Document title	**Proposal for a methodology for the calculation of Cs-137 threshold values in seawater and fish of the Baltic Sea**
Code	6-1
Category	DEC
Agenda Item	6 – Indicator reports, fact sheets and assessments
Submission date	5.5.2021
Submitted by	MORS EG and IAEA
Reference	

Background

During the 9th Meeting of HELCOM MORS EG and as agreed in HELCOM 41-2020 (Outcome, Annex 3 "Agreement on HELCOM objectives for the updated BSAP"), the need to redefine current threshold values for Caesium-137 in fish and seawater which were based on the old BSAP objective "Radioactivity at pre-Chernobyl level" is stated. During the Extra Meeting HELCOM MORS EG 10BA-2020, it was decided to use 10 µSv from Caesium-137 to humans from consumption of fish or contact to seawater as annual dose rate limit for the Baltic Sea and Caesium-137.

The following document provides the scientific basis for the selection of a proper protection target to be used for further assessments by presentation of threshold candidates calculated for the different dose criteria used in the approach of OSPAR (2016) for the North East Atlantic.

Action

The Meeting is invited to

- discuss on the proposal for methodology for deriving threshold values,
- agree on the selected threshold value candidates to be used as core indicators for radioactive substances.

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

Introduction

Due to the accident of the Chernobyl power plant, significant amounts of radioactive isotopes were released into the Baltic Sea, making this waterbody one of the most contaminated, also due to the limited water exchange with the North Sea. The isotope of which the greatest amounts got into the waters of the Baltic Sea, thus shaping the level of anthropogenic radioactivity to this day, was caesium-137 (Cs-137) which is characterised by a relatively long half-life (30,05 y). This was the reason for selecting this isotope as an indicator for assessing the status of the Baltic marine environment. Its concentrations in seawater and fish reflect the most dynamic changes in the environment. 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 muscle of plaice and flounder (HELCOM, 2007), were originally selected as target values for activity concentrations and specific activities in the direct aftermath of the Chernobyl accident as no dose criteria for the environment and only a limited number of measured values were available for the Baltic Sea at that time. 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, 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 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 should be based on safety standards and refer to human safety related to fish consumption. In this way, the new ecological objective may also meet the requirements of the Marine Strategy Framework Directive assessments in terms of both Descriptor 8 (Concentrations of contaminants are at levels not giving rise to pollution effects) and 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 IAEA took steps to set new threshold values, taking into account the new BSAP ecological goal.

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 and the potential threats to marine organisms, it has been proposed:

1. Determination of threshold values for the protection of humans from exposure due to the consumption of selected fish species (based directly on safety standards)
2. Determination of 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. The key and required element is the 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 for shaping the levels of radioactivity in the Baltic Sea.

3. Definition of sub-regions of interest

The determined threshold values are valid in 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 the 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 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 ICRP for radiation protection of individual species in the environment (ICRP 2008). For this purpose, the ICRP reference animals and plant (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 characterized by ellipsoids, according to first dose models for humans. Finally, dose thresholds and dose conversion factors for radionuclides are calculated for the RAPs. In detail, the RAP “trout” is used for 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 the IAEA recommendation, two values of radiological reference criteria for human are considered within the process:

- the established annual dose limit (1 mSv) for members of the public in planned exposure situations
- the individual annual dose level (of the order of 10 µSv) used to grant exemption to activities and facilities

The present calculations adopted the more restrictive approach and used the annual threshold dose of 10 µSv from artificial radionuclides, which is an effective dose to members of the public for calculations, but a maximum of 100 Bq kg^{-1} for Cs-137 (EC Basic Safety Standards, 2013).

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 area of the Baltic Sea. These are on the one hand external exposure to radionuclides deposited on the shore, inadvertent ingestion of beach sediments, inhalation of particles resuspended from beach sediments, and inhalation of sea spray and on the other hand ingestion of seafood.

