Introduction to river plastic monitoring

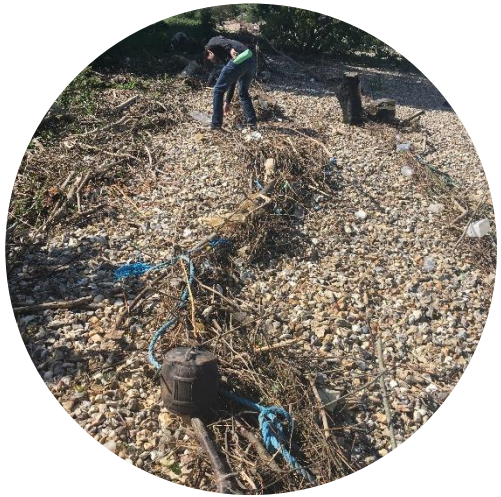
Tim H.M. van Emmerik[1], Sabrina Kirschke[2], Christian Schmidt[3]

[1]Wageningen University, the Netherlands

[2]Museum für Naturkunde, Germany

[3]UFZ, Leipzig, Germany

Contact: tim.vanemmerik@wur.nl



WAGENINGEN UNIVERSITY & RESEARCH

UFZ HELMHOLTZ Centre for Environmental Research

für Naturkunde MUSEUM FÜR NATURKUNDE BERLIN

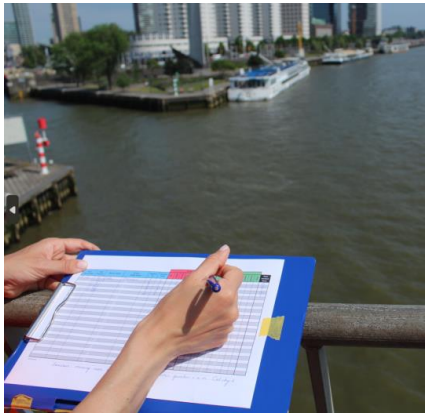
WWQA World Water Quality Alliance

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

NILE BASIN INITIATIVE INITIATIVE DU BASSIN DU NIL

Wageningen River Plastic Team

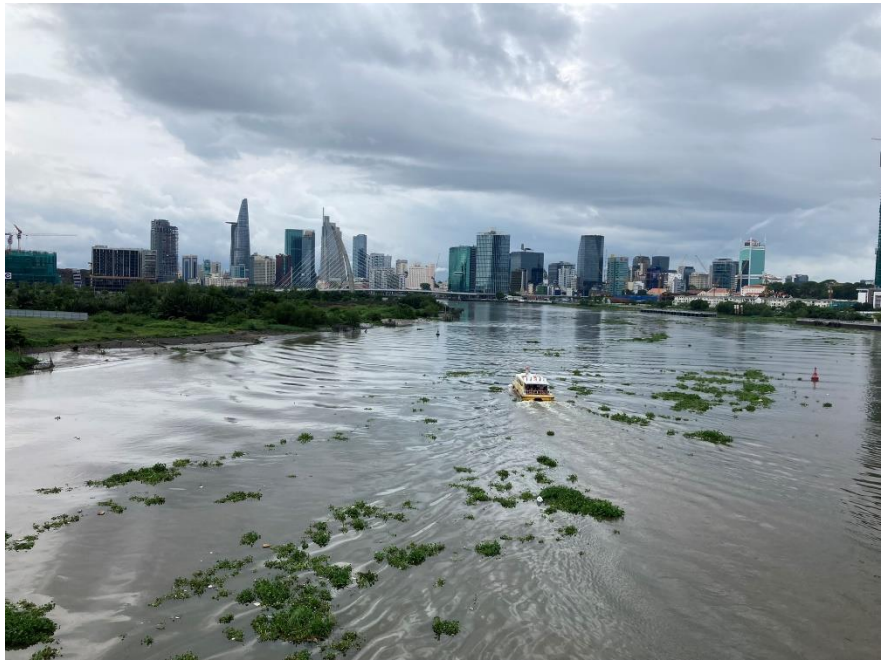
- Monitoring tools: Visual, sampling, image-based, AI, satellite, sonar
- Monitoring strategies: Netherlands, Rhine, Mekong, Ghana, Thailand
- Transport processes: Emission to ocean, retention, floods
- Capacity building: Japan, Netherlands, Germany, Cambodia, Ghana, Thailand



WAGENINGEN
UNIVERSITY & RESEARCH

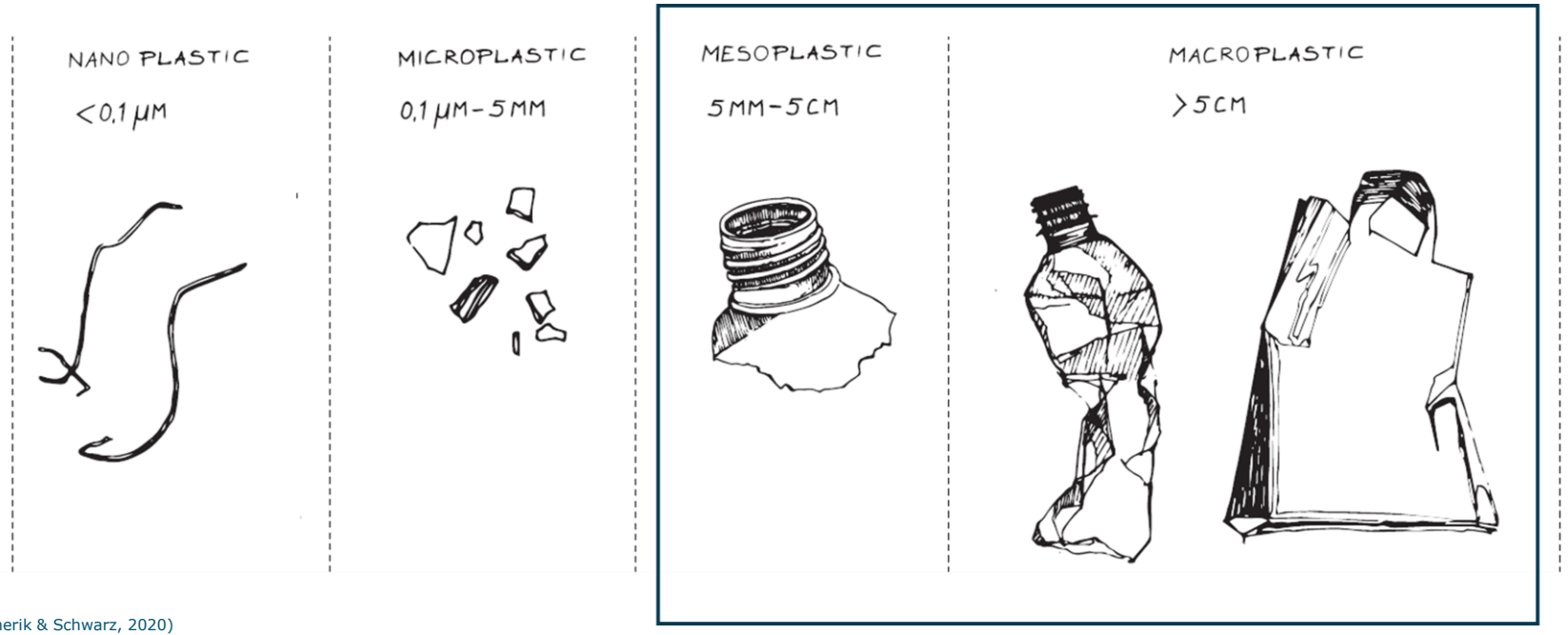
What you should remember

- There is no one-size-fits all for river plastic monitoring
- Best strategy depends on the goals, river, and resources
- Start simple, add complexity



WAGENINGEN
UNIVERSITY & RESEARCH

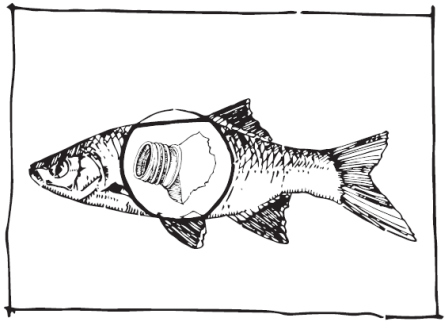
What I talk about, when I talk about plastic

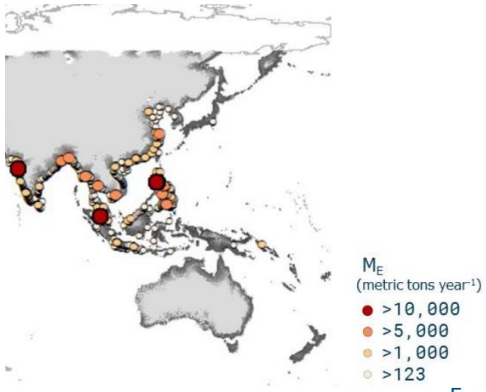


(van Emmerik & Schwarz, 2020)

Negative effects of macroplastics

- Kill and injure animals and plants
- Economic damage to vessels and infrastructure
- Largest source of microplastics



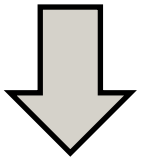


(van Emmerik & Schwarz, 2020; Honingh et al., 2020; Meijer et al., 2019)

WAGENINGEN
UNIVERSITY & RESEARCH

Rivers: Source or sink?

- 48.3–56.3 Mt/year entry into environment
- 0.5-2.5 Mt/year from rivers into the ocean
- 3.0 Mt plastic in the ocean
- What is the role of rivers?



???

WAGENINGEN
UNIVERSITY & RESEARCH

Rivers: Source or sink?

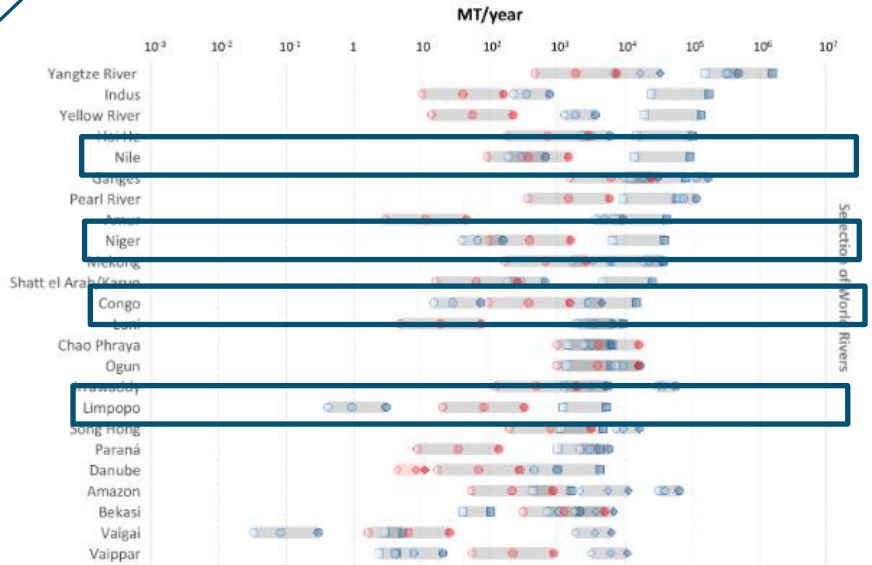
- 48.3–56.3 Mt/year entry into environment
- 0.5-2.5 Mt/year from rivers into the ocean
- 3.0 Mt plastic in the ocean
- What is the role of rivers?

Comment | Published: 12 June 2023

Diverging estimates of river plastic input to the ocean

Daniel González-Fernández, Caspar T. J. Roebroek, Charlotte Laufkötter, Andrés Cózar & Tim H. M. van Emmerik

Nature Reviews Earth & Environment **4**, 424–426 (2023) | Cite this article

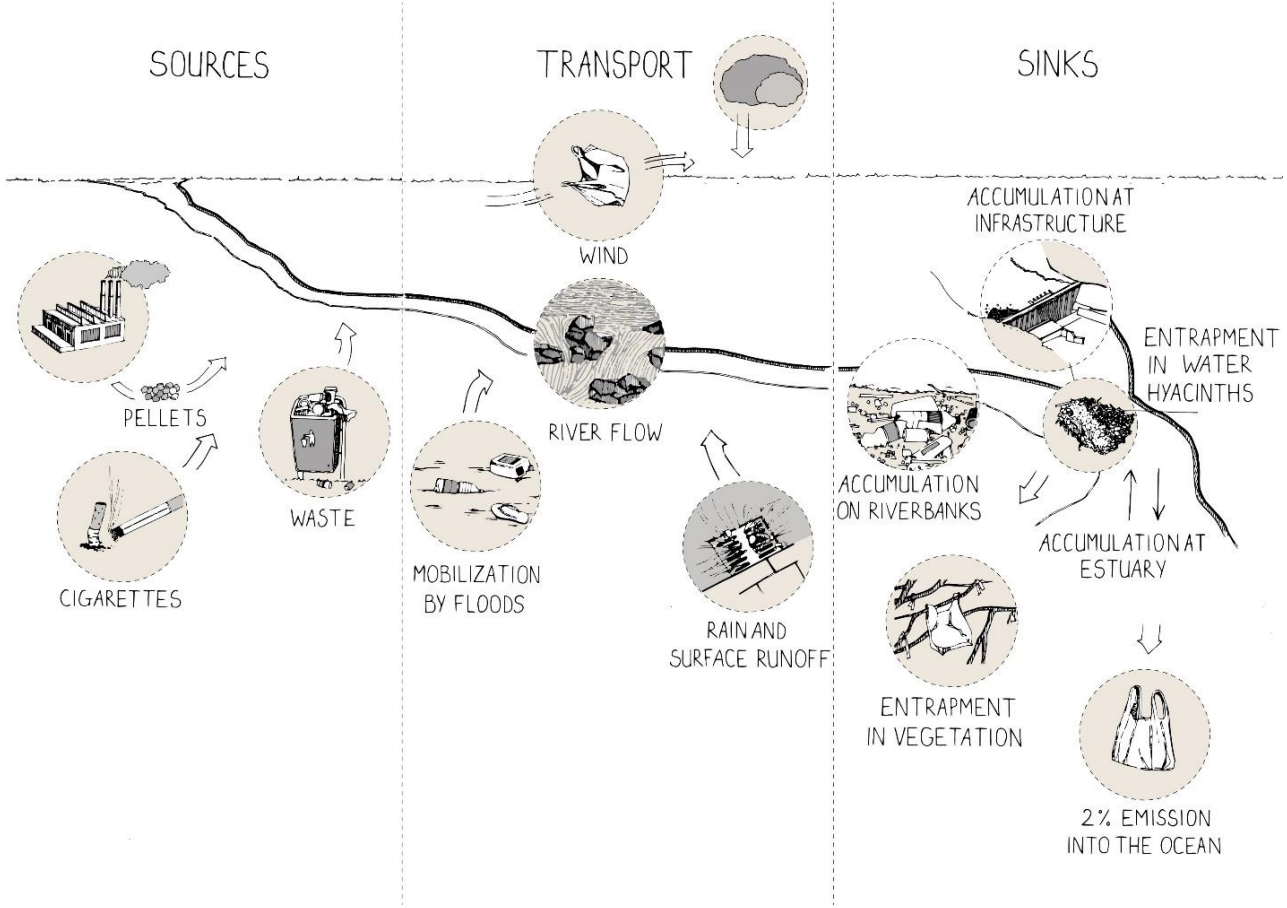


>4 orders of magnitude uncertainty for single river

Where does all the plastic go?

