Document title	Radioactive substances: Cesium-137 in fish and surface seawater
Code	3J-59
Category	DEC
Agenda Item	3J-Progress of relevant HELCOM expert groups and projects
Submission date	13.9.2021
Submitted by	Secretariat

Background

The document below provides a template filled by indicator leads to provide an overview of progress to STATE & CONSERVATION 15-2021. Key aspects such as methodologies, spatial extent changes, assessment scales and threshold values are presented, identifying ongoing work and other relevant issues towards HOLAS III. This process builds on the prior review of indicator development carried out under STATE & CONSERVATION 14-2021 (summarised in document 4J-16 Rev.1, and detailed within numerous documents under agenda item 4J). The focus of these development works is the completion of indicator development and adjustment work for HOLAS III by the end of 2021, as previously agreed under HOD 57-2019 (document 4-20, Outcomes paragraph 4.51).

The aspect of threshold values in particular is a key issue as threshold value approval will be carried out at HOD 61-2021, with these same templates being submitted to HOD at the same stage as submission to State and Conservation 15-2021 (to allow for the longer national processes required that culminate in approval at HOD).

The document below addresses a single indicator and as well as the generic 'action requests' relating to endorsement of the proposed application in HOLAS III (and the threshold values proposals, where relevant), specific additional requests or statements are also indicated within the separate sections of the document to help guide where further input/discussion/guidance may be needed.

This template aims to report the indicator development for HOLAS III, allowing for technical guidance and endorsement by STATE & CONSERVATION 15-2021 and also simultaneously to facilitate the threshold value approval process by HOD 61-2021.

Action requested

The Meeting is invited to:

- provide further technical guidance to the indicator leads and experts, including specific requests defined within the document;
- consider and endorse the proposed developments of the indicator for use in the HOLAS III assessment.

Radioactive substances: Cesium-137 in fish and surface seawater

Indicator name
Radioactive substances: Caesium-137 in fish and surface seawater
Scale of assessment for HOLAS III and rational
The assessment scale will not be changed from the existing indicator, as applied in HOLAS II.
Spatial coverage of the indicator for HOLAS III
Spatial coverage in HOLAS II is high and this is not expected to change for HOLAS III. The proposed revision of threshold values will not impact data availability or spatial coverage.
Methodology to be applied for HOLAS III and rational
The indicator methodology and monitoring will not change in for HOLAS III. The changes proposed are related to threshold values and their application, implemented in relation to meeting the objectives of the updated BSAP. A full explanation and justification is provided below.
Threshold value setting logic and rational
Due to the accident at the Chernobyl power plant in 1986, significant amounts of radioactive isotopes were released into the Baltic Sea, making this waterbody one of the most contaminated worldwide, a factor exacerbated by the limited water exchange with the North Sea. Therefore, the radioactive anthropogenic isotope caesium-137 (Cs-137), with a relatively long half-life of 30 years, was chosen as a core indicator of radioactivity levels in the Baltic Sea. Its activities in fish and seawater are used for the assessment and reflect changes in the environment. The three most common and commercially exploited fish species were selected for the assessment of the environmental status of the Baltic Sea: herring and the flatfish group (plaice and flounder). The current threshold values are based on available activity concentrations or specific activities from the time before the Chernobyl accident. In connection with the revision of the main goals of the Baltic Sea Action Plan (BSAP), the Expert Group on Monitoring of Radioactive Substances in the Baltic Sea decided to rephrase the current objective and suggested the following formulation in 2019 (HELCOM MORS EG9-2019): “Radioactivity at negligible risk level to humans and environment”. The proposed change forces the necessity to adapt the threshold values for the established indicators (Cs-137 concentration in fish and seawater) to reflect the current best available knowledge and to base it on safety standards which refer to human safety related to fish consumption. Furthermore, the new ecological objective shall also fulfil the requirements of the Marine Strategy Framework Directive regarding assessments in terms of both: (i) Descriptor 8 (Concentrations of contaminants are at levels not giving rise to pollution effects) and (ii) Descriptor 9 (Contaminants in fish and other seafood for human consumption do not exceed levels established by Community legislation or other relevant standards). Taking into account the potential human exposure related to the consumption of fish from the Baltic Sea area, the potential human exposure from contact with contaminated water, and the potential threats to marine organisms, the following procedure has been carried out: 1. Determination of threshold value proposals for the protection of humans due to exposure from the consumption of selected fish species (based directly on safety standards),

2. Determination of threshold value proposals for protecting humans from exposure due to contaminated seawater, adopting the same safety standards and based on actual data including exposure from internal and external sources (seawater and sediment),
3. Recommendation of a set of human safety values as new threshold value proposals for fish (herring and flatfish) protection,
4. Verification of the new threshold values by checking whether the doses derived from the proposed threshold values meet the criteria for protection of fauna and flora, which, according to ICRP (2008), is equal to the lower value of the 'derived consideration reference levels '(DCRL), which is equal to 40 µGy h^{-1}.

The starting point is the adoption of the value for radiological reference criteria for the protection of the public and the environment, which result from current legislation. According to EC (2013), IAEA (2014), EC (2018) and ICRP recommendations, three values of radiological reference criteria for human and non-human biota are considered within the process:

- the derived consideration reference levels (DCRL) to flora and fauna of 40 µGy h^{-1} (ICRP 108, 2008),
- the established annual dose limit (1 mSv) for members of the public in planned exposure situations (EC, 2013; IAEA, 2014),
- the individual annual dose level (of the order of 10 µSv) used to grant exemption to activities and facilities (EC, 2013; IAEA, 2014).

Exposures related to human consumption of fish and human exposure to contaminated seawater are based on the procedures of IAEA (2015).

The calculations of new threshold values adopt the most preventive approach and use the annual threshold dose of 10 µSv from artificial radionuclides, which is an effective dose to public members.

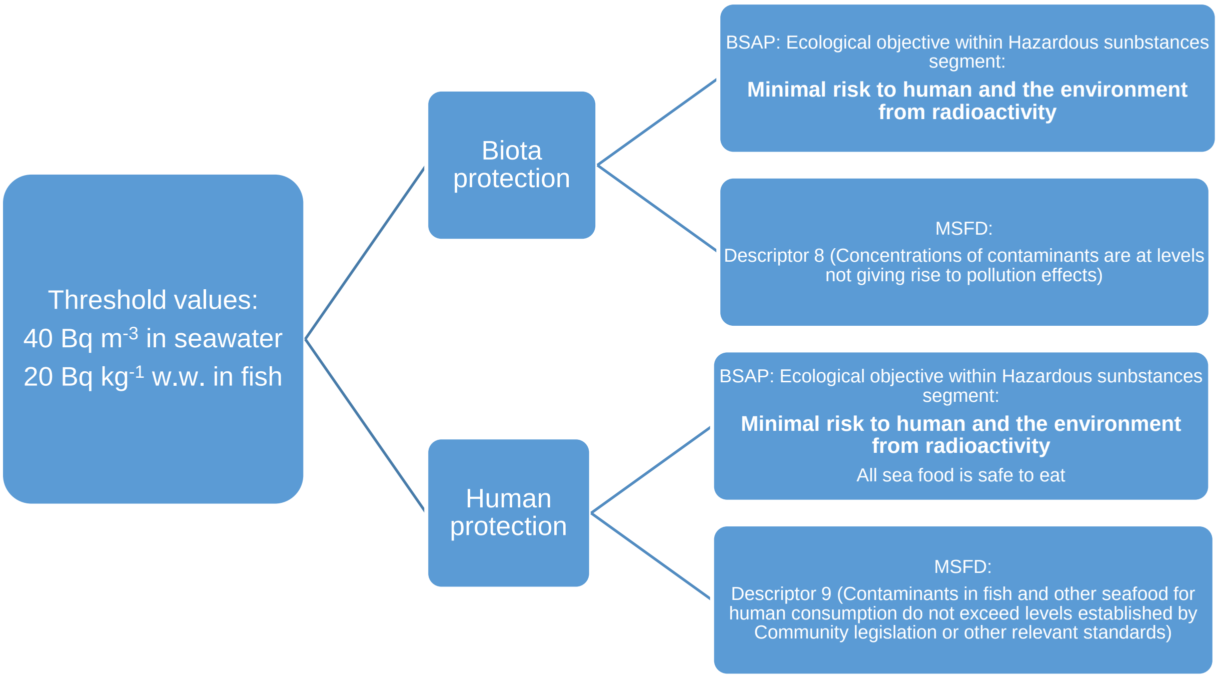
The basic calculations for estimating the new threshold value in fish related to the internal exposure to humans from seafood consumption uses: (i) the dose criterion of 10 µSv per year, (ii) maximum annual fish intake of inhabitants of the Baltic Sea neighbouring states according to Guillen et al. (2019) and the generic value for modelling of IAEA (2001).

For calculating a threshold value for Cs-137 in seawater, dose rates from exposure scenarios to humans as outlined in IAEA (2015) are assumed. The scenario included external exposure from contaminated sediment, internal exposure from ingestion of beach sediment, and inhalation of sea spray as well as beach sediment.

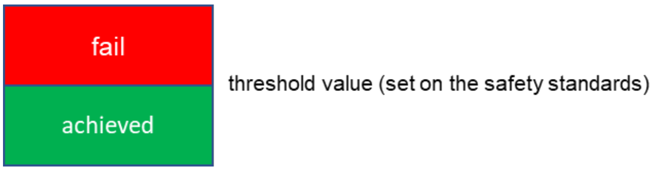
The values determined using the methods described above were, respectively: **28.3 Bq kg^{-1} w.w. for fish** and **47.2 Bq m^{-3} for seawater** (Document 6-1, HELCOM MORS EG 11-2021).