To obtain the final threshold value, using the previously calculated specific activity in biota or the activity concentration of Cs-137 in seawater, doses to marine reference plants and animals (RAPs) 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 dose is above the DCRL for the respective RAP, the seawater initial threshold is 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 internal exposure to humans from consumption of seafood uses the dose criterion of 10 µSv per year to humans as a starting point. Using this value and data on annual fish intake, the specific activities were 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) were used as listed in the appendix. 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)

For further calculations of dose rates from consumption of fish, the activity concentration at maximum fish consumption as a most protective option (**28.3 Bq kg^{-1} w.w.**) was used. Furthermore, the internal exposure to herring and the flatfish group from Cs-137 in was calculated (Table 2) using the dose conversion factors according to ICRP 136 (see Appendix Table 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 10^{-3}	42	5.09 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). The scenarios included external exposure from contaminated sediment and internal exposure from ingestion of beach sediment and inhalation of sea spray and beach sediment. Where suitable, the generic data from IAEA (2015) were used and modifications are explained; all used values for calculation of dose rates are listed in 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 10^{-03}	1.23 10^{-02}	µSv a^{-1}
dose rate from inhalation of beach sediment	$E_{inh\ shore,public(Cs-137)}$	3.20 10^{-07}	5.61 10^{-08}	µSv a^{-1}
dose rate from inhalation of sea spray	$E_{inh\ spray,public(Cs-137)}$	3.20 10^{-03}	5.61 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}**

To verify the new threshold value candidates, the doses derived from the threshold values of internal and external exposure 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).

Inetrnal and external dose rates from Cs-137 to biota were calculated using equations (14) to (18). This results in an 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 sum of internal and external ones:

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

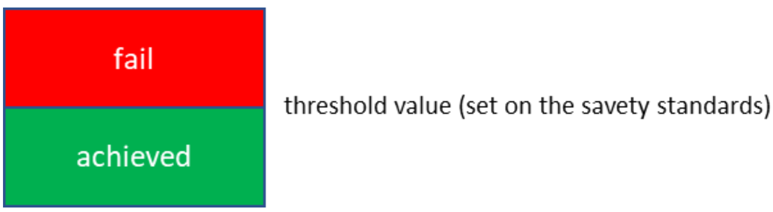
Total dose to herring: 5.09 10^{-3} + 1.32 10^{-05} **= 5.10 10^{-3} µGy h^{-1}**

The total doses to flatfish and herring 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 the protection of fish in the Baltic Sea environment.

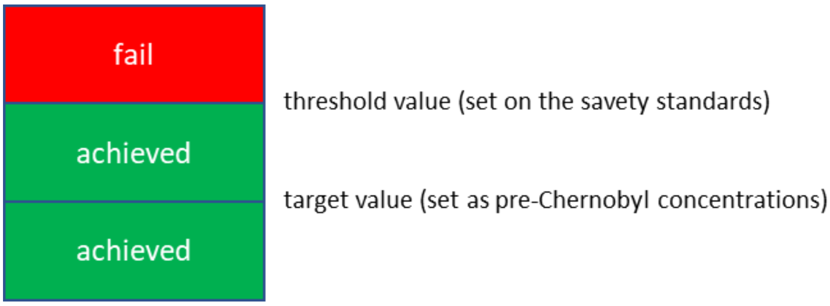
Therefore, new threshold values are 47.2 Bq m^{-3} for seawater and 28.3 Bq kg^{-1} w.w. for fish.

