Practical aspects of atmospheric corrosion

Trends, experiences from Europe,

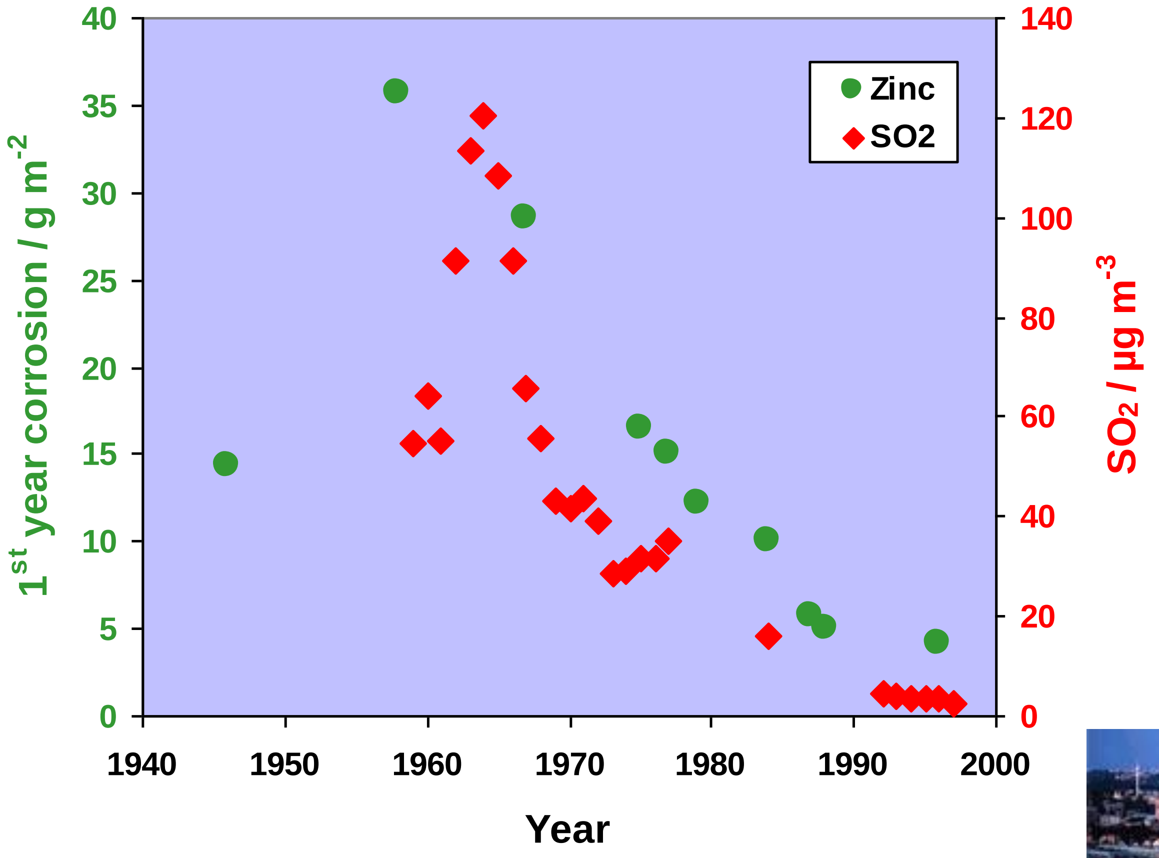
experiences from Asia/Africa

Policy aspects, costs

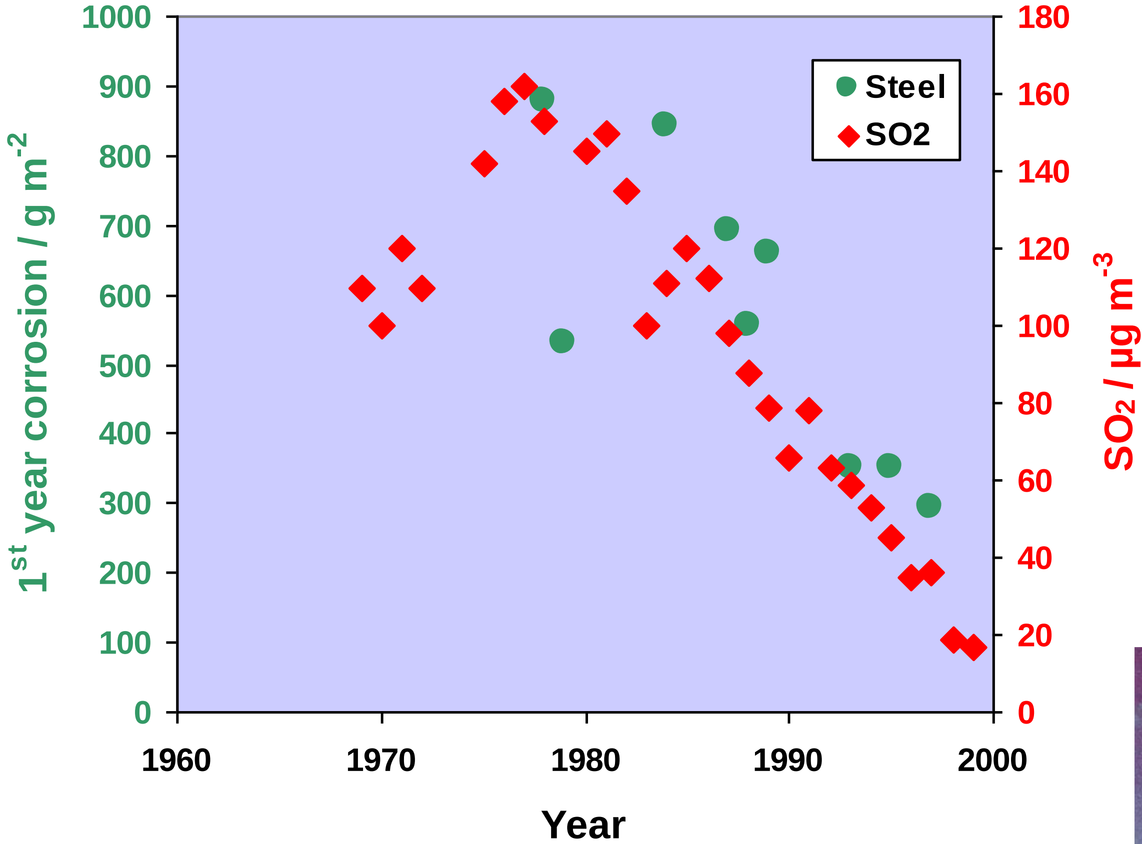
History of evidence of effects of air pollutants on materials

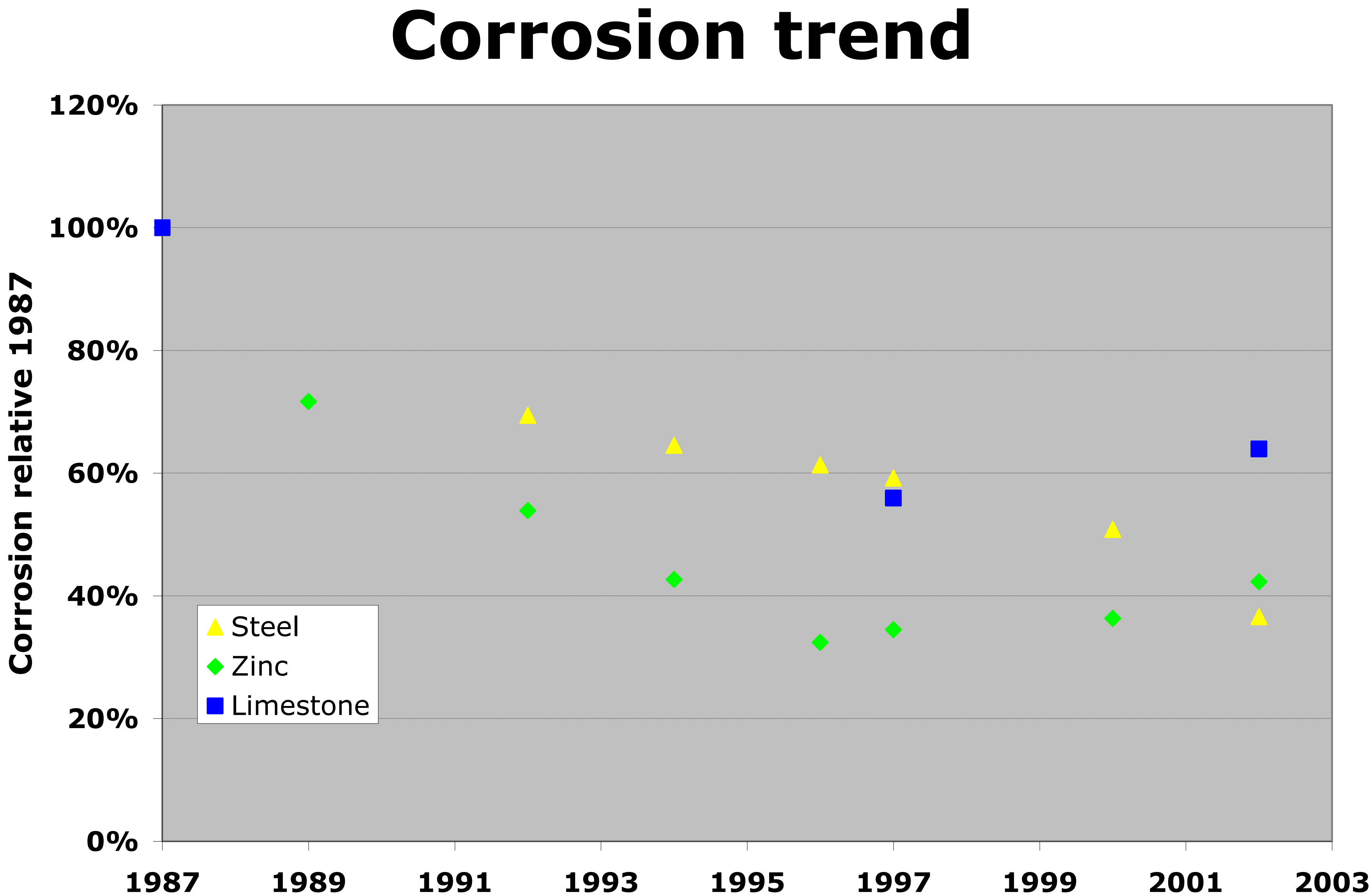
- In London an edict was issued in 1306 banning the use of 'sea-coal' as this is particularly high in chlorine
- Since the industrial revolution soiling and degradation of buildings in urban areas has been noticeable and often attributed to the effects of air pollution
- Systematic laboratory exposures in by Vernon in the 1930’s revealed the importance of SO_2
- Field exposures in Germany by Schikorr in the 1940’s revealed the practical importance of SO_2
- Field exposures in Nigeria by Ambler and Bain in the 1960’s revealed the practical importance of chlorides
- Field exposures within the Convention on Long-Range Transboundary Air Pollution (CLRTAP) lead to dose-response functions in the 1990’s

