Hot spots and highways for dispersal of aquatic invasive species in the European network of inland waterways

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Lecture
Benelux Conference on Invasive Species - Science for the New Regulation
Ghent, April 2, 2014

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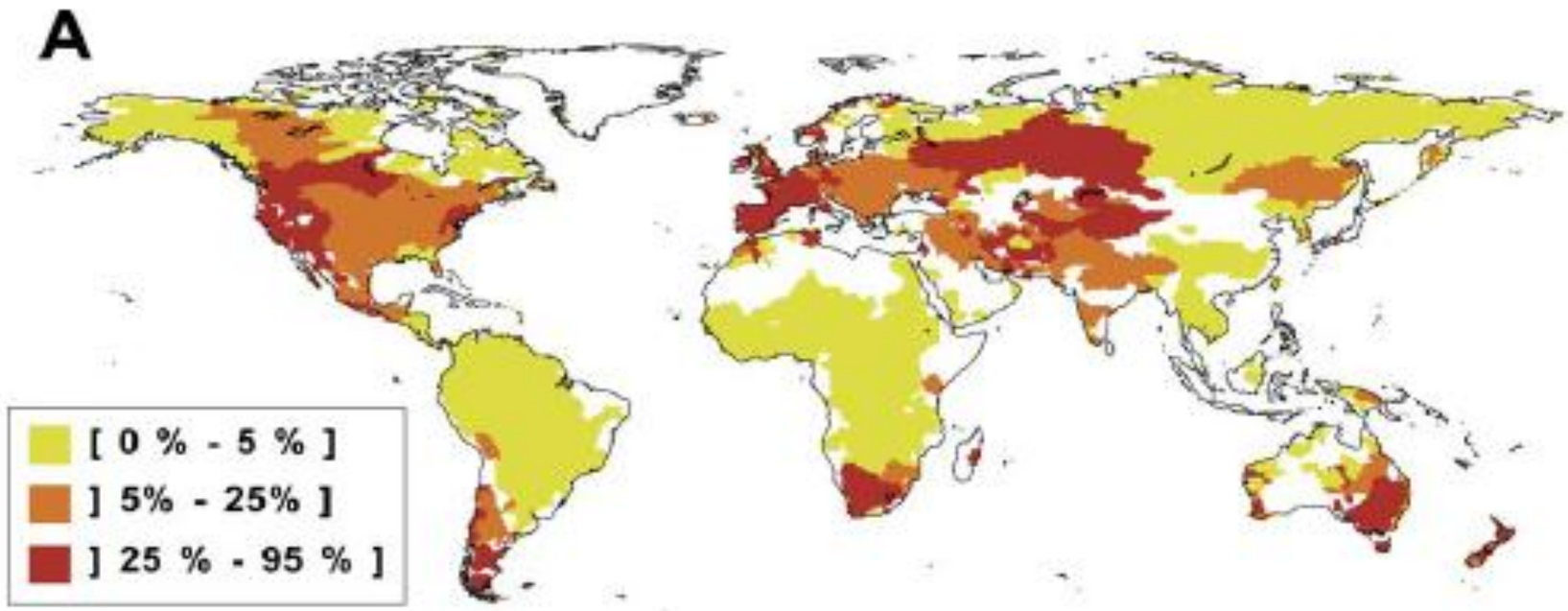
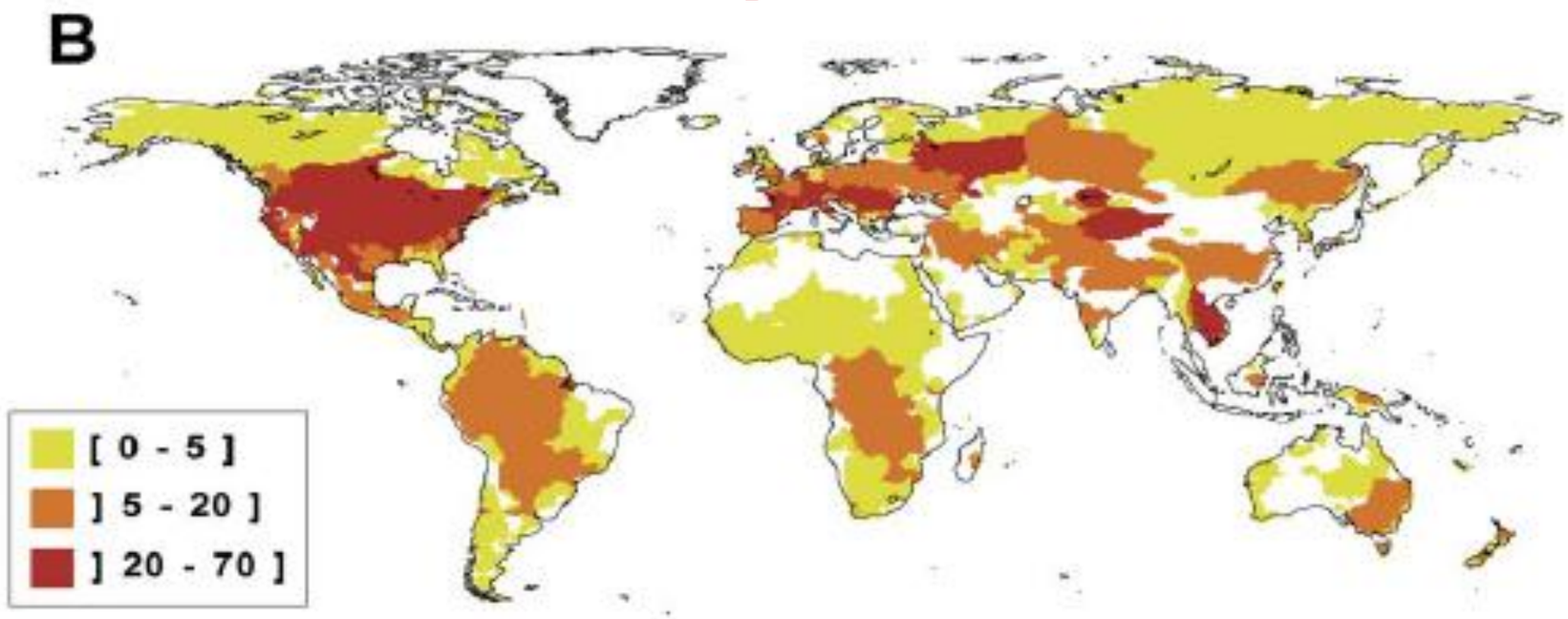
Content

- **Spatial-temporal trends of non-native species in rivers**
- **Conceptual framework for bioinvasion research**
- **Origin, hot spots, corridors, dispersal rates**
- **Environmental factors determining success of invasive species**
- **Differential sensitivity of native and invasive species to environmental factors**
- **Conclusions**

Global spread of non-native fish species in river basins



Ratio non-native / total number of species



Number of non-native species

Leprieur et al. (2008): PLOS Biology 6/2: 404-410

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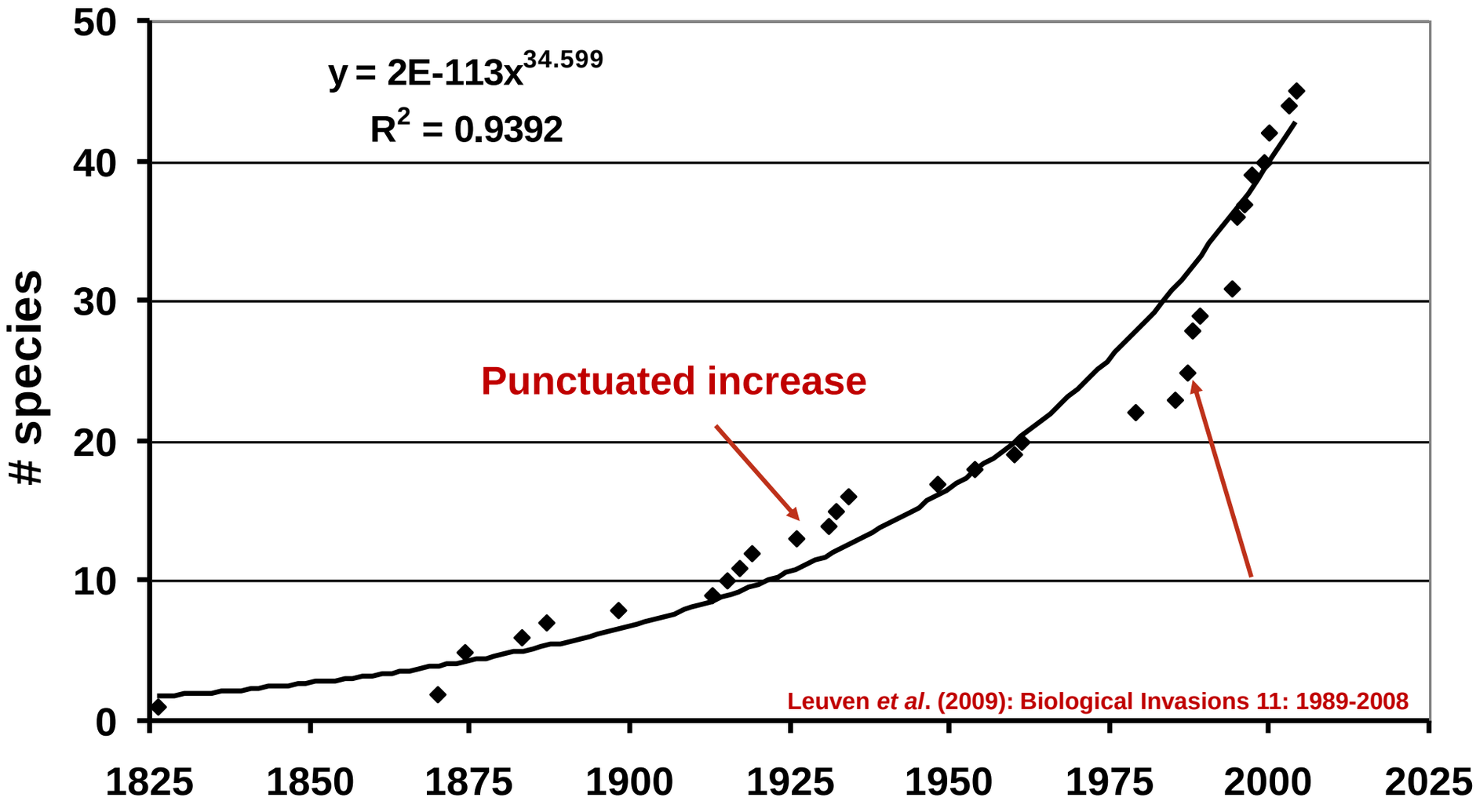
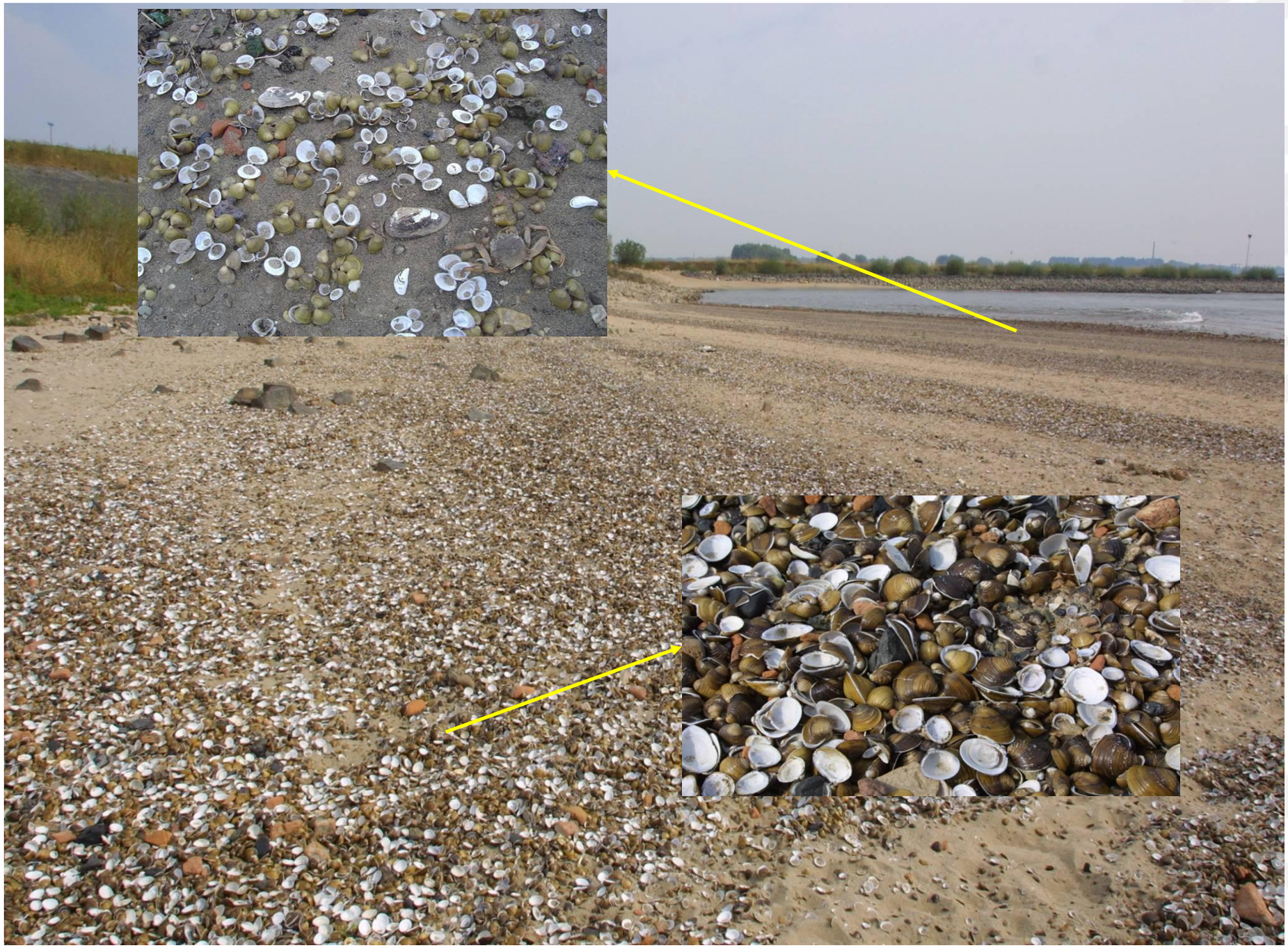
Exponential and increase of non-native species in European rivers

