Supplement to: *The 2022 Drought Needs to be a Turning Point for European Drought Risk Management*

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Abstract

The 2022 European drought has underscored critical deficiencies in European water management. This paper delves into these shortcomings and suggests a way forward for European drought risk management using a Europe-wide survey among water managers involved in the 2022 event. Information from the survey is enriched with climate-related information to offer a comprehensive overview of drought risk management in Europe. Our research focuses on four key aspects: the increasing risk of drought, its spatial and temporal impacts, current drought risk management approaches, and the evolution of drought risk management across the continent.

Our findings reveal a consensus on the growing risk of drought, which is confounded by the rising frequency and intensity of droughts. While the 2022 event affected most of the continent, our findings show significant regional disparities in drought risk management capacity among the various countries. Our analysis indicates that current drought risk management measures often rely on short-term operational concerns, particularly in agriculture-dominated economies, leading to potentially maladaptive practices. Finally, the study clearly shows an overall positive trend in drought risk management, with organizations showing increased awareness and preparedness. Still, our results also show awareness growing faster than preparedness, indicating how this crisis can be the ideal moment to mainstream European-wide drought risk management.

The study stresses the need for continent-wide coordination in drought risk management. Consequently, we advocate for a European Drought Directive, to harmonize and enforce drought risk management policies across the continent. This directive should promote a systemic, integrated, and long-term risk management perspective. Key principles should include managing drought risk holistically, recognizing droughts as continuous and systemic events, and prioritizing environmental sustainability and water demand reduction. The directive should also set clear guidelines for drought risk management at the national level and for cross-boundary drought collaboration.

This study and its companion paper *The 2022 Drought Shows the Importance of Preparedness in European Drought Risk Management* are the result of a study carried out by the Drought in the Anthropocene (DitA) network.

S1. Questionnaire

S1.1 Content of the questionnaire

Impacts and response during the 2022 European drought - questionnaire
Over the span of just five years, Europe has been hit by two major drought events, the 2018-2019 drought, and 2022 drought which is still ongoing in parts of Europe. In particular, the latter has been reported as being the worst drought hitting the

continent in 500 years. While drought risk has risen on the agenda in many European countries, Europe is still largely unprepared to manage severe, spatially large and recurring drought events with no European-wide drought management schemes in place.

The Panta Rhei Drought in the Anthropocene working group is an interdisciplinary organization of researchers investigating drought impact and management. This questionnaire was devised to collect information from water managers and managers of drought-affected sectors that can be used to further our knowledge of drought impact and management from a European perspective. With your collaboration you will be contributing to the advancement of the knowledge on drought in Europe. By responding to this questionnaire you are giving your consent to use this data for scientific purpose. Please, take 15 minutes of your time to answer to this questionnaire.

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1. What type of organization do you belong to? _____

2. At which level does your organization operate?

3. In which country is your organization located?

4. In which municipality/region do you operate (name, region, country)?

5.a. How does your organization identify that drought is happening?

- Based on analysis of indices (e.g. SPEI; SPI...)
- Based on observed impact
- Based on external reporting (e.g. bulletin from the meteorological service)
- Based on internal reporting
- My organization doesn't have a systematic way to define it
- I don't know

5.b. Does your organization use a forecasting system?

- Yes, seasonal forecast (1-7 months)
- Yes, sub-seasonal (0-5 weeks)
- Yes, both seasonal and sub-seasonal
- No
- I don't know

I. Impacted sectors

The following questions regard the sectors which are present in your area of operations, or that your organization manages directly. For multiple choice questions, you can leave the non-relevant sectors empty.