Zinc, Stockholm (Vanadis)



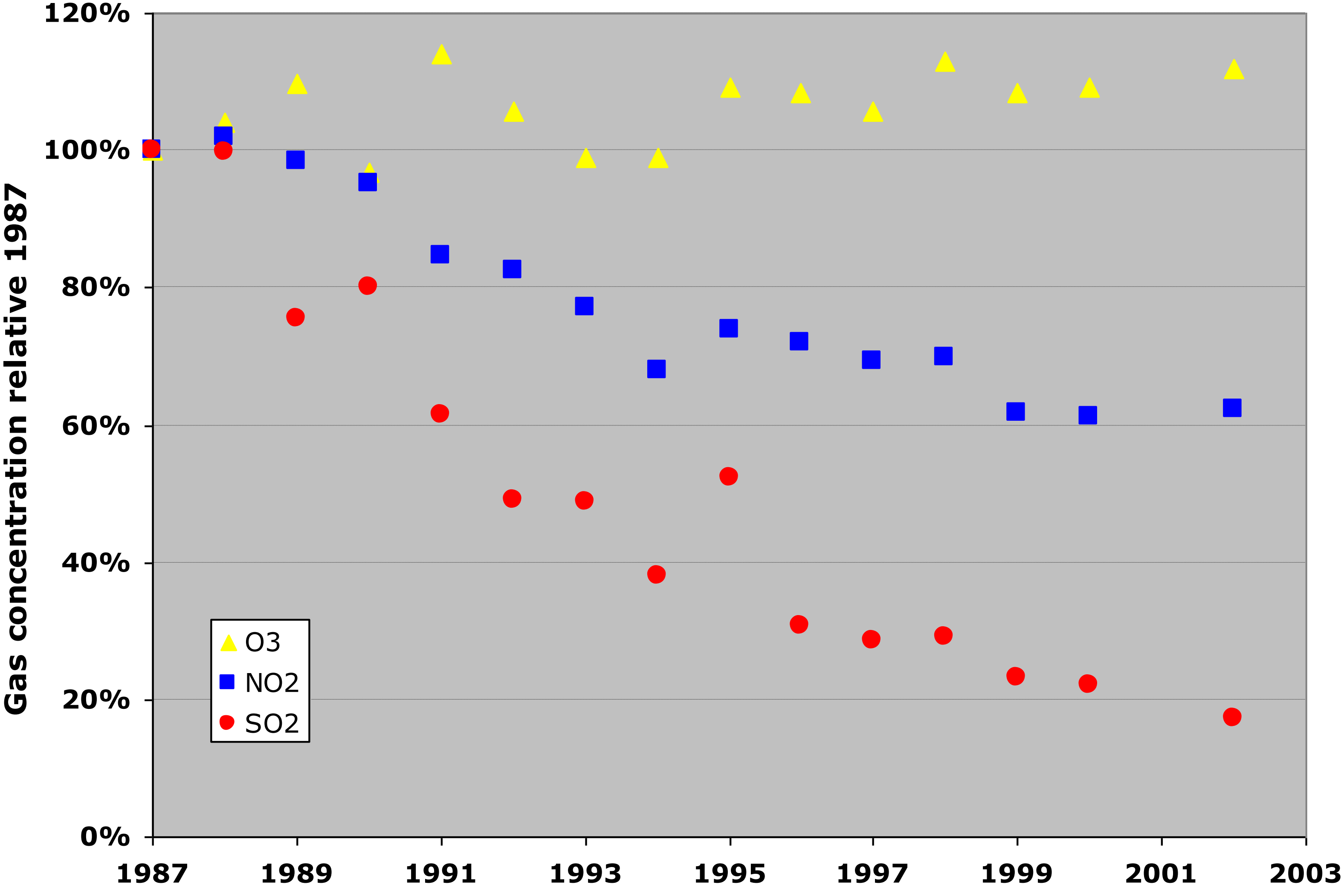
Steel, Kopisty (Czeck Republic)





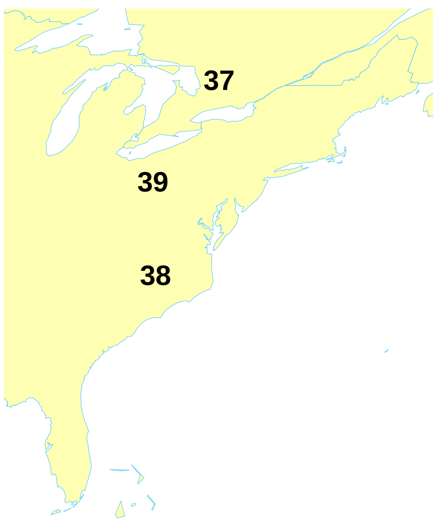
Corrosion trend
Corrosion relative 1987
120%
100%
80%
60%
40%
20%
0%
1987
1989
1991
1993
1995
1997
1999
2001
2003
Steel
Zinc
Limestone

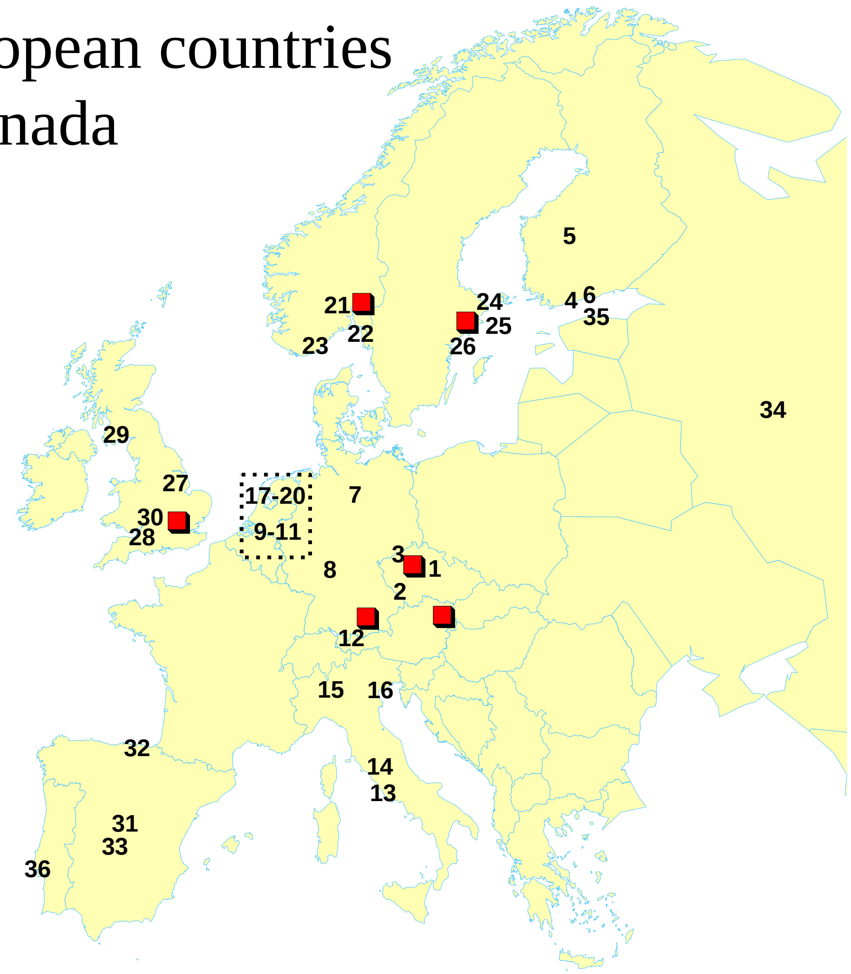
Gas concentration trend



ICP Materials - Test sites

39 (29) test sites in 12 (15) European countries and in the United States and Canada



