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Over 200,000 kilometers of free-flowing river habitat in Europe is altered due to impoundments

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AMBER

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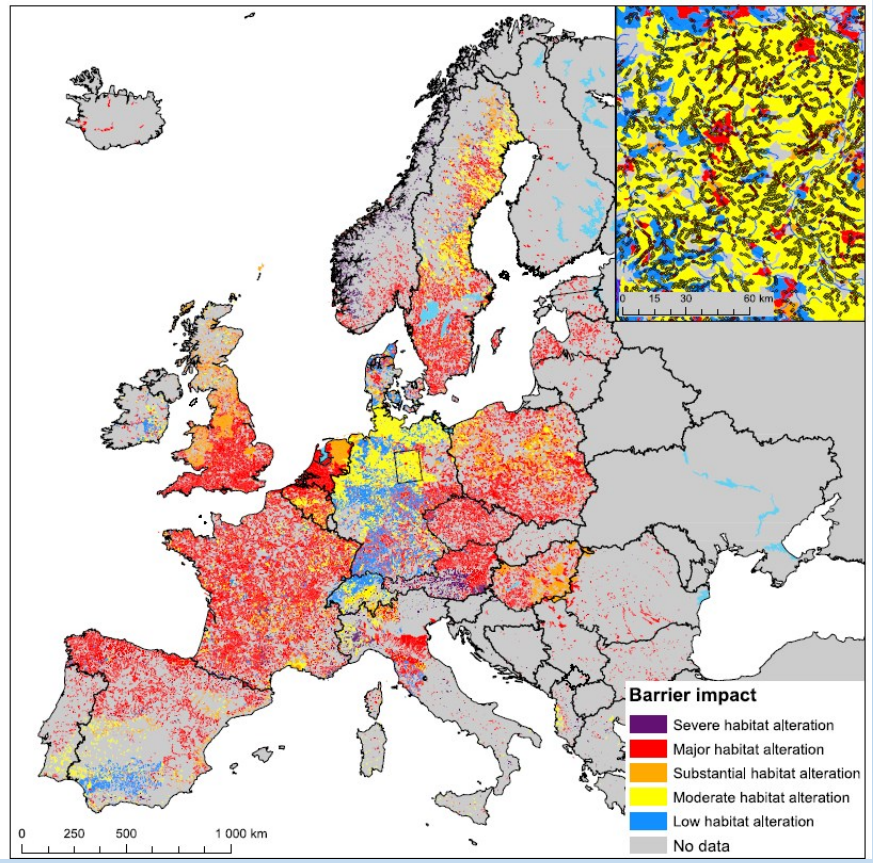
CHAMP
A Conceptual Habitat Alteration Model for Ponding



STEP 1 Assign fish species to Habitat Use Guilds

INPUT European fish species distribution available from European Intercalibration datasets, EFI+ dataset for Poland
METHOD Literature review, workshops and expert opinion
OUTPUT 11 Habitat Use Guilds (HUG)

STEP 2 Assess Altered Habitat Suitability (AHS) for fish

INPUT HUG, literature findings, expert opinion
METHOD Develop scoring procedure for fish habitat preferences (*HP*) and barrier habitat alteration (*HA*), normalization
OUTPUT Altered Habitat Suitability (*AHS*) index, remaining habitat proportion (*RHp*) index

STEP 3 Aggregate fish guilds with geography setting

INPUT HUG, geographic data
METHOD Two-step clustering (NHC and ANOSIM)
OUTPUT 15 macrohabitats (FCMacHT)

STEP 4 Define geographic distribution of macrohabitats

INPUT FCMacHT, geographic data
METHOD CART classification
OUTPUT Map of FCMacHT types

STEP 5 Assess regional sensitivity of fish to ponding

INPUT *HP* scores, FCMacHT, river network
METHOD *PSI* index calculation, normalized weighted sum, classification
OUTPUT Map of fish community sensitivity to impoundment, barrier impact maps

STEP 6 Estimate barrier-specific habitat alteration

INPUT *RHp*, FCMacHT, river network
METHOD Weighted sum, classification
OUTPUT *wRHp* (%)

STEP 7 Estimate impoundment impact on European rivers

INPUT AMBER Barrier Atlas, river network, FCMacHT, *wRHp*
METHOD Impoundment length estimation, *wRHp* score application
OUTPUT Catchment scale assessment of impoundment impact
European scale estimation of free-flowing habitat alteration

Step 1: Habitat Use Guilds

Extended Data Table 1. **Habitat Use Guilds characteristics**. T
Melcher's guild classification for the Expected Fish Communities

No.	Habitat Use Guild
1.	Intolerant highly rheophilic species
2.	Rheophilic benthic species preferring sandy-gravel bottom substrate
3.	Rheophilic water column species preferring sandy-gravel bottom substrate
4.	Limnophilic benthic species of moderate tolerance
5.	Limnophilic water column species of moderate tolerance
6.	Intolerant rheophilic benthic species preferring detritus or pelal bottom substrate
7.	Intolerant water column species
8.	Limnophilic lithophilic species of moderate tolerance
9.	Limnophilic phytophilic species of moderate tolerance
10.	Benthic species of moderate tolerance
11.	Tolerant generalist species

* 1 – species belong to a guild, 0 – species do not belong to a guild, x

Extended Data Table 2. **Fish species assigned to Habitat Use Guilds.**

1	**Intolerant highly rheophilic species** (n=14)			
	Barbus caninus	*Parachondrostoma miegii*	*Salmo obtusirostris*	*Telestess souffia*
	Cobitis calderoni		*Salmo salar*	*Thymallus thymallus*
	Cottus poecilopus	*Romanichthys valsanicola*	*Salmo trutta fario*	*Zingel streber*
	Hucho hucho		*Salmo trutta trutta*	*Zingel zingel*
2	**Rheophilic benthic species preferring sandy-gravel bottom substrate** (n=56)			
	Acipenser gueldenstaedtii	*Barbus peloponnesius*	*Huso huso*	*Romanogobio albipinnatus*
	Acipenser naccarii	*Barbus plebejus*	*Luciobarbus steindachneri*	*Romanogobio banarescui*
	Acipenser nudiventris	*Barbus tyberinus*	*Oxynoemacheilus bureschi*	*Romanogobio benacensis*
	Acipenser oxyrinchus	*Chondrostoma knerii*	*Oxynoemacheilus pindus*	*Romanogobio elimeius*
	Acipenser ruthenus	*Chondrostoma nasus*	*Pachychilon pictum*	*Romanogobio kesslerii*
	Acipenser stellatus	*Chondrostoma soetta*	*Parachondrostoma arrigonis*	*Romanogobio uranoscopus*
	Acipenser sturio	*Chondrostoma vardarense*	*Parachondrostoma toxostoma*	*Rutilus pigus*
	Ballerus sapa	*Cobitis elongata*	*Protochondrostoma genei*	*Sabanejewia aurata*
	Barbatula barbatula	*Cobitis vardarensis*	*Pseudochondrostoma polylepis*	*Sabanejewia balcanica*
	Barbus barbus	*Cobitis vettonica*	*Pseudochondrostoma willkommii*	*Sabanejewia romanica*
	Barbus cyclolepis	*Cottus gobio*		*Vimba melanops*
	Barbus euboicus	*Cottus koshewnikovi*		*Vimba vimba*
	Barbus guiraonis	*Cottus petiti*		*Zingel asper*
	Barbus haasi	*Gobio gobio*		*Zingel balcanicus*
	Barbus macedonicus	*Gymnocephalus baloni*		
	Barbus meridionalis	*Gymnocephalus schraetser*		
3	**Rheophilic water column species preferring sandy-gravel bottom substrate** (n =24)			
	Achondrostoma arcasii	*Iberocypris palaciosi*	*Leuciscus pleurobipunctatus*	*Squalius illyricus*
	Achondrostoma	*Leuciscus aspius*		*Squalius keadicus*

