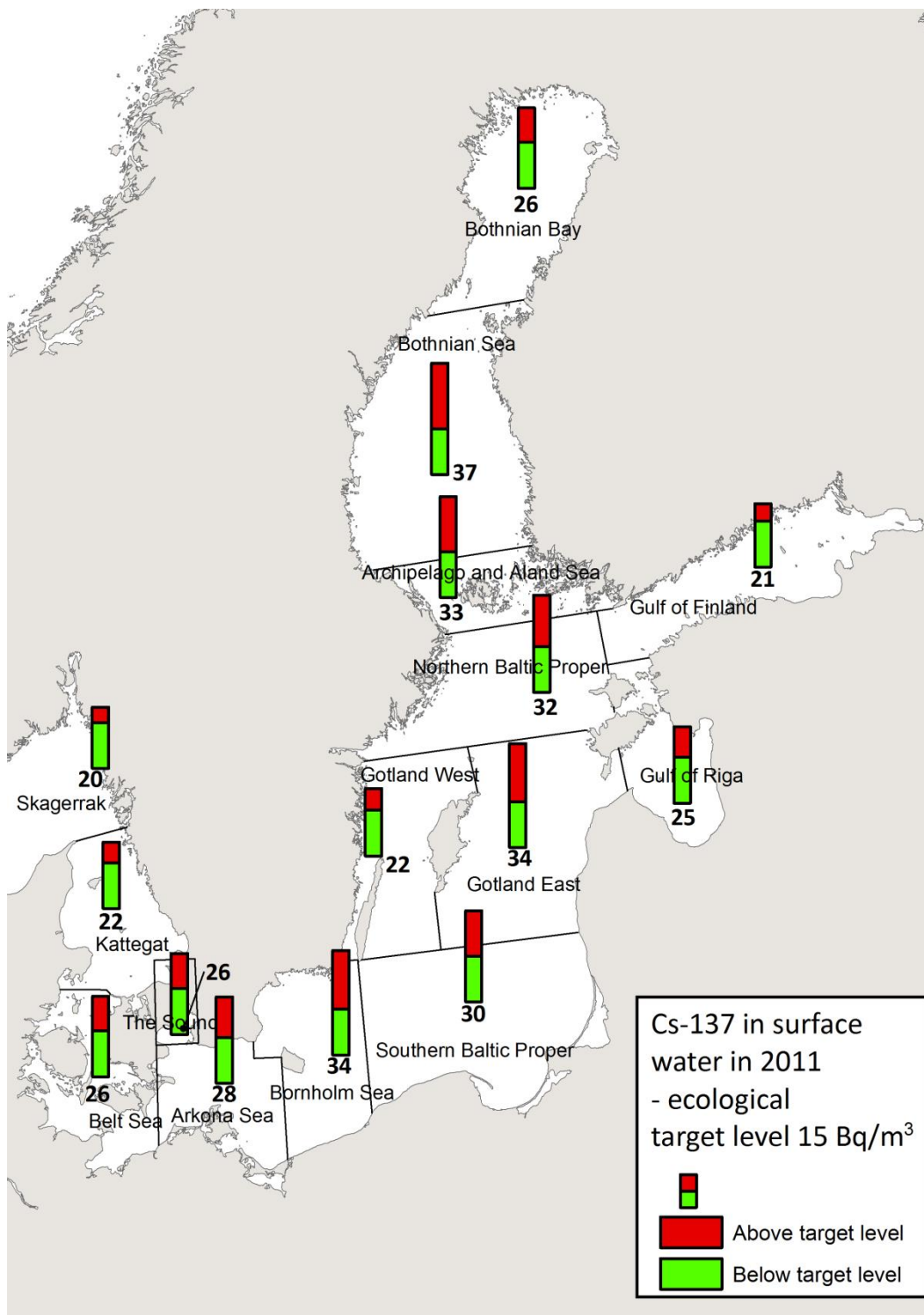


Figure 3. ¹³⁷Cs concentrations (in Bq/m³) in surface water (sampling depth ≤10 m) in 2011, as annual mean values by basin. Ecological target values have been calculated as average of pre-Chernobyl (1984–1985) concentrations.