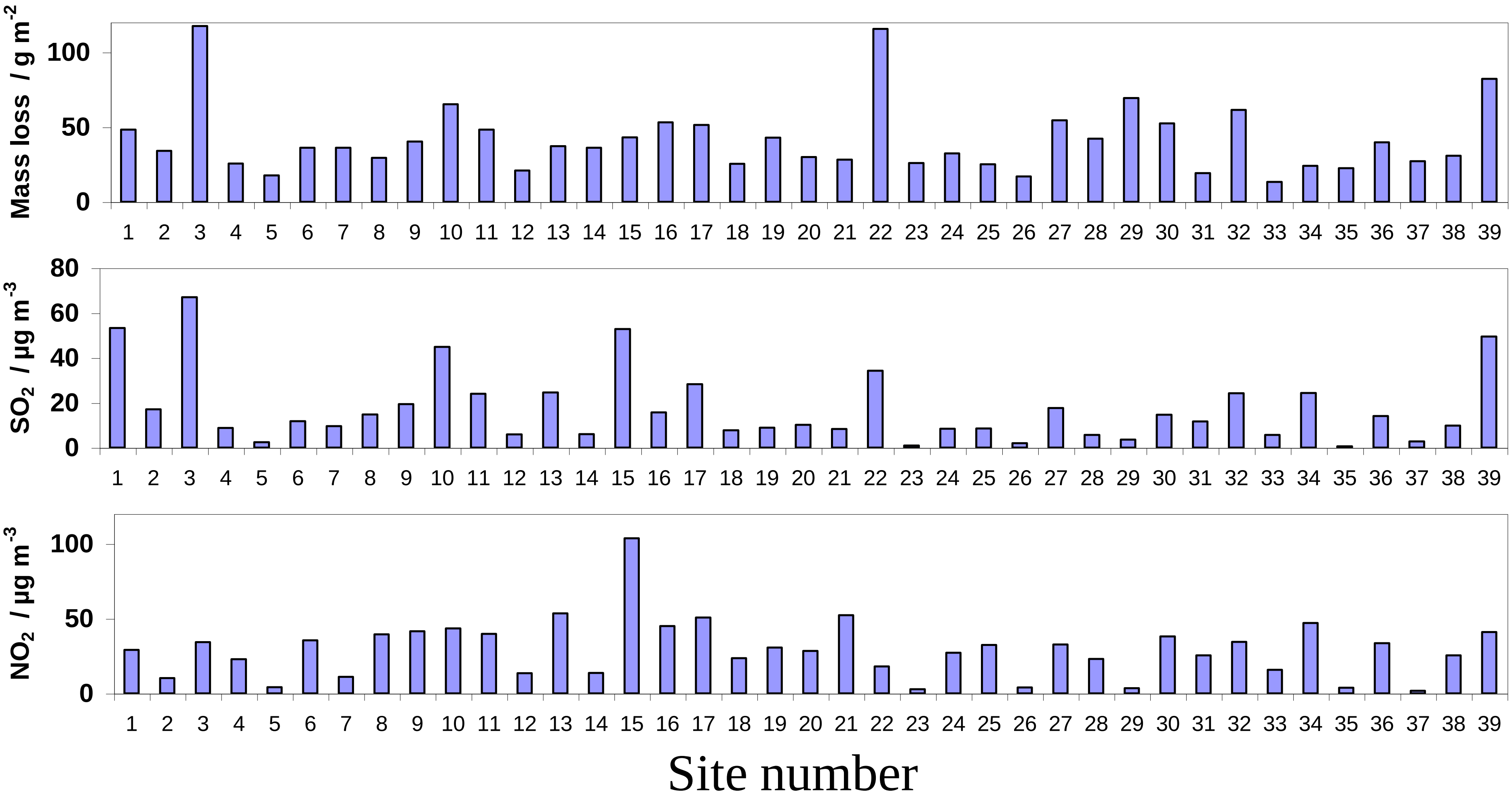


List of test sites

No	Name	Country	Type
1	Prague-Letnany	Czech Republic	Urban
2	Kasperske Hory	Czech Republic	Rural
3	Kopisty	Czech Republic	Industrial
4	Espoo	Finland	Urban
5	Ähtäri	Finland	Rural
6	Helsinki-Vallila	Finland	Industrial
7	Waldhof-Langenbrügge	Germany	Rural
8	Aschaffenburg	Germany	Urban
9	Langenfeld-Reusrath	Germany	Rural
10	Bottrop	Germany	Industrial
11	Essen-Leithe	Germany	Rural
12	Garmisch-Partenkirchen	Germany	Rural
13	Rome	Italy	Urban
14	Casaccia	Italy	Rural
15	Milan	Italy	Urban
16	Venice	Italy	Urban
17	Vlaardingen	Netherlands	Industrial
18	Eibergen	Netherlands	Rural
19	Vredepeel	Netherlands	Rural
20	Wijnandsrade	Netherlands	Rural

No	Name	Country	Type
21	Oslo	Norway	Urban
22	Borregard	Norway	Industrial
23	Birkenes	Norway	Rural
24	Stockholm South	Sweden	Urban
25	Stockholm Centre	Sweden	Urban
26	Aspvreten	Sweden	Rural
27	Lincoln Cathedral	United Kingdom	Urban
28	Wells Cathedral	United Kingdom	Urban
29	Clatteringshaws Loch	United Kingdom	Rural
30	Stoke Orchard	United Kingdom	Rural Industry
31	Madrid	Spain	Urban
32	Bilbao	Spain	Industrial
33	Toledo	Spain	Rural
34	Moscow	Russian Federation	Urban
35	Lahemaa	Estonia	Rural
36	Lisbon	Portugal	Urban
37	Dorset	Canada	Rural
38	Research Triangle Park	USA	Rural
39	Steubenville	USA	Industrial

Bronze corrosion, SO_2 and NO_2 concentrations 1987-1995



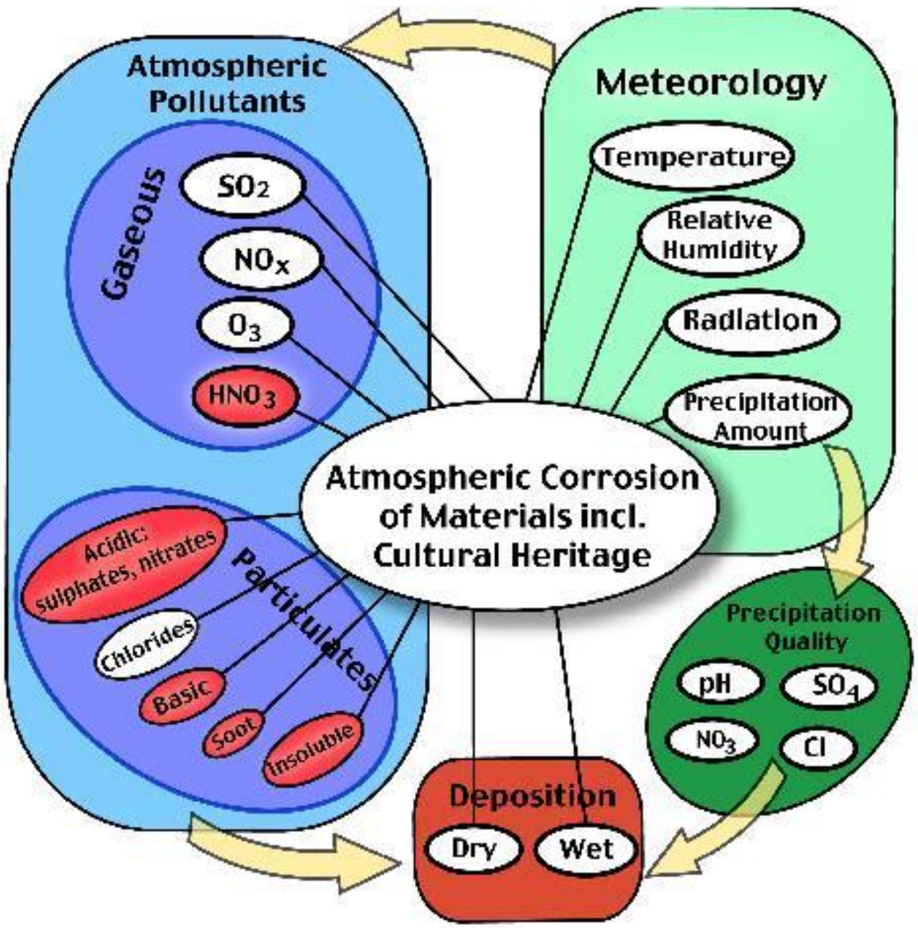
Important pollution parameters

Material	SO_2	NO_2	O_3	H^+	Cl^-
Carbon steel	x			x	
Weathering steel	x				
Zinc	x			x	
Aluminium	x				x
Copper	x		x	x	
Cast bronze	x			x	x
Nickel[a]	x	(x)			
Tin[a]			x		(x)
Alkyd/galvanised[b]	x				
Silicon alkyd/steel[b]	x				
Sandstone	x			x	
Limestone	x			x	
Glass	x	x		x	