Step 2: Altered Habitat Suitability index (AHS)

AHS = HP x AH

Habitat attributes

- flow velocity (high and low velocity)
- depth (deep and shallow areas)
- substrate (interstitial spaces, sandy or muddy bottom, and
- gravel)
- in-stream cover (woody debris or boulders)
- physico-chemical conditions (oxygenation, water temperature, and nutrient content)
- vegetation (rheophilic vegetation or mosses, macrophytes,
- canopy shading from banks, and overhanging vegetation)
- structure of banks (undercut banks)
- floodplain accessibility
- habitat continuity
- flow stability

Preference index (HP)

- 0 = not important
- 0.5 =moderately important
- 1 = very important

Habitat Alteration by Ponding (AH) index

- 0.0 = major reduction
- 0.5 = small reduction
- 1.0 = no change
- 1.5 = small increase
- 2.0 = major increase

Habitat attributes		Habitat attributes		Barrier impact							
				Dam	Weir	Sluice	Culvert	Ford	Ramp	Limnophilic phytophilic species of moderate tolerance	Benthic species of moderate tolerance
	Guild no.	1	high velocity	0	0	0	0.5	0.5	0.5	9	10
1	high velocity	2	low velocity	2	1.5	1.5	1.5	1.5	1.5	0	0.5
2	low velocity	3	deep areas	2	1.5	1.5	1	1	1.5	1	0
3	deep areas	4	shallows	0	0	0	1	1	1	0.5	0.5
4	shallows	5	interstitial space	0	0	0	0.5	0.5	0.5	1	0
5	interstitial space	6	sand	2	1.5	1.5	1.5	1	1	0	1
6	sand	7	mud	2	1.5	1.5	1.5	1	1	1	0
7	mud	8	gravel	0	0	0	0.5	1	0.5	1	0
8	gravel	9	boulder	0	0.5	0.5	1	1	1.5	0	1
9	boulder	10	woody debris	0	0.5	0.5	0.5	1	1	0	0.5
10	woody debris	11	oxygenated water	0	0.5	0.5	1	1	1	0.5	1
11	oxygenated water	12	cold water	0	0	0	1	1	1	0	0.5
12	cold water	13	low trophic level	0	0.5	0.5	1	1	1	0	0.5
13	low trophic level	14	rheophilic macrophytes, mosses	0	0	0	0.5	0.5	0.5	0	0.5
14	rheophilic macrophyt	15	macrophytes	2	1.5	1	1	1	1	0	1
15	macrophytes	16	canopy shading	0	0.5	0.5	1	1	1	1	0
16	canopy shading	17	overhanging vegetation	0	0	0.5	1	1	1	1	0.5
17	overhanging veget	18	undercut bank	0	0	0.5	0.5	1	1	1	0
18	undercut bank	19	floodplain accessibility	0	0.5	0.5	1	1	1	0	1
19	floodplain accessil	20	habitat continuity	0	0	0.5	0	0.5	0.5	1	0
20	habitat continuity	21	habitat stability	0	0.5	0.5	1	1	1	0.5	0.5
21	habitat stability		Number of “no change” cases	0	0	1	11	16	13	0.5	1
	Ponding Sensitivit									10	10

Step 2: Remaining Riverine Habitat Proportion (RHp) for Habitat Use Guilds

$$RHp_{i,b} = \frac{\sum_1^j \left(HP_{i,j} \times AH_{b,j} \right)}{\sum_1^j HP_{i,j}}$$