6. Which sectors does your organization operate in?

- Agriculture and Livestock Farming
- Forestry
- Freshwater Aquaculture and Fisheries
- Energy and Industry
- Waterborne transportation
- Tourism and Recreation
- Public Water Supply
- Water Quality
- Freshwater ecosystems: habitats, plants and wildlife
- Terrestrial ecosystems: habitats, plants and wildlife
- Soil system
- Wildfires

- Air quality
- Human health and public safety
- Conflicts
- Other

7. How severe was the impact of the 2022 drought on a scale from 1 (Not affected) to 5 (Severe)?

8. How severe was the impact of the 2022 drought compared to the 2018-2019 drought event?
- Less severe
- Same
- More severe
- I so not know
- Not relevant

9. When was the impact first seen (month)?
- Before March 2022
- March 2022
- April 2022
- May 2022
- June 2022
- July 2022
- August 2022

10. Which sectors were prioritized in the distribution of water resources?
- Low priority
- Medium Priority
- High priority
- I do not know

II. Cascading hazards

Sometimes, droughts can trigger other related hazards. You can leave the non-relevant hazards empty.

11. Have you observed any other hazard connected to the drought? When did it take place compared to the start of the drought?
- Coastal flooding
- Heavy rains
- Cold spell
- Disease outbreak
- Hail
- Heatwave
- Landslides
- Riverine flooding
- Smog
- Strong winds
- Wildfires

11.a. Write here if you observed hazards which are not on the list (optional)

III. Drought management

Drought management measures are aimed at mitigating drought risk or impact. These measures can be both proactive (if taken before the onset of the drought) or reactive (if taken after the onset). One example of drought management measure taken is the reduction of output of a power plant to reduce the temperature in the cooling tower due scarcity of cooling water.

12. What were the main measures taken by your organization?

13. When did your organization take measures to mitigate the impact of the 2022 drought?

14. How effective were the measures taken?
- Very effective
- Not effective
- I do not know
- Not relevant

IV. Drought management plan

A drought management plan is a framework for enacting drought management within an organization. This can either be specific for drought, or drought can be one of the risks present in a multi-hazard plan. Plans can be either designed for short-term response to drought, or management strategies aimed at making the organization more resilient to drought in the long term.

15. Does your organization have a drought management plan or a contingency plan for droughts both for the short-term response and the long-term (multi-year) management?
- Yes, both short-term response and long-term management plans
- Yes, only short-term response plan
- Yes, only long-term management plan
- No, we do not have either
- I don't know

16. Has your organization introduced or updated its drought management plan and/or contingency plan since 2018?
- Yes, both plans have been introduced after 2018
- Yes, only short-term response plan has been introduced after 2018
- Yes, only long-term management plan has been introduced after 2018
- No, we already had both plans before 2018
- No, we do not have any plan
- I don't know

V. Drought risk

Drought risk is the likelihood that a drought will cause damage and losses. It depends on the interactions between the severity of the drought event and how much society and the environment are susceptible and exposed to said drought.

17. Compared to the 2018-2019 drought, your organization was…
- (More , same , less , I do not know)
- Aware
- Prepared
- Effective in the response

18. Do you think that the risk posed by droughts is…
- Increasing
- Unchanged
- Decreasing

· I do not know

18.a. Elaborate (optional)

19. Do you expect the drought to become a more significant risk to manage for your organization in the future?
· Yes
· No
· I do not know

19.a. If yes, how is drought management changing in your organization (optional)

20. Please, leave us your email if you want to receive updates on the development of the research.

Thank you for your contribution!

S1.2. Links to questionnaires

Below are listed the links to the questionnaires that were created in all the available languages.

English:
https://docs.google.com/forms/d/e/1FAIpQLSeomRgskDrjK1WBYaMSWvGudv7ZhcfDFnkHk5vGAfEWohy3FQ/viewform?usp=sharing
German:
https://docs.google.com/forms/d/e/1FAIpQLScy3fTctPfB9KPlj6iHj6o_wXqyd5hGtU2orJ9X1QvEcuVvbg/viewform?usp=sharing
Italian:
https://docs.google.com/forms/d/e/1FAIpQLScy6IcBFfodRK8vePDoA1eYBOIaVcfTPQ63QHgyr2PzAkhbtA/viewform?usp=sharing
Dutch (NL):
https://docs.google.com/forms/d/e/1FAIpQLScT2dUAV36-lPb3WO0vbmakJGsGIkT9o9rMzl-rsENw8Th-Qw/viewform?usp=sharing