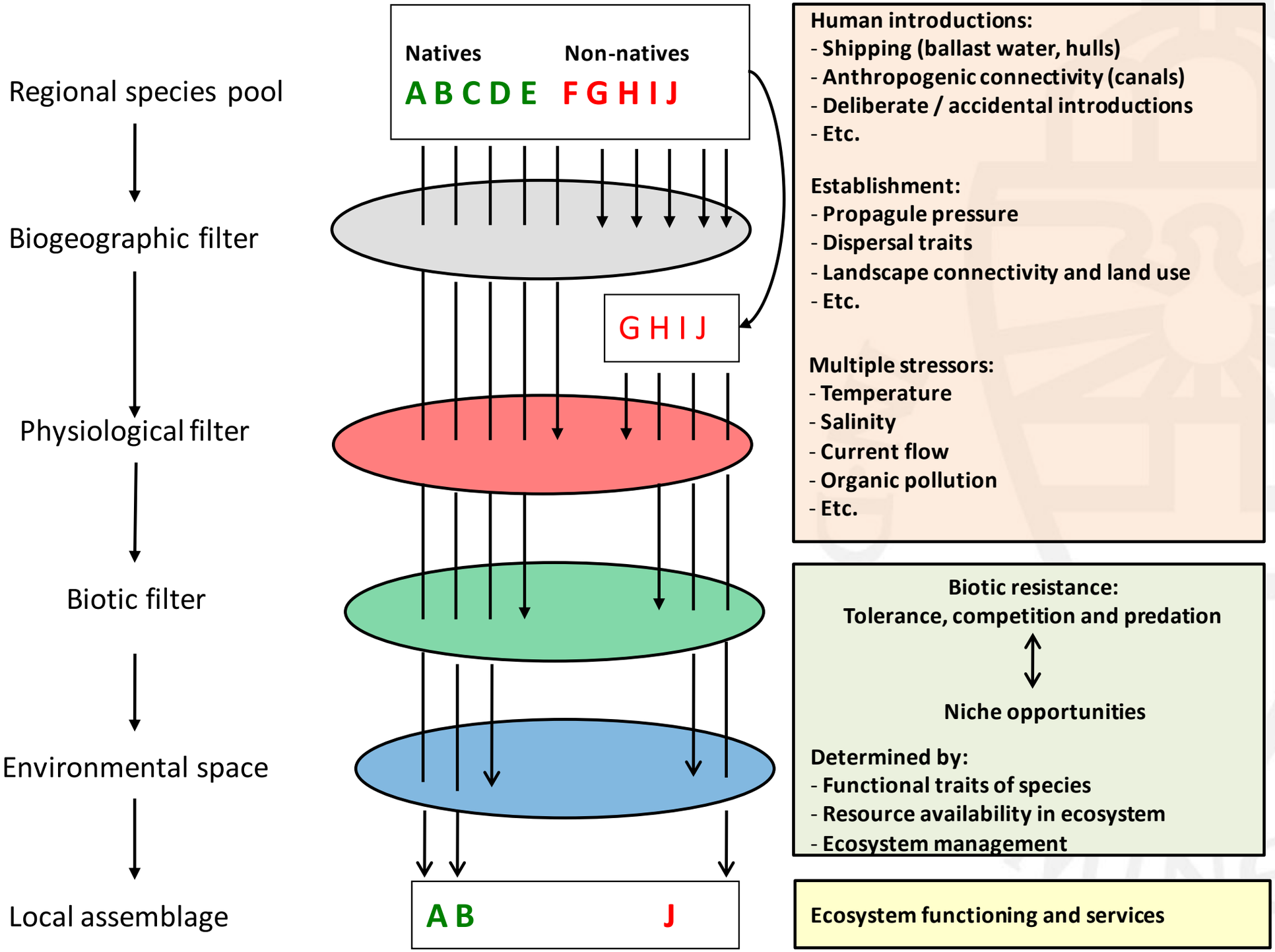


Example: cumulative number of non-native macroinvertebrate species in the river Rhine

Which species traits and environmental factors determine success of bioinvaders in rivers?



Conceptual frame work for bioinvasion research



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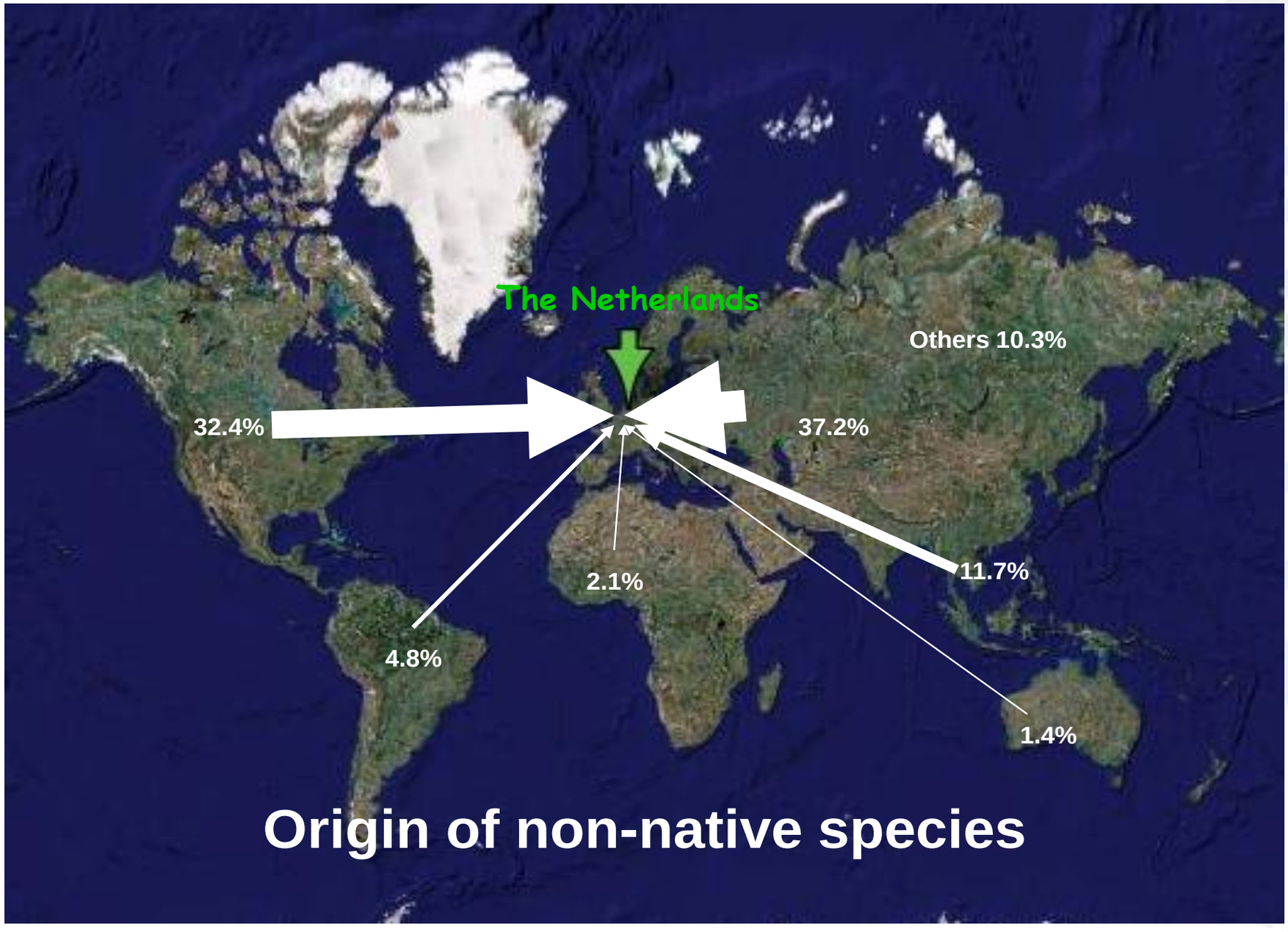
Origin of non-native species in freshwater ecosystems in the Netherlands



Leuven *et al*. (2009): Biological Invasions 11: 1989-2008

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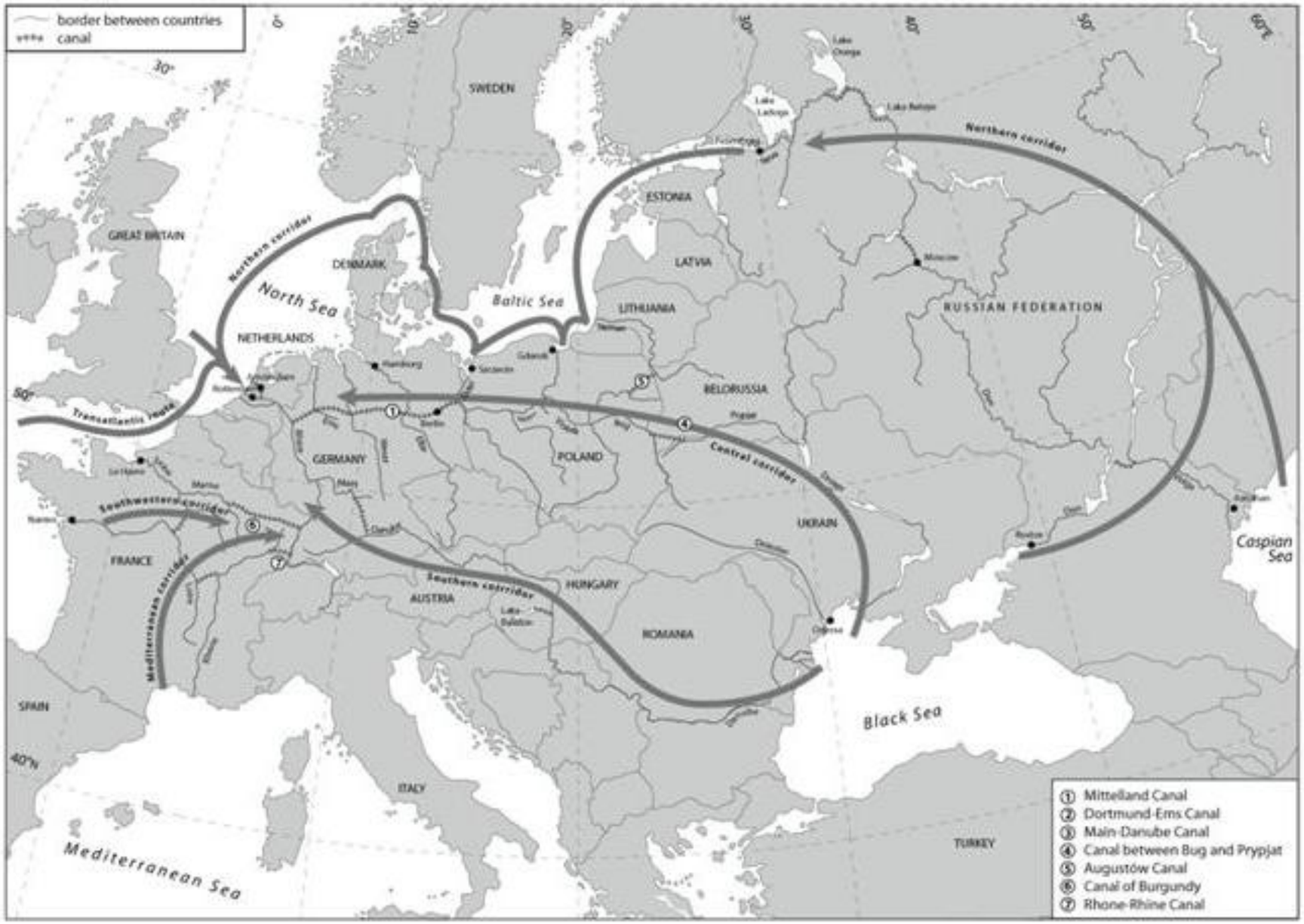
Invasion corridors of non-native species in Western European rivers



North Sea-Rhine:
- **165,000 ships per year**
- **160 million tons of goods per year**