→ Altered habitat suitability / Unaltered habitat suitability

where

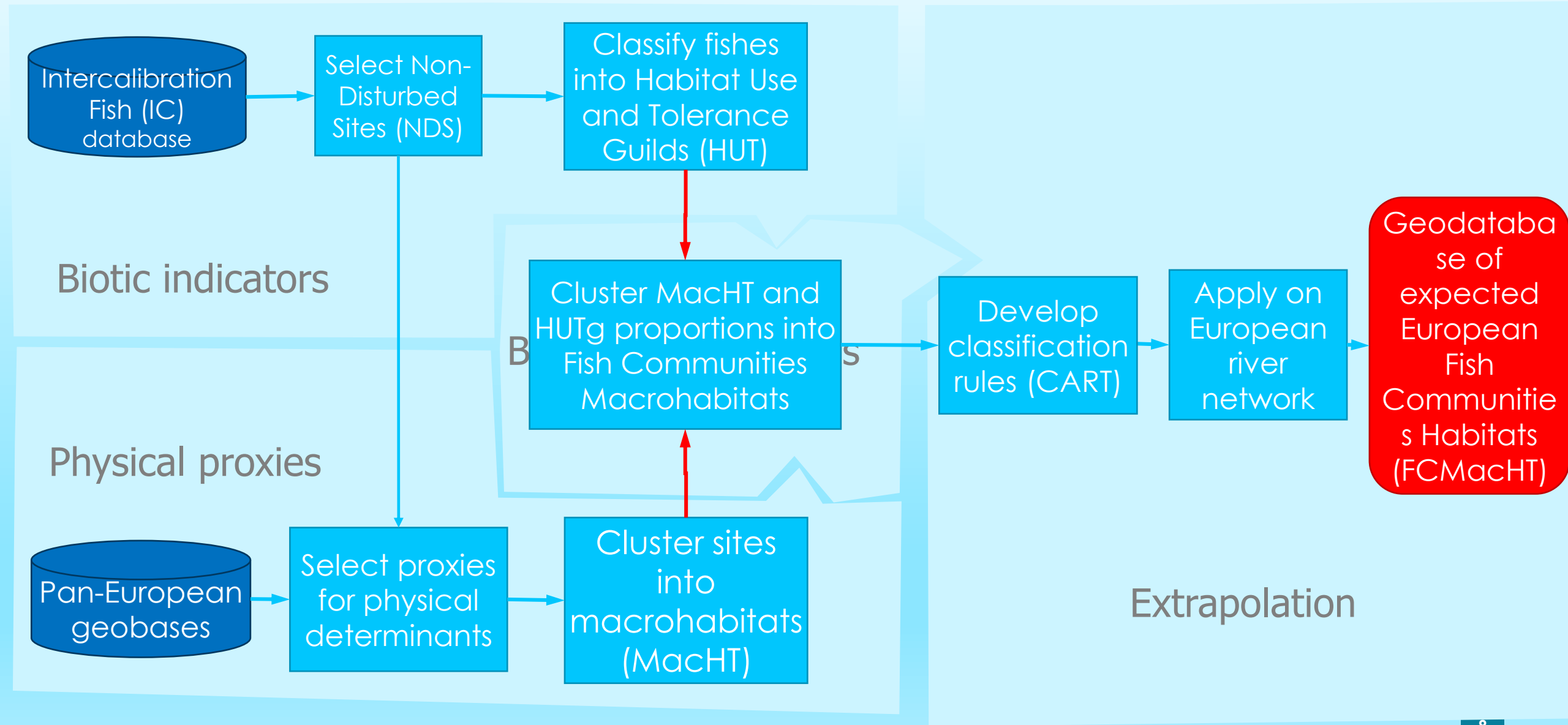
- $RHp_{i,b}$—remaining riverine habitat proportion (%) for barrier b and guild I
- $HP_{i,j}$—Habitat Preference index of habitat attribute j for guild i
- $AH_{b,j}$—Habitat Alteration index for habitat attribute j for barrier b

The same or larger habitat area but less valuable (suitable) !

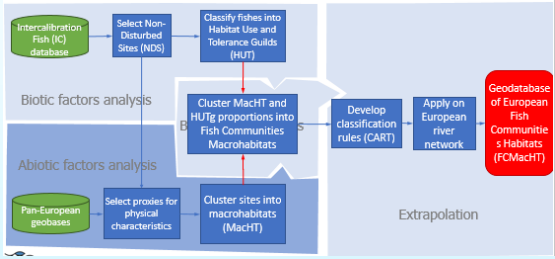
Step 2: Remaining Riverine Habitat Proportion (RHp) for Habitat Use Guilds

Habitat attributes		DAM										
		Highly rheophilic, intolerant species	Rheophilic benthic species, preferring sandy-gravel	Rheophilic water column species, preferring sandy-	Limnophilic benthic species of moderate tolerance	Limnophilic water column species of moderate tolerance	Rheophilic intolerant benthic species, preferring detritus or	Intolerant, water column species	Limnophilic lithophilic species of moderate tolerance	Limnophilic phytophilic species of moderate tolerance	Benthic species of moderate tolerance	Generalists tolerant species
	Guild no.	1	2	3	4	5	6	7	8	9	10	11
1	high velocity	0	0	0	0	0	0	0	0	0	0	0
2	low velocity	0	0	1	2	2	1	0	2	2	0	1
3	deep areas	1	0	2	2	2	0	2	1	1	1	2
4	shallows	0	0	0	0	0	0	0	0	0	0	0
5	interstitial space	0	0	0	0	0	0	0	0	0	0	0
6	sand	0	0	0	1	2	1	0	0	2	0	1
7	mud	0	0	0	2	2	1	0	0	2	0	2
8	gravel	0	0	0	0	0	0	0	0	0	0	0
9	boulder	0	0	0	0	0	0	0	0	0	0	0
10	woody debris	0	0	0	0	0	0	0	0	0	0	0
11	oxygenated water	0	0	0	0	0	0	0	0	0	0	0
12	cold water	0	0	0	0	0	0	0	0	0	0	0
13	low trophic level	0	0	0	0	0	0	0	0	0	0	0
14	rheophilic macrophytes, mosses	0	0	0	0	0	0	0	0	0	0	0
15	macrophytes	0	0	0	1	1	0	0	0	2	0	1
16	canopy shading	0	0	0	0	0	0	0	0	0	0	0
17	overhanging vegetation	0	0	0	0	0	0	0	0	0	0	0
18	undercut bank	0	0	0	0	0	0	0	0	0	0	0
19	floodplain accessibility	0	0	0	0	0	0	0	0	0	0	0
20	habitat continuity	0	0	0	0	0	0	0	0	0	0	0
21	habitat stability	0	0	0	0	0	0	0	0	0	0	0
	Sum = Guild's habitat sens	**1**	**0**	**3**	**8**	**9**	**3**	**2**	**3**	**9**	**1**	**7**
	Remaining habitat (RHp	0.08	0.00	0.26	1.14	1.29	0.23	0.17	0.35	0.90	0.10	1.75