Background

Man-made radioactive substances enter the marine environment either as direct fallout from the atmosphere or indirectly as runoff from rivers. Radionuclides may also be discharged directly into the ocean as liquid waste or from dumped solid wastes. Some radionuclides will behave conservatively and stay in the water in soluble form, whereas others will be insoluble or adhere to particles and thus, sooner or later, be transferred to marine sediments and marine biota.

The most significant source of artificial radioactivity in the Baltic Sea is fallout from the Chernobyl accident. The direct total input of ^{137}Cs from Chernobyl to the Baltic Sea was estimated at 4700 TBq. Secondary riverine input from Chernobyl fallout added further 300 TBq of ^{137}Cs .

Other important sources are global fallout from atmospheric nuclear weapons tests performed during the late 1950s and early 1960s (UNSCEAR, 2000) and discharges from the nuclear reprocessing plants Sellafield and La Hague, located at the Irish Sea and the English Channel which enter the Baltic Sea via sea currents from the North Sea. The latter sources have become of minor radiological importance, due to significant reduction of ^{137}Cs discharges from Sellafield in the past two decades (HELCOM 2009). Authorised discharges of radioactivity into the sea occurring during the routine operation of nuclear installations in the Baltic Sea region (nuclear power plants and nuclear research reactors) have also contributed to a lesser extent.

The Chernobyl accident resulted in the very uneven ^{137}Cs deposition in the Baltic Sea region with the Bothnian Sea and the Gulf of Finland having been the two most contaminated sea areas. Since 1986, the spatial and vertical distribution of Chernobyl-derived ^{137}Cs has changed as a consequence of river discharges, the mixing of water masses, sea currents, and sedimentation processes (Ilus 2007). In the early phase after Chernobyl, ^{137}Cs concentrations decreased rapidly in the Gulf of Finland and in the Bothnian Sea, while at the same time increasing in the Baltic Proper (Figures 5–7).

Policy relevance

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. Explosions of nuclear weapons in the atmosphere distribute radioactive substances in the environment, while underground nuclear explosions release little or no radioactivity into the environment. The routine operations of nuclear power plants give rise to small controlled discharges of radioactive substances, but accidents at nuclear power plants can cause releases of considerable amounts of radioactivity into the environment. Man-made radionuclides of particular concern to man and the environment are ^{90}Sr and ^{137}Cs , which are both formed by nuclear fission.

A study on worldwide marine radioactivity enables a comparison of levels of anthropogenic radionuclides in Baltic seawater against those in other marine areas of the world (Figure 4). The Baltic Sea has the highest average ^{137}Cs levels in surface water (IAEA, 2005). Radioactive fallout from the Chernobyl accident in 1986 is the dominating source for ^{137}Cs in the Baltic Sea. The levels of ^{137}Cs in the Baltic Sea, both in water and biota, have shown declining trends since the early nineties.