To verify the effectiveness of fish protection, the doses to fish from internal and external exposure arising from the new threshold concentrations were calculated. These need to be equal to or smaller than the lowest value of the 'derived consideration reference levels (DCRL), which is 40 µGy h^{-1} (ICRP, 2008). The total doses to flatfish ($4.82 \cdot 10^{-3}$ µGy h^{-1}) and herring ($5.10 \cdot 10^{-3}$ µGy h^{-1}) are far below the value of the 'derived consideration reference levels' (DCRL), which is equal to 40 µGy h^{-1}. That means that the proposed threshold values for fish and seawater meet the requirements for protecting fish in the Baltic Sea environment.

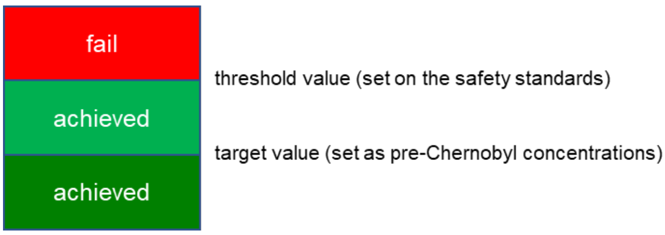
Finally, taking into account the precautionary principle and using values rounded down to the lower 'ten' (i.e. 47 to 40), the new threshold values for the protection of humans and the environment are proposed: 40 Bq m^{-3} for seawater, and 20 Bq kg^{-1} w.w. for fish, which at the same time meet the requirements specified by BSAP and MSFD:



Good environmental status within MSFD Descriptor 8 is achieved when the activity concentration of the radionuclide Cs-137 is below 20 Bq kg^{-1} w.w. in fish and 40 Bq m^{-3} in seawater. Good environmental status within Descriptor 9 is achieved when the activity concentration of radionuclide Cs-137 is below 20 Bq kg^{-1} w.w. in fish.



Considering the significant contamination with radioactive isotopes, including Cs - 137, which mainly occurred due to the Chernobyl accident, the most desirable situation from the point of view of the environmental status of the Baltic Sea would be to achieve pre-Chernobyl concentrations. Therefore, target values have also been set. The activity concentrations of the radionuclide Cs-137 set as target values for fish are 2.5 Bq kg^{-1} w.w. for herring, 2.9 Bq kg^{-1} w.w. for flatfish, and 15 Bq m^{-3} for seawater. The quantitative boundaries used for defining the target values correspond to pre-Chernobyl activity concentration levels, the levels before 1986.



The determined threshold values are proposed to be valid throughout the Baltic Sea assessment area, including assessment basins compliant with the HELCOM Monitoring and Assessment Strategy. There are therefore no proposals to alter monitoring procedures for the indicator and the changes outlined above are simply carried out via the calculation of the indicator results.

EG MORS recommends accepting the new values for both the assessment under D8 and D9 and using them in CHASE. The indicator evaluation based on these new threshold values, that are suitable to directly address the new BSAP objectives and also MSFD D8 and D9, will be the component integrated into the CHASE integrated assessment of hazardous substances for HOLAS III.’
Threshold value(s)
The newly proposed threshold values are set as when the activity concentration of the radionuclide Cs-137 is below 20 Bq kg^{-1}w.w. in fish and 40 Bq m^{-3} in seawater. These threshold values address the updated objectives of the BSAP. **The State and Conservation Meeting is invited to endorse the new threshold values and thus their application in the indicator and CHASE integrated assessment for HOLAS III.**
Other significant issues that need to be addressed or presented to State and Conservation
Not relevant.
Latest indicator report or (for new indicators) initially completed indicator template
The latest version of the indicator, as applied in HOLAS II, is available on the indicator web page. The Annex provided as an attachment to this document contains a full and detailed description of process carried out and the scientific justification for the proposed threshold values and approach.

Proposal for a methodology for the calculation of Caesium-137 threshold values in seawater and fish of the Baltic Sea

Introduction

Due to the accident of the Chernobyl power plant in 1986, significant amounts of radioactive isotopes were released into the Baltic Sea, making this waterbody one of the most contaminated worldwide, also due to the limited water exchange with the North Sea. The isotope of which the most significant amounts were released into the waters of the Baltic Sea, thus shaping the level of anthropogenic radioactivity to this day, was caesium-137 (Cs-137), characterised by a relatively long half-life (30 y). This was the reason for selecting this isotope as an indicator for assessing the status of the Baltic marine environment concerning radioactivity. Concentrations of Cs-137 in seawater and fish reflect the most dynamic changes in the marine environment. Therefore, they are the basis of HELCOM CORE INDICATOR: Radioactive substances: Caesium-137 in fish and surface seawater (https://helcom.fi/wp-content/uploads/2019/08/Radioactive-substances-HELCOM-core-indicator-2018.pdf). The current core indicator threshold values are derived from the old BSAP Objective "Radioactivity at pre-Chernobyl level". These pre-Chernobyl levels, in detail 14.6 Bq m^{-3} for seawater, 2.5 Bq kg^{-1} w.w. for herring muscle and 2.8 Bq kg^{-1} w.w. for the muscle of plaice and flounder (HELCOM, 2007), were initially selected as target values for activity concentrations and specific activities in the direct aftermath of the Chernobyl accident. At that time, no dose criteria for the environment, and only a limited number of measured values were available for the Baltic Sea. Therefore, these target values of Cs-137 do not reflect the actual exposure situation due to the presence of Cs-137 in the Baltic Sea and the actual state of knowledge, but relate to a historical situation and do still describe the long-term objective.

In connection with the revision of the provisions of the main goals of the Baltic Sea Action Plan (BSAP), the Expert Group on Monitoring of Radioactive Substances in the Baltic Sea decided to rephrase the current objective and suggested the following formulation in 2019 (HELCOM MORS EG9/2019): "**Radioactivity at negligible risk level to humans and environment**". The proposed change forces the necessity to change the threshold values for the established indicators (Cs-137 concentration in fish and seawater), which shall be based on safety standards and refer to human safety related to fish consumption. The new ecological objective should also fulfil the requirements of the Marine Strategy Framework Directive (EC, 2008) regarding assessments in terms of both: (i) Descriptor 8 (Concentrations of contaminants are at levels not giving rise to pollution effects) and (ii) Descriptor 9 (Contaminants in fish and other seafood for human consumption do not exceed levels established by Community legislation or other relevant standards).

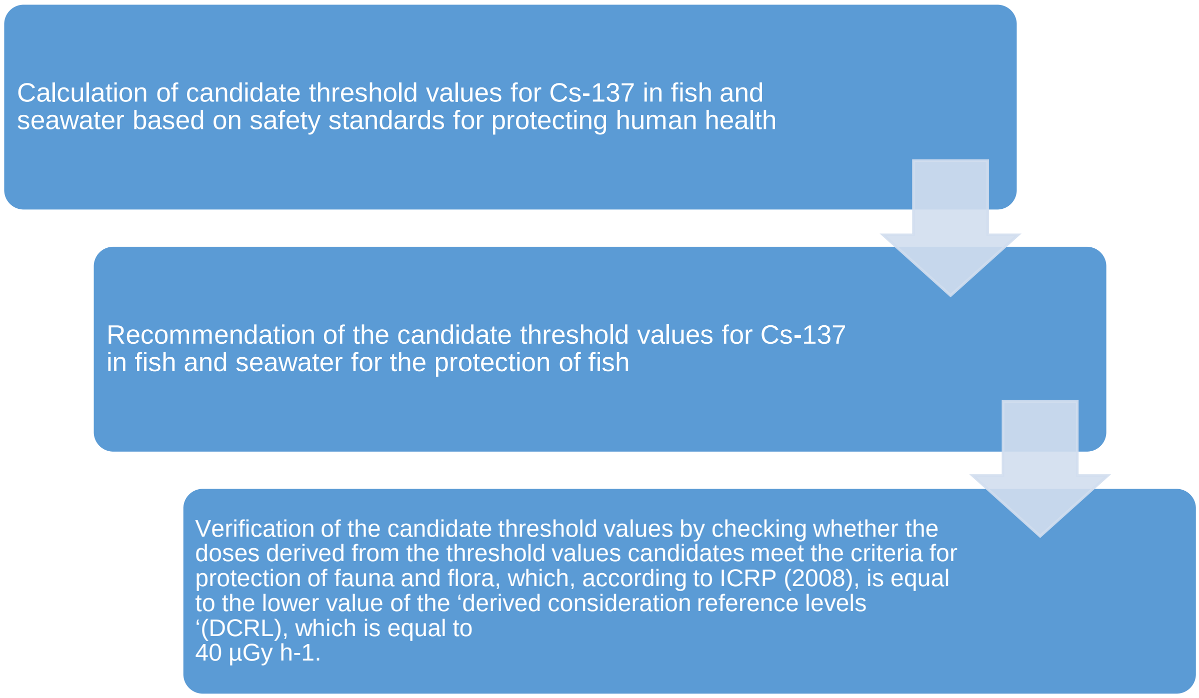
Therefore, HELCOM MORS EG, in cooperation with the International Atomic Energy Agency (IAEA), took steps to set new threshold values, taking into account the new BSAP ecological goal regarding human and non-human biota.