Leuven *et al*. (2009): Biological Invasions 11: 1989-2008

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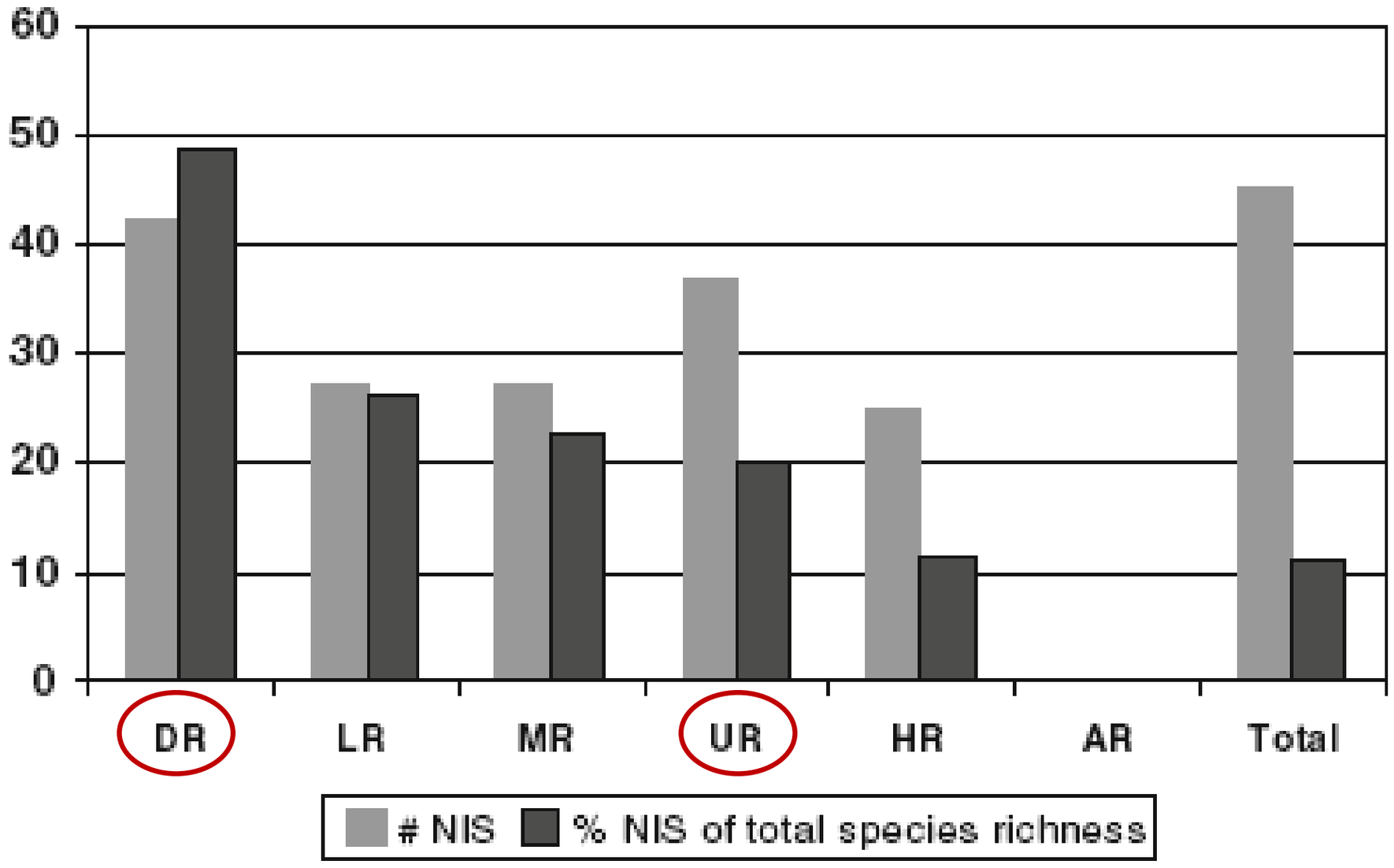
Total number of non-native macroinvertebrate species in freshwater sections of the river Rhine



DR: Delta Rhine
LR: Lower Rhine
MR: Middle Rhine
UP: Upper Rhine
HR: High Rhine
AP: Alpine Rhine

Invasion hot spot

Leuven *et al*. (2009): Biological Invasions 11: 1989-2008

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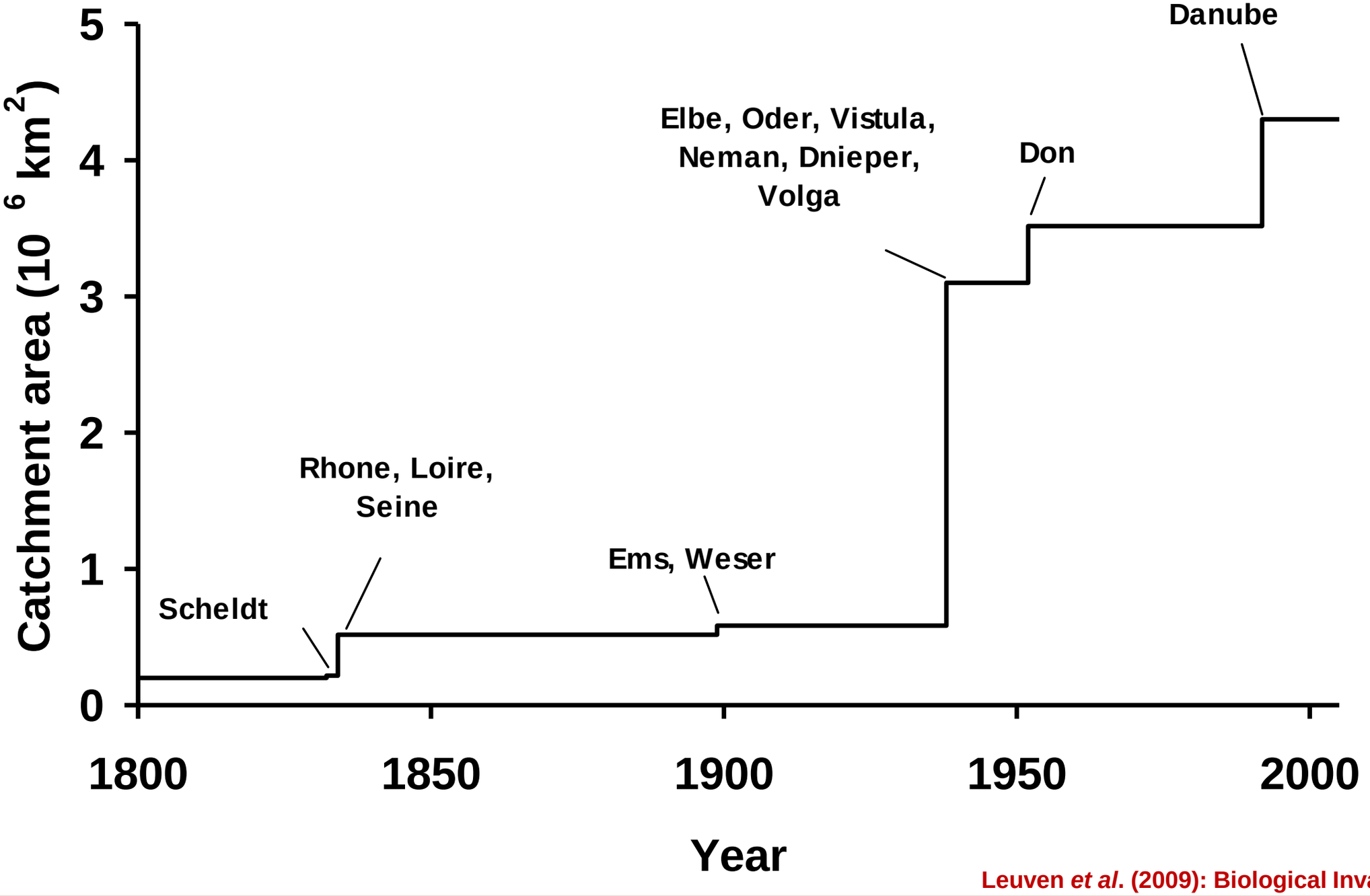
Punctuated increase in catchments connected to the rivers Rhine and Meuse by constructions of canals



Leuven *et al*. (2009): Biological Invasions 11: 1989-2008

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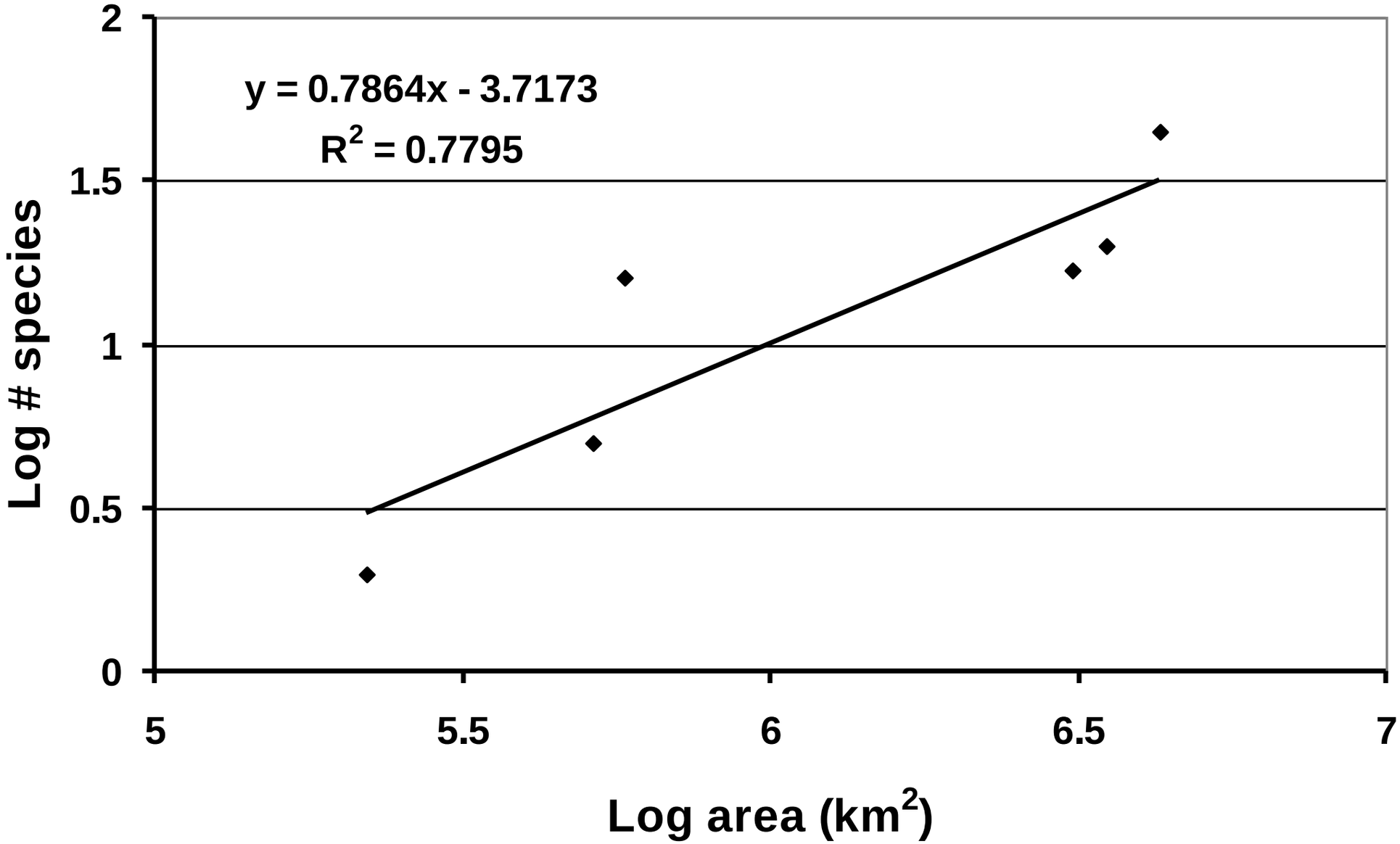
Number of non-native species in Rhine versus cumulative area of connected river



Leuven *et al*. (2009): Biological Invasions 11: 1989-2008

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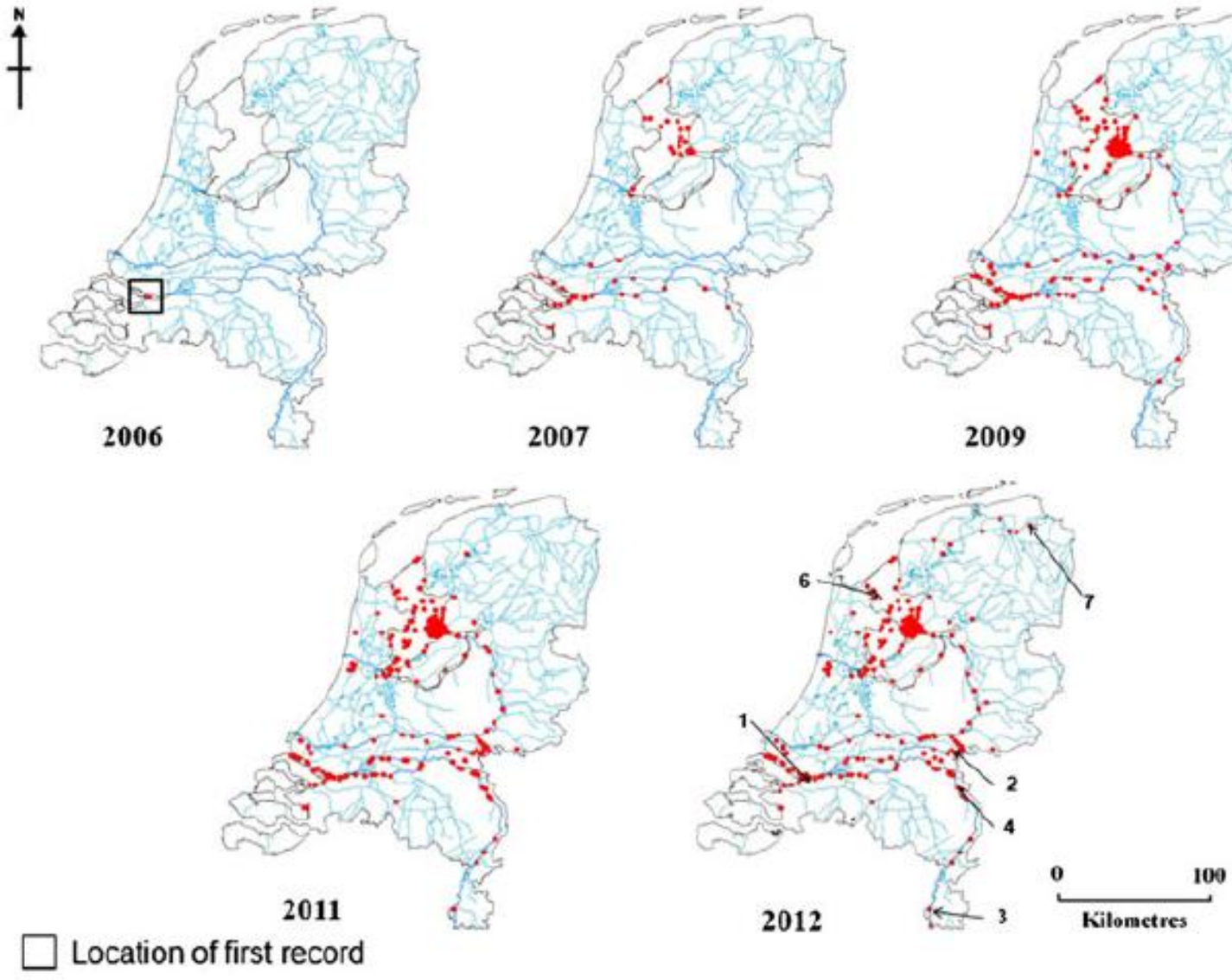
Rapid spread of quagga mussel in Dutch waterways