Photos: Eric Hamer

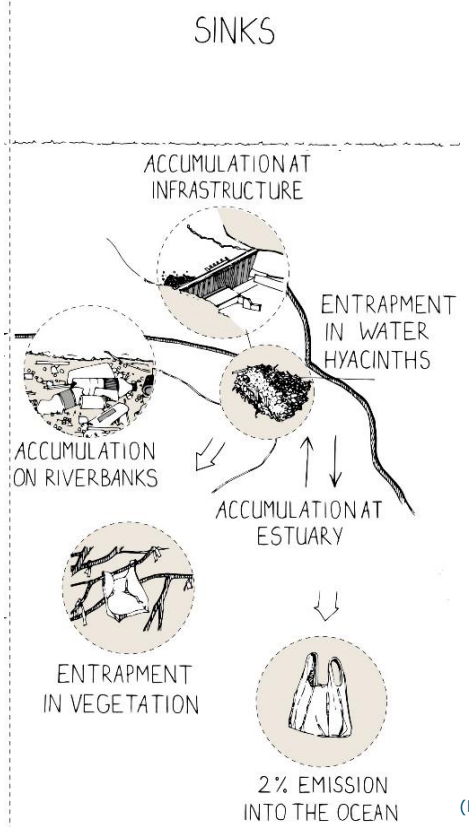
Rivers act as plastic **reservoirs**



(Meijer et al., 2021;

van Emmerik et al., 2022)

Most plastic **does not** flow into the ocean



(Meijer et al., 2021;

van Emmerik et al., 2022)

River plastic monitoring is crucial

to reduce uncertainties

Photos: Eric Hamer

Monitoring river plastic pollution

- Set baseline – what is the level of pollution?
- Optimize interventions – what to prioritize?
- Evaluate interventions – is it working?
- Trend analysis – more/less pollution?

WAGENINGEN
UNIVERSITY & RESEARCH

Observing river plastic pollution

Sampling

Visual counting

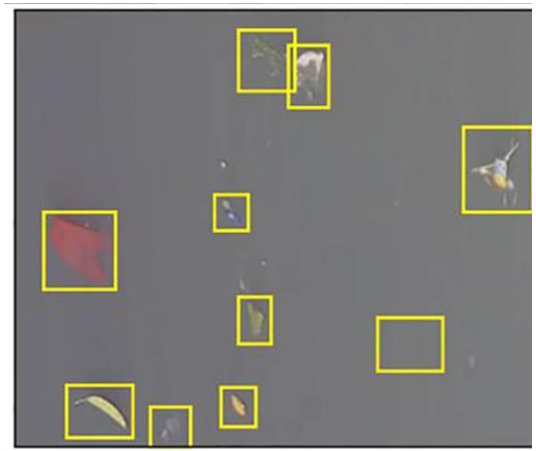
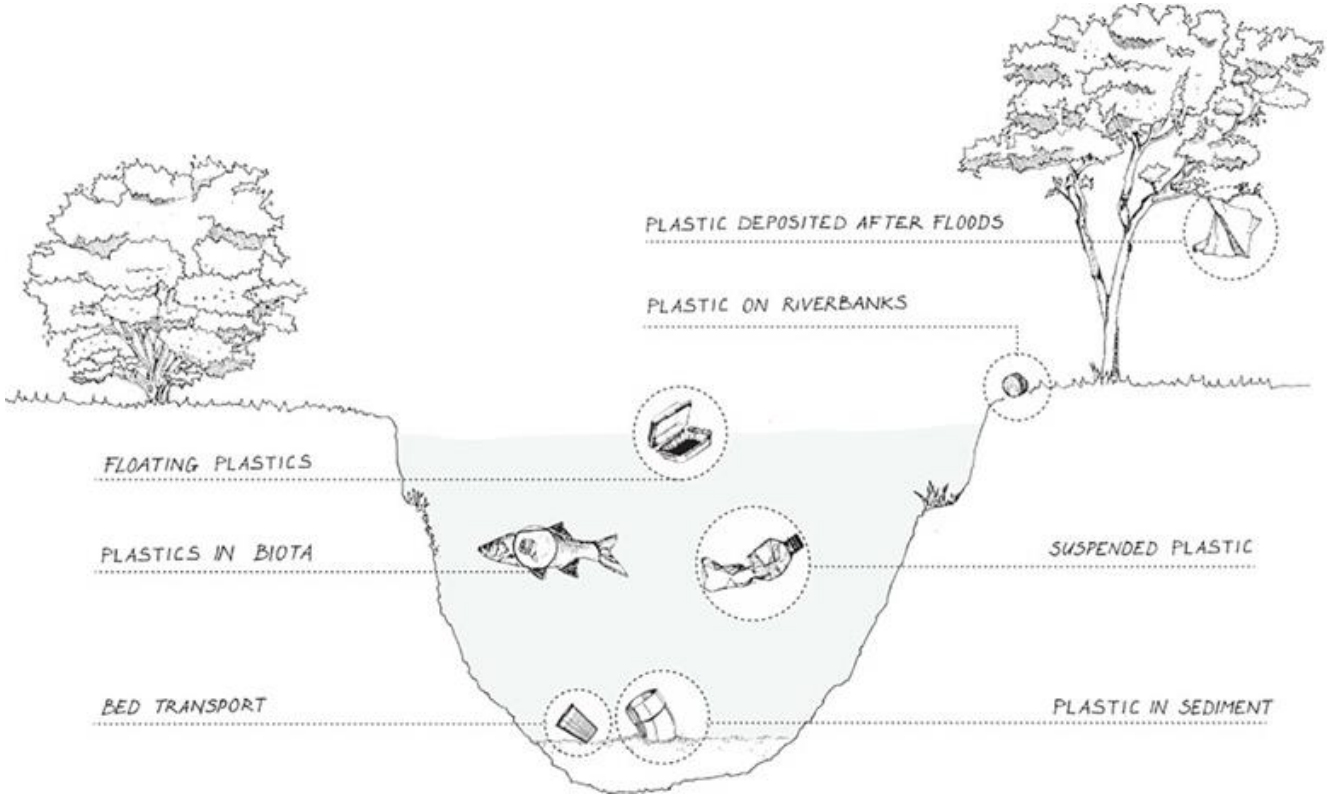


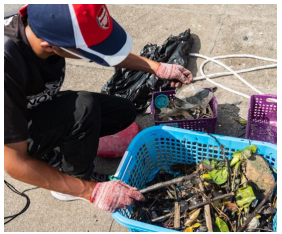
Image-based

Monitoring river plastic pollution



WAGENINGEN
UNIVERSITY & RESEARCH

Monitoring river plastic pollution



Sampling

Visual counting

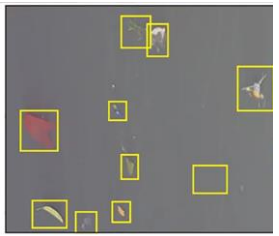
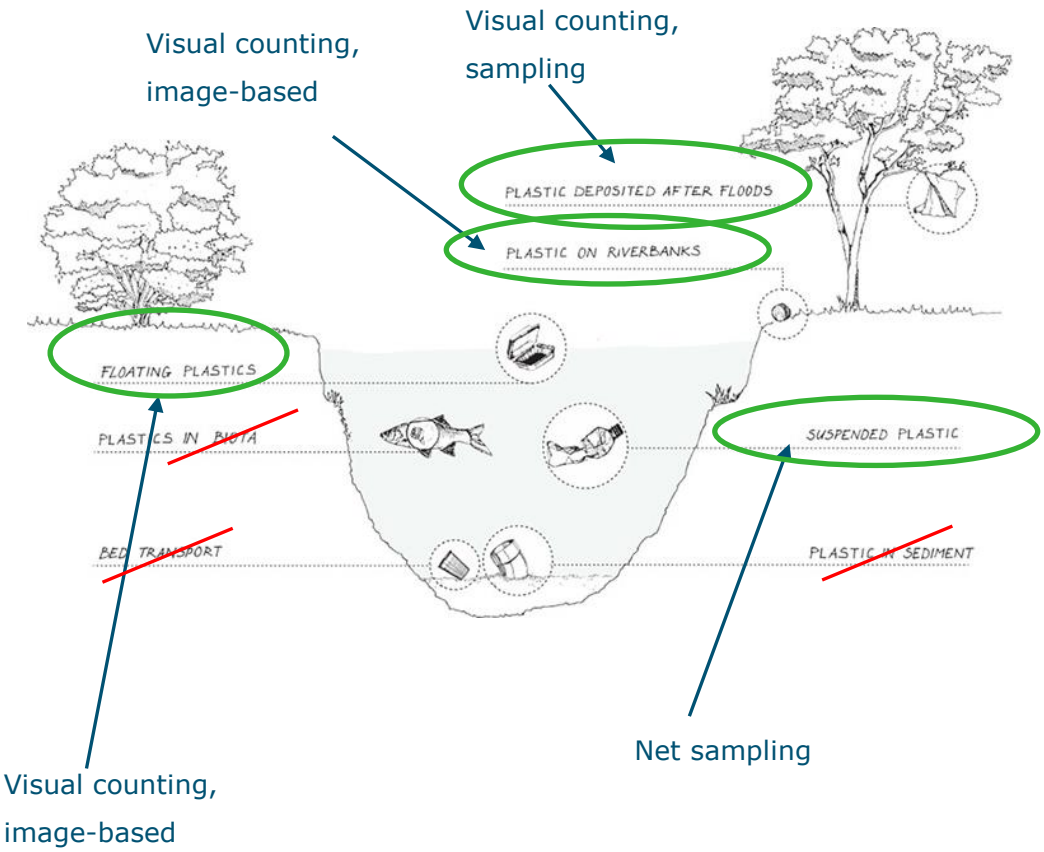


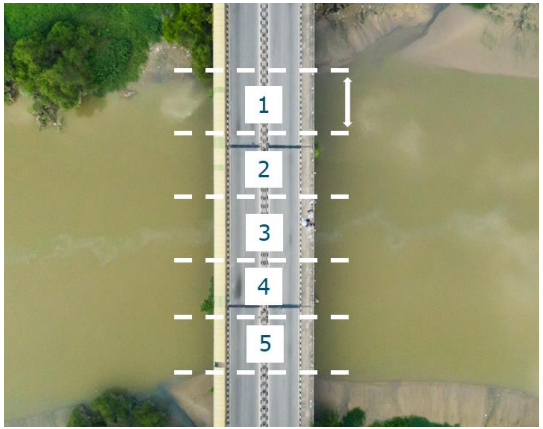
Image-based



WAGENINGEN
UNIVERSITY & RESEARCH

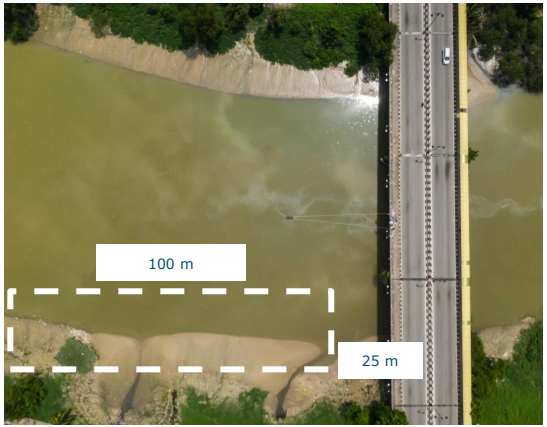
Method overview

METHOD	Riverbank	Floating	Suspended	Sediment
Visual counting	✓	✓	✗	✗
Net sampling	✓	✓	✓	✓
Other sampling	✓	✓	✓	✗
Drones	✓	✓	✗	✗
Cameras	✓	✓	✗	✗
Citizen science	✓	✓	✗	✗
Satellite remote sensing	✓	✓	✗	✗



FLOATING

- Divide bridge in segments
- Count all floating items
- Express plastic flux in items/hour or items/min



RIVERBANK

- Sampling area of 100 m long and 25 wide
- Count all items using (River-)OSPAR item list
- Express in items/km or items/m^2

VISUAL COUNTING

\+

ADVANTAGES

- Quick, easy, and consistent data
- Suitable for monitoring with students or citizen science
- Insights in order of magnitude of transport, emission and item types

−

DISADVANTAGES

- Only floating or riverbank plastics
- Observer bias
- No data on the mass
- Need safe bridge and riverbank access

FLOATING

- Deploy from bridges or boats
- Measure flow velocity to calculate concentration
- Options of further analysis

SUSPENDED

- Deploy from bridges or boats
- Multilayer net for deeper samples
- Bottom trawls for deepest layers

WAGENINGEN
UNIVERSITY & RESEARCH

(NET) SAMPLING

+

ADVANTAGES

- Can be quick and easy, if nets are small and deployed from bridges
- Samples offer any options for further analysis (item/mass distribution, polymer type)
- Flexible application

−

DISADVANTAGES

- Need additional equipment or infrastructure
- Can be unsafe and/or heavy
- Deeper layers still challenging

LITTER TRAPS

- Use available litter traps to collect and analyze waste
- Note down important characteristics (location, depth, sampling volume)

RIVERBANK

- Collect litter on riverbanks, e.g. during visual counting
- Measure mass, size and item/polymer type

UNIVERSITY & RESEARCH

OTHER SAMPLING

\+

ADVANTAGES

- Use available infrastructure
- Allows for rapid assessment
- New opportunities, e.g. fishing (research) infrastructure, dredging.

\-

DISADVANTAGES

- Constrained by available infrastructure
- Not flexible
- No transport flux or emission estimates

FLOATING/ RIVERBANK

- Select flying altitude
- Trade-off between battery life and observation locations/duration
- Manual and automated processing

DRONES

+

ADVANTAGES

- No need for a bridge
- Unbiased raw data
- Flexible monitoring approach

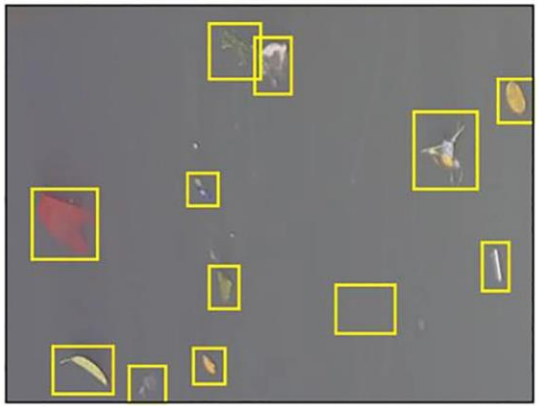
−

DISADVANTAGES

- Often permits are required
- Data processing time consuming
- RGB images not best for detecting plastics

HARDWARE

- Install camera on bridges
- Monitor distance to water level
- Choose videos or images



SOFTWARE

- Manual labeling for training dataset
- Choose an algorithm
- Training/testing

WAGENINGEN
UNIVERSITY & RESEARCH

CAMERAS

+

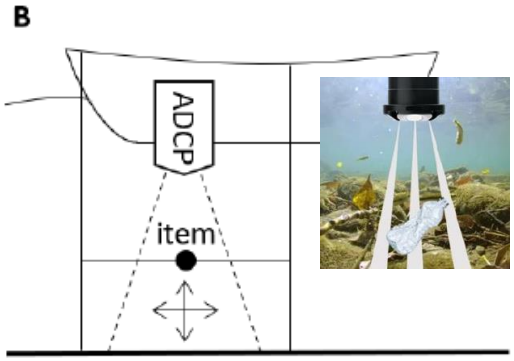
ADVANTAGES

- Potential for automated monitoring
- Once working, possibilities for upscaling
- Potential for mobile phone cameras

−

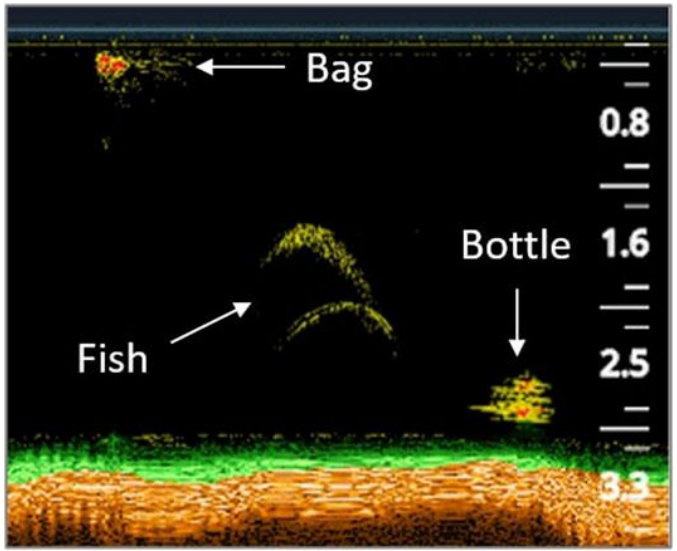
DISADVANTAGES

- Substantial amount of manual processing required
- AI models not well transferable
- Relatively expensive