7. Environmental Status Assessment

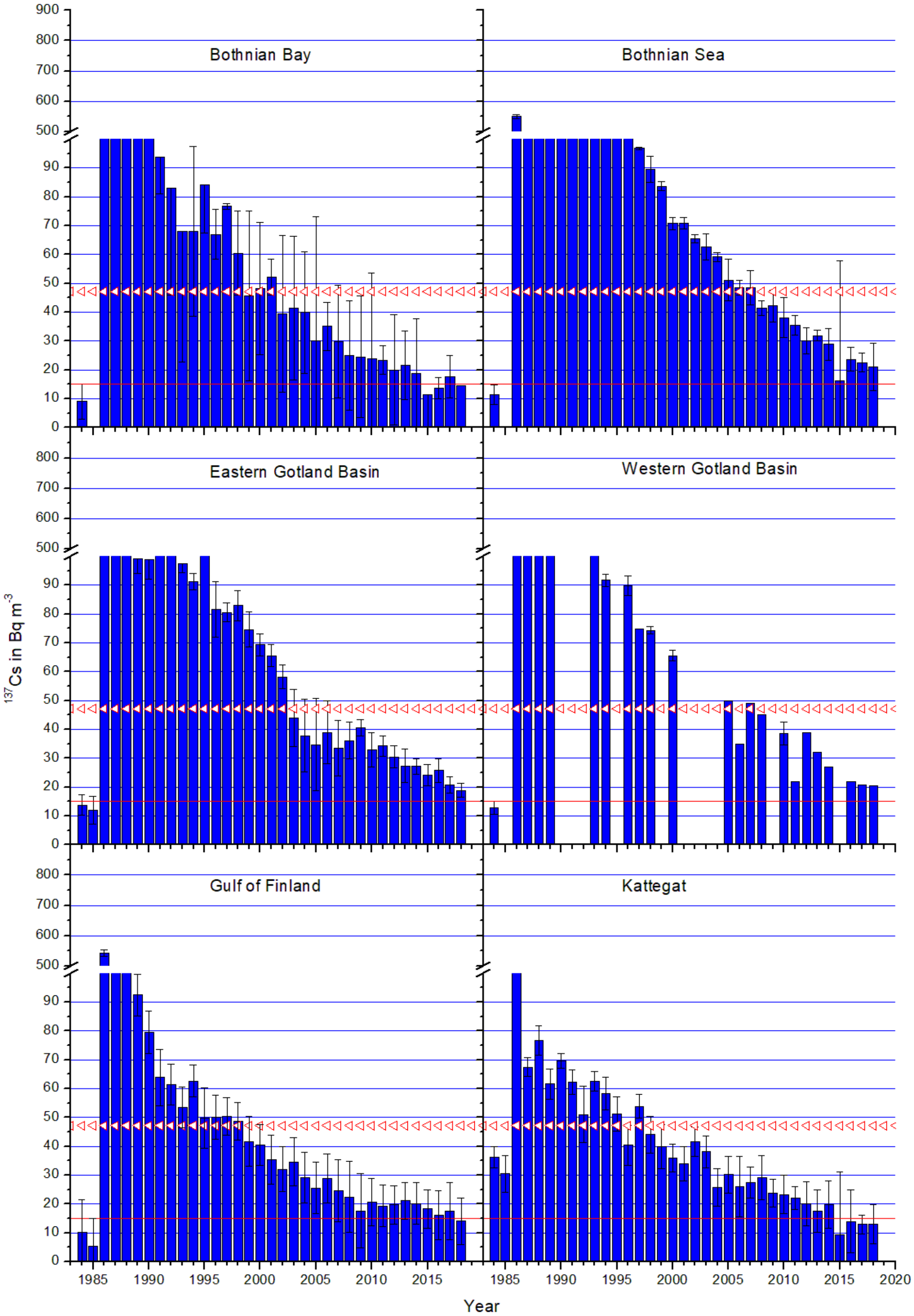
Good environmental status is achieved when the activity concentration of radionuclide Cs-137 is below 28.3 Bq kg^{-1}w.w.for fish and 47.2 Bq m^{-3} for seawater.



Considering the significant contamination with radioactive isotopes, including Cs - 137, which occurred as a result of the Chernobyl accident, the most desirable situation from the point of view of environmental status of the Baltic Sea would be to achieve pre-Chernobyl concentrations. Therefore, target values have also been set. The activity concentration of the radionuclide caesium-137 (137Cs) 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 corresponds to pre-Chernobyl activity concentration levels, in other words the levels before 1984.



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). Taking into account the new TV values, the environmental status of the Baltic Sea in terms of contamination with the Cs-137 isotope can be considered good in all areas, which confirms the information that there are no threats to fish and people.


Bothnian Bay
Bothnian Sea
Eastern Gotland Basin
Western Gotland Basin
Gulf of Finland
Kattegat
137Cs in Bq m-3
Year