Species	Number of records	Mean rate ± SD	Minimum rate	Maximum rate
Dreissena bugensis	5	68 ± 31	23	105

Matthews et al. (2014): Biological Invasions 16/1: 23-42

Rapid spread of Ponto-Caspian gobies in Dutch waterways

a) Western tubenose goby (*Proterorhinus semilunaris*); b) Monkey goby (*Neogobius fluviatilis*);
c) Kesslers goby or bighead goby (*Ponticola kessleri*); d) Round goby (*Neogobius melanostomus*)

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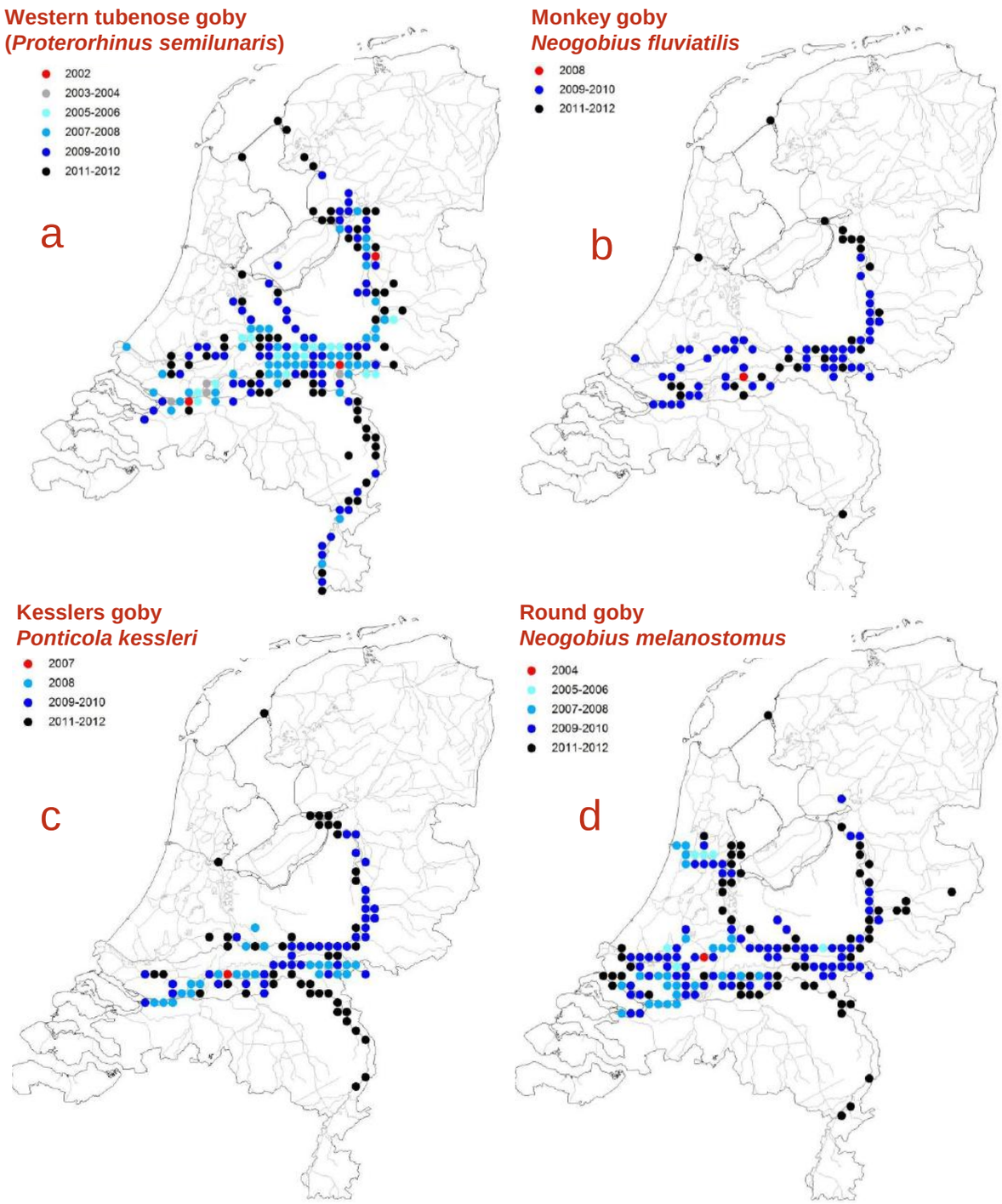
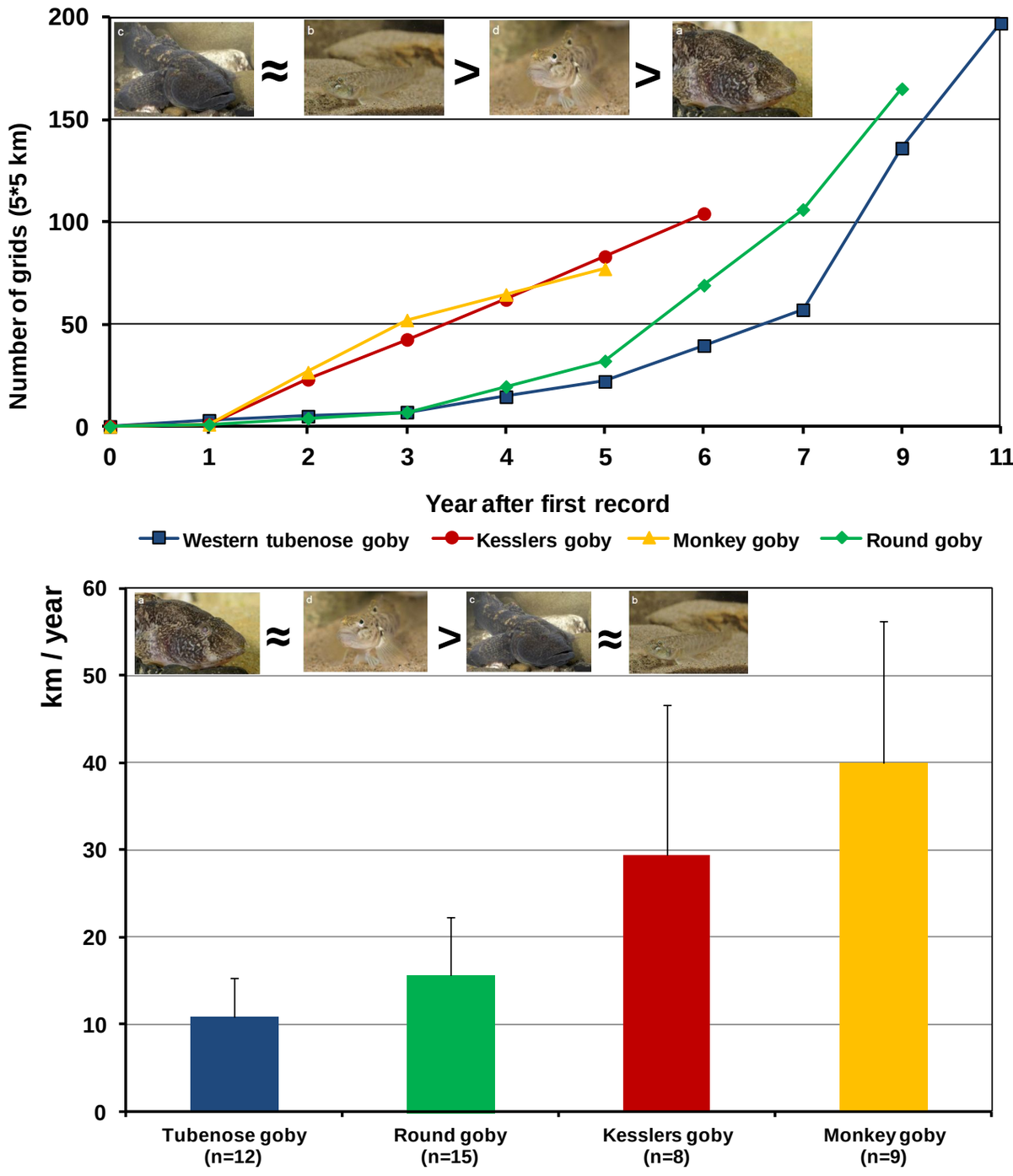
Rapid spread of Ponto-Caspian gobies in Dutch waterways





Van Kessel, et al. (2013). DES-RUN Reports 436: 1-91

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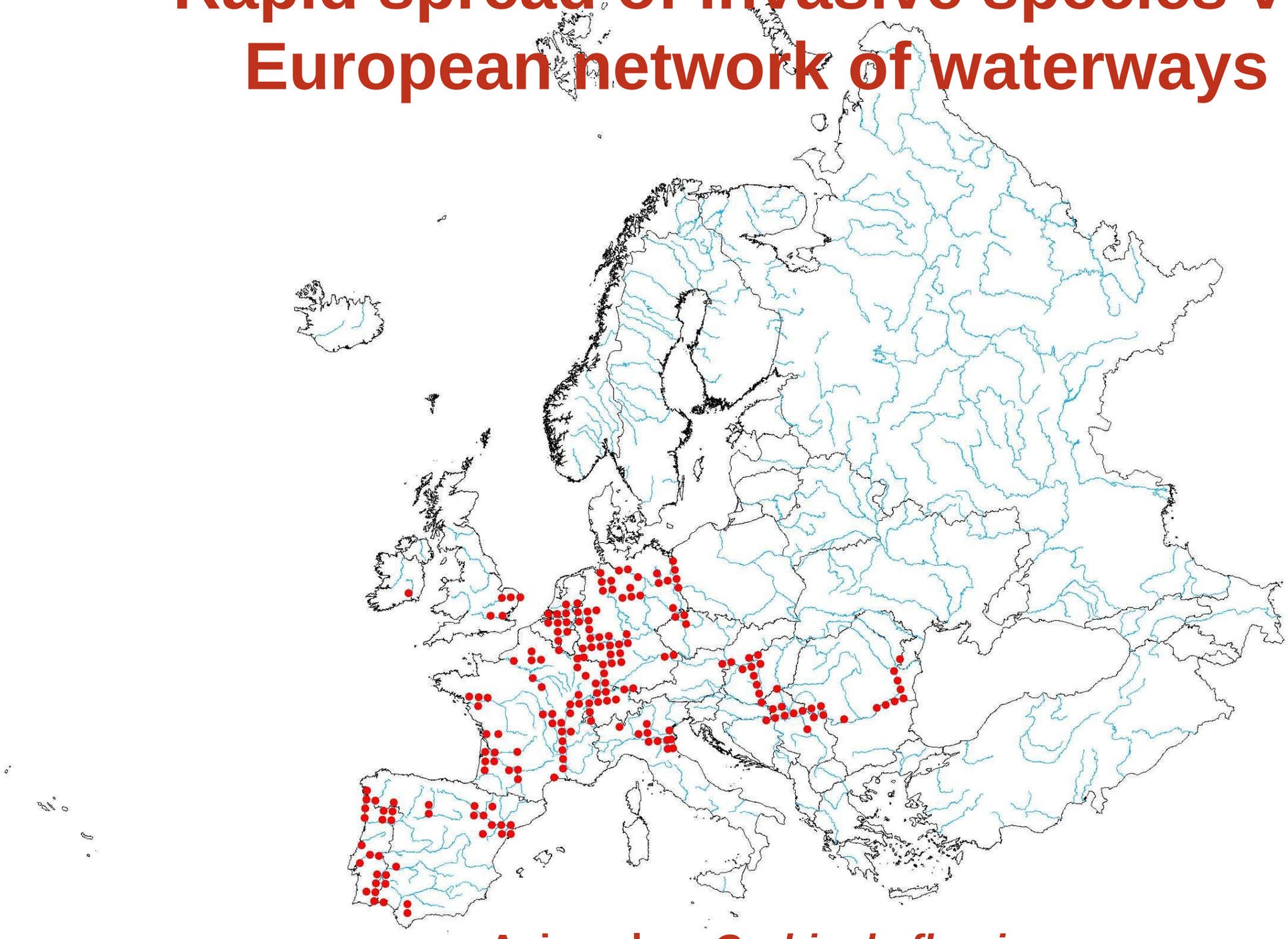
Rapid spread of invasive species via European network of waterways



Asian clam *Corbicula fluminea*
Period 1978-2011

Collas et al. (2014) in prep.