SUSPENDED

- Acoustic sensors from boats or fixed points
- Detect plastic items over water column
- Manual or automatic detection



ACOUSTIC SENSING

ADVANTAGES

+

- No need for invasive measurements
- No need for large vessels or cranes
- Continuous measurements

DISADVANTAGES

−

- Early stage of development
- Known items can be detected, not possible to infer information from signal yet
- Plastic similar to organic material

RIVERBANK

- Counting and collecting litter along river shores
- Done by citizens, schoolkids, students

FLOATING

- Sampling through cleanup activities
- Analysis of the sampled materials

UNIVERSITY & RESEARCH

CITIZEN SCIENCE

+

ADVANTAGES

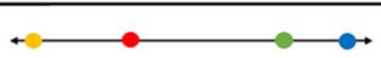
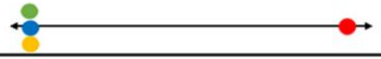
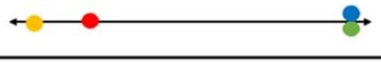
- Suitable for upscaling over time and space
- Large-scale monitoring
- Community engagement
- Additional (anecdotal) data

−

DISADVANTAGES

- Dependent on volunteers
- Limitations on what can be asked
- Quality control
- Need strong local network

Choose your own adventure

Element	Sub-element	Range		
Space	Domain	Sub-basin		Multi-basin
	Sampling area	Subsampling		Sampling larger area
	Structure	Structured		Unstructured
Time	Period	4 Weeks		Single day
	Frequency	Yearly		Daily
	Structure	Structured		Unstructured
	Duration	Singular		Multi-year
Observers		Citizen Scientists		Trained Professionals
Categorization	Category	Material Based		Identity Based
	Size Range	Macro		Macro and Micro

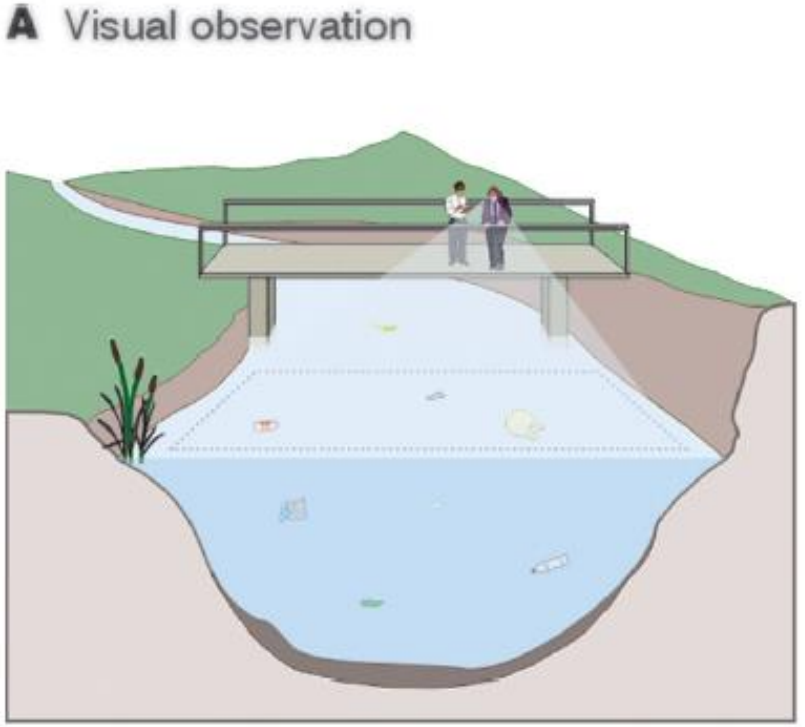
Visual Counting

WAGENINGEN
UNIVERSITY & RESEARCH

@TimVanEmmerik | tim.vanemmerik@wur.nl

Visual counting

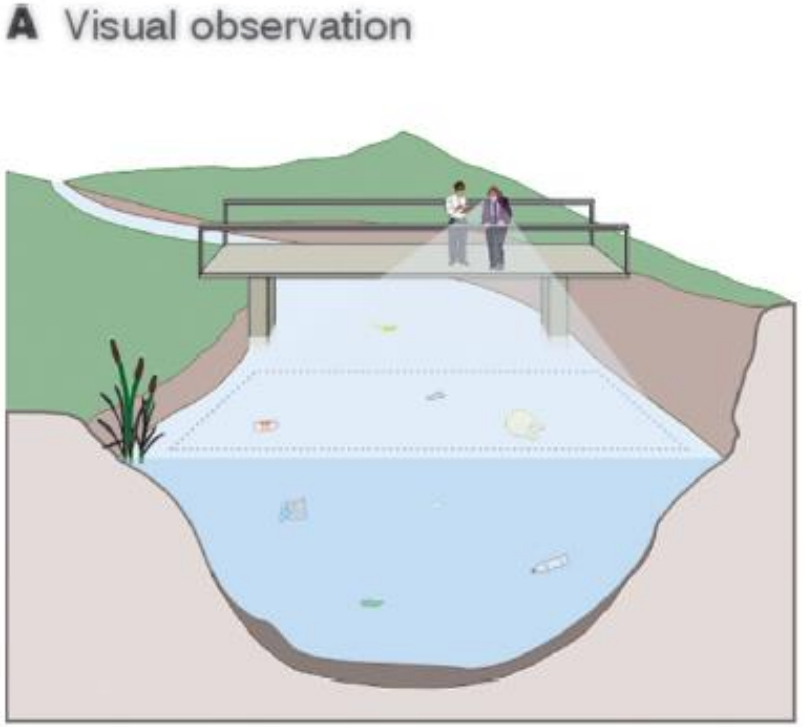
- Visual counting is a cost-effective method for easy upscaling
- Used around the world, from Europe to Asia
- Potential for combining with citizen science



Visual counting: The concept

$$T_p = I_P \cdot \overline{m_p}$$

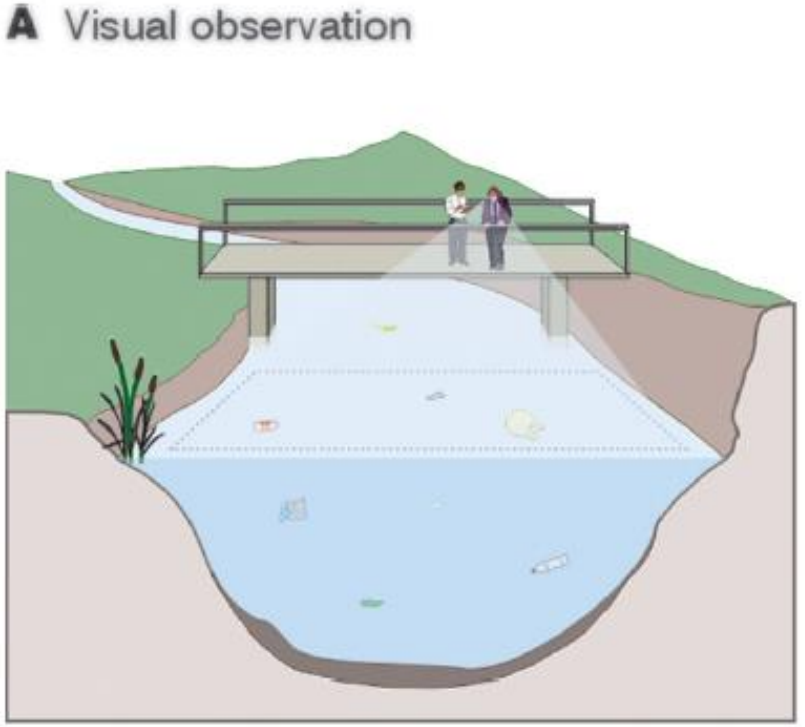
- Tp: Plastic mass transport
- Ip: Plastic item transport
- Mp: Mean mass per item



Visual counting: The concept

$$T_p = I_P \cdot \overline{m_p}$$

- Tp: Calculated
- Ip: Measured
- Mp: Measured or literature



Visual counting: The measurement

- Count floating items from bridges
- Divide bridge in *n* segments
- For a measurement, all floating items are counted for duration *t*
- Results in items/minute or items/hour

Visual counting: The measurement

- Calculate average items/min or items/hour per segment
- Extrapolate to for total width
- Example:
    - 5 items/min
    - 5 segments
    - Total: 25 items/min

Visual counting in practice

Step 1: Find safe and suitable locations

Step 2: Divide bridge into segments

Step 3: Determine observation time

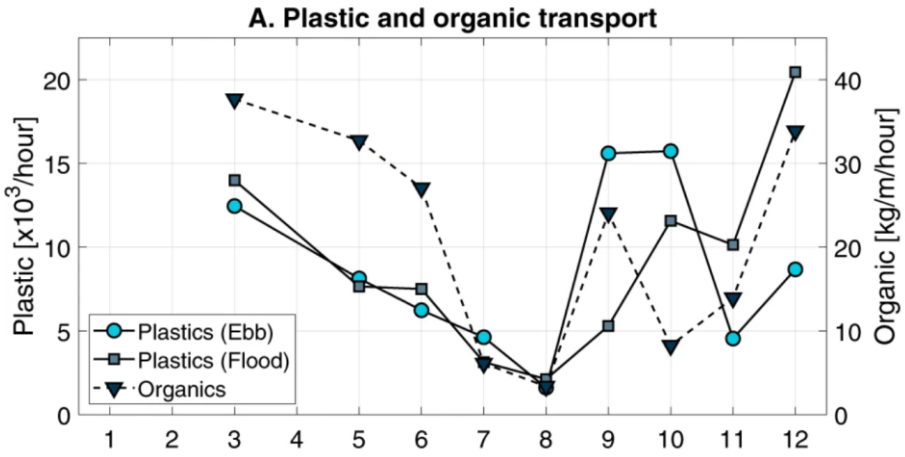
Step 4: Determine observation frequency

Example 1: Saigon river, Vietnam

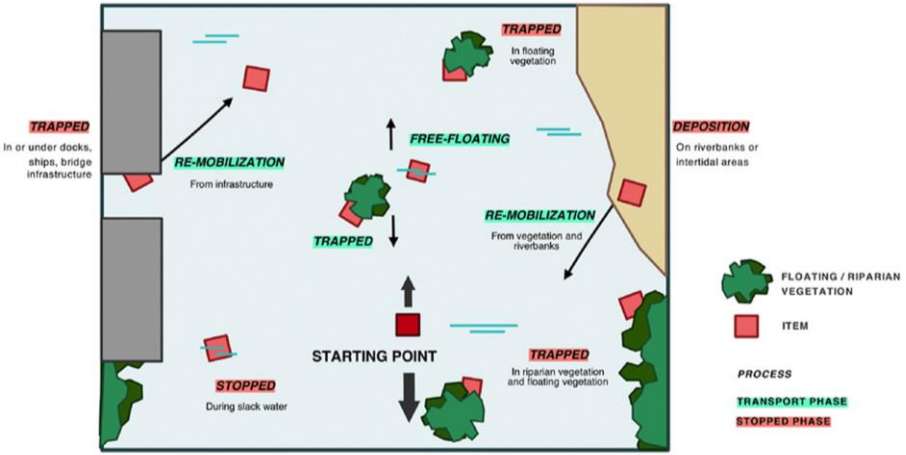
Seasonal cycle and processes

- 1 bridge in Saigon
- 12 segments per bridge
- 8 measurements per day
- 2-5 measurements per week
- One person full-time

Example 1: Saigon river, Vietnam



Example 1: Saigon river, Vietnam



Plastics and water hyacinths

- Up to 80% of plastics in hyacinths
- Relevant for transport, fate, and monitoring.

WAGENINGEN
UNIVERSITY & RESEARCH

Visual counting: Advanced options

- Count specific categories
- 7 polymer categories, based on specific items
- More clues about sources, sinks, and fate

Name	Properties	Common uses	Pictures
PET *(Polyethylene Terephthalate)*	Always clear Softens at 80dg	Soft drink bottles Salad containers	 
PO Soft ***PE (HD/LD) and PP Foils*** ***(High/Low Density Polyethylene)***	Coloured Waxy surface Softens at 70dg	Shopping bags	 
PO Hard *PE (HD/LD) and PP Ridgid* *(High/Low Density Polyethylene)*	Waxy surface Softens at 70dg	Milk bottles Shampoo and chemical bottles Ice cream tubs Lunch boxes	 
Multilayer *PE / others (Polyehtylene & others)*	Flexible, glossy surface, printed foils		 
PS *(Polyststyrene)*	Clear Rigid Glassy Softens at 195dg	Brittle toys Plastic cutlery CD cases	
PS-E *Expanded polystyrene*	Foams	Polystyrene cups Foamed meat trays	 

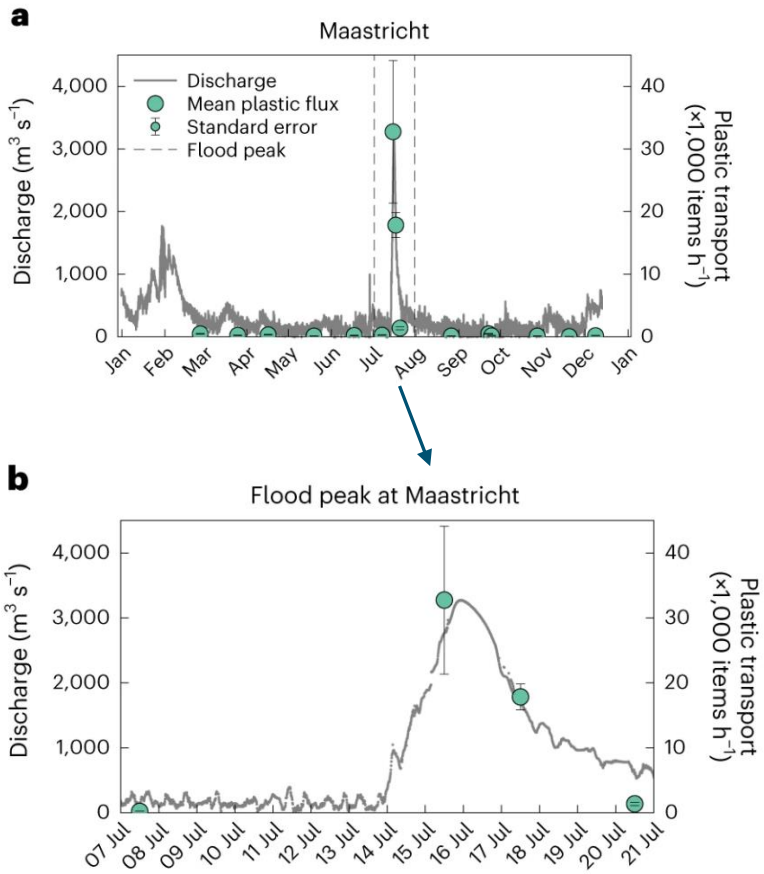
Example 2: The Dutch Delta

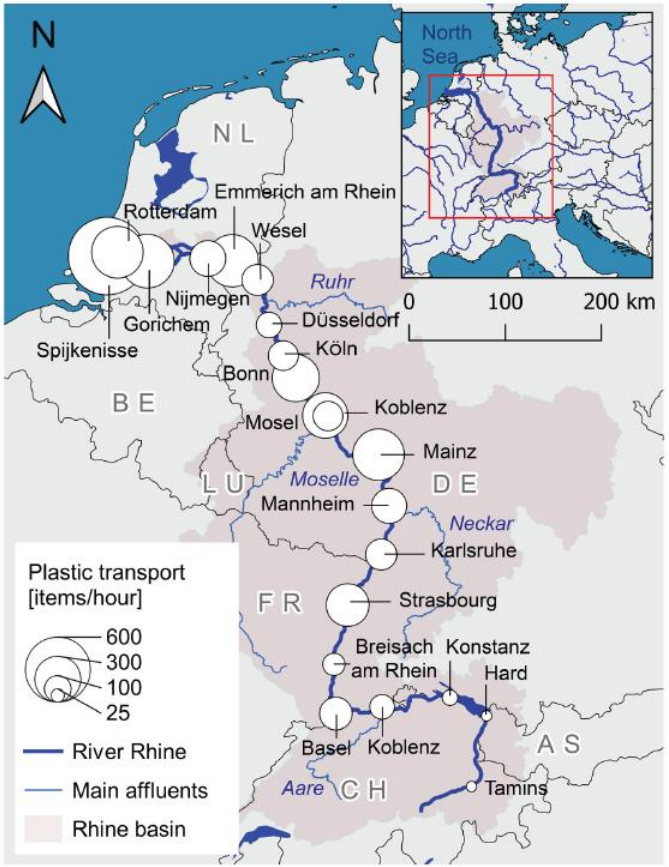
Transport through Rhine and Meuse

- 26 bridges across the country
- 5 to 12 segments per bridge
- 4 measurements per day
- 1 day per month + 2 extra days after flood event
- Team of 40 students and colleagues