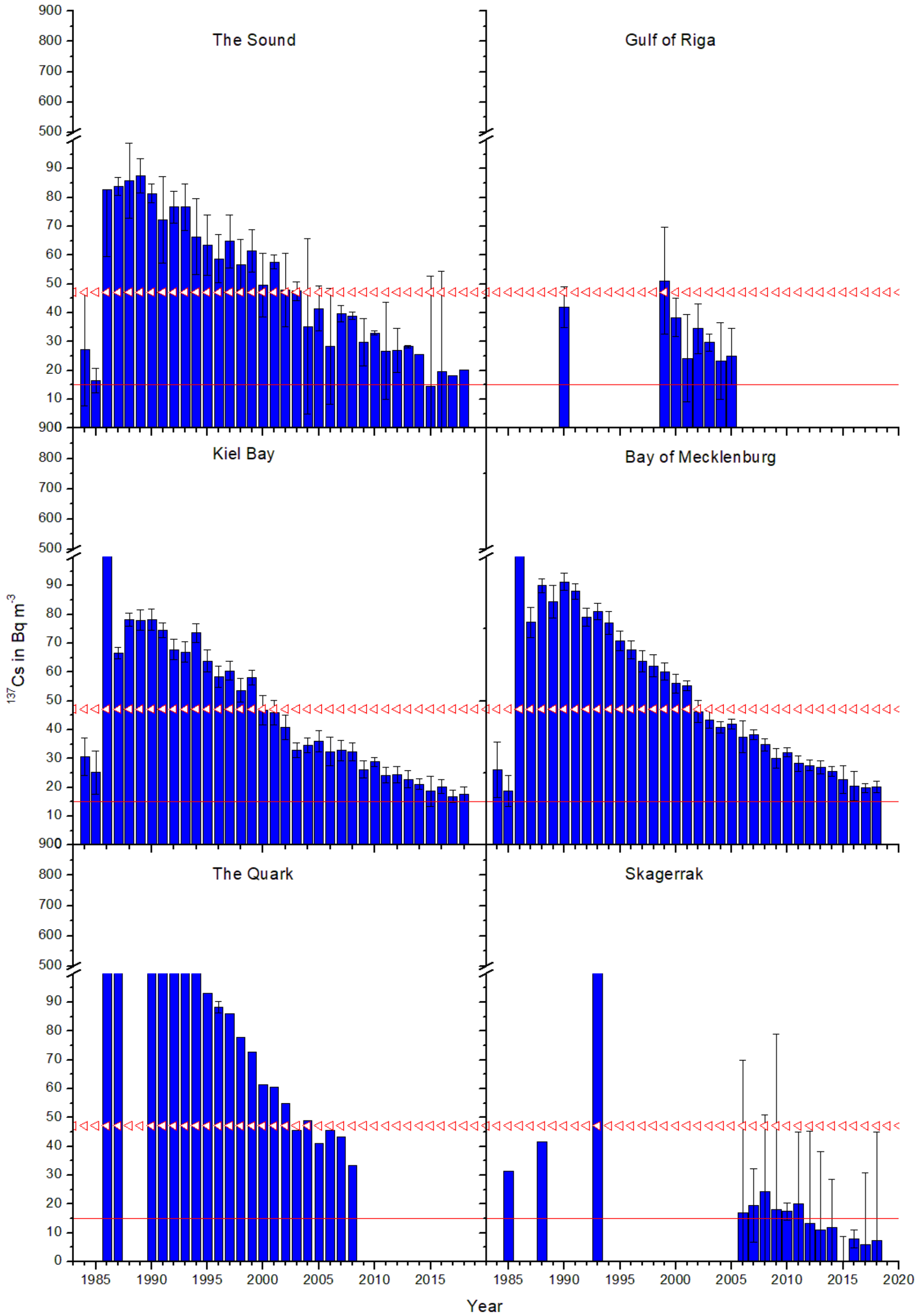