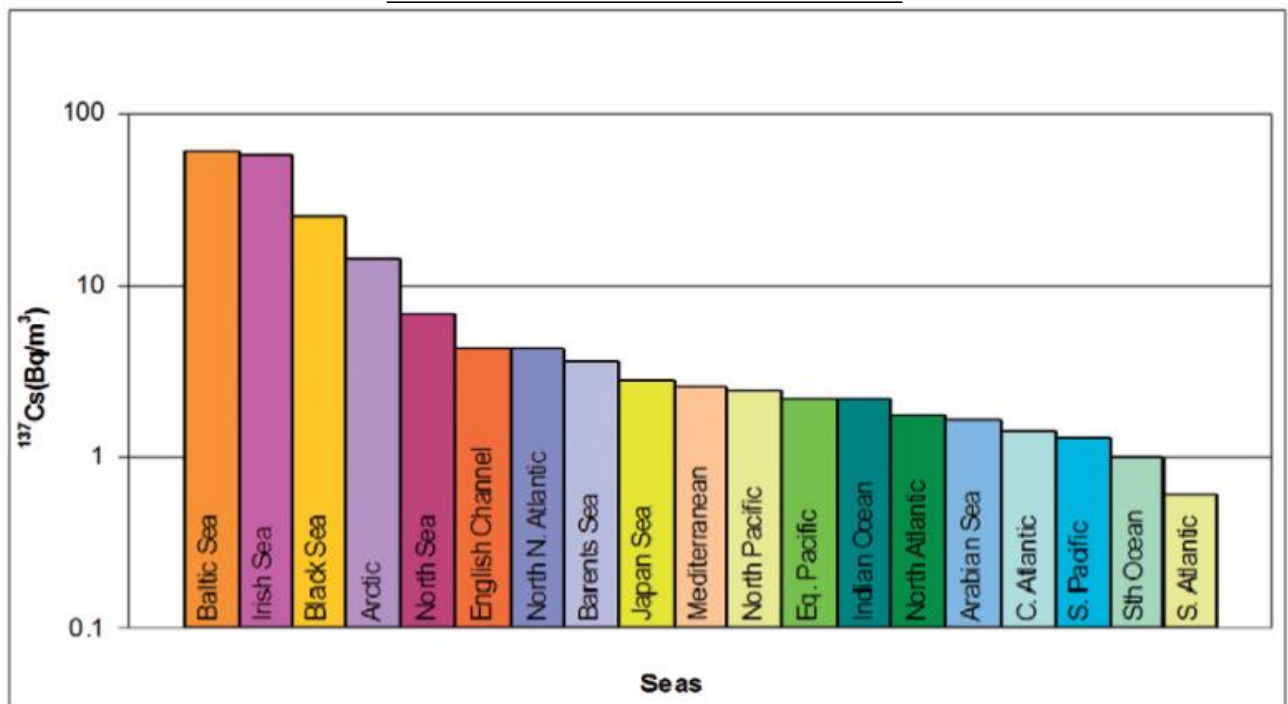


Figure 4. Average levels of ^{137}Cs in surface waters of the world's oceans and seas (estimates for 01.01.2000).

Ingestion of ^{137}Cs in fish is the dominating exposure pathway of humans from man-made radioactivity in the Baltic Sea. Therefore, ^{137}Cs concentrations in herring, plaice and flounder are well suited as indicators for man-made radioactivity in the Baltic Sea.

Internationally recommended maximum permitted concentrations of ^{137}Cs in foodstuff are in the range 100–1250 Bq/kg (EU, 2012 and EC, 2010).

Reaching one of the ecological objectives given by the BSAP, i.e. “radioactivity at pre-Chernobyl level” defined by associated target values, will help to assure healthy wildlife and all fish being safe to eat, both with respect to radiation exposure. Concentrations of radioactivity in marine wildlife in the Baltic Sea have always been low causing negligible risks to wildlife from radiation exposure and to humans from consumption of seafood.

HELCOM Monitoring of Radioactive Substances (MORS) projects, and now the HELCOM MORS Expert Group, have 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 and supports the work of the HELCOM Monitoring and Assessment Group (HELCOM MONAS), by assessing the progress towards the ecological objective *Radioactivity at pre-Chernobyl level* which was defined in the HELCOM Baltic Sea Action Plan (BSAP).

This indicator supports the implementation of the EU Marine Strategy Directive (MSFD) Descriptor 9 on *contaminants in fish and seafood for human consumption*.

The work of HELCOM MORS also supports the implementation of the Euratom Treaty, of which all EU Member States are signatories, which requires actions in relation to monitoring and effects of discharges on neighbouring states.

References

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Temporal trends in concentrations of the artificial radionuclide cesium-137 in herring, plaice and flounder muscle as well as sea water in the Baltic Sea basins

Key message

- 😊 Overall, the ^{137}Cs activity concentrations in plaice and flounder muscle, as well as of surface waters, in the Baltic Sea basins are approaching pre-Chernobyl levels.
- 😬 ^{137}Cs is continuously transported from the Baltic Sea to the North Sea via Kattegat. Routine discharges of radioactivity from nuclear power plants into the Baltic Sea area are small and only detectable locally.