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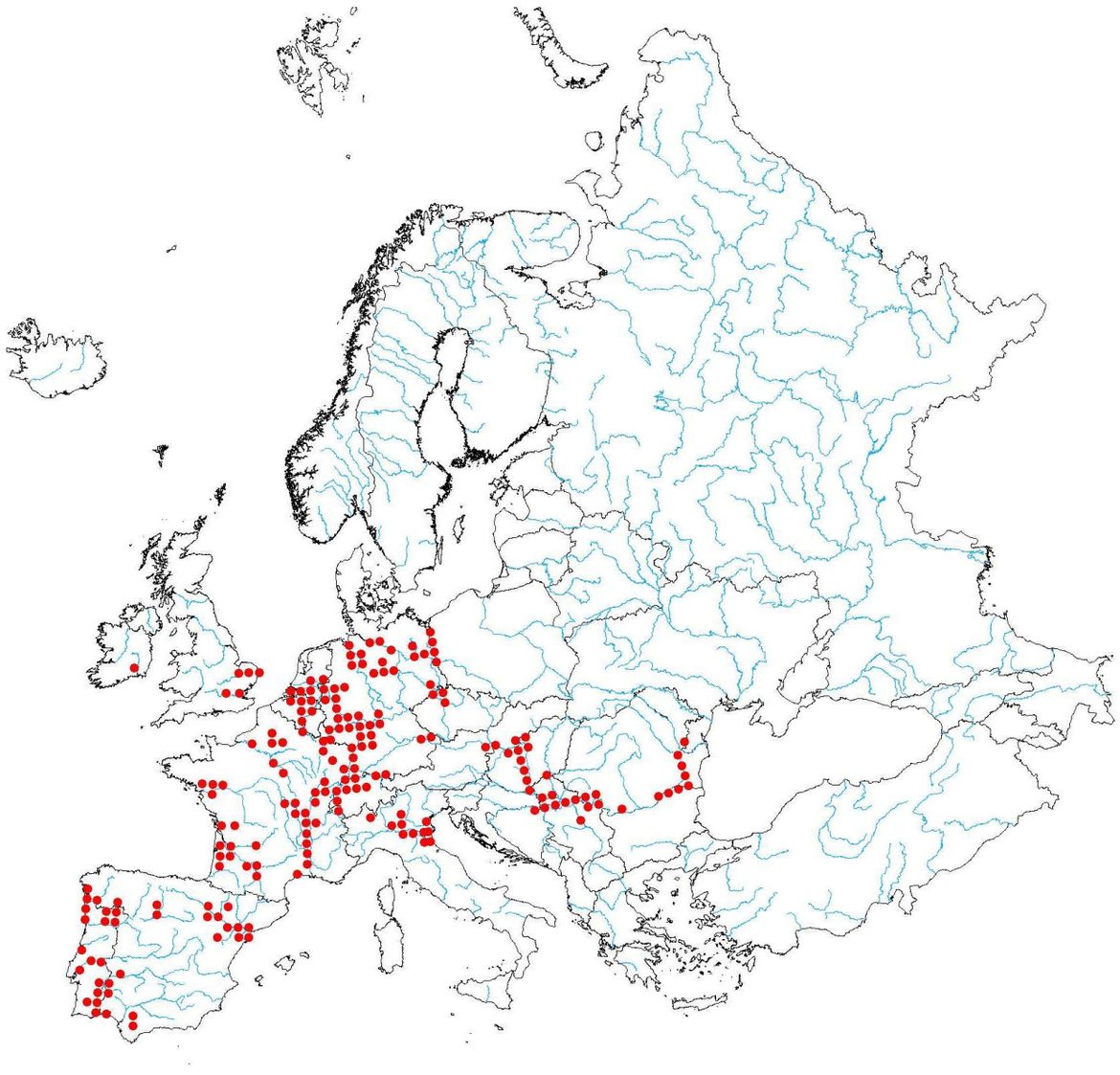
Rapid spread of invasive species via European network of waterways



Spread in 2011

Asian clam *Corbicula fluminea*

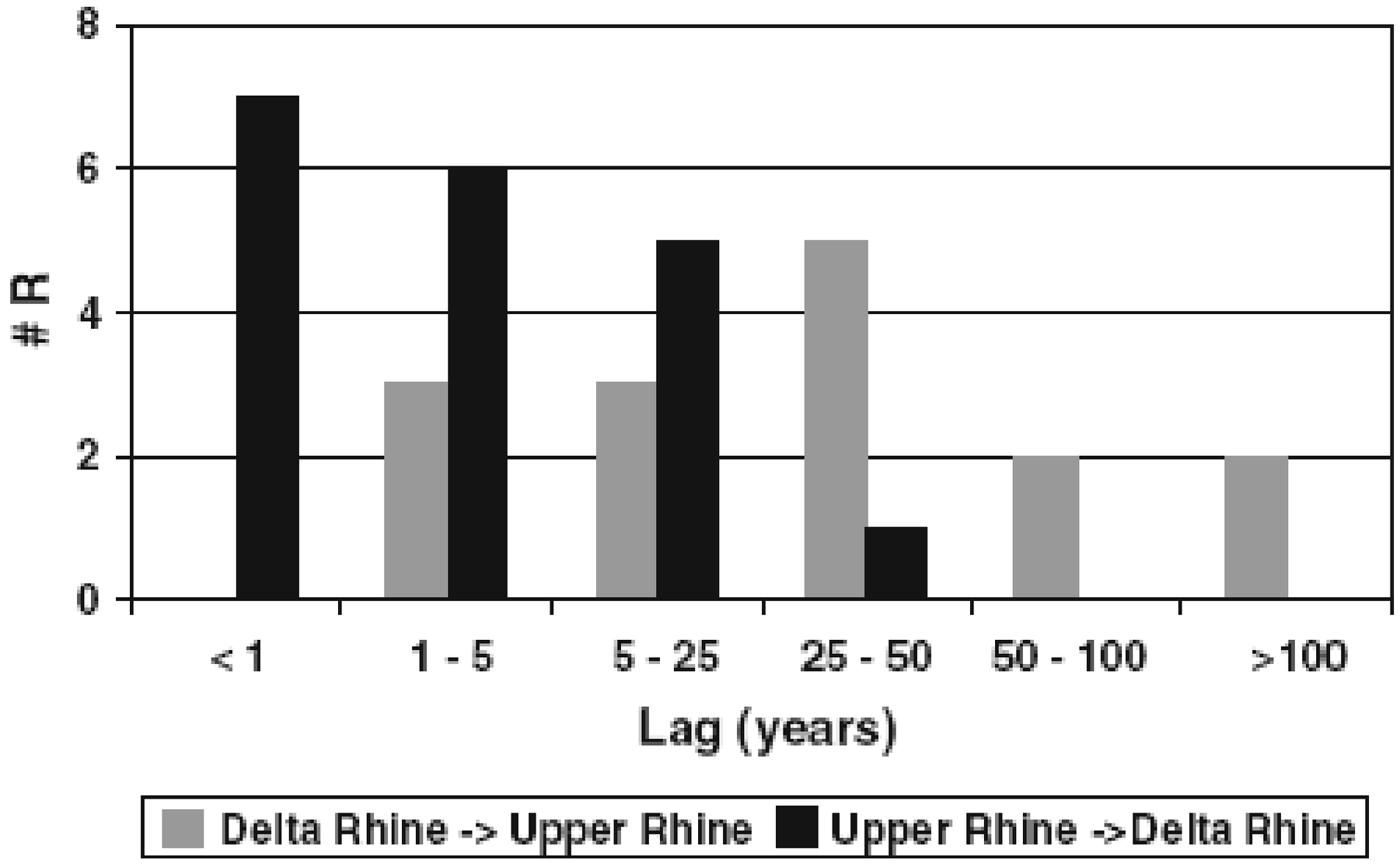
1. Multiple hotspots for primary introductions:
   - Intentional introduction sites?
   - Estuaries (harbours)
2. Rapid secondary spread in European network of waterways: via all corridors
3. Gradual upstream dispersal and hopping pattern
4. Vectors: shipping, fish, waterfowl
5. Dispersal rates: 27 – 276 km y^{-1}

Collas et al. (2014) in prep.

Dispersal rates of aquatic invasive species in European waterways (km y^{-1})

Taxon / species	Number of records	Mean rate ± SD	Minimum rate	Maximum rate
Bivalves (EU)				
Corbicula fluminea	**6**	63 ± 95	**27**	**276**
Dreissena polymorpha	**3**	65 ± 93	**14**	**199**
Dreissena bugensis	**6**	120 ± 132	**23**	**383**
Crustaceans (EU)				
Chelicorophium curvispinum	**6**	44 ± 46	**14**	**137**
Dikerogammarus villosus	**4**	112 ± 194	**40**	**461**
Jaera istri	**5**	109 ± 68	**31**	**185**
Obesogammarus obesus	**3**	130 ± 203	**58**	**424**
Fish (NL)				
Neogobius fluviatilis	**9**	40 ± 16	**23**	**66**
Neogobius melanostomus	**15**	16 ± 7	**8**	**23**
Ponticola kessleri	**8**	29 ± 17	**17**	**65**
Proterorhinus semilunaris	**12**	11 ± 4	**4**	**20**

Lag in first record patterns of non-native freshwater macroinvertebrates in the River Rhine



n = 15 **n=19**

Leuven *et al*. (2009): Biological Invasions 11: 1989-2008

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First record patterns of non-native freshwater macroinvertebrates in the River Meuse

River Meuse (n=31)	
First arrivals:	
River Rhine	77 %
River Meuse	13 %
Rhine-Meuse delta	10 %

Pfau et al. (2014)

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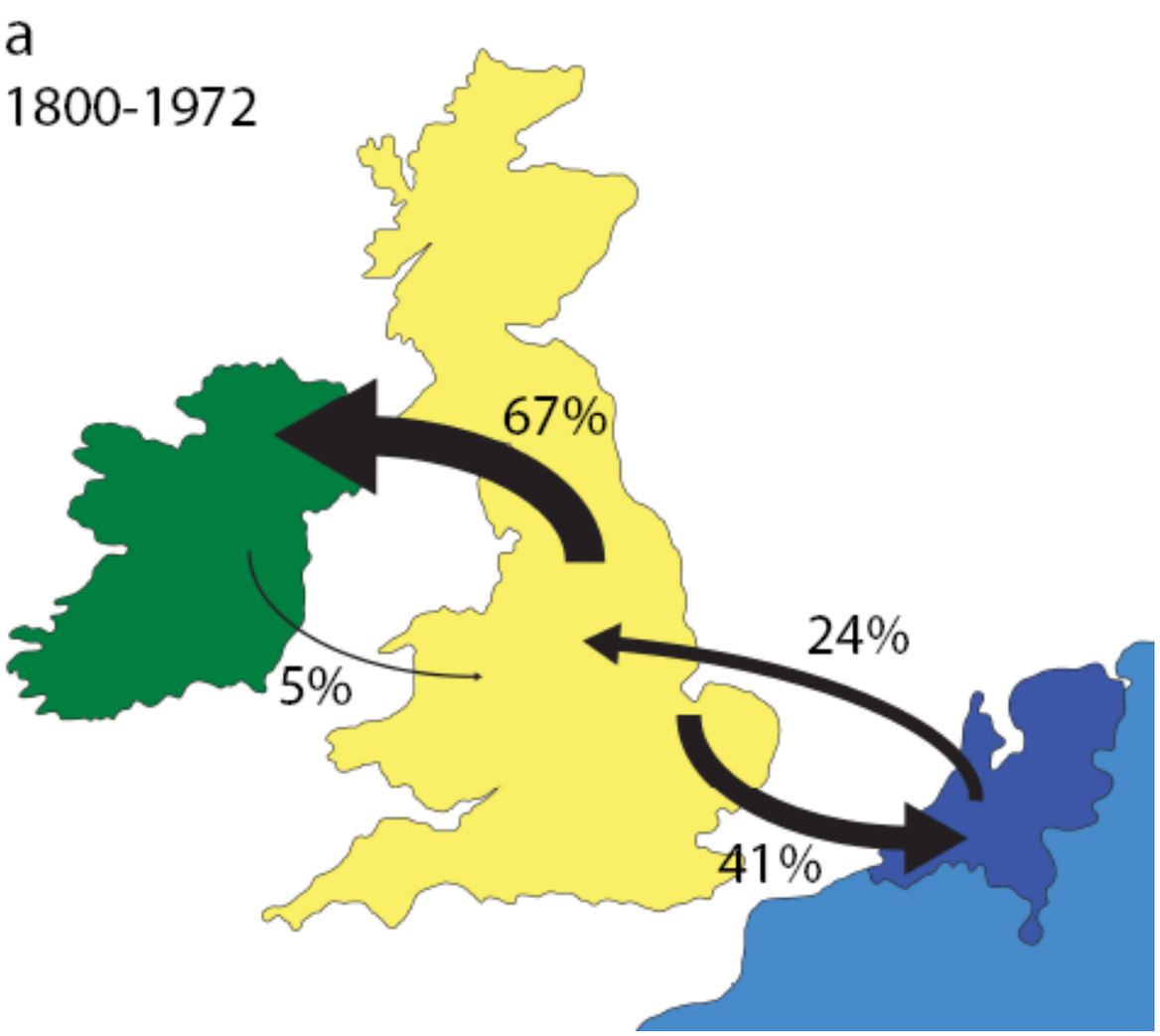
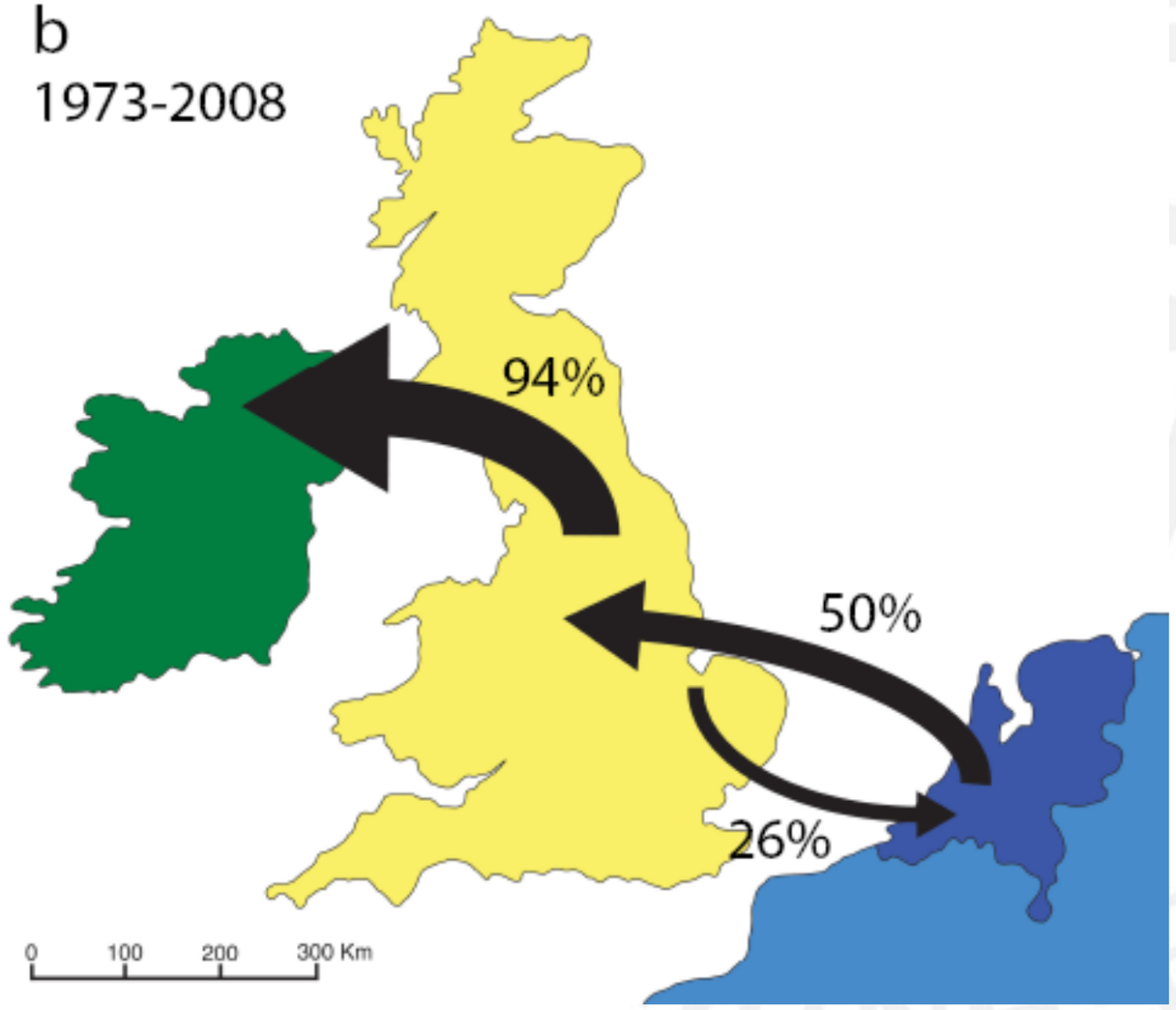
Changing patterns in island hopping freshwater invaders





