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RADIOCARBON IN SWEDISH COASTAL WATERS

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Carbon-14 often dominates the committed effective dose to the public

from globally dispersed and long-lived
radionuclides emitted from the nuclear power
industry

Legislation:

Annual effective dose
(from all radionuclides
emitted from the NPP)
to any member of the
public must not
exceed 0.1 mSv/year!



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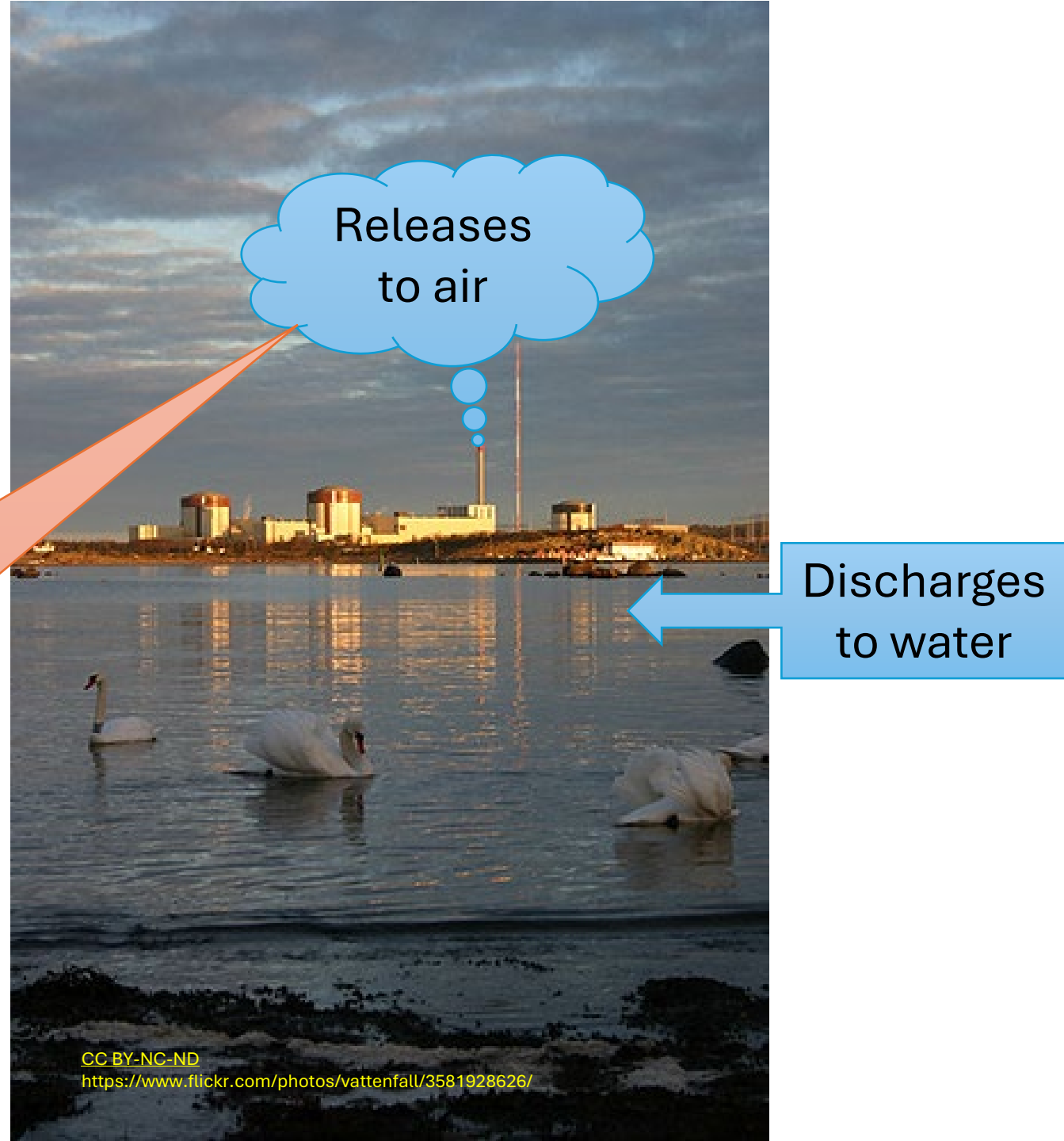
Discharges
to water

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Carbon-14 often dominates the committed effective dose to the public

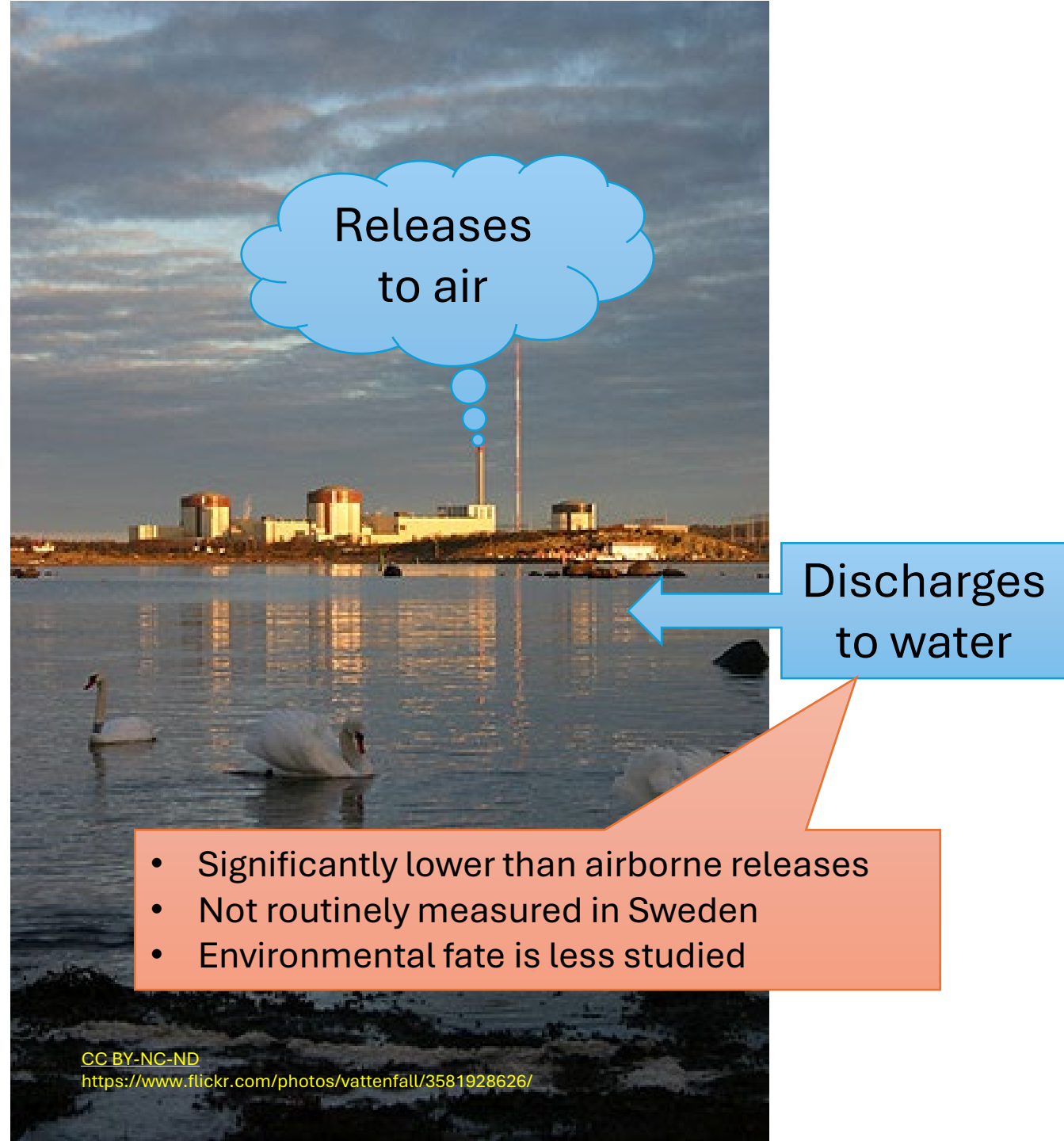
from globally dispersed and long-lived
radionuclides emitted from the nuclear power
industry

- Is measured routinely in Sweden
- Uptake and turnover in the terrestrial environment is well known
- Typical terrestrial excess: from single % to ~10% above reference level (light-water reactors)



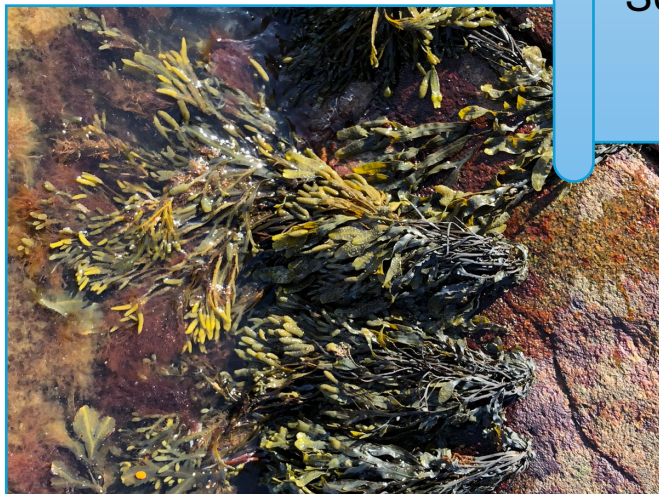
Carbon-14 **often dominates the** **committed effective dose to** **the public**

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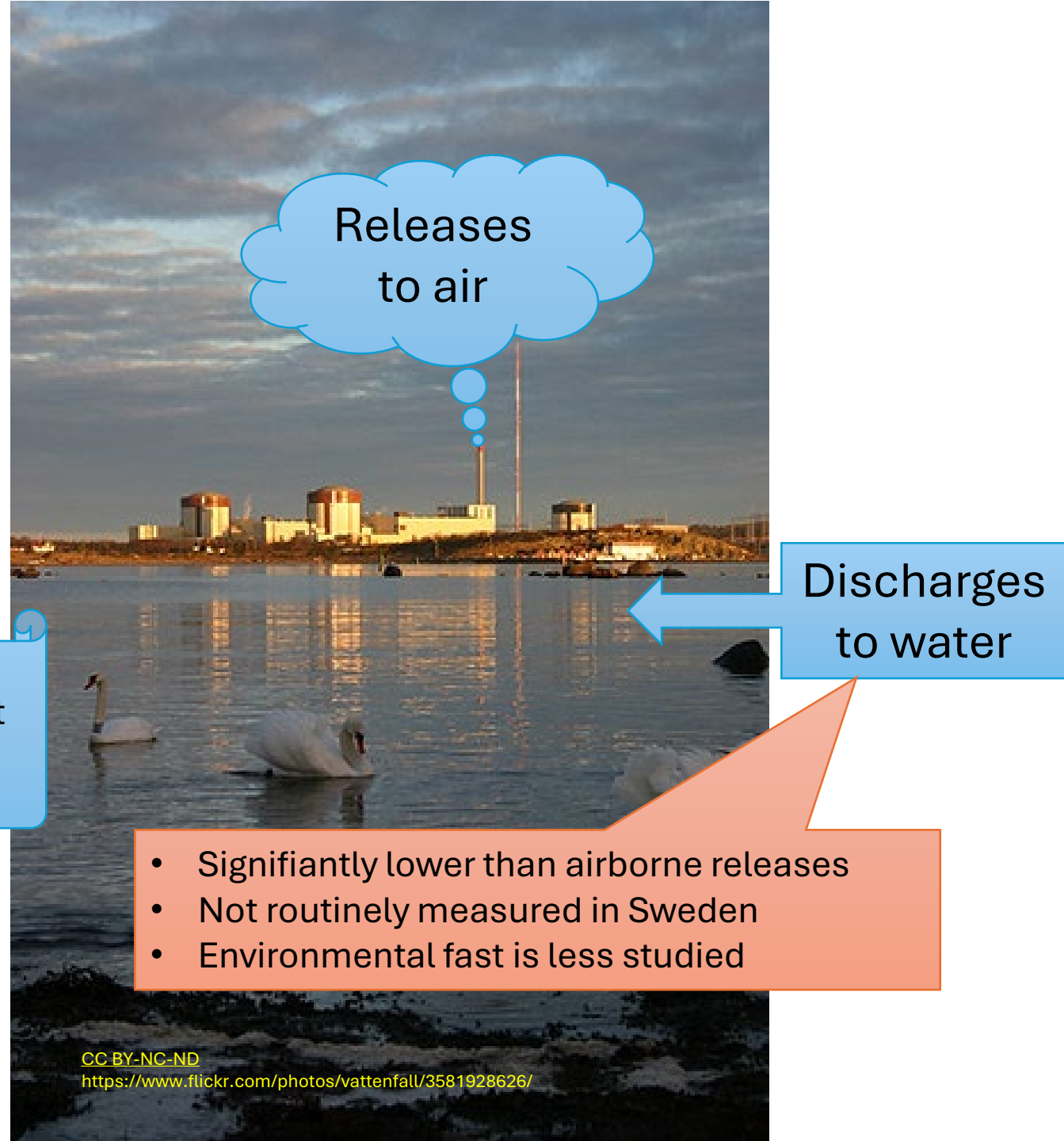