Figure 5. ^{137}Cs concentrations (in Bq/kg) in herring muscle in 1984–2011 by sub-basin. Target values have been calculated as averages of pre-Chernobyl (1984–1985) concentrations. (Note: variable scales in the graphs)

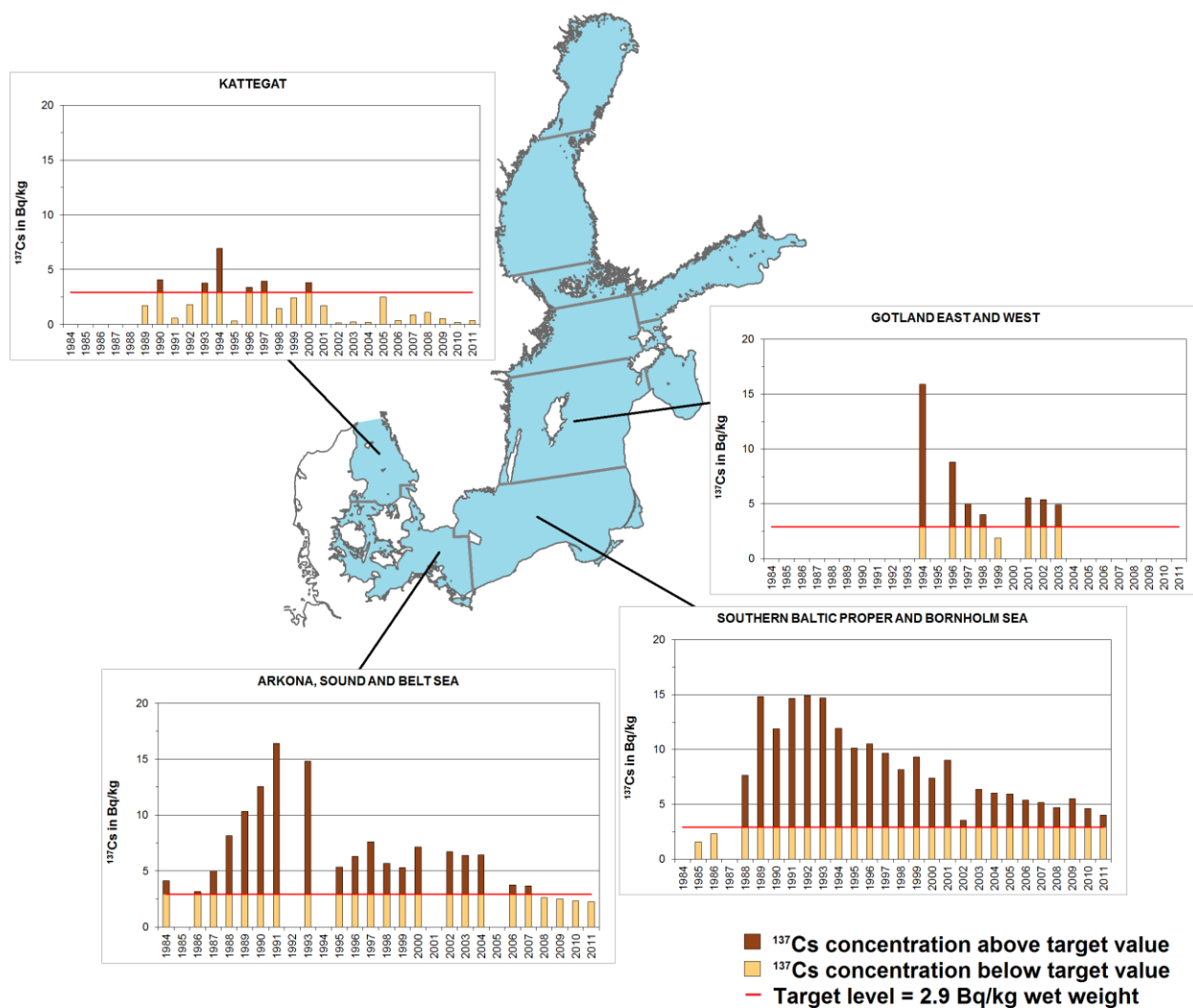


Figure 6. ¹³⁷Cs concentrations (in Bq/kg) in plaiice and flounder muscle in 1984–2011, as annual mean values by basin. Target values have been calculated as average of pre-Chernobyl (1984–1985) concentrations.