1. Definition of the criteria according to the exposure situation

Taking into account the potential human exposure related to the consumption of fish from the Baltic Sea area, the potential human exposure from contact with contaminated water and the potential threats to marine organisms, the following procedure has been proposed:

1. Determination of candidate threshold values for the protection of humans due to exposure from consumption of selected fish species (based directly on safety standards),
2. Determination of candidate threshold values for the protection of humans from exposure due to contaminated seawater, adopting the same safety standards and based on actual data including exposure from internal and external sources (seawater and sediment),

3. Recommendation of a set of human safety values as a new candidate threshold values for the protection of fish (herring and flatfish),
4. Verification of the new threshold values by checking whether the doses derived from the threshold value candidates meet the criteria for protection of fauna and flora, which, according to ICRP (2008), is equal to the lower value of the 'derived consideration reference levels '(DCRL), which is equal to 40 µGy h^{-1}.



2. Definition of radionuclides of interest

Threshold values are determined for the Cs-137 isotope - as an isotope of anthropogenic origin - which is currently the most responsible one for shaping the levels of radioactivity in the Baltic Sea.

3. Definition of sub-regions of interest

The determined threshold values are valid throughout the Baltic Sea assessment area, including assessment basins compliant with the HELCOM Monitoring and Assessment Strategy (https://helcom.fi/media/publications/Monitoring-and-assessment-strategy.pdf).

4. Definition of representative person exposure scenario/pathway

Exposures related to human consumption of fish and human exposure to contaminated seawater are based on the procedures of IAEA (2015).

5. Definition of reference animals and plants

The two most common and commercially exploited fish species were selected for the assessment of the environmental condition of the Baltic Sea: herring and the flatfish group (plaice and flounder). In detail, the calculation of dose rates was carried out using the concept of reference animals and plants established by the ICRP for radiation protection of individual species in the environment (ICRP 2008). For this purpose, the ICRP reference animals and plants (RAP) were defined; these are deer, rat, duck, bee, earthworm, pine tree and wild grass for the terrestrial and trout, flatfish, crab, frog and brown seaweed for the aquatic environment. All RAP are characterised by ellipsoids, according to first dose models for humans. Finally, dose thresholds and dose conversion factors for radionuclides are calculated for the RAP. In detail, the RAP "trout" is used for the calculation of dose rates to herring and the RAP "flatfish" representing the flatfish group.

6. Methodology for the calculation of Cs-137 threshold values (humans combined with flora and fauna)

The starting point is the adoption of the value for radiological reference criteria for the protection of the public and the environment, which result from current legislation. According to EC (2013), IAEA (2014), EC (2018) and ICRP recommendations, three values of radiological reference criteria for human and non-human biota are considered within the process:

- the derived consideration reference levels (DCRL) to flora and fauna of 40 µGy h^{-1} (ICRP 108, 2008),
- the established annual dose limit (1 mSv) for members of the public in planned exposure situations (EC, 2013; IAEA, 2014),
- the individual annual dose level (of the order of 10 µSv) used to grant exemption to activities and facilities (EC, 2013; IAEA, 2014).

The present calculations adopt the more prohibitive approach and use the annual threshold dose level of 10 µSv from artificial radionuclides, which is an effective dose to public members.

Based on the adopted dose criterion, the specific activity of Cs-137 in biota and the activity concentration in seawater are back-calculated depending on the matrix using the exposure pathways relevant to humans in the Baltic Sea area. These are (i) external exposure to radionuclides deposited on the shore, inadvertent ingestion of beach sediments, inhalation of particles re-suspended from beach sediments, inhalation of sea spray and (ii) ingestion of seafood.

Using the previously calculated specific activity in biota and the activity concentration of Cs-137 in seawater, doses to marine reference plants and animals (RAP) are calculated considering external exposure from radionuclides in the seawater and internal exposure to radionuclides incorporated within the organism. Such summed doses are compared to the relevant radiological criteria for the protection of non-human biota (e.g. ICRP DCRLs). If any of the resulting doses are above the DCRL for the respective RAP, the proposed initial threshold values should be reduced accordingly.

The calculated specific activity in biota or activity concentration in seawater for Cs-137 will correspond to the threshold value for good environmental status guaranteeing safety for both, fish and humans.

The basic calculation for estimating the new threshold value in fish related to the internal exposure to humans from seafood consumption uses the dose criterion of 10 µSv per year to humans as a starting point. Using this value and the annual fish intake, specific activities in fish are calculated. For ingestion of biota, the minimum, mean and maximum annual fish intake of inhabitants of the Baltic Sea neighbouring states according to Guillen et al. (2019) and the generic value for modelling of IAEA (2001) are used as listed in Table 1 and the Appendix (Table 4). Together with the dose coefficient for ingested Cs-137 of 1.3 10^{-8} Sv Bq^{-1} (ICRP 119, 2012), the specific activities in fish flesh were obtained (Tab. 1):

Table 1: Specific activities of Cs-137 in fish related to the dose rate (10 µSv a^{-1}) associated with the consumption of inhabitants of the Baltic Sea neighbouring states and the generic value used of IAEA for dose modelling.

	Fish consumption (H_B) of Baltic Sea inhabitants	Specific activities of Cs-137 in fish, Bq kg^{-1} w.w.
Baltic Sea neighbours, minimum*	7.4	104
Baltic Sea neighbours, mean*	15.9	48.3
Baltic Sea neighbours, maximum*	27.2	**28.3**
Generic modelling value of IAEA (2001)	50	15.4

* (Guillen et al., 2019)

The most protective value of **28.3 Bq kg^{-1} w.w.** is used for further calculations for the internal exposure to herring and the flatfish group from Cs-137 (Tab. 2) using the dose conversion factors according to ICRP 136 (see Appendix Tab. 6).

Table 2: Dose rates connected to the internal exposure of fish from Cs-137 at the maximum annual fish consumption of inhabitants of the Baltic Sea neighbouring states

	internal dose rate to the flatfish group		internal dose rate to herring	
	µGy h^{-1}	µGy a^{-1}	µGy h^{-1}	µGy a^{-1}
Doses based on Cs-137 concentration in fish calculated for maximum annual fish consumption	$4.81 \cdot 10^{-3}$	42	$5.09 \cdot 10^{-3}$	45

For calculating a threshold value for Cs-137 in seawater, dose rates from exposure scenarios to humans considered as outlined in IAEA (2015) are assumed. The scenario included external exposure from contaminated sediment, internal exposure from ingestion of beach sediment, and inhalation of sea spray as well as beach sediment. Where suitable, the generic data from IAEA (2015) were used, and modifications are explained; all values used for calculation of dose rates are listed in the Appendix (Tables 4 – 7).

The criterion of an annual dose rate of 10 µSv to adults from the dose components listed in Table 3 converged at a seawater concentration of 47.2 Bq m^{-3} using the goal seek function in Microsoft Excel. As the resulting sum of dose rates to infants is considerably smaller, they are also protected.

Table 3: Dose components to humans from different exposure situations due to contaminated seawater calculated using equations (5) to (13)

	symbol	adults	infants	unit
dose rate from external exposure of Cs-137 deposited at the shore	$E_{ext,public(Cs-137)}$	9.97	6.23	µSv a^{-1}
dose rate from ingestion of beach sediment	$E_{ing\ shore,public(Cs-137)}$	$1.96 \cdot 10^{-03}$	$1.23 \cdot 10^{-02}$	µSv a^{-1}
dose rate from inhalation of beach sediment	$E_{inh\ shore,public(Cs-137)}$	$3.20 \cdot 10^{-07}$	$5.61 \cdot 10^{-08}$	µSv a^{-1}
dose rate from inhalation of sea spray	$E_{inh\ spray,public(Cs-137)}$	$3.20 \cdot 10^{-03}$	$5.61 \cdot 10^{-04}$	µSv a^{-1}
Sum of dose rates	$E_{public(Cs-137)}$	9.97	6.24	µSv a^{-1}
Maximum concentration of Cs-137 in seawater	$\boldsymbol{C_{w(Cs-137)}}$	**47.2**		**Bq m^{-3}**

The activity concentration in seawater of **47.2 Bq m^{-3}** is used for further calculations for the external exposure to herring and the flatfish group from Cs-137 in seawater.

To verify the effectiveness of fish protection, the doses of internal and external exposure arising from the new threshold concentrations were calculated. These need to be equal to or smaller than the lowest value of the DCRL, which is 40 µGy h^{-1} (ICRP, 2008).