Carbon-14 often dominates the committed effective dose to the public

from globally dispersed and long-lived
radionuclides emitted from the nuclear power
industry



Seaweeds are excellent
bioindicators

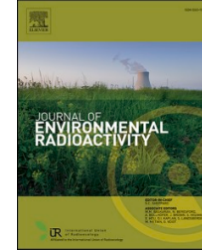




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Spatial and temporal variations of ^{14}C in *Fucus* spp. in Swedish coastal waters

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Previous study financed by the Swedish Radiation Safety Authority SSM2019-5225

Natural variations?

Anthropogenic influence?



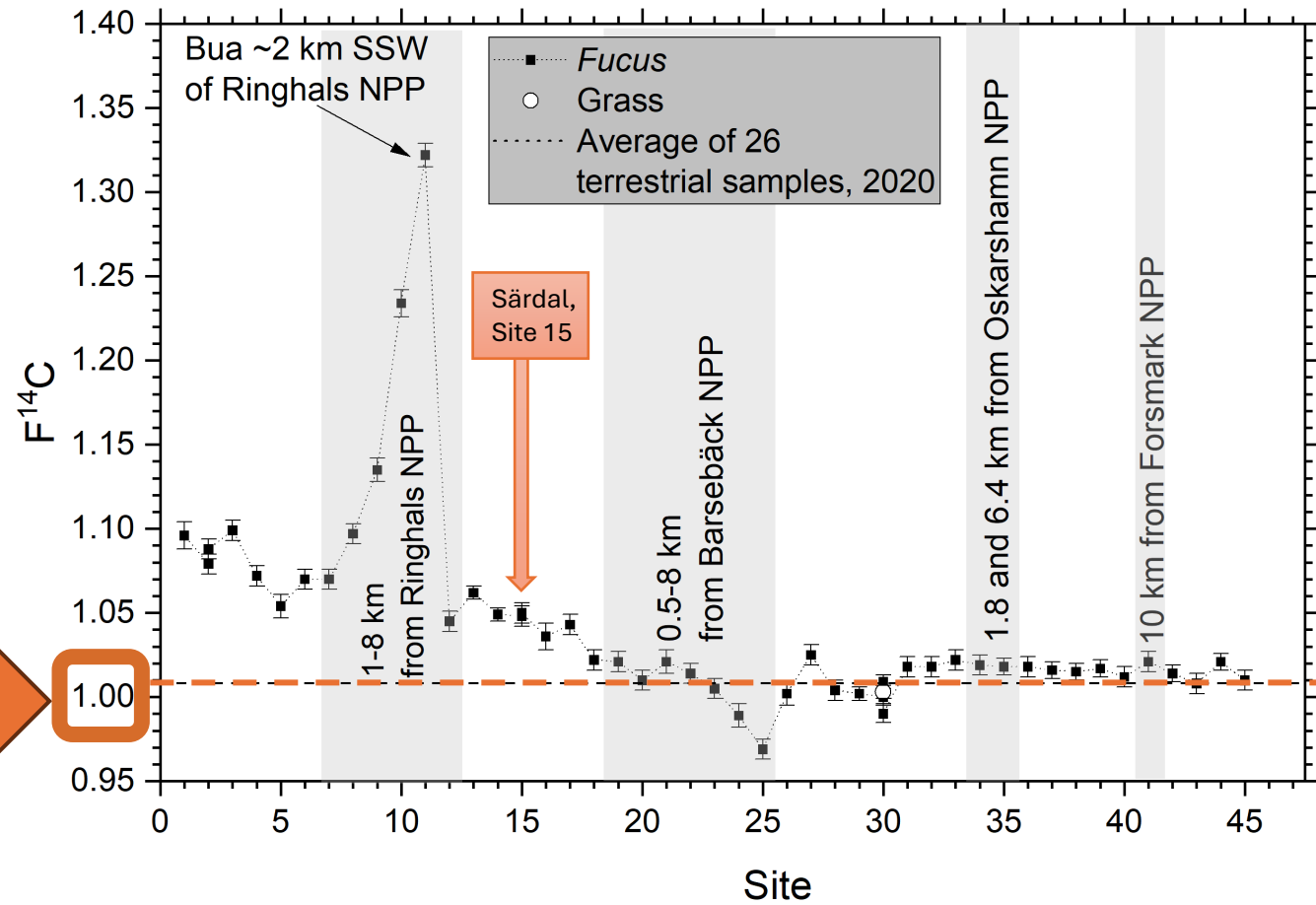
^{14}C in seaweed along the Swedish coast in 2020

Spatial and temporal variations of ^{14}C in *Fucus* spp. in Swedish coastal waters

Kristina Eriksson Stenström^{a,*}, Sören Mattsson^b

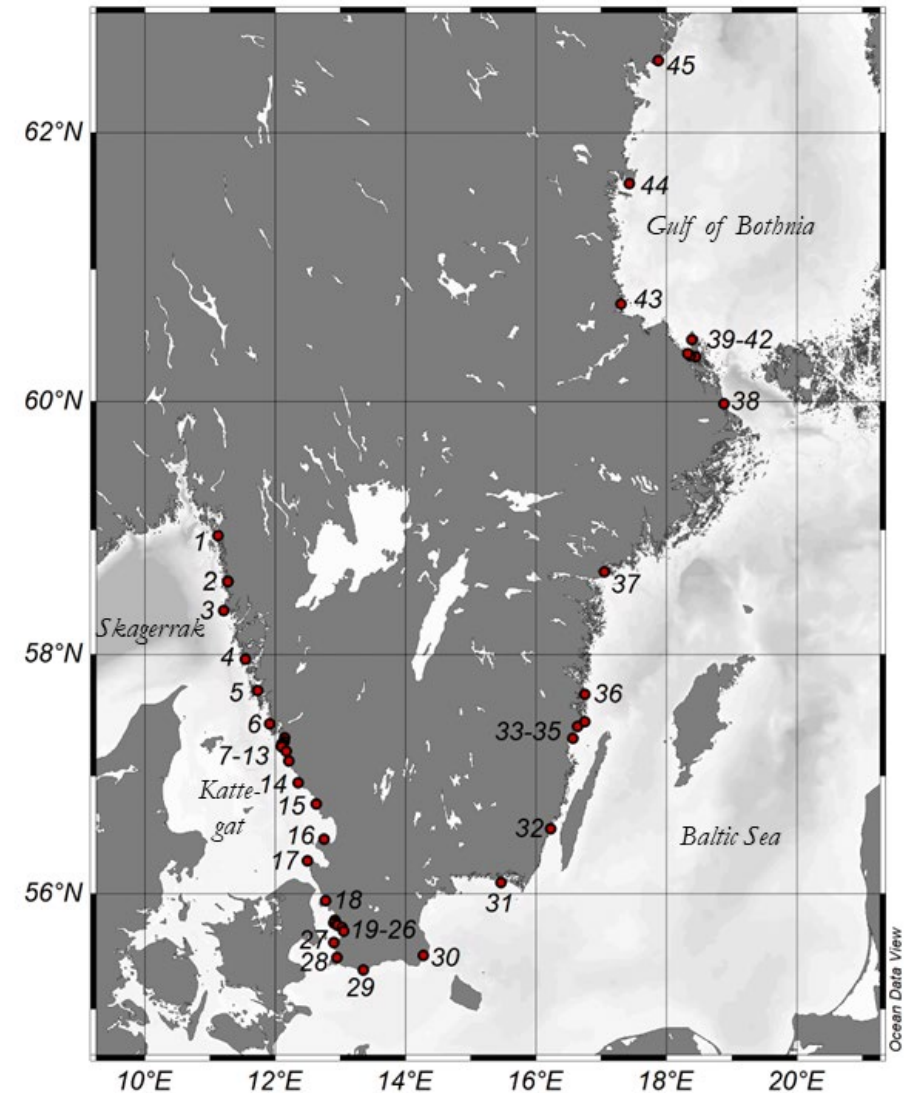
^a Lund University, Department of Physics, Division of Nuclear Physics, Professorgatan 1, SE-223 63, Lund, Sweden

^b Lund University Department of Translational Medicine, Medical Radiation Physics, Carl-Bernil Laurells gata 9, SE-205 02, Malmö, Sweden