HELCOM Core Indicator of Hazardous Substances Radioactive substances

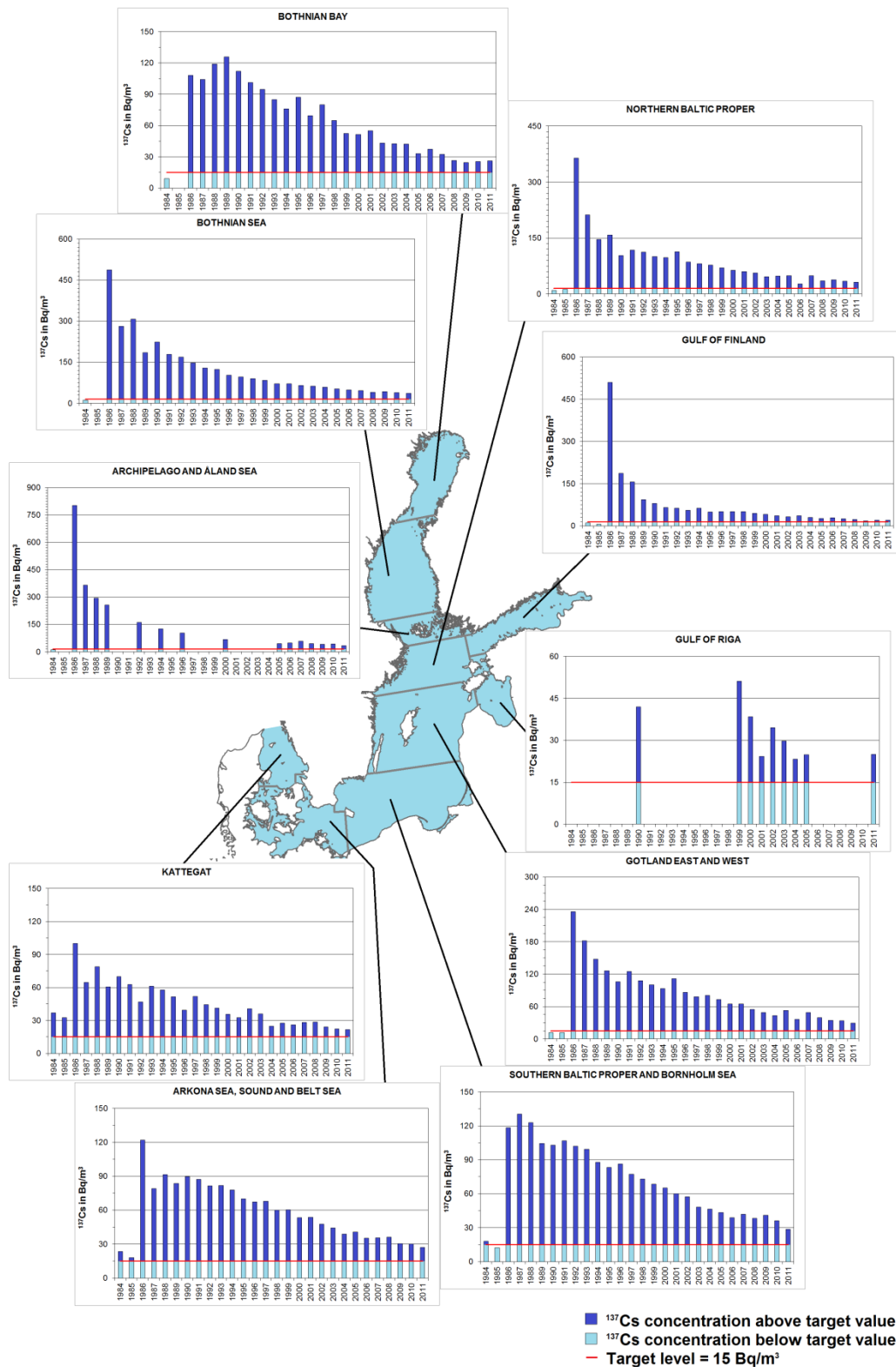


Figure 7. ^{137}Cs concentrations (in Bq/m³) in surface water (sampling depth ≤ 10 m) in 1984–2011, as annual mean values by basin. Target values have been calculated as average of pre-Chernobyl (1984–1985) concentrations.