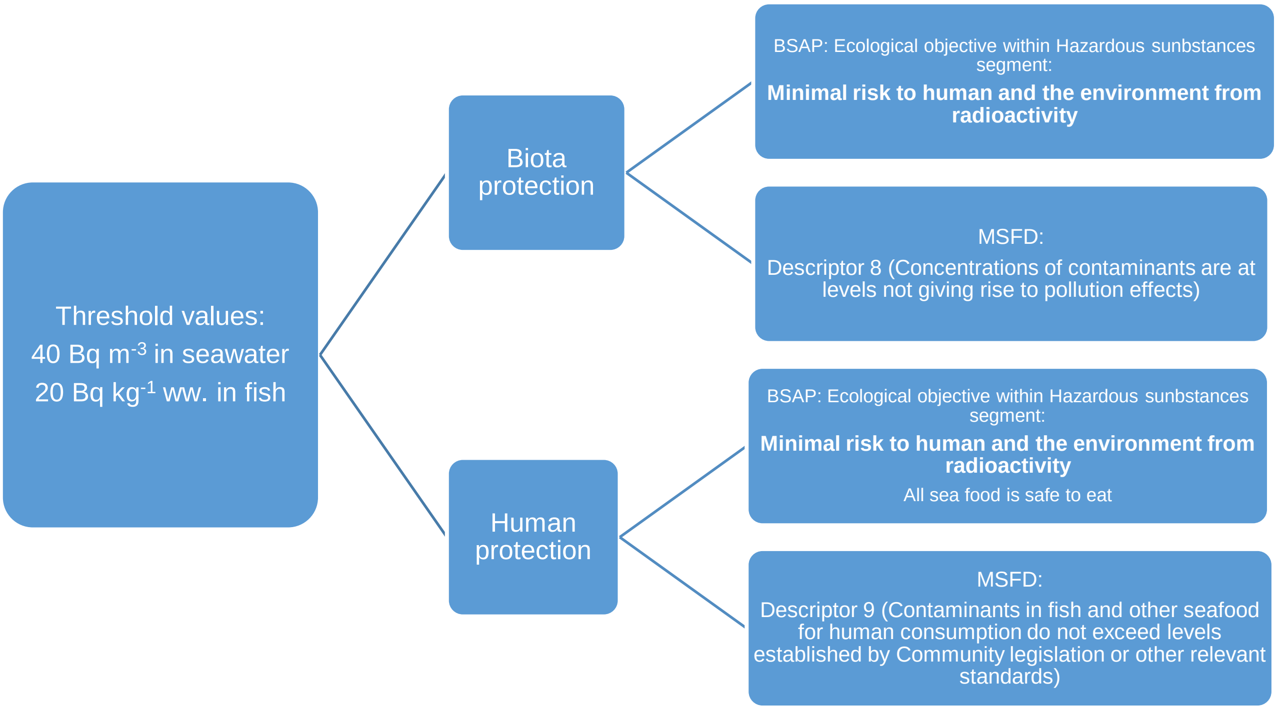
Internal and external dose rates from Cs-137 to biota were calculated using equations in the Appendix (14-18). These result in the following external dose rates: 1.42 10^{-05} µGy h^{-1} to flatfish and 1.32 10^{-05} µGy h^{-1} to herring. The internal dose rates were 8.02 10^{-07} µGy h^{-1} to flatfish and 8.50 10^{-07} µGy h^{-1} to herring. The total dose rates were calculated as the sum of internal and external ones:

Total dose to flatfish: $4.81 \cdot 10^{-3} + 1.42 \cdot 10^{-05}$ **= $4.82 \cdot 10^{-3}$ µGy h^{-1}**

Total dose to herring: $5.09 \cdot 10^{-3} + 1.32 \cdot 10^{-05}$ **= $5.10 \cdot 10^{-3}$ µGy h^{-1}**

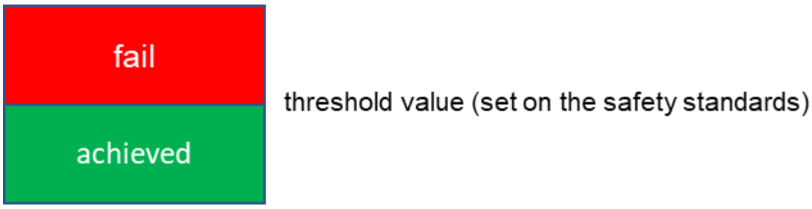
The total doses to flatfish and herring are far below the value of the DCRL, which is 40 µGy h^{-1}. That means that the proposed threshold values for fish and seawater meet the requirements for protecting fish in the Baltic Sea environment.

Finally, taking into account the precautionary principle and using values rounded down to the lower ten, the new threshold values for the protection of humans and the environment are proposed: 40 Bq m^{-3} for seawater, and 20 Bq kg^{-1} w.w. for fish, which at the same time meet the requirements specified by BSAP and MSFD:

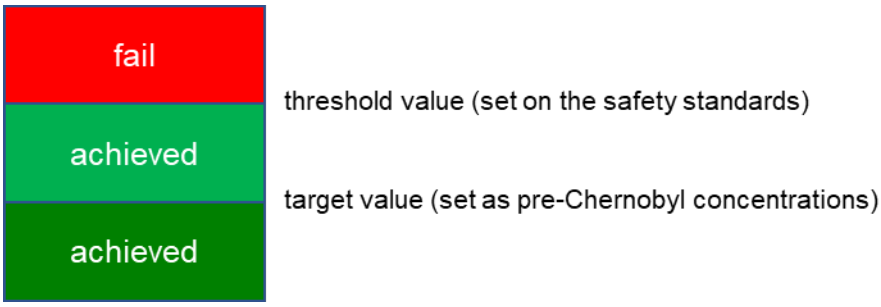


7. Environmental Status Assessment

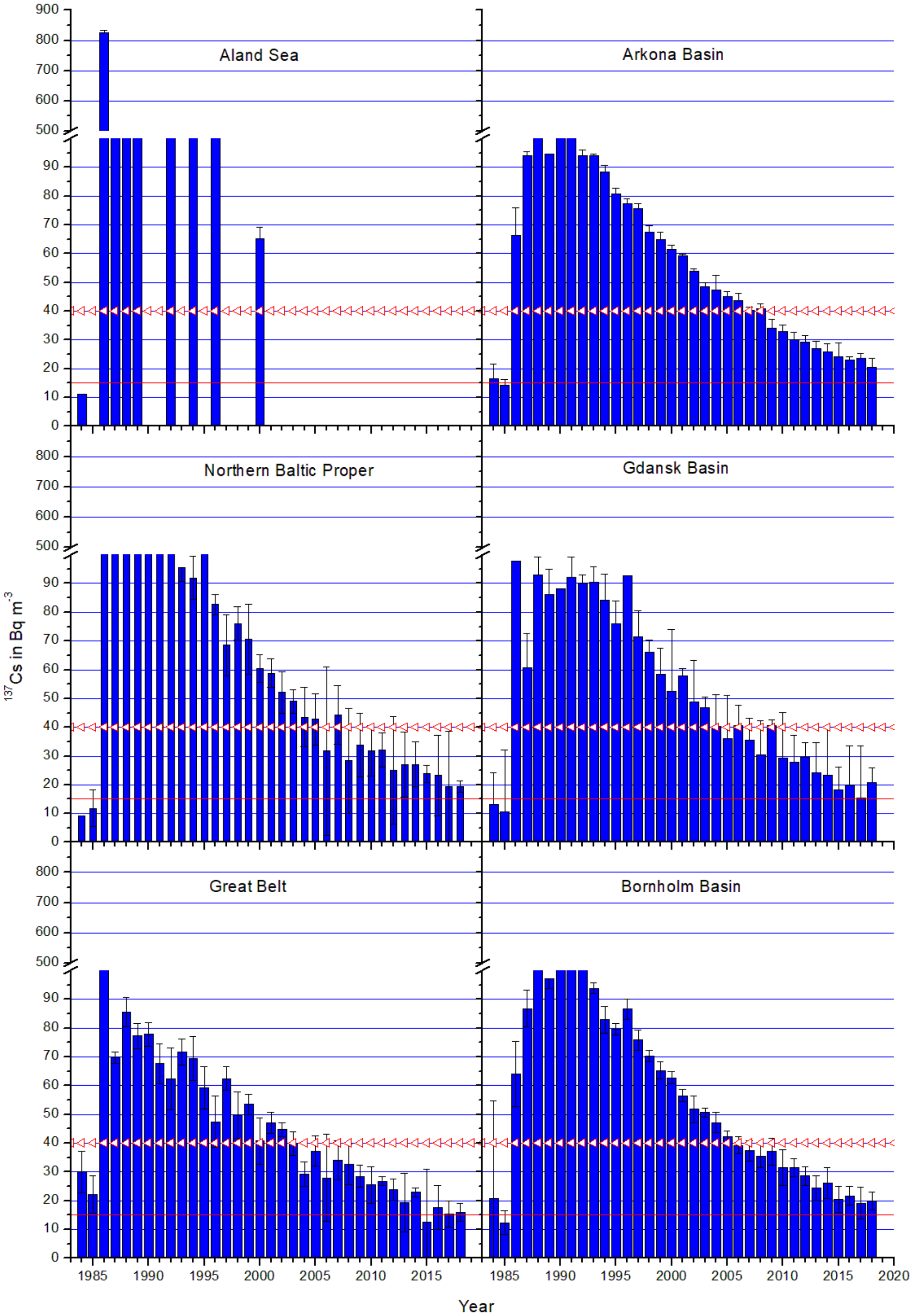
Good environmental status within Descriptor 8 is achieved when the activity concentration of the radionuclide Cs-137 is below 20 Bq kg^{-1}w.w. in fish and 40 Bq m^{-3} in seawater. Good environmental status within Descriptor 9 is achieved when the activity concentration of the radionuclide Cs-137 is below 20 Bq kg^{-1} w.w. in fish.