$F^{14}\text{C} = 1$ corresponds to $\sim 226 \text{ Bq (kg C)}^{-1}$

Natural ^{14}C

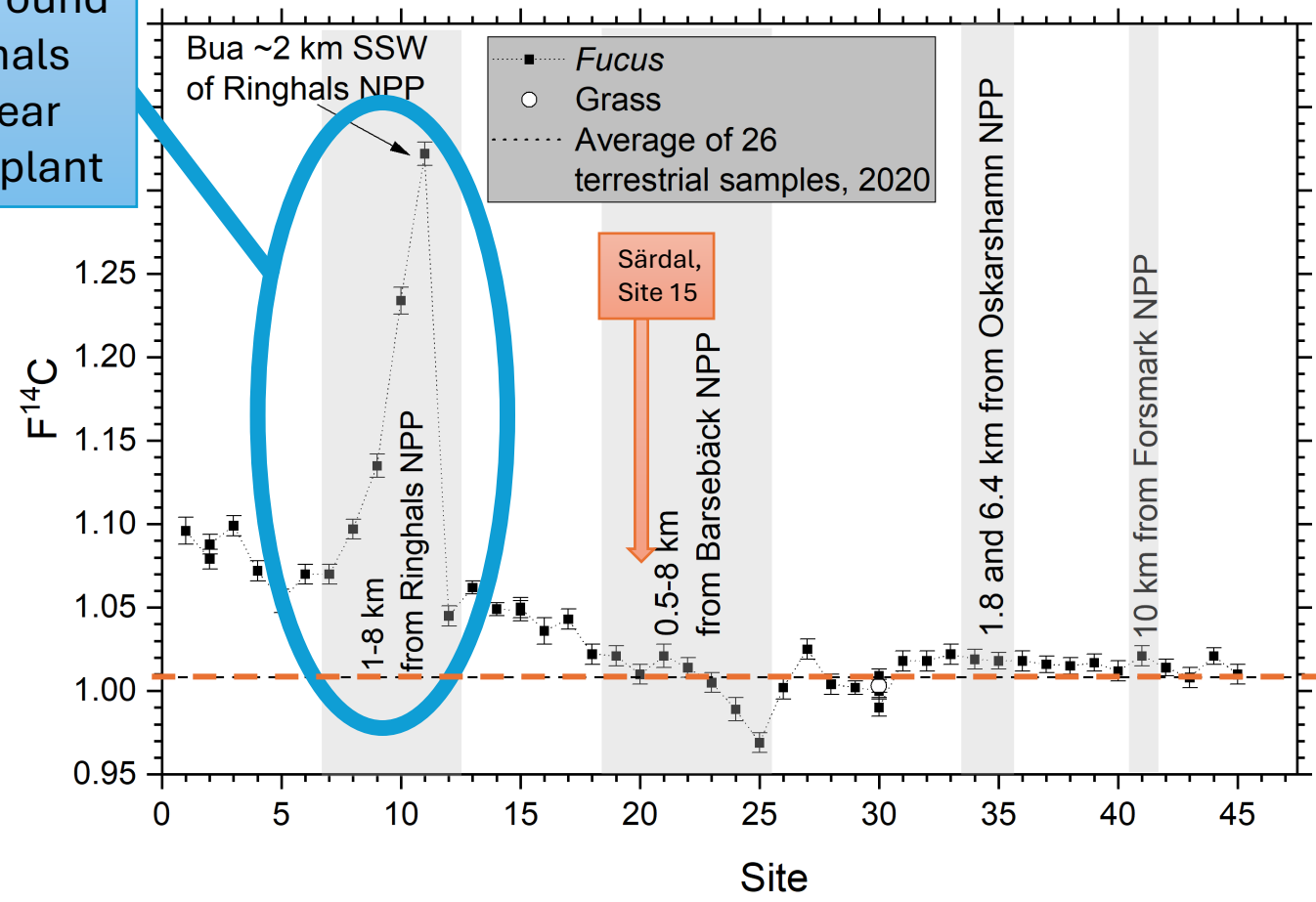




Higher than expected

¹⁴C in seaweed along the Swedish coast in 2020

Peak around Ringhals nuclear power plant

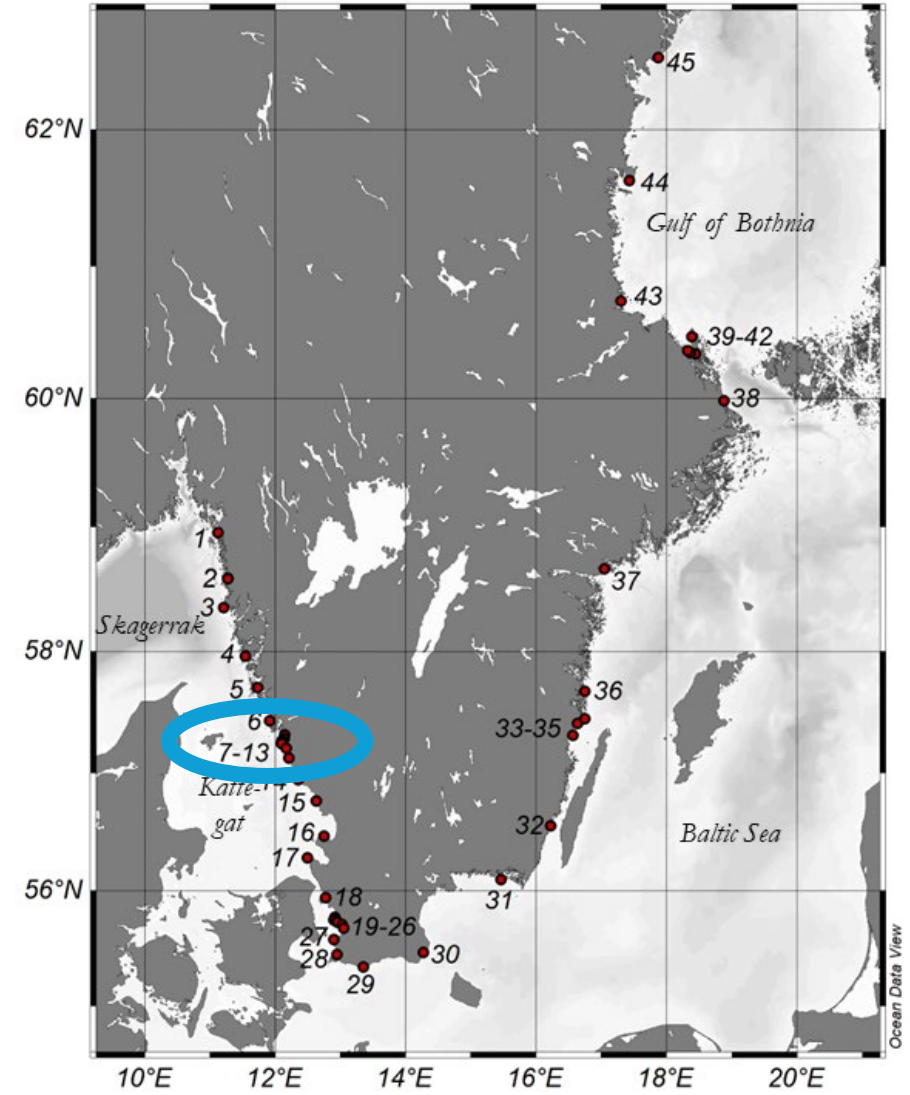


F¹⁴C = 1 corresponds to ~226 Bq (kg C)⁻¹

Spatial and temporal variations of ¹⁴C in *Fucus* spp. in Swedish coastal waters

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Spatial and temporal variations of ^{14}C in *Fucus* spp. in Swedish coastal waters

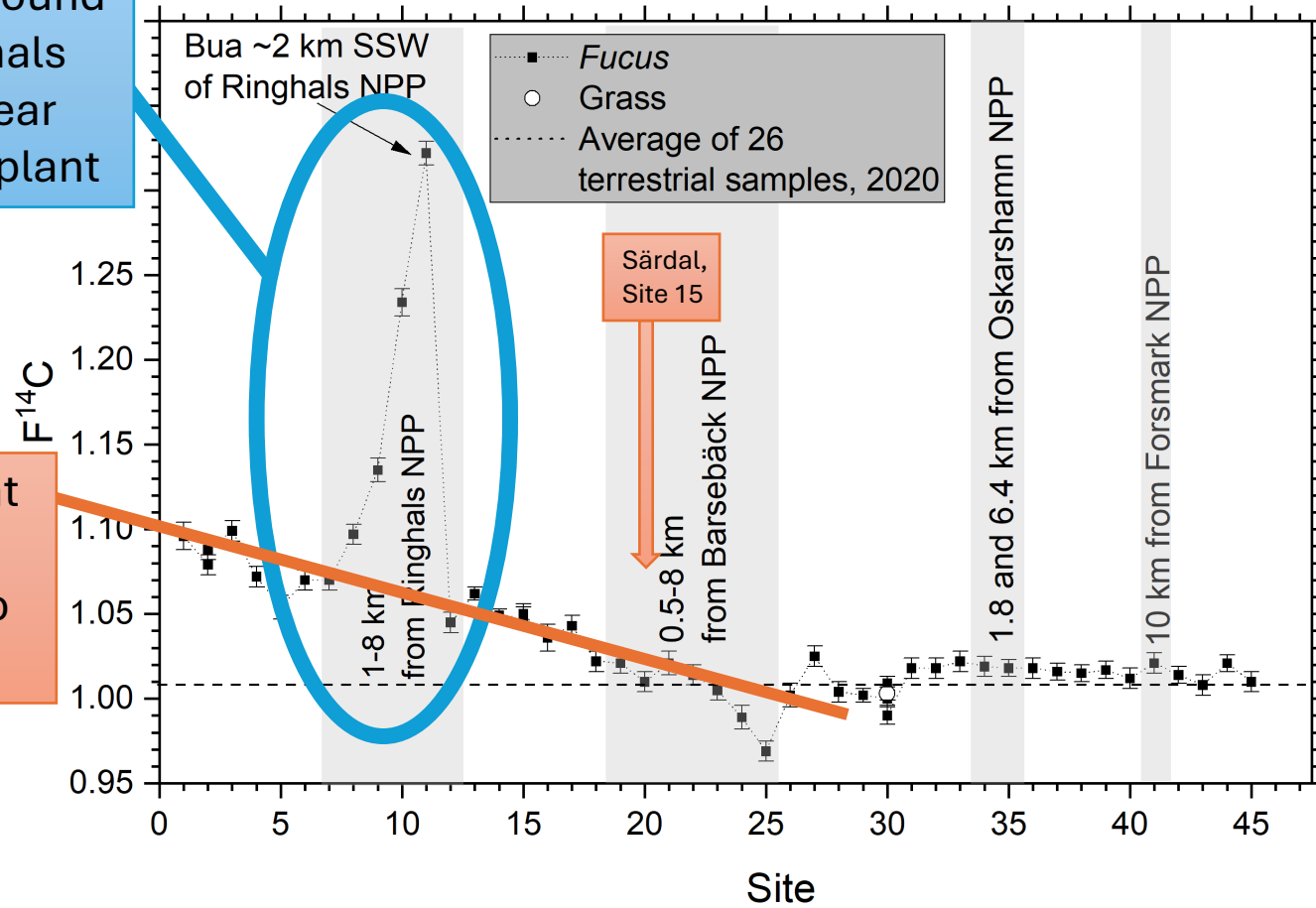
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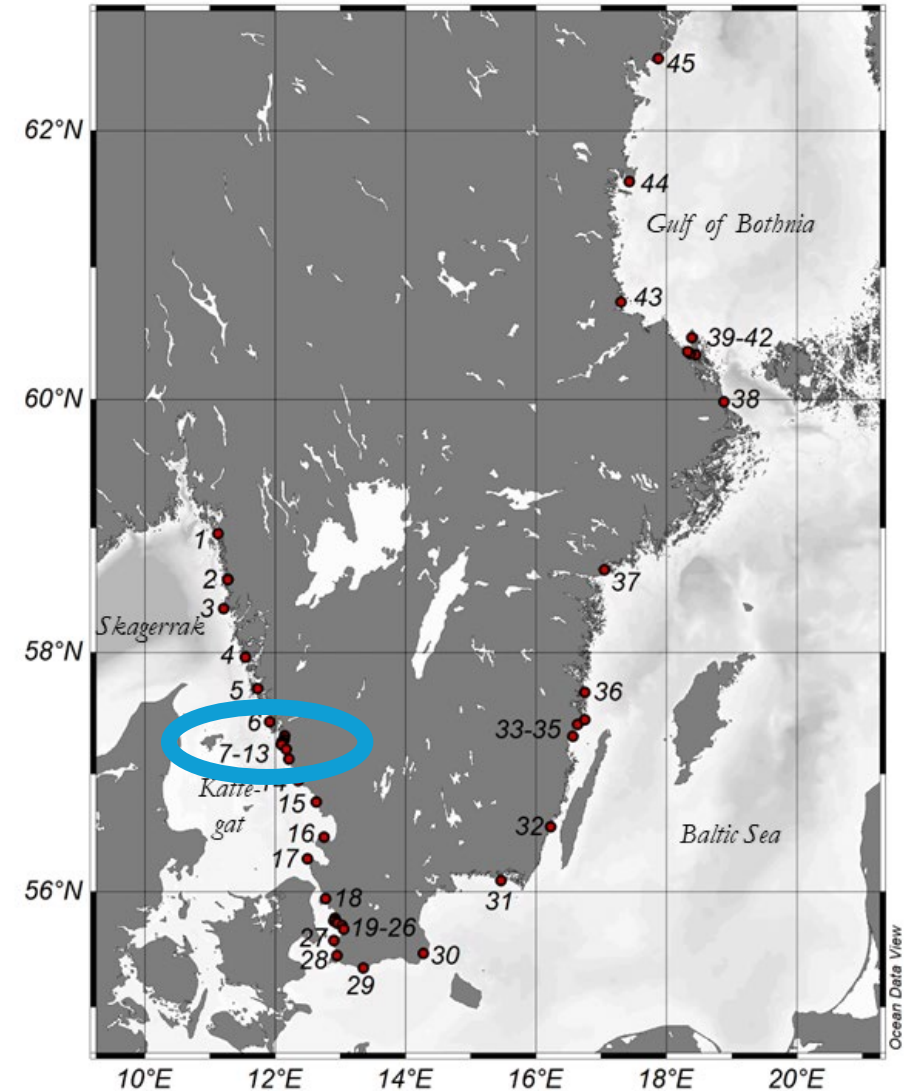
^b Lund University Department of Translational Medicine, Medical Radiation Physics, Carl-Bernil Laurells gata 9, SE-205 02, Malmö, Sweden