Step 3: Aggregate HUGs with Geography settings



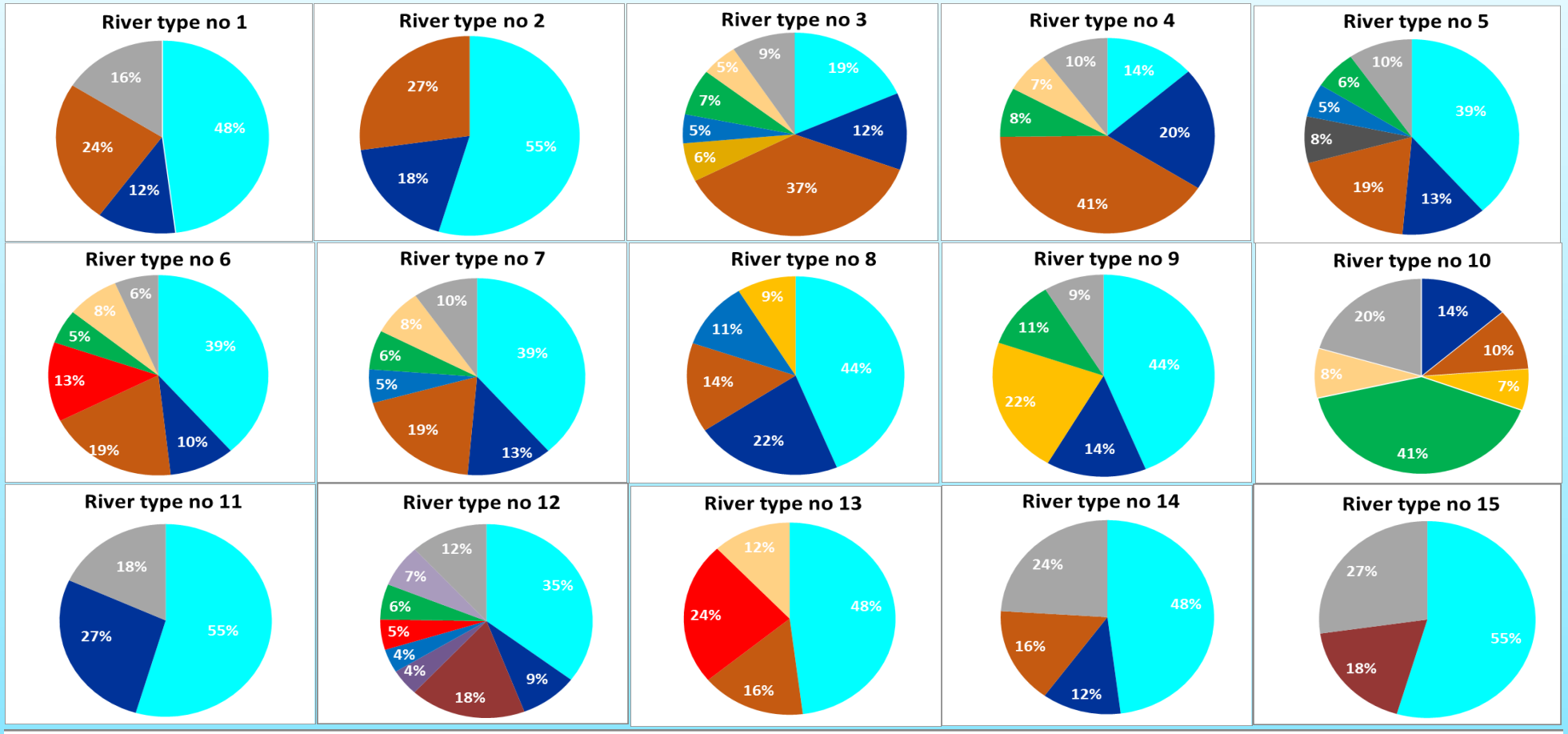
Step 3: Proxies for abiotic factors



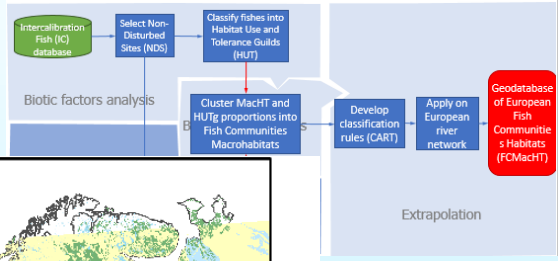
Factors addressed		Proxy
Hydrology, hydromorphology	→	STREAM ORDER
Hydrology, hydromorphology	→	SLOPE
Climate, hydromorphology	→	ALTITUDE
Hydrology, hydromorphology	→	CATCHMENT SIZE
Hydromorphology, hydrochemisty	→	LITHOLOGY OF CATCHMENT
Climate, hydrology, ecosystems	→	ENVIRONMENTAL STRATIFICATION OF EUROPE (EnS)

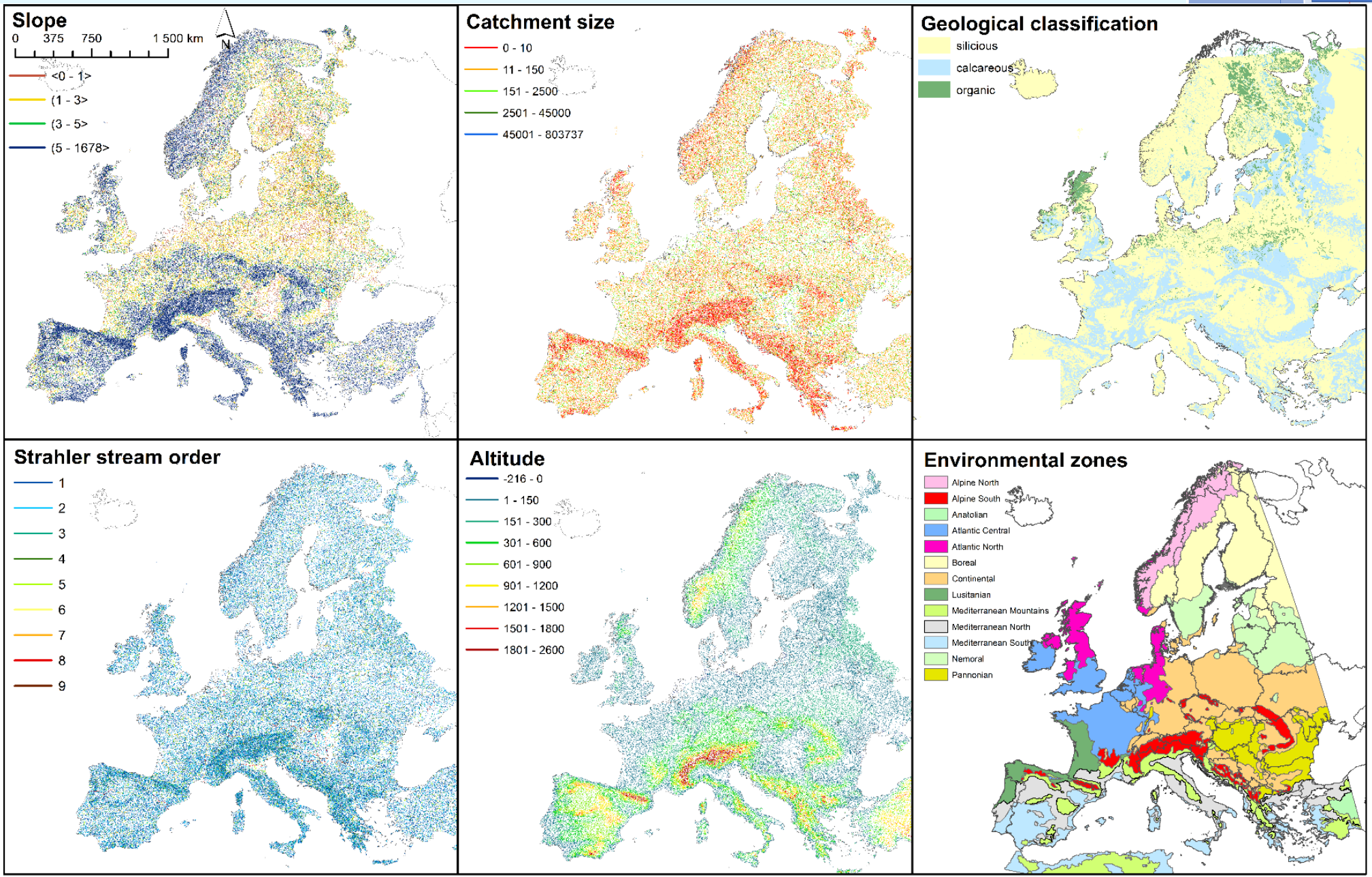
Step 3: Fish Community MacroHabitat River Types