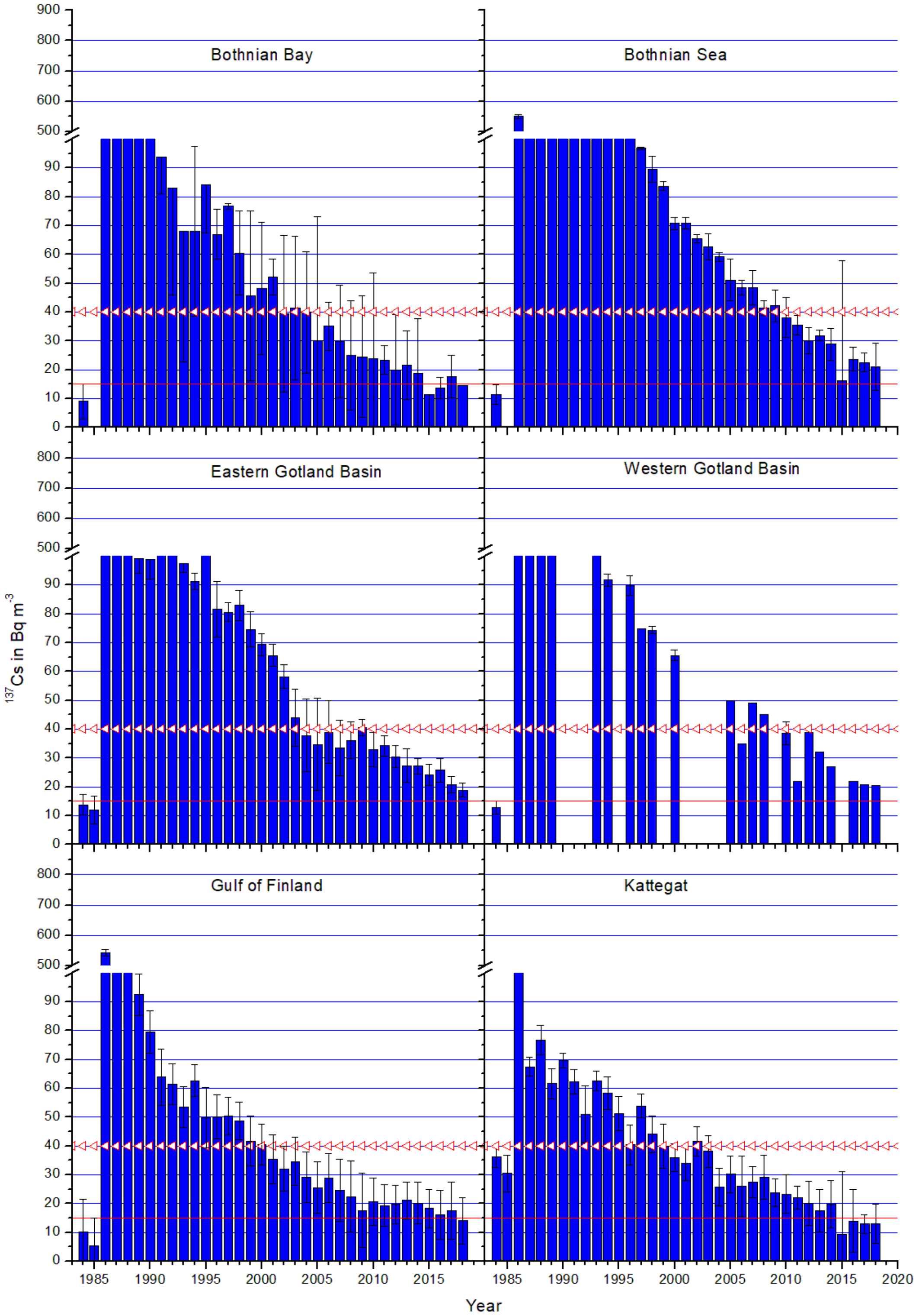
Considering the significant contamination with radioactive isotopes, including Cs-137, which mainly occurred due to the Chernobyl accident, the most desirable situation from the point of view of the environmental status of the Baltic Sea would be to achieve pre-Chernobyl concentrations. Therefore, target values have also been set. The activity concentrations of the radionuclide Cs-137 set as target values for fish are 2.5 Bq kg^{-1} w.w. for herring, 2.9 Bq kg^{-1} w.w. for flatfish, and 15 Bq m^{-3} for seawater. The quantitative boundaries used for defining the target values correspond to pre-Chernobyl activity concentration levels, the levels before 1986.



The monitoring data of Cs-137 from 1984 – 2018 in fish and seawater were compared to the proposed threshold values and target values (Fig. 1 and Fig. 2). It is obvious that the new threshold values will also be exceeded after increased inputs like those of the Chernobyl accident in the affected Baltic Sea subbasins at least for seawater and herring. For the flatfish group, the effect is smaller as their area of distribution is limited to the more westerly subbasin, which were only slightly affected by the Chernobyl input. Furthermore, the recent environmental status of the Baltic Sea in terms of contamination with the Cs-137 isotope can be considered as good in all areas, which confirms the information that there are no threats to fish and people.



Aland Sea
Arkona Basin
Northern Baltic Proper
Gdansk Basin
Great Belt
Bornholm Basin
^{137}Cs in Bq m^{-3}
Year


Bothnian Bay
Bothnian Sea
Eastern Gotland Basin
Western Gotland Basin
Gulf of Finland
Kattegat
^{137}Cs in Bq m^{-3}
Year
900
800
700
600
500
90
80
70
60
50
40
30
20
10
0
1985
1990
1995
2000
2005
2010
2015
2020