Ukrainian:
https://docs.google.com/forms/d/e/1FAIpQLSfIGvSapTqRi80sd9TtTNvd1ED2l9jsp4jnLxn4BoAYtxCO3A/viewform?usp=sharing
Hungarian:
https://docs.google.com/forms/d/e/1FAIpQLSd0Gbvge5mjHT2U_3bZoTuohvGUBcr7dgr6g_vRUIm-OsWwbQ/viewform?usp=sharing
Turkish:
https://docs.google.com/forms/d/e/1FAIpQLSdKlcdVYBjcX0l4zfoRaf3ejTx3rmm1q0xN5WSbV3_ehRYKeA/viewform?usp=sharing
Portuguese:
https://docs.google.com/forms/d/e/1FAIpQLSec3lOpMSG0qSQS_Cp4fwI3VlUhp-lQ7Tm7JAwpoMSa3Dadew/viewform?usp=sharing

French:
https://docs.google.com/forms/d/e/1FAIpQLScIjfR63i1Fy7cxMctX--iclRdc2CxB3aWOVox2ynGAM4L-bQ/viewform?usp=sharing
Polish:
https://docs.google.com/forms/d/e/1FAIpQLSd3VU7k5ImWaNF4VQP8v7h5MKbqsis0n-KJzzcK7Zr3MZbCcA/viewform?usp=sharing
Spanish:
https://docs.google.com/forms/d/e/1FAIpQLSd3VU7k5ImWaNF4VQP8v7h5MKbqsis0n-KJzzcK7Zr3MZbCcA/viewform?usp=sharing
Swedish:
https://docs.google.com/forms/d/e/1FAIpQLSfWdMLtuI3gzHm9MvrGuc6tw4E5A0RYhkjdIpoRoyU_6tKGqg/viewform?usp=sharing
Romanian:
https://docs.google.com/forms/d/e/1FAIpQLSfMyCX1Fyp_fY6guwMAPGX4n1Dn4t4j0v1e1JYvvZcZXxFABw/viewform?usp=sharing
Czech:
https://docs.google.com/forms/d/e/1FAIpQLSfMyCX1Fyp_fY6guwMAPGX4n1Dn4t4j0v1e1JYvvZcZXxFABw/viewform?usp=sharing
Croatian, Bosnian, and Montenegrin:
https://docs.google.com/forms/d/e/1FAIpQLSfMyCX1Fyp_fY6guwMAPGX4n1Dn4t4j0v1e1JYvvZcZXxFABw/viewform?usp=sharing
Russian:
https://docs.google.com/forms/d/e/1FAIpQLSdpp-NnENqs0Kzk-rH3jZr-UJaBsHLnJUf0BK8BzOEwqqWrUA/viewform?usp=sharing
Serbian:
https://docs.google.com/forms/d/e/1FAIpQLSdpp-NnENqs0Kzk-rH3jZr-UJaBsHLnJUf0BK8BzOEwqqWrUA/viewform?usp=sharing