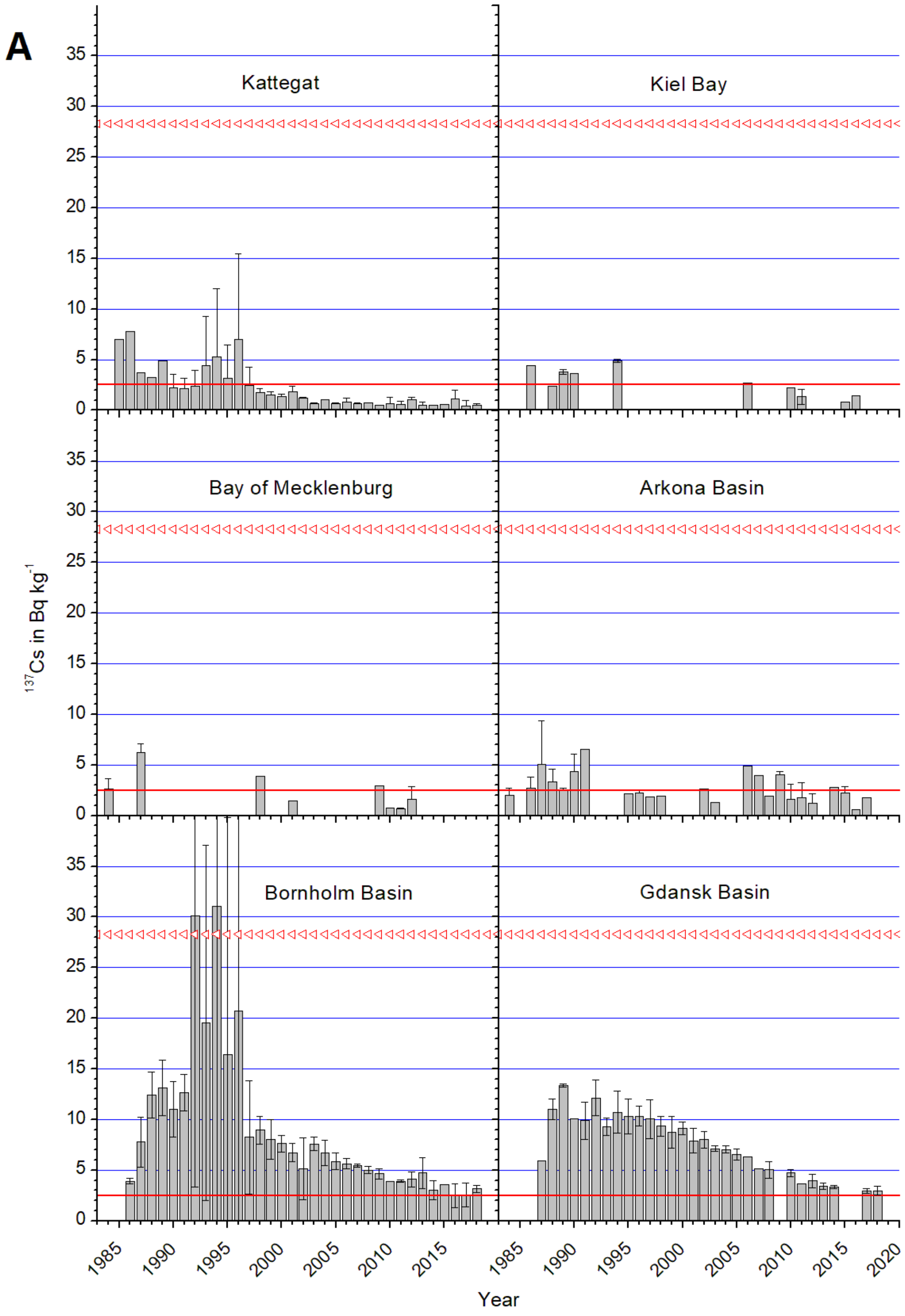