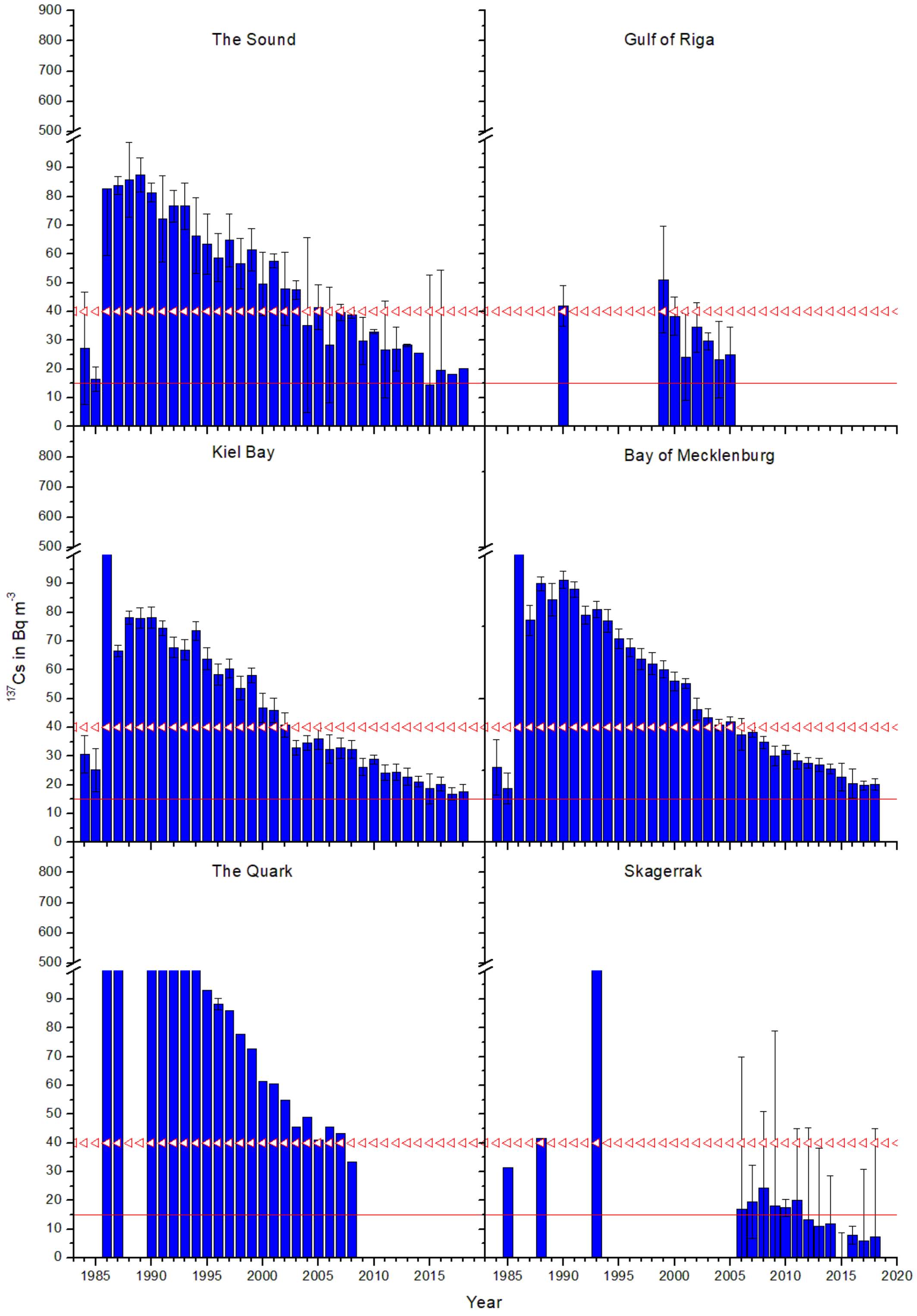
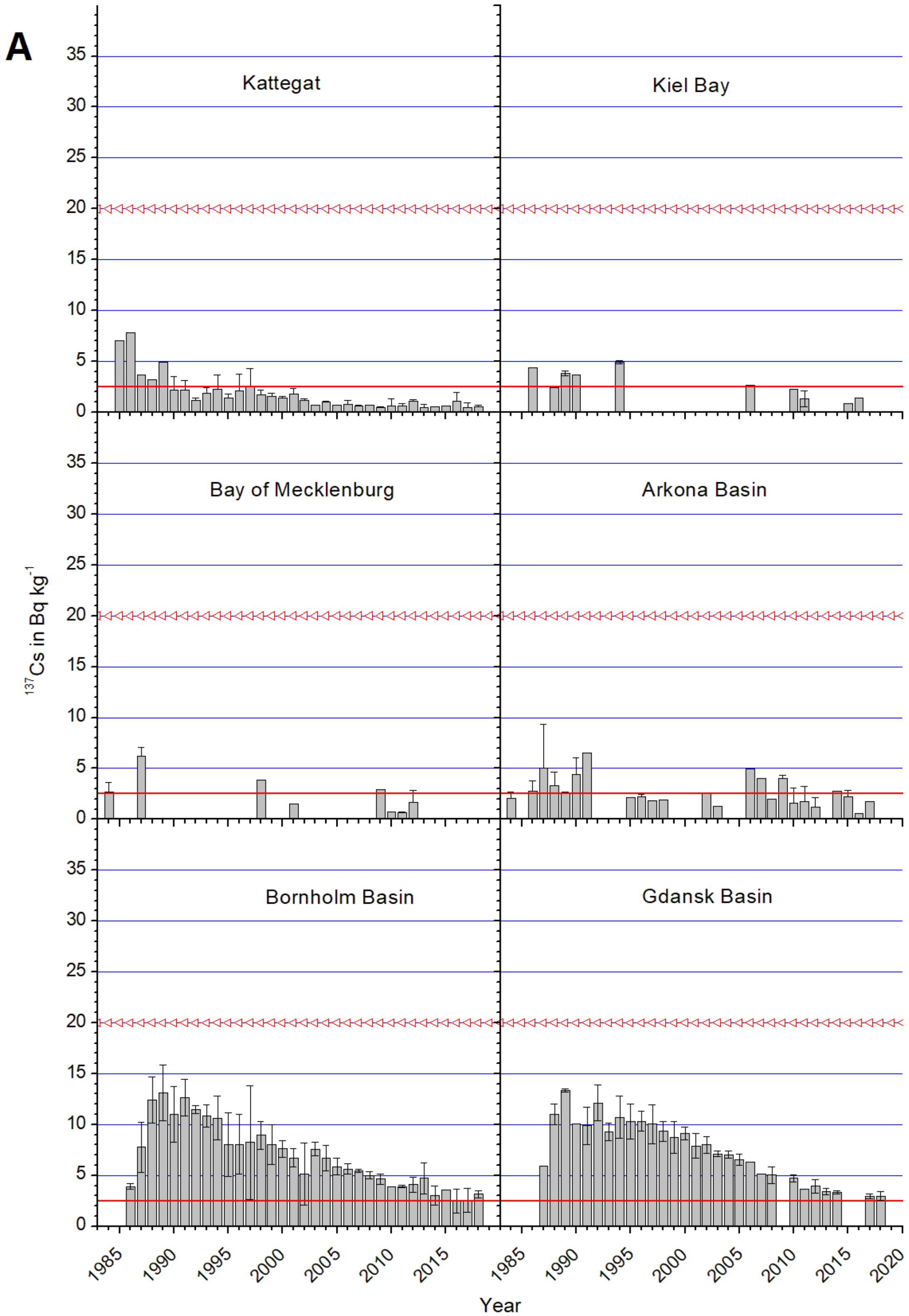
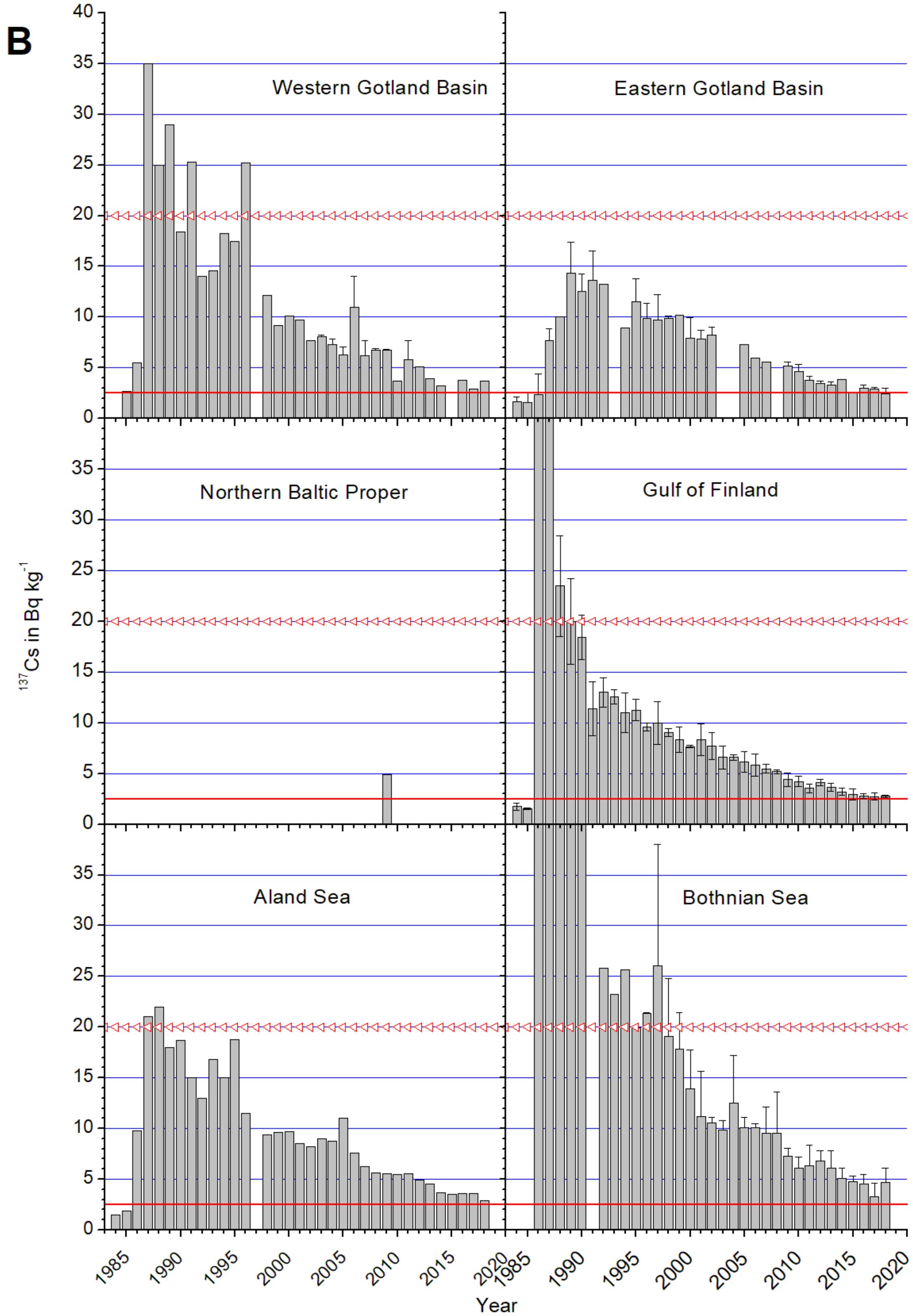


Figure 1: Concentration of Cs-137 (in Bq m^{-3}) in seawater (sampling depth less than 10 m) in 1984 to 2018, as annual mean values by subbasin. Red line indicates the target value (15 Bq m^{-3}) calculated as average of pre-Chernobyl (1984/1985) concentrations, open red triangles represent the proposed threshold value (40 Bq m^{-3}) calculated from the exemption criterion to humans.


A
Kattegat
Kiel Bay
Bay of Mecklenburg
Arkona Basin
Bornholm Basin
Gdansk Basin
137Cs in Bq kg-1
Year
0
5
10
15
20
25
30
35
1985
1990
1995
2000
2005
2010
2015
2020


B
Western Gotland Basin
Eastern Gotland Basin
Northern Baltic Proper
Gulf of Finland
Aland Sea
Bothnian Sea
137Cs in Bq kg-1
Year
0
5
10
15
20
25
30
35
40
1985
1990
1995
2000
2005
2010
2015
2020

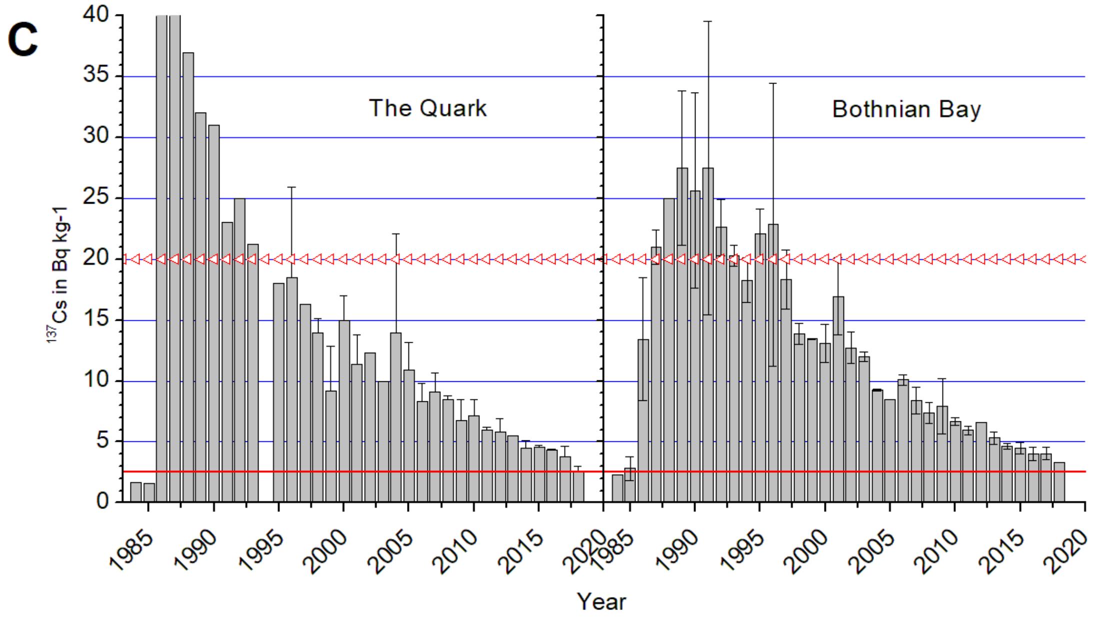


Figure 2: Annual average specific Cs-137 activity (Bq kg^{-1} wet weight) in herring (flesh without bones and whole fish without head and entrails) in 1984-2015 in the more westerly (A) and more easterly (B and C) subbasins of the Baltic Sea) in the period 1984-2018. Red line indicates the target value (2.5 Bq kg^{-1} wet weight) calculated as average of pre-Chernobyl (1984 1985) concentrations, while the open red triangles represent the proposed threshold value of 20 Bq kg^{-1} w.w. based on the exemption criterion of 10 µSv a^{-1} to humans from consumption of fish.