Peak around Ringhals nuclear power plant

Gradient from north to south



$F^{14}\text{C} = 1$ corresponds to $\sim 226 \text{ Bq (kg C)}^{-1}$





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Spatial and temporal variations of ¹⁴C in *Fucus* spp. in Swedish coastal waters

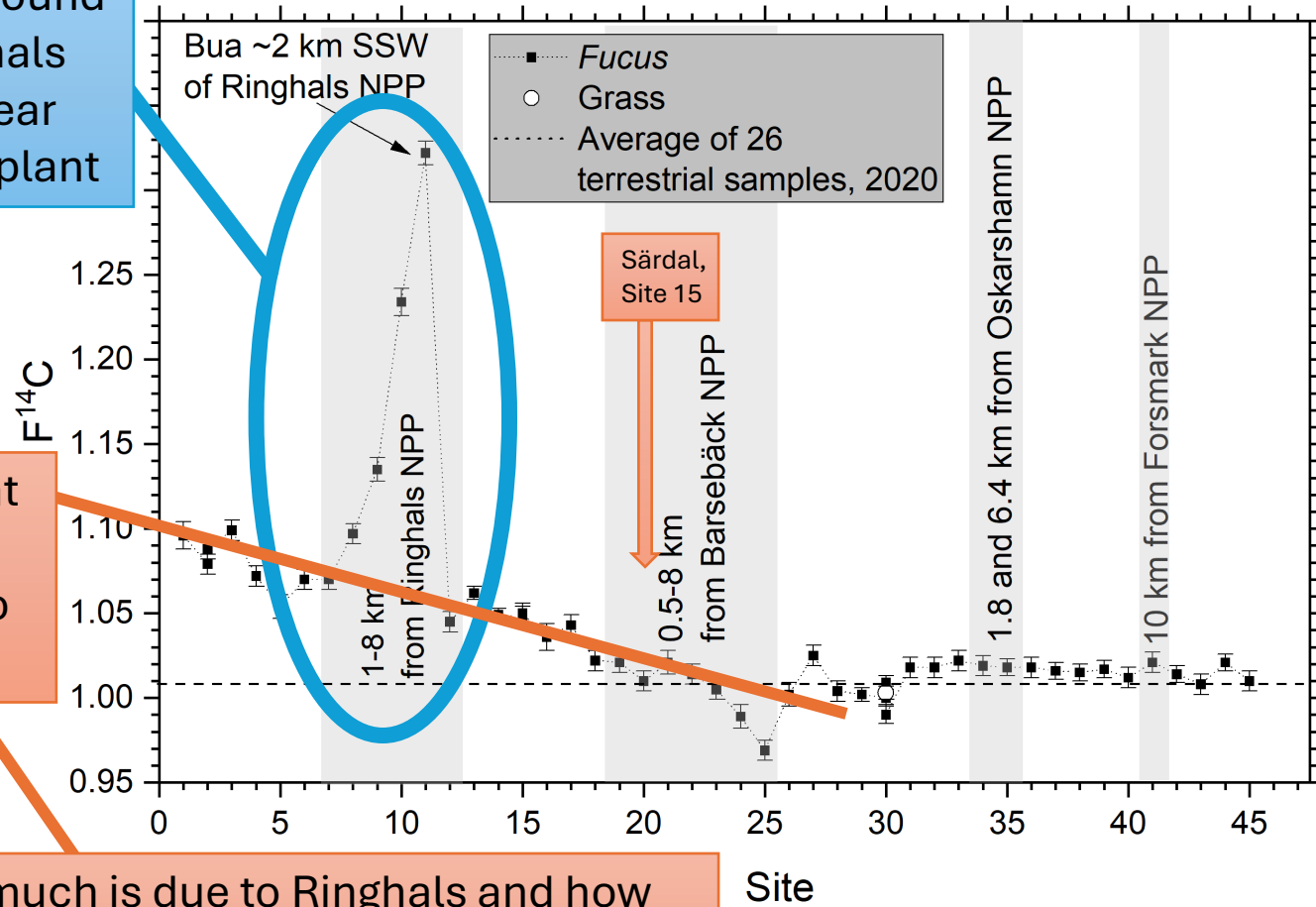
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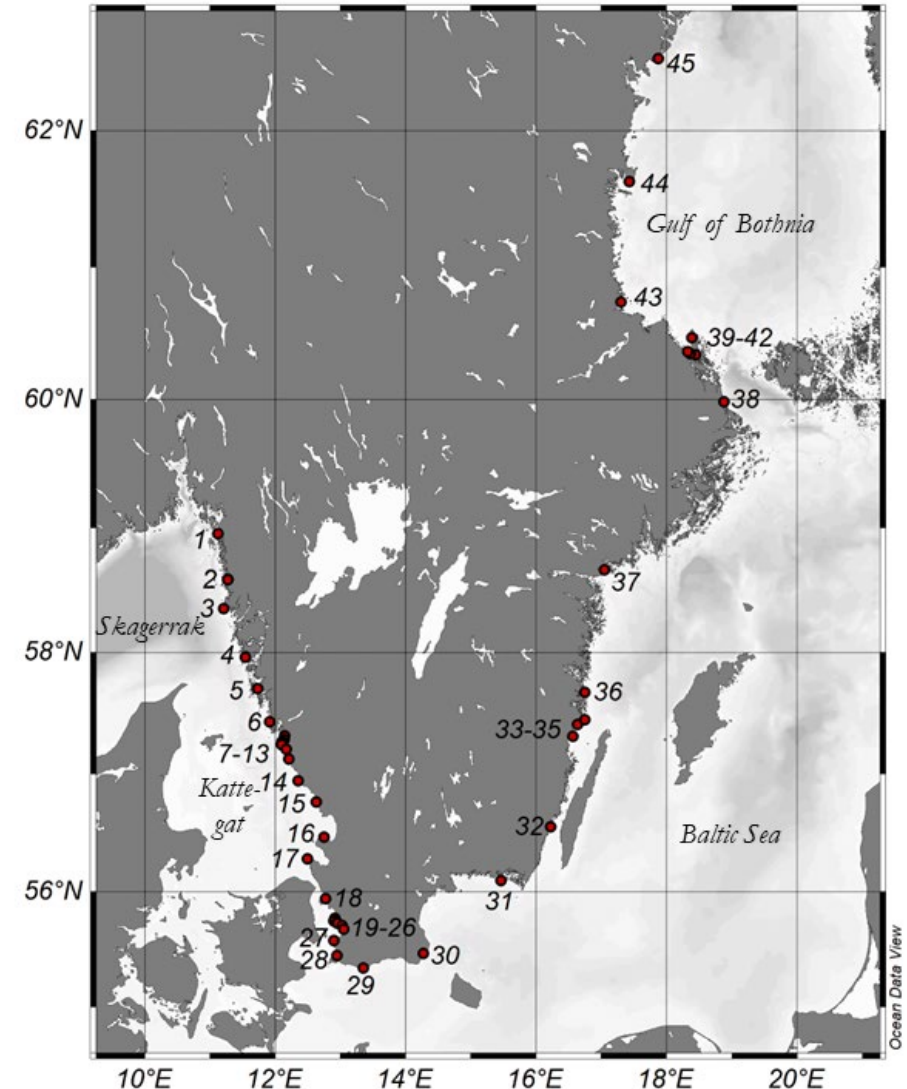
Peak around Ringhals nuclear power plant

Gradient from north to south

How much is due to Ringhals and how much is due to other sources??
 Local radioecology at Ringhals NPP?

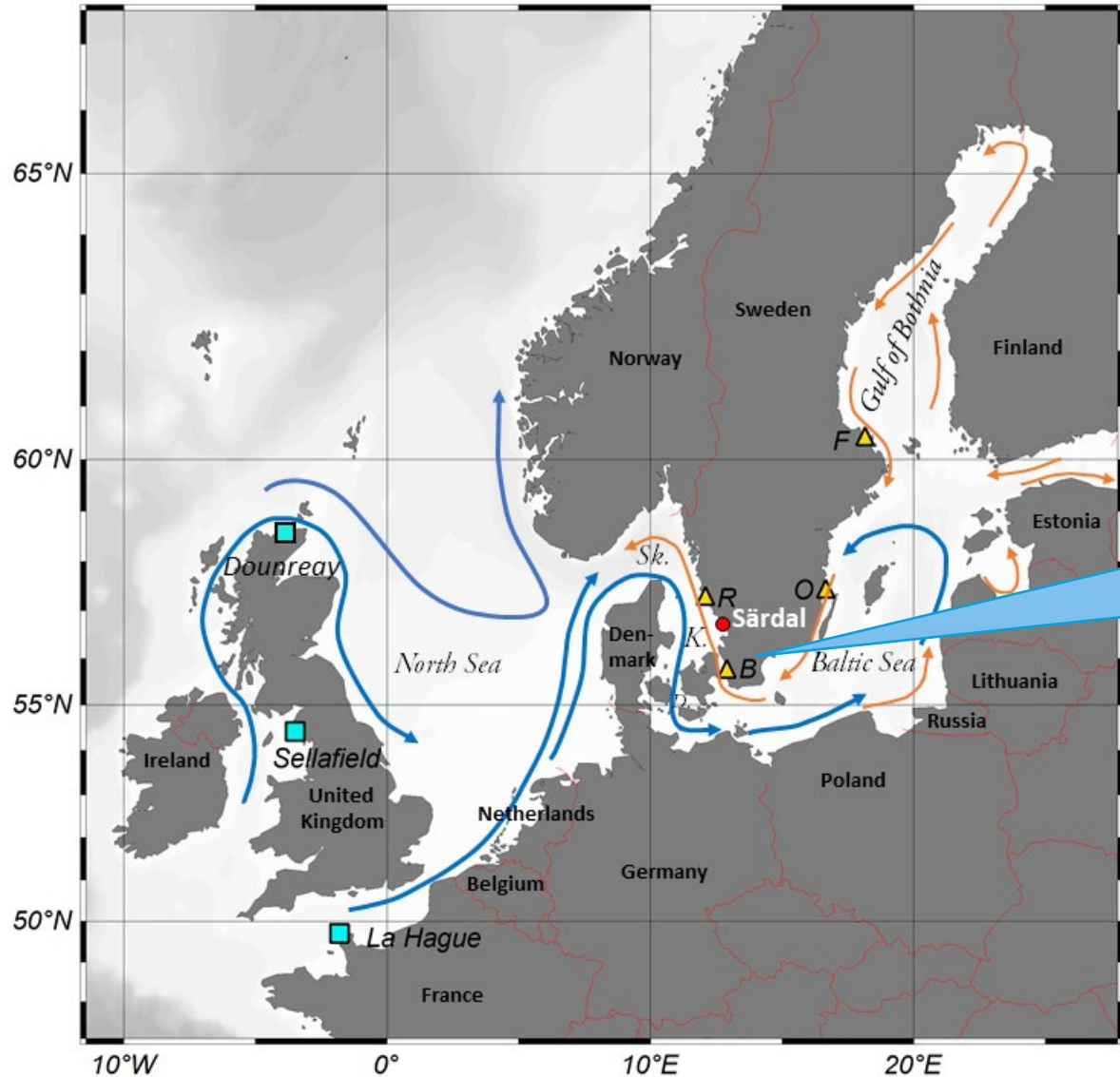


F¹⁴C = 1 corresponds to ~226 Bq (kg C)⁻¹



Ocean Data View

^{14}C from spent nuclear fuel reprocessing plants reaches Swedish coastal waters



Strong correlation between salinity and $F^{14}\text{C}$

Correlation between La Hague and Sellafield discharge rates and $F^{14}\text{C}$ at Särödal (samples series since 1967)

Arrows represent surface water movement in orange and bottom water movement in blue.