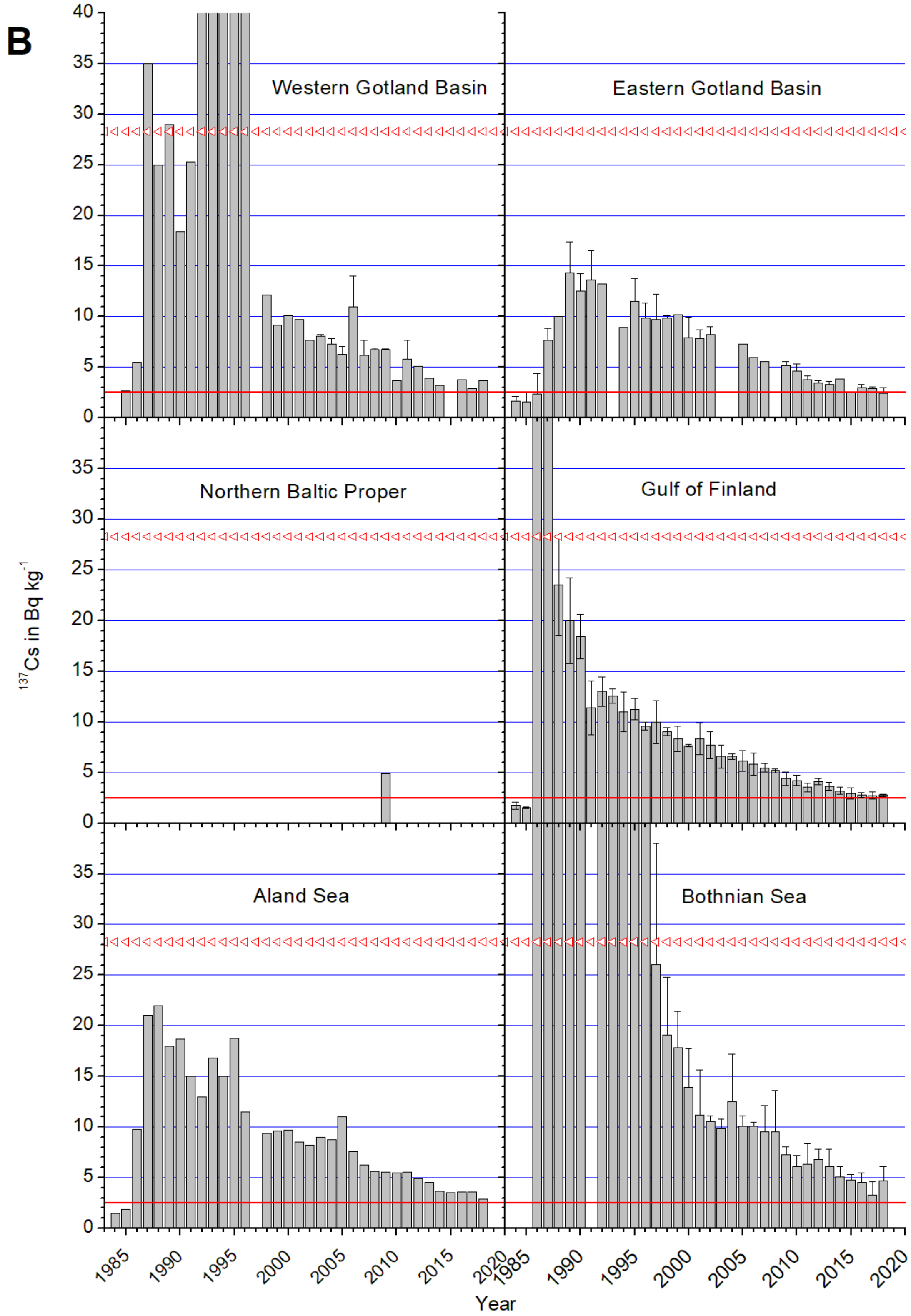