(ANOSIM R=0.98, p < 0.001)



Step 4: Pan-European geodata used

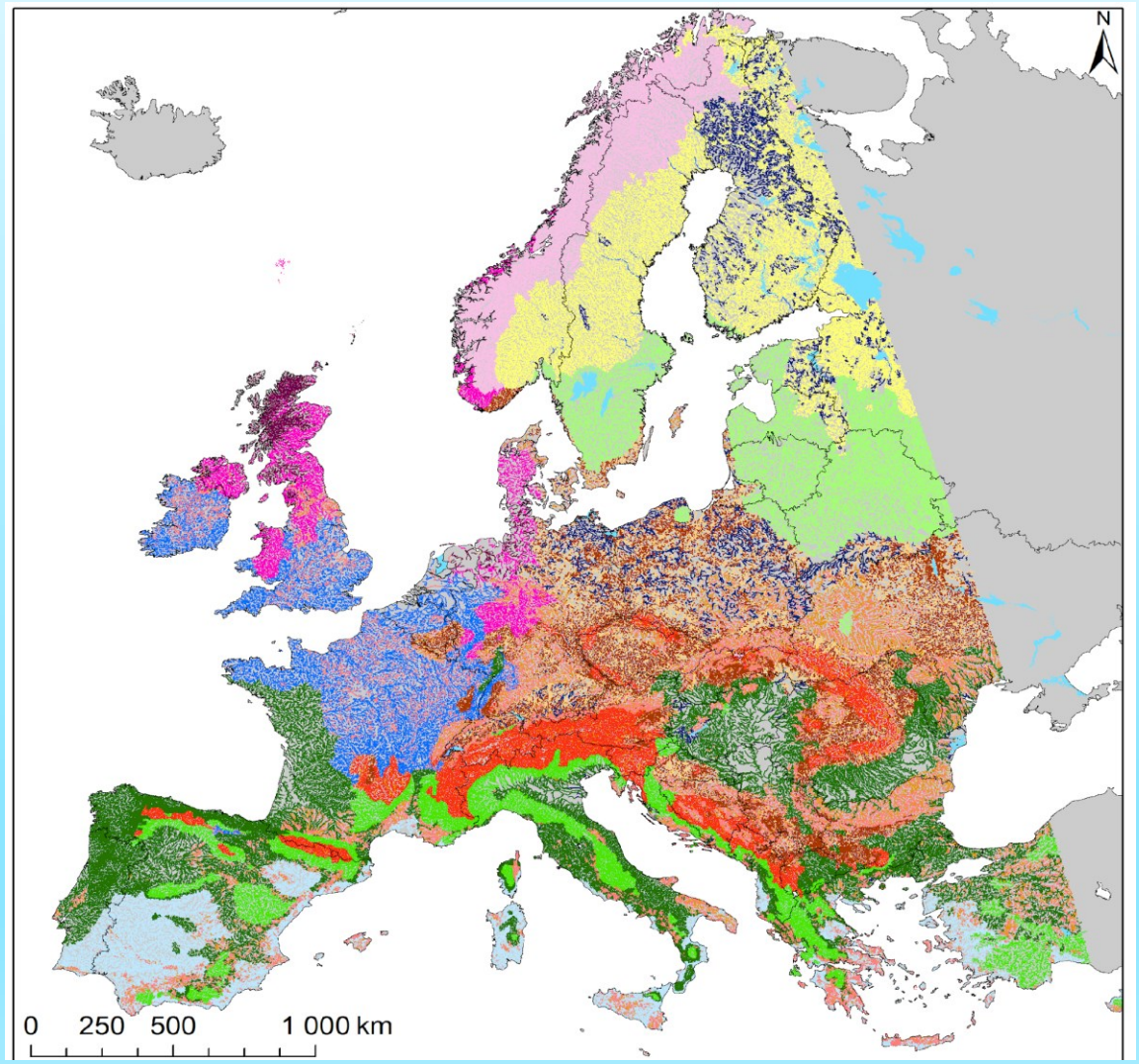




Step 4: Fish Community Macrohabitat Types (FCMacHT)

(CART Kappa = 0.86)

1. Pan-European calcaerous headwaters
2. Mountain, Alpine
3. Central European sub-mountain and highland
4. Calcareous Alpine and highland
5. Continental upland and lowland headwaters
6. Boreal lowland
7. Nemoral lowland
8. Mediterranean mountain and upland
9. South European plains and highland
10. Mediterranean lowland
11. Western European and Atlantic lowland
12. Lowland organic
13. Boreal mountain and highland
14. North Atlantic lowland and upland
15. North Atlantic peatland