Assessment

Concentrations of ^{137}Cs in fish and sea water have continued to decrease in all regions of the Baltic Sea since they reached their maximum values in the late 1980s and early 1990s after the Chernobyl accident (Figures 5–7).

The effective half-life of a radioactive contaminant is the time required for its concentrations to decrease by 50 % as a result of physical, chemical and biological processes. Half-lives are specific to each radionuclide and each environment where they may occur. Effective half-lives have been calculated for ^{137}Cs in various parts of the Baltic Sea. Currently, the effective half-lives of ^{137}Cs in surface water vary from 9 years in the Bothnian Bay to 15 years in the Baltic Proper. The longer residence time of ^{137}Cs in the Baltic Proper is most likely due to inflows of more contaminated water from the northern part of the Baltic Sea. In the time period following Chernobyl, 1986-1988, the effective half-lives of ^{137}Cs were much shorter in most contaminated regions: 0.8 years in the Gulf of Finland and 2.5 years in the Bothnian Sea. The shorter effective half-life of ^{137}Cs in Gulf of Finland as compared to the Bothnian Sea during 1986-1988 was probably due to different water exchange and sedimentation processes in these two regions (Illus et al. 1993).

Based on the inventory estimates, the effective half-life of ^{137}Cs in Baltic seawater during the period 1993–2006 has been 9.6 years. With this decay rate, the ^{137}Cs inventory in the Baltic Sea would reach pre-Chernobyl levels (250 TBq) by the year 2020, presuming that the effective half-life will stay constant, and no substantial remobilization of ^{137}Cs from sediments will occur.

Levels of radionuclides in marine biota are linked to the corresponding levels in seawater and sediments, via accumulation through food chains. The complexity of food chains increases with the trophic level of the species considered. Fish, the biota type in the Baltic Sea most important for human consumption, accumulate most of their radionuclides from food, not from water.

The biota of the Baltic Sea received the most significant contribution to their radionuclide levels following the Chernobyl accident in 1986, predominantly in the form of ^{137}Cs and ^{134}Cs . As shown in Figure 5, concentrations of ^{137}Cs are continuing to show generally slowly decreasing trends in herring muscle. In the western parts of the Baltic Sea, i.e. the Kattegat, the Sound, the Belt Sea and the Arkona Sea, the values already show levels slightly below the target value of 2.5 Bq kg⁻¹ wet weight. In the remaining Baltic Sea basins, the target value is still exceeded, in the Bothnian Bay and in the Gotland area, by a factor of up to 5.

Figure 6 shows the ^{137}Cs time series for the flat fish group, consisting of flounder (*Platichthys flesus*) and plaice (*Pleuronectes platessa*), in the western and southern Baltic Sea areas. Samples of fillets/flesh were used for these measurements. At the end of the assessment period, the values were below about 6 Bq kg⁻¹ wet weight.

The $^{134}\text{Cs}/^{137}\text{Cs}$ ratio in Baltic biota agree very well with that of the Chernobyl fallout. High trophic level species, including 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 trends in seawater. In the long-term, ^{137}Cs time trends in biota closely follow the trends in seawater.

Marine biota concentration factors (CF) show clearly that for marine fish species the ^{137}Cs CF values increase from western Baltic Sea areas to eastern/northern areas, which is explained by the corresponding increase of freshwater contributions to the seawater (HELCOM 2009).

Doses

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 Chernobyl fallout, about one quarter (650 manSv) from fallout from nuclear weapons

testing, about 8 % (200 manSv) from European reprocessing facilities, and about 0.04 % (1 manSv) from nuclear installations bordering the Baltic Sea area.

Dose rates and doses from natural radioactivity dominate 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.