Figure 1: Concentration of Cs-137 (in Bq m^{-3}) in seawater (sampling depth less than 10 m) in 1984 to 2018, as annual mean values by sub-basin. Red line indicates the target value (15 Bq m^{-3}) calculated as average of pre-Chernobyl (1984/1985) concentrations, open red triangles represent the proposed threshold value (47.2 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

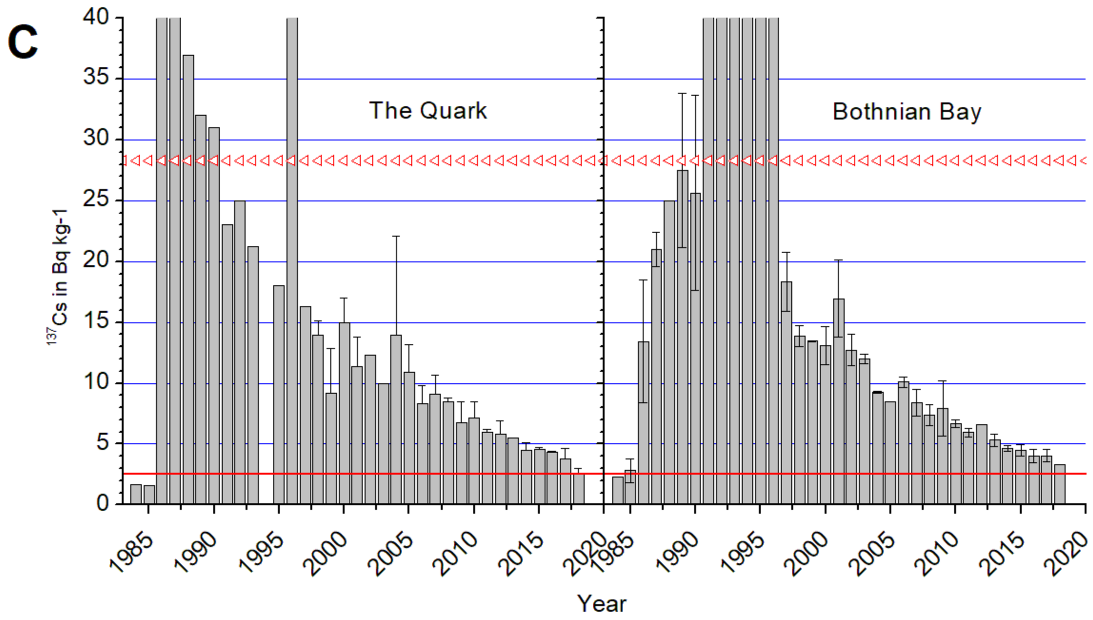


Figure 2: Annual average specific Cs-137 activity (Bq kg^{-1} wet weight) in herring (flesh without bones and whole fish without head and entrails) in 1984-2015 in the more westerly (A) and more easterly (B and C) basins of the Baltic Sea) in the period 1984-2018. Red line indicates the target value (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 28.3 Bq kg^{-1} w.w. based on the exemption criterion of 10µSv a^{-1} to humans from consumption of fish.