Zu Ermgassen et al. (2014)

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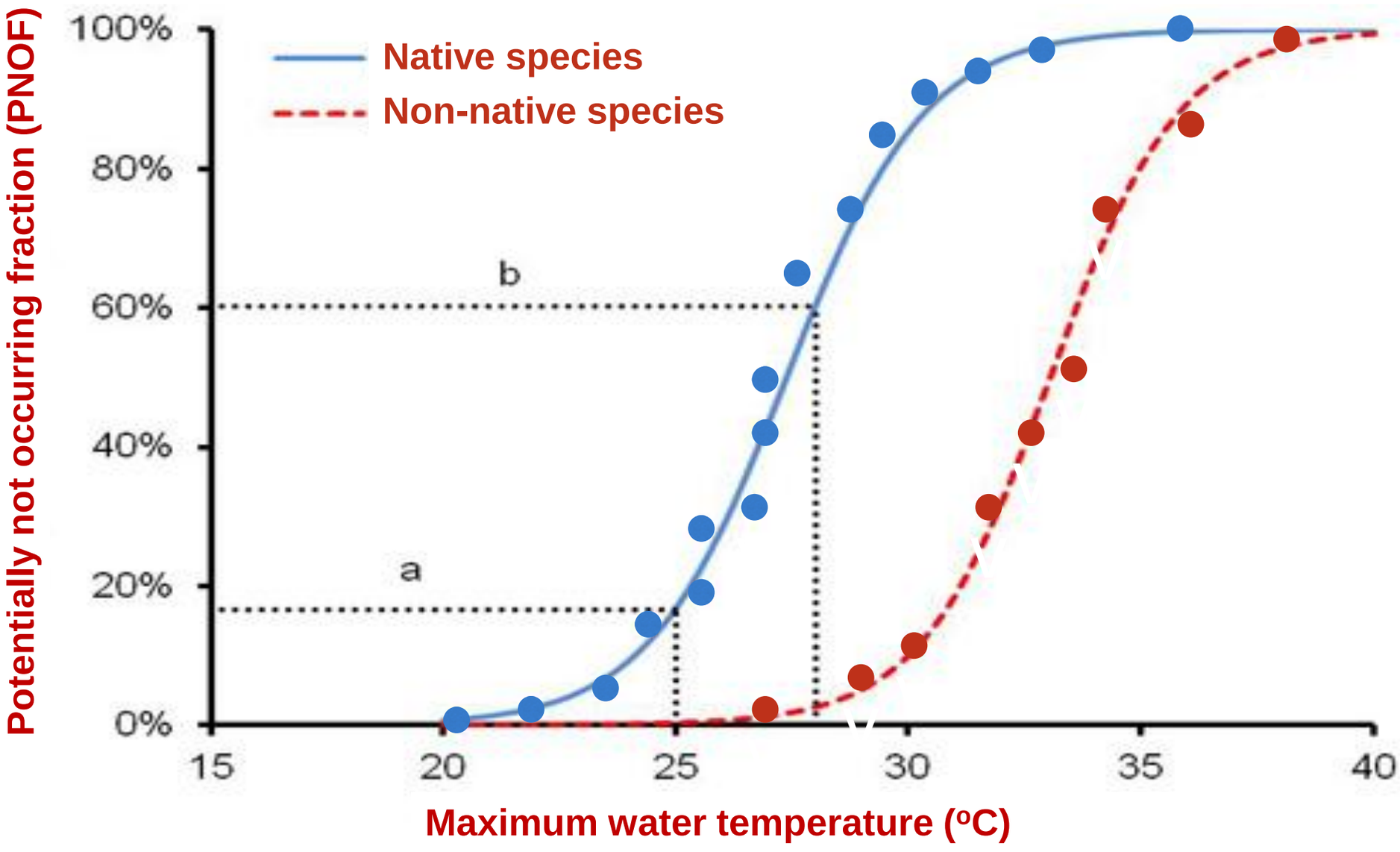
Species-environment match: species sensitivity distributions (SSDs)



Biodiversity
- Individual species
- Species groups

Environmental factors
- Temperature
- Salinity
- Current velocity
- Desiccation
- pH
- O_2
- Nutrients
- Toxic substances
- Combined effects

In progress:
- Substrate / grain size
- Habitat heterogeneity

Leuven et al. (2011) Current Zoology 57(6): 852−862

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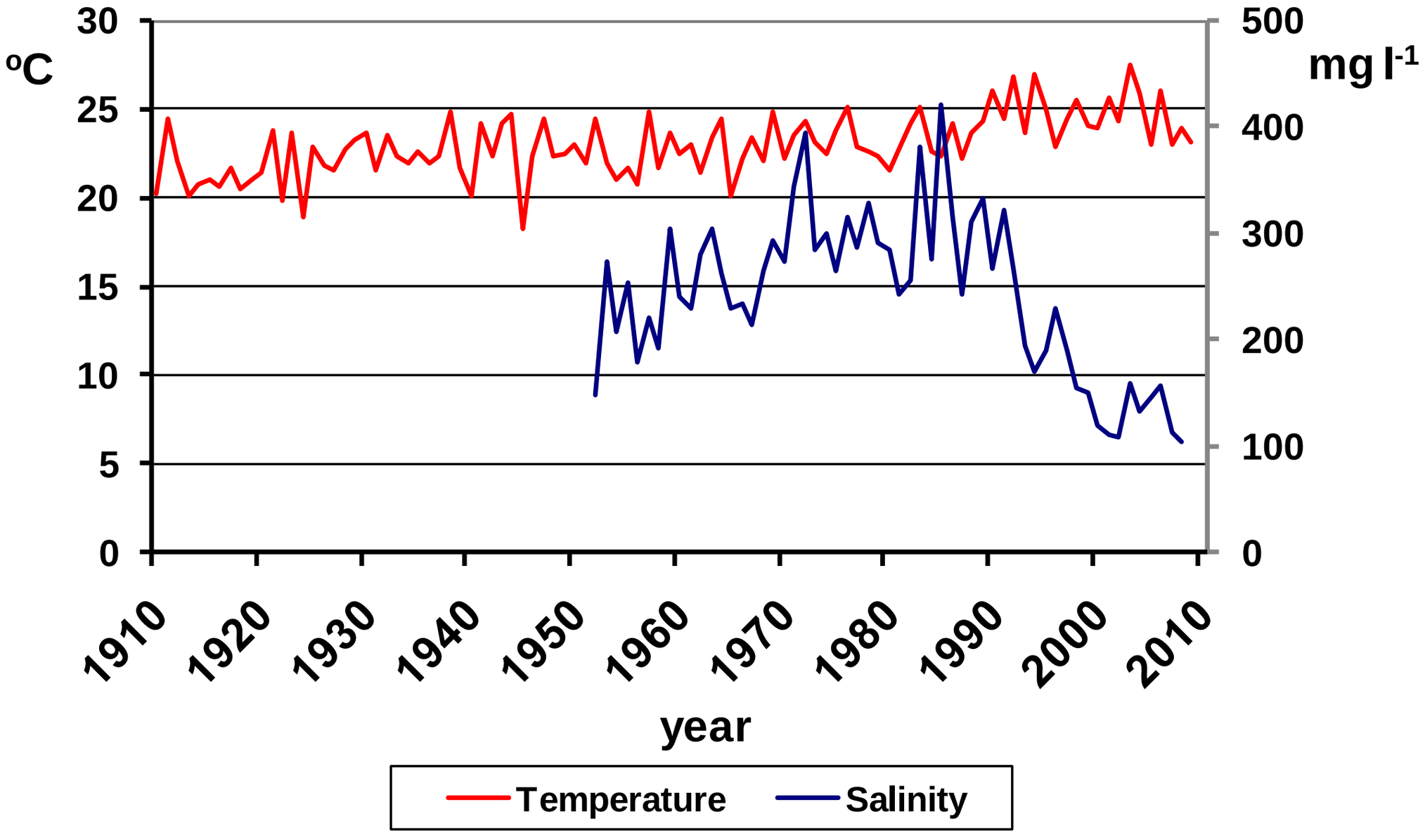
Longitudinal differences in potentially not occurring fractions of mollusc species pools in the River Rhine

Calculated for maximum temperature and salinity values during an extremely hot dry year

Station	River section	Salinity		Temperature	
		Native	Non-native	Native	Non-native
Maassluis	DR	78.8	49.6	14.9	0.3
Lobith	DR/LR	1.8	0.8	61.7	2.7
Koblenz	MR	1.4	0.6	69.3	3.8
Lauterborg	UR	1.0	0.4	40.2	1.1
Wheil am Rhein	UR/HR	0.8	0.3	32.5	0.8
Reckingen	HR	0.7	0.3	32.5	0.8
Diepoldsau	AR	0.7	0.3	0.1	0.0