The maximum annual equivalent dose since 1950 to individuals from any critical group in the Baltic Sea area due to ¹³⁷Cs is estimated at 0.2 mSv y⁻¹, which is below the dose limit of 1 mSv y⁻¹ for the exposure of members the public set out in the IAEA International Basic Safety Standards (IAEA 1996). It is unlikely that any individual has been exposed from marine pathways at a level above this dose limit considering the uncertainties involved in the assessment. 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.

Fallout from Fukushima incident

The tsunami in Japan in March 2011 caused destruction of three nuclear power reactors and substantial releases of radioactive substances to air and sea. These airborne releases were carried by wind over the northern hemisphere and also to the Baltic Sea area. Here levels were extremely low and presented negligible risks to humans. However, the levels were sufficiently high to be detected by sensitive systems monitoring radioactivity in air. The airborne radioactivity over Europe from the Fukushima disaster occurred during two months from mid-March to mid-May 2011 and caused deposition of radioactivity on ground.

Observations of radioactive cesium isotopes in air over the Baltic region indicate deposition of about 2 Becquerel per square metre of ¹³⁴Cs and similar for ¹³⁷Cs. Considering the surface area of the Baltic Sea of 415,266 km², a total input 1.6 TBq of radiocesium¹ may be estimated.

Model calculations made by the MORS EG has estimated the impact in the Baltic Sea region in terms of radiation doses to man from this fallout considering marine exposure pathways. The model has been used by the MORS EG on previous occasions and shows good agreement between calculated and observed environmental levels of radioactivity (HELCOM 2009).

The equivalent doses to man in the Baltic area estimated from Fukushima fallout are insignificant compared to the doses from present levels in the Baltic Sea from Chernobyl fallout. The table below summarises the results of the dose calculations.

Table 1. Summary of the effects of Fukushima fallout on the Baltic Sea

Item	Value
Deposition of radiocesium over Baltic Sea	4 Bq/m ²
Input of radiocesium to Baltic Sea	1.6 TBq
Annual dose rate in 2011 due to Chernobyl fallout	0.9 µSv/a
Additional dose rate in 2011 due to Fukushima fallout	0.003 µSv/a

¹ Radiocesium is the sum of all radioactive cesium isotopes

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Conceptual model of the sources, transport and impacts of cesium-137 in the Baltic ecosystem