WAGENINGEN
UNIVERSITY & RESEARCH

Example 2: The Dutch Delta



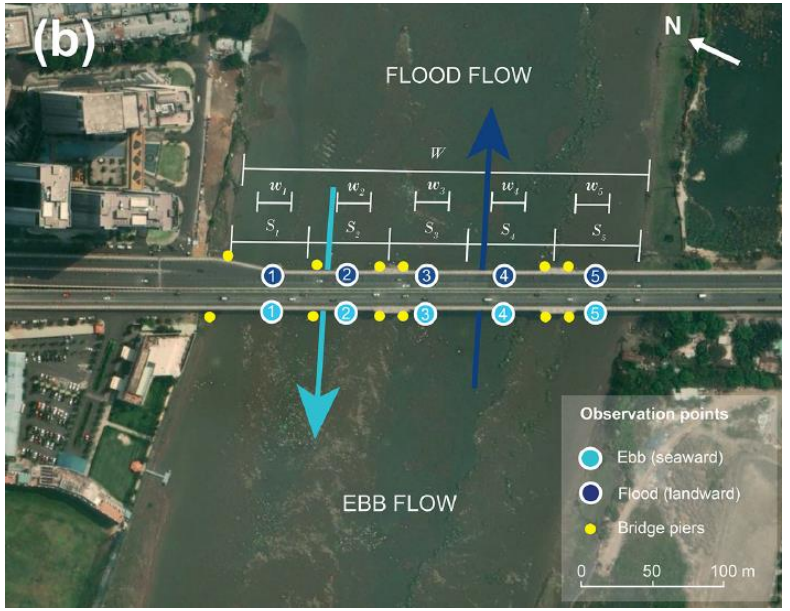


Example 2: The Dutch Delta

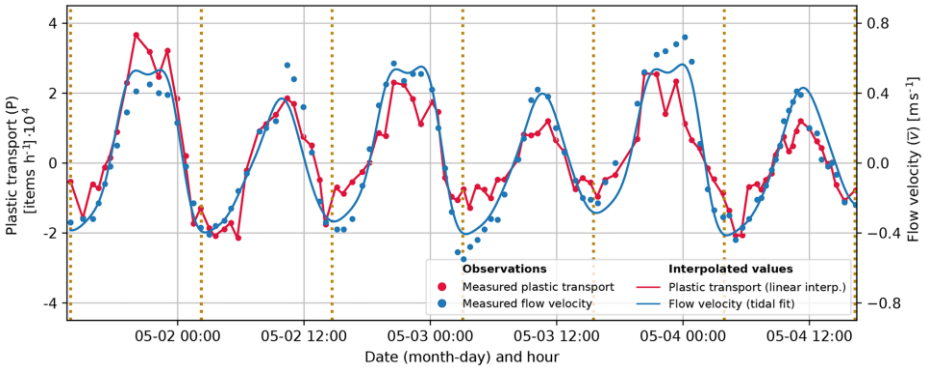
Example 3: Emissions into the ocean

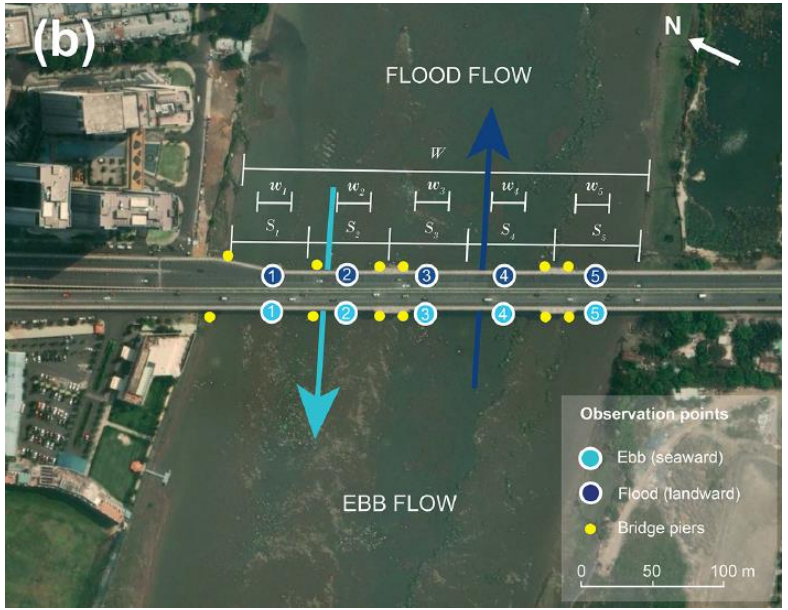
Emissions from river into the sea

- Net transport affected by the tide
- Cover two consecutive tidal cycles (24.8 hours)
- Saigon: <25% of total plastic is transported downstream



Example 3: Emissions into the ocean



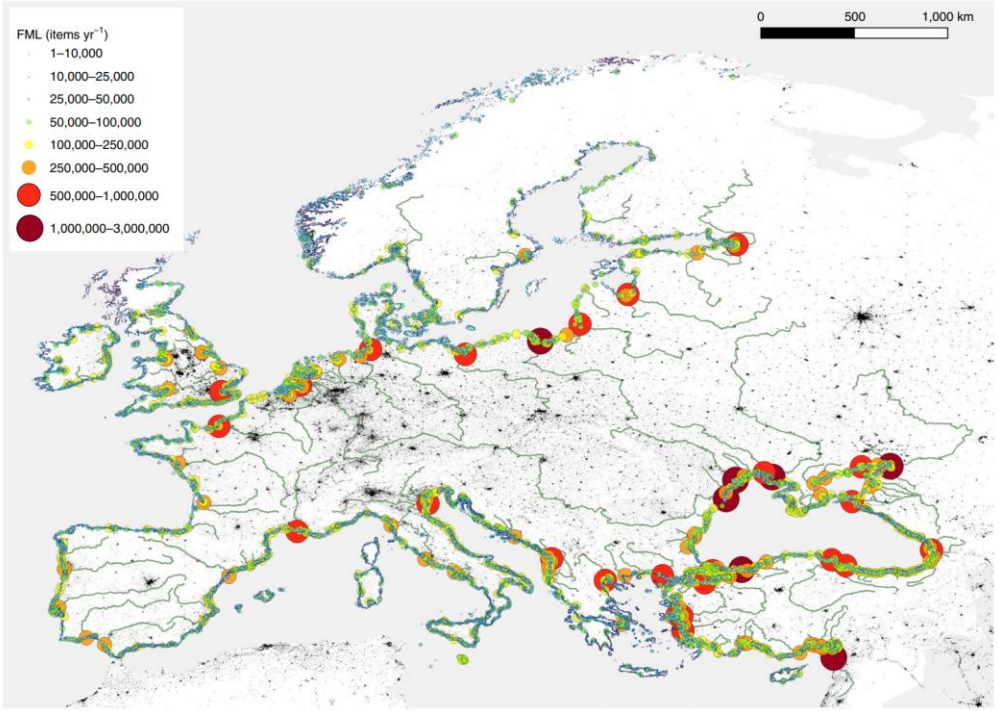


Example 4: European project RIMMEL

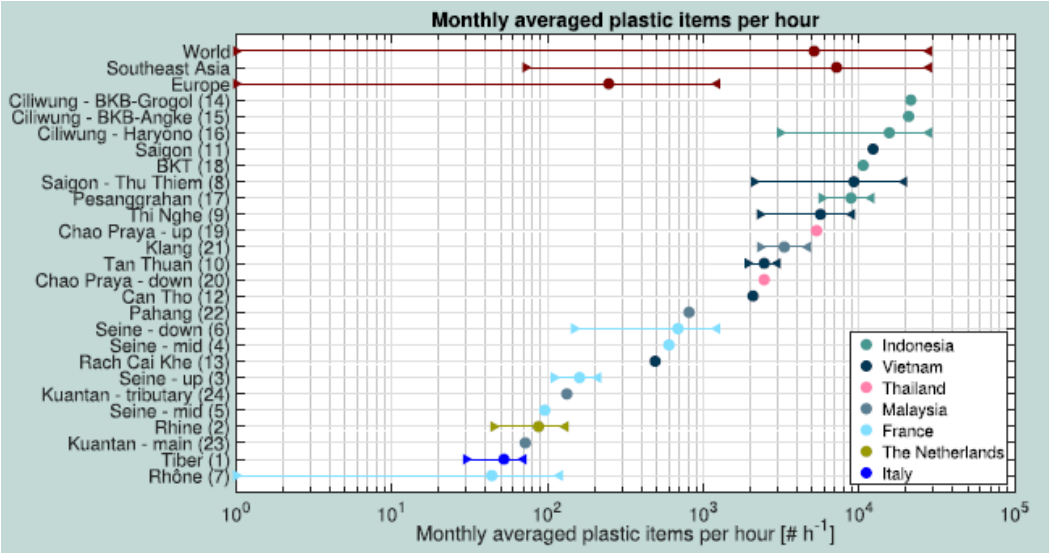
Europe's share in the plastic soup

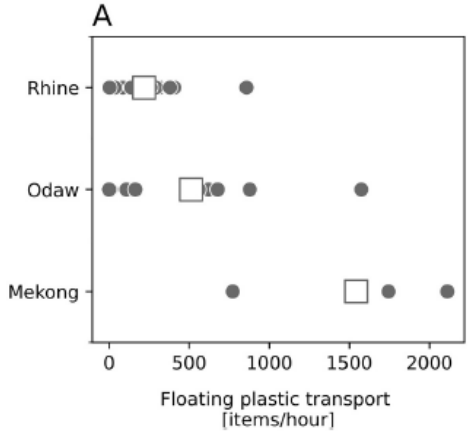
- 42 rivers, one bridge per river
- One segment per bridge
- One 30-minute measurement
- 10-30 measurements per year

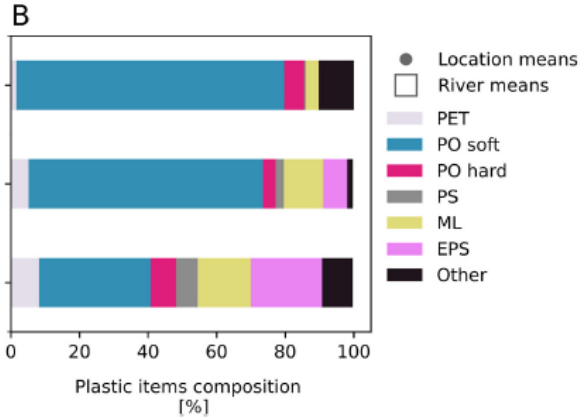
Example 4: European project RIMMEL



Example 5: Global baseline





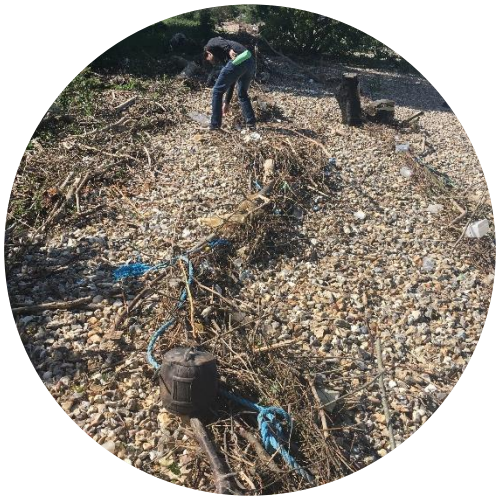


WAGENINGEN
UNIVERSITY & RESEARCH

Visual counting

- Good method for first order assessment
- Flexible approach, can be tailored to specific questions
- Easy to scale up, also with citizen scientists

Riverbank sampling

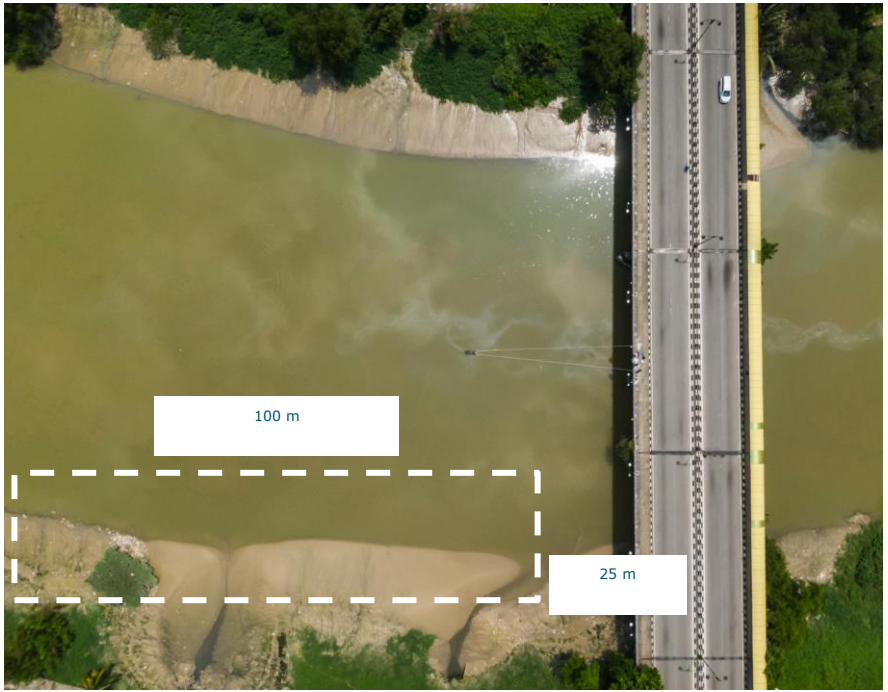


WAGENINGEN
UNIVERSITY & RESEARCH

@TimVanEmmerik | tim.vanemmerik@wur.nl

Riverbank sampling

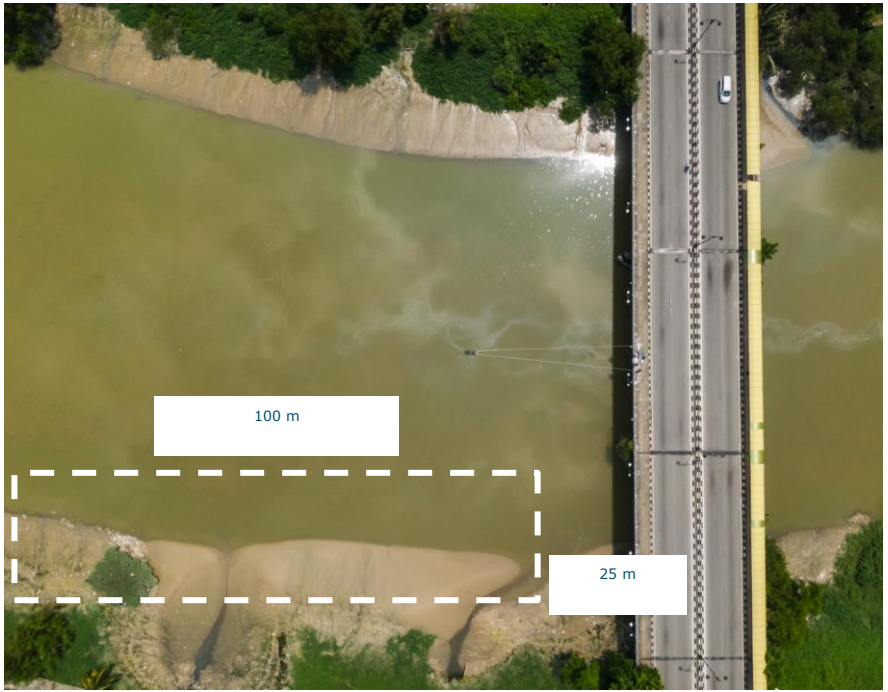
- Good method for detailed assessment
- Flexible approach, can be tailored to specific questions
- Find trade-off between level of detail and required effort