S2. Overview of the responders

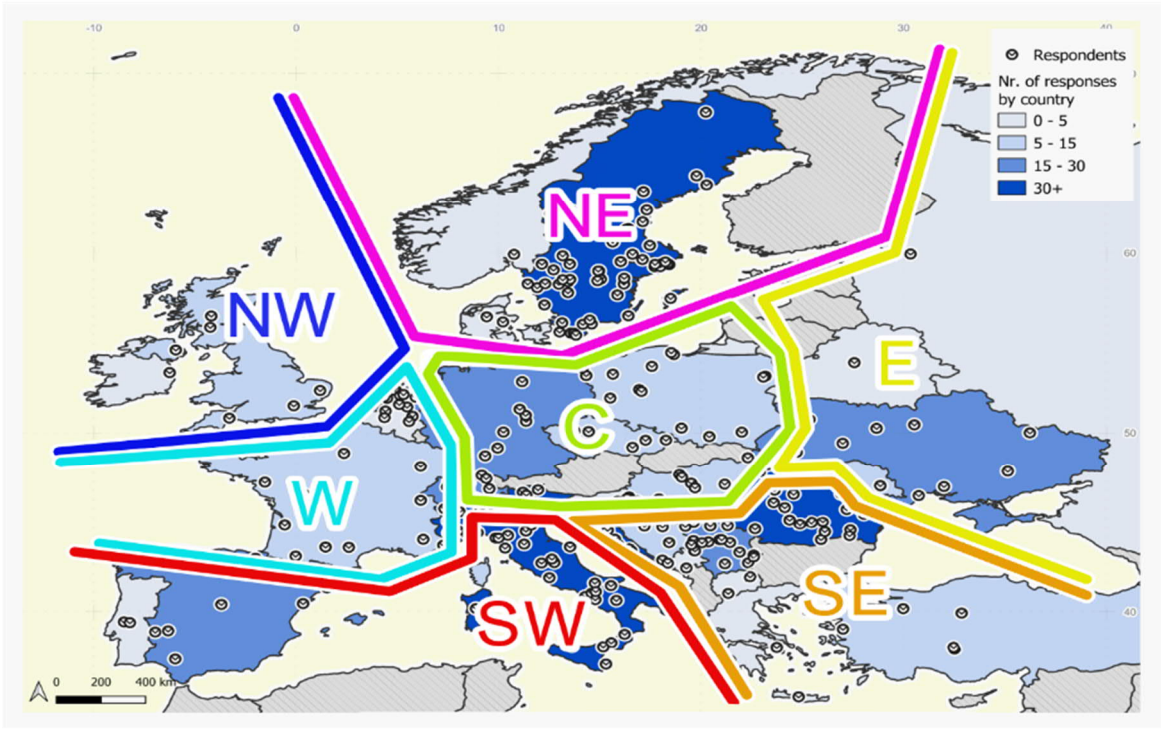

Figure S1 – European regions as defined by this study. The regions are adapted from those used in The World Factbook. The only difference being that Southern Europe instead being divided in three parts (i.e. SW, S, and SE), is divided in only two, with Italy, Vatican and San Marino, being grouped with the SW region and Greece and Cyprus with the SE region.

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Table S1 – List of countries represented by the responders to the questionnaire, the corresponding country code, English country names, the corresponding European Regions (according to this study, see Fig S1 for explanation of regions), and the number of responses for each region and country.

Country/ Region			
Code		**Name**	**N**
NW	North Western Europe		17
	IE	Ireland	3
	UK	United Kingdom	14
C	Total		74
	CH	Switzerland	16
	CZ	Czechia	7
	DE	Germany	24
	HU	Hungary	11
	PL	Poland	15
	SI	Slovenia	1
W	Western Europe		47
	BE	Belgium	4
	FR	France	15
	NL	Netherlands	28
SW	South Western Europe		110
	ES	Spain	19
	IT	Italy	87
	PT	Portugal	4

Country/ Region			
Code		**Name**	**N**
NE	Total		61
	DK	Denmark	3
	NO	Norway	2
	SE	Sweden	56
E	Eastern Europe		38
	BLR	Belarus	5
	MD	Moldova	7
	RU	Russia	1
	UA	Ukraine	25
SE	South Eastern Europe		131
	BIH	Bosnia Herzegovina	7
	GR	Greece	3
	HR	Croatia	44
	ME	Montenegro	1
	NMK	N. Macedonia	2
	RO	Romania	35
	RS	Serbia	29
	TR	Turkey	10
Europe (total)			481