[a]sheltered only
[b]unsheltered only

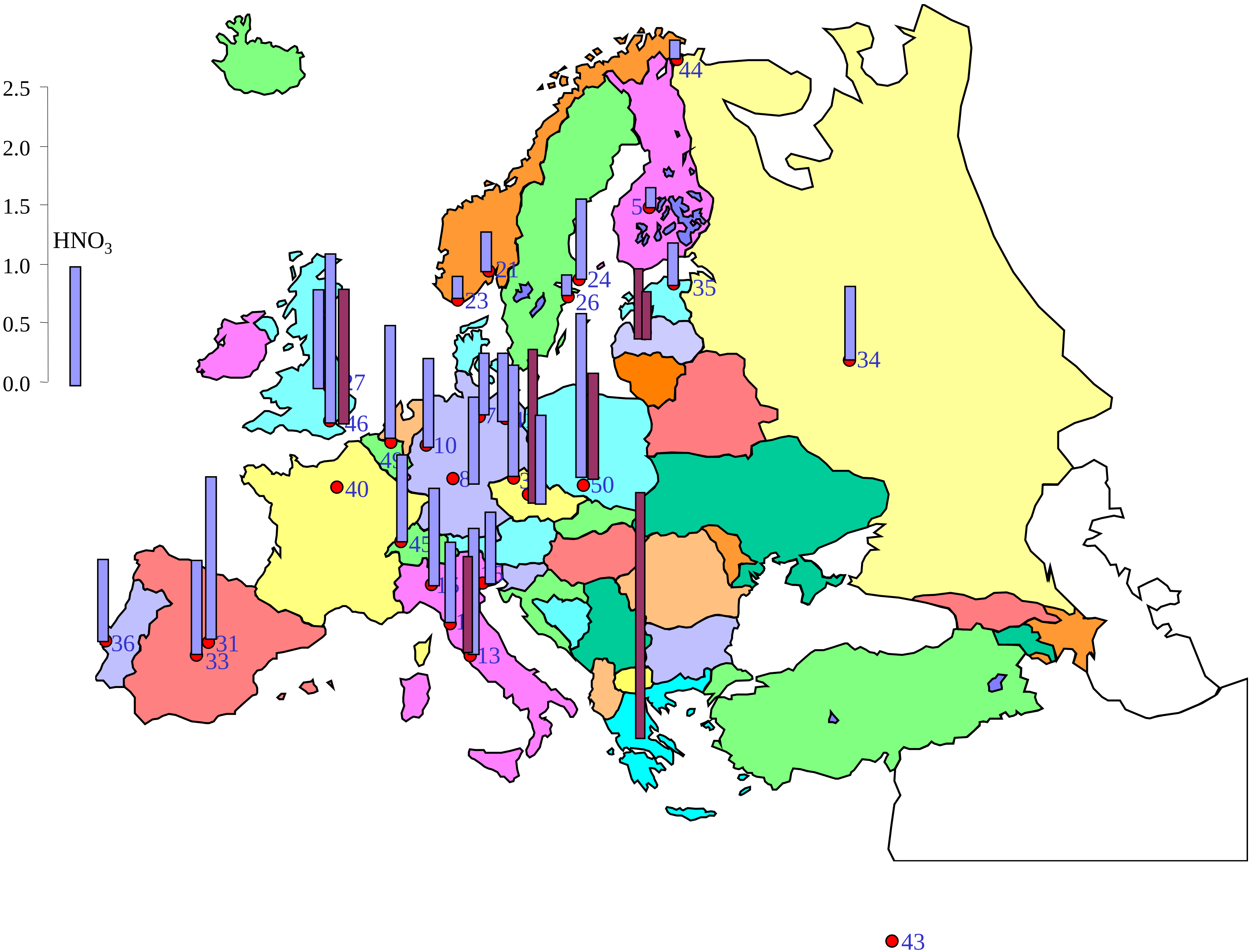
Model for multi-pollutant impact and assessment of threshold levels for cultural heritage

Interaction of atmospheric pollutants, meteorological conditions and deposition mechanisms in the process of atmospheric corrosion



Filled fields (■): MULTI-ASSESS
Unfilled fields: ICP Materials

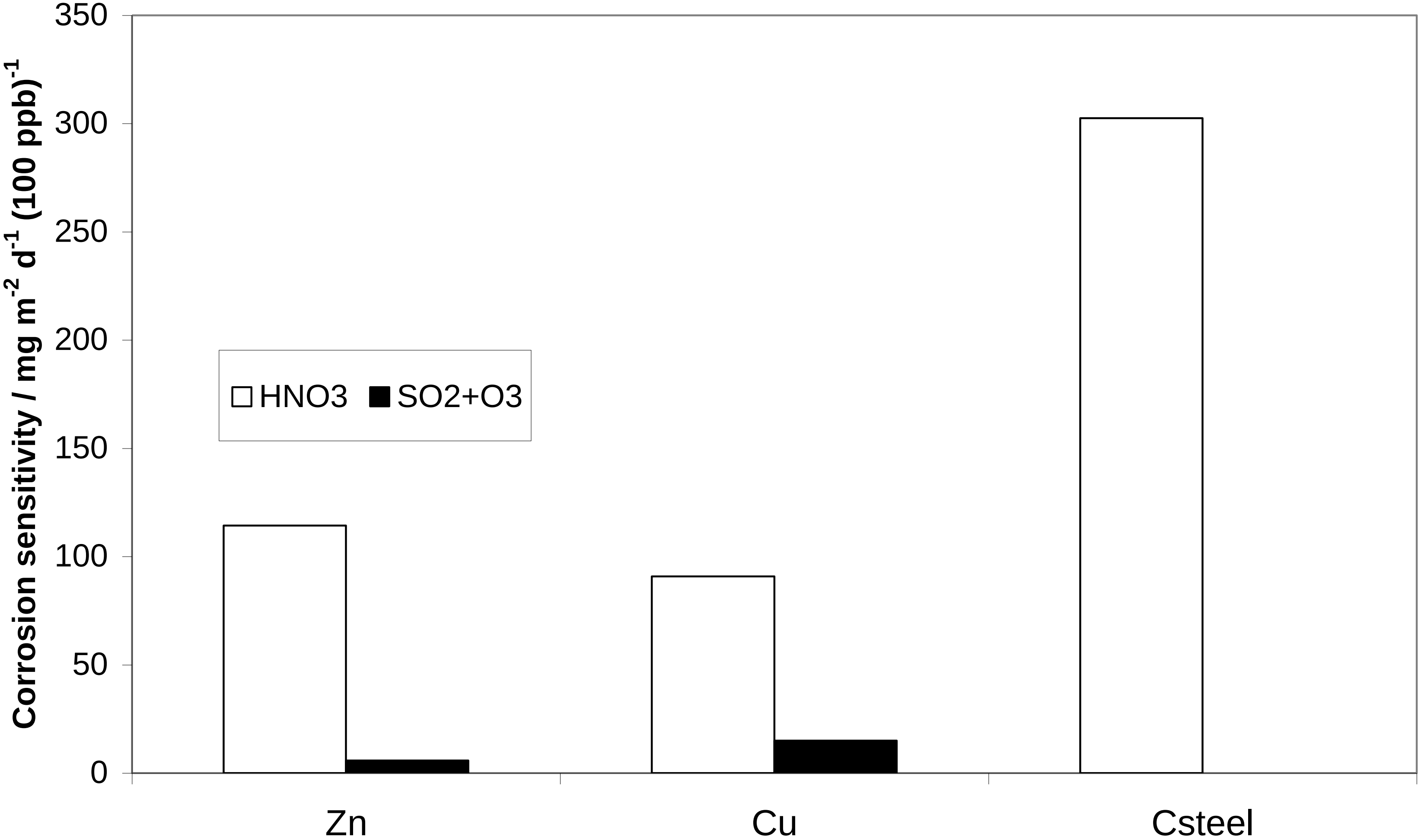
HNO_3 concentration



Important parameters in the multi-pollutant situation

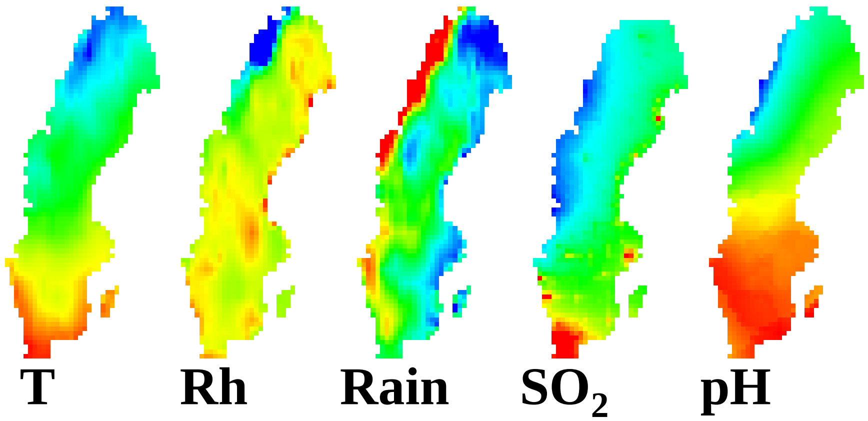
Material	T	Rh	SO_2	NO_2	O_3	HNO_3	PM_{10}	Rain	pH
carbon steel	X	X	X				X	X	X
zinc	X	X	X			X		X	X
copper	X	X	X		X			X	X
bronze	X	X	X				X	X	X
limestone		X	X			X	X	X	X
glass	X	X	X	X					