Step 5: Fish Community sensitivity to ponding

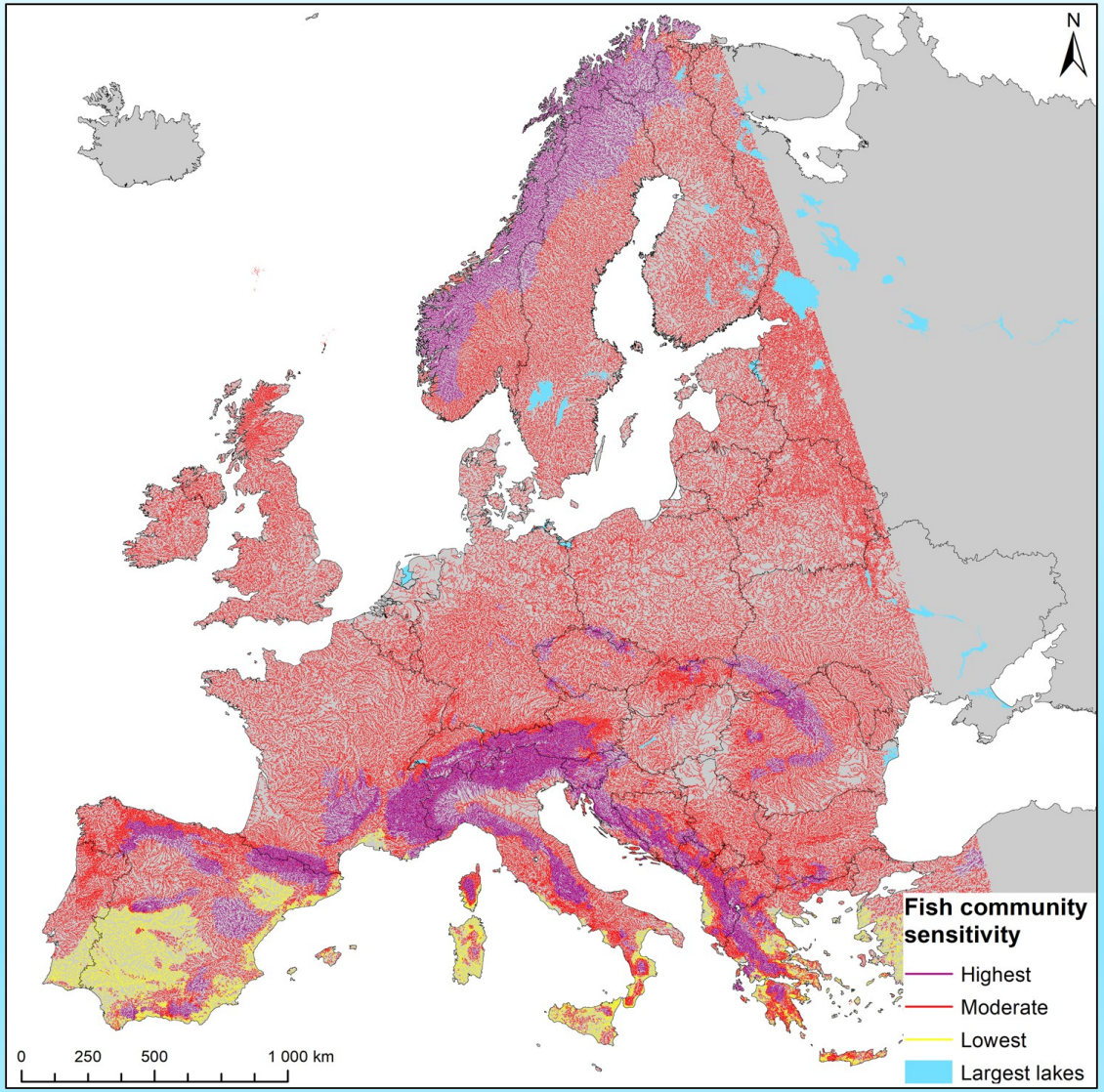
$$FCMacHT\ sensitivity = \frac{\sum_1^i (PSI_i \times GP_i)}{21} \times 100$$

where

- PSI_i—Ponding Sensitivity Index for guild (Unaltered Habitat Suitability)
- GP_i—Habitat Use Guild i proportion in a FCMacHT
- 21 – maximum PSI

Classes:

- Highest PSI > 55%
- Lowest PSI<45%



Step 6: Weighted Riverine Habitat Proportion (wRHp)

$$wRHp = \sum_{1}^{i} (GP_i \times RHp_{i,b})$$

where

- wRHp—weighted Riverine Habitat proportion (%) in a FCMacHT for barrier b
- GP_i—Habitat Use Guild proportion of guild i (%)
- $RHp_{i,b}$—remaining riverine habitat proportion (%) for barrier b and guild i.

Step 6: Barrier type impact on fish habitats in FCMacHTs

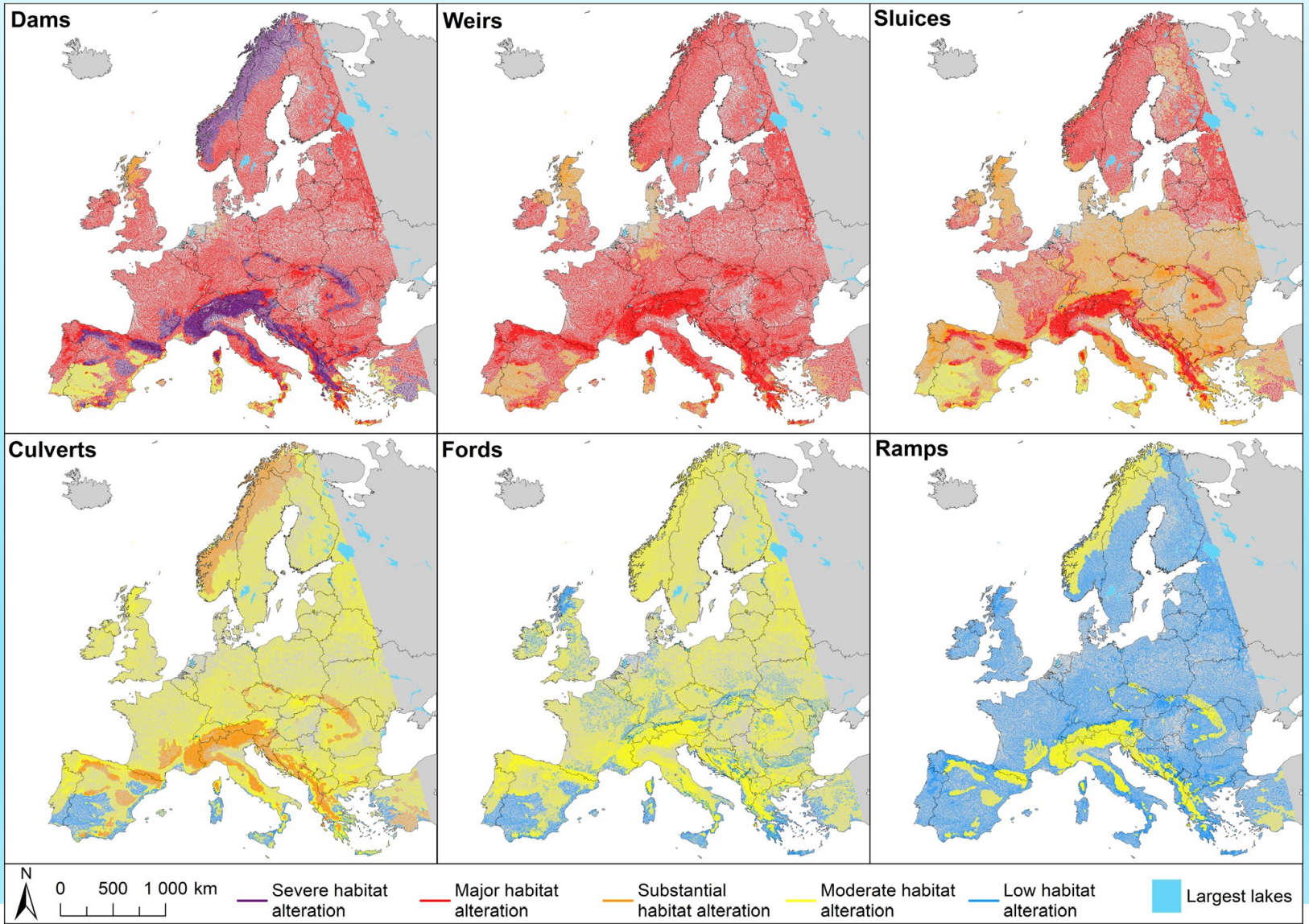
	BARIER DESCRIPTION	PHOTO	PICTOGRAM
1	**Dam** - a barrier that blocks or constrains the flow of water and raises the water level. Fish passage facility provided		
2	**Weir** - a barrier aimed at regulating flow conditions and water levels. Fish passage facility provided		
3	**Sluice** - a movable barrier aimed at controlling water levels and flow rates in rivers and streams. Not blocking migration when open		
4	**Culvert** - a structure aimed at carrying a stream or river under an obstruction. Connected to river bed and substrate, free flowing		
5	**Ford** - a structure in a river or stream which creates a shallow place for crossing the river or stream by wading or in a vehicle. Water depth guarantee fish passing most of the year		
6	**Ramp** - a ramp or a bed sill is a structure aimed at stabilizing the channel bed and reducing erosion and is recognizable by its stair-like shape. Space in-between stones guarantee fish passing		