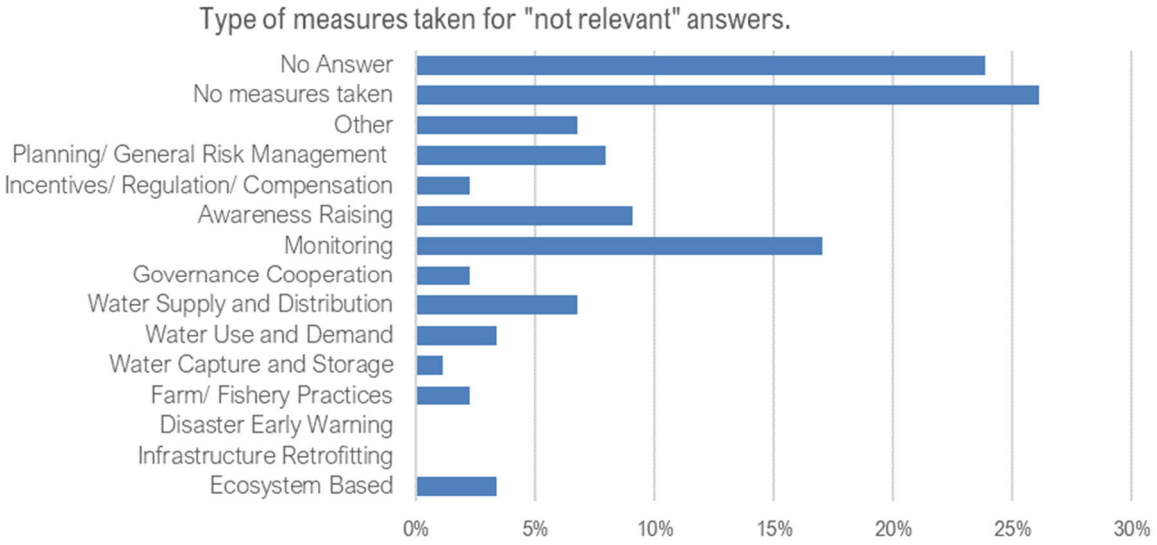

Figure S2 – Type of measures taken by the respondents who selected their measures to be "not relevant" in question 14 of the questionnaire. The type of measure taken is reported in the answer to question 13.

S3. Drought impact on streamflow

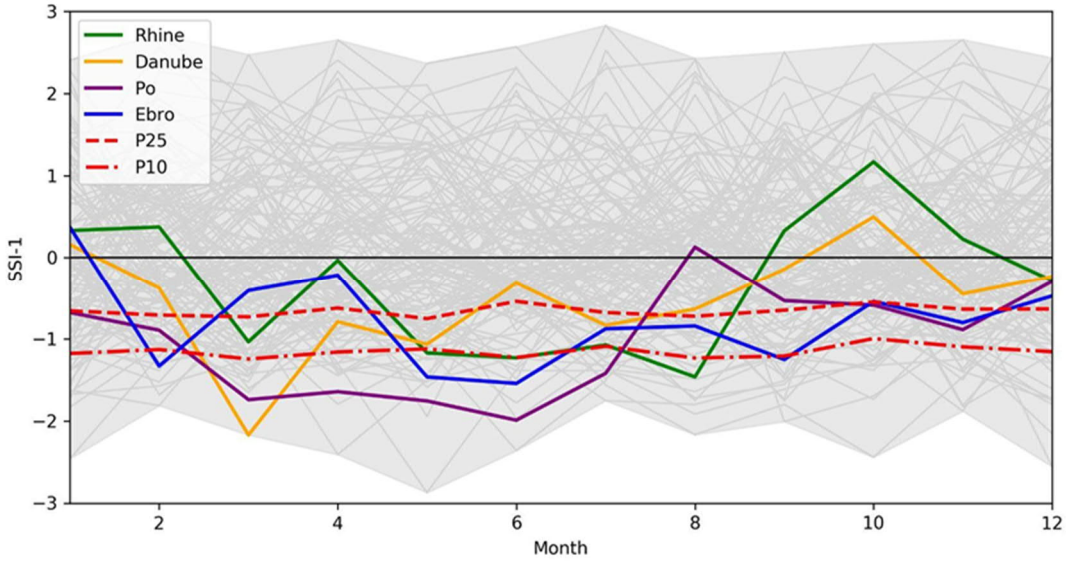

Figure S3 - Streamflow droughts derived from the Standardized Streamflow Index (SSI-1) for Rhine (close to Lobith), Danube (close to Hungary), Po (close to Ferrara), and Ebro (close to Zaragosa) rivers in year 2022. The 10th and 25th percentiles (P10 and P25, respectively) were calculated from all SSI-1 values of these selected rivers depicted in grey shaded area (1991-2022).