WAGENINGEN
UNIVERSITY & RESEARCH

Riverbank sampling: The concept

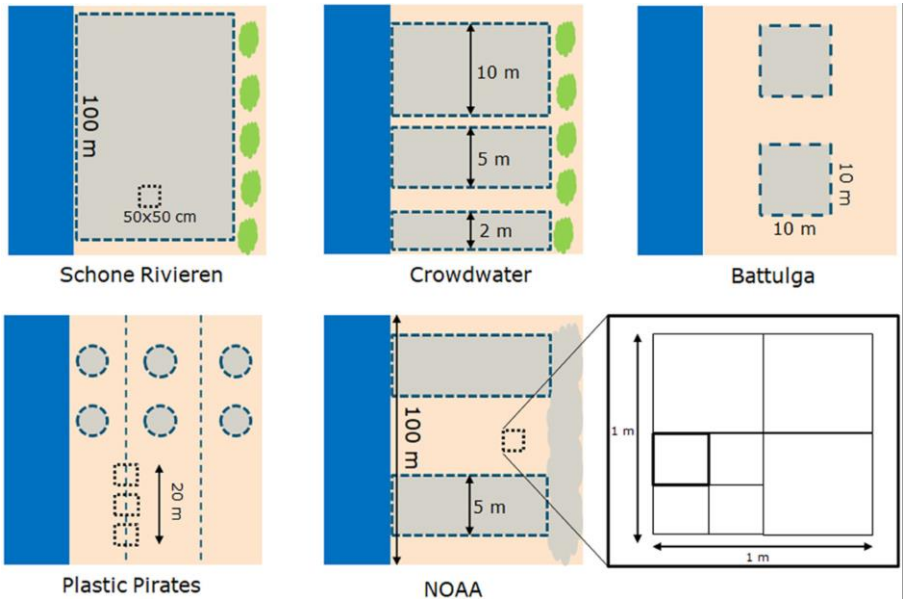
- Select sampling area
- Choose level of detail
- Collect the waste, or tally the items without collection
- Choose measurement frequency
- Determine number of locations



Riverbank sampling: The concept

Select sampling area

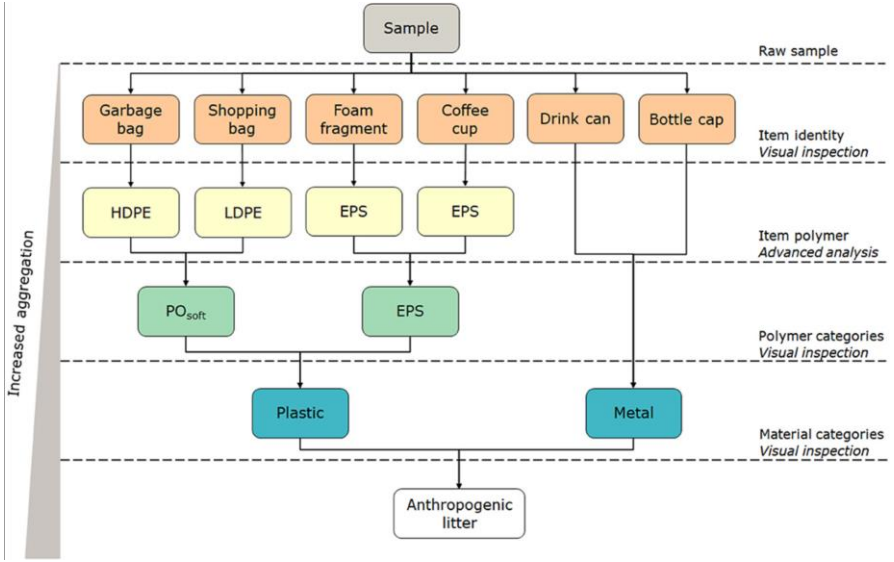
- Rectangular areas or circles
- Depends on the level of pollution
- Micro or macro?



Riverbank sampling: The concept

Choose level of detail

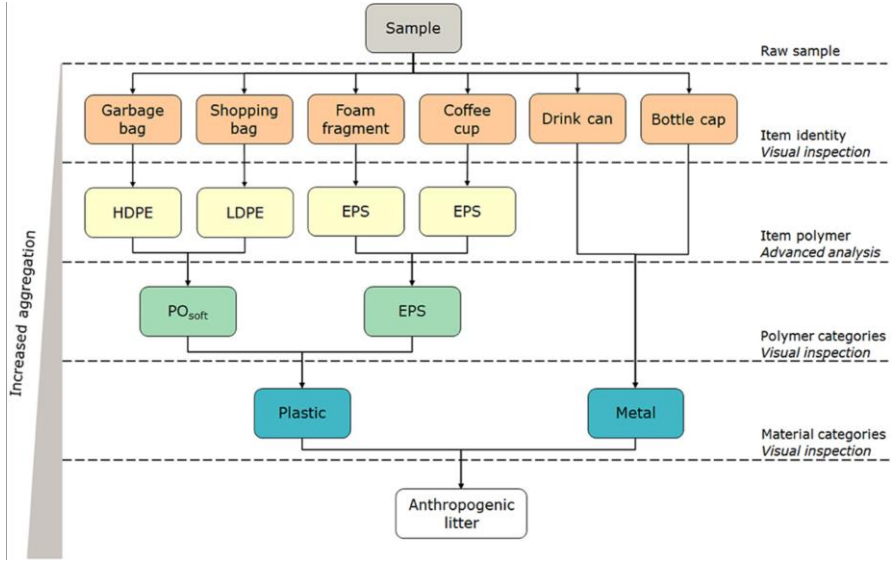
- More detail, more information
- More detail, more effort
- What is the question, and what information is needed?



Riverbank sampling: The concept

Choose level of detail

- More detail, more information
- More detail, more effort
- What is the question, and what information is needed?



Example:

Litter → Plastic → PO hard → PE or PP → "Food" → 22. Cutlery

Riverbank sampling: The concept

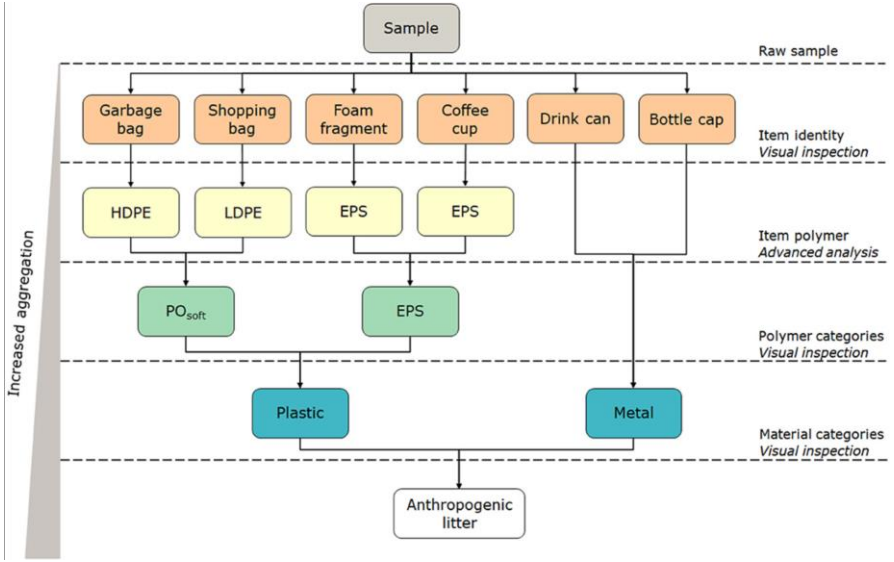
Name river	
Province	
Area ID	
Date riverbank sampling	
Name Researcher #1	
Name Researcher #2	
Name Researcher #3	

Riverbank side	Left / Right
Sampling executed?	Yes / No
→ if not, why?	
Length sampled area (m)	
Width sampled area (m)	

OSPAR ID	Plastic and foam	Count
15	Caps and lids	
4.2	Bottles (<0.5 litre)	
4.1	Bottles (>0.5 litre)	
40	Industrial packages	
3	Small bags	
117.1	Hard fragments (<2.5 cm)	
46.1	Hard fragments (2.5 – 50 cm)	
47.2	Hard fragments (>50 cm)	
1172	Foams (<2.5 cm)	
462	Foams (2.5 – 50 cm)	
472	Foams (>50 cm)	
6.1	Foam food packages (e.g. hamburgers)	
212	Foam cups	
21	Drinking cups	
117.2	Soft fragments (i.e. foils) (<2.5 cm)	
46.2	Soft fragments (i.e. foils) (2.5 – 50 cm)	
47.1	Soft fragments (i.e. foils) (>50 cm)	
22.1	Plates & straws	
22.2	Mixing sticks (e.g. to stir your coffee)	
19	Food wrappers (multilayer) (e.g. chips)	
6	Food packages (e.g. snackbar fries box)	
4.3	Labels that were wrapped around bottles	
5	Packages from cleaning products	
1	Six-pack rings	
16	Lighters	
14	Parts from cars	
22	Cutlery	
481	Biofilm water filters	
36	Glow in the dark sticks	
38	Buckets	
38.1	Plant pots or trays	
43	Gun rounds	
25	Cleaning gloves (bit softer plastic)	
113	Professional gloves (bit harder plastic)	
42	Helmets	
10	Jerrycans	
11	Tubes of caulking (Dutch: *kitspuiten*)	
13	Crates	
39	Bands & tie wraps	
39.1	Tape (Dutch: *plakband*) & duct tape	
19.1	Lolly sticks	
8	Motor oil packages (<50 cm)	
9	Motor oil package (>50 cm)	
24	Net bags (e.g. nets for onions or fruit)	
2.1	Garbage bags	
17	Writing instruments (e.g. pens)	
20	Toys	
35	Fishing gear	
2	Big plastic bags	
31	Pieces of rope (diameter >1 cm)	
32	Pieces of rope (diameter <1 cm)	
35.1	Pieces of fishing line (nylon)	
43.1	Fireworks	
48	Other unidentifiable plastic items	
OSPAR ID	**Rubber**	**Count**
49	Balloons & ribbons	
52	Tires (e.g. from bikes or cars)	
53	Other unidentifiable rubber items	
OSPAR ID	**Textile**	**Count**
54	Clothes	
57+44	Shoes, boots & flipflops	
55	Pieces of carpet	
59	Other unidentifiable textile items	

OSPAR ID	Paper	Count
62.1	Carton drinking packages (e.g. milk)	
67.1	Other unidentifiable paper items	
64	Cigarette filters ("cigarette butts")	
63	Cigarette packages	
61	Carton	
65	Carton drinking cups	
66	Newspapers	
60	Bags	
67	Other unidentifiable paper items	
OSPAR ID	**Wood**	**Count**
72	Ice cream sticks	
68	Corks	
73	Paint brushes	
69	Pallets	
74	Other unidentifiable wood items (<50 cm)	
75	Other unidentifiable wood items (>50 cm)	
OSPAR ID	**Metal**	**Count**
81	Aluminium foils	
81.1	Capsules (e.g. coffee or coffee-milk)	
78	Soda cans	
79	Electrical wires	
83	Old metal (iron) (e.g. pipes)	
77	Caps (Dutch: *kroonkurken*) & beer caps	
84	Oil drums (Dutch: *olie vaten*)	
88	Barbed wires (Dutch: *prikkeldraad*)	
76	Spray cans	
86	Paint cans	
80	Fish lead	
82	Food cans	
120	Single use BBQ's/grills	
89	Other unidentifiable metal items (<50 cm)	
90	Other unidentifiable metal items (>50 cm)	
OSPAR ID	**Glass**	**Count**
91	Bottles (e.g. wine) & pots	
92	Light bulbs & (fluorescent) tube TL lamps	
93	Other unidentifiable glass items	
OSPAR ID	**Sanitary**	**Count**
7	Cosmetic packages (e.g. shampoo, deo)	
98	Plastic cotton swabs	
982	Wooden cotton swabs	
102.2	Wet tissues	
97	Condoms	
99	Sanitary towels & packages thereof	
18	Plastic hairbrush or hair comb	
100	Tampons & tampon applicators	
102.3	Pieces of toilet paper	
101	Toilet refreshers	
102	Other unidentifiable sanitary items	
OSPAR ID	**Medical**	**Count**
103	Packages (e.g. pills, contacts)	
104	Injection needles / syringes	
105	Other unidentifiable medical items	
OSPAR ID	**Nurdles**	**Count**
	Nurdles (per area of 50 by 50 cm)	

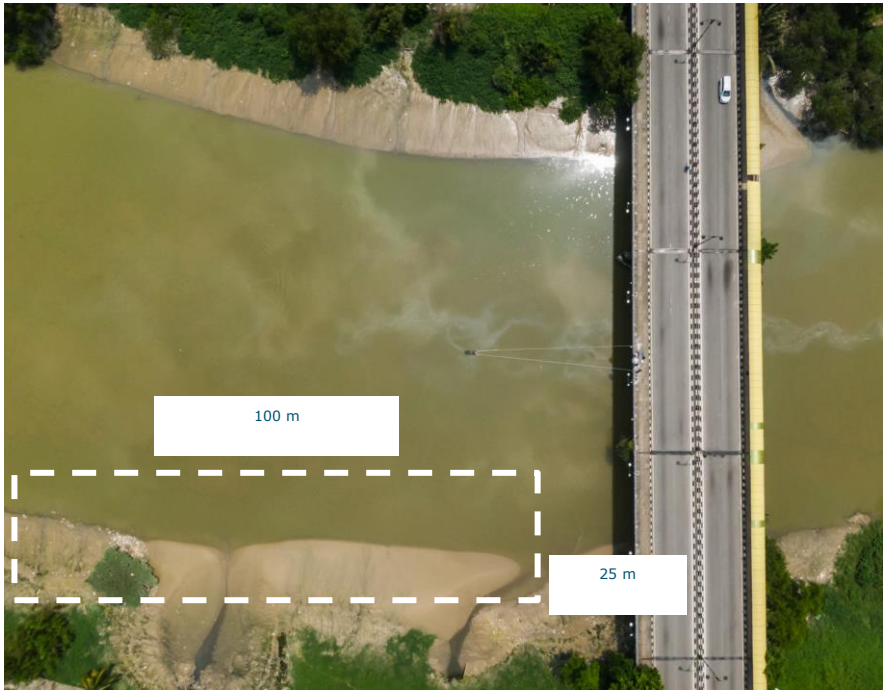
Notes .....