Comparison of corrosivity of HNO_3 and SO_2+O_3 in laboratory exposure



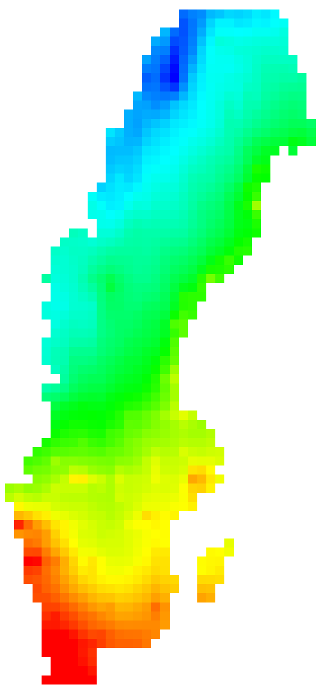
Mapping

Base maps



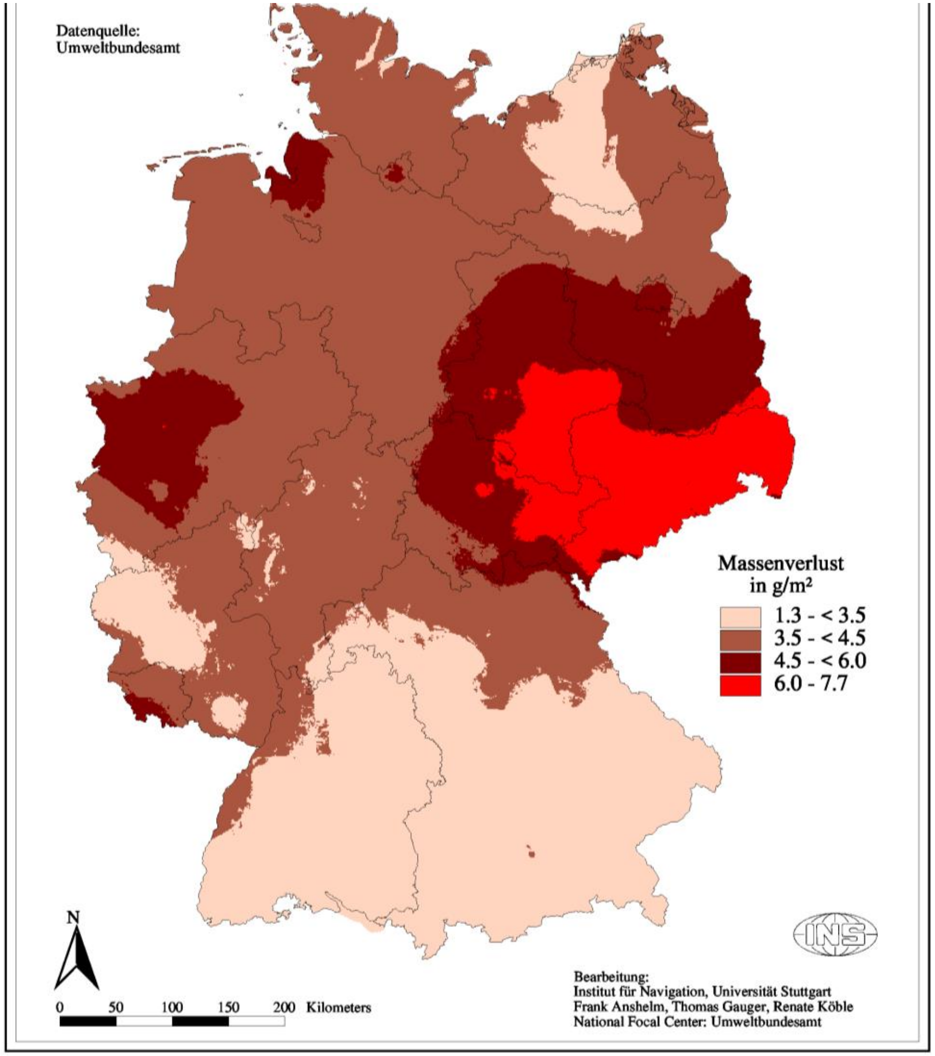
Corrosion = f(T, Rh, Rain, SO_2, pH)