S4. Drought risk management measures

Table S2 – Agreement between the classification of the measures taken by the respondents as classified according to the typology by Reckien et al. (2023). The initial information was collected as an open question. Responses were translated from the original languages to English. The classification was carried out by two researchers. Agreement between the two researchers was then calculated. Agreement by row means that the two researchers indicated the same typology of measures for one response. This can include multiple types of measures. Agreement by cell indicates that the same type of measure was identified individually. For example, if researcher 1 classified a response as: "nature based"; "Agricultural practices"; Demand-side reduction", and researcher 2 only as "Agricultural practices"; Demand-side reduction", this would not be an agreement by row, yet it would be two agreements and one disagreement by cell.

	Total	**Agreed**	**Disagreed**		**Agreement**
			Type I	*Type II*	
Rows	20	14	6		70%
Cells	59	51	3	5	86%

Table S3 – Effectiveness of the measures taken by the respondent's organization as reported in question 14 of the survey. The values 1 to 5 on a scale from "not effective" to "very effective" respectively, "I don't know", "not relevant", and the option to leave the question blank. The column "N valid" indicates the number of valid answers, meaning it excludes "Don't know", "not relevant" and "NA". The column "Mean" indicates the average effectiveness for said subgroup.

Category		**Group**	**N**	**N valid**	**Mean eff**	**1 (not eff.)**	**2**	**3**	**4**	**5 (very eff.)**	**Don't know**	**Not relevant**	**#N/A**
Organization type		Other	24	16	3,6		4	3	4	5	2	3	3
		NGO	19	14	2,6	3	4	4	1	2	1	2	2
		Sci	34	11	3,2	1	1	4	5		4	9	10
		Private	37	26	3,5	2	3	7	8	6	3	7	1
		Public	366	204	3,5	10	21	68	70	35	53	67	42
Organization level		Internat.	37	20	3,6	1	2	5	8	4	2	7	8
		Nation.	130	67	3,3	7	6	25	20	9	23	22	18
		Region.	312	183	3,5	8	24	57	59	35	38	29	62
Country with 10+ responses (by region)	SW	ES	19	15	3,7	1		4	*7*	3	1	1	2
		IT	87	70	3,6	2	9	22	19	18	4	6	7
	SE	HR	44	19	3,0	4	2	6	4	3	8	11	6
		RS	29	21	3,4	1	3	6	9	2	1	4	3
		RO	35	19	3,3	2	3	5	5	4	8	5	3
		TR	10	5	2,8		2	2	1		3	1	1
	E	UA	25	6	3,2		2	2	1	1	8	4	7
	C	PL	15	6	2,7	1	1	3	1			6	3
		HU	11	7	3,3	1		3	2	1		2	2
		DE	24	13	3,2		5	2	5	1	2	6	3
		CH	16	9	3,7		1	3	3	2	2	3	2
	W	NL	28	22	3,7		1	7	11	3	3	1	2
		FR	15	12	3,7		1	5	3	3		1	2
	NW	UK	14	10	3,4		1	6	1	2	2	2	

	NE	SE	56	10	4,0			2	6	2	12	24	10
Regional average		SW	110	89	3,6	3	9	27	29	21	5	7	9
		SE	131	70	3,3	7	10	20	22	11	24	23	14
		E	38	14	2,9	3	2	4	3	2	10	5	9
		C	74	38	3,2	3	7	12	12	4	5	21	10
		W	47	37	3,6		4	13	14	6	3	2	5
		NW	17	10	3,4		1	6	1	2	3	3	1
		NE	61	12	3,8			4	6	2	13	26	10
All		Europe	478	244	3,5	12	31	78	78	45	54	77	53