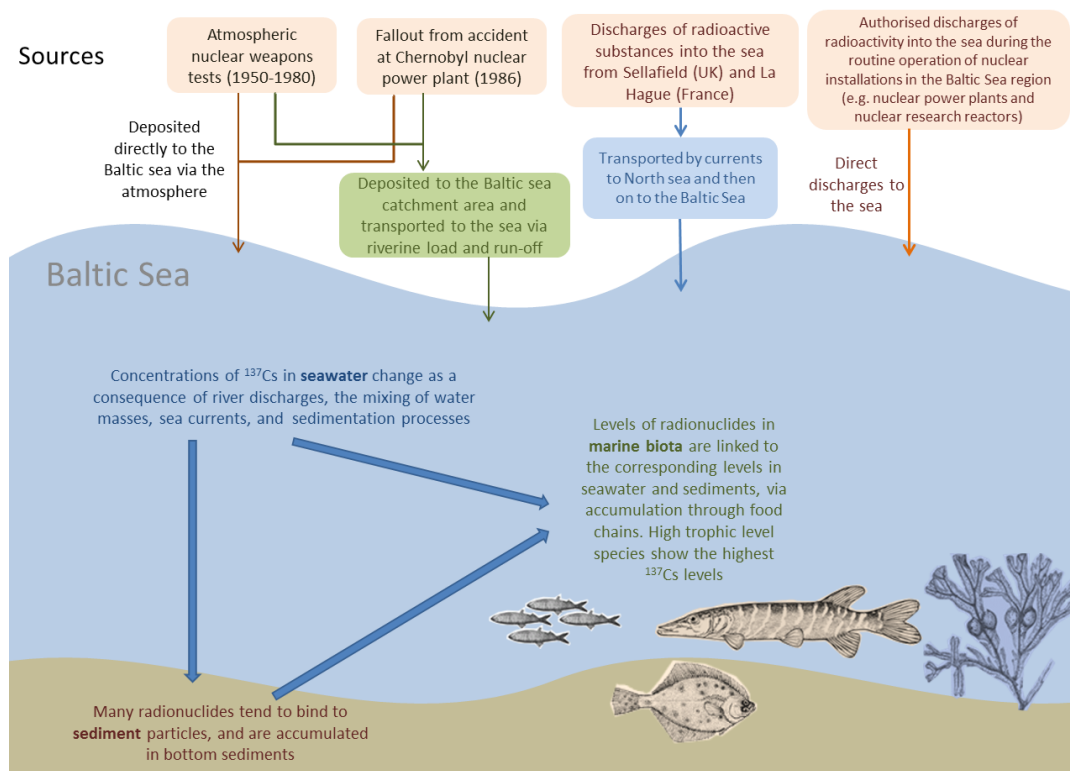


Figure 8. Conceptual model illustrating the sources and pathways of ¹³⁷Cs in the Baltic Sea.

Levels of radionuclides in marine biota are linked to the corresponding levels in seawater and sediments, via accumulation through food chains. The complexity of food chains increases with the trophic level of the species considered. Fish, the biota type in the Baltic Sea most important for human consumption, accumulate most of their radionuclides from food, not from water.

References

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Technical data on assessing concentrations of artificial radionuclide ¹³⁷Cs in biota

Data source

Data have been collected by the Contracting Parties of HELCOM and submitted to the MORS (Monitoring of Radioactive Substances) database.

Description of data

The data are based on ¹³⁷Cs concentrations of 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 made either from round fish (without head and entrails) or filets (herring), and for plaice and flounder from filets, only. Concentrations (Bq/kg) have been calculated from wet weight of the samples.

Seawater concentrations (Bq/m³) have been analyzed from surface water samples 0–10 m.

Data of each media (herring, plaice and flounder and sea water) have been averaged by basin and by year.

Spatial and temporal coverage

Herring data covers all the areas except Gulf of Riga (only years 2003 and 2005) and the area of Gotland East and West (only years 2003–2009). In the Northern Baltic Proper years 2003–2008 and 2010–2011 are missing. In the Sound, Belt and Arkona Sea several years of data are missing (1992–1994, 1999–2000, 2004–2009).

Plaice and flounder data are very scarce both temporarily and spatially covering only four sea areas and several years missing. Sampling on plaice and flounder takes place only in some of the countries.

Sea water data coverage is almost complete, except the missing years in the Gulf of Riga and in the Archipelago and Åland Sea.

Methodology and frequency of data collection

The average number of biota samples collected annually by the MORS-PRO group through the sampling period 1999–2011 was about 111. Over the whole period the numbers of samples collected were 1107 for fish, 196 for *aquatic plants*, and 146 for benthic animals.

More detailed information on national monitoring activities are available for [Finland](#), [Germany](#), [Lithuania](#) and [Poland](#).

Methodology of data analyses

More than ten laboratories from the nine countries bordering Baltic Sea have contributed to the monitoring programmes of Baltic Sea by analyzing radionuclides from 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).

Strengths and weaknesses of data

Quality assurance is a fundamental part of radioanalytical work, 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 intercomparisons were organised during the HELCOM MORS-PRO project period (1999–2006) for seawater and sediment samples, and their results are also presented in the HELCOM thematic assessment (HELCOM 2009). The intercomparisons confirm that the data produced by the MORS group is of very good quality and can be considered comparable. Less than five percent of the results were considered outliers

Target values and classification method

The target values for ¹³⁷Cs concentrations in sea water, sediments and biota have been set at pre-Chernobyl levels.

Average concentrations of ¹³⁷Cs prior the Chernobyl accident have been used as target values. These are for herring (2.5 Bq/kg), flounder and plaice (2.9 Bq/kg) and seawater (15 Bq/m³).

Further work required

The reported uncertainties in data vary considerably between laboratories. Each laboratory calculates uncertainties in its own particular way, and the harmonization of uncertainty calculations would improve the comparability of the data.

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For more information, see also:

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