(R: Ringhals; B: Barsebäck; O: Oskarshamn; F: Forsmark).
Sk. – Skagerrak; K. – Kattegat.

Research

Long-time variations of radionuclides and metals in the marine environment of the Swedish west-coast studied using brown algae

(*Fucus serratus* and *Fucus vesiculosus*)



Professor emeritus Sören Mattsson has regularly, **since 1967**, collected seaweed (*Fucus*) in **Särdal** on the west coast.



Authors:

Sören Mattsson

Kristina Eriksson Stenström

Guillaume Pedehontaa-Hiaa

Available at: www.ssm.se

2022:13

Authors: Sören Mattsson ¹⁾, Kristina Eriksson Stenström ²⁾, Guillaume Pedehontaa-Hiaa ³⁾

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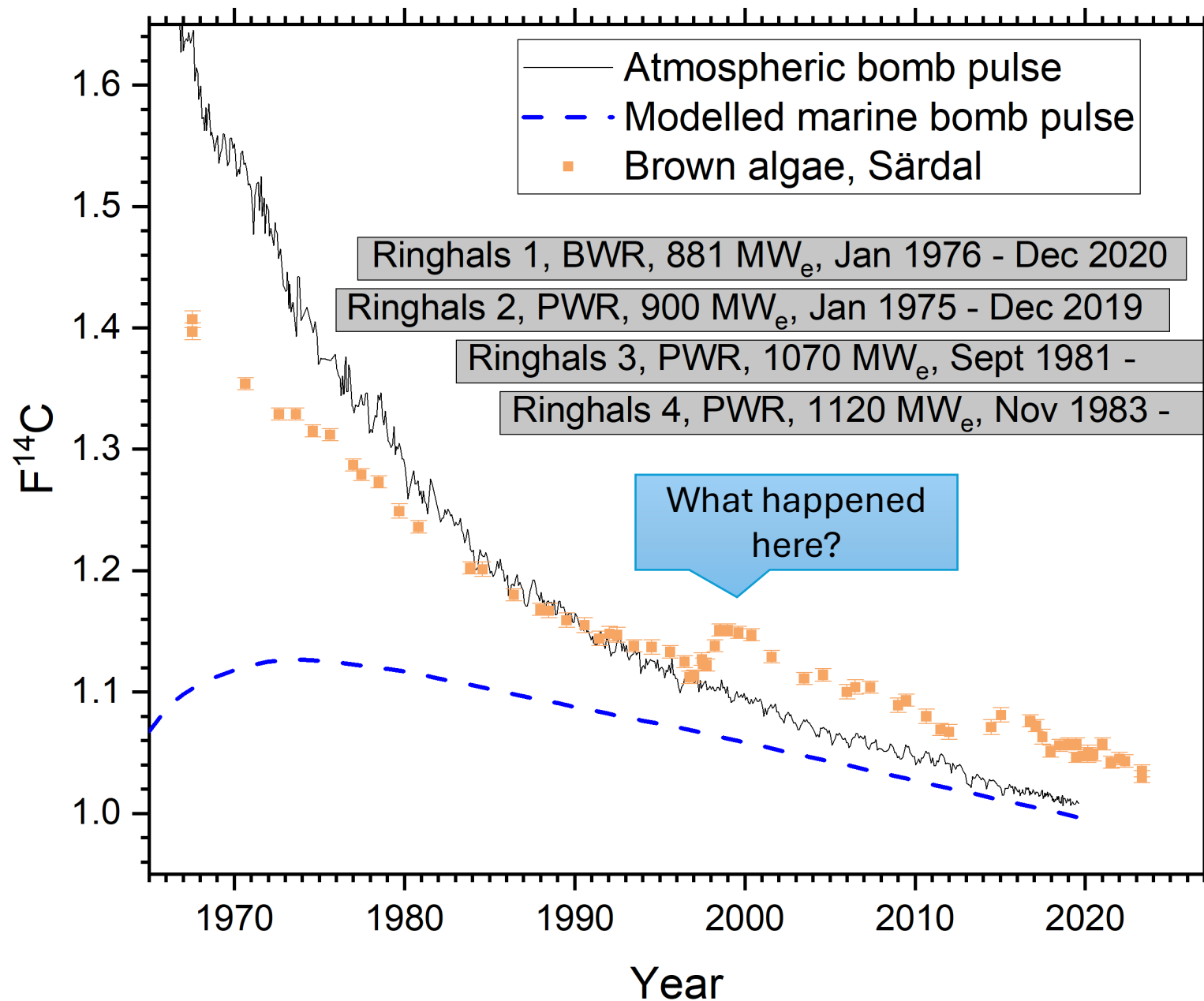
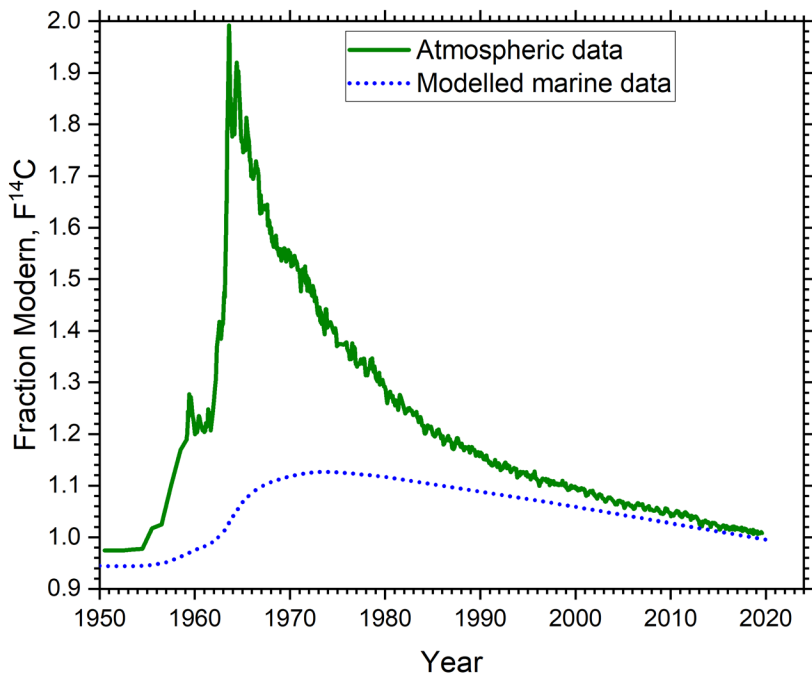
Report number: 2022:13

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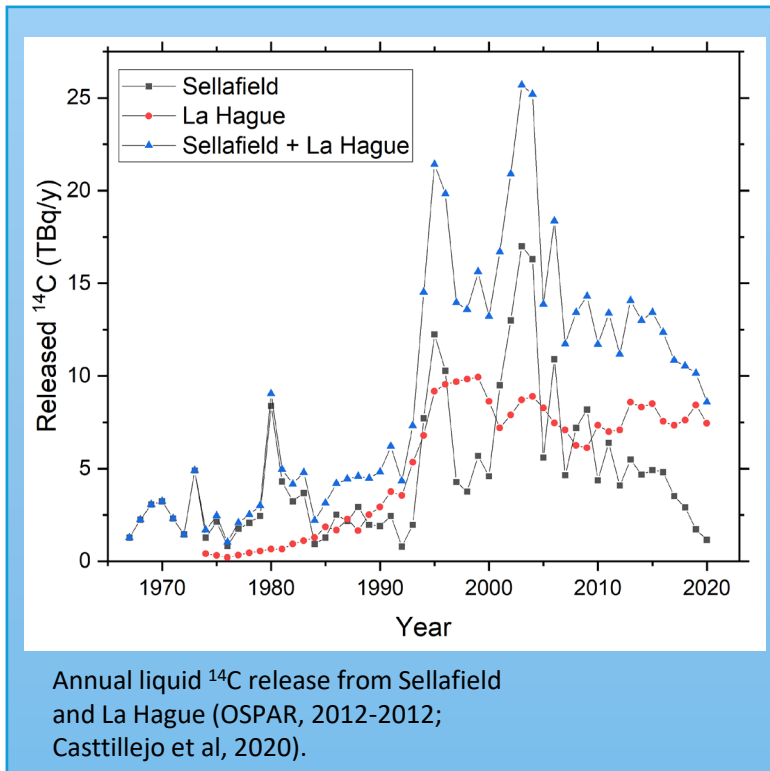
Available at: www.ssm.se



The Särödal biobank with *Fucus* samples may provide some answers!



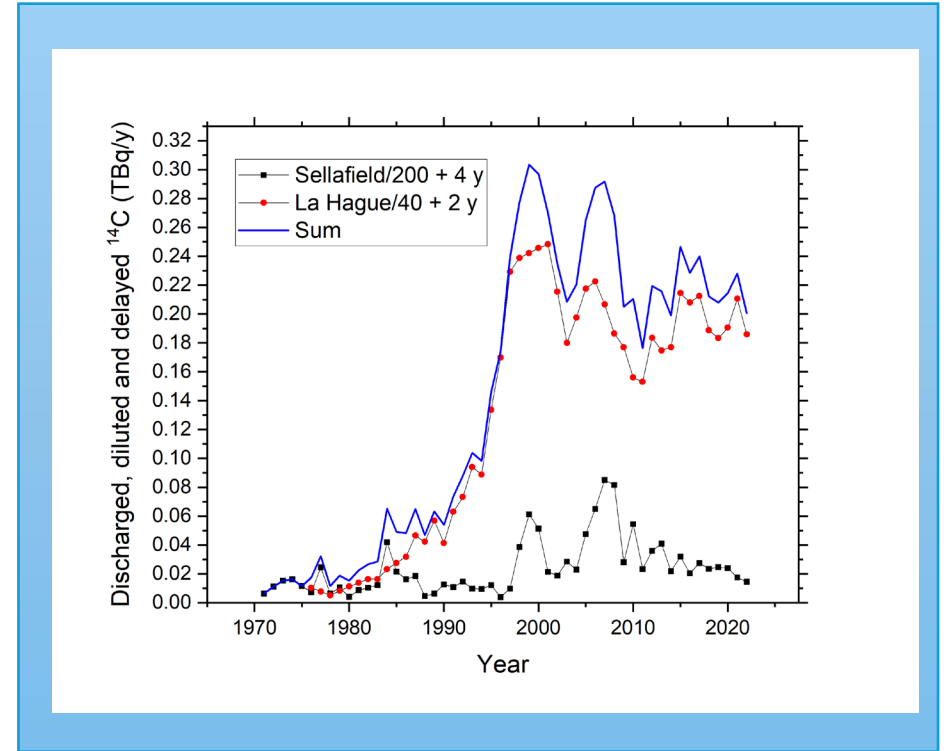
A look at La Hague and Sellafield release data



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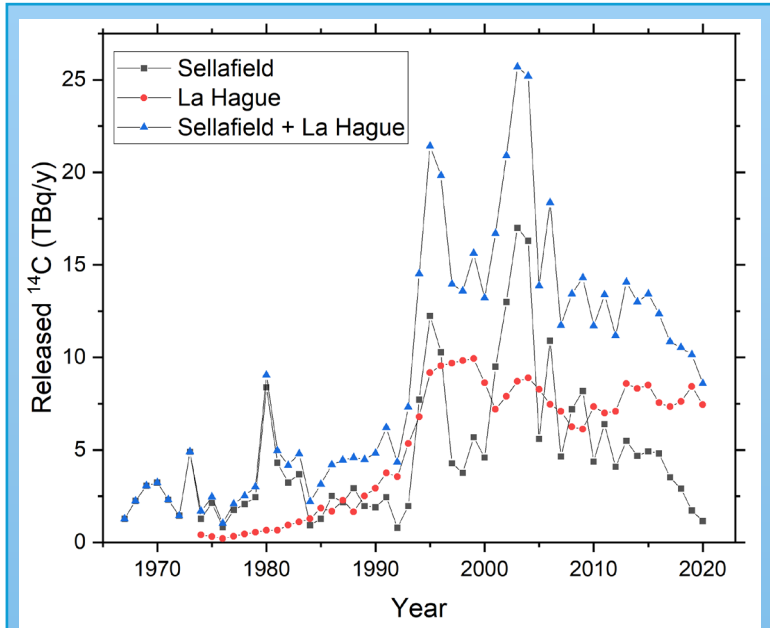
Data on dilution and transport time of ^{99}Tc from Sellafield and La Hague to Särödal