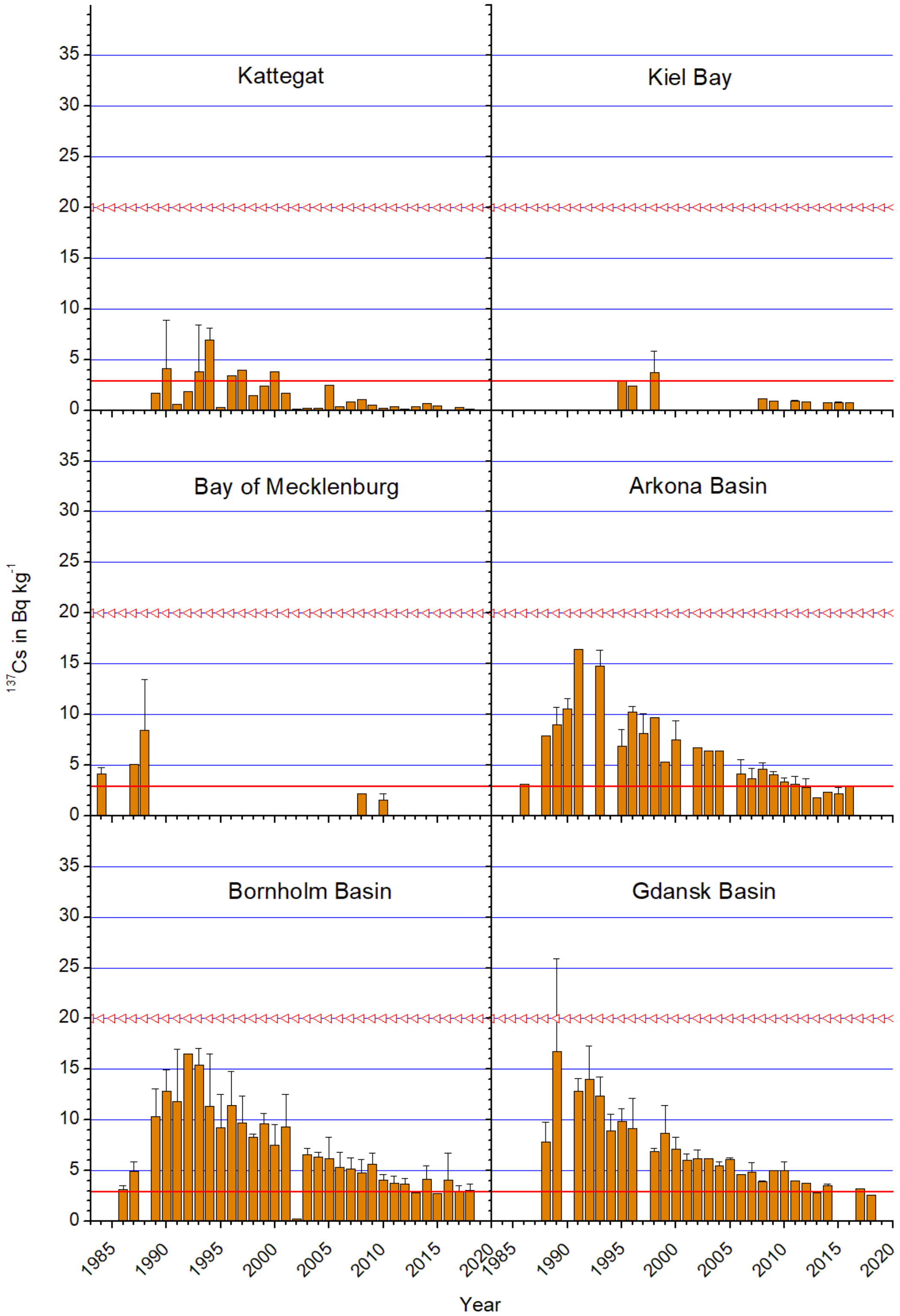


Figure 3: Annual average specific Cs-137 activities (Bq kg^{-1} wet weight) in plaice and flounder (flesh without bones/fillets/ muscle) in 1984-2018. The target value (red line, 2.9 Bq kg^{-1} wet weight) has been calculated as average of the specific pre-Chernobyl (1984-1985) activities, while the open red triangles represent the proposed threshold value of 20 Bq kg^{-1} w.w. based on the exemption criterion of 10 µSv a^{-1} to humans from consumption of fish.

References:

European Commission (EC, 2018): Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). Available Online at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0056&from=EN [last verified: 14.06.2021]

European Commission (EC, 2013): Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom. Available Online at: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32013L0059 [last verified: 15.05.2020]

Guillen J., Natale F., Carvalho N., Casey J., Hofherr J., Druon J.-N., Fiore G., Gibin M., Zanzi A., Martinsohn J.Th. (2019): Global seafood consumption footprint. Ambio 48/2, 111-122

International Atomic Energy Agency (IAEA, 2001) – Safety Report Series No. 19: Generic models for use in assessing the impact of discharges of radioactive substances to the environment. — Vienna: International Atomic Energy Agency, 2001. 229 pp., ISSN 1020–6450, ISBN 92-0-100501-6

International Atomic Energy Agency (IAEA, 2004) – TECDOC 422: Sediment distribution coefficients and concentration factors for biota in the marine environment. — Vienna: International Atomic Energy Agency, 2004. 103 pp., ISSN 0074–1914, ISBN 92-0-114403-2

International Atomic Energy Agency (IAEA, 2014) - General Safety Requirements (GSR) Part 3: Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, Vienna: International Atomic Energy Agency, 2014, 471pp. ISBN 978–92–0–135310–8

International Atomic Energy Agency (IAEA, 2015) - TECDOC 1759: Determining the suitability of materials for disposal at sea under the London Convention 1972 and London Protocol 1996: a radiological assessment procedure. — Vienna: International Atomic Energy Agency, 2015. 100 pp., ISBN 978–92–0–100215–0

International Commission on Radiological Protection (ICRP, 2012) – Publication 119: Compendium of Dose Coefficients based on ICRP Publication 60. Annals of the ICRP 41 supplement 1. 132 pp. ISBN 978-1-4557-5430-4

Appendix:

Table 4: Generic values for parameters used in the calculation of activity concentrations in environmental matrices (seawater, sediment, fish) according to IAEA (2015):

Parameter	symbol	value	unit
sediment distribution	$K_{d(Cs\text{-}137)}$	4	$m^3\ kg^{-1}$
external dose coefficient for surface deposition of Cs-137	$DC_{gr(Cs\text{-}137)}$	$2.20 \cdot 10^{-12}$	$Sv\ m^2\ h^{-1}\ Bq^{-1}$
sea spray concentration in air	C_{spray}	$1.00 \cdot 10^{-02}$	$kg\ m^{-3}$
dust loading on shore	DL_{shore}	$2.50 \cdot 10^{-10}$	$kg\ m^{-3}$
bulk density beach sediment	ρ_S	$1.50 \cdot 10^{03}$	$kg\ m^{-3}$
effective beach sediment thickness	d_S	0.1	m
density of seawater	ρ_w	1000	$kg\ m^{-3}$

Table 5: Generic values of parameters used in the calculation of individual doses according to IAEA (2015):

Parameter	symbol	value		unit
		adult	infant	
annual time spent at shore	t_{public}	$1.60 \cdot 10^{03}$	$1.00 \cdot 10^{03}$	$h\ a^{-1}$
breathing rate	$R_{inh,public}$	0.92	0.22	$m^3\ h^{-1}$
ingestion rate of sediment on the beach	H_{shore}	$5.00 \cdot 10^{-06}$	$5.00 \cdot 10^{-05}$	$kg\ h^{-1}$
internal dose coefficient from ingestion of sediment	DC_{ing}	$1.30 \cdot 10^{-08}$	$1.20 \cdot 10^{-08}$	$Sv\ Bq^{-1}$
internal dose coefficient from inhalation of sea spray	DC_{inh}	$4.6 \cdot 10^{-09}$	$5.4 \cdot 10^{-09}$	$Sv\ Bq^{-1}$