Riverbank sampling: The concept

Collect the waste, or tally the items without collection

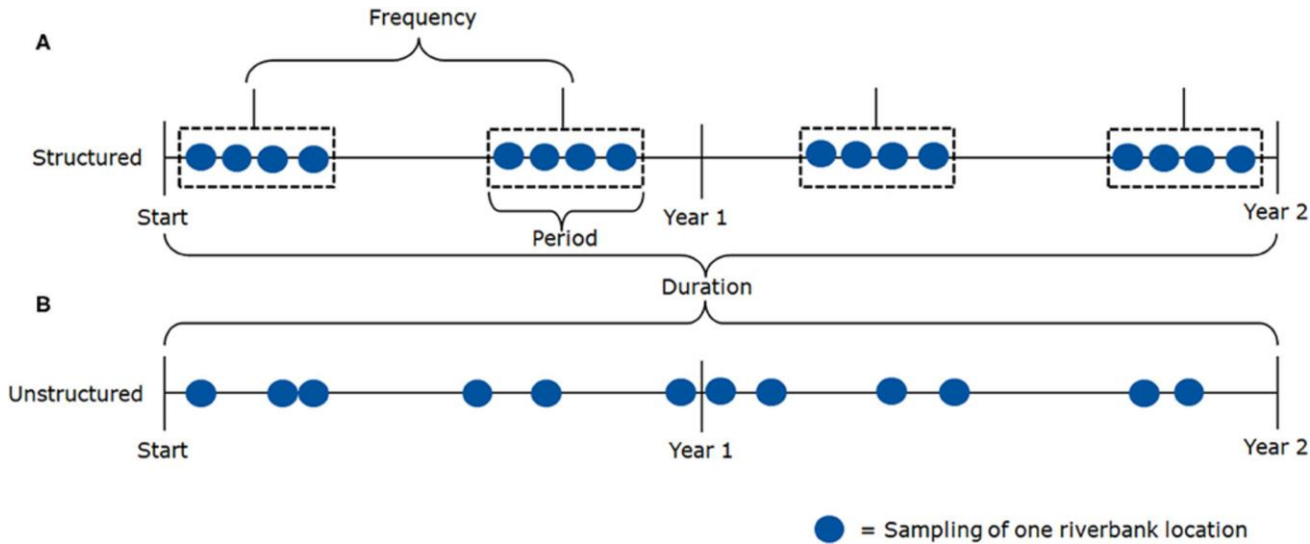
- Collection: Can also measure the mass and the size (and it’s remove from the environment)
- Tallying: Less effort, and “no disturbance of system”



Riverbank sampling: The concept

Choose measurement frequency

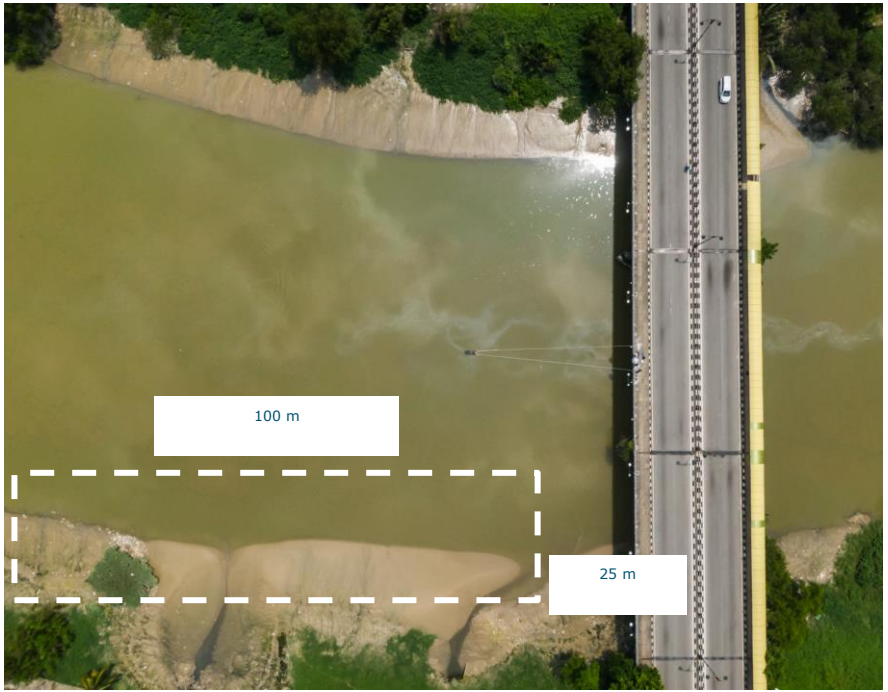
- Yearly, monthly, daily?
- Structured or unstructured?



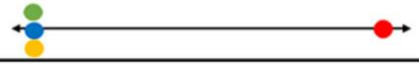
Riverbank sampling: The concept

Determine number of locations

- One location in detail, or many locations superficially?
- How to mobilize observers?



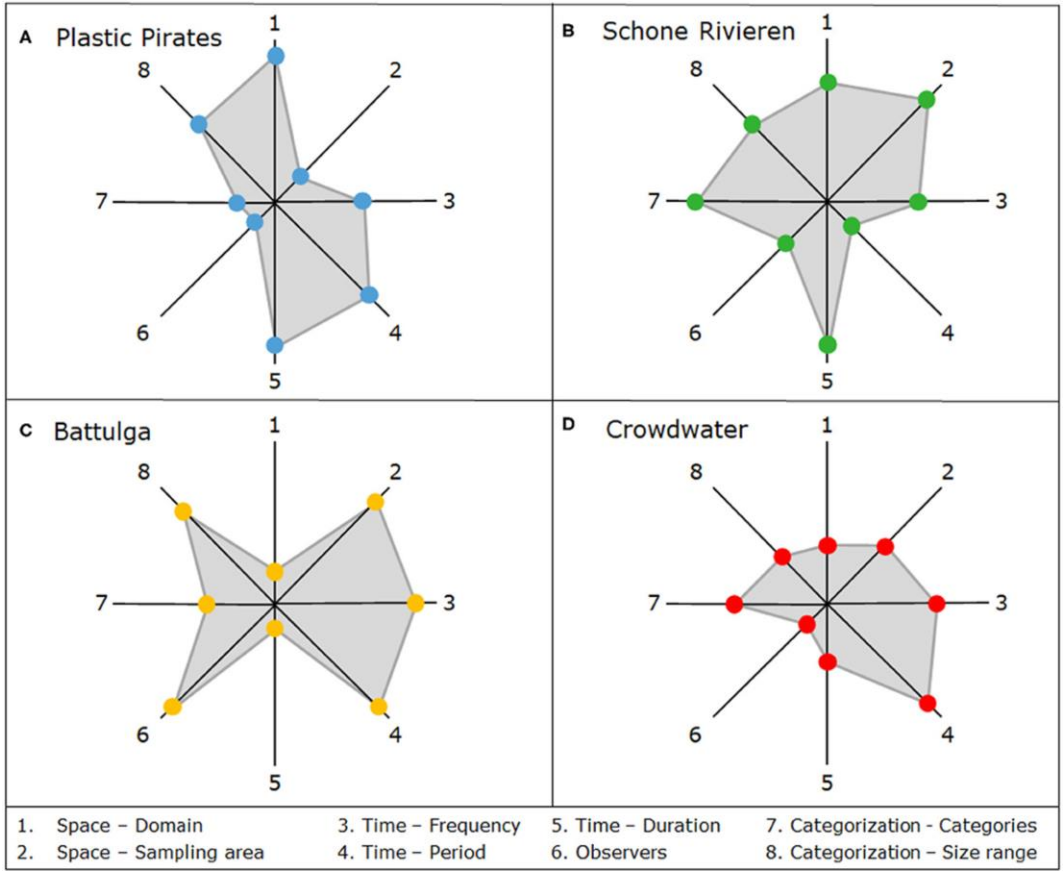
Riverbank sampling: The concept

Element	Sub-element	Range		
Space	Domain	Sub-basin		Multi-basin
	Sampling area	Subsampling		Sampling larger area
	Structure	Structured		Unstructured
Time	Period	4 Weeks		Single day
	Frequency	Yearly		Daily
	Structure	Structured		Unstructured
	Duration	Singular		Multi-year
Observers		Citizen Scientists		Trained Professionals
Categorization	Category	Material Based		Identity Based
	Size Range	Macro		Macro and Micro

WAGENINGEN
UNIVERSITY & RESEARCH

Riverbank sampling: Examples

- Plastic Pirates
- Schone Rivieren
- Battulga et al.
- CrowdWater

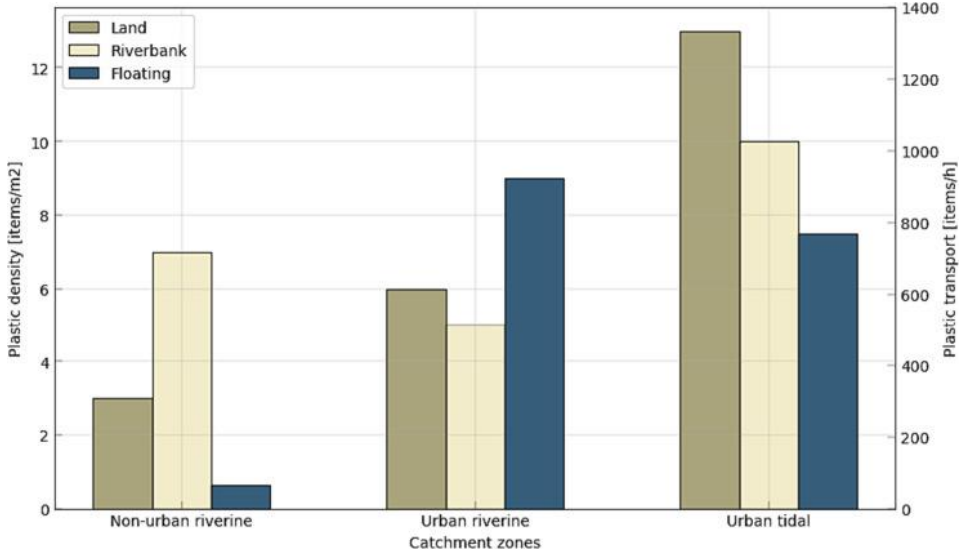


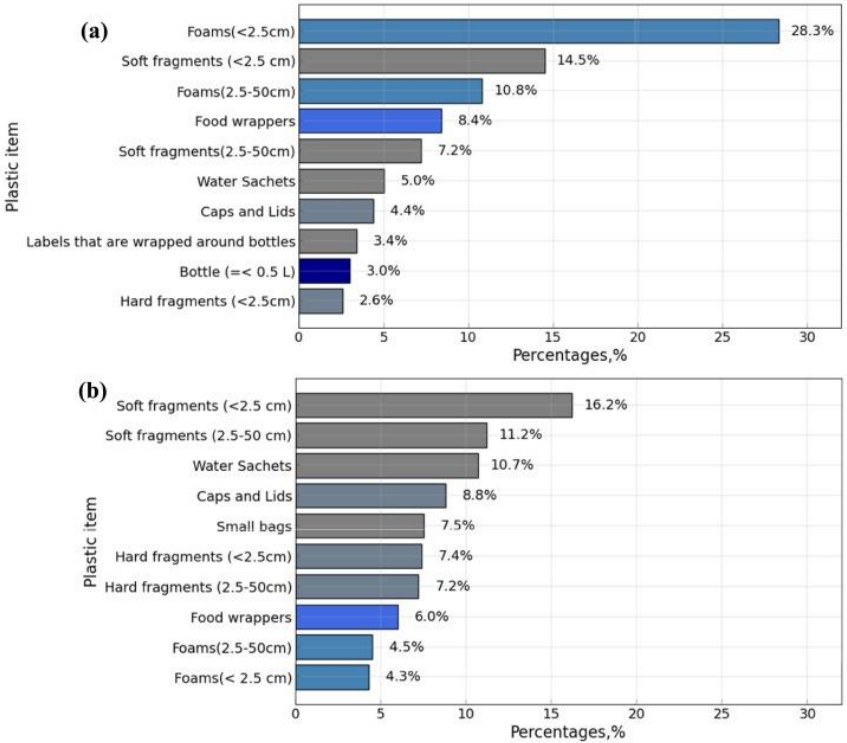
Example 1: Odaw river basin

Riverbank and land

- Ten locations along river
- Riverbank and land sampling areas
- Three times within a month
- Detailed analysis of composition

Example 1: Odaw river basin



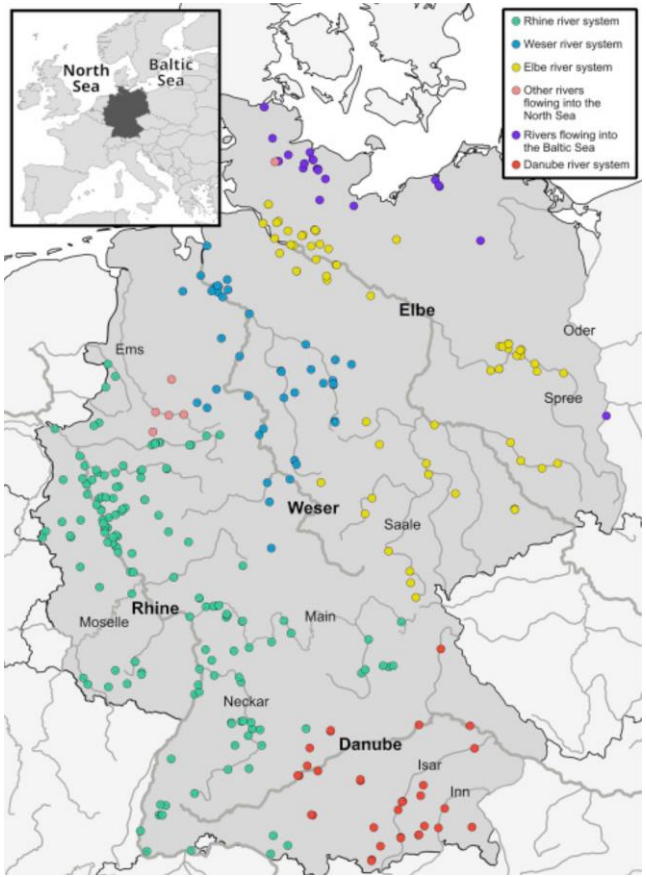


WAGENINGEN
UNIVERSITY & RESEARCH

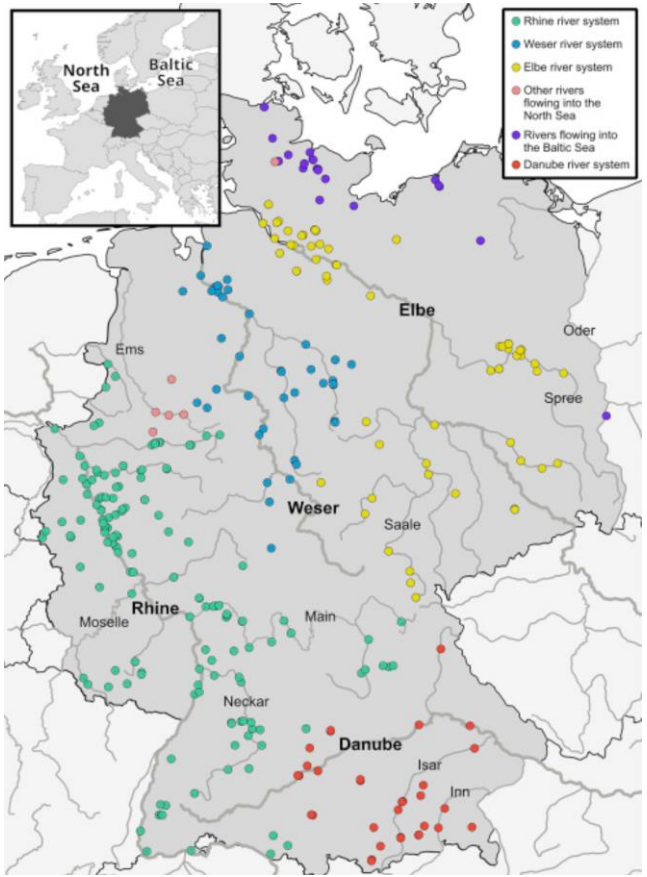
Example 2: German rivers

Rivers across the country

- 6 main rivers
- Schoolkids did the sampling
- Simple categorization



Example 2: German rivers

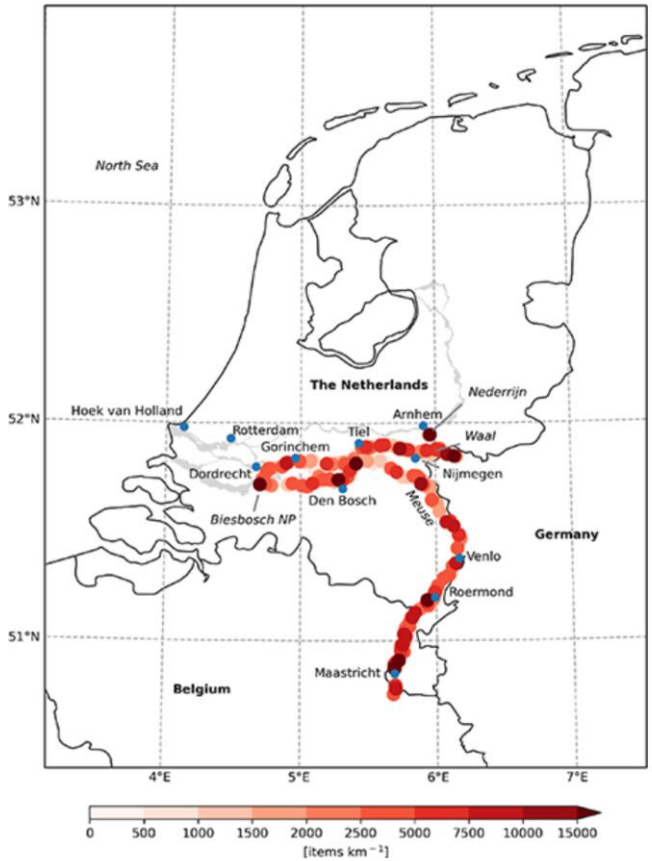


Example 3: Rhine and Meuse

Clean Rivers project

- Over 300 locations along Rhine and Meuse delta
- Over 1000 volunteers
- Bi-annual monitoring
- Detailed classification