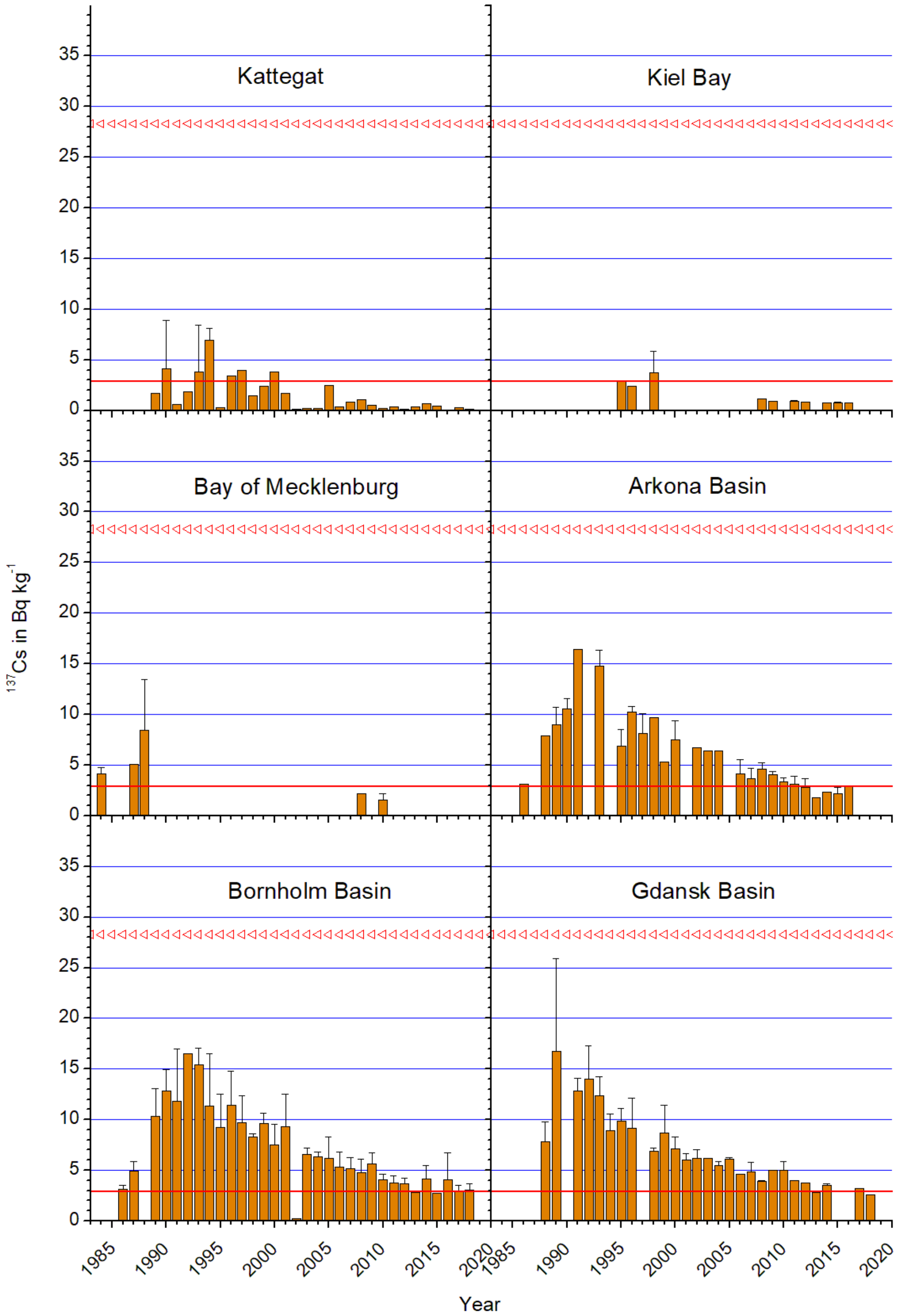


Figure 3: Annual average specific Cs-137 activities (Bq kg^{-1} wet weight) in plaice and flounder (flesh without bones/fillets/ muscle) in 1984-2018. The target value (red line, 2.9 Bq kg^{-1} wet weight) has been calculated as average of the specific pre-Chernobyl (1984-1985) activities, while the open red triangles represent the proposed threshold value of 28.3 Bq kg^{-1} w.w. based on the exemption criterion of 10µSv a^{-1} to humans from consumption of fish.

References:

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Appendix:

Table 4: Generic values for parameters used in the calclation of activity concentrations in environmental media (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	$DC_{gr(Cs\text{-}137)}$	$2.20\ 10^{-12}$	$Sv\ m^2\ h^{-1}\ Bq^{-1}$
Sea spray concentration in air	C_{spray}	$1.00\ 10^{-02}$	$kg\ m^{-3}$
dust loading on shore	DL_{shore}	$2.50\ 10^{-10}$	$kg\ m^{-3}$
bulk density beach sediment	ρ_S	$1.50\ 10^{03}$	$kg\ m^{-3}$
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}	$1.60\ 10^{03}$	$1.00\ 10^{03}$	$h\ a^{-1}$
breathing rate	$R_{inh,public}$	0.92	0.22	$m^3\ h^{-1}$
ingestion rate of sediment on the beach	H_{shore}	$5.00\ 10^{-06}$	$5.00\ 10^{-05}$	$kg\ h^{-1}$
Internal dose coefficient from ingestion of sediment	DC_{ing}	$1.30\ 10^{-08}$	$1.20\ 10^{-08}$	$Sv\ Bq^{-1}$
Internal dose coefficient from inhalation of sea spray	DC_{inh}	$4.6\ 10^{-09}$	$5.4\ 10^{-09}$	$Sv\ Bq^{-1}$

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 10^{-04}	3.00 10^{-04}	µGy 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 10^{-04}	1.70 10^{-04}	µGy 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):

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

For the maximum annual fish consumption, this means:

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

The resulting internal dose rate for fish would result in:

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

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

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 shore, from ingestion of beach sediment and from inhalation of sea spray and beach sediment:

$$\begin{aligned} E_{public(Cs-137)} = {} & E_{ext,public(Cs-137)} + E_{ing\ shore,public(Cs-137)} + E_{inh\ shore,public(Cs-137)} \\ & + E_{inh\ spray,public(Cs-137)} \end{aligned} \tag{5}$$

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 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:

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

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 ($DC_{ing(Cs-137)}$).

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

This means for adults:

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

Dose rates from internal Cs-137 exposure after inhalation of contaminated beach sediments are calculated from adsorbed Cs-137 from seawater to sediment particles ($C_{w(Cs-137)}$ * $K_{d(Cs-137)}$), 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:

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

This means for adults:

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

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:

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

The seawater concentration of Cs-137, $C_{w(Cs-137)}$, was obtained by using the goal seek function in Microsoft Excel. For adults, the criterion converged at a $C_{w(Cs-137)}$ 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 $DCF_{ext(j,Cs-137)}$:

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

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

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

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

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

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-137}:

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

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

This means for the flatfish group:

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

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