S5. Changes in drought risk management

Table S4 – Changes in awareness, preparedness, and effectiveness in the response between 2018 and 2022 according to the respondents of the survey. The respondents could answer more, same, or less to the three questions "How aware/prepared/effective was your organization in 2022 compared to 2018?". The option "I don't know" and the possibility to leave the question blank (i.e. "#N/A") were also available. The results are presented at the European level (i.e. all responses), country level, regional level, operational level, and type of organization.

		AWARENESS					**PREPAREDNESS**					**EFFECTIVENESS**				
Group		**More**	**Same**	**Less**	**I don't know**	**#N/A**	**More**	**Same**	**Less**	**I don't know**	**#N/A**	**More**	**Same**	**Less**	**I don't know**	**#N/A**
Europe		232	141	13	46	49	141	160	22	86	72	134	155	25	94	73
Country	BE	2	2				3	1				1	1		1	1
	BIH	4	2			1	2	2	1	1	1	2	4	1		
	BLR	2	1		2		1	2		1	1	1	2		1	1
	CH	7	8		1		7	8		1		4	9	1	2	
	CZ	3	3		1		1	4		2		1	2		4	
	DE	9	9		1	5	8	10		2	4	7	10		2	5
	DK	1	2					3					3			
	ES	11	8				9	8			2	8	8			3
	FR	9	6				5	8	1	1		6	7	1	1	
	GR	2	1				3					2	1			
	HR	19	11	3	5	6	9	16	3	4	12	13	13	3	5	10
	HU	6	3			2	5	4			2	4	4	1		2
	IE	2			1		1			2		1			2	
	IT	42	31	2	6	6	39	30	1	7	10	39	29	1	9	9

	MD	1	2		1	3	1	1	1	1	3	1	3		1	2
	ME		1					1					1			
	NL	22	4		1	1	19	7		1	1	16	8		2	2
	NMK				2					2					2	
	NO		2				1	1				1	1			
	PL	5	9			1	1	9		1	4	1	9		1	4
	PT	2	2				2	2				2	2			
	RO	9	10		7	9	5	11		7	12	4	9	1	7	14
	RS	9	12	2	1	5	5	11	2	2	9	5	12	1	3	8
	RU	1									1					1
	SE	42			14		1	3	6	46		2	1	7	46	
	SI	1					1					1				
	TR	8	1	1			4	4	2			4	4	2		
	UA	5	6	3	2	9	3	7	4	3	8	1	7	4	3	10
	UK	8	3	2	1		5	6	1	2		6	4	2	2	
Region	SW	55	41	2	6	6	50	40	1	7	12	49	39	1	9	12
	SE	51	38	6	15	21	28	45	8	16	34	30	44	8	17	32
	E	9	9	3	5	12	5	10	5	5	13	3	12	4	5	14
	C	31	32		3	8	23	35		6	10	18	34	2	9	11
	W	33	12		1	1	27	16	1	2	1	23	16	1	4	3
	NW	10	3	2	2		6	6	1	4		7	4	2	4	
	NE	43	4		14		2	7	6	46		3	5	7	46	
Org. level	Internat.	16	15		1	5	10	20		1	6	12	15		1	9
	National	59	36	4	14	17	39	47	7	17	20	37	46	8	18	21
	Regional	155	90	9	31	27	92	92	15	68	45	85	93	17	75	42
Type of organiz.	NGO	10	5		1	3	5	8	1	1	4	6	6	1	1	5
	Other	11	7	1	2	3	9	8		3	4	10	7	1	2	4
	Private	19	16		1	1	10	21		2	4	12	16		4	5
	Public	176	103	11	39	37	108	110	20	74	54	98	113	22	81	52
	Scientific	15	10	1	3	5	9	12	1	6	6	8	13		6	7