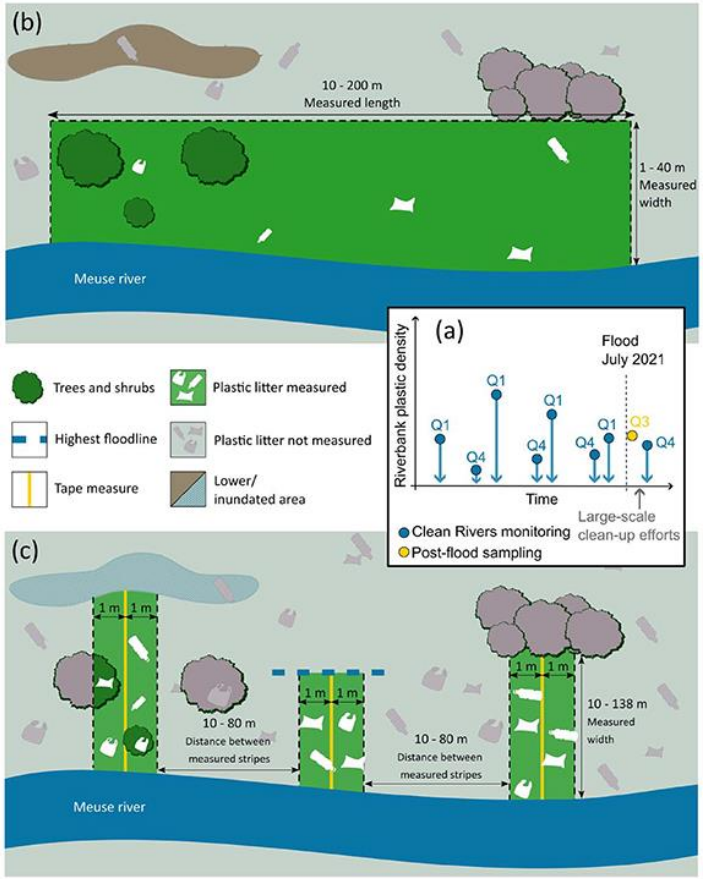
Example 3: Rhine and Meuse



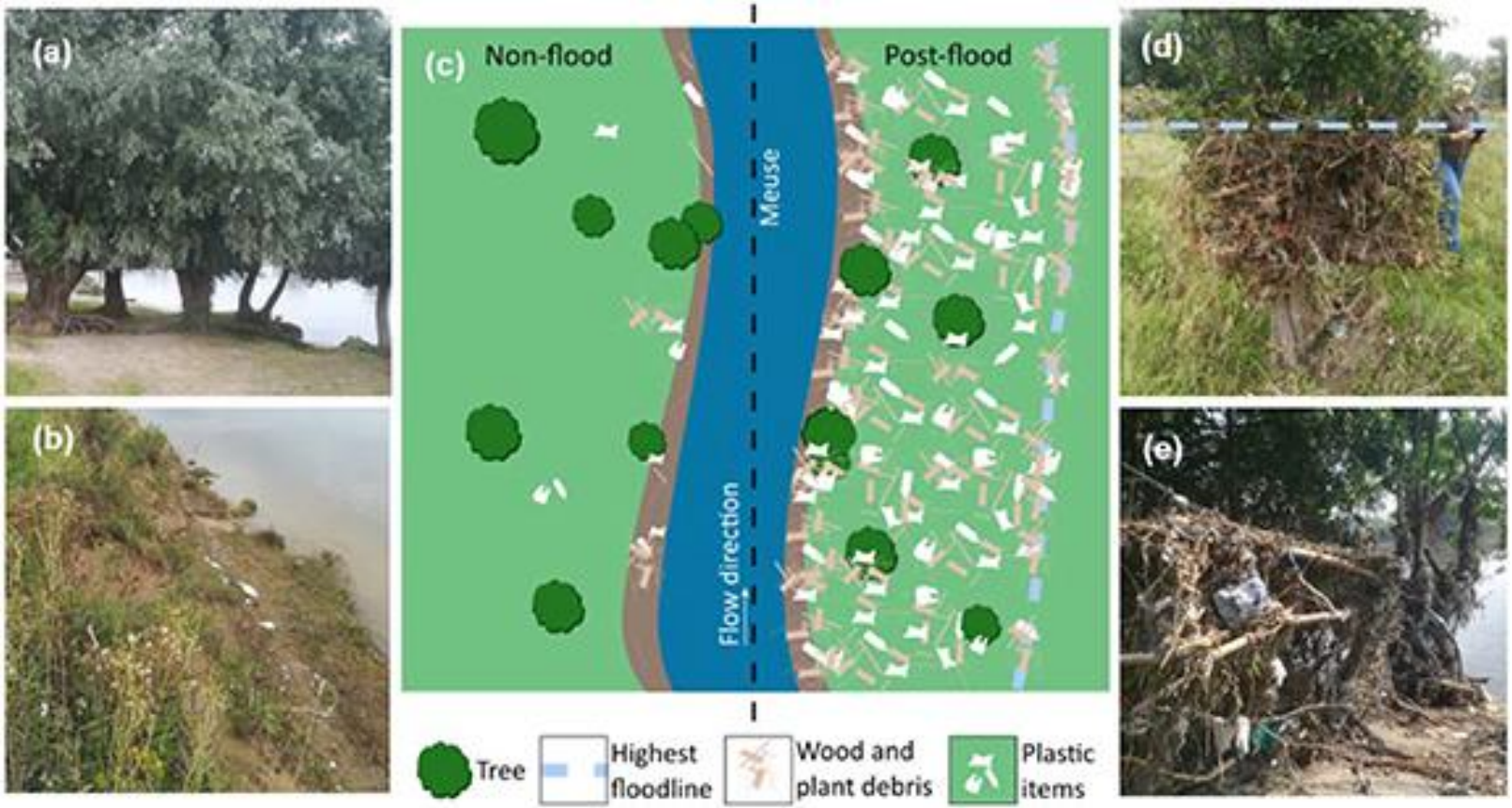
Example 4: Basin-scale post-flood sampling

Spatial variation

- 25 sampling points
- Cover entire Dutch Meuse
- Compare with non-flood conditions

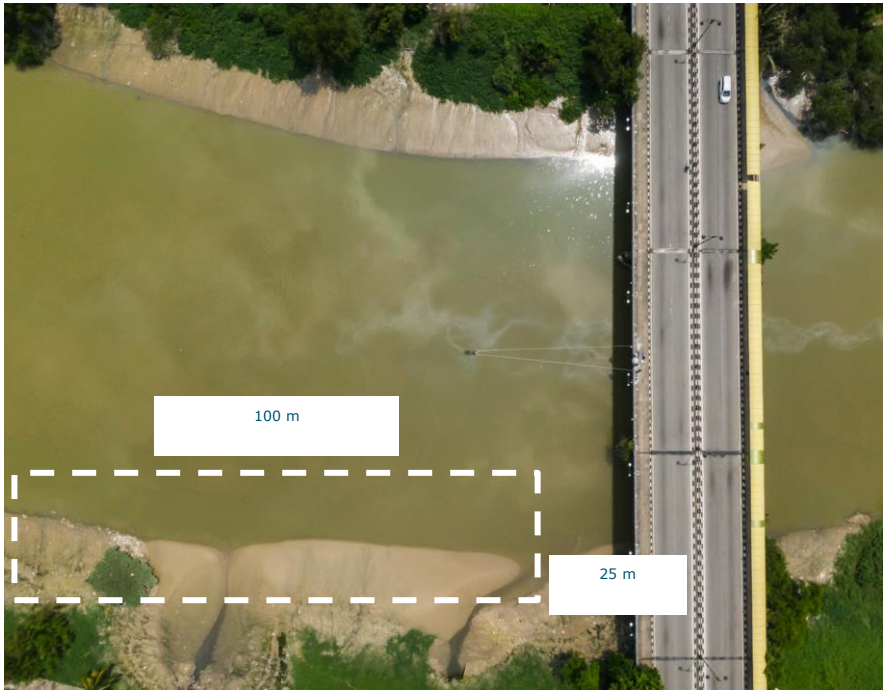


Example 4: Basin-scale post-flood sampling



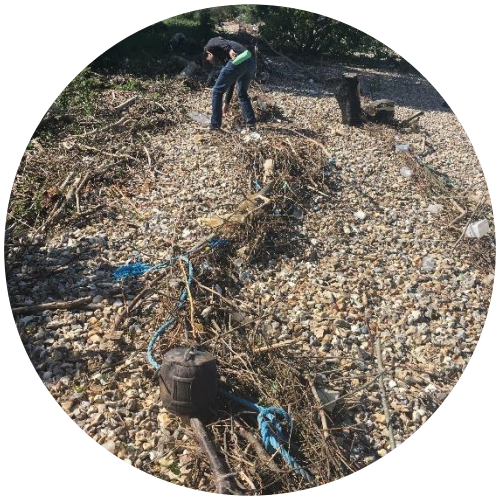
Riverbank sampling

- Good method for detailed assessment
- Flexible approach, can be tailored to specific questions
- Find trade-off between level of detail and required effort



WAGENINGEN
UNIVERSITY & RESEARCH

Future developments



WAGENINGEN
UNIVERSITY & RESEARCH

@TimVanEmmerik | tim.vanemmerik@wur.nl

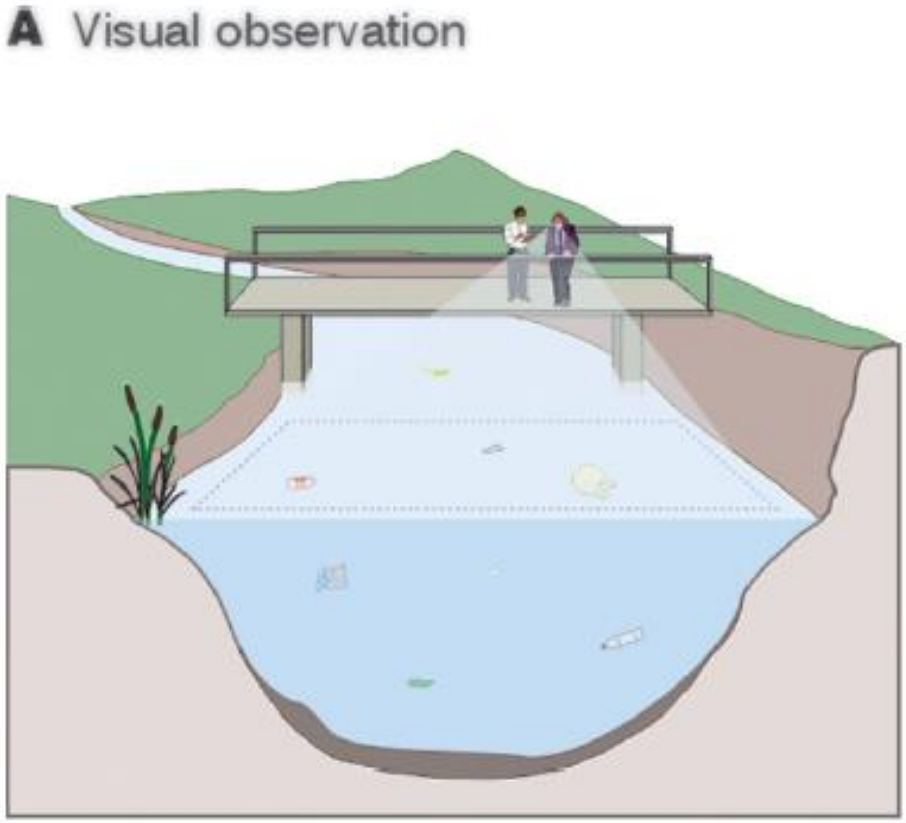
Opportunities for upscaling

Citizen Science

- Trained volunteers

Camera (+ AI)

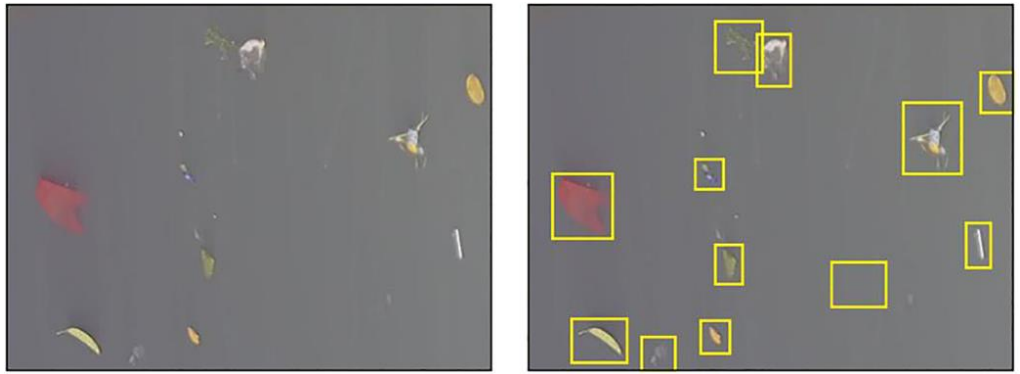
- Fixed
- Drones

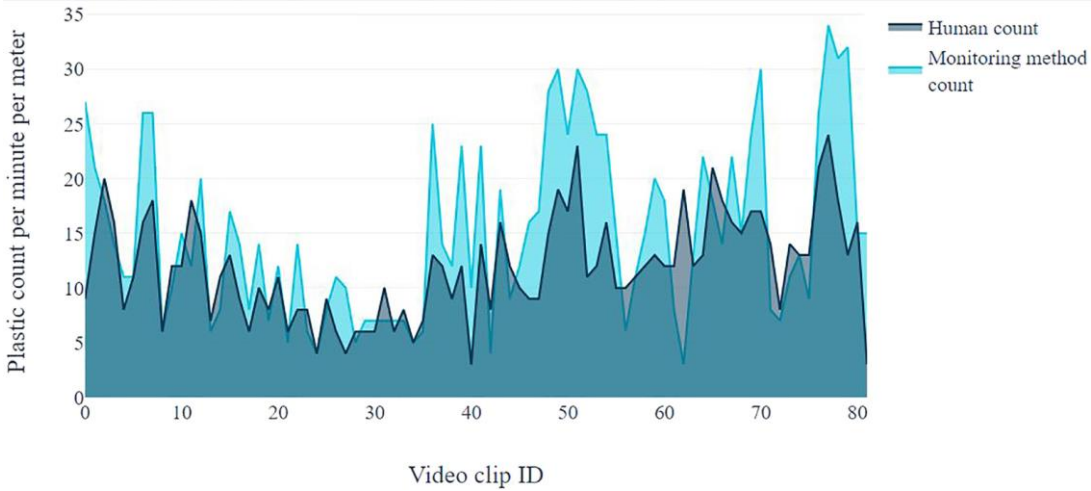


Hurley et al. (2023)