	Fish Community Macrohabitat Type (FCMacHT)	Dam *wRHp %*	Weir *wRHp %*	Sluice *wRHp %*	Culvert *wRHp %*	Ford *wRHp %*	Ramp *wRHp %*
1	Pan-European calcareous headwaters	38	46	52	81	91	94
2	Mountain, Alpine	11	28	37	73	88	89
3	Central European sub-mountain and lowland	42	49	56	83	92	95
4	Calcareous Alpine and highland	38	45	53	80	91	94
5	Continental upland and lowland headwaters	42	49	55	84	92	95
6	Boreal lowland	27	39	46	77	89	91
7	Nemoral lowland	33	43	50	80	90	93
8	Mediterranean mountain and upland	13	30	38	74	88	89
9	South European plains and highland	36	46	52	81	91	94
10	Mediterranean lowland	78	74	77	97	98	100
11	Western European and Atlantic lowland	36	45	50	82	90	93
12	Lowland organic	41	48	54	82	91	94
13	Boreal mountain and highland	13	30	38	72	87	88
14	North Atlantic lowland and upland	50	54	59	85	92	96
15	North Atlantic peatland	57	59	63	87	93	98

Step 6: Habitat alteration potential for different barrier types and regions

Alteration classes

- Severe < 26% wRHp
- Major 26-50% wRHp
- Substantial 51-75% wRHp
- Modrate 76-90% wRHp
- Low > 90 % wRHp



Step 7: Estimating from Barrier Atlas free-flowing river habitat alteration of European rivers

$$HAB_{alt} = \sum_{1}^{T} \left(\frac{\sum_{1}^{b} \left(\frac{h}{s}\right)}{(1 - Err_b) \times p_b} - \frac{\sum_{1}^{b} \left(\frac{h}{s} \times wRHp_b\right)}{(1 - Err_b) \times p_b} \right)$$

where

- h—barrier height (m)
- s—river slope (‰)
- T—number of barrier types, indexed by b
- wRH_{pb}—weighted Riverine Habitat proportion (%) for barrier type b
- p_b—the proportion of barriers (%) of type b with height information
- Err_b—reporting error for barrier type b based on modeled barrier density

Barrier type	Number of barriers with height info	Calculated impoundment length (km)	Calculated remaining habitat (km)	Calculated habitat loss (km)	Proportion of barriers with height info (%)	Under-reporting error (%)	Est. impoundment length (km)	Est. remaining habitat length (km)	Est. habitat loss (km)
dam	28,913	22,180	8,591	13,588	48.3%	15.7%	54,473	21,100	33,373
weir	59,099	38,195	18,000	20,196	32.0%	58.2%	285,552	134,566	150,986
sluice	4,155	6,686	3,553	3,132	59.5%	72.0%	40,129	21,328	18,801
total	92,167	67,061	30,144	36,917	-	-	380,154	176,994	**203,160**

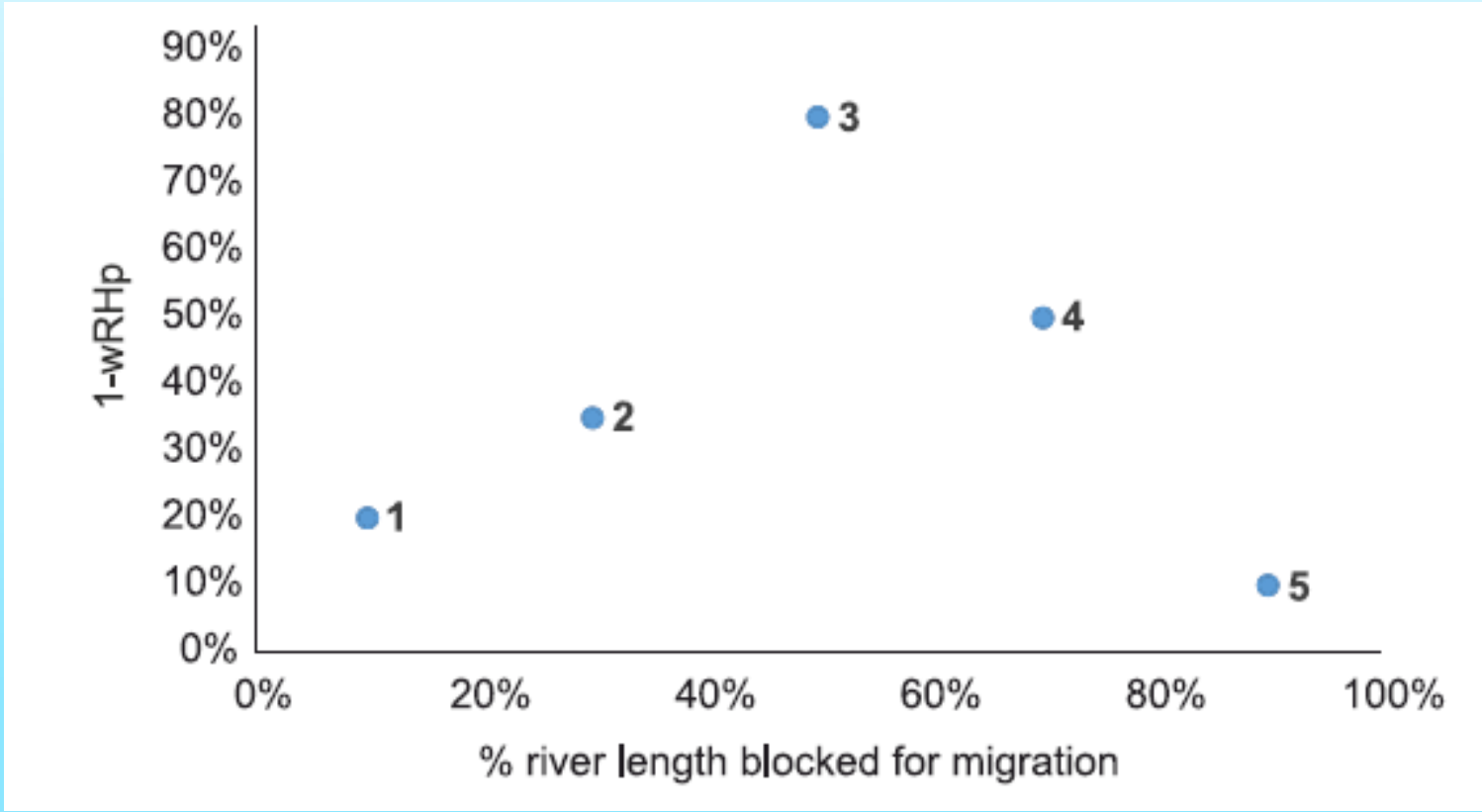
10% of river length in Europe
Equivalent to all the rivers of Italy.