Table 6: Dose conversion factors used for dose estimation to marine fish according to ICRP 136 (2012):

	symbol	value		unit
		herring (RAP trout)	flatfish	
dose conversion factor for external Cs-137 exposure of marine reference organism j	$DCF_{ext(j,Cs-137)}$	$2.80 \cdot 10^{-04}$	$3.00 \cdot 10^{-04}$	$\mu Gy\ kg\ Bq^{-1}\ h^{-1}$
dose conversion factor for external Cs-137 exposure of marine reference organism j	$DCF_{int(j,Cs-137)}$	$1.80 \cdot 10^{-04}$	$1.70 \cdot 10^{-04}$	$\mu Gy\ kg\ Bq^{-1}\ h^{-1}$

Equations and examples for the calculation of dose rates:

The specific activity $A_{Cs\text{-}137,fish}$ from consumption of fish at a dose rate $E_{ing,food,public}$ of 10 µSv a^{-1} were calculated by equation (1):

$$A_{Cs-137,fish} = \frac{E_{ing,food,public}}{DC_{ing} \cdot H_B} \quad (1)$$

For the maximum annual fish consumption, this means:

$$A_{Cs-137,fish} = \frac{10}{1.30 \cdot\ 10^{-08}\ \cdot 27.2 \cdot 1000000} \frac{\mu Sv \cdot\ Bq \cdot Sv}{Sv\ \ \cdot kg \cdot \mu Sv} = 28.3\ \frac{Bq}{kg} \quad (2)$$

The resulting internal dose rate for fish results in:

$$E_{int(Cs-137)} = A_{Cs-137,fish} \cdot DC_{int(Cs-137,fish)} \quad (3)$$

$$E_{int(Cs-137)} = 103.95 \cdot 1.80 \cdot\ 10^{-04}\ \frac{Bq}{kg} \cdot \frac{\mu Gy \cdot kg}{h \cdot Bq} = 1.87 \cdot\ 10^{-02} \frac{\mu Gy}{h} \quad (4)$$

or 163.91 µg a^{-1}.

For an estimation of a maximum seawater concentration, dose rates from exposure situations to humans at the shore were estimated according to IAEA (2015) by dose rates from external exposure to Cs-137 deposited at the coast, from ingestion of beach sediment and inhalation of sea spray as well as beach sediment:

$$E_{public(Cs-137)} = E_{ext,public(Cs-137)} + E_{ing\ shore,public(Cs-137)} + E_{inh\ shore,public(Cs-137)} + E_{inh\ spray,public(Cs-137)} \quad (5)$$

or, using the criterion of an annual dose rate of 10 µSv a^{-1}:

$$10\ \mu Sv\ a^{-1} = E_{ext,public(Cs-137)} + E_{ing\ shore,public(Cs-137)} + E_{inh\ shore,public(Cs-137)} + E_{inh\ shore,public(Cs-137)}$$

Dose rates from external Cs-137 exposure deposited at the shore are calculated from the time spent at the beach ($t_{(public)}$), the seawater concentration ($C_{w(Cs-137)}$), the distribution coefficient for adsorption of Cs-137 to sediment ($K_{d(Cs-137)}$), the density of the sediment (ρ_S), and the dose coefficient for external exposure from the contaminated ground ($DC_{gr(Cs-137)}$). The factor of 10 considers the fact that beach sediments mainly consists of sand, which has a significantly lower sorption capacity compared to other texture classes.

$$E_{ext,public(Cs-137)} = t_{public} \cdot \frac{C_{w(Cs-137)} \cdot K_{d(Cs-137)} \cdot \rho_s \cdot d_s}{10} \cdot DC_{gr(Cs-137)} \quad (6)$$

This means for adults:

$$E_{ext,public(Cs-137)} = \\ = \frac{1.6 \cdot 10^{03} \cdot C_{w(Cs-137)} \cdot 4 \cdot 1.5 \cdot\ 10^{03} \cdot 0.1 \cdot 2.2 \cdot 10^{-12}}{10} \frac{h}{a} \frac{Bq}{m^3} \frac{m^3}{kg} \frac{kg}{m^3} m \frac{Sv \cdot m^2}{h \cdot Bq} \quad (7)$$

Dose rates from internal Cs-137 exposure via ingestion of contaminated beach sediments are calculated mainly from the components from equation (6), but the properties of the beach sediment layer are replaced by the ingestion rate (H_{shore}) and the specific dose coefficient for ingestion ($DC_{ing(Cs\text{-}137)}$).

$$E_{ing,shore\ public(Cs-137)} = t_{public} \cdot H_{shore}\ \frac{C_{w(Cs-137)} \cdot K_{d(Cs-137)}}{10} \cdot DC_{ing(Cs-137)} \tag{8}$$

This means for adults:

$$E_{ing,shore\ public(Cs-137)} = \frac{1.6 \cdot 10^{03} \cdot 5 \cdot 10^{-06} \cdot\ C_{w(Cs-137)} \cdot 4 \cdot 1.3 \cdot 10^{-08}}{10} \frac{h}{a}\frac{kg}{h}\frac{Bq}{m^3}\frac{m^3}{kg}\frac{Sv}{Bq} \tag{9}$$

Dose rates from internal Cs-137 exposure after inhalation of contaminated beach sediments are calculated from adsorbed Cs-137 from seawater to sediment particles ($C_{w(Cs\text{-}137)}$ * $K_{d(Cs\text{-}137)}$), this time not divided by 10 as only texture components with high sorption capacity are able to fly. Furthermore, the inhalation rate ($R_{inh,public}$) and the dust loading at the shore are to be considered:

$$E_{inh,shore\ public(Cs-137)} = t_{public} \cdot R_{inh,public}\ \cdot DL_{shore}\ \cdot C_{w(Cs-137)} \cdot K_{d(Cs-137)} \cdot \\ \cdot DC_{inh(Cs-137)} \tag{10}$$

This means for adults:

$$E_{ing,shore\ public(Cs-137)} = 1.6 \cdot\ 10^{03} \cdot 0.92\ \ \cdot 2.50 \cdot\ 10^{-10} \cdot\ C_{w(Cs-137)} \cdot 4 \cdot \\ \cdot\ 4.6 \cdot\ 10^{-09}\ \frac{h}{a}\frac{m^3}{h}\frac{kg}{m^3}\frac{Bq}{m^3}\frac{m^3}{kg}\frac{Sv}{Bq} \tag{11}$$

Doses rate from internal Cs-137 exposure after inhalation of contaminated sea spray:

$$E_{inh,shore\ public(Cs-137)} = t_{public} \cdot R_{inh,public}\ \cdot \frac{c_{spray}}{\rho_w} \cdot C_{w(Cs-137)} \cdot DC_{inh(Cs-137)} \tag{12}$$

This means for adults:

$$E_{ing,shore\ public(Cs-137)} = 1.6 \cdot\ 10^{03} \cdot 0.92\ \ \cdot \frac{1.00\ 10^{-02}}{1000} \cdot\ C_{w(Cs-137)} \cdot \\ \cdot\ 4.6 \cdot\ 10^{-09}\ \frac{h}{a}\frac{m^3}{h}\frac{kg}{m^3}\frac{m^3}{kg}\frac{Bq}{m^3}\frac{Sv}{Bq} \tag{13}$$

The seawater concentration of Cs-137, $C_{w(Cs\text{-}137)}$, was obtained by using the goal seek function in Microsoft Excel. For adults, the criterion converged at a $C_{w(Cs\text{-}137)}$ of 47.2 Bq m^{-3}. At this concentration, infants are also protected as the sum of dose rates results in 6.24 µSv a^{-1}.

The dose rates to species j are calculated from an external and an internal component of dose rates. The external dose rate consists of the concentration in seawater $C_{w(Cs-137)}$ and the respective dose coefficient $DCF_{ext(j,Cs-137)}$:

$$E_{ext(j,w,Cs-137)} = C_{w(Cs-137)} \cdot DCF_{ext(j,Cs-137)} \tag{14}$$

For flatfish, the external dose rate from seawater calculates to:

$$E_{ext(j,w,Cs-137)} = \frac{47.2}{1000} * 3.00 \cdot 10^{-04} \frac{Bq}{m^3}\frac{m^3}{kg}\frac{\mu Gy\ kg}{Bq\ h} = \ 1.42 \cdot 10^{-05}\ \frac{\mu Gy}{h} \tag{15}$$

The same concept is used for the calculation of the internal dose rate:

$$E_{int(j,Cs-137)} = a_{f(Cs-137)} \cdot DC_{int(j,Cs-137)} \tag{16}$$

If the specific activity of Cs-137 in fish $A_{Cs-137,fish}$ is not available, it also can be estimated from the seawater concentration $C_{w(Cs-137)}$ and the concentration factor $CF_{Cs\text{-}137}$:

$$A_{Cs-137,fish} = \ C_{w(Cs-137)} \ \cdot CF_{Cs-137} \tag{17}$$

If a site and species-dependent concentration factor is not available, the generic $CF_{Cs\text{-}137}$ as a dimensionless factor of 100 (IAEA, 2004) may be used.

This means for the flatfish group:

$$E_{int(flatfish,Cs-137)} = \frac{47.2}{1000} \cdot 100 \cdot 1.70 \cdot 10^{-04} \frac{Bq}{m^3}\frac{m^3}{kg}\frac{\mu Gy\ kg}{Bq\ h} = \ 1.42 \cdot 10^{-05}\ \frac{\mu Gy}{h} \tag{18}$$

As a consequence, biota are also protected as the external dose rate to the flatfish group results in $1.42 \cdot 10^{-05}$ µGy h^{-1}, and to herring in $1.32 \cdot 10^{-05}$ µGy h^{-1}, and the internal dose rate to the flatfish group results in $8.02 \cdot 10^{-07}$ µGy h^{-1}.