(Dahlgaard et al, 1995; Lindahl et al., 2003)



^{14}C from La Hague dominates over Sellafield at Särödal

A look at La Hague and Sellafield release data

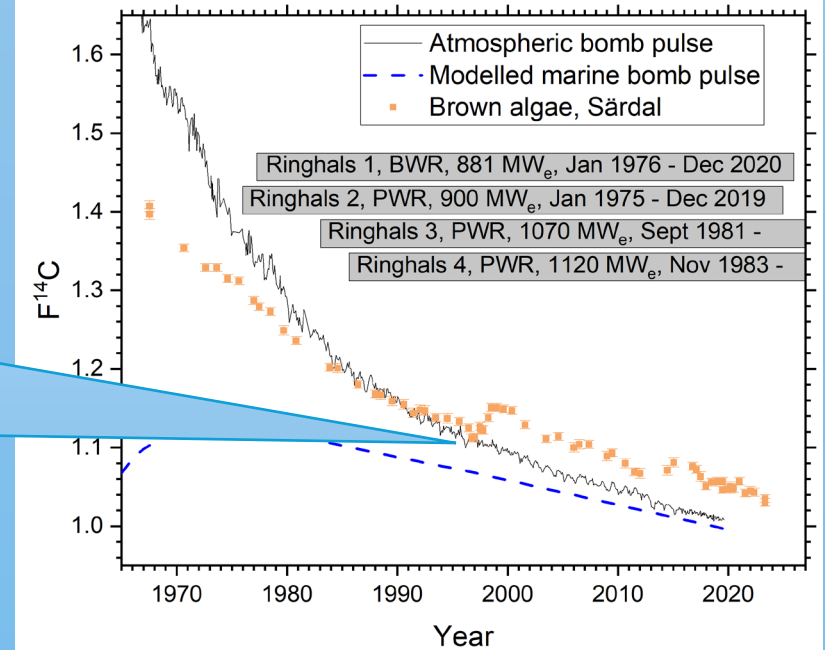
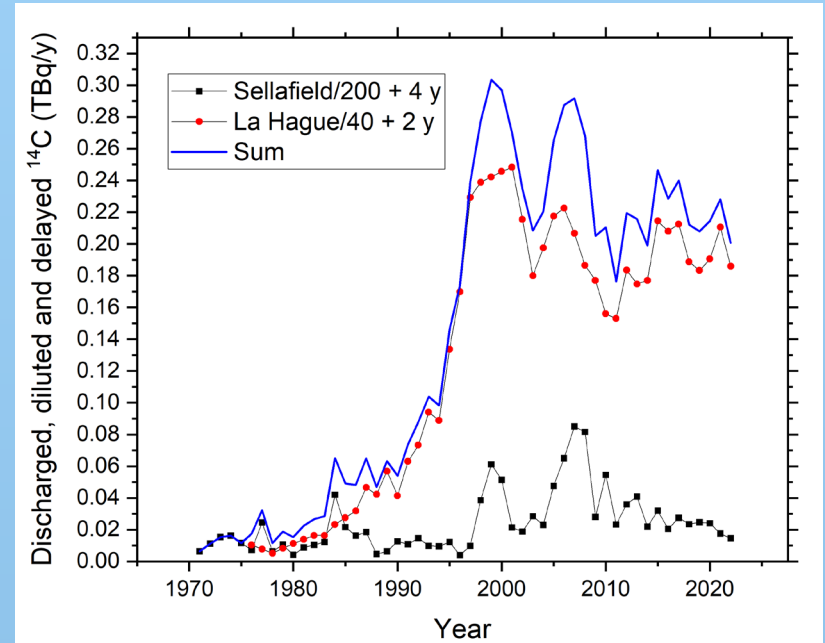


Annual liquid ^{14}C release from Sellafield and La Hague (OSPAR, 2012-2012; Castillejo et al, 2020).

+

Data on dilution and transport time of ^{99}Tc from Sellafield and La Hague to Särödal

(Dahlgaard et al, 1995; Lindahl et al., 2003)



What happened here?

Coincides with discharge data from La Hague!

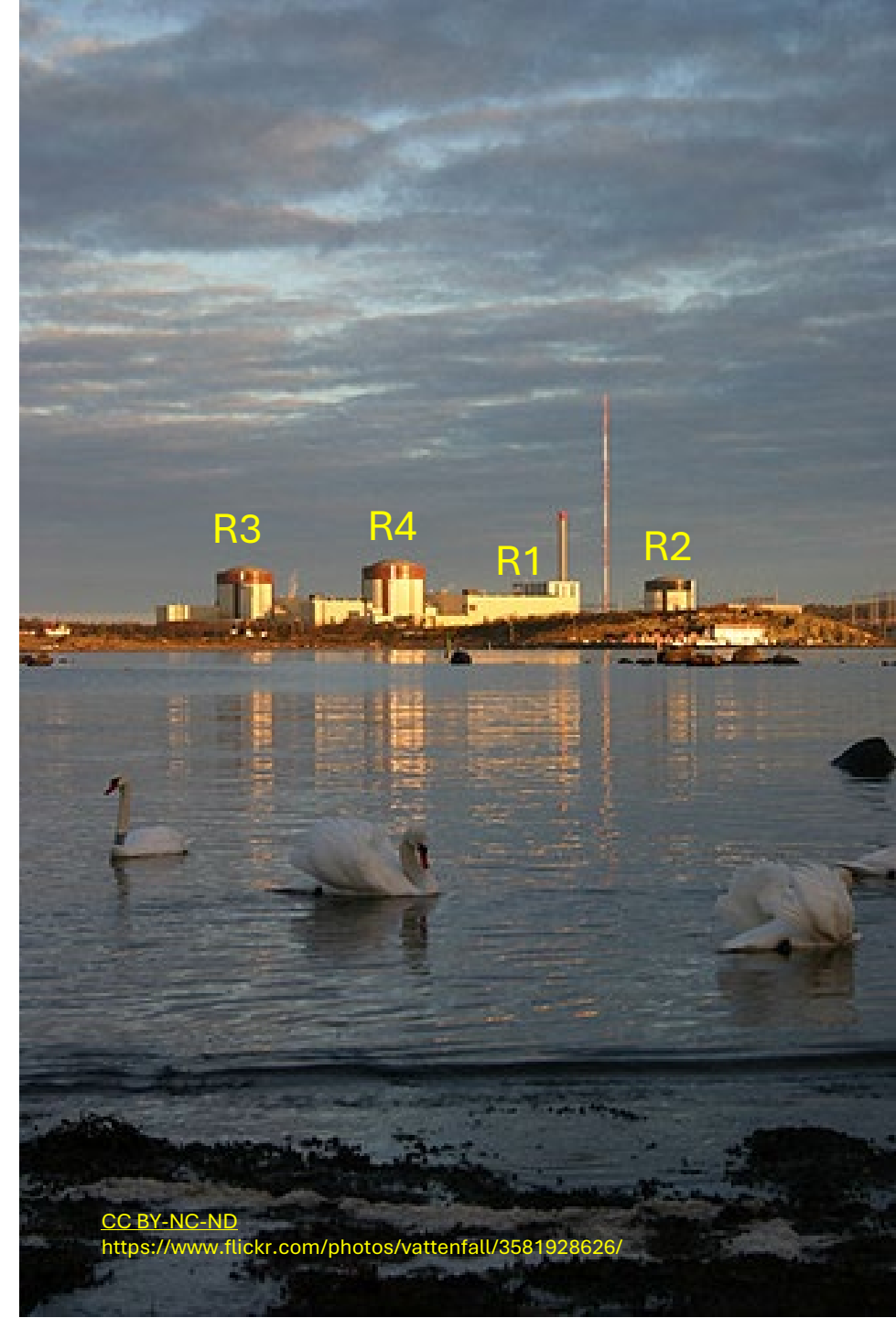
Ringhals NPP

1 Light Water Reactor – Boiling Water Reactor (LWR-BWR)

- R1, 881 MW_e, in operation from 1976 to the end of 2020

3 Light Water Reactor – Pressurized Water Reactors (LWR-PWR)

- R2, 900 MW_e, in operation from 1975 to the end of 2019
- R3, 1070 MW_e, in operation since 1981
- R4, 1120 MW_e, in operation since 1983



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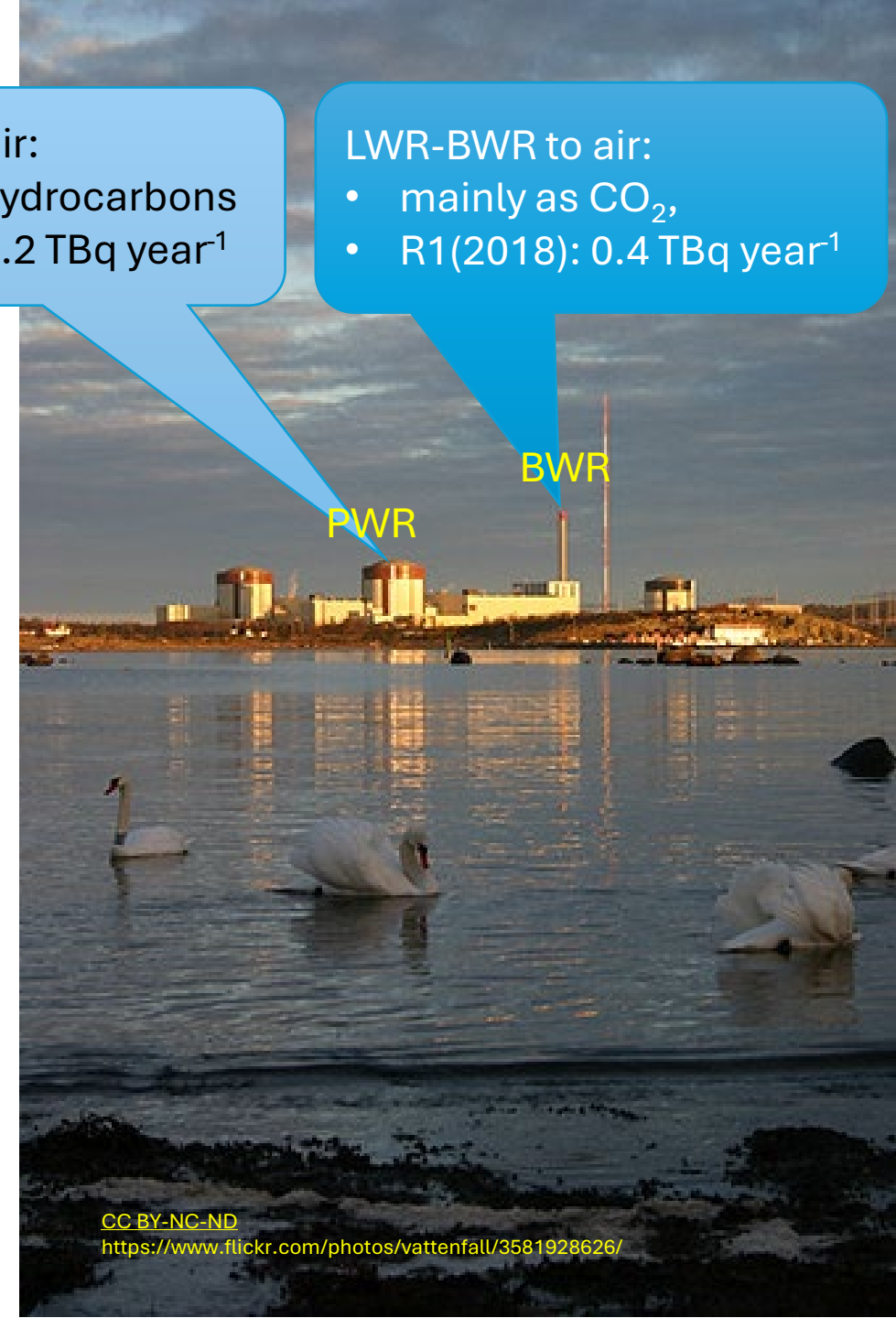
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LWR-PWR to air:

- mainly as hydrocarbons
- R4(2018): 0.2 TBq year⁻¹

LWR-BWR to air:

- mainly as CO₂,
- R1(2018): 0.4 TBq year⁻¹



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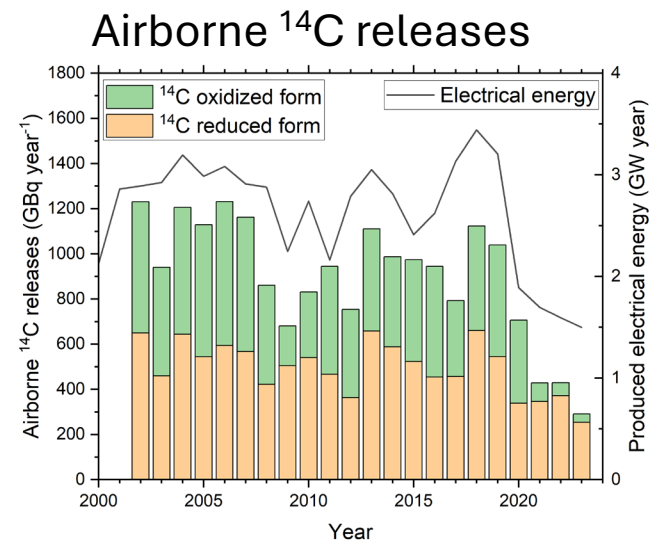
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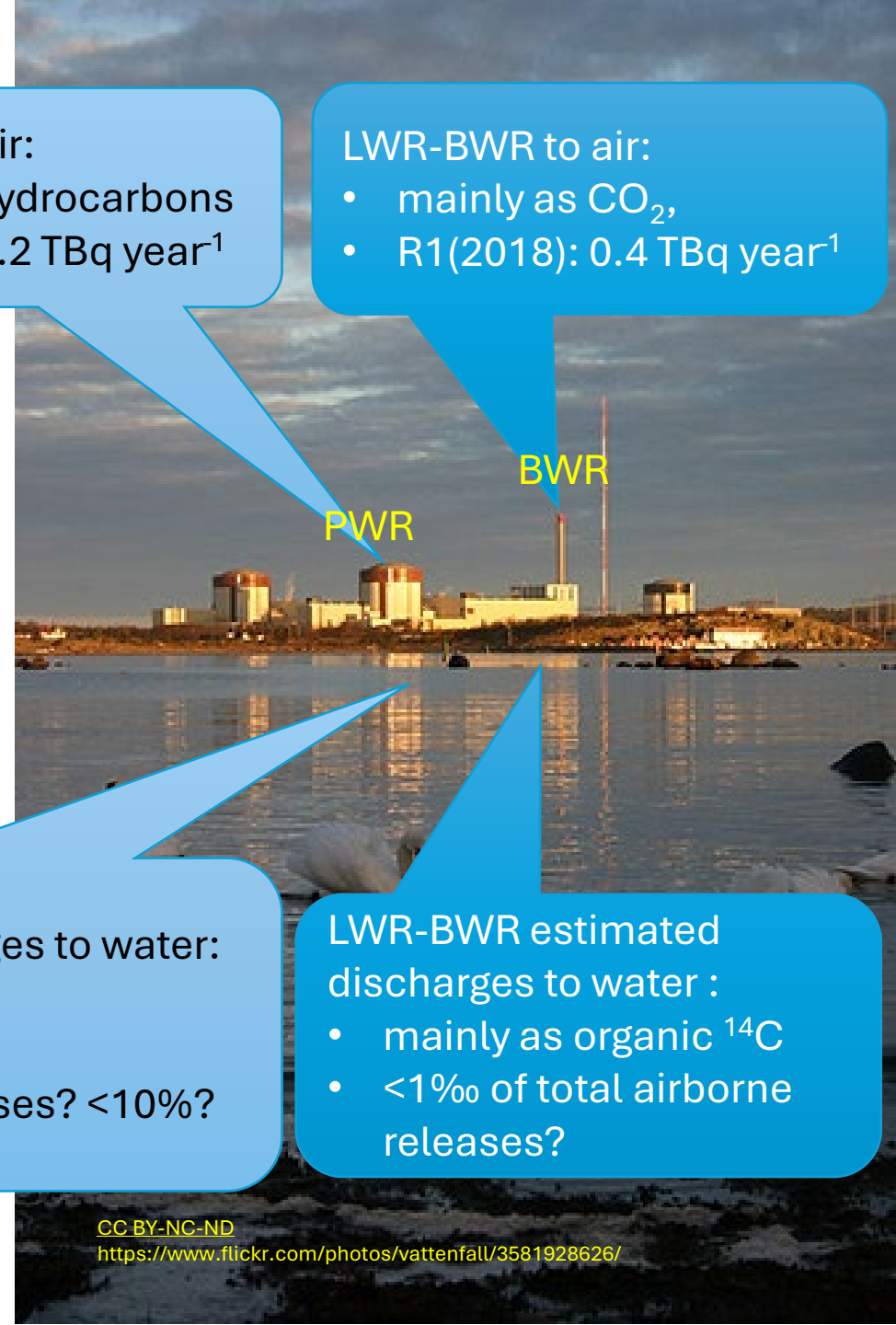
- mainly as CO₂,
- R1(2018): 0.4 TBq year⁻¹

LWR-PWR estimated discharges to water:

- mainly as inorganic ¹⁴C?
- some organic ¹⁴C?
- <1% of total airborne releases? <10%?






LWR-BWR estimated discharges to water :

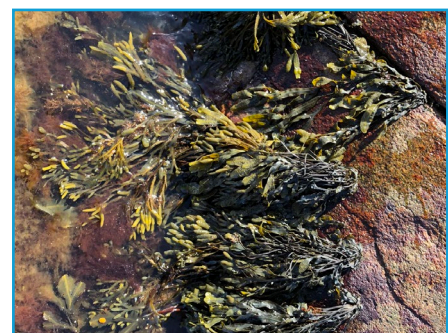
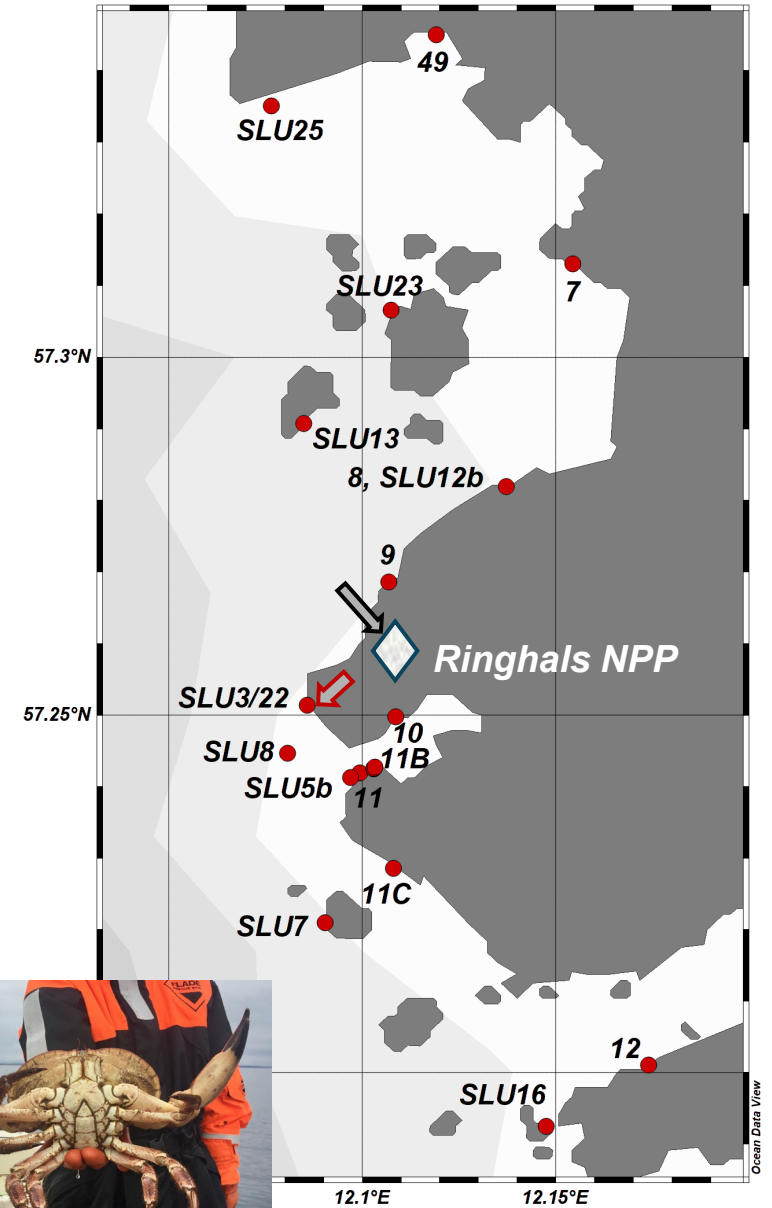
- mainly as organic ¹⁴C
- <1‰ of total airborne releases?