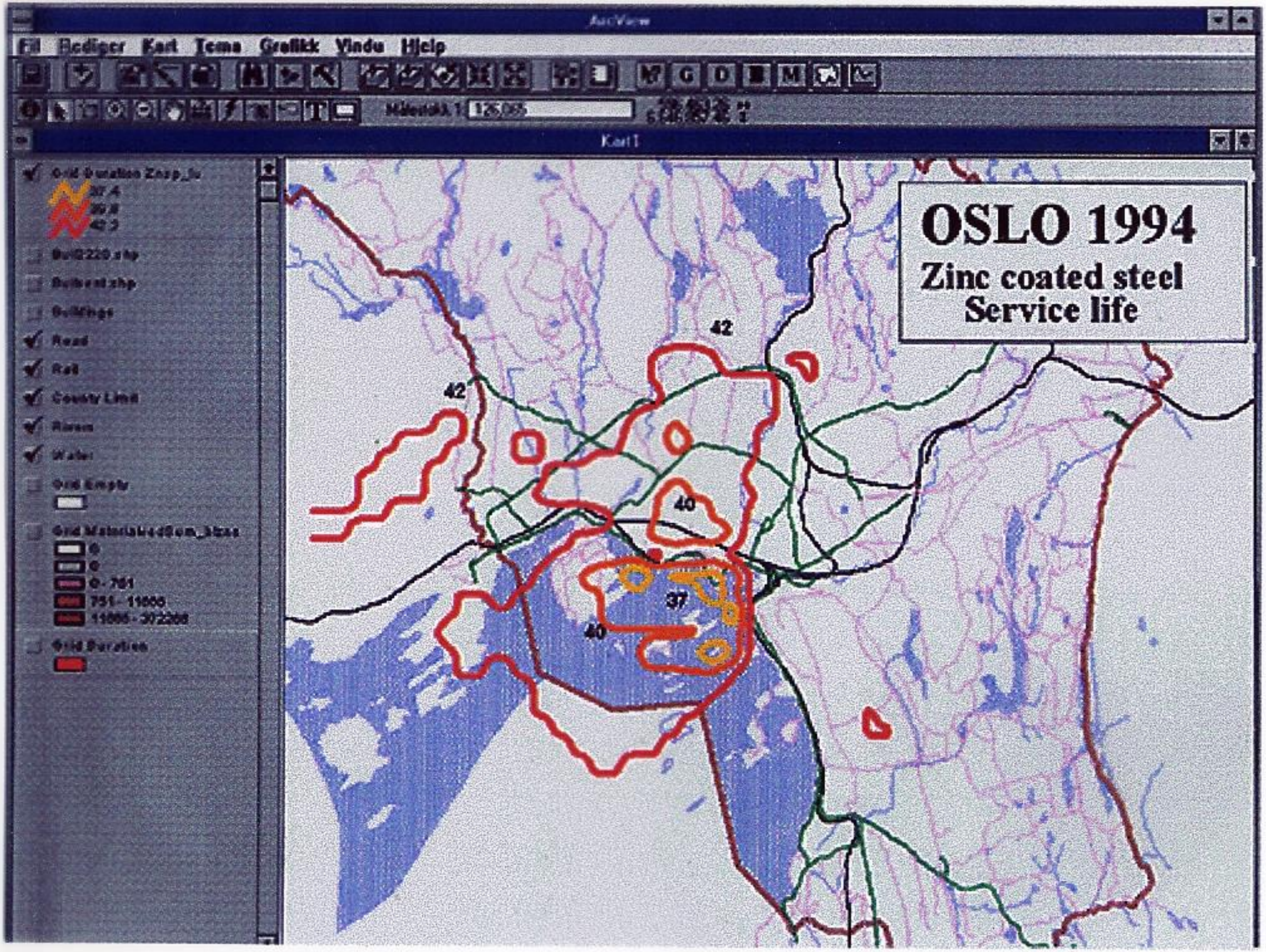
Corrosion map



Map of corrosion rate of bronze in Germany

Source:
Federal Environmental Agency, Berlin, Germany

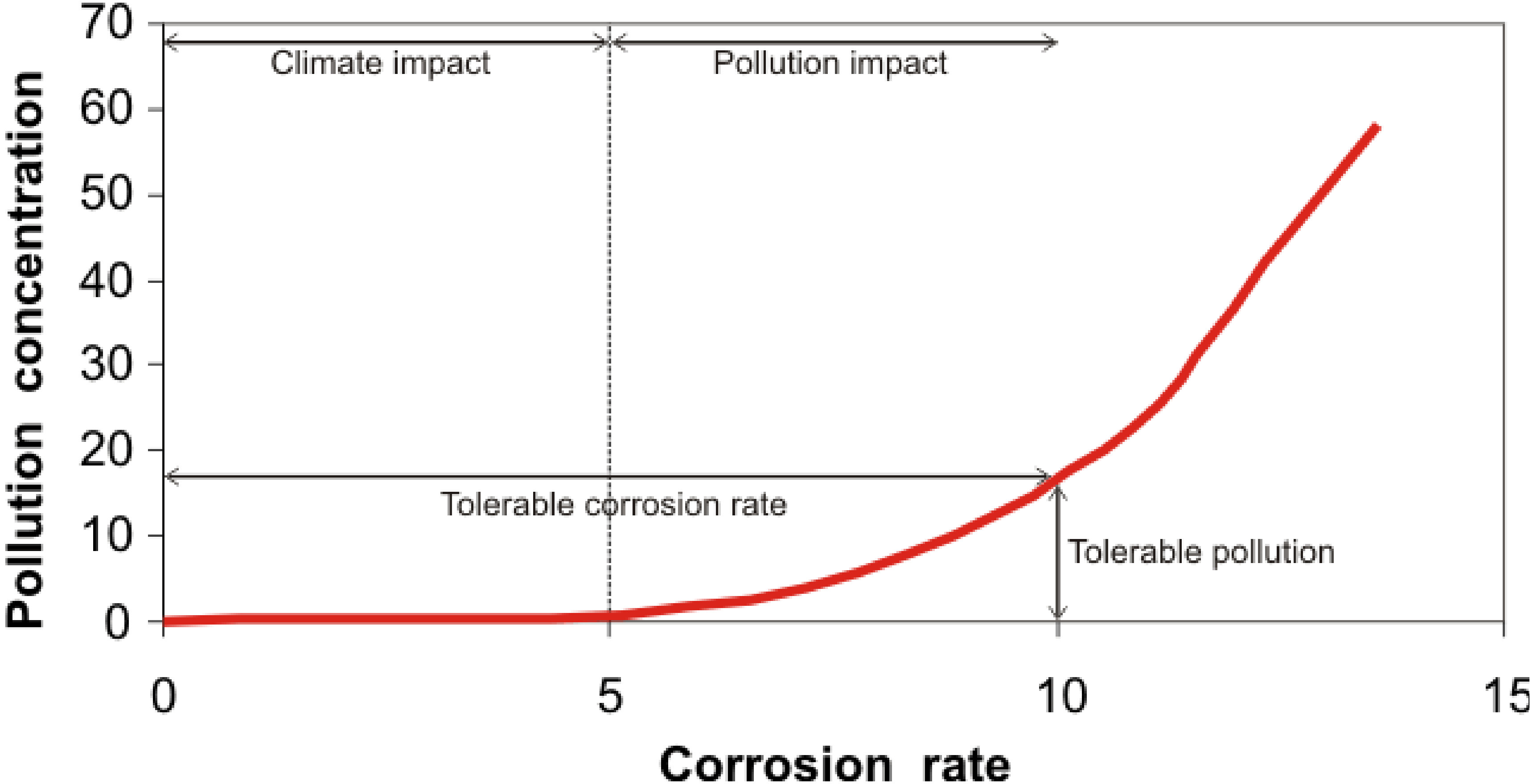



Fil Rediger Kart Tema Grafikk Vindu Hjelp
Kart1
OSLO 1994
Zinc coated steel
Service life
42
42
40
37
40

Acceptable and tolerable levels, target levels and limit values

- The **acceptable level** is the maximum level at which an acceptable response occurs. The acceptable response should be based on technical and economic considerations.
- The **tolerable level** is the maximum level at which a tolerable response occurs. The tolerable response should be based on experiences from restoration / maintenance work for cultural heritage objects.
- A **target level** is a specified level in a given context which should not be exceeded.
- A **limit value** is a target level that is legally binding.

Tolerable corrosion and pollution



Tolerable pollution levels in the multi-pollutant situation

Definition of a tolerable corrosion rate, K_t, depending on use and material, implicitly defines a tolerable multi-pollution situation, which can be reached by reducing one or several of the multi-pollutants:

$$K_t = f_{dry}(T, RH, [SO_2]_t, [HNO_3]_t, ...)$$

$$+ f_{wet}(Rain[H^+]_t)$$

Recent information on effects-based approaches for the Protocol reviews

Table 4.0 Effects, important parameters and proposed target levels for materials

Effect	Material	SO_2	HNO_3	PM	Tolerable effect	Target SO_2 level[a]	Target PM10 level
Corrosion	Zinc	X	X		1.1 µm $year^{-1}$	10 µg m^{-3}	
	Carbon steel	X		X	20 µm $year^{-1}$		
	Limestone	X	X	X	8 µm $year^{-1}$		
Soiling	Painted steel			X	35% loss of reflectance in 10-15 years		15 µg m^{-3}
	White plastic			X			
	Limestone			X			

[a]this level will protect about 80% of the areas. For a complete protection, levels of N-pollutants, especially HNO_3 also need to be considered.

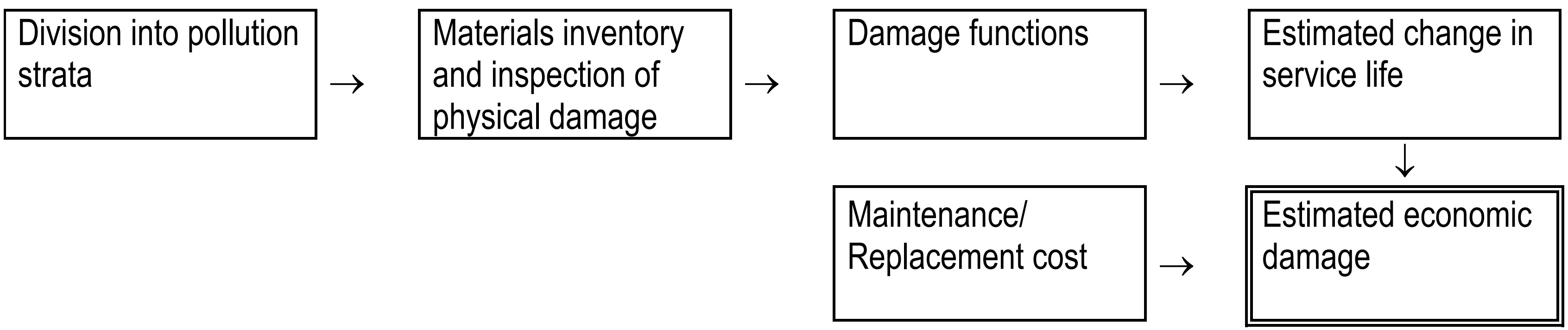
Source: MULT-ASSESS Publishable final report, www.corr-institute.se/MULTI-ASSESS

Air Quality Directive 99/30/EC

Limit values of pollutants, $\mu g\ m^{-3}$

	SO_2	NO_2	PM_{10}
Urban zones – health effects			
Hourly limit value	350	200	
Daily limit value	150		50
Annual limit value		40	40
Rural areas - ecosystems			
Annual limit value	20	30	

Assessing corrosion costs



Corrosion costs

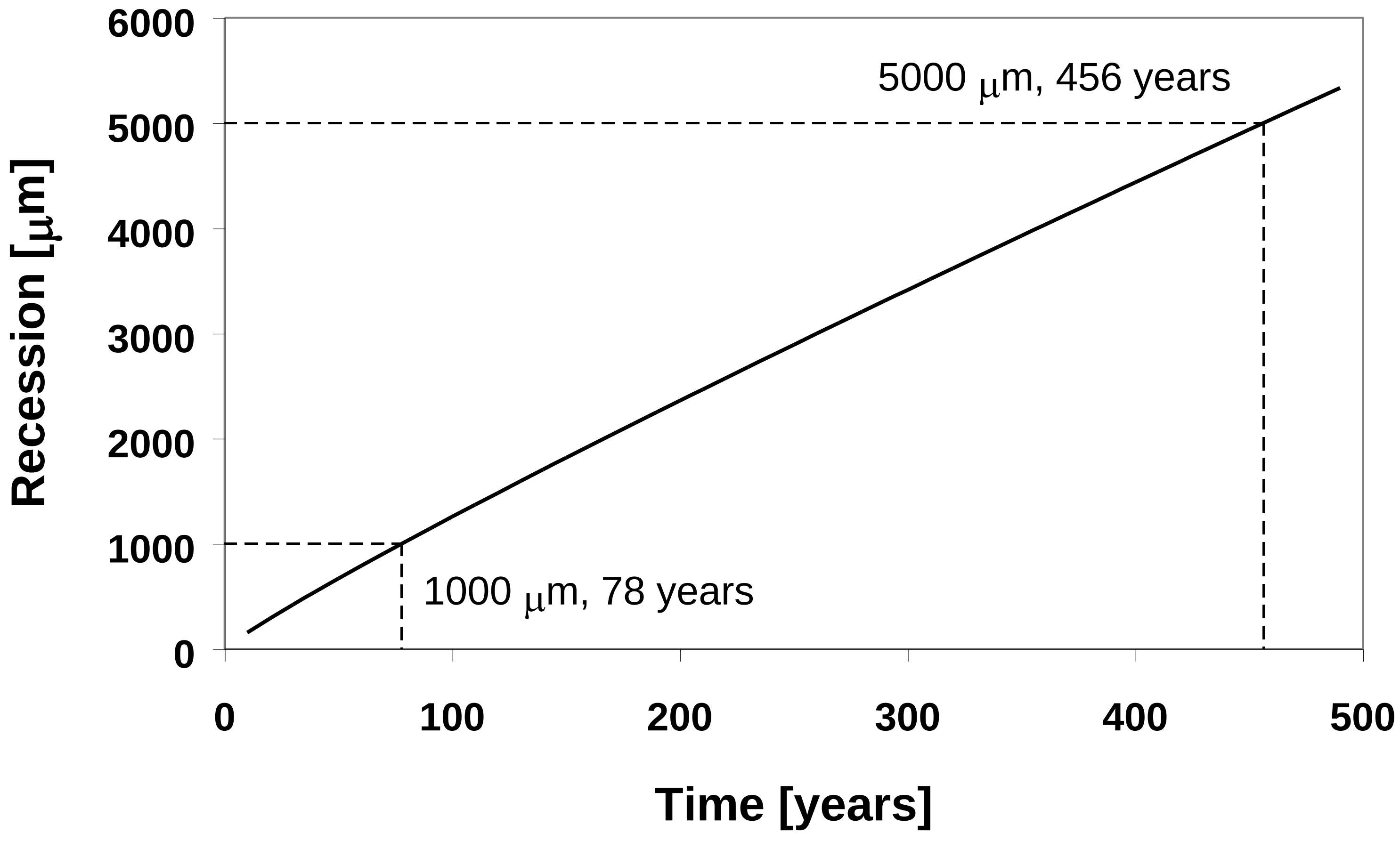
Specification of a level of corrosion attack where replacement or maintenance is necessary makes it possible to calculate the lifetime, t:

$K = f_{dry}(T, RH, [SO_2], t) + f_{wet}(Rain[H^+], t)$

Stock at risk + lifetime $\Rightarrow$ Corrosion costs

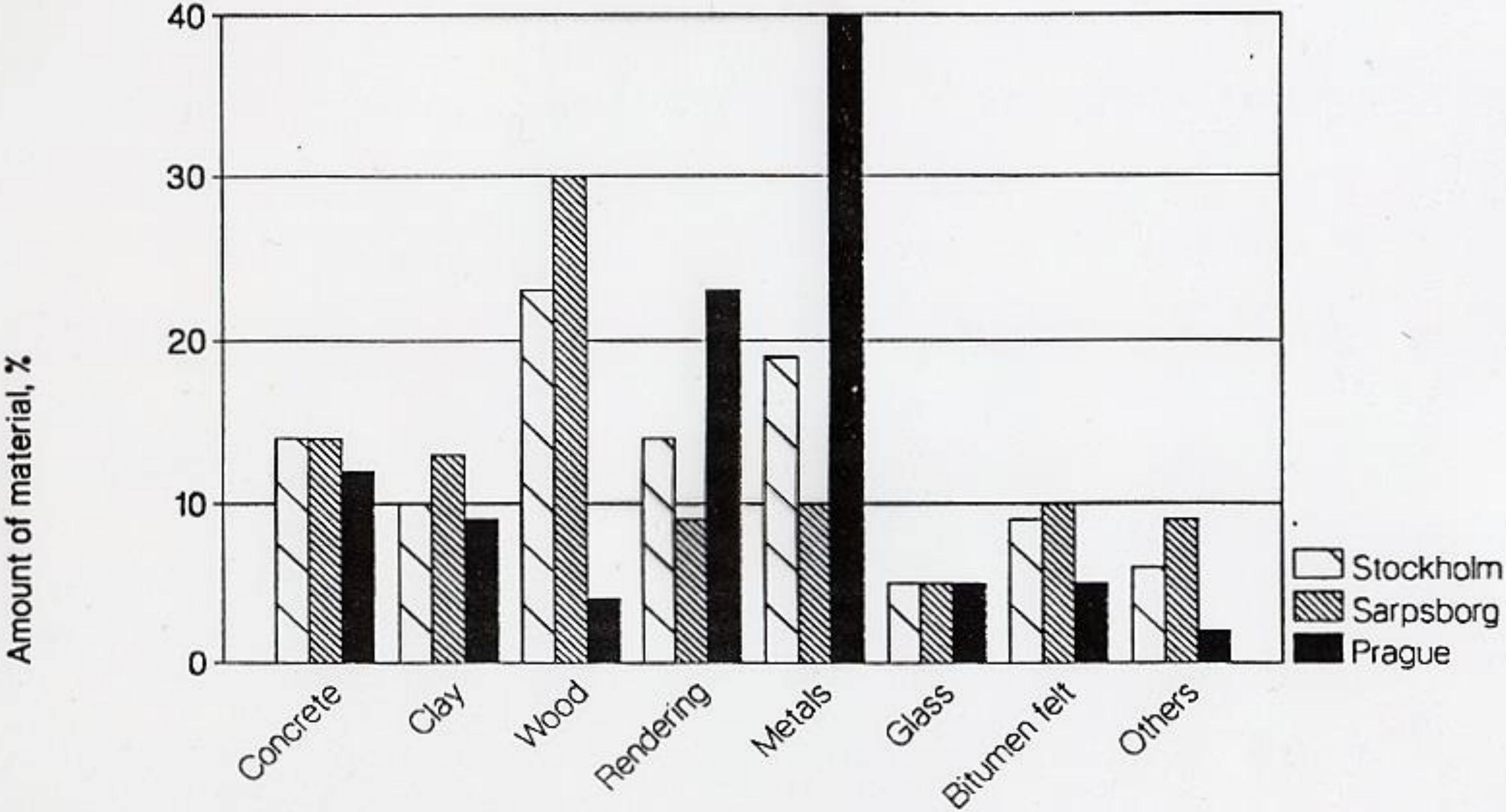
Sandstone

Critical thickness for	technical objects	ornaments and inscriptions
	R_{crit} = 5 mm = 5000 μm	R_{crit} = 1 mm = 1000 μm



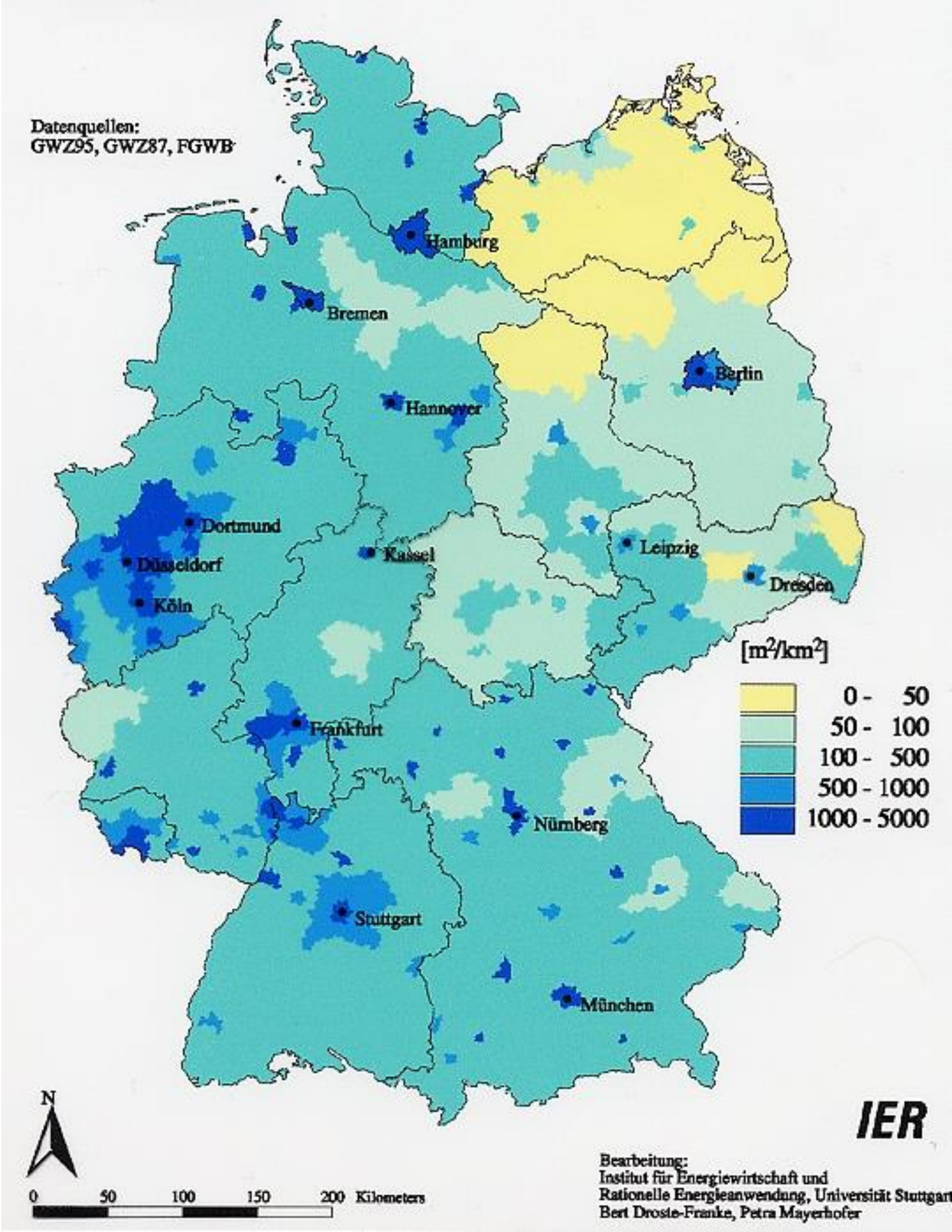
Estimation of stock at risk

- Inspection (Individual building)
- Building Registers (District/City)
- Identikits (National)
- Allocation to census data (Regional)