Application of CHAMP: Barrier mitigation prioritization

Hypothetical example

- 5 barriers along the rivers
- Observed:
  - proporion of alterred habitat
  - river length blocked

-> first 3 barriers are the highest priority

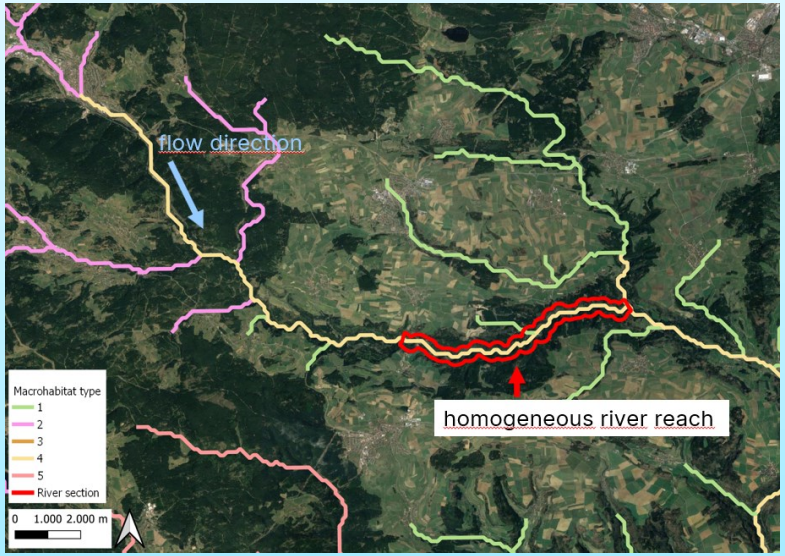


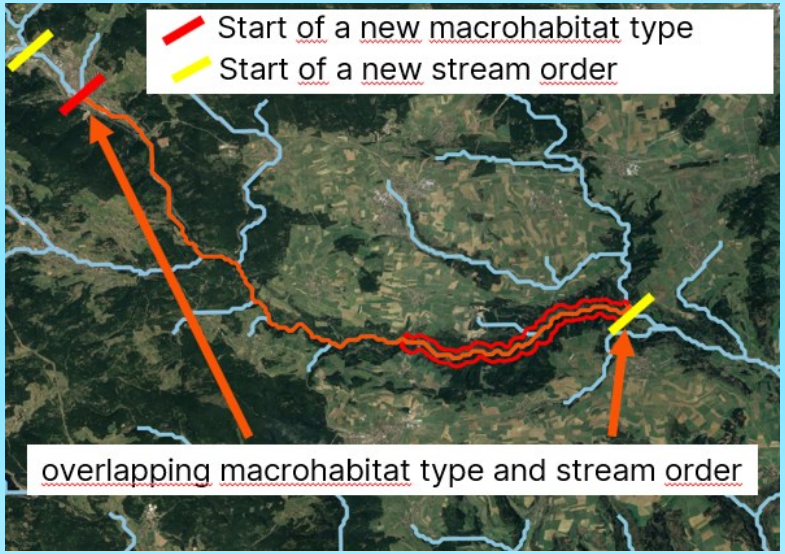
Application of FCMacHT: Selecting minimum length for Free Flowing Rivers

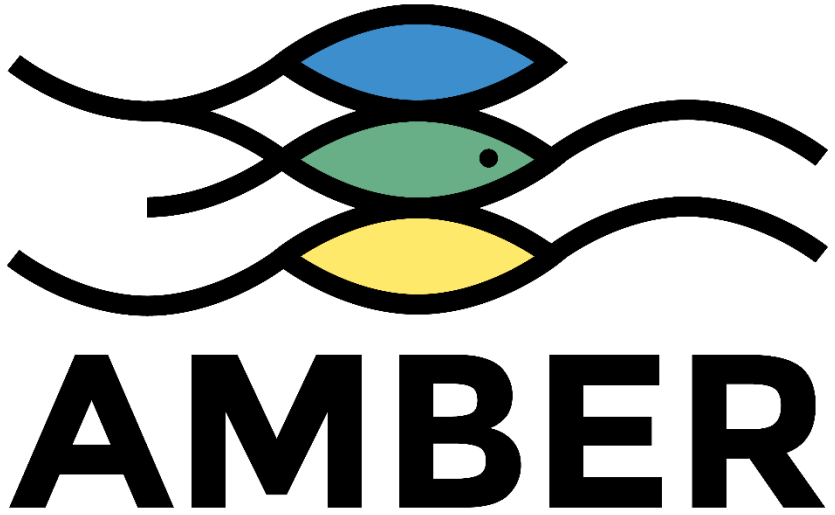
Assumptions

- FCMacHT = specfic fish community structure
- Strahler Stream Order – community change
- Continuous stretch with one FCMacHT and Strahler stream order = homing range of specific fish community
- **Aichi target 11**: 17% of inland waters conserve biodiversity

-> 20% of Homing Range







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