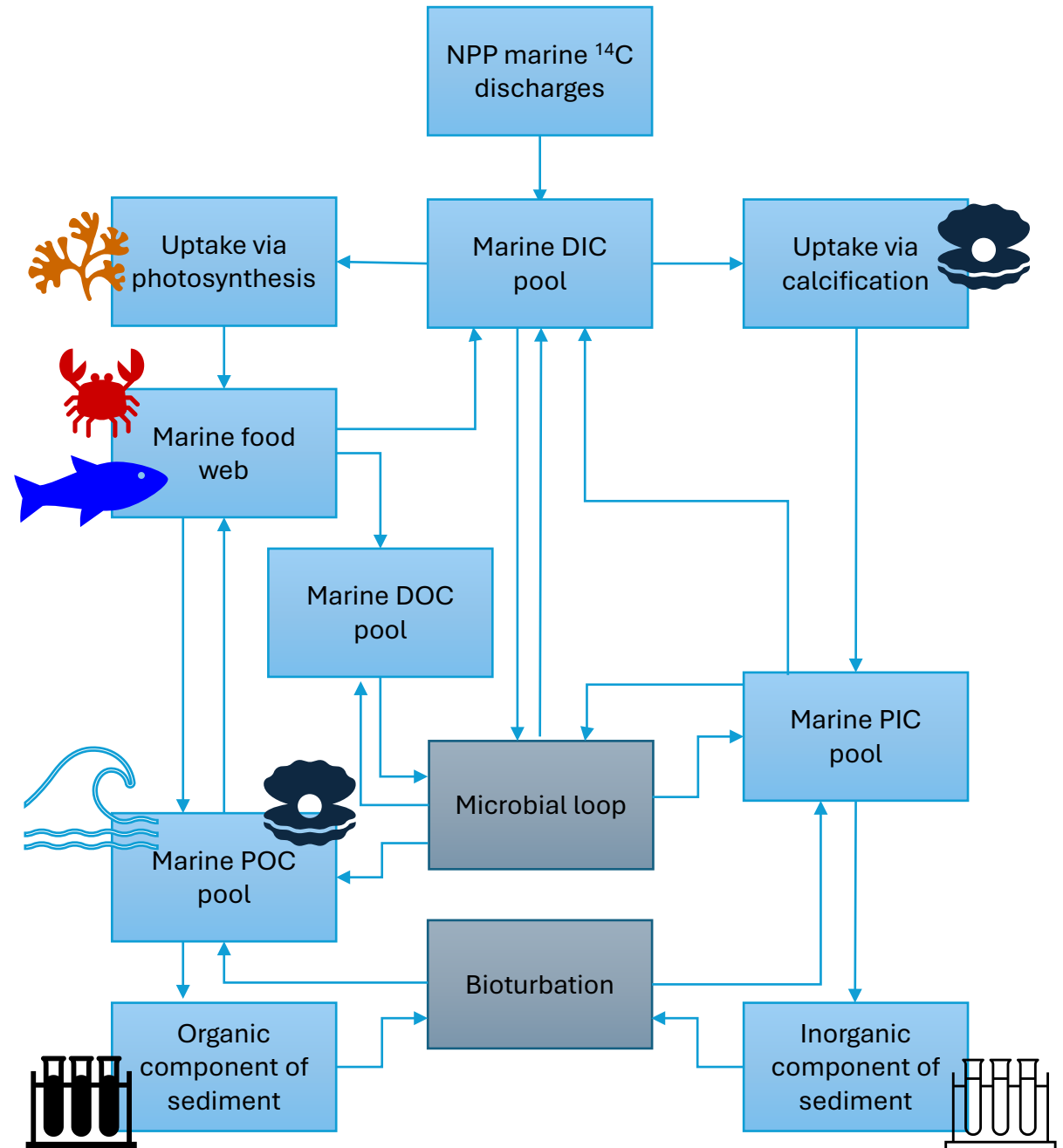
Radioecology at Ringhals NPP

Ongoing project

- Intensified one-year study at Ringhals
 - Seaweed (*Fucus*) 
 - Fish corkwing wrasse (*Symphodus melops*) 
 - Mussels (*Mytilus edulis*)
 - Soft tissue and shell 
 - Oyster (*Magallana gigas*)
 - Crab (*Cancer pagurus*) 
 - Biofouling plates
 - Particulate organic carbon (POC) in seawater 
 - Sediment



Marine radioecology



Marine radioecology of ^{14}C . Modified from [1].

- DIC – Dissolved Inorganic Carbon,
- DOC – Dissolved Organic Carbon,
- PIC – Particulate Inorganic Carbon,
- POC – Particulate Organic Carbon.

[1] Tierney, K.M. *Marine ecosystem uptake of nuclear reprocessing derived radiocarbon (^{14}C)*. PhD thesis. University of Glasgow. 2017.

Biofouling plates

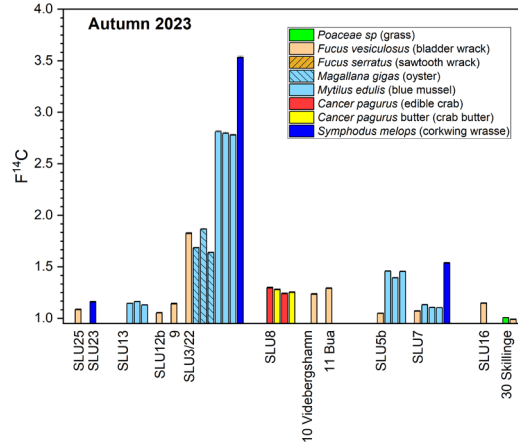
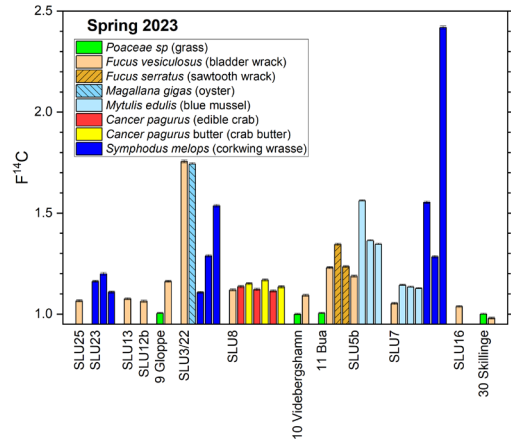
2 plates located just at the cooling water outlet

Date	Plate	F ¹⁴ C
11 Dec 2023	1	3.494 ± 0.011
2 Jan 2024	2	1.897 ± 0.007
4 March 2024	1	8.250 ± 0.023
4 March 2024	2	3.835 ± 0.011

If a human (obviously not),
about 0.1 mSv/year!



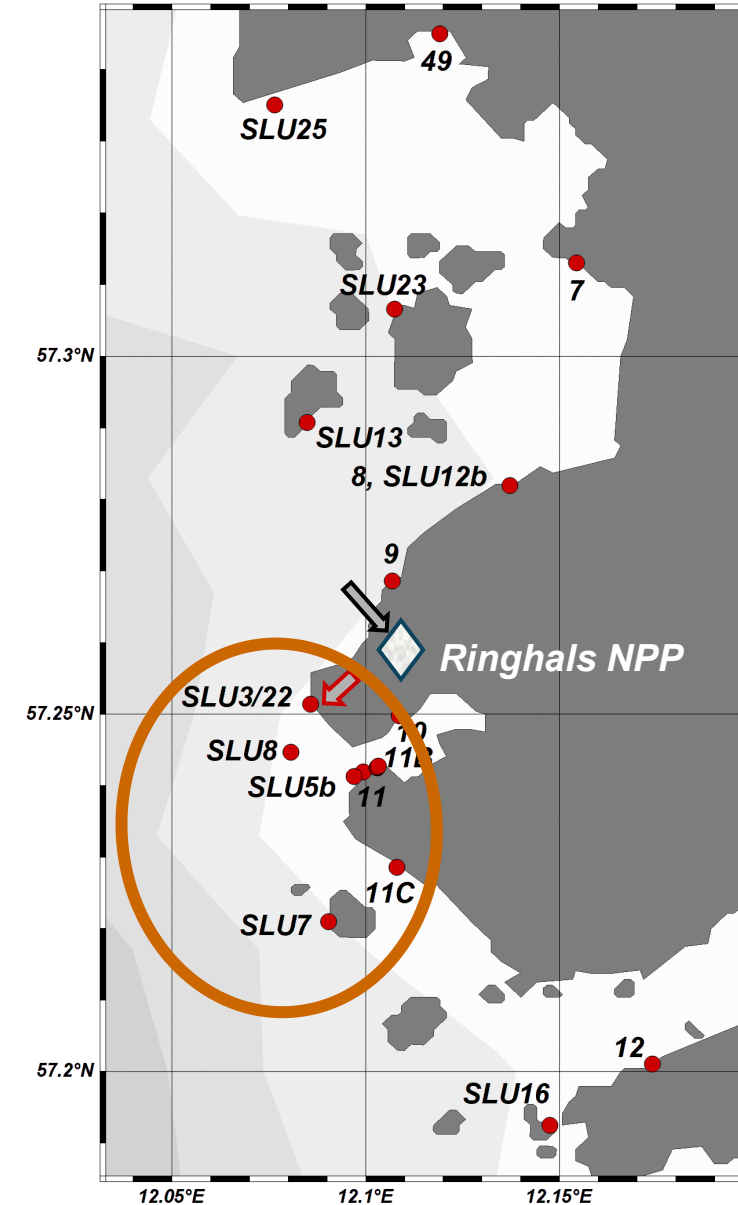
Some results (not published)



- Highest values at cooling water outlet and southwards
- Up to $F^{14}C \sim 3.5$ in fish



- Bioaccumulation/ biomagnification of organic ^{14}C ?
- Heterotrophic and methane oxidizing bacteria?
- Higher discharges in the past, now in sediments?

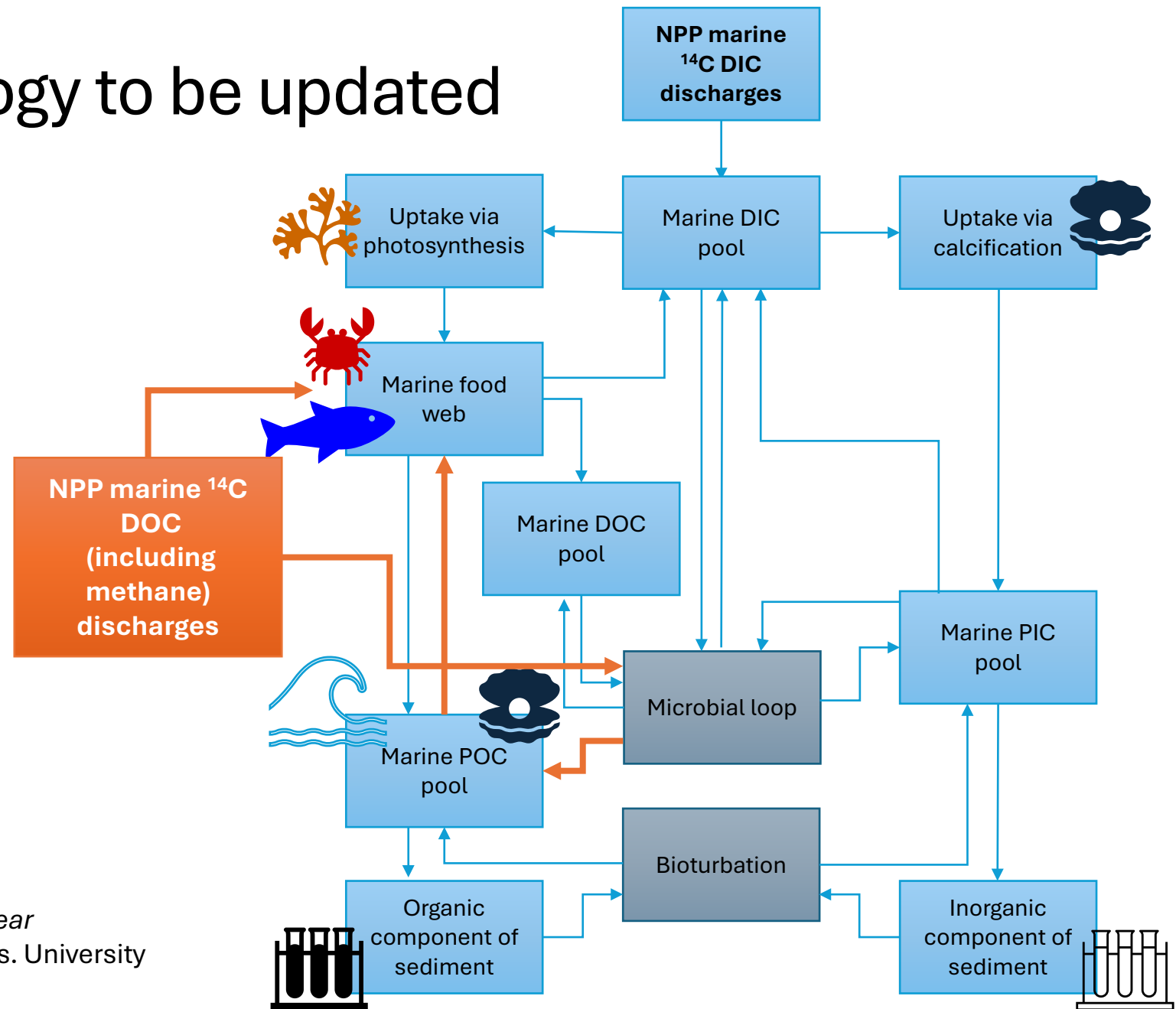


Marine radioecology to be updated

Fate of organic ^{14}C discharged in the past and present?

Heterotrophic and methane oxidizing bacteria?

Bioaccumulation/ biomagnification?



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[1] Tierney, K.M. *Marine ecosystem uptake of nuclear reprocessing derived radiocarbon (^{14}C)*. PhD thesis. University of Glasgow. 2017.

My message:

**^{14}C releases from
nuclear power plants
should be monitored!**

Source monitoring

Environmental
monitoring



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Please approach me for discussions!