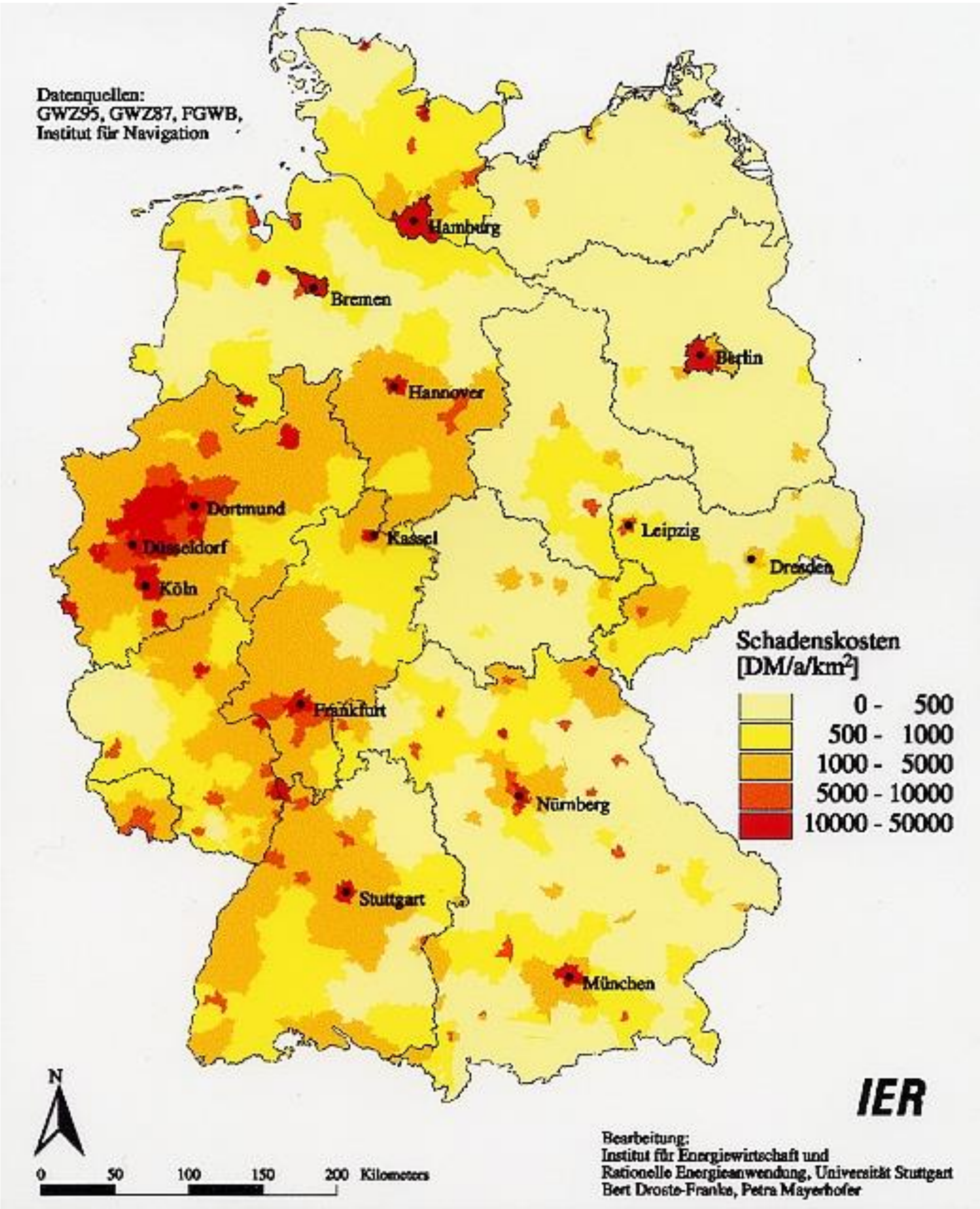


External building materials in Stockholm, Sarpsborg and Prague

Stock at risk of galvanised steel in Germany in m²/km²



Yearly corrosion cost of galvanised steel in Germany due to pollution (DM/km^2)

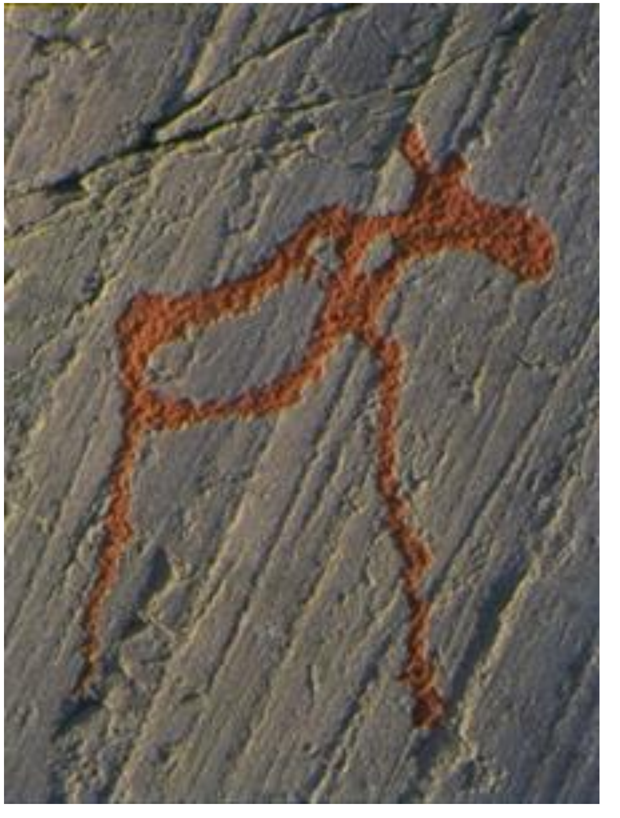


Reduction of costs due to decreased corrosion damage after execution of the 2nd sulphur protocol (US$·$10^6$)

	Rural areas	Urban areas	Total
Eastern Europe	3 700	2 100	5 800
Western Europe	3 000	700	3 700
Total	6 700	2 800	9 500

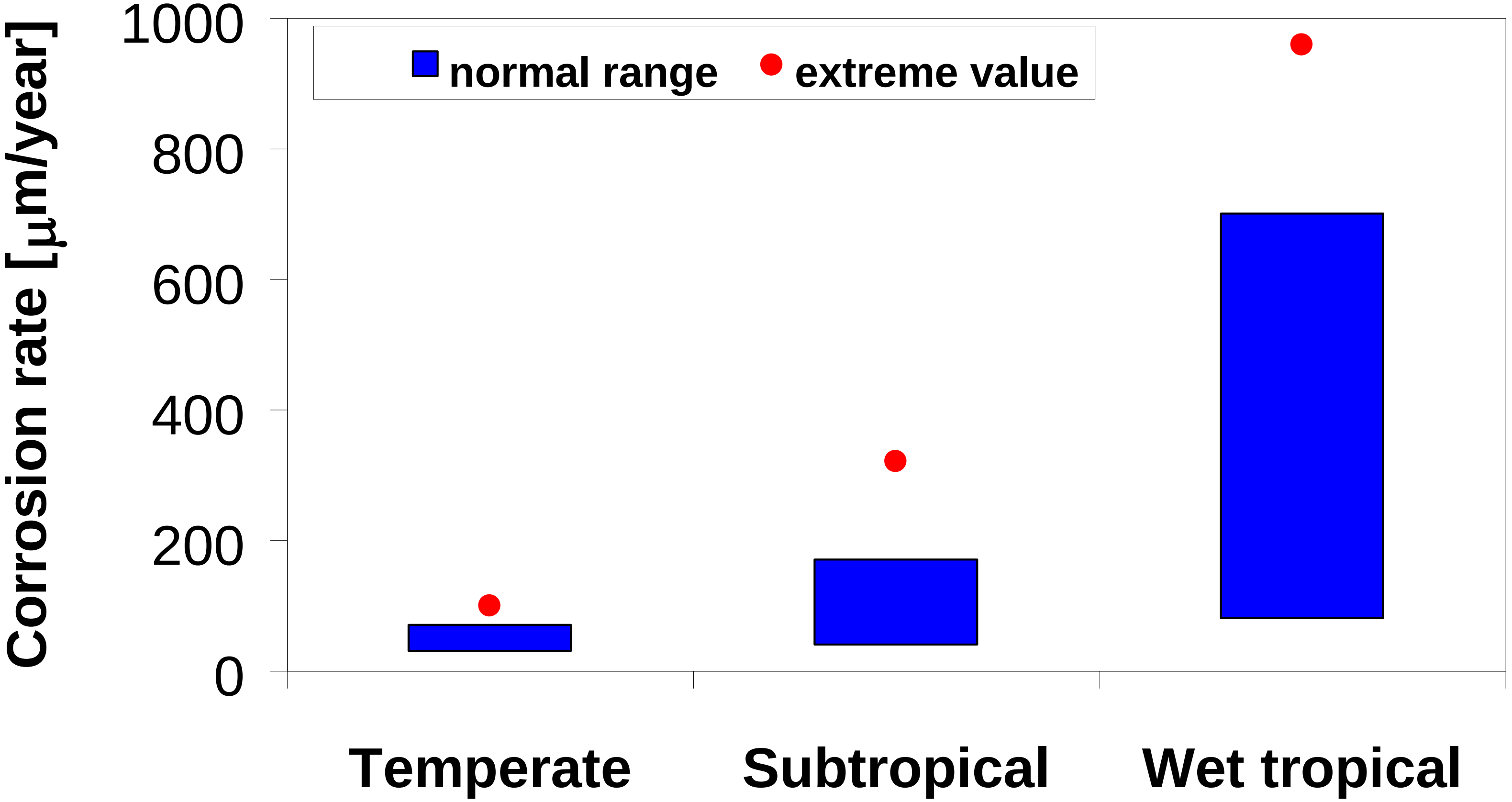
Quantification of costs and benefits for cultural heritage

- Difficult to express in monetary terms the loss of objects of cultural heritage
- Indirect method for calculation of costs
  - willingness to pay (contingent valuation method)
- Direct benefits (reduced maintenance etc)
- Indirect benefits (incomes from tourism, increased employment etc)



Rock Carving in Tanum, Sweden

Evidences of high corrosion rates



Results from Europe not transferable