Visual observations with cameras

- Continuous monitoring
- Many challenges in data processing
- Hardware setup not trivial

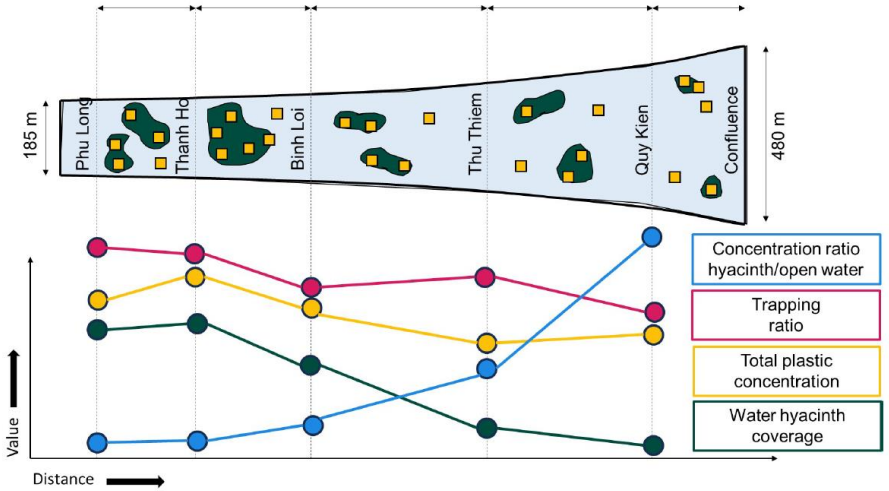




Van Lieshout et al. (2020)

Visual observations with drones

- Alternative for locations without bridge
- Suitable for system scale applications
- Data processing + legal challenges

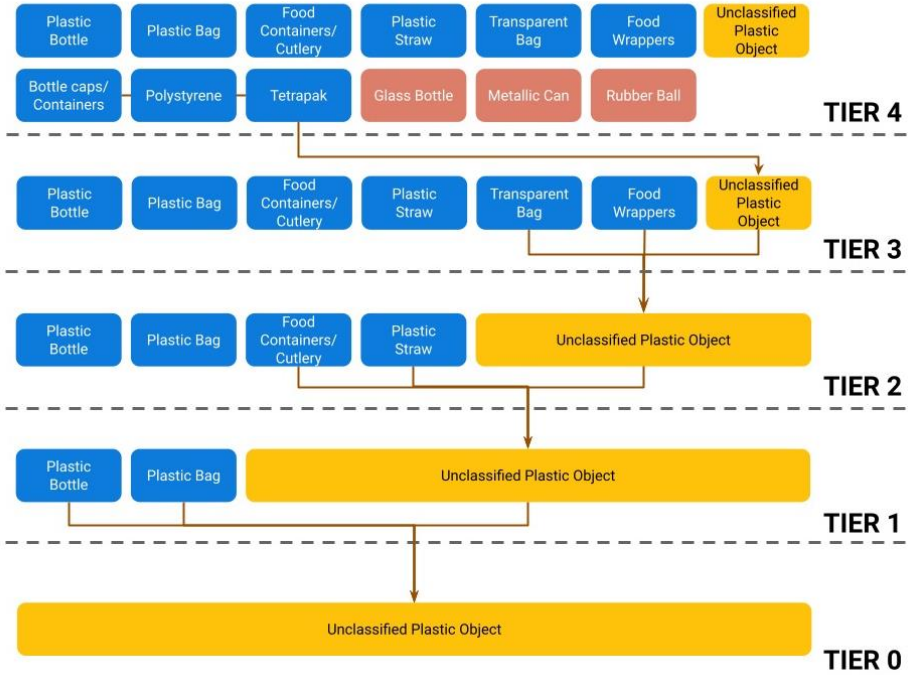


Van Emmerik et al. (2024)

WAGENINGEN
UNIVERSITY & RESEARCH

Role of AI

- Promising method to increase datasets (yolo, (Faster R-)CNN, etc)
- Models struggle to get overall high performance (precision, recall, mAP)
- Optimize number of classes



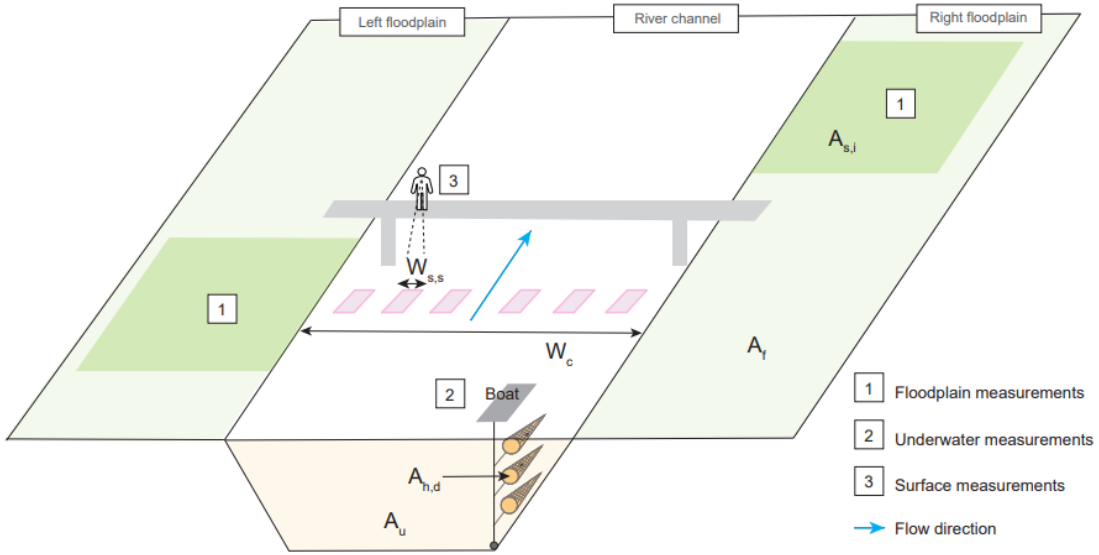
Saddi et al. (in prep.)

Future of visual counting

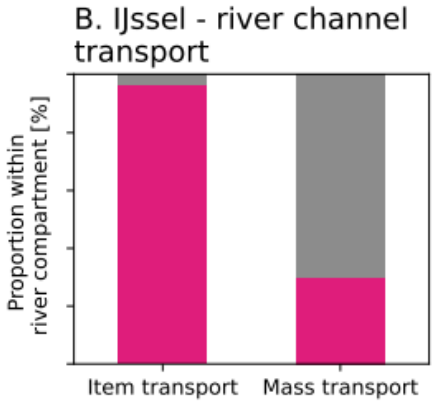
- Simple method to upscale
- Used for transport, export, composition
- Quantify uncertainties
- Camera, drones and AI offer alternatives, TRL still low

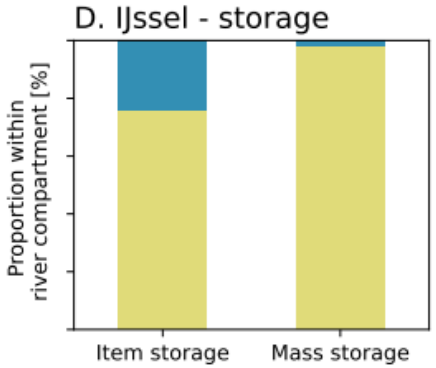
Photos: Paul Vriend

Towards a river plastic budget



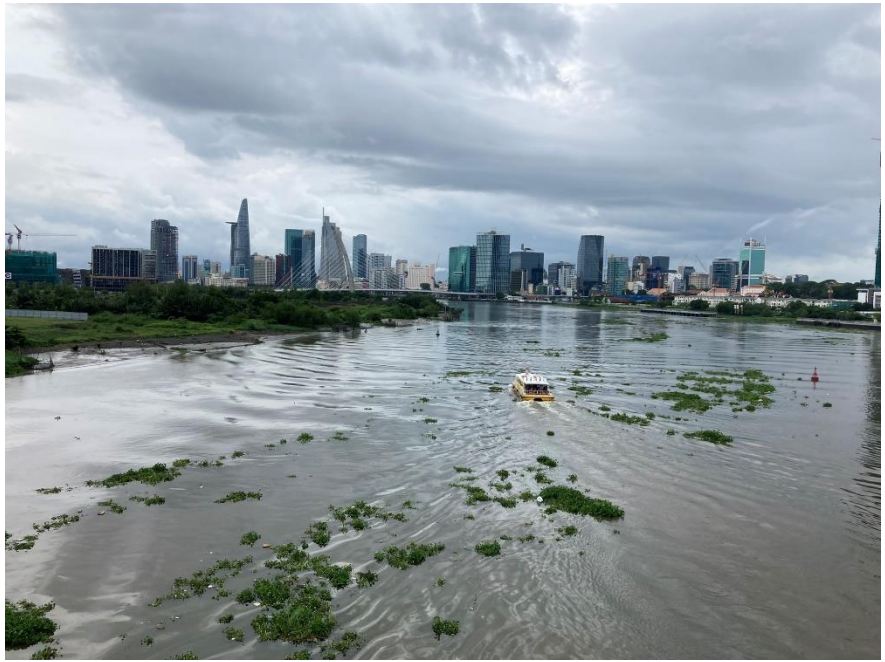
(Schreyers et al., 2024





What you should remember

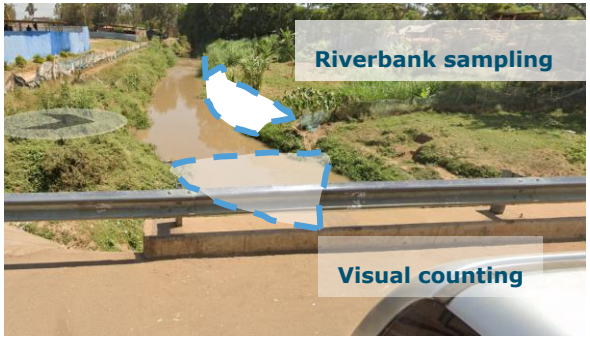
- There is no one-size-fits all for river plastic monitoring
- Best strategy depends on the goals, river, and resources
- Start simple, add complexity

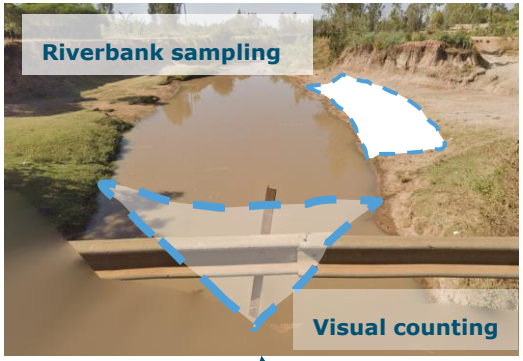


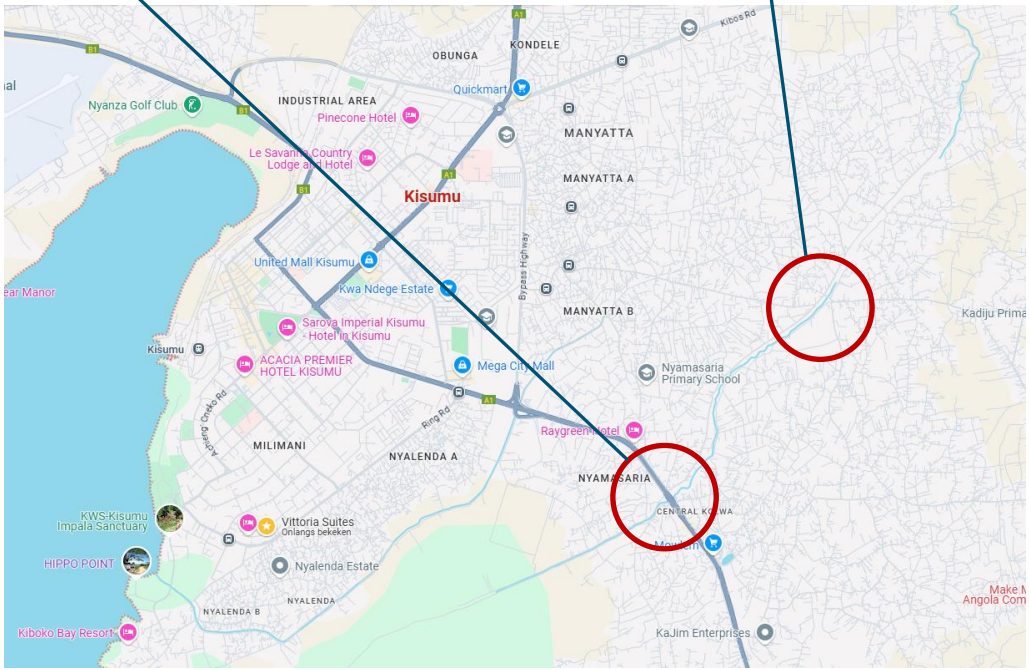
WAGENINGEN
UNIVERSITY & RESEARCH

Excursion!

- Two groups
- Nyamasaria river
- Practice with methods
- Visual counting + riverbank sampling
- Back around 13:00
- Afternoon: clean, process and visualize the data







WAGENINGEN
UNIVERSITY & RESEARCH

Introduction to river plastic monitoring

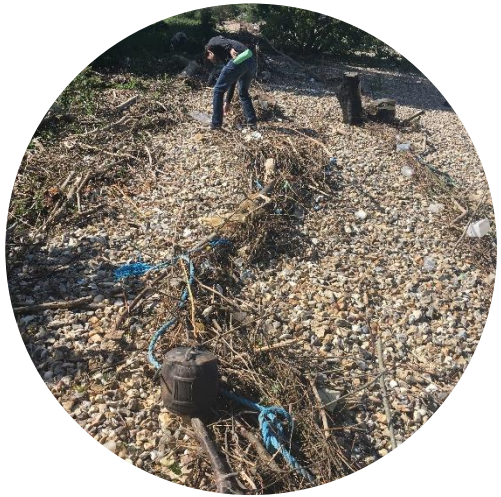
Tim H.M. van Emmerik[1], Sabrina Kirschke[2], Christian Schmidt[3]

[1]Wageningen University, the Netherlands

[2]Museum für Naturkunde, Germany

[3]UFZ, Leipzig, Germany

Contact: tim.vanemmerik@wur.nl



WAGENINGEN UNIVERSITY & RESEARCH

UFZ HELMHOLTZ Centre for Environmental Research

für Naturkunde MUSEUM FÜR NATURKUNDE BERLIN

WWQA World Water Quality Alliance

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

NILE BASIN INITIATIVE INITIATIVE DU BASSIN DU NIL

Assignment – 10 min!

- Pick a river
- Determine your research question
- Design the visual counting and/or riverbank sampling strategy
- Estimate the required capacity and/or funding
- Evaluate the feasibility