Verbrugge et al. (2012) Biological Invasions 14: 1187-1199

Maximum salinity and temperature of Rhine River at Lobith



Verbrugge et al. (2012) Biological Invasions 14: 1187-1199

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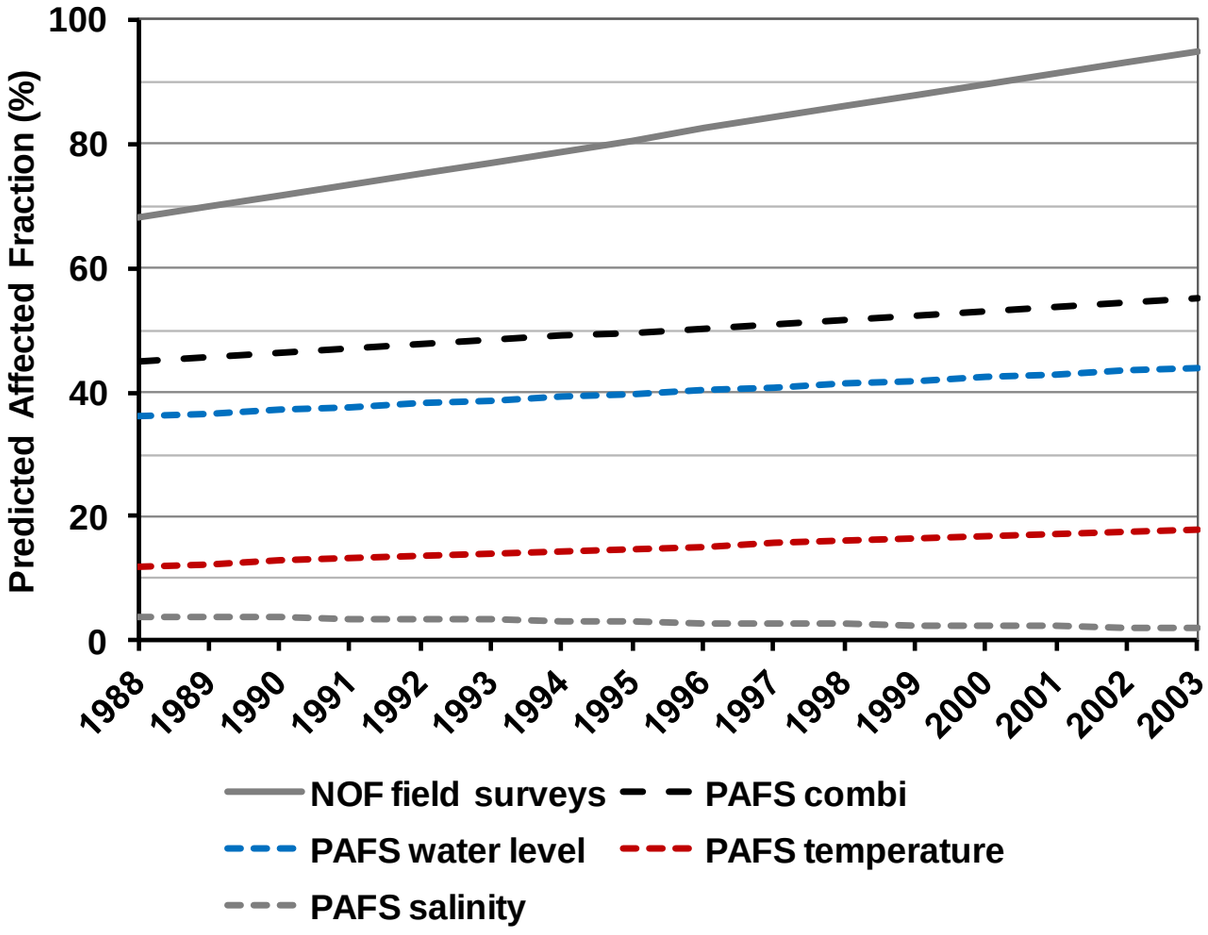
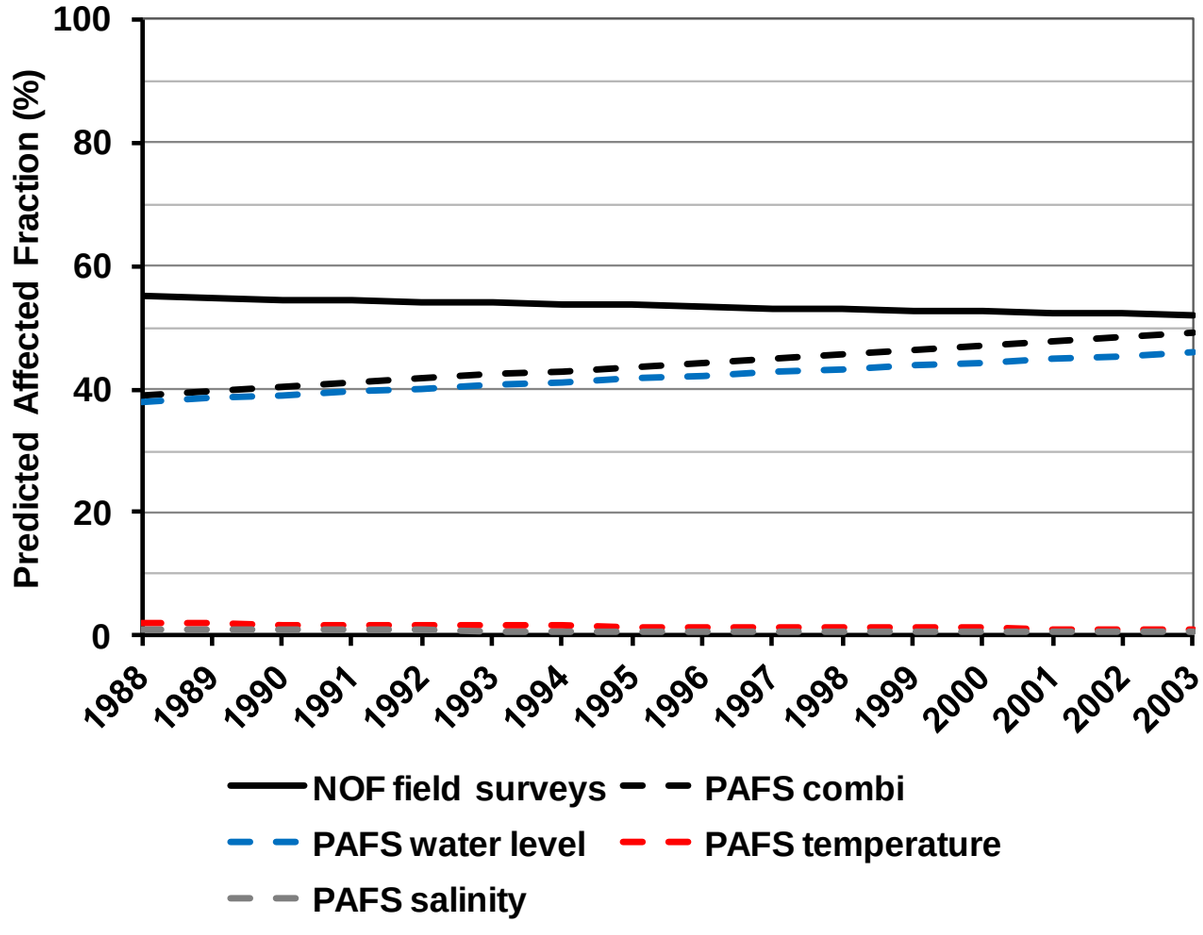
Species – environmental factor match for molluscs in the River Rhine at Lobith

Native species



Non-native species



Collas et al. (2014) Freshwater Biology 59/1: 41-55

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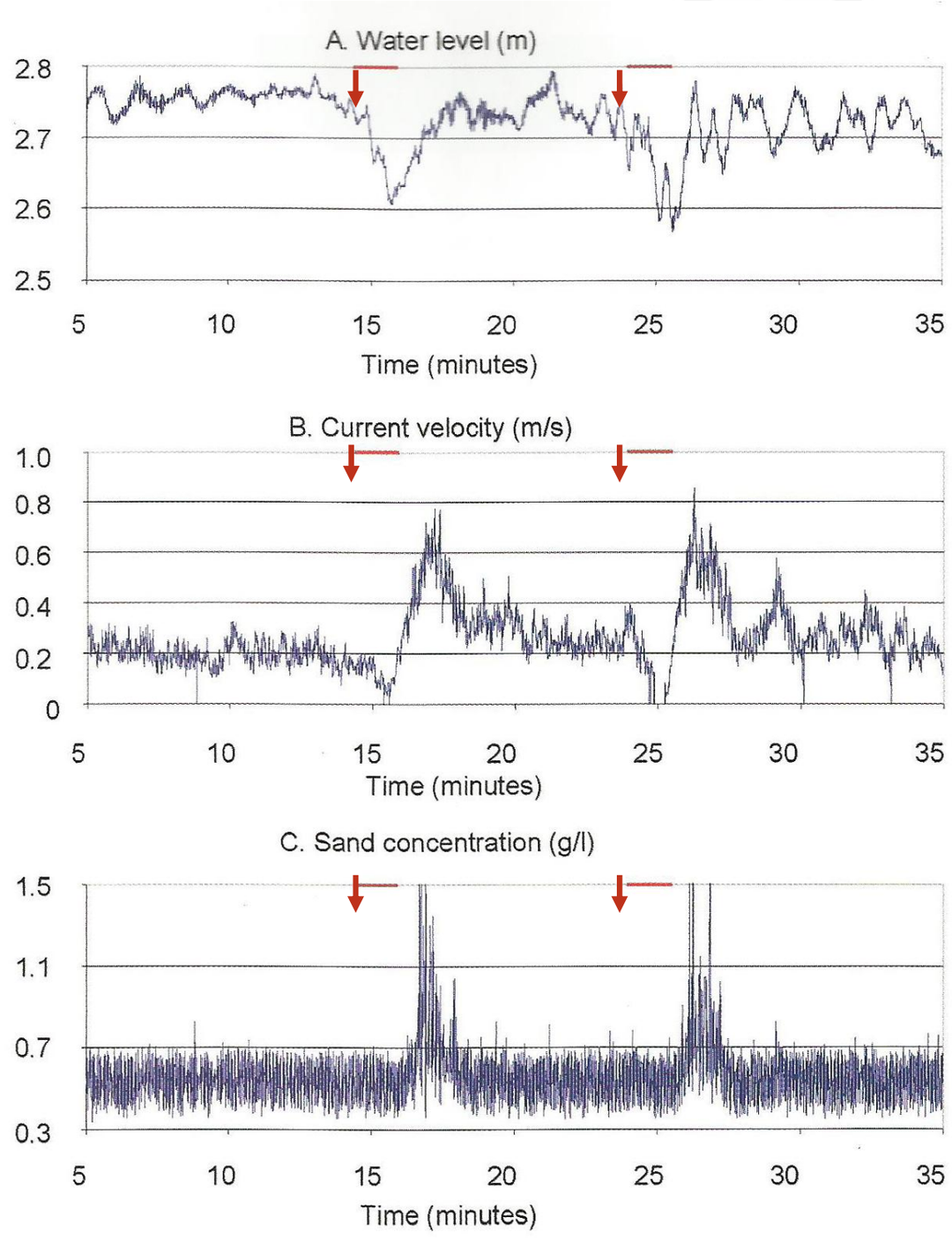
Shipping induced water turbulence

Effects of towboats with four loaded barges passing a groyne field in the River Waal



Ten Brinke (2004) The Dutch Rhine. Veen Magazines, Diemen

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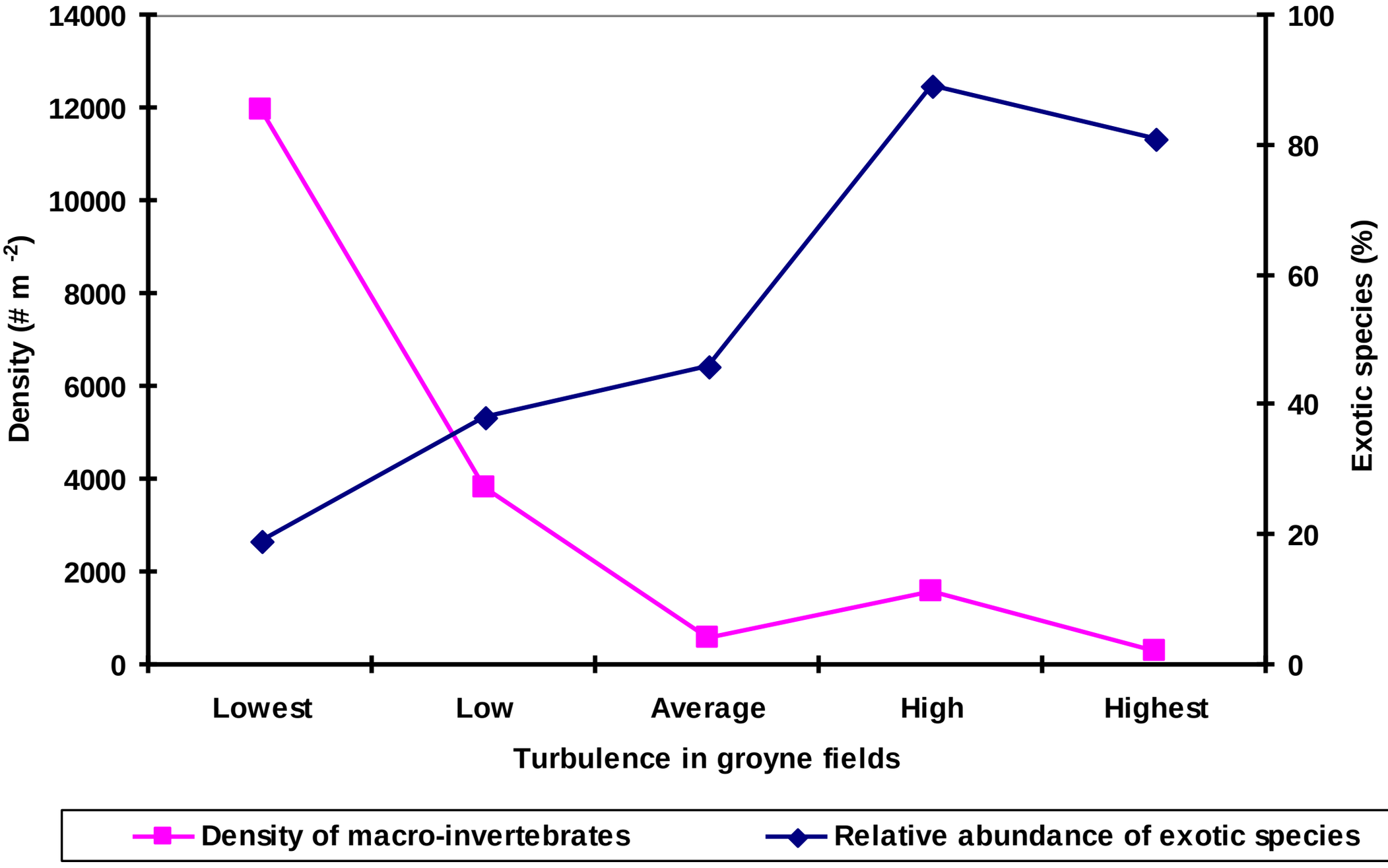
Shipping induced water turbulence: Effects on macroinvertebrates in River Rhine



Data: Reeze et al. (2005)

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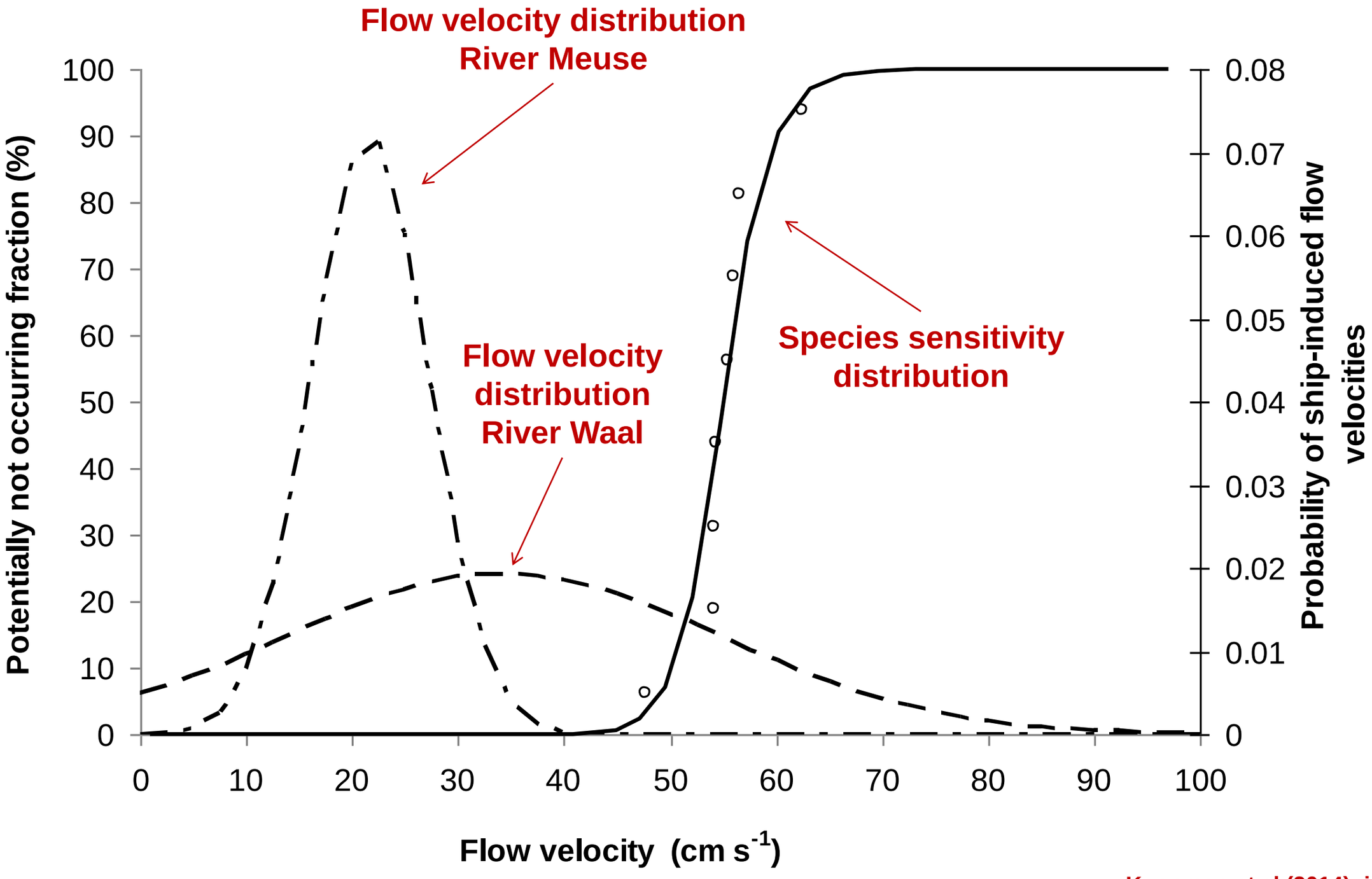
Shipping induced water turbulence: effects on snails



Koopman et al (2014): in prep.

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Shipping induced water turbulence: effects on snails

Ship type	Vmax (cm/s)	$PNOF_{EC95}$ (%)
Recreational ship	13	2.3E-12
Container ship	18	1.7E-10
River cruise ship	21	1.3E-09
Tanker	24	7.5E-09
Freight ship	25	1.3E-08
Towboat no barge	39	4.5E-06
Service ship	47	5.3E-05
Towboat 4 barges	130	26.4
Towboat 6 barges (long)	160	84.7
Towboat 6 barges (wide)	175	94.8

Koopman et al (2014): in prep.

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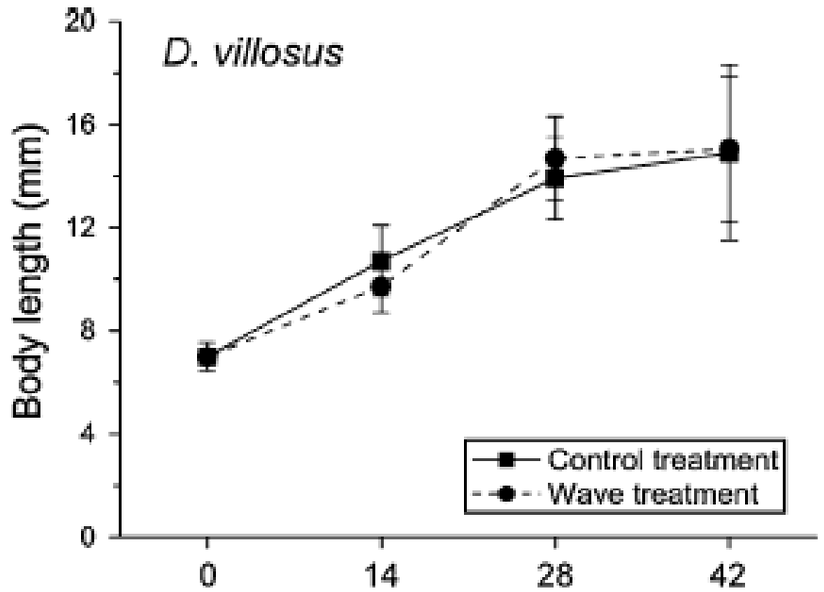
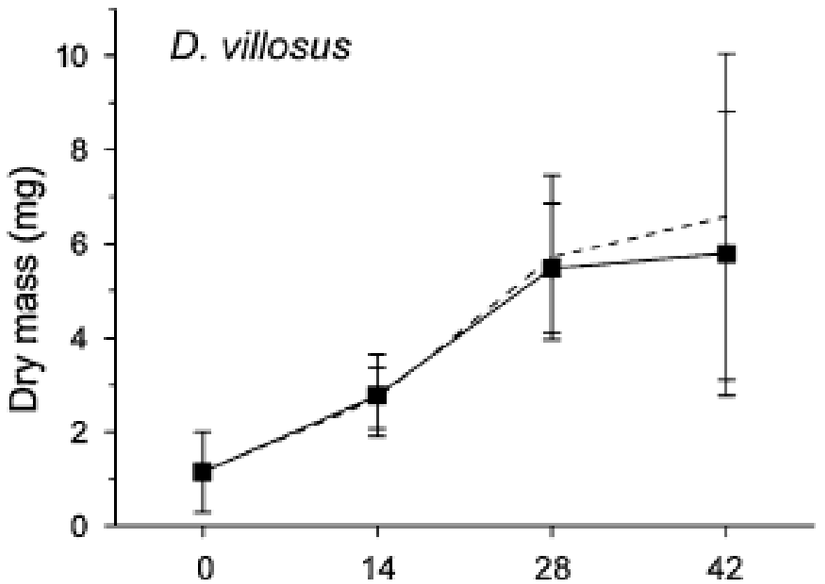
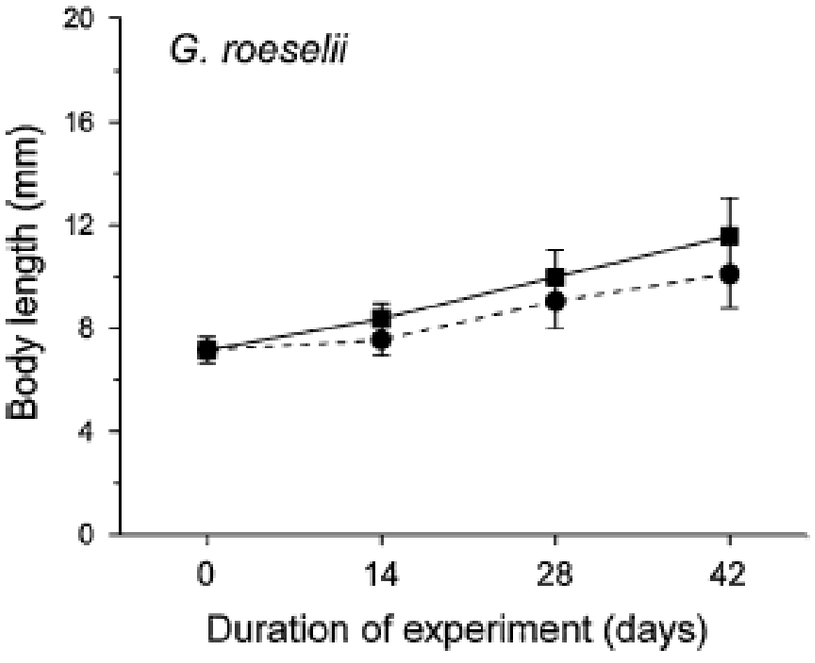
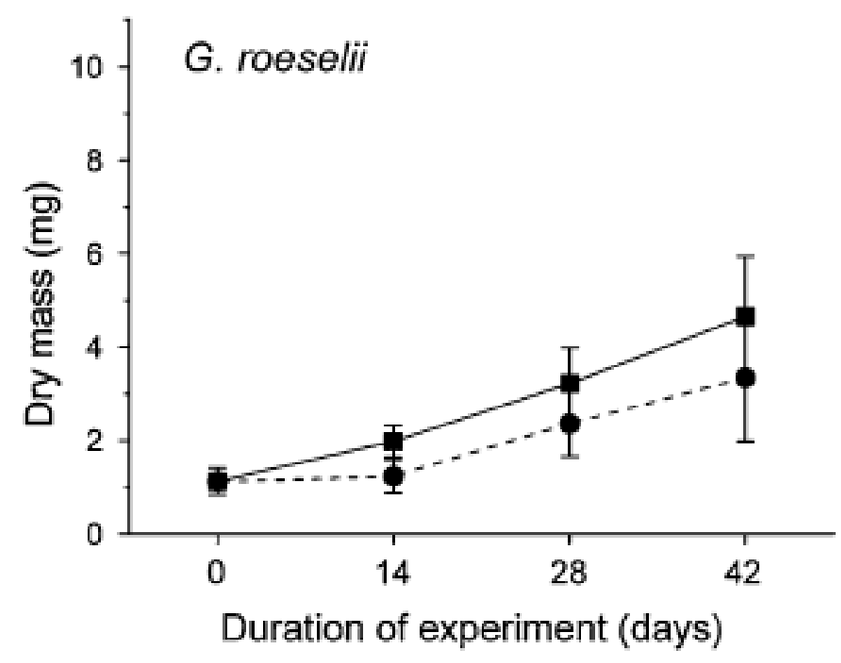
Shipping induced water turbulence: Effects on growth of native and invasive species







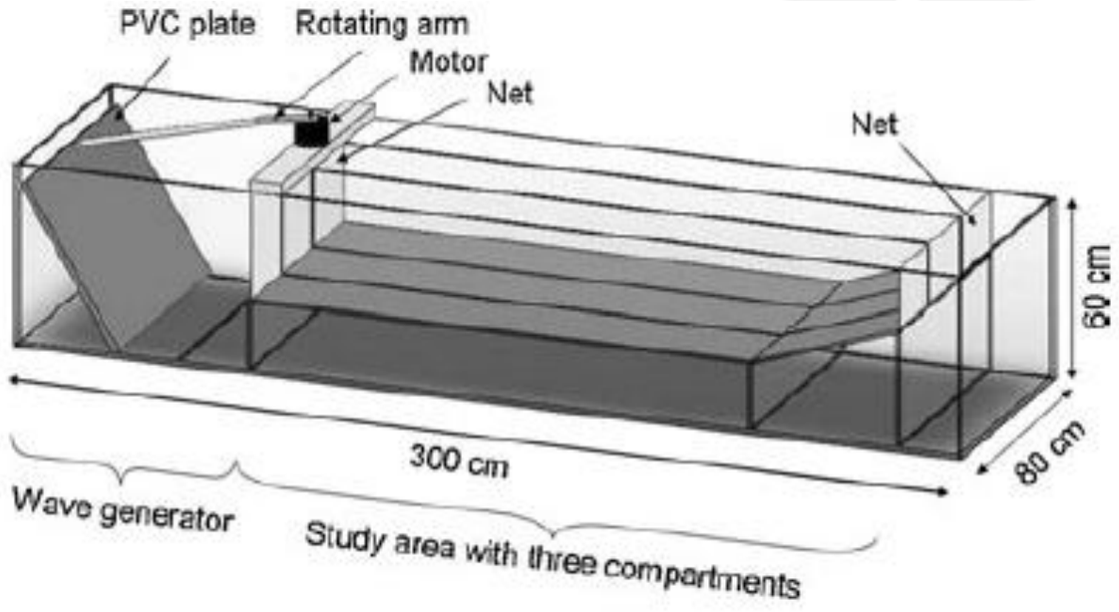


Gabel et al. (2011) Biological Invasions 13: 1843-1853

Shipping induced water turbulence: Effects on behaviour of native and invasive species

In addition field experiments: differential detachment of species from various types of substrates (sand, reed, roots, stones etc.)

Gabel et al. (2012) Freshwater Biology 57: 2425-2435



Species	Treatment/statistics	Time spent feeding (min)	Time spent swimming (s)	Mortality (%)	Glycogen content (mg g^{-1})
G. roeselii	Wave treatment	11.1 ± 6.4	18.0 ± 10.2	73.3 ± 11.7	3.3 ± 0.8
	Control	10.4 ± 6.3	11.8 ± 7.4	41.7 ± 11.7	4.8 ± 0.5
	Mann–Whitney *U*	8575.0	5823.5	0.0	0.0
	P	0.401	**<0.001**	**0.025**	**0.009**
D. villosus	Wave treatment	14.3 ± 9.6	10.6 ± 6.2	47.5 ± 53.3	5.3 ± 0.8
	Control	15.0 ± 9.0	10.7 ± 5.8	34.2 ± 20.0	5.6 ± 0.7
	Mann–Whitney *U*	2225.5	2296.5	14.5	8.0
	P	0.607	0.834	0.575	0.624

Gabel et al. (2011) Biological Invasions 13: 1843-1853

Conclusions

1. The Rhine-Main-Danube waterway is a global high way for invaders
2. Exponential increase in non-native species (Rhine: <1 to 13 per decade)
3. Surface area of interconnected river basins increased with a factor 21.6
4. Interconnected basin area significantly correlated with ∑ non-native species
5. Most important vectors: ballast water, ship hulls and dispersal via waterways
6. Environment-species match strongly determines success of invaders
7. Performance of native species is more limited by environmental deteriorations that that of invaders
8. Ranking of key factors: desiccation > temperature > shipping induced turbulence > salinity. The latter is more important in tidal areas.

Thanks for your attention!

Questions?

For more information or cooperation:
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Radboud University Nijmegen & Netherlands Center of Expertise - Exotic species